South Africa's Third National Communication under the United Nations Framework Convention on Climate Change

Appendix B

Department of Environmental Affairs

Republic of South Africa

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Environmental Affairs
REPUBLIC OF SOUTH AFRICA

2030 NDP

Table of Contents

List of Figures

List of Tables

3 Climate Change over South Africa from Trends and Projected Changes to Vulnerability Assessments and the Status Quo of National Adaptation Strategies

3.1 Introduction

Climate change is projected to impact drastically on the African continent during the 21st century under low mitigation futures (Niang *et al.,* 2014). African temperatures are projected to rise rapidly, at 1.5 to 2 times the global rate of temperature increase (Engelbrecht *et al.,* 2015; James & Washington, 2013). Moreover, the southern African region and Mediterranean North Africa are likely to become generally drier under enhanced anthropogenic forcing, whilst East Africa and most of tropical Africa are plausible to become wetter (Christensen *et al.,* 2007; Engelbrecht *et al.,* 2009; James & Washington, 2013; Niang *et al.,* 2014). More uncertainty surrounds the projected climate futures of West Africa and the Sahel, with some climate models projecting wetter conditions and equally credible models projecting drier conditions under climate change (e.g. Christensen *et al.,* 2007; Niang *et al.,* 2014). The changing African climate is likely to have a range of impacts across the continent, including impacts on energy demand (in terms of achieving human comfort within buildings and factories), agriculture (e.g. reductions of yield in the maize crop under higher temperatures and reduced soil moisture), livestock production (e.g. higher cattle mortality as a result of oppressive temperatures), water security (through reduced rainfall and enhanced evapotranspiration) (Engelbrecht *et al.,* 2015; Garland *et al.,* 2015; Thornton *et al.,* 2011) and infrastructure (mostly through the occurrence of more large-scale floods in particular regions).

Since the SNC, updated observed climate datasets and developments through the Coordinated Regional Downscaling Experiment (CORDEX) have served to fill some of the gaps in our understanding of regional climate change. The NCCRP in 2011 and the conclusion of Phase 2 of the Long Term Adaptation Scenarios (LTAS) have also been amongst the key milestones since the SNC with particular significance to understanding impacts, vulnerability and adaptation in South Africa.

This chapter uses comprehensive observed data sets of SAWS, the custodian of climate data in South Africa to document the observed trends in the temperature and rainfall over South Africa for the period of 1921 – 2015. A review of the comprehensive analysis of trends in sea-level along the South African coast is also presented. The fine-scale projections of future climate change generated by UCT and the CSIR for the LTAS (2013) report have also been significantly extended over the last two years. This extended data set has been used as a baseline to describe the projected climate futures over southern Africa in this communication.

A review of the most significant climate change risks and vulnerabilities for the following sectors; Agriculture and Forestry, Water Resources, Forestry, Terrestrial Ecosystems, Coastal Zone, Health, Urban and Rural Settlements, and Disaster Risk Management is presented in this chapter. This is followed by a summary of the progress made toward developing a National Adaptation Plan for the country.

Indeed, climate change is not to take place only through changes in average temperatures and rainfall patterns, but also through changes in the attributes of extreme weather events. For the southern African region, generally drier conditions and the more frequent occurrence of dry spells are plausible over most of the interior (Christensen *et al.,* 2007; Engelbrecht *et al.,* 2009). Cut-off low related flood events are also projected to occur less frequently over South Africa (e.g. Engelbrecht *et al.,* 2013) in response to a poleward displacement of the westerly wind regime. Tropical cyclone tracks are projected to shift northward, bringing more flood events to northern Mozambique and fewer to the Limpopo province in South Africa (Malherbe *et al.,* 2013). Further to the north, over Tanzania and Kenya, more large-scale flood events may plausibly occur should the future climate regime be characterised by a higher frequency of occurrence of strong El Niño events. Intense thunderstorms are plausible to occur more frequently over tropical and subtropical Africa in a generally warmer climate (e.g. Engelbrecht *et al.,* 2013). More uncertainty surrounds the climate futures of West Africa, the Sahel and the Horn of Africa, particularly within the context of how climate change may impact on the occurrence of mega-droughts over these regions (Lyon and DeWitt, 2012; Roehrig *et al.,* 2013; Williams *et al.,* 2012).

The findings described above are all based on global climate model (GCM) projections of future climate change, or on the downscaling of these projections over Africa through the use of regional climate models (RCMs). The GCMs analysed in Assessment Report Five (AR5) of the Intergovernmental Panel on Climate Change (IPCC) typically had a horizontal resolution of about 200 km. RCMs have typically been applied over parts of the African continent at a resolution of about 50 km in the horizontal, and more recently over the entire continent at a resolution of about 50 km, through the endeavours of the Coordinated Regional Downscaling Experiment (CORDEX) of the World Climate Research Programme (WCRP).

3.2 Observed trends in climate over South Africa

3.2.1 Introduction: Trends in southern African and African climate

Studies of historical climate trends have been steadily increasing during the last decade, given the increasing concerns about anthropogenically induced global warming and climate change. For the African continent, the studies of Engelbrecht *et al.,* (2015) and Jones *et al.,* (2012) are indicative of drastic increases in surface temperature occurring over the last five decades. In the African subtropics, temperatures are increasing at a rate of about twice the global rate of temperature increase. For South Africa, the most noteworthy recent investigations of trends in temperature are those of Kruger & Nxumalo (2016), Kruger & Sekele (2012), and MacKellar *et al.,* (2014). These studies are indicative of wide-spread and statistically significant temperature increases occurring across South Africa over the last five decades (and longer). The strongest warming has been observed in the west over the Western Cape and Northern Cape, and in the north-eastern provinces of Limpopo and Mpumalanga, extending southwards to the coastal areas of KwaZulu-Natal. Moreover, increases have not been observed only in the annual and seasonal averages of minimum and maximum temperature, but also in their extremes. In particular, warm extremes exhibit strong increasing trends, whilst cold nights are decreasing across the country.

The most noteworthy studies on historical trends in rainfall over South Africa are those by Kruger (2006) and MacKellar *et al.,* (2014). Whilst the study of Kruger (2006) spanned the period 1910 – 2004, Mackellar *et al.,* (2014) used a larger number of stations spanning the more recent period of 1961-2010. Both these studies were indicative of statistically positive trends over parts of the central interior of South Africa, with statistically negative trends largely confined to the northeastern parts of Limpopo and Mpumalanga in the northeast and the winter rainfall region in the southwest. Over most of the country, however, recorded trends in rainfall are largely statistically insignificant, and trends are also small in magnitude over the entire country (in the order of 10 mm/century, or smaller).

The updated analysis of trends in South African temperatures presented in this chapter of the TNC builds in particular on the studies of Kruger & Sekele (2012) and Mackellar *et al.,* (2014). The study of Mackellar *et al.,* (2014) was commissioned by the Department of Environmental Affairs Long Term Adaptation Scenarios Report on climate trends and projections in South African climate (LTAS, 2013). One of the shortcomings of the results included in the LTAS (2013) report, and in fact most research initiatives on long-term climate trends, is the relatively short time periods of analysis relative to the cyclical behaviour inherent to the regional climate. This could have a significant effect on the eventual trend results obtained, and in particular on the rainfall trends analysis. Both the studies of Kruger & Sekele (2012) and MacKellar *et al.,* (2014) focused on periods of about five decades starting in the early 1960s, in which exist four clear cycles of wet-dry conditions (with plausibly associated temperature cycles). This makes linear trend analysis somewhat susceptible to the specific time window analysed (Kruger, 1999). A further shortcoming of the LTAS (2013) analysis is the absence of data homogenisation for the case of the temperature time-series used. Trend analysis based on such data sets may produce artificial trends produced by shifts in station location, or changes in instrumentation. Limiting the analysis to stations with homogeneous time-series greatly reduce the number of stations available for analysis, however.

In the TNC a two-prong approach is therefore followed, towards obtaining defensible insights into the observed trends in climate over South Africa. Firstly, the analysis of MacKellar (2014) is updated with the most recent observations to obtain a spatial view of South African temperature and rainfall trends over the period 1960-2015. Secondly, building on the work of Kruger (2006) and Kruger & Sekele

(2012), a carefully constructed analysis of longer term station time-series data was performed. For the case of temperature, it was possible to construct time-series data with the desired property of temperature homogeneity for the period 1931-2015 (Kruger & Nxumalo, 2016). In the case of the time-series analysis of rainfall, although the construction of homogeneous time-series data was not feasible, the analysis was performed for the extended period 1921-2015 (rainfall). The latter analysis is thought to be more reliable in detecting long-term trends amidst the pronounced inter-annual and decadal variability exhibited by rainfall patterns over South Africa.

3.2.2 Data and methodology

3.2.2.1 Data quality and homogeneous time-series data

Analysis of climate trends is challenging for two reasons. The first is that many climate variables, in particular those related to rainfall, exhibit very high variance on time scales ranging from daily through to multi-decadal. This challenge is particularly relevant for South Africa, a country that displays pronounced variability in rainfall, partially because of a strong El Niño Southern Oscillation (ENSO) signal in southern African rainfall patterns (e.g. Kruger, 1999). Moreover, there is also evidence of decadal and multi-decadal cycles affecting rainfall variability in southern Africa (e.g. Kruger, 1999; Malherbe *et al.,* 2014). High variability through time means that, while linear (or linear-like) trends can be calculated, the probability that the calculated trend reflects systematic climate change is somewhat reduced. This presence of systematic change is typically evaluated by various statistical tests of “significance” of trends. Trends whose odds of occurrence in view of the observed variability are low (typically less than 1 in 20) are usually considered statistically significant and are interpreted as indicative of systematic change contrary to the expected natural variability, and likely forced by factors external to the climate system (such as anthropogenic climate change). A comprehensive discussion of the methodologies used to study the statistical significance of trends in the TNC is provided in Appendix B1.

The second challenge is the lack of consistently observed data over time. In particular, there are very few weather stations in the country that have for a period of more than 50 years been located in the same position, consistently using the same type of instrumentation over time. That is, the construction of homogeneous time-series data from weather stations is problematic – an acute problem for South Africa, but also internationally. A discussion of the quality of weather station data in South Africa is provided in Appendix B1, whilst the methodologies applied to construct longer-term and homogeneous time-series data for analysis within the TNC are discussed in Appendices B.2 and B.3. These methodologies resulted in a set of 27 weather stations being used for the temperature trends analysis spanning the period 1931-2015, whilst 60 stations were used for the rainfall trend analysis spanning the period 1921-2015. The locations of the stations applied in the temperature trend analysis are shown in Figure B.2, with more details of the stations are provided in Table B.1. Details on the rainfall stations utilized are provided in Table B.1.

3.2.2.2 Extreme event analysis

Apart from the trends in the annual mean minimum, maximum and average temperatures, and average diurnal temperature range presented in this report, the analyses also includes the determination of trends in extreme temperatures, of which the indices considered are based on those developed by the World Meteorological Organization (WMO) Expert Team on Climate Change Detection and Indices (ETCCDI) (Wang and Feng, 2013). These are presented in Table 0.1. The base period was selected as 1981 – 2010, applicable to the six percentile-based indices.

Table 0.1: ETCCDI extreme temperature indices utilized for the TNC

Index	Definition	Units	Description
TX90P	Annual number of days when TX > 90th percentile	days	Annual number of hot days
TX10P	Annual number of days when TX < 10th percentile	days	Annual number of cool days
TXx	Annual maximum value of TX	°C	Annual daytime hottest temperature
TXn	Annual minimum value of TX	°C	Annual daytime coolest temperature
WSDI	Annual number of days with at least 6 consecutive days when TX > 90th percentile	days	Annual longest hot spell
TNx	Annual maximum value of TN	°C	Annual nighttime warmest temperature
TNn	Annual minimum value of TN	°C	Annual nighttime coldest temperature
TN90P	Annual number of days when TN > 90th percentile	days	Annual number of warm nights
TN10P	Annual number of days when TN < 10th percentile	days	Annual number of cold nights
CSDI	Annual number of days with at least 6 consecutive days when TN < 10th percentile	days	Annual longest cold spell

Apart from the trends in the annual rainfall totals, long-term changes in rainfall can manifest in changes in rainfall extremes. Therefore, while general trends in rainfall are analysed, an extreme rainfall trend analysis is also performed, based on rainfall extreme indices developed by the WMO ETCCDI. These are presented in

Table 0.2:. The base period, from which the annual index values of all indices are determined (except the annual maxima and minima) was selected as 1981 – 2010, which can be considered to be the present general norm for similar trend studies.

Table 0.2: ETCCDI extreme rainfall indices utilized for the TNC

Index	Definition	Unit	Description
prcptot	Annual total precipitation when daily precipitation ≥1 mm	mm	Annual total precipitation in wet days
r95p	Annual total precipitation from daily precipitation > 95th percentile	mm	Annual total precipitation from high daily rainfall
r99p	Annual total precipitation from daily precipitation > 99th percentile	mm	Annual total precipitation from very high daily rainfall
rx1day	Annual maximum 1-day precipitation	mm	Highest daily rainfall per year
r10mm	Annual count of days when precipitation ≥ 10mm	days	Annual number of days with moderate rainfall
r20mm	Annual count of days when precipitation ≥ 20mm	days	Annual number of days with moderate to high rainfall
r25mm	Annual count of days when precipitation ≥ 25mm	days	Annual number of days with high rainfall
SDII	Annual mean of daily precipitation intensity	mm	Annual mean amount of daily rainfall, indicating mean daily rainfall intensity
CWD	Maximum number of consecutive days with precipitation ≥ 1mm	days	Annual maximum length of wet spell
CDD	Maximum number of consecutive days with precipitation < 1mm	days	Annual maximum length of dry spell

3.2.3 A spatial analysis of temperature trends over South Africa

3.2.3.1 Average temperature

For the annual mean temperature the general tendency for the period 1931-2015 for the homogeneous time-series (Figure 3.1), as reflected in previous studies, is the significant warming trend exhibited by the vast majority of stations (Engelbrecht *et al.,* 2015; Kruger, 2010; Kruger & Sekele, 2012; MacKellar *et al.,* 2014). Some of the stations show trends in excess of 2 °C per century, which are significantly higher than the mean global warming trend, which is in the region of 1 °C for the last century. Consistent with the analysis of temperature extremes as presented by Kruger & Sekele (2012), the largest warming trends are occurring over the drier western parts of the country (North Cape and Western Cape) and in the northeast (Limpopo and Mpumalanga, extending southwards to the east coast of KwaZulu-Natal). The relatively strong warming over Gauteng province is also noteworthy, and it may be postulated that an increasing heat island effect could have contributed to the warming, due to continuous urbanization of the province.

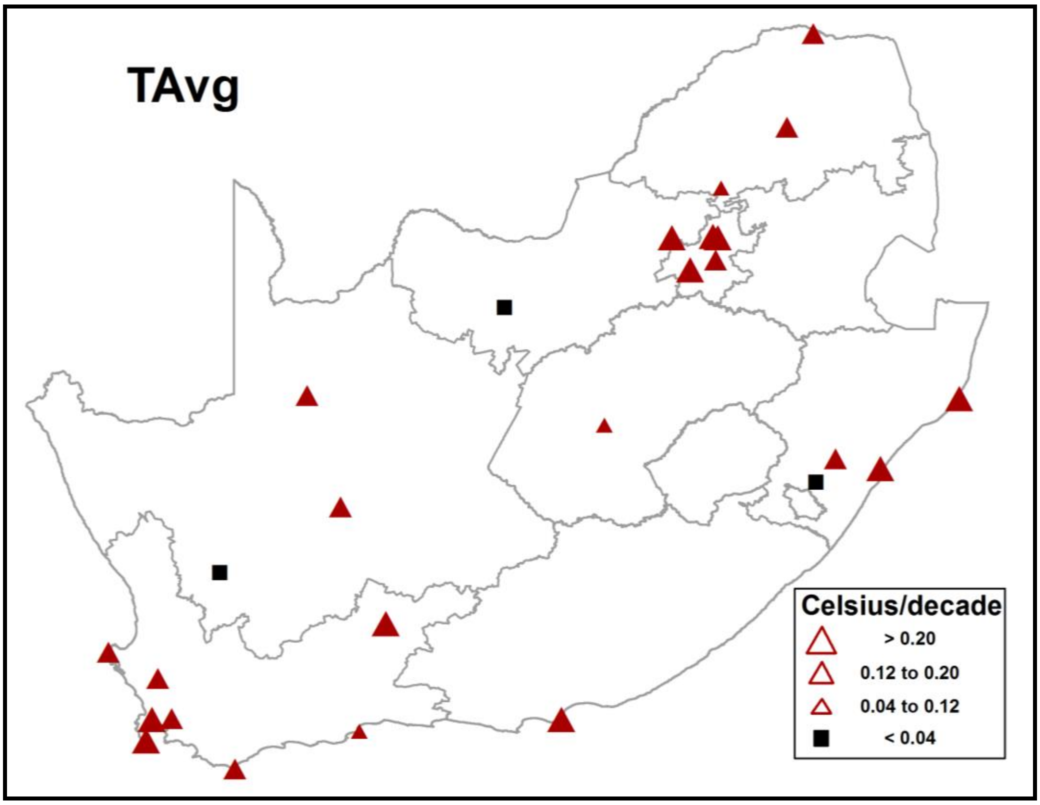


Figure 0.1: Linear trends in annual average temperatures (**1931-2015**)**. Filled triangles indicate significance of trend at the 95% confidence level** (**Kruger & Nxumalo, 2016**).

3.2.3.2 Minimum and maximum temperature

The trends in the annual mean maximum and minimum temperatures over the period 1931-2015 as recorded in the SAWS homogeneous time-series data is presented in Figure 3.2. The results for the maximum temperatures reflect approximately the same tendencies as presented in the LTAS (**DEA,** 2013a) report. While stations in the Western Cape, east coast of KwaZulu-Natal and Gauteng exhibit strong increases in annual maximum temperatures, there are stations over the central interior showing relatively small and even statistically insignificant trends. Minimum temperatures have not been found to exhibit negative trends over the central interior of South Africa, contrary to the findings of previous studies (Kruger & Sekele, 2012; LTAS, 2013; MacKellar *et al.,* 2014). This may be attributed to the longer period utilized in the analysis, as well as the homogenisation procedure applied to the station data.

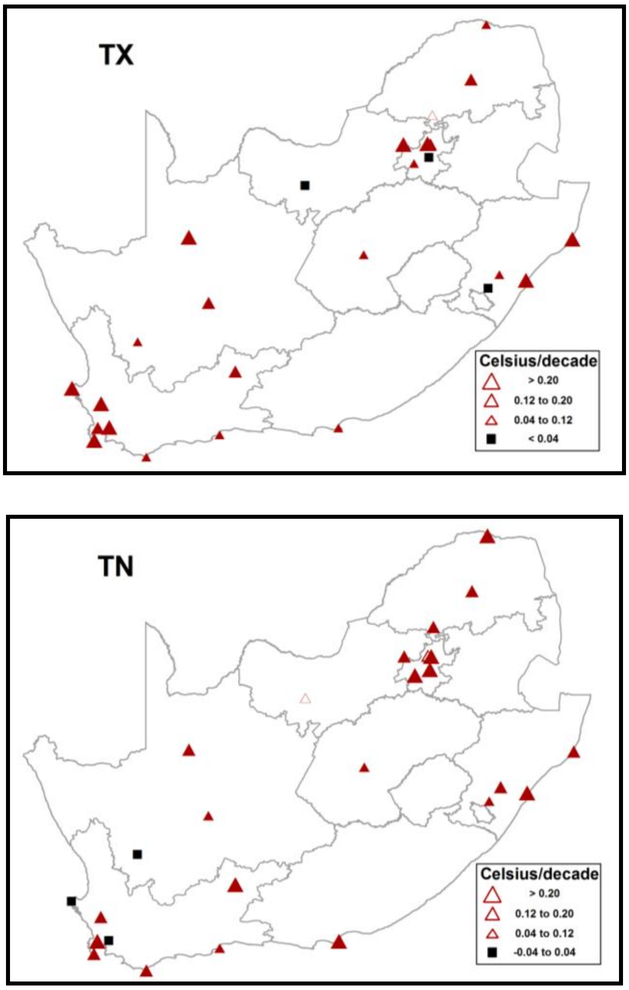


Figure 0.2: Linear trends in annual maximum temperatures (TX, top) and minimum temperatures (TN, bottom) in °C (1931-2015). Filled triangles indicate significance of trend at the 95% confidence level (Kruger & Nxumalo, 2016)

The trends in the annual diurnal temperature range (DTR) are presented in Figure 3.3 for the case of the homogeneous temperature time-series. Due to the different trends in the annual maximum and minimum temperatures it is to be expected that there should be spatial variations in the trends for DTR. While most stations show decreases in DTR (indicating that the minimum temperature trends are more positive than the maximum temperatures for most stations) there are some regional contradictions in the results. This may be an indication of localized influences that play a role in urban areas, e.g. in Gauteng and the southwestern Cape.

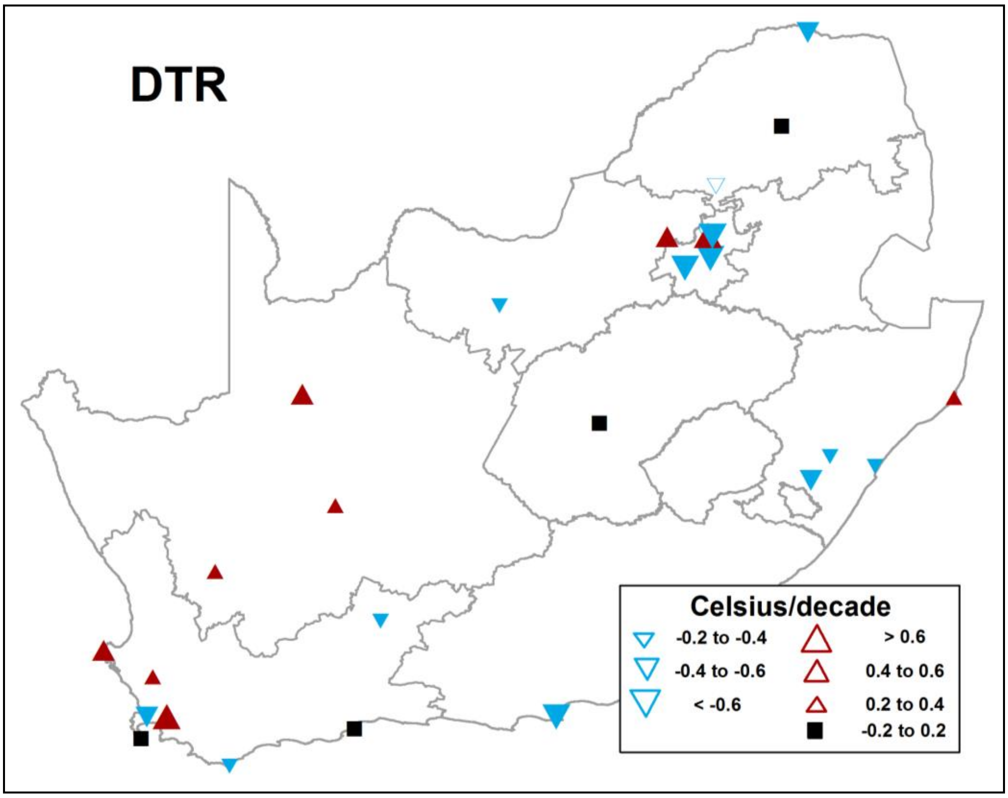


Figure 0.3: Linear trends in annual diurnal temperature range (DTR) in °C (1931-2015). Filled symbols indicate significance of trend at the 95% confidence level

3.2.3.3 Warm and cold nights

The decadal trends in the annual number of warm and cold nights, as defined by the 10th and 90th percentiles (TN90P and TN10P) respectively of daily minimum temperatures during the baseline period, are presented in Figure 3.4. For warm nights there are mostly relatively small and non-significant trends over the western parts, while the remainder of the country significantly positive trends, strongest along the coast and Gauteng province, can be detected.

For most of the country significant decreases are evident in cold nights which, in absolute terms, are generally stronger than the increases in warm nights. While there were very small insignificant trends for most stations in the interior with regards to warm nights, most stations in this region showed statistically significant decreases in cold nights, although the magnitudes of change are relatively small.

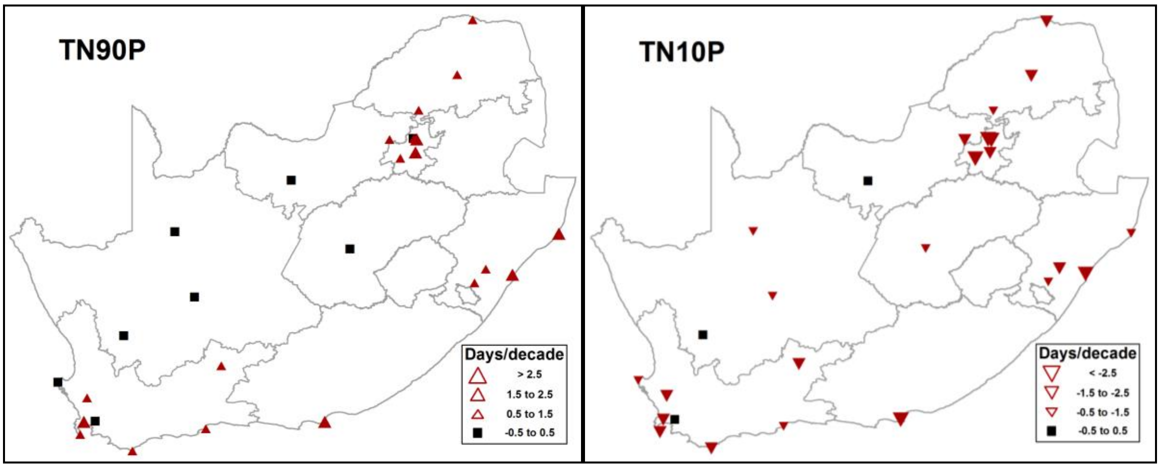


Figure 0.4: Linear trends in annual number of warm nights (**TN90P**) **and cold nights** (**TN10P**) **over the period 1931-2015. Filled symbols indicate significance of the trend at the 95% confidence level** (**Kruger & Nxumalo, 2016**)

3.2.3.4 Hot and cool days

The decadal trends in the annual number of hot and cool days, indicated by TX90P and TX10P respectively, are displayed in Figure 3.5. These threshold values were calculated from daily maximum temperature values as recorded over the baseline period. In contrast to the results for warm and cool nights (previous section), the results here are spatially less coherent and also smaller in absolute magnitude. Notwithstanding, the results still show trends that are consistent with widespread warming of the country.

Both of the results of TN10P (previous section) and TX90P indicate that the use of longer time series with homogenisation removes the cooling trends which was evident in previous analyses where some stations in the central interior showed significant increases in cold nights and decreases in hot days (DEA, 2013).

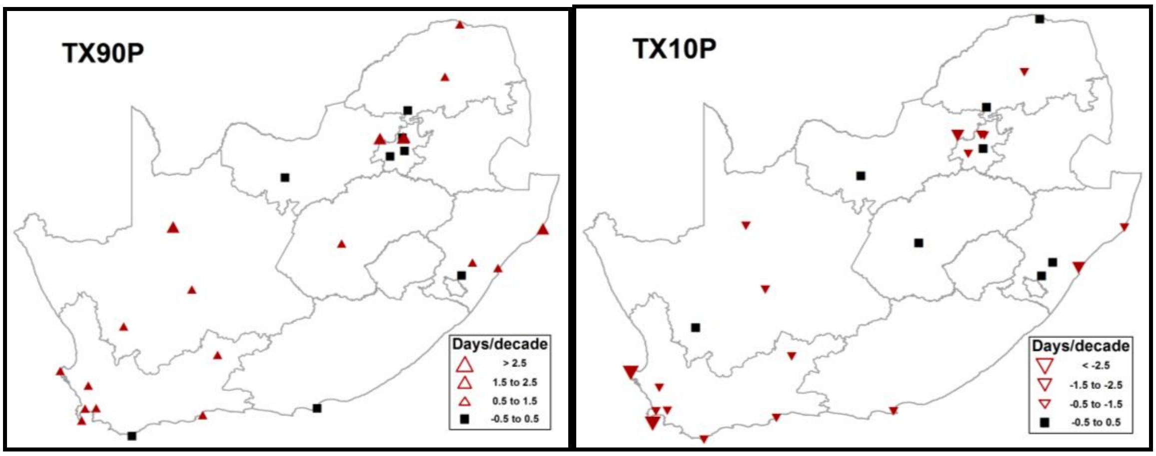


Figure 0.5: Decadal trends in annual number of hot days (**TX90P**) **and cool days** (**TX10P**) (**1931-2015**)**. Filled symbols indicate significance of trend at the 95% confidence level** (**Kruger & Nxumalo, 2016**)

3.2.3.5 Warm and cold spells

The trends in the annual maximum lengths of hot and cold spells, indicated by WSDI and CSDI respectively, are displayed in Figure 3.6. It is only in the western parts of the interior where significant increases in warm spells are evident. In contrast to warm spells, cold spells have decreased significantly for most stations.

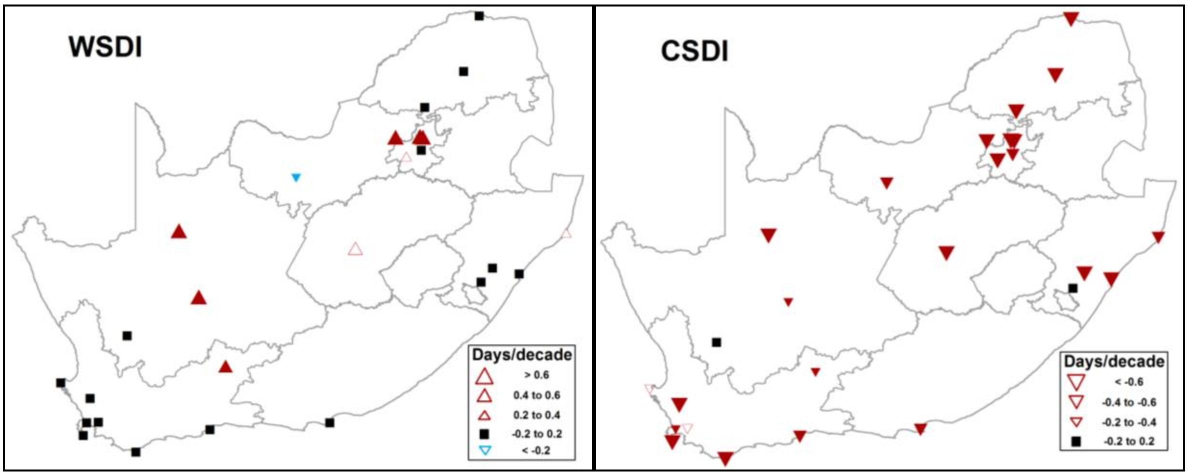


Figure 0.6: Linear trends in annual maximum lengths in warm spells (**WSDI**) **and cold spells** (**CSDI**) **in days** (**1931-2015**)**. Filled symbols indicate significance of trend at the 95% confidence level** (**Kruger & Nxumalo, 2016**)

3.2.4 A spatial analysis of rainfall trends over South Africa

3.2.4.1 Extreme event analysis

The results in the trends of annual rainfall for individual rainfall stations are presented in Figure 3.7, for case of the SAWS analysis performed for the period 1921-2015. The most evident result is a positive trend in annual rainfall totals over the central southern interior, extending to some extent to the north. Negative trends in rainfall have been recorded over the northern parts of the Limpopo Province. Otherwise, the recorded trends in annual average rainfall totals are largely statistically insignificant over the remainder of the country.

Figure 3.8 presents the associated trends in seasonal totals. While for most seasons there are no large-scale spatial coherence in statistically significant trends, it is clear that the positive trends in annual rainfall totals over the southern interior is reflected mostly in the summer rainfall trends, which is the main rainfall season for this particular region. The decreasing trends in annual rainfall over Limpopo, on the other hand, seem to be largely the result of decreasing rainfall trends in autumn.

In the analysis of the extended LTAS data set for 1960-2015, the positive trends in rainfall over the central interior extends westwards to the Western Cape, with statistical significant trends identified over much larger areas than in the SAWS analysis for 1921-2015 (Appendix B1, Figure B.1b). These differences may be partially attributable to the shorter period of analysis, which is more susceptible to impacts of decadal variability on the trends identified.

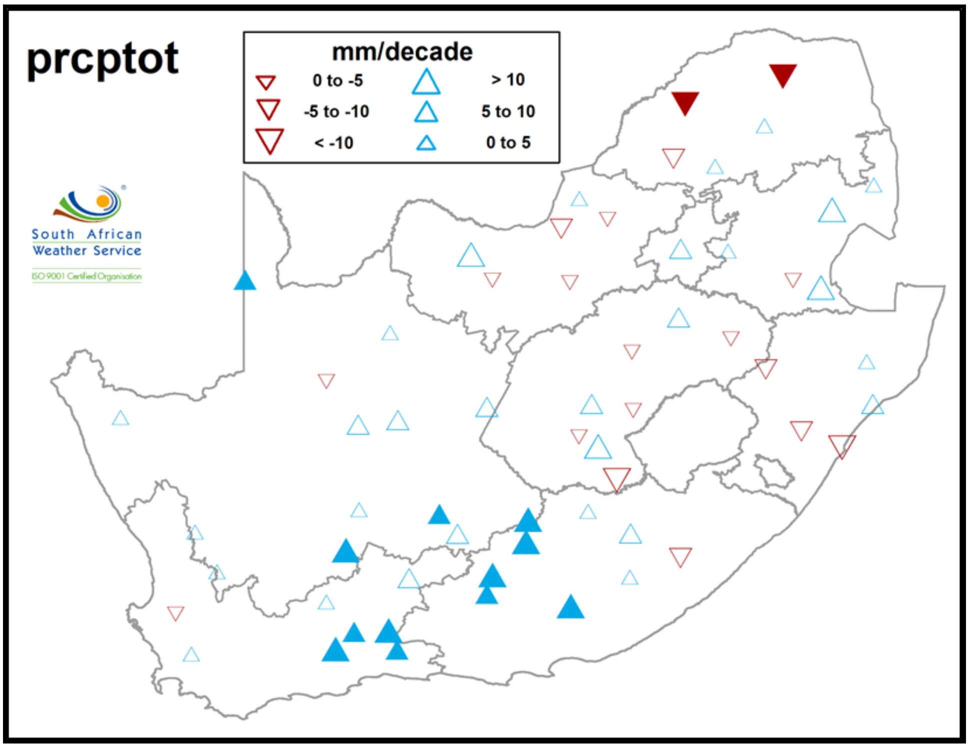
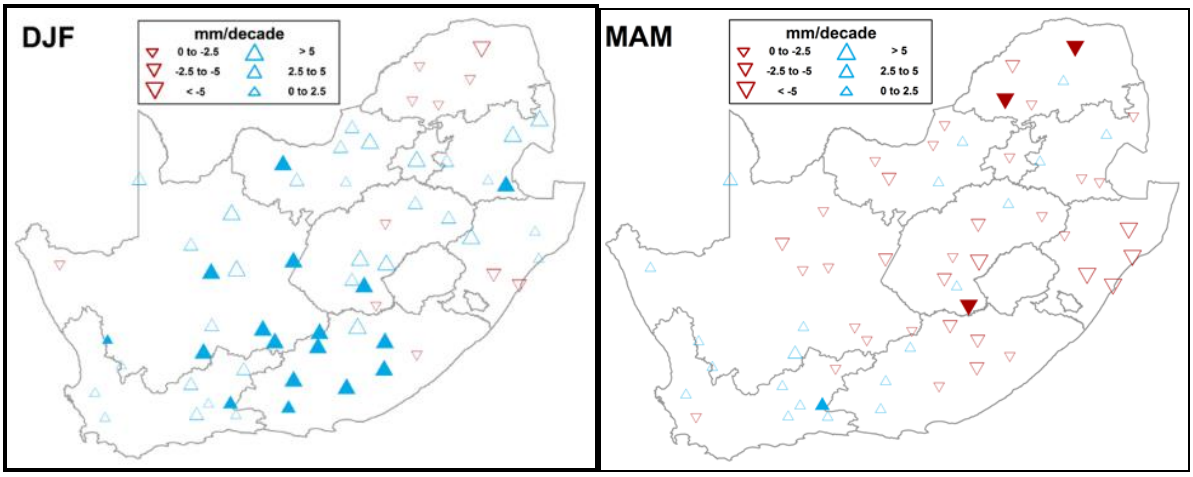


Figure 0.7: Trends in total annual rainfall for individual stations for the period 1921 – 2015. Symbology is indicated in the figure, and shaded symbols indicate significant trends at the 5% level.



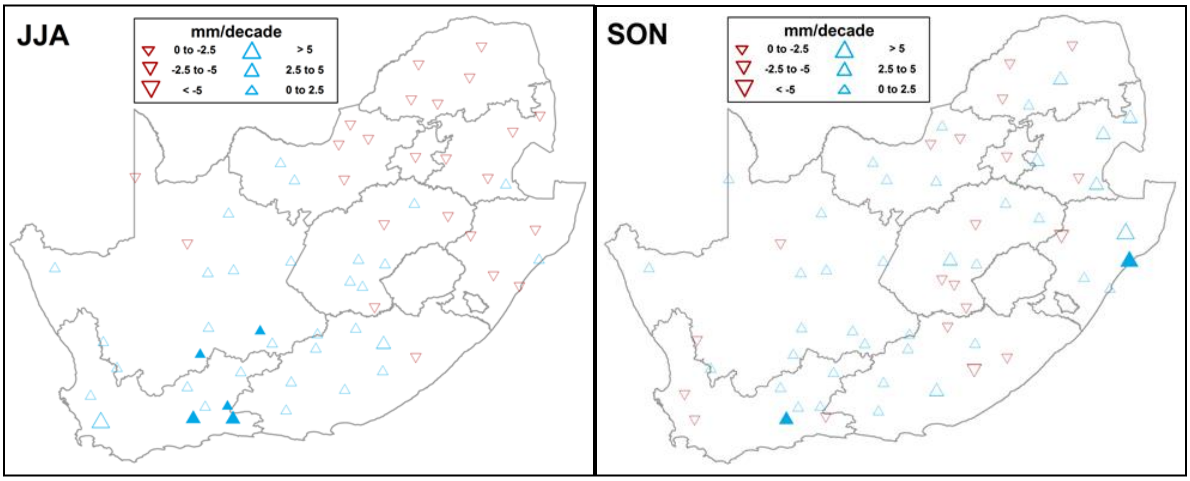


Figure 0.8: Trends in seasonal rainfall totals (**1921-2015**)**. Shaded symbols indicate significant trends at the 5% level.**

3.2.4.2 Annual total precipitation from daily precipitation > 95th percentile

Trends in rainfall extremes have the strongest presence in the ETCCDI r95p and r99p indices, and to a lesser degree in the r10mm, r20mm, r25mm and rx1day indices (all these thresholds were calculated relative to the baseline period). The r95p and r99p indices measure the total rainfall per year with rainfall above the 95^{th} and 99^{th} percentile daily rainfall totals respectively. Both indices calculated for the SAWS data spanning the period 1921-2015 indicate that there have been significant increases occurring in very high daily rainfall totals in the central southern interior and adjacent coastal regions (Figure 3.9), extending westwards to the winter rainfall region of the southwestern Cape. In the opposite side of the country in the far north-east, these indices indicate decreases. Except for these decreases recorded over parts of Limpopo for r95p, almost all stations are reporting increases in the metric, although these increases are statistically insignificant at most locations. The analysis of a corresponding metric from the extended LTAS (DEA, 2013a) analysis is presented in Appendix B1, Figure B.6.

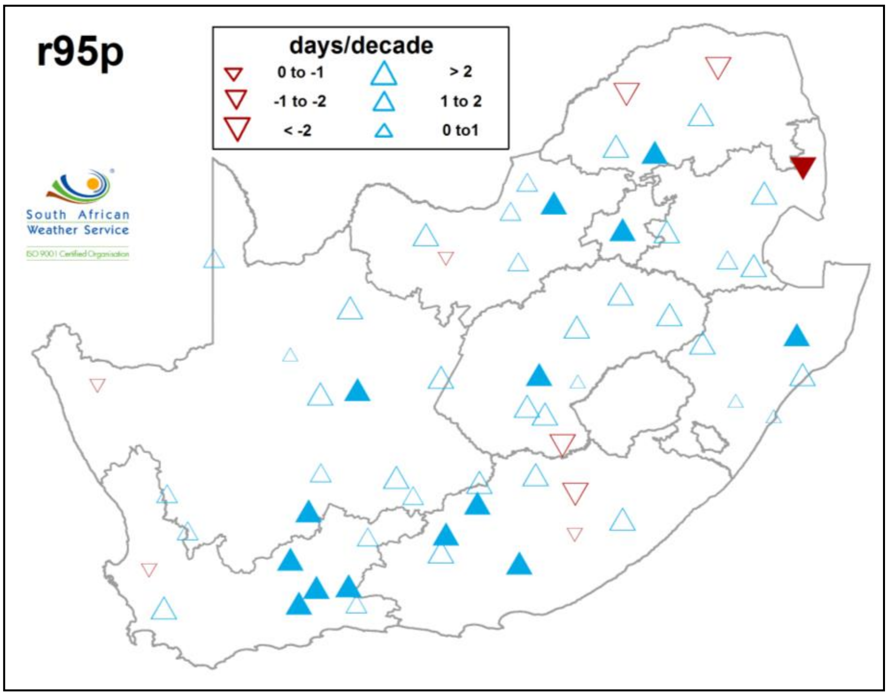


Figure 0.9: Trends in the 95th percentile of precipitation (1921-2015). Shaded symbols indicate significant trends at the 5% level

3.2.4.3 Annual total precipitation from daily precipitation > 99th percentile

Most weather stations considered in the SAWS analysis for 1921-2015 are reporting positive trends in the number of days per year experiencing rainfall above the 99th percentile as determined by the baseline period thresholds. However, these trends are generally not statistically significant, except for a cluster of stations over and to the north of Gauteng (Figure 3.10). For the related metric of the amount of annual precipitation occurring above the 99th percentile threshold, the analysis of the extended LTAS (2013) data set for 1960-2015 is consistently indicating general increases at most locations in the country (Figure B.7 in Appendix B1).

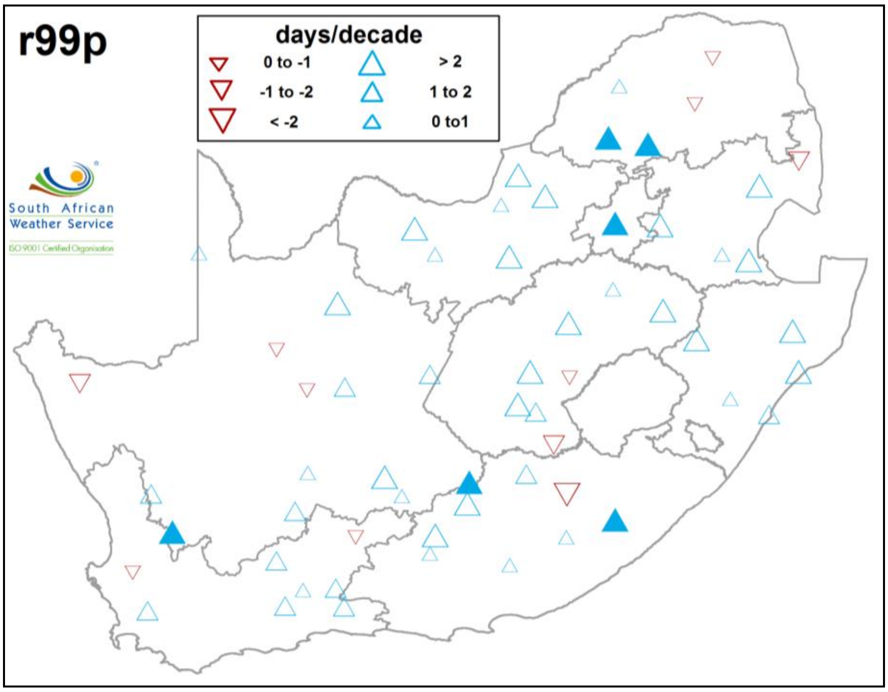


Figure 0.10: Trends in the 99th percentile of precipitation (**1921-2015**)**. Shaded symbols indicate significant trends at the 5% level**

3.2.4.4 Annual maximum 1-day precipitation

The rx1day index indicates whether there are trends in the annual maximum of daily rainfall amounts. For the SAWS analysis performed for the period 1921-2015 the results are similar to that obtained for r95p and r99p, in that statistically significant increases are found over the southern interior (Figure 3.11). Although the majority of stations are reporting statistically insignificant trends in this metric in the case of the SAWS-analysis, almost all stations are reporting positive trends, consistent with the analysis of the extended LTAS (2013) data set (Figure B.8 in Appendix B1).

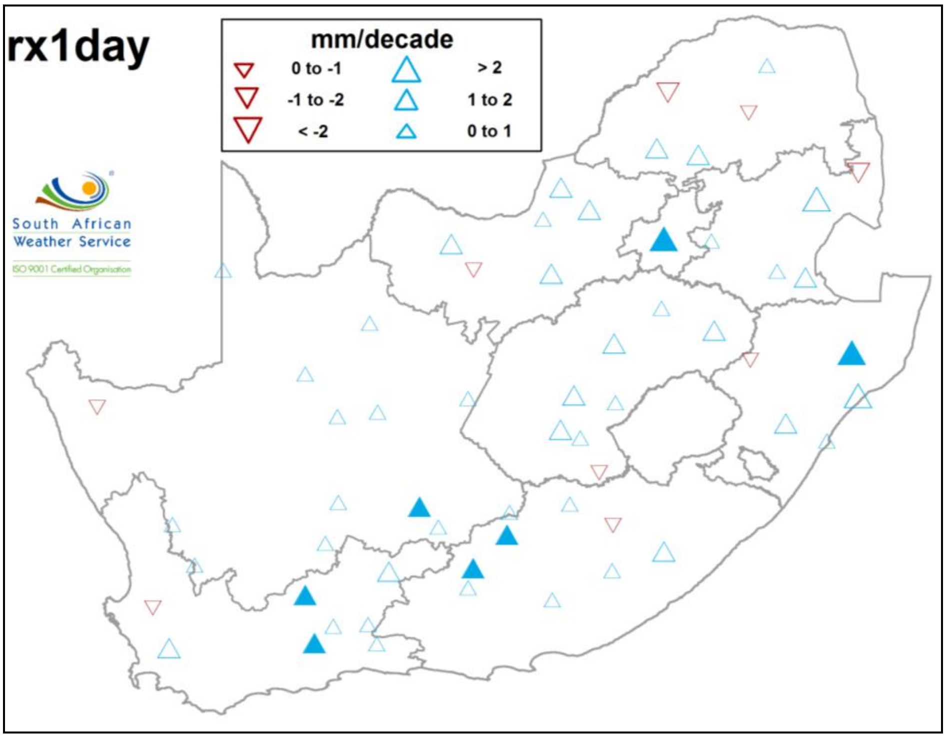


Figure 0.11: Same as in Figure 3.10 but shows annual trends of Rx1day

3.2.4.5 Annual count of days when precipitation ≥ 10 mm, ≥ 20 mm and ≥ 25 mm

Analysis of the SAWS data for the period 1921-2015 reveals that statistically significant increases have occurred over the southern and central interior in the number of days experiencing rainfall above the 10 mm (Figures 3.12), 20 mm (Figures 3.13) and 25 mm (Figures 3.14) thresholds. A seasonal analysis for the case of the 20 mm threshold (Figure 3.15) reveals that these changes in the annual number of events are largely driven by increases occurring during the summer season.

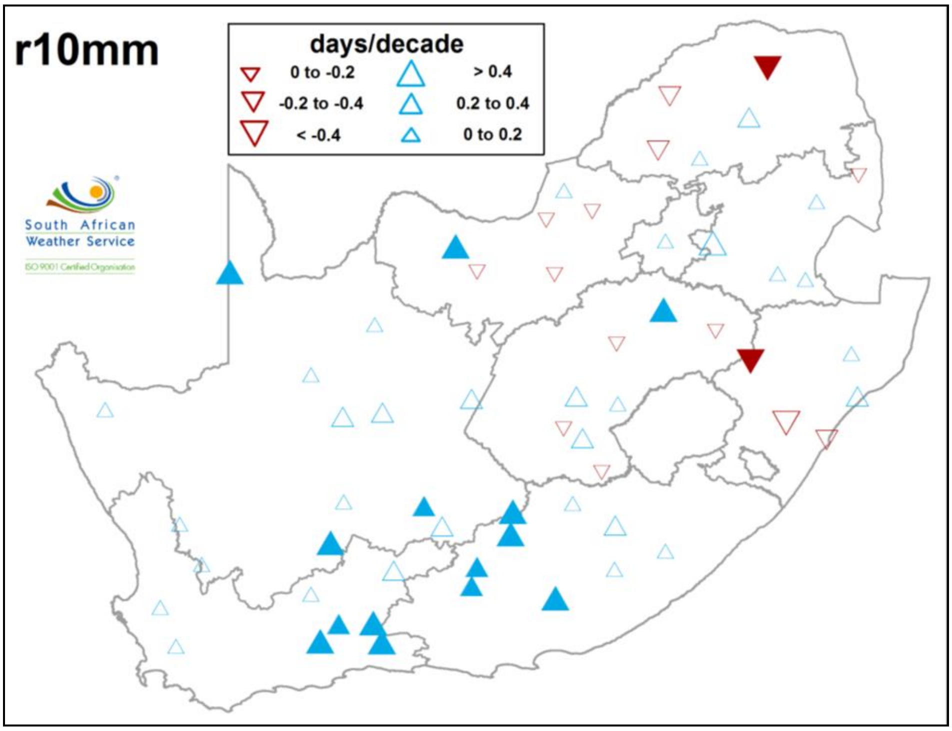


Figure 0.12: Same as in Figure 3.10 but shows trends in annual number of days with rainfall equal or greater than 10mm (r10mm)

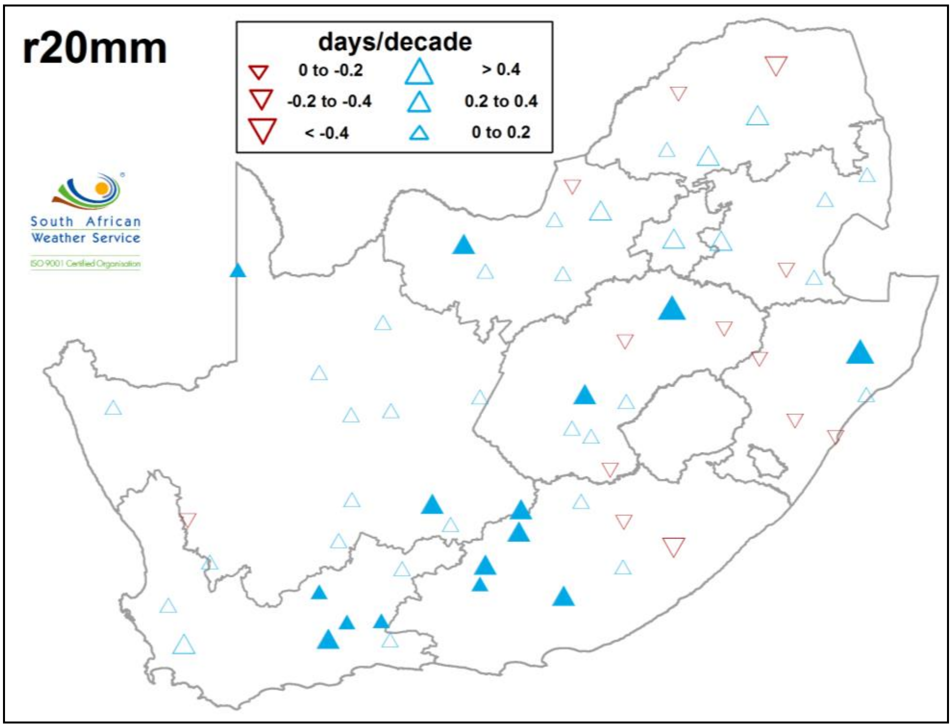


Figure 0.13: Same as in fig 3.10 but shows trends in annual number of days with rainfall equal or greater than 20mm (r20mm)

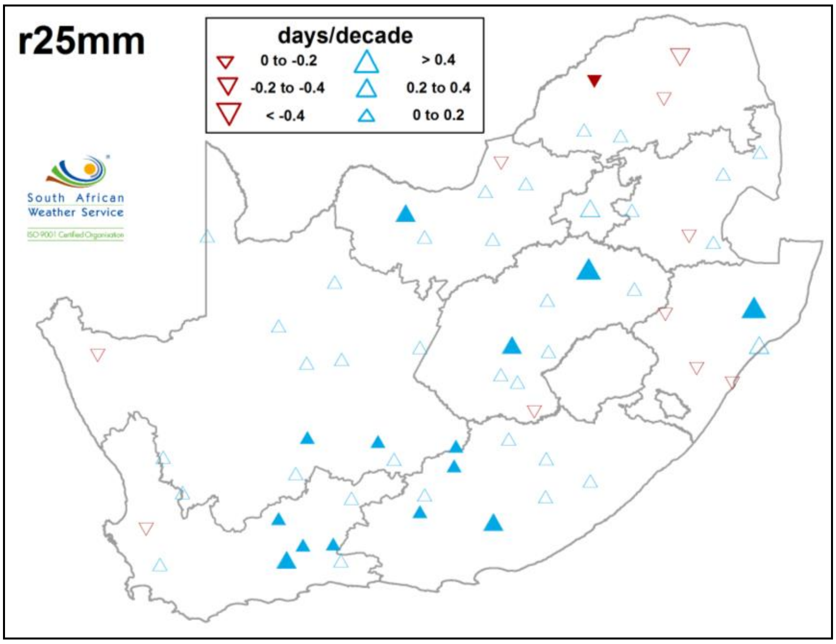


Figure 0.14: Same as in fig 3.10 but shows trends in annual number of days with rainfall equal or greater than 25mm (r25mm)

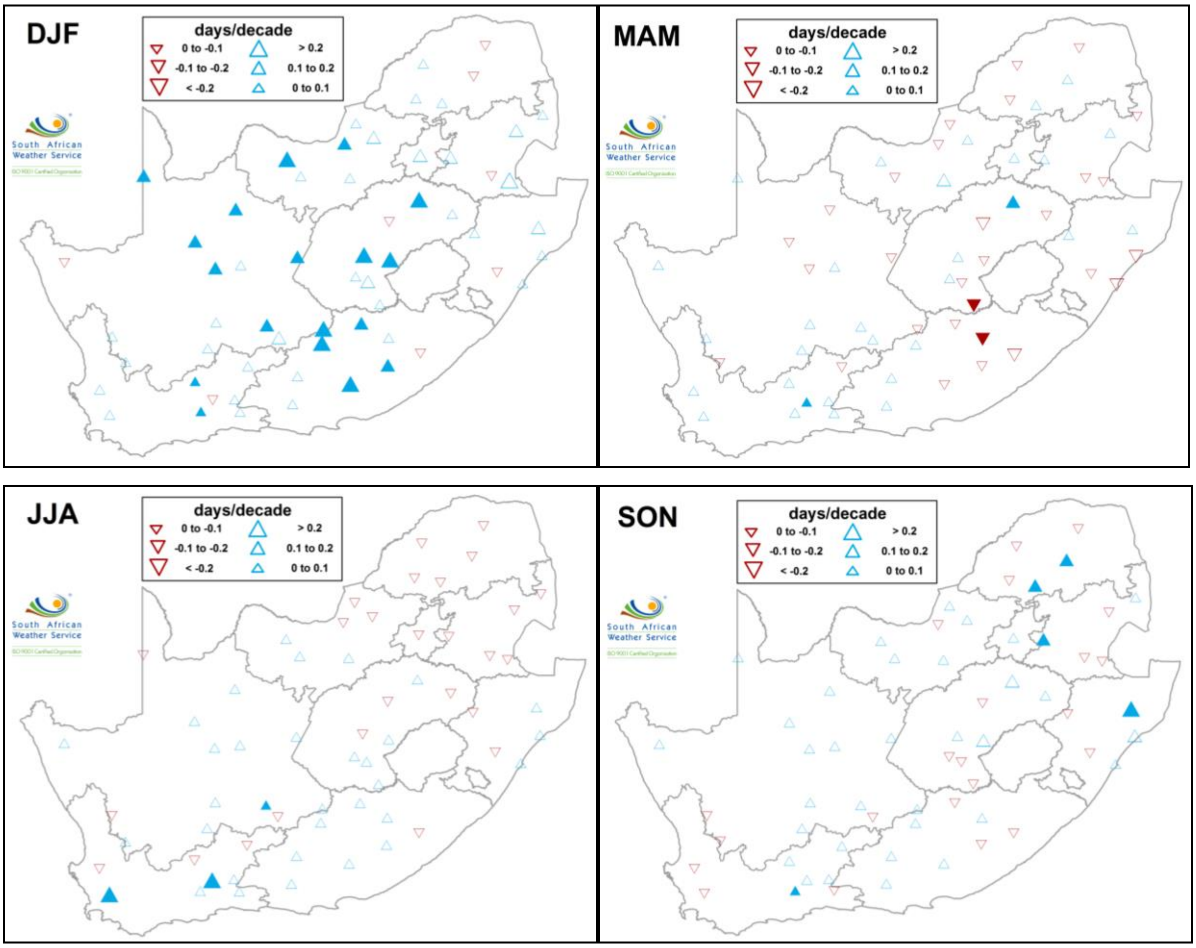


Figure 0.15: Same as in fig 3.10 but shows seasonal trends in number of days with rainfall equal or greater than 20mm (r20mm)

3.2.4.6 Simple Daily Intensity Index, annual mean of daily precipitation intensity

The SDII index indicates whether there are trends in the average amount of rainfall that is received on a day with rainfall. Significant increases might indicate that the risks of high rainfall intensity became more prevalent, which in turn indicates a higher probability of related disasters such as flash floods more likely. General increases occurred in the daily intensity of rainfall in the central and southern interior and as far north as the North-West, Gauteng and eastern Free State provinces. Decreases are evident in the eastern parts of the country, according to the SAWS analysis for 1921-2015 (Figure 3.16). These results are largely consistent with the analysis of the extended LTAS (2013) data (Appendix B1 Figure B.9).

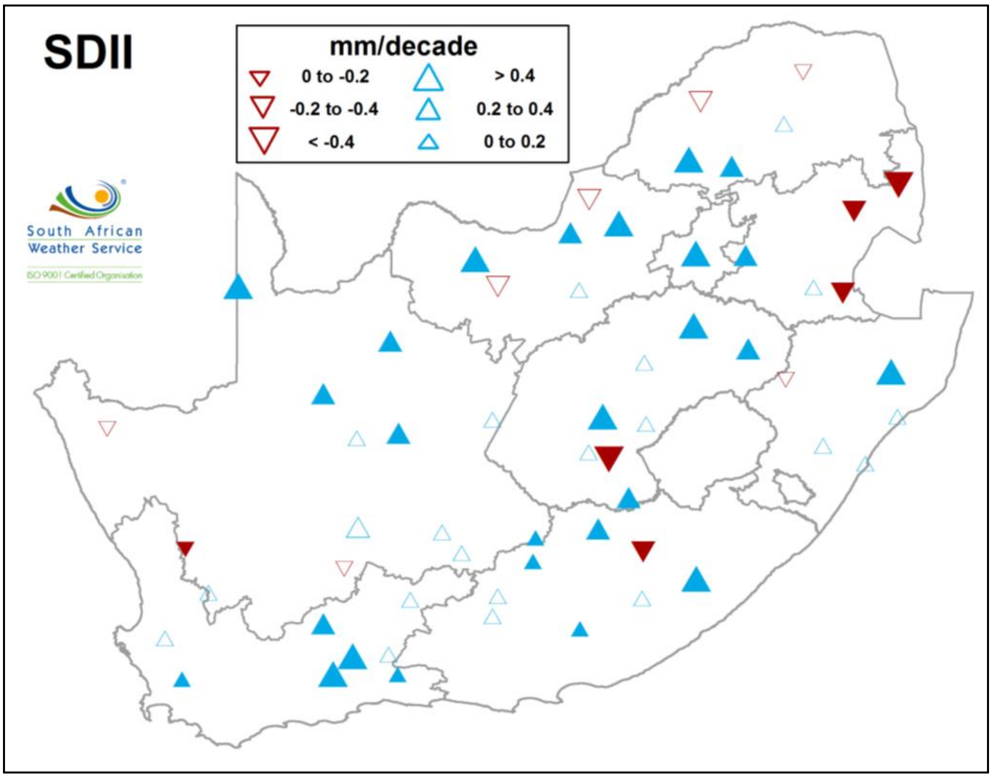


Figure 0.16: Trends in SDII for the period 1921-2015. Shaded symbols indicate significant trends at the 5% level

3.2.4.7 Annual maximum length of wet spell, maximum number of consecutive days with precipitation ≥ 1mm

For the south-western Cape the longest annual wet spell usually occurs during winter, while in the remainder of the country it usually falls in summer. Figure 3.17, which presents the trends in CWD, shows predominantly a decrease in the largest part of the north-eastern half of the country, with some stations indicating statistically significant decreases in excess of 0.2 days per decade. This result corresponds to the decrease of rainfall observed in some of the eastern parts of the country. For the south-western half of the country the trends are mostly non-significant, except for three stations in the Eastern Cape interior, which show significantly positive trends between 0.1 and 0.2 days per decade.

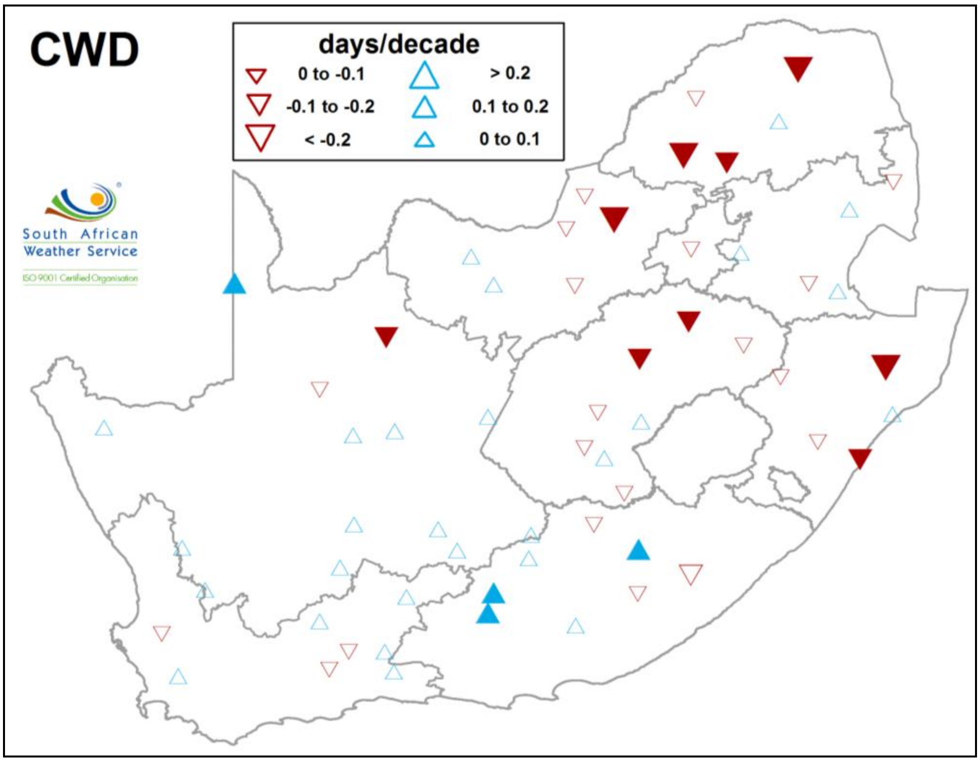


Figure 0.17: Trends in CWD, the annual maximum length of wet days, for the period 1921-2015. Shaded symbols indicate significant trends at the 5% level

The rx5day index determines the highest annual amount of rainfall received in a continuous five day episode, which provides an indication of the trend in the intensity of continuous rainfall episodes. The trend results, presented in Figure 3.18, indicate that the maximum annual amount of continuous rainfall in a five-day episode has increased in parts of the southern interior. Most stations in the country show increases, although not statistically significant. Significant changes elsewhere are isolated and therefore no conclusions can be made thereof in a regional sense.

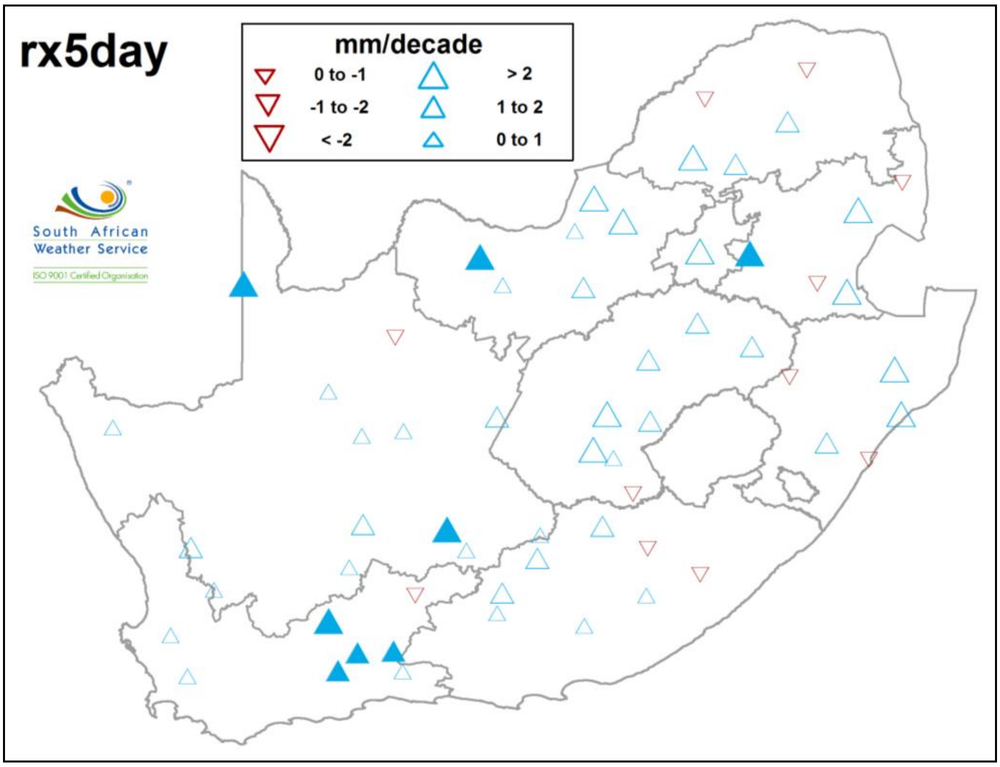


Figure 0.18: Trends in rx5day, the annual maximum consecutive 5-day precipitation, for the period 1921-2015. Shaded symbols indicate significant trends at the 5% level

3.2.4.8 Annual maximum length of dry spell, maximum number of consecutive days with precipitation < 1mm

The Continuous Dry Days (CDD) index defines the length of the longest annual period in days with no significant rain, which indicates that this period should fall in the winter months over most of the country, but in the summer months over the south-west where most rainfall is received during winter. While most of the north-eastern half of the country indicated a decrease in the longest annual period of wet days, and the south-western half mostly an increase, the opposite applies for the annual maximum period of dry days. However, it is mostly the stations along the escarpment which show significant decreases in CDD (Figure 3.19). This could indicate that there might be a historical long-term increase in the annual period when there is sufficient influx of moisture from the ocean over the adjacent interior to produce rainfall along the escarpment, which is the main source of rainfall for these areas.

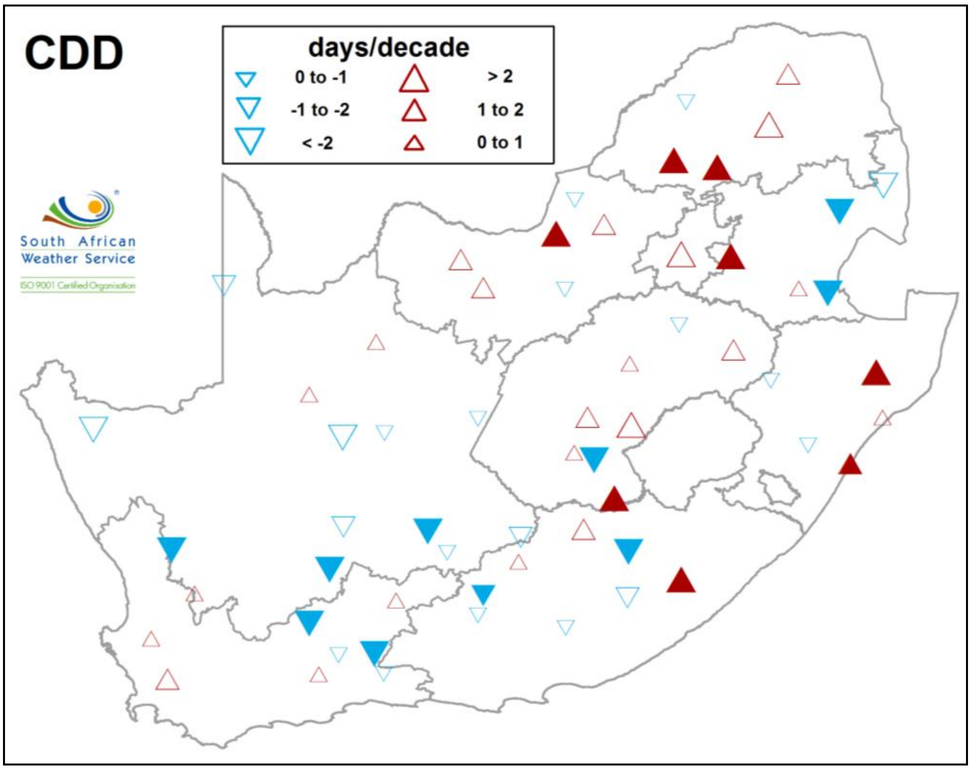


Figure 0.19: Trends in CDD for the period 1921 - 2015. Shaded symbols indicate significant trends at the 5% level

3.2.5 Observed trends in sea-level along the South African coastline

3.2.5.1 Background

Global sea-level rise is a topic of wide spread research, given the larger context of global warming and global climate change. The quantification of sea-level rise (SLR) is not a trivial question due to the non-uniform nature of this phenomenon (Clark, *et al.,* 1978). This is due to the non-uniform deformation of the earth’s shape or geoid due to water and ice loads, the continental configurations and gravitation (Bosboom & Stive, 2015). To explain this non-uniform behaviour of SLR a few definitions are required, as adapted from (Bosboom & Stive, 2015). Local mean sea-level is defined as the vertical height of the sea with regards to a land based beacon. This mean sea level does not take into account the more frequent sea-level fluctuations caused by atmospheric perturbations (e.g. waves, storm surges, etc.) and averages out the astronomic perturbations (tides). In South Africa the mean level (ML) is defined as the mean of the heights of mean high water springs (MHWS), mean high water neaps (MHWN), mean low water springs (MLWS) and mean low water neaps (MLWN), and which vary around the South African coast (Kampfer, 2016). Chart datum (CD) in South Africa is defined as the lowest astronomical tide (LAT) and MSL is usually measured with respect to CD.

The geological environment of the oceans and coasts are also important when definitions of SLR are made. If the SLR is measured with respect to the Earth's centre it is called *eustatic* or *absolute* sea-level change and refers to climate related global changes (Bollmann, 2010). If the vertical movements of the Earth's crust are taken into account it is called r*elative* sea level change (Bosboom & Stive, 2015). Relative SLR is thus the combined effect of both absolute SLR and land subsidence or uplifting and is thus the locally perceived sea-level change (Bosboom & Stive, 2015). In Figure 3.20 these definitions are explained schematically.

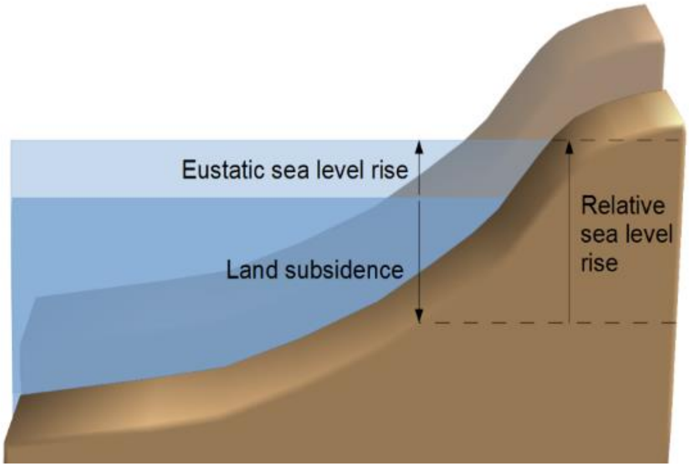
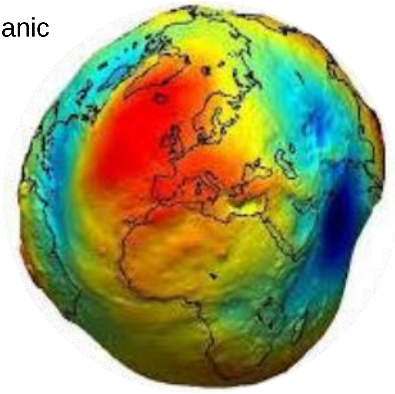


Figure 0.20: Graphical illustration defining Eustatic (**Absolute**) **SLR and Relative SLR.** (**adapted from (Bosboom & Stive, 2015)**)

The change in the sea level can thus be increasing or decreasing and depends on the local land movements. According to Cooper (1995a) the southern part of the African continent is situated on a geologically stable cratonic base which implies that the land masses are not expected to rise or sink significantly (Mather, 2007). This stable base makes southern Africa one of the ideal locations in the world to study global SLR (Mather, 2007).

The causes of eustatic SLR were summarised by (Bosboom & Stive, 2015) and are given as:

- Changes in the actual volume of the ocean due to factors like glaciations and deglaciations (*glacio-eustasy*) or the expansion of the ocean volume due to alterations in atmospheric and / or oceanic temperature or salinity distributions (*steric* alterations),
- Changes in the ocean basin volume due to factors like tectonic plate movements (*tectono-eustasy*), marine sedimentation or the uplift that occurs in oceanic crust during ice ages (*hydro-isostasy*),
- Changes due to alterations in the Earth's gravitational field that result in changing the oceanic geoid or shape of the oceans (*geoidal-eustasy*). In the adjacent figure the



variance of the Earth’s current gravitational field is illustrated (gravimetry). The regions with high gravitational effect are indicated in red and uplifted and the areas with less gravity are indicated in blue and depressed. These types of figures are recently being created with the use of satellite technologies (Anon., 2014).

The complexity of SLR is made even more complex through the reactions of the Earth’s crust due to the loading and unloading of water. Additional water in the ocean will result in an additional force on the Earth’s crust that might have the impact of the ocean floor sinking. In the same response this phenomenon can cause the margins of the continents to flex upwards. The glaciation and deglaciation of the continents can have a similar effect on the landmasses themselves; with land subsidence surrounding land upliftment where glaciers are retreating (Bosboom & Stive, 2015). These changes are called *isostatic changes* and are generally regional and caused by tectonic movements (Bollmann, 2010). Even though the melting and reformation of glacial ice is a natural process the tempo that this process is taking place is alarming (Science Communication Unit, 2016). The past 50 years resulted in extreme warming of the Antarctic and resulted in rapid losses in glacial masses (Abram, *et al.,* 2013). The accelerated tempo of ice loss can be considered an early warning of sea-level rise (Rignot *et al.,* 2011; Science Communication Unit, 2016).

3.2.5.2 Rate of sea level rise

Recent calibrated observations from satellites indicate that global sea level rise over approximately the last decade has been 3.3 +/- 0.4 mm/year (Rahmstorf *et al.,* 2007). The IPCC AR5 SPM 2013 (IPCC, 2013) concludes that anthropogenic global warming and sea-level rise will continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations are stabilised or reduced. In Figure 3.21 an example is provided from (IPCC, 2013) of absolute sea level rise measurements and future scenario sea-level predictions.

Limited research has been done in South Africa regarding SLR. Some literature regarding the topic may be found in Brundrit (1984), Hughes *et al.,* (1991), Mather (2008), Mather *et al.,* (2009) and Mather & Stretch (2012). Climate change and its potential impacts on the South African coastal domain may be found in studies performed by Brundrit (2008), Cartwright (2008), Cooper (1991, 1993, 1995a, 1995b, 2001), Fairhurst (2008); Mather (2012), Midgley *et al.,* (2005), Theron, 2007, 2011) and Theron *et al.,* (2016).

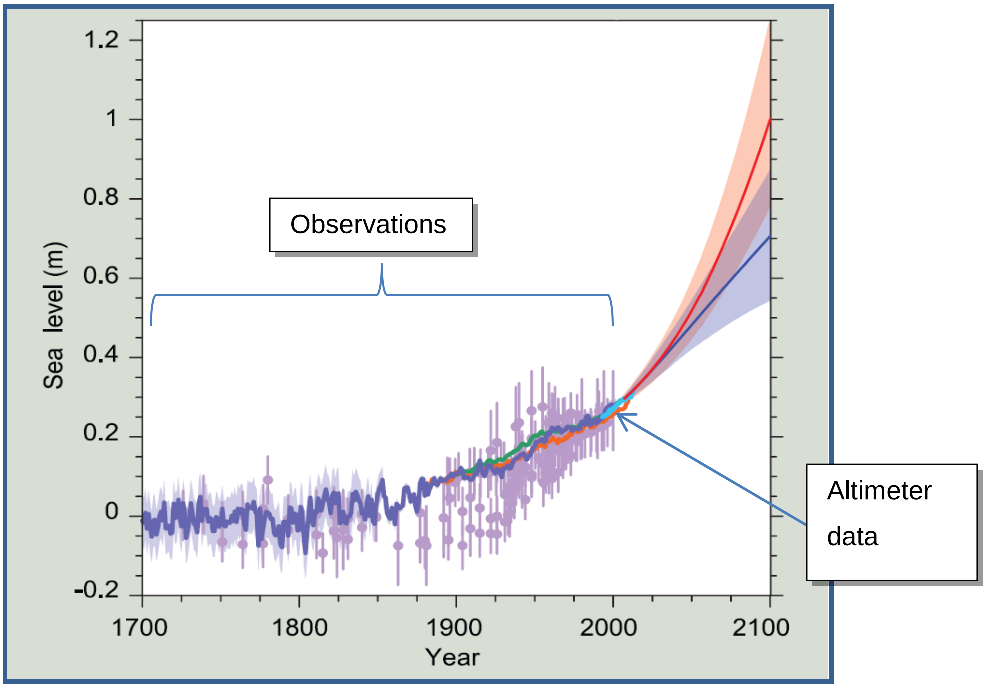


Figure 0.21: Example of measured and predicted sea-level rise adapted from (IPCC, 2013)

The measurements are a compilation of paleo sea-level data (purple), tide gauge data (blue, red and green), and altimeter data (light blue). The projections of the absolute mean sea level rise over the 21st century relative to 1986–2005 formulated on process-based models together with the error ranges indicated in the shaded areas and the corresponding mean value as a solid horizontal line (IPCC, 2013). All of these values are relative to the pre-industrial values.

Relative sea-level rise is a local phenomenon and the study presented by (Mather, *et al.,* 2009) for South Africa and Namibia took into account the vertical local movements of the earth's crust as well as the recorded changes in atmospheric or barometric pressure. The results of their study showed that the West, South and eastern coast of Southern Africa can expect different rates of relative sea-level rise. Both crust movements and barometric pressure varied around the southern tip of Africa resulting in a varying *relative sea level* rise of:

- +1.87 mm/year for the South African West coast (based on intermitted data from 1959 to 2006),
- +1.48 mm/year for the South African South coast (based on intermitted data from 1957 to 2006) and
- +2.74 mm/year for the South African East coast (based on intermitted data from 1967 to 2006).

It should also be mentioned that according to (Douglas, 1997) sea level trends obtained from tide gauges time series shorter than 50 to 60 year will produce misleading trends due to interdecadal sea level variations (Avsar *et al.,* 2016; Parker *et al.,* 2013). Even with long-term records, less than 25% of records indicate consistent global absolute sea level rise trends (Douglas, 1997). Coastal sea levels also tends to have a much stronger interannual, annual and seasonal variability compared to sea level measurements in the global or open ocean (Church & White, 2011), (Feng & Jin, 2015).

New technologies are also becoming more readily available to measure and monitor sea level rise. In a recent study by (Avsar *et al.,* 2016) sea level change along the Black sea coast were analysed using satellite altimetry, tide gauges and GPS observations. They found good agreement between the predicted values of these three measurement techniques. Satellite technologies have not yet been employed in sea level rise studies around the coast of South Africa. Not only can these techniques benefit southern Africa and Africa in estimations of absolute sea level rise scenarios but it can also be utilised in coastal vulnerability assessments.

3.2.6 Provincial trends in climate

3.2.6.1 Northern Cape

The Northern Cape has been experiencing strong temperature increases of 1.5 - 2 °C per century as recorded over the 1931-2015 period. Extreme warm events have also been increasing across the province, and particularly so over the northern interior. Here hot days have been increasing in frequency of occurrence, at a rate of about 2 days/decade. Annual rainfall totals show statistically significant increases over the southeastern interior parts of the province (at a rate of about 5 mm/decade), with associated increases in extreme daily rainfall events (rate of increase is about 2 days/decade in days with rainfall above the 90th percentile threshold). The rate of sea-level rise along the Northern Cape coast has been measured over the last five decades to be in the order of 20 cm/century.

3.2.6.2 Western Cape

The Western Cape has been experiencing a drastic rate of temperature increase of more than 2 °C per century at some locations, as recorded over the 1931-2015 period. Extreme warm events have also been increasing during this period, for example hot days have been increasing at a rate of about 1 day per decade. Annual rainfall totals show statistically significant increases over the eastern interior parts of the province over the last few decades, with the rate of rainfall total increase as high as 10 mm/decade. Associated increases in the number of days with extreme rainfall (daily rainfall above the 90th percentile threshold) have also occurred, at a rate of about 2 days per decade. The rate of sea-level rise along the Western Cape coast has been measured over the last five decades to be in the order of 20 cm/century along the west coast and 15 cm/century along the south coast.

3.2.6.3 Eastern Cape

Over the Eastern Cape, a lack of long-term homogeneous time series data prevents an extensive analysis of temperature trends, and trends in extreme temperature events, to be performed. There is some evidence though, that strong temperature increases of about 2 °C per century has occurred over the western interior of the province over the 1931-2015 period. Annual rainfall totals show statistically significant increases over the western interior parts of the province (rate of increase about

10 mm/year), with associated increases in extreme daily rainfall events (rate of increase about 2 days/decade). The rate of sea-level rise along the Eastern Cape coast has been measured over the last five decades to be in the order of 15 cm/century along the Cape south coast region (in the west), but larger towards the east.

3.2.6.4 KwaZulu-Natal

KwaZulu-Natal has experienced drastic warming over the 1931-2015 period, with stations along the coast reporting temperature increases of more than 2 °C/century. Hot days have been increasing at a rate of about 0.5 days per decade. There is no clear evidence of statistically significant changes in annual precipitation totals or daily rainfall extremes. The rate of sea-level rise along the KwaZulu-Natal coast has over the last five decades been measured to be in the order of 30 cm/century.

3.2.6.5 Mpumalanga

A lack of stations with sufficiently long homogeneous temperature records complicate the identification of temperature trends over Mpumalanga. It is plausible though that the trends are strong though, given the drastic temperature increases recorded over Gauteng to the west, Limpopo to the north and KwaZulu-Natal to the south. There is no evidence of statistically significant trends in annual rainfall or extreme daily precipitation events, but an indication of spatially coherent increases in rainfall over the Highveld areas in the west, and spatially coherent decreases over the Lowveld areas in the east.

3.2.6.6 Limpopo

Strong warming of more than 1 °C per century has been recorded for the province over the period 1931-2015, with the number of hot days increasing by about 1 day/decade over the same period. Stations in the northern parts of the province have also recorded statistically significant decreases in annual precipitation (at a rate of more than 10 mm/decade), but with no statistically significant increases in extreme daily rainfall events that can be discerned.

3.2.6.7 Gauteng

Drastic temperature increases of more than 2 °C/century have been recorded in Gauteng over the period 1931-2015. The number of hot days has been increasing over the same period at a rate of about 1 day/decade. Annual rainfall totals at stations in the province do not exhibit statistically significant trends, but there is evidence of increases in the occurrence of extreme daily rainfall events (rate of increase as high as 2 days per decade).

3.2.6.8 Free State

The analysis of temperature trends over the Free State is hampered by a lack of station data with sufficiently long and homogeneous records. There is evidence though that the warming that is occurring is statistically significant but less in magnitude than over the Northern Cape to the west and

Gauteng to the north. Rainfall stations do not report statistically significant increases in annual precipitation totals or extreme precipitation events, although a spatially coherent pattern of extreme daily precipitation increases is present over the province.

3.2.6.9 North West

A lack of stations with sufficiently long homogeneous temperature records complicate the identification of temperature trends over North West. It is plausible though that the trends are strong given the drastic temperature increases recorded over the Northern Cape to the west, Botswana to the north and Gauteng to the east. There is no evidence of systematic changes in annual rainfall totals, but some evidence of an increase in extreme daily rainfall events.

3.2.7 Conclusions

South Africa has been warming significantly over the period 1931-2015. Over the western parts of the country including much of the Western and Northern Cape, and also in the east over Gauteng, Limpopo and the east coast of KwaZulu-Natal, the observed rate of warming has been 2 °C/century or even higher – more than twice the global rate of temperature increase. Associated increases in extreme maximum temperature events have occurred, but with a decrease in cold nights over most of the country. There is strong evidence of statistically significant increases in rainfall occurring over the southern interior regions over the period 1921-2015, extending from the western interior of the Eastern Cape and eastern interior of the Western Cape northwards into the central interior region of the Northern Cape. Extreme daily rainfall events have increased over these same areas, with these increases also being statistically significant and extending northwards into North West, the Free State and Gauteng. Over Limpopo there is strong evidence of statistically significant decreases in annual rainfall totals.

3.3 Projected climate change futures for South Africa

3.3.1 Introduction: Plausible climate futures for southern African and Africa under low and high mitigation

Climate change is projected to impact drastically on the African continent during the 21st century under low mitigation futures (Niang *et al.,* 2014). African temperatures are projected to rise rapidly, at 1.5 to 2 times the global rate of temperature increase (James and Washington, 2013; Engelbrecht *et al.,* 2015). Moreover, the southern African region and Mediterranean North Africa are likely to become generally drier under enhanced anthropogenic forcing, whilst East Africa and most of tropical Africa are plausible to become wetter (Christensen *et al.,* 2007; Engelbrecht *et al.,* 2009; James and Washington, 2013; Niang *et al.,* 2014). More uncertainty surrounds the projected climate futures of

West Africa and the Sahel, with some climate models projecting wetter conditions and equally credible models projecting drier conditions under climate change (e.g. Christensen *et al.,* 2007; Niang *et al.,* 2014). The changing African climate is likely to have a range of impacts across the continent, including impacts on energy demand (in terms of achieving human comfort within buildings and factories), agriculture (e.g. reductions of yield in the maize crop under higher temperatures and reduced soil moisture), livestock production (e.g. higher cattle mortality as a result of oppressive temperatures), water security (through reduced rainfall and enhanced evapotranspiration) (Thornton *et al.,* 2011; Engelbrecht *et al.,* 2015; Garland *et al.,* 2015) and infrastructure (mostly through the occurrence of more large-scale floods in particular regions).

IClimate change is not to take place only through changes in average temperatures and rainfall patterns, but also through changes in the attributes of extreme weather events. For the southern African region, generally drier conditions and the more frequent occurrence of dry spells are plausible over most of the interior (Christensen *et al.,* 2007; Engelbrecht *et al.,* 2009). Cut-off low related flood events are also projected to occur less frequently over South Africa (e.g. Engelbrecht *et al.,* 2013) in response to a poleward displacement of the westerly wind regime. Tropical cyclone tracks are projected to shift northward, bringing more flood events to northern Mozambique and fewer to the Limpopo province in South Africa (Malherbe *et al.,* 2013). Further to the north, over Tanzania and Kenya, more large-scale flood events may plausibly occur should the future climate regime be characterised by a higher frequency of occurrence of strong El Niño events. Intense thunderstorms are plausible to occur more frequently over tropical and subtropical Africa in a generally warmer climate (e.g. Engelbrecht *et al.,* 2013). More uncertainty surrounds the climate futures of West Africa, the Sahel and the Horn of Africa, particularly within the context of how climate change may impact on the occurrence of mega-droughts over these regions (Lyon and DeWitt, 2012; Williams *et al.,* 2012; Roehrig *et al.,* 2013).

The findings described above are all based on global climate model (GCM) projections of future climate change, or on the downscaling of these projections over Africa through the use of regional climate models (RCMs). The GCMs analysed in Assessment Report Five (AR5) of the Intergovernmental Panel on Climate Change (IPCC) typically had a horizontal resolution of about 200 km. RCMs have typically been applied over parts of the African continent at a resolution of about 50 km in the horizontal, and more recently over the entire continent at a resolution of about 50 km, through the endeavours of the Coordinated Regional Downscaling Experiment (CORDEX) of the World Climate Research Programme (WCRP).

In this section, the most recent projections of future climate change obtained for South Africa are reviewed. The baseline of the discussion is the GCM projections of AR5 of the IPCC and their downscalings to Africa and South Africa, obtained through both statistical and dynamic methodologies. The projections are discussed for both low mitigation (RCP8.5) and high mitigation (RCP4.5) futures, and for near-future (2016-2035), mid-future (2040-2060) and far-future (2080-2099) time-slabs. The discussion focuses not only on the projected changes in average temperatures and rainfall totals, but also in the futures of extreme weather events under climate change.

3.3.2 Methodology

The starting point of the analysis of future climate change over South Africa as described in the TNC, are the projections of the CGCMs of CMIP5 and AR5 of the IPCC. These projections are used to inform on the uncertainty range of the large-scale climate change futures over the southern African region. However, the resolution of the CMIP5 CGCMs are relatively low, in the order of 200 km in the horizontal. These resolutions are too course for the projections to directly find impact in climate change impact studies at municipal and provincial scales. Downscaling methodologies are therefore needed, to obtain projections of future climate change of sufficient detail to aid climate change impacts studies and the formulation of adaptation strategies at the provincial and local scales. In LTAS, and subsequently in the TNC, the most extensive sets of regional downscalings ever obtained in South Africa were used for this purpose. These were obtained using both dynamical and statistical downscaling procedures.

At the CSIR, a dynamic regional climate model CCAM (conformal-cubic atmospheric model) (McGregor, 2005) of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) was used to downscale CMIP5 CGCM projections to 50 km resolution over Africa. These downscalings were performed for the period 1960-2099, and for both Representative Concentration Pathway 8.5 (RCP8.5) and Representative Concentration Pathway 4.5 (RCP4.5) of AR5 of the IPCC. These represent low and modest-high mitigation pathways, respectively. The CGCMs downscaled are the Australian Community Climate and Earth System Simulator (ACCESS1-0); the Geophysical Fluid Dynamics Laboratory Coupled Model (GFDL-CM3); the National Centre for Meteorological Research Coupled Global Climate Model, version 5 (CNRM-CM5); the Max Planck Institute Coupled Earth System Model (MPI-ESM-LR); the Norwegian Earth System Model (NorESM1-M) and the Community Climate System Model (CCSM4). The simulations were performed on supercomputers of the CSIRO and on the Centre for High Performance Computing (CHPC) of the Meraka Institute of the CSIR in South Africa. The CCAM regional climate model has a long track-record of being applied over southern Africa and has been shown to represent many aspects of present-day climate over the region realistically (e.g. Engelbrecht *et al.,* 2009; Engelbrecht *et al.,* 2015). At CSAG statistical downscalings of future climate change over South Africa were performed, using a methodology based on that of Hewitson and Crane (2006). These downscalings were also generated for the period 1960-2099, and for RCP4.5 and RCP8.5. A total of eleven CGCMs of CMIP5 were downscaled.

Although the CSIR dynamic downscalings and CSAG statistical downscalings represent the largest ensemble of downscalings analysed to date over southern Africa, it should be noted that the resulting set of projections sample only a subset of the larger set of CGCM projections obtained for the southern African region. That is, the downscalings may not represent the full uncertainty range of climate change over the region, as represented in the GCM projections. For this reason, the TNC also considers the projections of a larger set of fourteen CGCM projections analysed over southern Africa. Moreover, the results obtained are interpreted against the background of the full set of AR5/CMIP5 CGCM projections for Africa, as described in AR5 of the IPCC (Niang *et al.,* 2014). It may be noted that the analysis presented in the TNC represents a step-up over the SNC, when only a single dynamically derived downscaling and a small set of statistical downscalings were available for reanalysis. In the future, towards the Fourth National Communication, even larger sets of regional projections will be available from local and international downscaling efforts, including CORDEX.

3.3.3 Projected temperature futures for South Africa

3.3.3.1 Average temperature

3.3.3.1.1 Projections from the CMIP5 GCMs under RCP4.5

The GCM projections under RCP4.5 show similar patterns of warming across southern Africa with the strongest warming projected for the interior of the sub-continent, and the weakest warming along the coastal areas. Most of the GCMs are indicative of the western and central interior regions of South Africa warming the most. For the near-future period warming is projected to be between 0.5 to 1 °C at most locations (relatively to the baseline period), reaching values as high as 2 °C over parts of the western interior of South Africa, extending into Botswana (in some of the projections) (Figure B.10a). A greater degree of heterogeneity exists in the GCM projections for the mid-future period 2040-2060 under RCP4.5, but the western interior regions of southern Africa are projected to warm most in almost all the projections, with the magnitude of temperature increases ranging between 2 and 3 °C in most models (Figure B.10b). Warming continues deeper into the 21st century, reaching values of 3-4 °C over the western interior regions for the period 2080-2099 in most of the model projections (Figure B.10c).

3.3.3.1.2 CSAG statistical downscalings under RCP4.5

Under RCP4.5 the CSAG statistically downscaled temperature projections are largely consistent with those of the GCMs (Figures C2a, C2b and Figure 3.22). An exception is that for the near-future period (2016-2035) some of the statistical downscalings are more conservative compared to the forcing GCM projections, producing temperature increases of less than 0.5℃. Consistent with the GCM projections, a number of the statistical downscalings are indicative of temperature increases of more than 4 °C over the western and central subtropical interior regions by the far-future period of 2080-2099 under RCP4.5.

3.3.3.1.3 CCAM dynamic downscalings under RCP4.5

As for the cases of the GCM projections and statistical downscalings, there is close correspondence between the different dynamic downscalings obtained for the period 2016-2035 under RCP4.5 (**Error! Reference source not found.**B.12a). General temperature increases of 1-2 °C are projected for the central interior, with increases of less than 1 °C projected for the coastal areas. One of the projections is indicative of temperature increases as large as 2.5℃ over parts of the central interior, including the Free State and North West provinces. Only relatively slight further temperature increases of up to 2.5 °C are projected for the central and western interior by 2040-2060, with increases reaching 1-2 °C over the remaining parts of the country, under RCP4.5 (Figure B.12b). There is a single downscaling in which the warming reaches up to 3.5 °C over the western to central interior by the mid-future. For the far-future time-slab of 2080-2099, further warming is projected to occur (Figure 3.23). Over the western and central interior, the projected warming ranges from 3 °C to 4.5 °C across the ensemble.

3.3.3.1.4 Projections from the CMIP5 GCMs under RCP8.5

The GCM projections under RCP8.5 show close correspondence for the RCP4.5 projections for the near-future period of 2016-2035, warming is projected to range be between 0.5 to 1 °C at most locations reaching values as high as 2 °C over parts of the western interior of South Africa (Figure **Error! Reference source not found.**B.13a). However, by for the mid-future period of 2046-2065 the projected warming is significantly stronger under RCP8.5, ranging from 3 – 4 °C over the western and central interior (Figure B.13b), and exceeding 4 °C over some of the western parts. For the far-future period of 2080-2099 drastic warming of more than 4 °C is projected for the entire southern African region, with the exception of the southern coastal regions (Figure B.13c).

3.3.3.1.5 CSAG statistical downscalings under RCP8.5

Close correspondence exists between the statistical downscalings of temperature and the projections of the host GCMs under RCP8.5, for each of the future periods 2016-2035, 2045-2065 and 2080-2099 (Figure B.14a and C5b). For the far-future period of 2080-2099 drastic warming of more than 4 °C is projected for the entire southern African region, with the exception of the southern coastal regions (Figure 3.24). In fact, warming of more than 6 °C is projected for much of the western interior by some of the downscalings for the far-future under RCP8.5.

3.3.3.1.6 CCAM dynamic downscalings under RCP8.5

As for the cases of the GCM projections and statistical downscalings, there is little difference between the RCP4.5 and RCP8.5 dynamic downscalings for the near-future period 2016-2035 (Figure B.15a). General temperature increases of 1-2 °C are projected for the central interior, with increases of less than 1 °C projected for the coastal areas. One of the projections is indicative of temperature increases as large as 2.5℃ over parts of the central interior, including the Free State and North West provinces. Significant differences exist between the RCP4.5 and RC8.5 dynamic downscalings for the mid-future period, however, with warming projected to range from 2.5 °C to as high as 4.5 °C over the western and central interior regions (Figure B.15b). For the far-future time-slab of 2080-2099, drastic warming of more than 5 °C is projected for most of the southern African region, with only the southern and eastern coastal areas and adjacent interiors projected to experience relatively smaller increases (Figure 3.25).

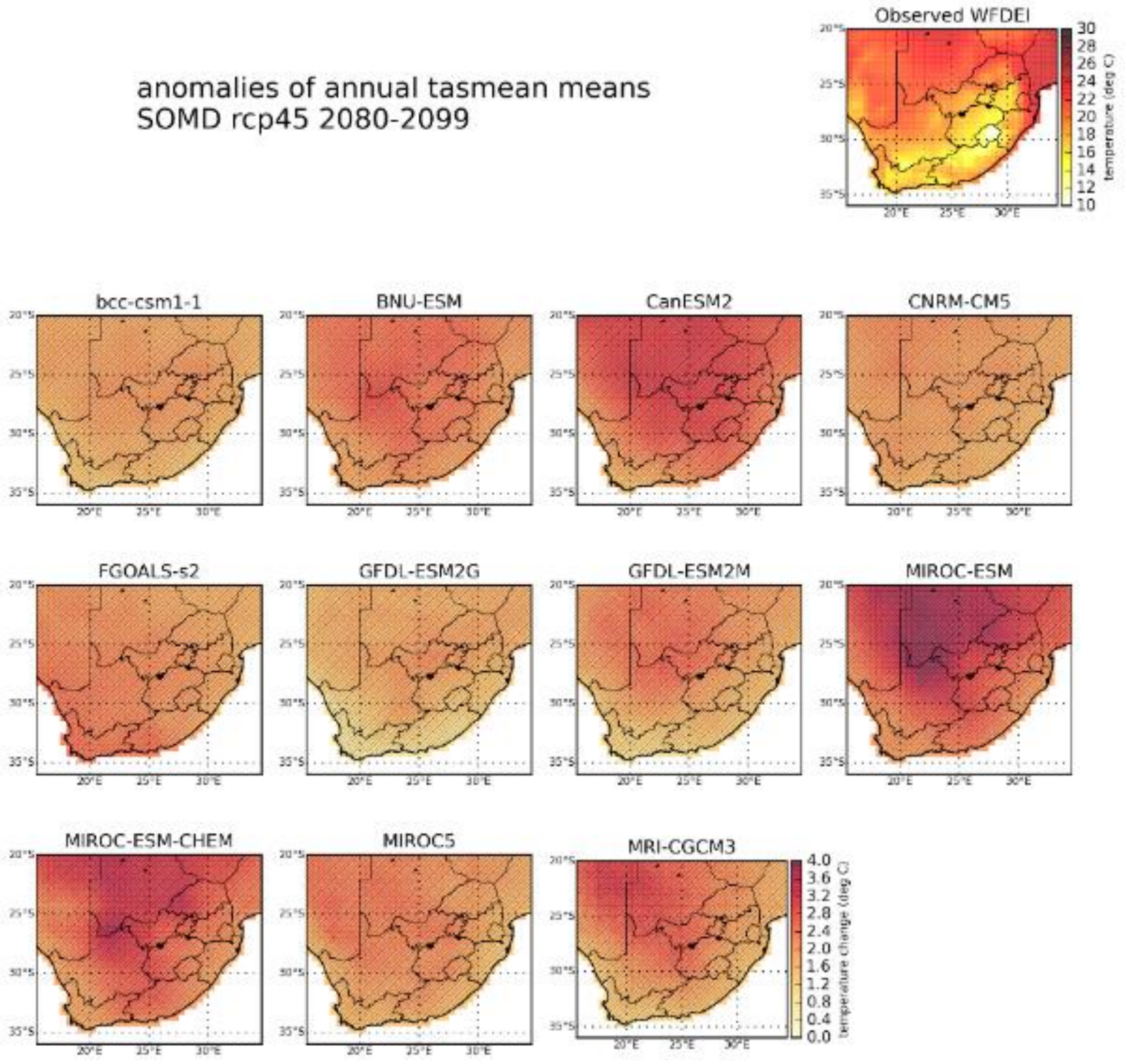


Figure 0.22: Downscaled projected changes in annual mean temperature under RCP 4.5 for the 2080-2099 period

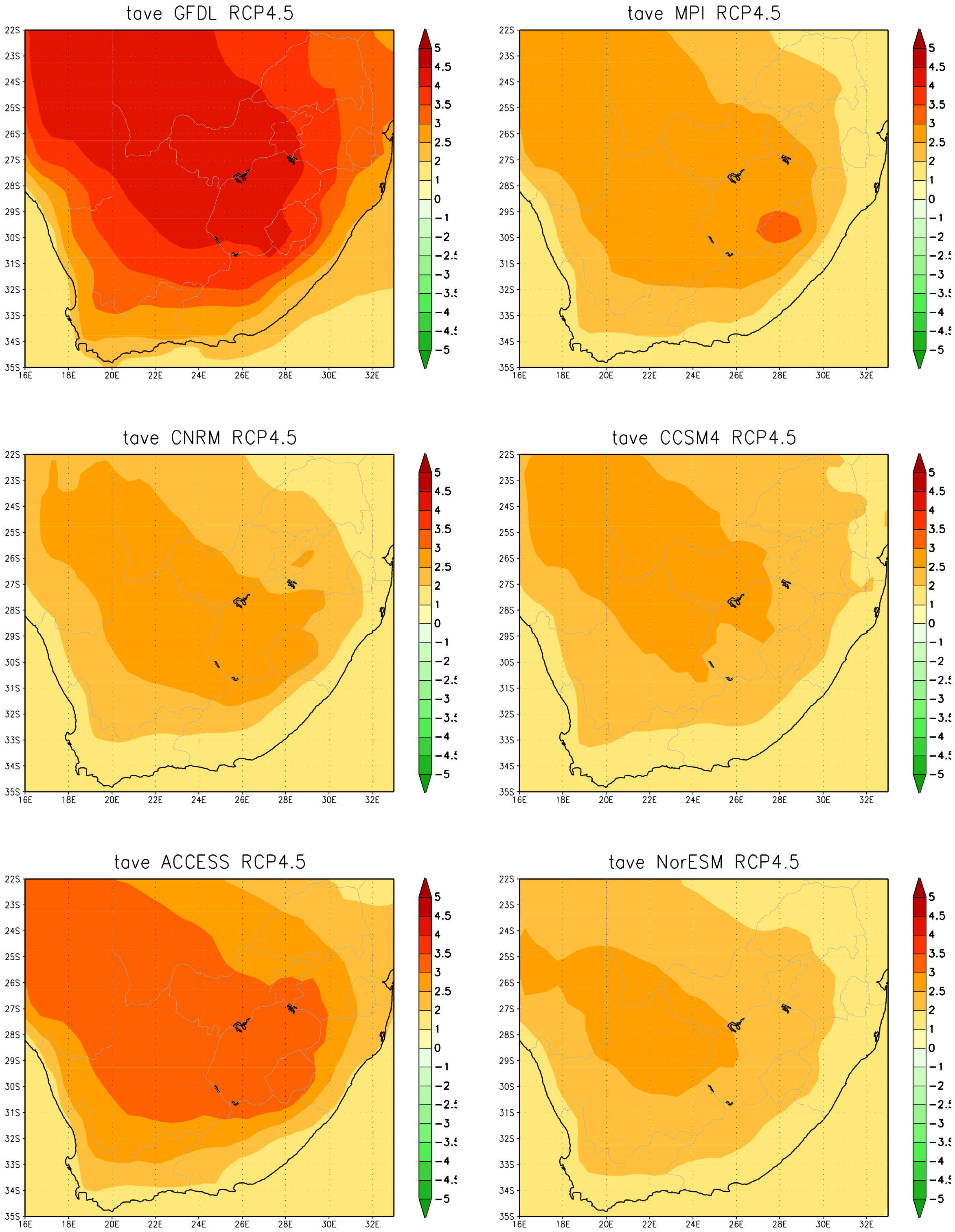


Figure 0.23: CCAM dynamically downscaled projected changes in annual mean temperature under RCP 4.5 for the 2080-2099 period

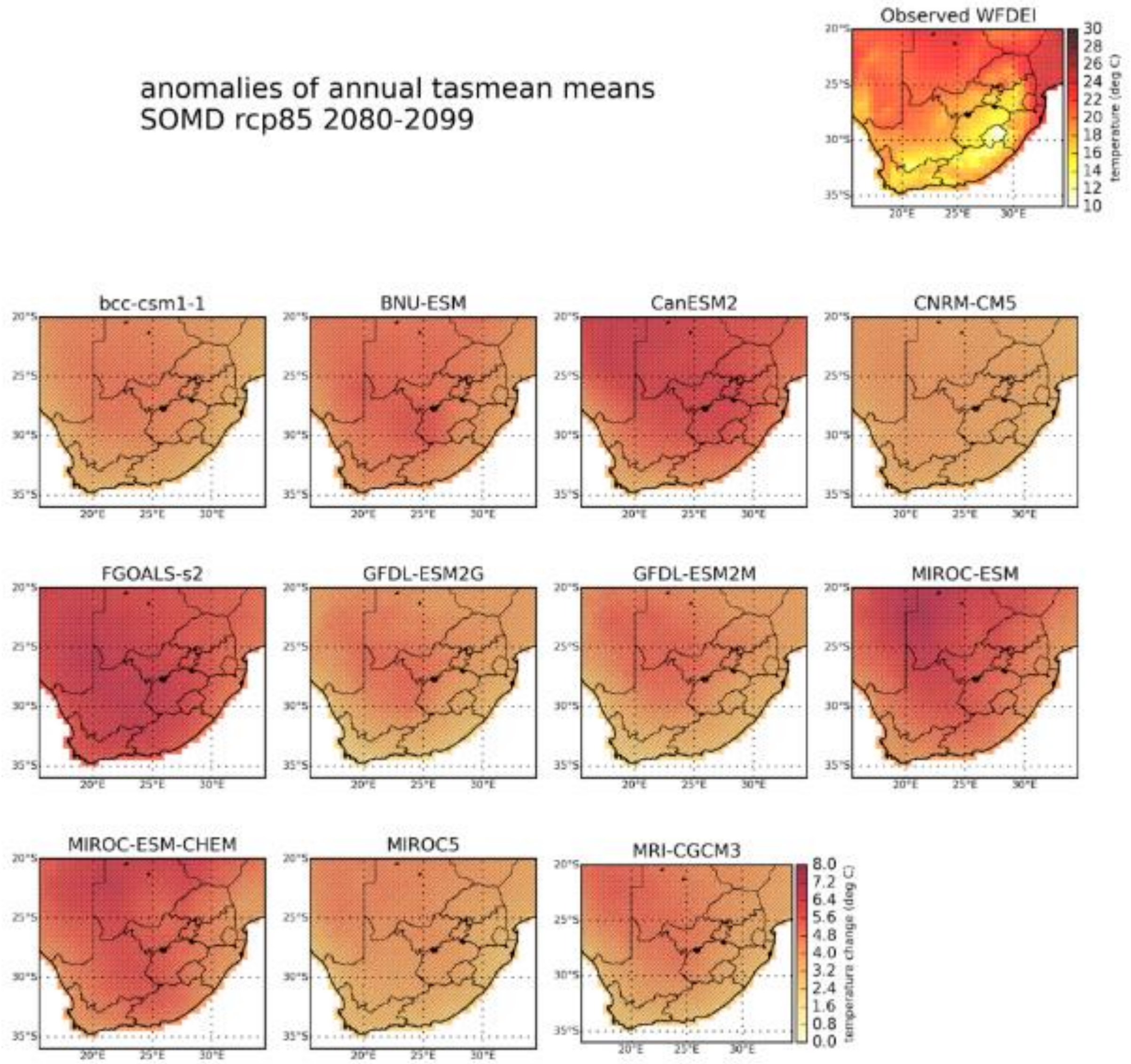


Figure 0.24: Downscaled projected changes in annual mean temperature under RCP 8.5 for the 2080-2099 period

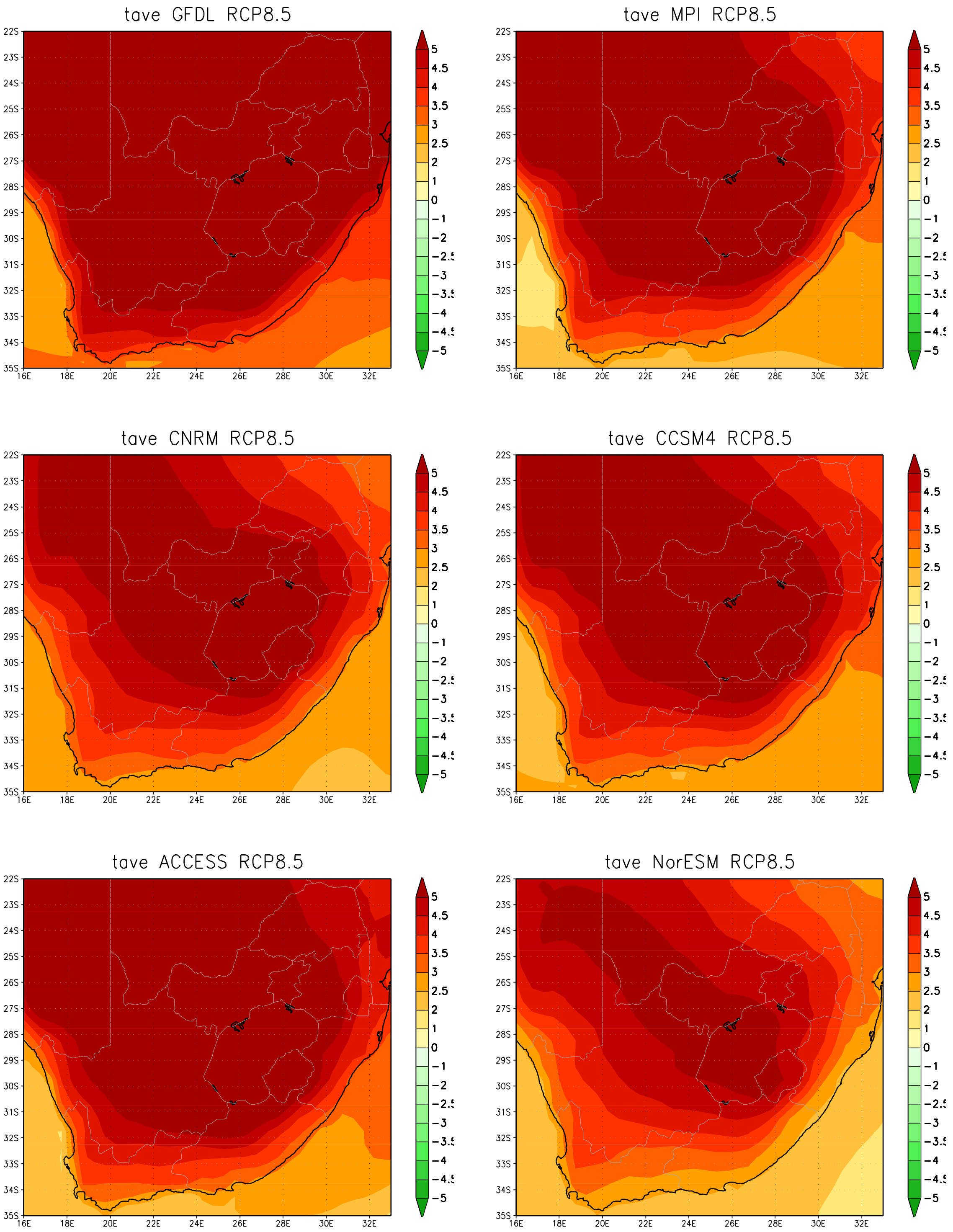


Figure 0.25: CCAM dynamically downscaled projected changes in annual mean temperature under RCP 8.5 for the 2081-2099 period

3.3.3.2 Very hot days

3.3.3.2.1 Projections from the CMIP5 GCMs under RCP4.5 and RCP8.5

As one of the most problematic consequences of increasing mean temperatures is an increase in the number of very hot days (here defined as days when the maximum temperature exceeds 35 °C) with serious societal consequences including health (Kovats, 2008; Campbell, 2007), energy demand (Isaac, 2009) and agriculture (Schlenker and Lobell, 2010). While changes in the statistics for the near future are largely insignificant for the near future period (except for the Northern Cape, North West, and Limpopo), for RCP8.5 for the far-future, increases as large as 120 days are projected (Figure to B.167c and Figure B.10a to B.10c). Considering that for the Northern Cape, currently only around 60 days a year exceed this threshold, such large changes would have severe consequences in many areas. Even under the more conservative RCP4.5 scenario, increases as high as 80 days a year are projected by some models by the end of the century. It is clear that for sectors currently sensitive to extreme temperatures, exposure to such events will almost certainly pose a serious risk in the future.

3.3.3.2.2 CSAG statistical downscalings under RCP4.5 and RCP8.5

The CSAG statistical downscalings are consistent with the forcing GCMs (Figure B.17a, B.17b and 3.26; B.20a, 3B.20b and 3.28) the western parts of southern Africa, increases in the number of very hot days may reach 40 as early as 2016-2035 even under RCP4.5, with increased of as many as 80 or more of these days occurring widespread over the southern African interior under RCP8.5

3.3.3.2.3 CCAM dynamic downscalings under RCP4.5 and RCP8.5

The dynamic downscalings are indicative of increases in the number of very hot days by as many as 20-40 per year over the western and central interior for the period 2016-2035, even under the high mitigation scenario RCP4.5 (Figure B.18a and B.21a). For the period of 2046-2065, these increases are projected to be as high as 40-80 days per year, with more than 80 more very hot days plausible for the far-future period (Figure C9b and C12b). Under RCP8.5, increases of in the number of very hot days may be as high as 80 days in the far west, with these drastic changes spreading to the entire southern African interior by the far-future period of 2080-2099 (Figure 3.27 and 3.29).

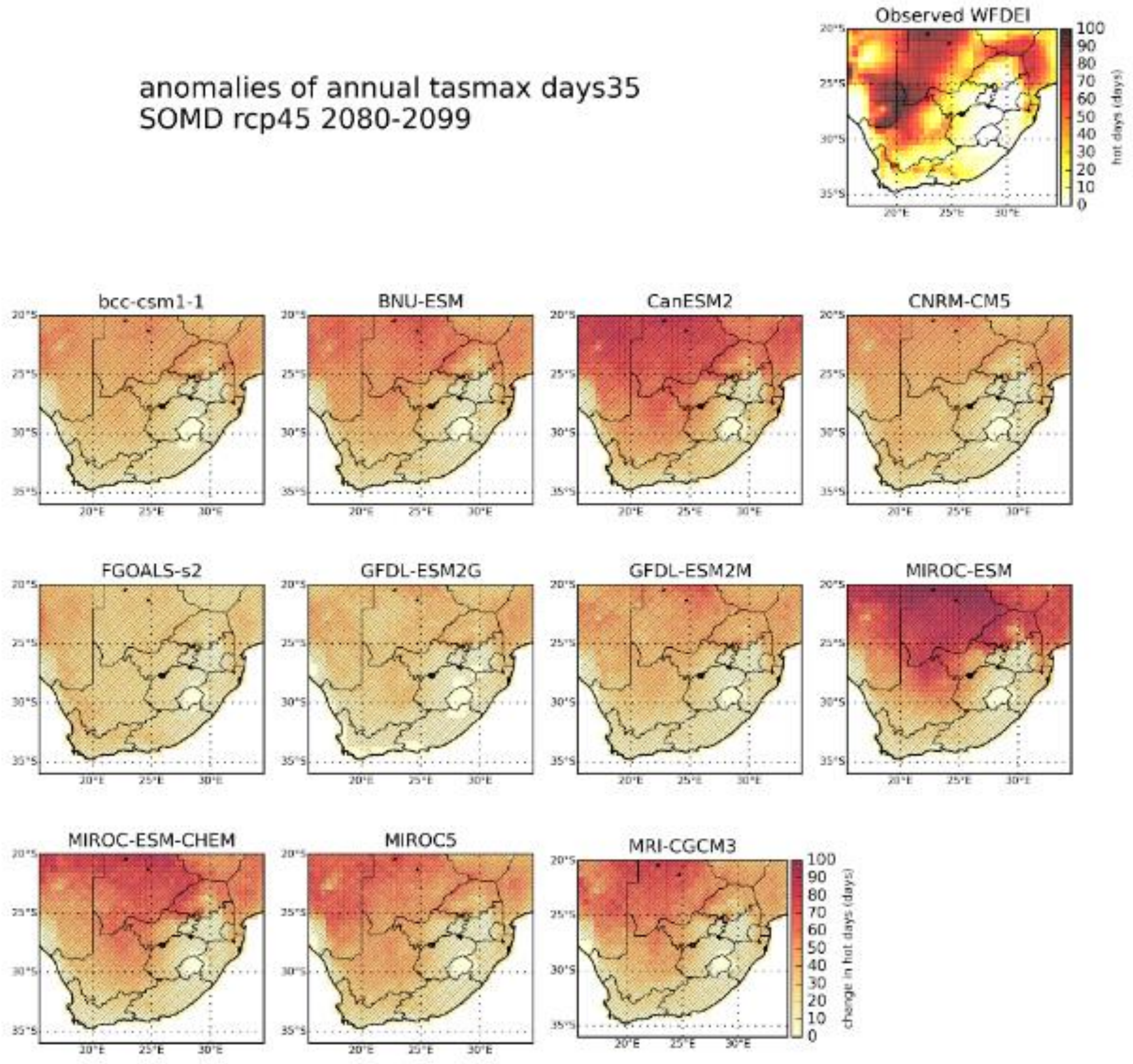


Figure 0.26: Statistically downscaled changes in the number of very hot days under RCP4.5 for the 2080-2099 period.

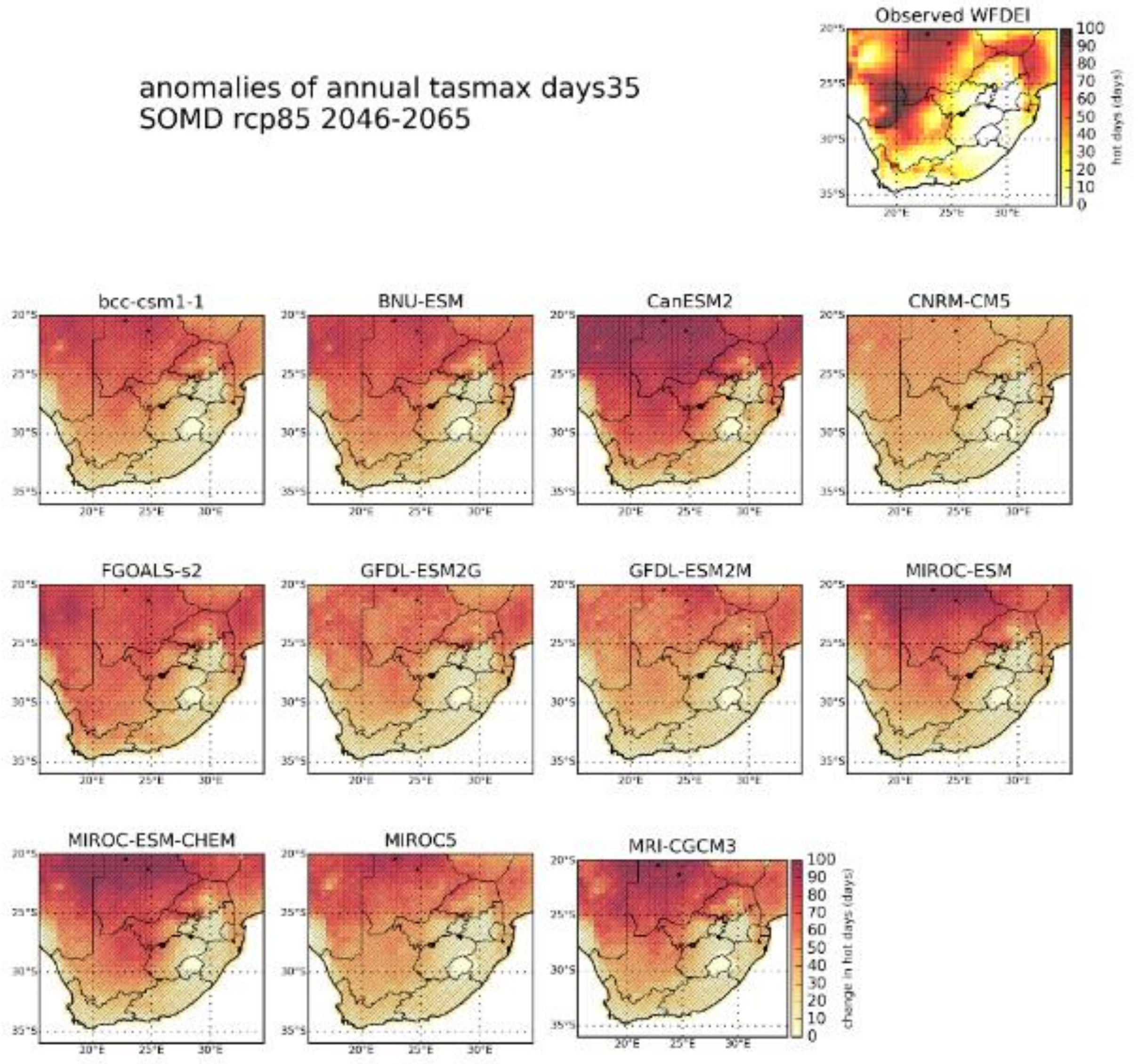


Figure 0.27: Statistically downscaled changes in the number of very hot days under RCP8.5 for the 2046-2065 period

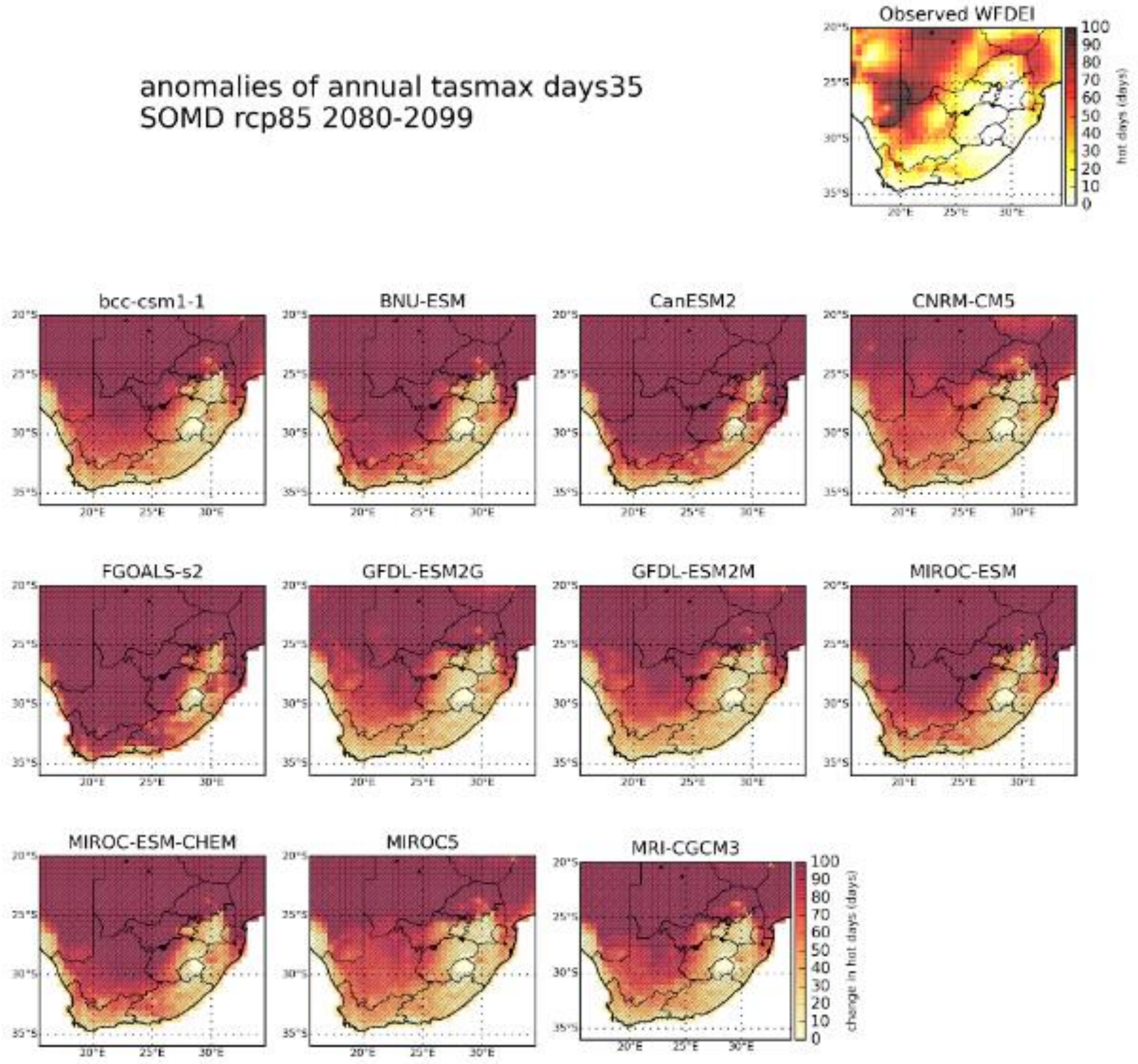


Figure 0.28: Statistically downscaled changes in the number of very hot days under RCP8.5 for the 2080-2099 period

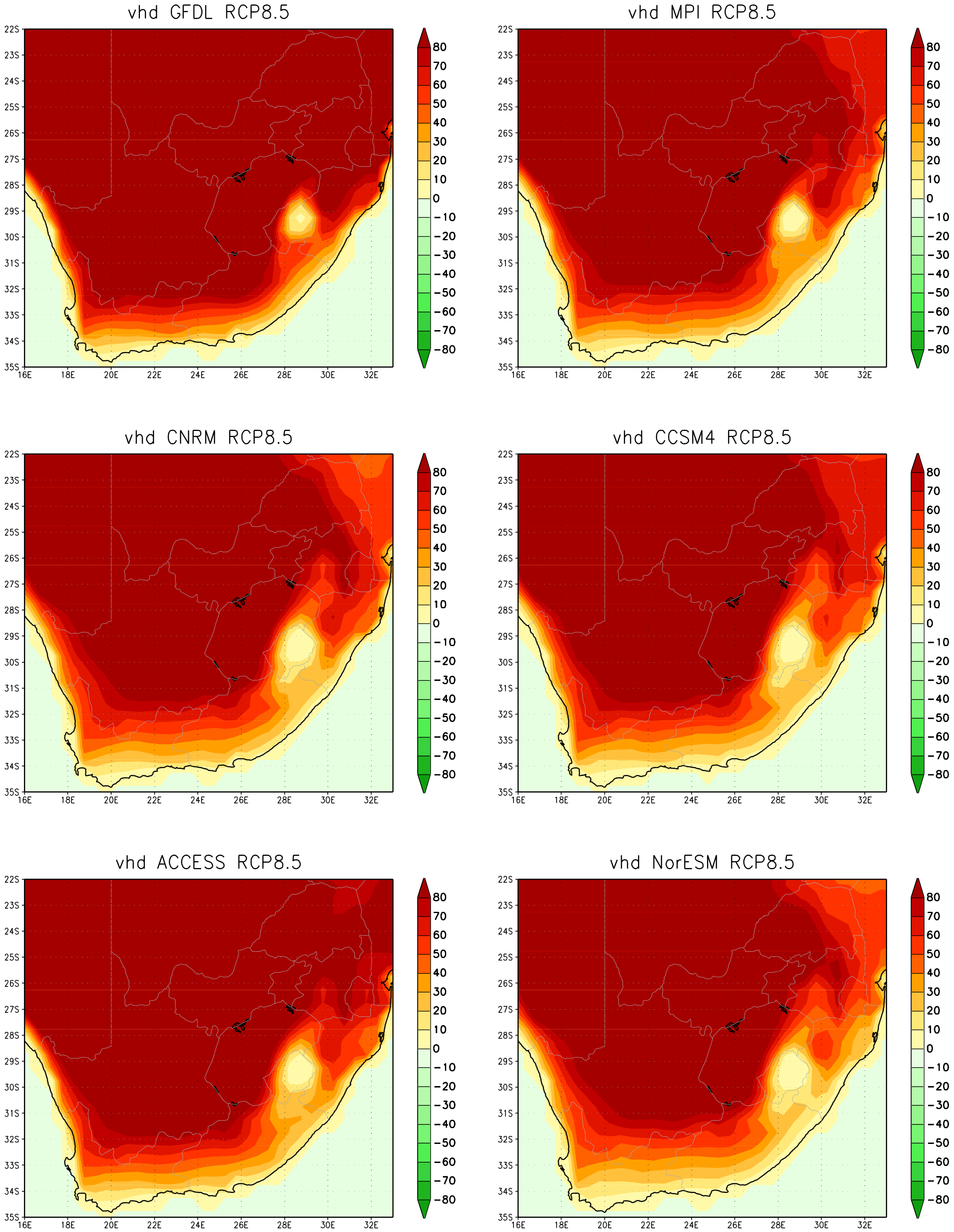


Figure 0.29: Dynamically downscaled changes in the number of very hot days under RCP8.5 for the 2080-2099 period.

3.3.4 Projected rainfall futures for South Africa

3.3.4.1 Rainfall totals

Projected changes in rainfall totals and other statistics derived from GCMs need to be treated with some caution. As explained in the introduction to this section, GCMs necessarily simplify various aspects of the climate system including topography, convective rainfall processes, and cloud microphysics processes, which are all critically involved in the production of rainfall. As a result, GCMs typically do not capture local or regional scale rainfall patterns and often have significant biases (too much rainfall or too little rainfall) relative to observations. However, GCMs are able to capture large scale shifts in circulation features such as the Hadley circulation, or the positioning of the southern hemisphere jet stream. In many cases GCMs agree on shifts in these large scale processes into the future (e.g. Barnes 2013). It is therefore important to (a) focus on large scale shifts in rainfall produced by GCMs, rather than focus on local scale changes which are likely poorly represented in the models, and (b) to explore downscaling approaches to gain insights into local scale precipitation changes as a result of large scale circulations changes.

3.3.4.1.1 GCM projections of changing rainfall patterns under RCP4.5 and RCP8.5

For the early (2016-2035) period, regardless of RCP, the models show mixed but relatively weak and not statistically significant messages of change in annual total rainfall across the country (Figure B.22a and B16a). Towards the mid period (2046-2065) in both RCPs many models show significant changes with the majority of models showing decreased rainfall and a few showing increased rainfall in various regions (Figures C13B. and C16b). Towards the late period this message increases with the majority of models showing significant drying over many parts of the country and only a few models showing increased rainfall under RCP8.5 (Figure B.25c). Under RCP 4.5 some models continue to show increased rainfall through to the end of century (Figure B.22c).

3.3.4.1.2 CSAG statistical downscalings of changing rainfall patterns under RCP4.5 and RCP8.5

For the early (2016-2035) period, regardless of RCP, the downscaled models show mixed but relatively weak and not statistically significant messages of change in annual total rainfall across the country (Figure **Error! Reference source not found.**B.23a and B.26a). Towards the mid period (2046-2065) in both RCPs many models show significant changes (Figures B.23b and B.25b). However, the Self-Organising Map (SOM) downscaled projections show a much more even split between increasing and decreasing rainfall compared to the driving CMIP5 GCM projections. Towards the late period for both RCPs, but particularly for RCP 8.5, this message increases with stronger changes emerging but still a more equal split between increasing rainfall and decreasing rainfall projections (Figures B.22c and B.25c).

3.3.4.1.3 CCAM dynamic downscalings of changing rainfall patterns under RCP4.5 and RCP8.5

The general pattern that emerges from the CCAM projections is one of a generally drier southern Africa, under both RCP4.5 (Figures B.24a, B.24b and 3.21) and RCP8.5 (**Error! Reference source not found.**B.27a, B.27b and 3.33). However, for high mitigation (RCP4.5) and for RCP8.5 in the near-future there is uncertainty in this signal for some regions, with a number of downscalings indicating wetter conditions over particularly the central and northeastern interior regions of South Africa (Figures B.24a and B.27a). However, for the stronger climate-change signal projected under RCP8.5, the signal of a generally drier southern Africa becomes a consistent message across the different downscalings for the mid-future and far-future periods.

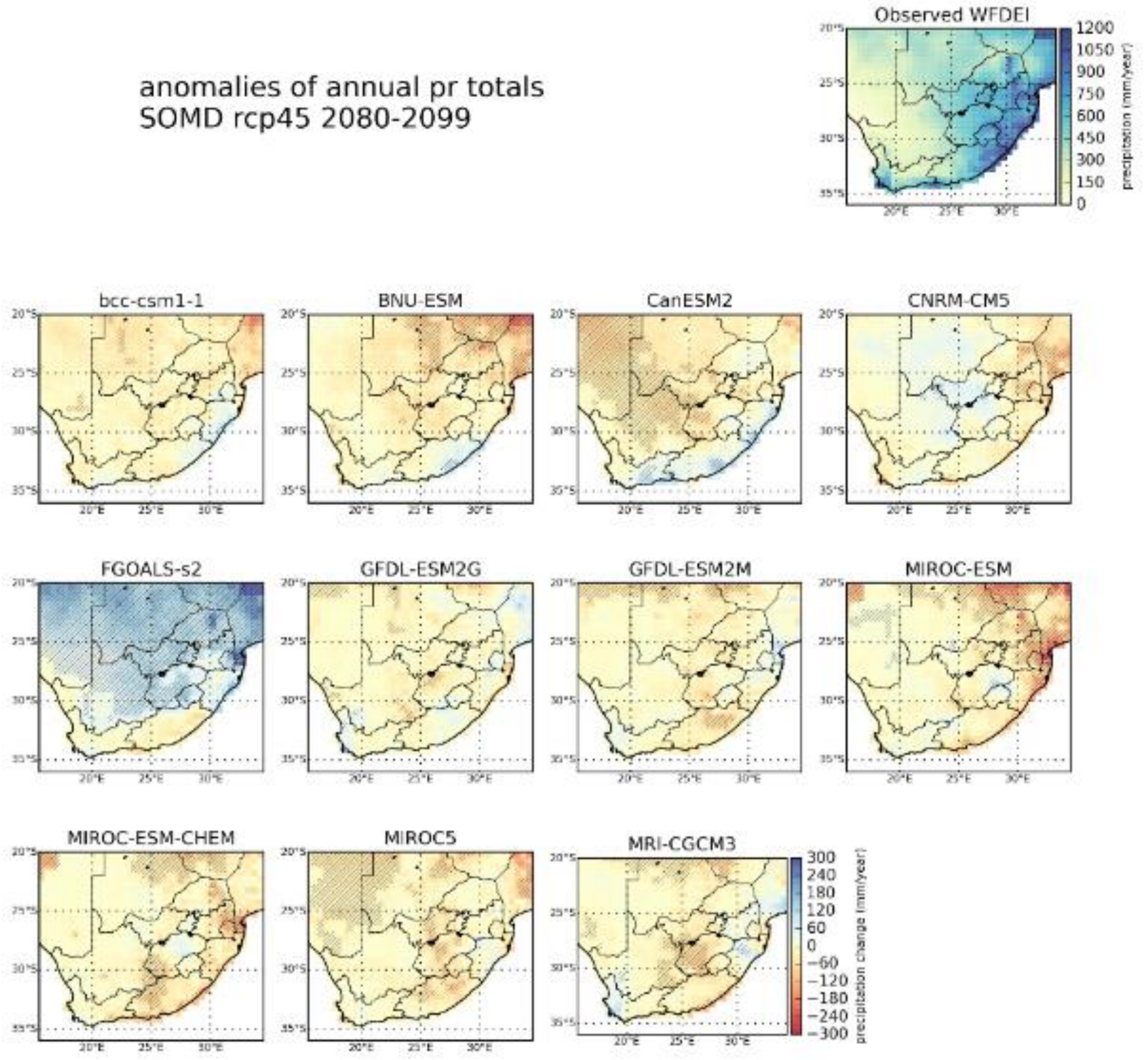


Figure 0.30: Statistically-downscaled projected changes in annual total rainfall (**mm**) **under the RCP 4.5 pathway for the 2080-2099 period.**

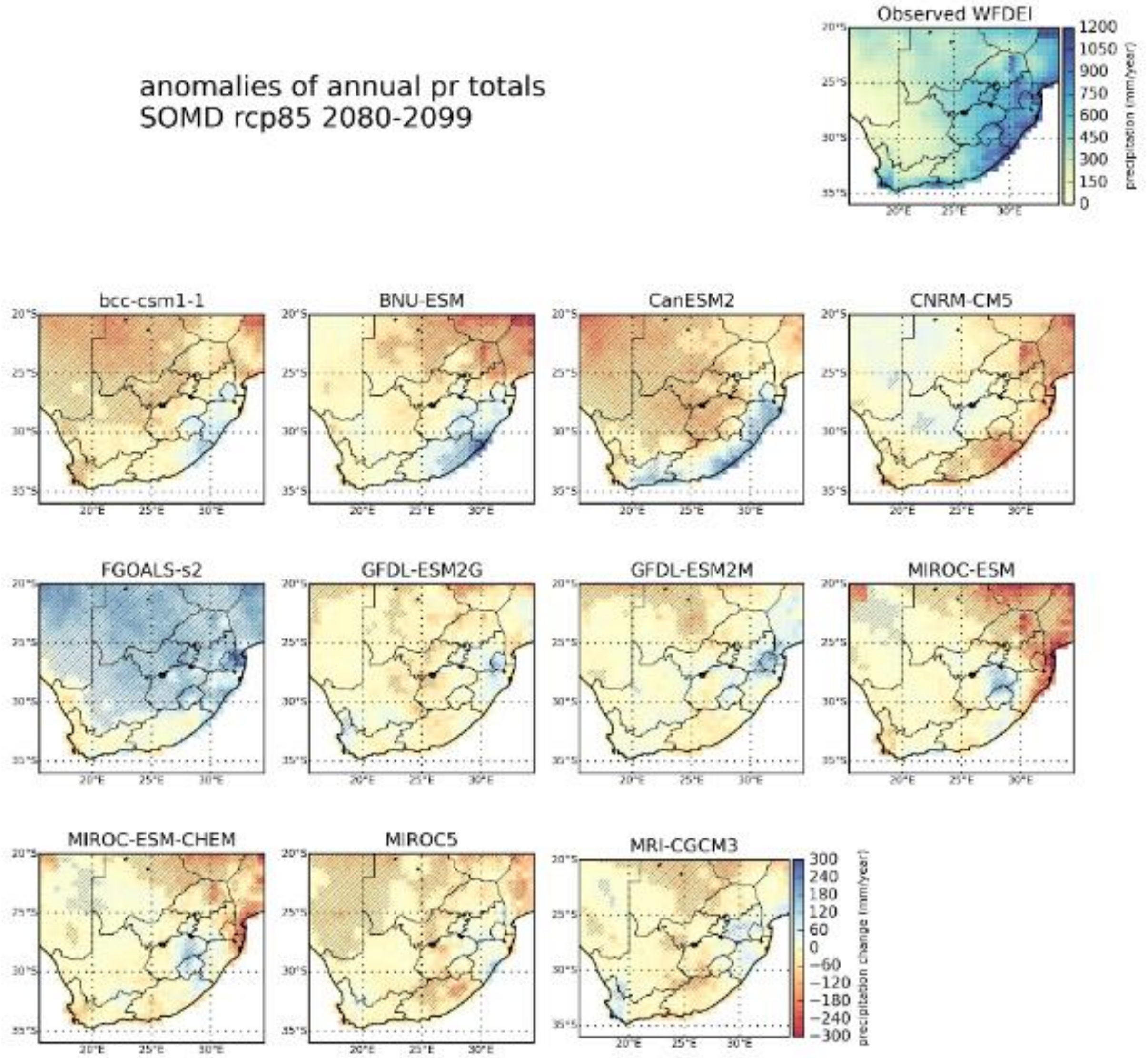


Figure 0.31: Statistically-downscaled projected changes in annual total rainfall (mm) under the RCP 8.5 pathway for the 2080-2099 period.

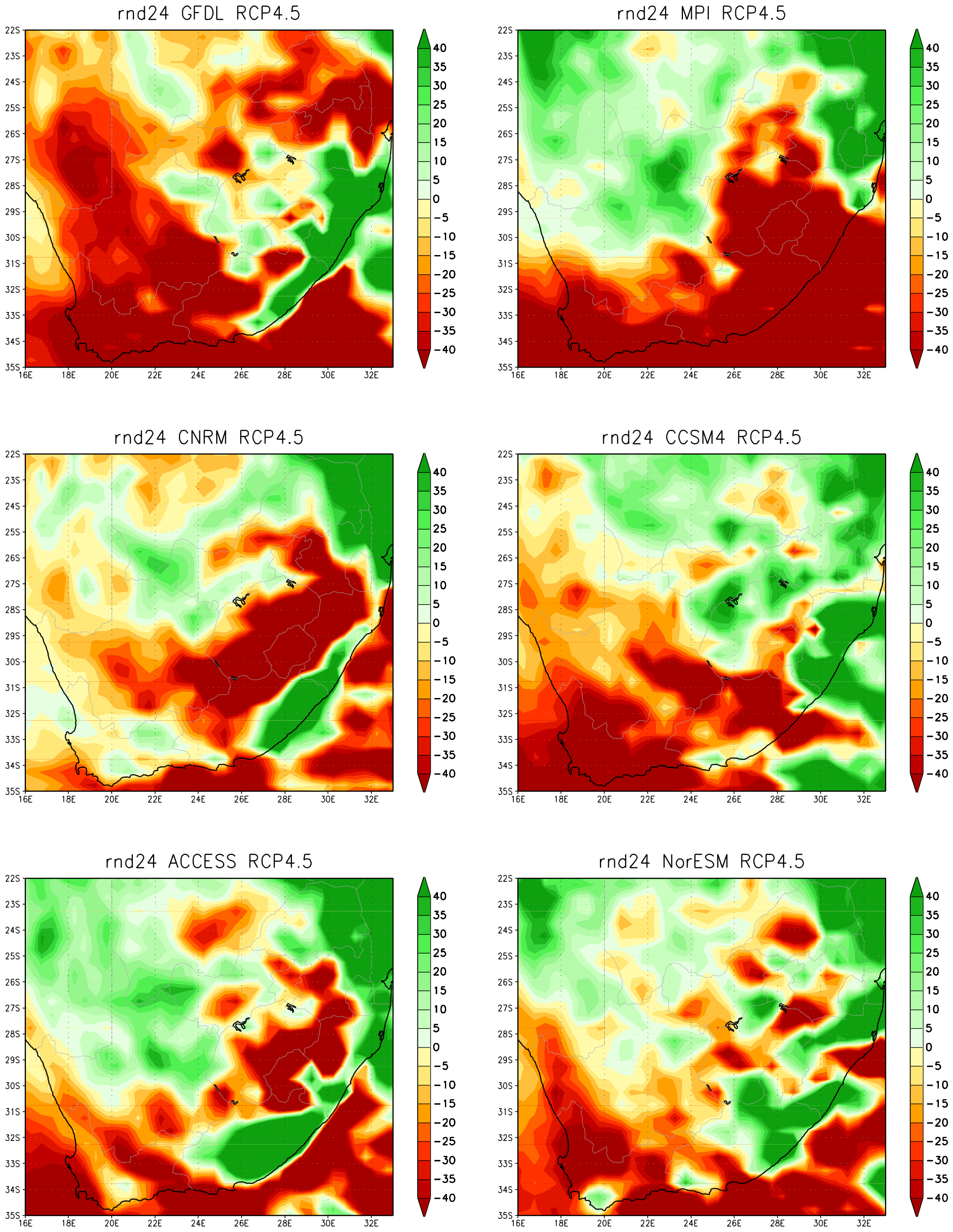


Figure 0.32: CCAM dynamically downscaled projected changes in annual total rainfall (mm) under the RCP 4.5 pathway for the 2080-2100 period.

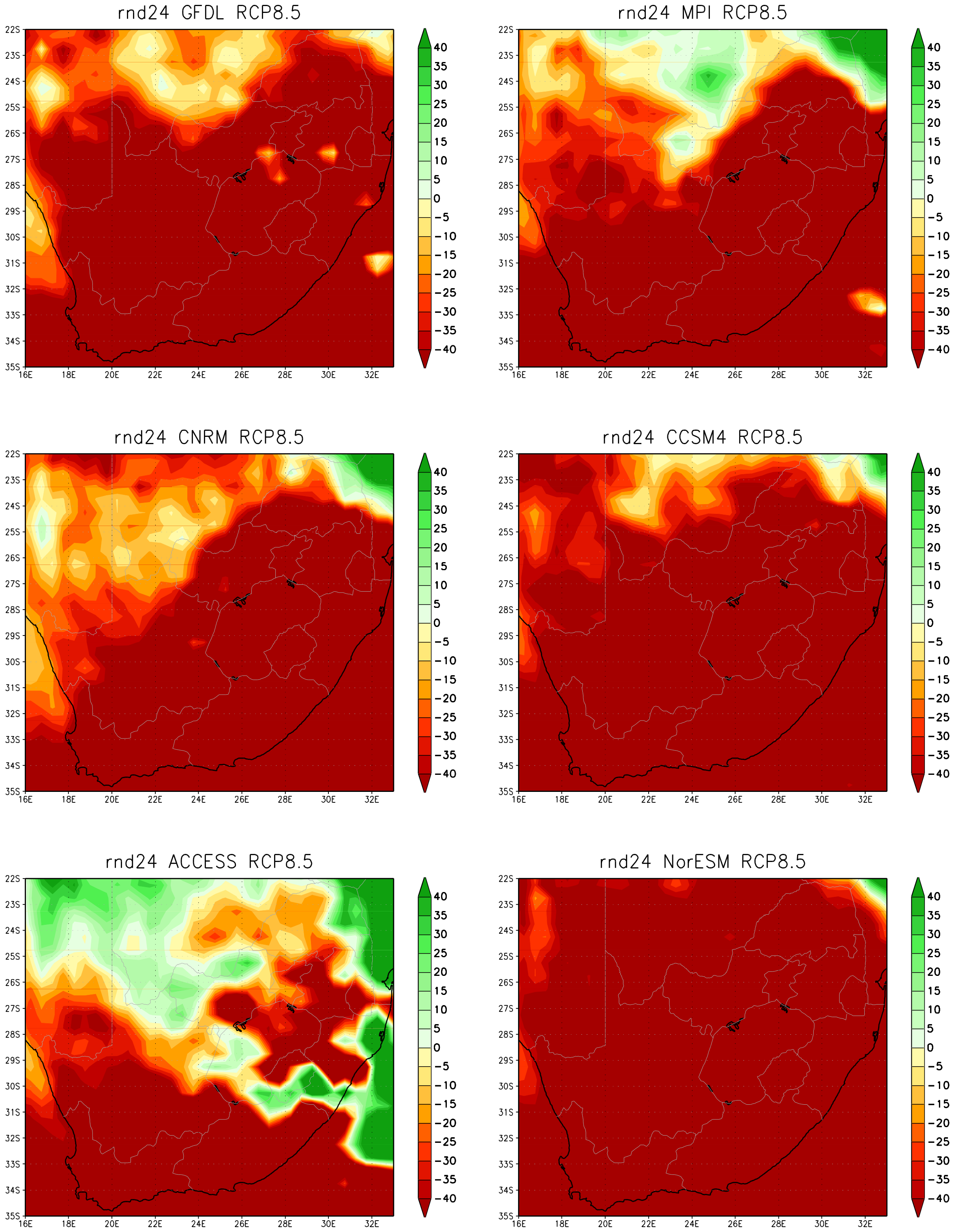


Figure 0.33: CCAM dynamically downscaled projected changes in annual total rainfall (mm) under the RCP 8.5 pathway for the 2080-2099 period.

3.3.5 Projected changes in sea-level along the South African coastline

3.3.5.1 Background

The frequency and intensity of extreme weather events will plausibly increase during the 21st century under enhanced anthropogenic forcing (IPCC 2007). This includes plausible decreases in the return period of extreme storm surges (high sea-level events), which may well be as large as an order of magnitude by the end of the century (IPCC, 2013). Surge events (and associated storms) are region specific, however, and as a consequence the projections of detailed regional changes are of relatively low confidence (IPCC, 2013). In South Africa, increases in either intensity or frequency, or changes in seasonality have been reported at a local scale for certain coastal areas (Guastella and Rossouw 2012, Harris 2010) - although for periods of insufficient length to deduce whether these changes can be attributed to systematic climate change (as opposed to natural variability). Other short-term and local evidence of changing storminess can be found in the fishery sector: climate change can potentially influence fisheries though alterations in temperature, oxygen, coastal upwelling, currents and biological and ecological changes. Moreover, increases in the number of days with adverse weather conditions will negatively affect the number of days fishermen can go out to sea. Such changes have indeed been observed for the South African south coast in recent years, as reported by CCAMPF (2016). The number of fishing days for small-craft fisheries has dropped significantly due to an increase in the amount of days with strong wind events. Small-scale fisheries that operate from the shore or from small, relatively unprotected harbours or slipways are most vulnerable to this increase of storminess days (CCAMPF, 2016). It is unlikely though that this phenomena is due to long-term climate change effects - rather it is the outcome of natural climate variability. Nevertheless, the long term monitoring of these types of impacts might play a valuable role in understanding and mitigating climate change effects on the daily lives of people living in the coastal zone.

Generally, increases in sea-level rise alone may greatly increase the impacts of extreme sea-storm events (Theron 2007). The regional variation in the global wave climate was demonstrated by Mori *et al.,* (2010), who, in simulating future trends, predicted that mean wave height might generally increase in the regions of the mid-latitudes (both hemispheres) and the Antarctic ocean, while decreasing towards the equator. Wang *et al.,* (2004), Komar and Allan (2008) and Ruggierio *et al.,* (2010) provide further evidence of a general wave height increase and increasing storm intensities in the Northern Hemisphere. Such changes in the regional ocean climates are expected to have significant impacts on local coastal areas. It is therefore important to also investigate possible future climatic changes off the southern African coastline as well as the expected associated impacts. As can be anticipated, a more severe wave climate (or related oceanic wind climate) will result in more storm related erosion (*episodic erosion*), potentially more coastal sediment transport, and greater coastal impacts.

3.3.5.2 Wave-generating mechanisms for the southern African coast

The following section gives a brief overview of the typical weather systems responsible for generating the waves along the coast. This section also presents a description of the wave climate derived for the SA coast, in terms of general and extreme climates.

The general weather climate of the southern African oceans is influenced by different types of synoptic pattern (MacHutchon, 2006). These include the following pattern types:

- The semi-permanent subtropical high-pressure cells off the west and east coasts (Figure B.28a). This weather system is responsible for the higher-frequency wave conditions on the west coast. During the summer season, this system generates waves on the west coast that propagate in a north-north-easterly to northerly direction with peak wave periods (Tp) ranging from about 5 to 10 seconds.
- The cold front system comprising a low-pressure cell associated with a front of cold air coming from the south or south-west (**Error! Reference source not found.**B.28b). This type of weather system is responsible for most of the wave conditions along the South African coast, which include long-period swell to local sea conditions. The waves can approach from a westerly direction on the west coast to a south-westerly direction on the south coast. The peak period and range vary from 5 s to 20 s. Significant wave heights of more than 10 m can be expected during extreme storm events.
- Cut-off low (COL) systems (Figure B.28c). These systems normally consist of a low-pressure cell blocked by two high-pressure cells on either side. COL systems are relatively common but during stationary periods can result in extreme storms along the south-east and east coasts.
- Tropical cyclones (**Error! Reference source not found.**B.28d). These systems occur mainly on the east coast, along the Mozambican and SA east coast, to the north of Durban. Apart from being able to produce significant rain floods, these cyclones can generate extreme wave conditions, similar to those of the COL systems.

The waves occurring off the east coast are generated by basically three different mechanisms apart from local winds. The general waves originate from a frontal system (low-pressure cells) passing the South African coast. The system is responsible for the major storm events on the Cape south-west coast but has less of an impact on the east coast. An example of this type of system is shown in **Error! Reference source not found.**B.20.

Most of the swell waves encountered off the east coast are generated by this type of weather system. However, it appears that the large wave events on this part of the east coast are generated by COL systems. These systems normally consist of a low-pressure cell blocked by two high-pressure cells on either side. COL systems are relatively common but during stationary periods can result in severe storms along the south-east and east coasts. The COL system responsible for the March 2007 storm event is shown in **Error! Reference source not found.**B.30. The high-pressure systems surrounding the COL are prominent on the synoptic chart.

These intense COL systems do not occur frequently. Furthermore, when such a COL system is blocked, it appears that it could occur anywhere along the east coast. For example, a COL system intensified off the East London area during June 1997, resulting in severe damage along this section of the coast. Therefore, the storm event of March 2007 was an exceptional event but could occur again. It is also worth noting that since these systems cover a wide stretch of coast, the waves can approach the coast from a wide range of directions.

The third type of weather system refers to tropical cyclones. These systems generally originate in the Indian Ocean, east of Madagascar. Mavume *et al.,* (2009) produced a map with cyclone tracks covering the period 1952 to 2007. This map is presented in **Error! Reference source not found.** B.31. Note that this map covers the months of November till April, the period when cyclones occur in the region.

Up to the present, only one extreme cyclone wave event has been recorded in SA waters. Tropical cyclone Imboa passed the east coast in February 1984 (Figure B.32). At the peak of the storm, a significant wave height of 8.5 m was recorded off Richards Bay. Note that the wave buoy recorded at a six-hour interval. It is thus not certain that the 8.5 m was indeed the peak of the storm event. As depicted by the map in **Error! Reference source not found.**B.31, the area covering Mozambique and Madagascar is vulnerable to cyclone activity. As the cyclone moves south of the Mozambican channel, the tracks indicate that the cyclone moves off in an easterly direction, decreasing in strength. It is not clear at this stage whether cyclones will migrate in a more southerly direction as a result of climate change or perhaps move in a more northerly direction. More research on this issue is required.

Therefore, due to the variable nature (strength and location) of the extreme event (e.g. COL system) that provides the design waves for a particular port , there is no guarantee that under future climate change the highest waves will approach from the typical direction of approach under present-day conditions. For example, if COL systems would settle at slightly more northly locations than has been the case until now, the highest waves will approach the port from a more easterly or north-easterly direction.. Records are considered too short to provide a definitive statement on whether such changes can already be detected, and designs to withstand future extreme events should therefore take projections of future directional shifts in the approach of high waves into account. .

3.3.5.3 General offshore wave climate

The wave climate around the SA coast shows a clear seasonal pattern and varies in intensity and directionality around the coast. This variation in wave height is graphically shown in **Error! Reference source not found.**B.33, which shows the wave height contours based on Topex satellite data for the southern Atlantic and Indian oceans. During winter, the wave height increases along the coasts as the frontal systems travel along a more northerly trajectory. During summer, the high-pressure systems along the west coast force the low-pressure systems farther south, resulting in a general decrease in wave height along the coast.

An overview of the annual variation in wave height and period along the SA coast is given in Figure B.34. Two wave heights are presented. The first value represents the median significant wave height (Hmo-50%), which is exceeded for 50% of the time. The second wave height is exceeded for only 1% of the time (Hmo-1%), giving an indication of the more extreme condition. Also presented is the most likely range of peak wave periods that can be expected for each location. These values are based on about 11 years of WaveWatch III forecast model data of the National Centers for Environmental Prediction (NCEP) as very little measured data were available in the offshore domain. The only offshore data available were the dataset from the FA platform on the Agulhas Bank (the “FA platform” refers to an oil platform located in the FA gas field in the Agulhas bank region). Comparison with this dataset indicated that the NCEP data represented the offshore wave climate very well. Thus, the NCEP data were used in this study. For the purposes of this study, a number of data grid-points were selected. These locations are also indicated in Figure B.34.

The annual variation in directionality around the coast is illustrated by the wave roses in **Error! Reference source not found.**B.35. The dominant wave direction is south-west, representing the general direction of the passing low-pressure systems. Note that during winter months, when the trajectories of the lows are farther northwards, the waves will approach from a more west-south-westerly direction on the Cape south-west coast. Farther northwards on the west coast, there is also a more south-south-westerly component, representing seas generated by the more local southerly wind conditions.

As indicated in **Error! Reference source not found.**B.36, the largest waves occur along the south-west towards the south coast but decrease in magnitude along the west and east coasts. The distribution of wave period remains fairly constant, due to the swell propagating northwards. The wave direction is predominantly south-west but migrates more toward a south-south-westerly direction on the east coast. Therefore, the waves arriving at the coast depend on the prevailing offshore conditions.

3.3.5.4 Climate change projections

Wave climate is largely determined by ocean winds (velocity, duration, fetch, occurrence, decay, etc.). Projections of changes in the regional wind regimes off the southern African coast are lacking however – or at least, the analysis of extensive ensembles of projected changes is lacking. An example of such projections can be obtained from the ensemble of dynamic downscalings analysed in the TNC. The simulated present-day wind patterns and projected changes are presented in the Appendix. No quantitative studies have to date been performed, where dynamic climate model projections such as those represented by Figures B.36-B.41 have been linked to quantitative wave modelling, This represents a gap in southern African climate change impacts assessments, and an area of future work. To gain some quantitative understanding of climate change impacts on coastal processes and to enable an assessment of the potential impacts of stronger winds, a relatively modest increase of 10% could be assumed. Thus, a modest 10% increase in wind speed, implies a 12% increase in wind stress, a 26% increase in wave height, and as much as an 80% increase in wave power (Theron 2007). This means that a modest 10% increase in wind speed could also result in a potentially significant increase in coastal sediment transport rates and consequently impact on estuarine mouth regimes. The dynamic processes in the ocean, and especially on the coast, are thus mostly a non-linear system and small changes in the atmospherics could have a drastic effect on our coast. It should be noted however, that many of the regional changes in circulation over southern Africa argue for the decreasing impact of severe storm events along the South African coastline: the westerly wind regime and cold fronts are projected to be displaced polewards (Christensen *et al.,* 2007; Engelbrecht *et al.,* 2009), implying a poleward displacement of the swell and wind waves these systems generate. Moreover, this poleward displacement of frontal systems will plausibly be associated with a strengthening of the sub-tropical high-pressure belt over southern Africa. Consequences of these changes may include the decreasing occurrence of cut-off lows (Engelbrecht *et al.,* 2013) and equatorward displacement of landfalling tropical cyclone tracks (Malherbe *et al.,* 2013). However, it should be noted that these are the only studies that have to date explored changes in synoptic-scale weather systems important to the generation of damaging wind and wave events along the South African coastline – more work is needed towards quantifying the impact of these weather systems under climate change.

3.3.6 Narratives of climate change for South Africa and its provinces

3.3.6.1 Northern Cape

The Northern Cape is the driest province in South Africa, with some areas receiving less than 70 mm/year on average. The north western parts of the province are arid and experience very infrequent rainfall events produced either by the passage of rare cold fronts in winter or occasional convective rainfall during summer. The south western parts experience infrequent winter rainfall, while the eastern two thirds of the province experience summer rainfall associated with local or large scale convective rainfall systems. The south and west of the province experience low rainfall during winter. The eastern part of the province responds partly to ENSO oscillations while the south and western areas having very weak, if any, association with ENSO.

The northern parts of the province also experience some of the highest maximum temperatures in the country, with places like Upington experiencing average daytime temperatures in summer of over 32 °C and more than 30% of days in January exceed 36 °C. However, typical of many arid and semi-arid inland locations, winter night time temperatures can regularly drop below 0 °C. The western coastline is very dry, and the northern extremes transition into coastal desert. In these areas coastal marine fog forms an important source of water for ecosystems.

Historical trends show no detectable trend in annual rainfall totals over the past 50 years, though there are some weak indications of increases in number of wet days. Daily maximum temperatures have been increasingly steadily and more rapidly than nighttime minimum temperatures, with a resultant increase in the day/night temperature differences.

3.3.6.1.1 Narrative 1: A hotter drier future

In this narrative for the Northern Cape the province continues to experience cycles of dry years and wet years, with dry years typically associated with higher temperatures. The spatial size of the province and north-east, south-west climate gradient means that it is not uncommon for the north and east of the province to be experiencing dry conditions while the south and west are not, and vice versa. The province experiences more rapid warming than the most of the rest of the country, particular in the northern and eastern interior. This means that temperatures in the province will reach 2 °C warmer than the recent past by between 2040 and 2060. This has important impacts on hot spells, with days exceeding 36 °C reaching 20-30 days a month in the north of the province in summer. The most rapid warming is experienced in the months before the summer rainfall begins.

Retreating cold fronts as a result of a southerly shift in the mid-latitude jet-stream means that the frequency of frontal winter rainfall events in the south west of the province decrease, resulting in lower annual rainfall totals. To the east of the province, increased subsidence, caused by more intense subtropical high pressure systems, suppresses convective rainfall processes reducing summer rainfall. However, more intense heating and increased atmospheric humidity under a warmer climate produces more intense rainfall events when they do occur, causing localised flooding and infrastructure damage.

Reduced rainfall together with substantially higher temperatures combine to increase evaporation, which places strain on natural environments as well as dams for irrigation and human consumption. Ground water is an important source of water in the west of the province, and reduced rainfall begins to reduce ground water recharge rates reducing well point yields. While the province does not contain many large cities, urbanisation places increased strain on existing water sources. Natural eco-systems are the foundation of much tourism in the province, and as these are placed under strain tourism is forced to adapt.

3.3.6.1.2 Narrative 2: A hotter, mixed rainfall future

In this narrative for the Northern Cape the province continues to experience cycles of dry years and wet years, with dry years typically associated with higher temperatures. The spatial size of the province and north-east, south-west climate gradient means that it is not uncommon for the north and east of the province to be experiencing dry conditions while the south and west are not, and vice versa. The province experiences more rapid warming than most of the rest of the country, particularly in the northern and eastern interior. This means that temperatures in the province will reach 2 °C warmer than the recent past by between 2040 and 2060. This has important impacts on hot spells, with days exceeding 36 °C reaching 20-30 days a month in the north of the province in summer. Most rapid warming is experienced in the months before the summer rainfall begins.

Retreating cold fronts as a result of a southerly shift in the mid-latitude jet-stream means that the frequency of frontal winter rainfall events in the south west of the province decreases, resulting in lower annual rainfall totals. To the east of the province, an intensified heat low combined with increased atmospheric moisture and moisture transport into the interior results in increased summer rainfall. These same dynamics of heating and increased moisture produces more intense rainfall events when they do occur, causing localised flooding and infrastructure damage.

Reduced rainfall in the south and east together with substantially higher temperatures combine to increase evaporation, which places strain on natural environments as well as dams for irrigation and human consumption. Groundwater is an important source of water in the west of the province, and reduced rainfall begins to reduce groundwater recharge rates reducing well point yields. While the province does not contain many large cities, urbanisation places increased strain on existing water sources. Natural ecosystems are the foundation of much tourism in the province, and as these are placed under strain by increasing temperatures and rainfall changes, tourism is forced to adapt.

3.3.6.2 Western Cape

The Western Cape, dominated by ocean, mountains and plains (coastal and inland), has a very diverse climate. Locations such as Bethlehem in the Hottentots Holland mountains experience some of the highest annual rainfall totals in the country (1500 mm/year), whereas Laingsberg only receives around 120 mm/year. Temperatures also range widely from cool coastal mountains often covered by low orographic cloud where even in summer temperature rarely exceed 25 °C, through to semi-arid Karoo valleys where summer temperatures can average 35 °C.

Rainfall in the coastal regions and coastal mountains is largely produced by cold fronts generated in the mid-latitudes that bring cold weather and rainfall to the province. Cold fronts interact with the mountains such that far more rainfall falls in the mountains than on the coastal plains. The mountains also impede the inland progression of cold fronts and so produce a rain shadow inland marked by much lower rainfall. These inland areas of the province actually experience summer rainfall resulting from strong surface heating and thunderstorm type weather, similar to the rest of the summer rainfall regions in South Africa. However, strong cold fronts can sweep inland bringing cold weather and rainfall or even snow. While this is more common in winter, strong cold fronts have been experienced during summer.

Southerly winds transporting relatively moist but cool air from the southern oceans to the Western Cape are also key to the province’s climate. There is some evidence that the very common orographic clouds that cloak the mountains of the Western Cape contribute a great deal of water to mountain runoff through cloud droplet capture as well as through low intensity rainfall. Moist surface winds coupled with high altitude lower pressure systems are responsible for more significant rainfall events in the province, colloquially known as “black south-easters” which have even been known to produce flooding.

The Western Cape has experienced droughts in the past and will continue to do so going into the future as natural climate variability continues. There are currently no long term changes in rainfall identifiable in historical weather records. This does not mean that changes are not occurring, it just means that currently there is insufficient evidence to suggest that any changes identified are not just an artefact of natural cycles (10-30 year cycles) rather than long term steady change. Some small changes in the number of rainy days per year have been detected, with decreases in the number of rainy days in some areas. Both daytime maximum and nighttime minimum temperatures have been increasing steadily over the past 50 years.

3.3.6.2.1 Narrative 1: A drier hotter, windier future

In this narrative the climate of the Western Cape will continue to be characterised by cycles of drier years and wetter years for the next 20 to 30 years. At the same time average temperatures rise at around 0.5 °C /decade so the average temperatures will reach 1.5 °C higher than recent historical averages somewhere between 2040 and 2060. The impact of these higher temperatures will increase the frequency and length of hot spells in summer, as well as decrease the frequency and duration of cold spells in winter. The increasing effect of the sub-tropical high pressure systems combined with more intense inland heating will result in stronger summer south-easter winds. Higher wind speeds combined with higher temperatures will strongly influence evaporation and evapotranspiration either resulting in drier soils and crops or increasing demand for irrigation, particularly of summer crops. Higher evaporation from dams, combined with competing demands from agriculture and rapidly growing urban populations will place significant strain urban water supply systems.

Moving towards the middle of the 21st century natural cycles of rainfall begin to shift towards more frequent dry years and consecutive dry years (such as the 2014-2015 years). Temperatures will continue to rise along with summer wind speeds which enhance evaporation, so reduced rainfall will only exacerbate the challenge of increased evaporation from agricultural land, natural ecosystems, and water storage dams. Competition for water between agriculture, industry and urban water supply could become critical with water cuts becoming the only viable solution during extreme dry years.

With average temperatures now reaching 2 °C higher than the recent past agricultural activities will become unviable, including some fruit farming which requires low temperatures to develop and possibly certain livestock that are unable to cope with sustained higher temperatures. Added to these summer stresses, winter storm intensity begins to increase resulting in more frequent heavy rainfall events in winter which produce flooding and related damage.

3.3.6.2.2 Narrative 2: A warmer wetter future

In this narrative the climate of the Western Cape will continue to be characterised by cycles of drier years and wetter years for the next 20 to 30 years. At the same time average temperatures rise at around 0.5 °C /decade so the average temperatures will reach 1.5 °C higher than recent historical averages somewhere between 2040 and 2060. The impact of these higher temperatures will increase the frequency and length of hot spells in summer, as well as decreased frequency and duration of cold spells in winter. The increasing effect of the sub-tropical high pressure systems combined with more intense inland heating will result in stronger summer south-easter winds. Higher wind speeds combined with higher temperatures will strongly influence evaporation and evapotranspiration either resulting in dry soils and crops or increasing demand for irrigation, particularly of summer crops. Higher evaporation from dams, combined with competing demands from agriculture and rapidly growing urban populations will place significant strain urban water supply systems.

Moving towards the middle of the 21st century natural cycles of rainfall will continue, but changes in average rainfall begin to emerge. Rainfall in the mountains increases as a result of more moist and energetic winter storms, as well as increased moist warm southerly flow off the ocean in the summer months. While coastal and inland plains do not experience these changes directly, they have important impacts on water supply and irrigation as river flows increase and runoff into dams increase.

However, increased rainfall is offset by increased evaporation due to higher temperatures (reaching 2 °C higher than current) and stronger winds. This results in increasing demand for irrigation and higher losses from dams. Higher urban populations also place ever increasing demands on water supply systems. Therefore, while the relatively small increases in rainfall may partly delay the need for adaptation measures, adaption to reduce water demands is still required. Higher temperatures will still result in some agricultural activities being unviable, regardless of changes in rainfall. Inland plains do not receive increased rainfall, and so follow very similar story lines to the dry narrative above.

3.3.6.3 Eastern Cape

The Eastern Cape, like the Western Cape, is characterized by a very diverse climate due to the proximity to the ocean and extensive mountain ranges and altitude variations. Minimum temperatures in Barkley East (1800 m) hover around 0 °C during the winter months, with snow not an unusual occurrence. Port St Johns on the other hand experienced average winter temperatures more than 10 °C warmer. The significant east-west mountain ranges produce stark rainfall climate gradients. Willomore receives around 240 mm/year with mostly summer rainfall, whereas Tsitsikamma, a mere 120 km south, receives around 720 mm/year of all year around rainfall.

Rainfall is produced by a combination of three processes. The influence of cold fronts sweeping over the south of the country produces rainfall through the winter months along the coast and in the coastal mountains. Further inland (*north*) *the influence of these cold fronts diminishes and summer rainfall dynamics* (*surface heating and convective/thunderstorms*) *dominate. During summer, onshore flow of relatively moist air forced to rise by coastal mountains produces substantial summer rainfall.*

Historical rainfall trends over the last 50 years are very unclear, with little significant changes detectable except for a possible increase in wet days in summer in the western side of the province and the opposite signal in the north east. Temperature trends exhibit consistent warming of daytime maximums, and some less consistent increases in nighttime minimum temperatures.

3.3.6.3.1 Narrative 1: A warmer future

In this narrative for the Eastern Cape, the province continues to experience cycles of dry years and wet years. Temperatures rise consistently by 1.5 °C higher than recent averages between 2040 and 2060. The impact of these warming temperatures will be increased frequency and length of hot spells in summer, as well as decreased frequency and duration of cold spells in winter. Higher temperatures will strongly influence evaporation and evapotranspiration, either resulting in drier soils and crops or increasing demand for irrigation, particularly of summer crops. Higher evaporation from dams, combined with competing demands from agriculture and rapidly growing urban populations will place significant strain on urban water supply systems.

Warming results in a stronger heat low pressure in the interior of the country, which influences the northern part of the province and results in more intense rainfall events, even if long term annual rainfall totals are largely stable. These intense events have great impact on infrastructure such as roads and storm water systems. Increased ocean temperatures in the warm Algulhas current produce intense local convective storm systems, resulting in heavy rain and flooding along the coast and coastal mountains. Associated storm surge superimposed on rising sea-levels begins to impact coastal infrastructure, much of which is associated with tourism.

3.3.6.3.2 Narrative 2: A warmer drier future

In this narrative for the Eastern Cape, the province continues to experience cycles of dry years and wet years. Temperature increases over the period 2040-2060 frequently exceed 1.5 °C compared to present-day climate. The impact of these temperature increases will be increased frequency and length of hot spells in summer, as well as decreased frequency and duration of cold spells in winter. However, the frequency of dry years begins to increase, and multi-year droughts become more common. Higher temperatures, combined with low rainfall in dry years, strongly influence evaporation and evapotranspiration either resulting in drier soils and crops or increasing demand for irrigation, particularly of summer crops. Higher evaporation from dams, combined with low rainfall in dry years, and competing demands from agriculture and rapidly growing urban populations will place significant strain on urban water supply systems.

Warming results in a stronger heat low pressure in the interior of the country, which influences the northern part of the province and results in more intense rainfall events, even if long term annual rainfall totals are slowly declining. These intense events have great impact on infrastructure such as roads and storm water systems. Increased ocean temperatures in the warm Agulhas current produce intense local convective storm systems, resulting in heavy rain and flooding along the coast and coastal mountains. Associated storm surge superimposed on rising sea-levels begins to impact coastal infrastructure, much of which is associated with tourism.

3.3.6.4 KwaZulu-Natal

KwaZulu-Natal is the wettest province in South Africa, with high rainfall totals occurring along both the eastern escarpment and over the coastal areas. It is a summer rainfall region that experiences hot and humid summers and mild winters.

3.3.6.4.1 Narrative 1: A hot and dry future

KwaZulu-Natal may plausibly experience a climate future that is significantly hotter and drier compared to the present-day climate. Under low mitigation, temperature increases as large as 3 °C may occur by 2040-2060, with associated drastic decreases in rainfall. Such a climate regime will also be associated with an increase in the frequency of occurrence of heat-wave days and high fire-danger days and more El Niño induced drought events. Key impacts under such a scenario include significantly reduced yield from both the forestry and sugar cane industries. Human health may be increasingly affected by oppressive temperatures.

3.3.6.4.2 Narrative 2: A hot future with increased rainfall

The main alternative future for KwaZulu-Natal is similar to narrative 1, but with the difference that rainfall over the province increases substantially, including an increase in intense thunderstorms and damaging flood events. Under such a future there are more options for the sugarcane and forestry sectors, but with frequent damage to infra-structure such as roads and bridges. In the increasingy hot and humid climate, pests and diseases affecting crops, the forestry sector and also human and animal health may become increasingly abundant.

3.3.6.5 Mpumalanga

Mpumalanga's Lowveld region experiences a sub-tropical climate, with high rainfall totals towards the escarpment in the west and with a drier climate to the east. The Mpumalanga Highveld experiences cold winters with frost events, with summers being warm and with rainfall occurring mostly in the form of thunderstorms.

3.3.6.5.1 Narrative 1: A hot and dry future

Mpumalanga may plausibly experience a climate future that is significantly hotter and drier compared to the present-day climate. Under low mitigation, temperature increases as large as 3 °C may occur by 2040-2060, with associated drastic decreases in rainfall. Such a climate regime will also be associated with an increase in the frequency of occurrence of heat-wave days and high fire-danger days. Such a change towards a generally warmer and drier climate would pose significant threats to the forestry sector, due to the likelihood for more frequent forest fires occurring during more frequent periods of drought.

3.3.6.5.2 Narrative 2: A wamer future with increased rainfall

The main alternative narrative for Mpumalanga still implies significant increases in temperature, consistent with narrative 1. The main difference in this scenario is that rainfall totals increase under climate change, rather than to increase. Such an increase may imply the more frequent occurrence of landfalling tropical lows over the Lowveld regions, with potentially significant impacts on tourism and infra-structure in areas such as Kruger Park an town in the Lowveld region. Under such a scenario drought will not be such a major problem for the forestry sector as under narrative 1, but the increased occurrence of pests and pathogens affecting forestry and agriculture may well pose an alternative set of challenges.

3.3.6.6 Limpopo

Limpopo is a summer rainfall region that generally experiences hot summers and cooler winters. Rainfall varies greatly across the province, with large parts of the Limpopo basin being semi-arid, and with high rainfall and rainforests along the eastern escarpment of the province. The province sporadically suffer from devastating flood events, when tropical lows or cyclones from the Indian Ocean make landfall over neigbouring Mozambique, or even over Limpopo itself.

3.3.6.6.1 Narrative 1: A hot and dry future

Limpopo is plausible, even likely, to experience a climate future that is significantly hotter and drier compared to the present-day climate. Under low mitigation, temperature increases as large as 7 °C may occur by the end of the century, with increases of about 4 °C plausible by the period 2040-2060. Such a climate regime will also be associated with an increase in the frequency of occurrence of heat-wave days and high fire-danger days. It is likely that the province may become drier under climate change, with more frequent El Niño induced drought events. Under such a scenario, dryland agriculture and livestock production in Limpopo will become increasingly less viable.

3.3.6.6.2 Narrative 2: A warmer future with more flood events

The main alternative future for Limpopo is a future that is in fact projected by a minority of climate models, namely a future where the province becomes wetter, at least in the Limpopo basin and along the escarpment, due to a greater frequency of more intense tropical lows and cyclones making landfall. Under such a scenario, the province will still need to deal with the negative impacts of increasing temperatures as described in narrative 1. In stead od drought, however, sporadic and devastating flood events will be a key impact to deal with.

3.3.6.7 Gauteng

The Gauteng Province is the economic heartland of South Africa. The province falls in the summer rainfall region, and receives the bulk of its rainfall in the form of thunderstorms. Annual rainfall totals reach 700 mm over much of the province. Winters over Gauteng are dry and associated with clear skies, cold nights that occur in association with the formation of strong inversion layers and polluted mornings. It is critical realise that Gauteng's water security does not only depend on local rainfall and streamflow and dams located within the province, but that about 40% of Gauteng's rainfall is provided by the mega-deam region of southeastern South Africa.

3.3.6.7.1 Narrative 1: a warmer future with reduced water security

Under low mitigation Gauteng may plausibly experience temperature increases of 3-4 °C in the during the period 2040-2060, with associated drastic inceases in the annual number of very hot days, heat-wave days and high fire danger days, but with decreases in the number of cold nights and days with frost. These changes in temperature, irrespective of rainfall changes, may be expected to impact drastically on the province. A key impact may be that of oppressive temperatures on human health and mortality, especially where people live in informal settlements with no access to air conditioning and without easy access to water. Under such conditons, the eldery is most vulnerable. Factories and households in Gauteng will experience an increasing need for air conditioning towards achieving human comfort, implying an increased energy demand. The local production of maize and livestock within the province will be negatively affected by rising temperatures, but the production of tomatoes will become viable in winter as the number of frost days decrease to insignificant values. In winter, strengthening inversion layers will lead to further deterioration in air quality. The drastic increases in temperature may occur in association with the more frequent occurrence of drought over southern Africa, including drought in the mega-dam region. This will significantly impact on Gauteng water security and may strongly constrain the province's future economic groth. Locally, increases intense thunderstorms bringing hail, damaging winds and flash floods are plausible.

3.3.6.7.2 Narrative 2: A warmer future but water secure future

An alternative narrative for Gauteng follows the same outcomes in terms of temperature than for narrative 1, but with the important exception that water yield in the mega-dam region of South Africa is not compromised by climate change. In fact, the opposite may occur, namely that more frequent and intense thunderstorms over the eastern escarpment region lead to enhanced streamflow. Under such a scenario Gauteng will still need to deal with significant problems caused by rising temperatures and local increases in extreme rainfall events, but with a relatively secure water supply.

3.3.6.8 Free State

The Free State spans the centre of the country, and ranges from the relatively dry, hot and arid west (Bloemhof receives around 450 mm/year) and south through to higher altitude cooler wetter climate in the north and east (Royal National Park receives 1200 mm/year). It is entirely a summer rainfall region, with rainfall resulting from either local small scale convective events or larger organised convection. Rainfall in the province is partly linked to ENSO, though it is not uncommon for El-Nino years to normal or even wetter than normal in a few cases. The province is the "bread basket" of the country with extensive maize, wheat, and other crop production. This is a result of generally good soils and moderate climate, with sufficient rainfall to allow rain-fed agriculture.

Historical rainfall trends are complex with no clear picture emerging. Some locations in the central areas seem to show decreased mid and late summer rainfall, while others in the west show slight increases. However patterns are very mixed, with most stations showing no significant changes. Temperatures have largely been increasing, particularly in winter.

3.3.6.8.1 Narrative 1: A warmer drier future

In this narrative for the Free State the province continues to experience cycles of wetter and drier years, with drier years tending to be warmer than wetter years. However, increasing temperatures reach 2 °C higher than current temperatures by between 2040 and 2060, resulting in increased frequency and duration of hot spells in summer with potential impacts on key crop development stages. Most rapid warming is experienced in the months before the summer rainfall begins.

Increased and more intense sub-tropical highs produce enhanced subsidence over the province, suppressing moisture transport into the region and convective activity. The result is reduced frequency and magnitude of rainfall events, and generally reduced annual rainfall totals. However convective events, when they occur, are more intense resulting in localised flooding and related damage.

Increasing temperatures increases evaporation, resulting in drier soils and greater loss from dams, particularly shallow farm dams. Combined with generally reduced rainfall, this means that even in relatively normal rainfall years crops experience greater water deficit and water supply for irrigation, human consumption, and livestock is placed under strain. Higher temperatures begin to impact some livestock as well. Dry years, combined with 2 °C higher temperatures produce higher impacts in the province than the 2015/2016 drought.

3.3.6.8.2 Narrative 2: A warmer wetter future

In this narrative for the Free State the province continues to experience cycles of wetter and drier years, with drier years tending to be warmer than wetter years. However, increasing temperatures reach 2 °C higher than current temperatures between 2046 and 2065, resulting in increased frequency and duration of hot spells in summer with potential impacts on key crop development stages. Most rapid warming is experienced in the months before the summer rainfall begins.

An intensified heat low, resulting in enhanced moisture transport into the east of the province, results in marginally increased annual rainfall totals in the east. These changes are however very limited towards the west, where increased subsidence suppresses convection and rainfall remains similar to the present-day day. Convective rainfall events, when they do occur are more intense, resulting in localised flooding and related damage.

Increasing temperatures increase evaporation, resulting in drier soils and increased loss from dams, particularly shallow farm dams. In wetter years the increased rainfall offsets the evaporative losses to some degree depending on the area. But even in relatively normal rainfall years crops experience greater water deficit and water supply for irrigation, human consumption, and livestock is placed under strain. Higher temperatures begin to impact some livestock as well. Dry years, though less frequent than currently experienced, combined with 2 °C higher temperatures produce greater impacts in agriculture and human settlements in the province than the 2015/2016 drought.

3.3.6.9 North West

North West is a summer rainfall region that receives almost all of its rainfall during the summer half-year period of October to March. The western half of the North West Province is a semi-arid region that receives less than 500 mm of rainfall annually, with rainfall totals only being slightly higher in the eastern parts of the province. The province is highly vulnerable to El Niño induced drought events, of which the devastating 2015/16 drought is a recent example.

3.3.6.9.1 Narrative 1: A hot and dry future

North West may plausibly (under low mitigation) experience a climate future that is significantly hotter and drier compared to the present-day climate. Under low mitigation, temperature increases as large as 6 °C may occur in the far-future, with associated drastic decreases in rainfall. Such a climate regime will also be associated with an increase in the frequency of occurrence of heat-wave days and high fire-danger days. Under this narrative, which represents a likely climate future for the province, climate change impacts will be devastating for both the livestock and dryland agriculture in the far-future under low mitigation.

3.3.6.9.2 Narrative 2: A warmer future with more frequent wet-spells

Under high mitigation, temperature increases may still be as high as 4 °C in the second half of the 21st century, but with the more frequent formation of tropical-temperate troughs and associated occurrence of wet spells. Both the livestock and dryland agriculture sectors will experience largely negative impacts under this narrative, mainly through the impact of oppressive temperatures.

3.3.7 Conclusion

Significant progress has been made in South Africa since the SNC, in terms of the local generation of detailed regional climate futures for the country. Extensive ensembles of projected climate change futures have been available for the TNC, derived using both statistical and dynamical downscaling techniques. These projections make feasible the identification of plausible climate futures for each of the South African provinces, and in some cases, the identification of actionable messages for adaptation. A key feature of the projected climate change futures of South Africa is that temperatures are to increase drastically under low mitigation. For the far-future period of 2080-2099, temperature increases of more than 4 °C are likely over the whole of South Africa, with increases of more than 6 °C plausible over large parts of the western, central and northern interior regions of the country. Such increases will also be associated with drastic increases in the number of heat-wave days and very hot days, with potentially devastating impacts on agriculture, water security, biodiversity and human health. The model projections are indicative that a modest-high mitigation pathway can still significantly decrease this amplitude of warming – most projections suggest that under RCP4.5, for example, temperature increases over the interior can be constrained to 2.5 to 4 °C. Nevertheless, it should be realised that South Africa is plausibly committed to relatively large increases in near-surface temperatures, even under modest-high mitigation futures.

Under low mitigation, it is also likely that the larger South African region will experience generally drier conditions. This pattern is projected robustly by GCMs and their statistical and dynamic downscalings, and is of great significance: South Africa exhibits even under present-day climate a generally dry and warm climate – should this low mitigation future of significantly hotter and drier conditions materialise, it will greatly limit the available opportunities for adaptation. It may be noted that under low mitigation, a minority of downscalings are indicative of rainfall increases over the central interior of South Africa, and/or over the southern interior regions and the Cape south coast. Moreover, extreme convective rainfall events are projected to plausibly increase over the interior regions under low mitigation, even in the presence of a generally drier climate. Under modest-high mitigation, the projections are indicative of potentially very different rainfall futures for South Africa. Even under RCP4.5, a modest-high mitigation pathway, the projected pattern of drying is significantly weaker. In fact, a fairly large number of projections are indicative of generally wetter conditions over the central and eastern interior regions, whilst the remaining projections remain indicative of generally drier conditions. This, in combination with the significantly reduced warming that is projected for southern Africa under high mitigation, emphasizes how important it is for South Africa to strive for a (global) high mitigation pathway.

3.4 Socio-economic scenarios for climate vulnerability assessment for South Africa

3.4.1 Rationale

The Intergovernmental Panel on Climate Change (IPCC) assessment of climate change indicated that without further mitigation action, average global temperatures could be as high as 4.8°C above pre-industrial levels by 2100 (IPCC Fifth Assessment Report). At a global level, warming of this magnitude will bring unprecedented climate variability and extremes, which would permanently alter both marine and terrestrial ecosystems and cause sea levels to rise. For Africa, global warming could translate into an increase in temperature by as much as 6°C in some areas, with **sub-Saharan Africa a region identified as being most vulnerable to drought and climate change-induced impacts** (IPCC, 2014). Climate change will also likely increase the frequency and magnitude of many extreme weather events. The impacts of such a climate will include increased natural disasters that will cause damage to infrastructure and have diverse **socio-economic impacts, with significant effects on agriculture and rural livelihoods** (World Bank, 2013).

The United Nations Framework Convention on Climate Change (UNFCCC, 1992), ratified by South African Government in August 1997, makes commitments to achieve stabilisation of the concentrations of greenhouse gases in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The most important provision by far is embedded in Article 2 which reads, **“***The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner*.” While the first part of the Convention’s objective addresses predominantly mitigation, the second part explicitly addresses adaptation, thereby highlighting the need to ensure that food production and sustainable development are not threatened. It can be argued that adaptation imperatives are the primary objective of the agreement, as the poorly defined concept of ‘dangerous anthropogenic interference’ can only be understood in the context of its potential negative impact upon people and ecosystems. In addition, mitigation action could limit the costs of adaptation significantly; since **without swift and concerted mitigation action, adaptation requirements and costs will grow and the adaptation gap will continue to widen**. This aspect is highlighted by Article 4.1: “*All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, shall:* (*f*) *Take climate change considerations into account, to the extent feasible, in their relevant social, economic and environmental policies and actions, and employ appropriate methods, for example impact assessments, formulated and determined nationally, with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken* *by them to mitigate or adapt to climate change*". However, while there are some **provisions to address adaptation in the UNFCCC**, their implementation in the first 20 years has been patchy, opportunistic and philanthropic in nature, rather than being **guided by the differentiated responsibilities and delivered as the obligations of the signatories.**

Many developing countries are heavily-reliant on natural resources, which are highly vulnerable to climate change. **Africa's low adaptive capacity to climate change is due to developmental challenges** including: endemic poverty; complex governmental and institutional aspects; limited access to capital, markets, poor infrastructure and technology; complex disasters and conflicts and degradation of the ecosystem (Boko, *et al.,* 2007). Therefore, Africa potentially faces **mutually reinforcing challenges to respond to climate change amidst a poor ability to do so**. The requirement to respond to climate change may seem like an unfair burden for developing countries in Africa that are responsible for a few percent (3.3 % in 2011) of the global carbon dioxide emissions. Furthermore, there is an increased poverty burden since developing countries are heavily reliant on natural resources and agriculture and hence highly vulnerable to climate change. In addition, there are **concerns that climate change mitigation could threaten the ability of African countries to follow the standard industrialisation pathway to high income status and stunt economic growth**. Implementing policies and plans to address the impacts of climate change also has an opportunity cost; by diverting resources away from other pursuits like poverty eradication and sustainable development. In pursuing material parity in climate change adaptation and achieving agreed multilateral processes for adaptation planning and action; the African Group has made a proposal for a Global Goal for Adaptation (GGA) in the Paris Agreement that reflects the linkages between mitigation effort, temperature increase, adaptation needs and differentiated responsibility or "fair share".

Therefore, the response of the earth system will depend on prevailing atmospheric conditions, as well as the success of **mitigation and adaptation** measures currently being tailored to anticipate and respond to climate change impacts. Mitigation and adaptation measures are influenced by a country's development pathway and take into consideration changes in population, consumption, governance and policy, economic development, as well as technology and innovation. Climate change has the potential to alter socio-economic development and prevent the country from achieving its development goals. While considerable efforts should be made to mitigate climate change and avoid impacts, it is recognised that **not all climate change risks can be mitigated and some climate change is inevitable**. Therefore, there is a need to **both mitigate and adapt to climate change, with the aim of minimising the climate change risks through improving climate change resilience**. Central to achieving this is an improved understanding of complex socio-ecological systems, and the **inter-connectedness between the climate change biophysical impacts and climate governance**. This chapter aims to provide a framework that incorporates socio-economic modelling scenarios into South Africa's climate change adaptation planning and response.

3.4.2 Climate risk and adaptation in South Africa

In South Africa climate risk is influenced by socio-economic factors such as governance, poverty and unemployment, and service delivery. Climate change will likely increase inequalities and poverty, since those that rely on the natural resource base for their livelihoods are more at risk. The National Climate Change Response Policy identified the need for developing national and sub-national adaptation scenarios for South Africa - under plausible future climate conditions and development pathways. This is being carried out through the Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) that aims to inform future planning and development decisions for a climate resilient society. The first phase of the Long Term Adaptation Scenarios (LTAS) established a collective understanding on South Africa's climate change trends and projections. It summarised key climate change impacts and identified potential response options for primary sectors; namely: water, agriculture and forestry, human health, marine fisheries, and biodiversity. Some of the key findings include:

(i) Agriculture and forestry. The effect of climate change on biophysical factors (i.e. temperature and rainfall) and the significant impacts on agricultural production have been well described. There are downstream economic impacts to value-adding of the agro-processing and socio-economic factors that affect policy and practice in agriculture and are less well understood. In addition, there is little information on the climate risks to small-scale and subsistence farmers that intimately depend on natural resources for their livelihoods (DEA, 2013b; DEA, 2014c).

(ii) Human health. There are recognised impacts to human-heath from climate change; including heat stress, increased vector-borne diseases, food insecurity, hunger and malnutrition. However, the combined effects of biophysical and socio-economic drivers of human health and disease and the required ability to manage and respond to these challenges are uncertain (DEA, 2013c; DEA, 2014j).

(iii) Marine and fisheries. The climate change risks to marine and fishery resources include rises in temperature, rainfall, and sea level, coastal storms and the acidification of estuaries. This may diminish fish stocks, alter markets, and influence tourism in the marine environment (DEA, 2013f; DEA, 2014i).

(iv) Biodiversity. Climate change will have numerous impacts on South African biodiversity and ecosystem services, and therefore requires a clear adaptation response (National Biodiversity Framework, the National Protected Area Expansion Strategy and the Climate Change Adaptation Plans for South African Biomes) Loss of Biodiversity and ecosystem services will impact all sectors, particularly those that rely on natural resources, such as agriculture, tourism and subsistence livelihoods. Ecosystem-based Adaptation and the use of biodiversity off-sets is a recommended response, and can be implemented using guidelines as outlined by the Strategic Framework and Overarching Implementation Plan for EbA. Although research has started to address the impacts of climate change on the extent, integrity and functioning South Africa's biomes, it is still unclear how diminishing biodiversity and ecosystem services influence socio-economic outcomes in terms of livelihoods and economic activity (i.e. medicinal plants, pollination and recreation) (DEA, 2013d).

(v) Water. The biophysical vulnerability assessment of the water sector has been assessed at catchment level, and adaptation options proposed to address growing water scarcity. However, there is a need to further understand the link between climate change, future population growth, and water supply and demand. In particular, there needs to be a better understanding of the influence of socio-economic factors on the water-supply and demand; such as migration, economic growth and energy demand, as well as the development of more integrated water-resource management (DEA, 2013e; DEA, 2014a)).

In general, LTAS identifies the bio-physical vulnerability of the sectors, but does not to quantify the number of people affected in terms of population at risk. In addition, the role of the economic growth and governance in the ability to adapt appropriately to climate change is poorly defined and the key role players required for implementation of climate change adaptation at the local scale not identified. Therefore, an improved understanding between the country’s development aspirations (as articulated in South Africa’s National Development Plan) and climate change adaptation needs to be understood (Figure 0.34).

Understanding climate risks and identifying key areas of concern is critical for developing appropriate adaptation policies and scenarios. The possibility of increased disaster risk is considered to be one of the most concerning and potentially costly impacts of future climate change in South Africa and globally. Disaster risk is defined as the likelihood, over a specified time period, of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions; leading to widespread adverse human, material, economic, or environmental effects that require immediate responses to satisfy critical human needs and may require external support for recovery. This implies that understanding such risks would be a function of the following:

Climate risk = frequency (probability per climate event) **X exposure** (assets at risk of potential loss) **X severity** (consequence/impact of the climate event)

Where:

Frequency: Probability of disruptive climate events due to higher temperature, rising sea-levels, changing precipitation, greater and intense storms, etc.

Exposure: A function of population growth and development.

Severity: A function of the consequence or impact of the scale of the asset loss due to the climate risk.

Our understanding of the futures climate risks, in terms of frequency (probability per climate event), is still at an early stage of development. The work to date, as illustrated by the first phase of the Long-Term Adaptation Scenarios, defines four possible climate futures for the country:

1. Warmer (<2 °C above 1961-2000) and wetter with greater frequency of extreme rainfall events;

2. Warmer (<2 °C above 1961- 2000) and drier, with an increase in the frequency of drought events and somewhat greater frequency of extreme rainfall events.

3. Hotter (> 2°C above 1961-2000) and wetter with substantially greater frequency of extreme rainfall events.

4. Hotter (> 2°C above 1961-2000) and drier, with a substantial increase in the frequency of drought events and greater frequency of extreme rainfall events.

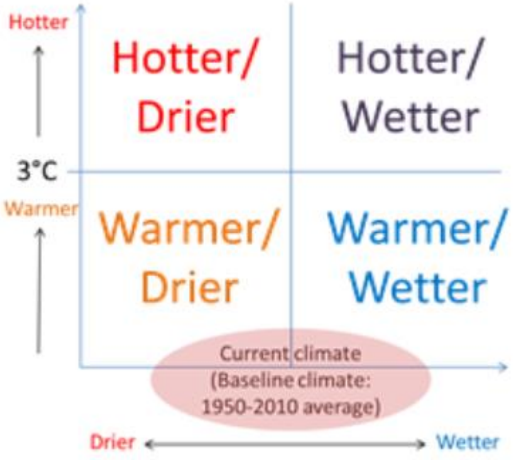


Figure 0.34: LTAS phase I plausible climate futures

These four scenarios were used to define some of the physical risks and impacts of climate change in South Africa for the **water, agriculture and forestry, human health, marine fisheries and biodiversity sectors**. This was very much an impact-based approach, but the results from the Long-Term Adaptation Scenarios Flagship Research Programme phase two project (LTAS) II) incorporated vulnerability assessments to help understand the capacity to manage climate risk and highlighted the need to understand the physical, social and ecological aspects of climate change. As vulnerability is a function of the impact of a risk on a system modified by the systems response to the risk, climate risk is a function of exposure, vulnerability and adaptive capacity. i.e.:

Climate risk = vulnerability X exposure (assets at risk of potential loss) **X severity** (consequence/impact of the climate event)**/ adaptive capacity**

Where:

> *Exposure*: the contact between the climate agent in question and the target (i.e. individual/community/population) in which it will impact.
>
> *Vulnerability*: the characteristics of the population and the extent to which social and biophysical elements are sensitive to changes in weather and climate.

Adaptive capacity: refers to those social and ecological elements that enable the system to respond to the risk.

Severity: A function of the consequence or impact of the scale of the asset loss due to the climate risk.

With the understanding of addressing climate risk through **exposure, sensitivity and adaptive capacity** there is a need to take into account the aspirations and objectives of South Africa's National Development Plan and align them with the climate change futures scenarios. Aside from the LTASII, there are few studies assessing climate risks, and how this will influence the social and economic wellbeing and growth of the country. There are virtually no studies on how changes in the structure and growth of the economy, and local and global governance can affect the capacity and ability to respond effectively to climate change. There has been a limited assessment of the costs of climate change impacts, as well as cost of climate change response - both for mitigation and adaptation. The Climate Change Response Policy (DEA, 2011a) confirms the need for additional research to understand and quantify the socio-economic risks resulting from a range of climate futures that should inform planning and practice. Therefore, there is a clear need to identify and cost-adaptation measures as this uncertainty has constrained implementation of climate change adaptation measures (Ziervogel *et al.,* 2014).

3.4.3 Socio-economic modelling

The NDP outlines South Africa's socio-economic aspirations whereby all South Africans have a decent standard of living through the elimination of poverty and inequality by 2030 (NPC, 2012). Climate change has the potential to exacerbate poverty and inequality while also undermining social justice and cohesion (DEA, 2014a). In order for South Africa to progress to the level of development that is envisioned in the NDP, there is a need to transform the country's economy while building the capability of individuals and communities to respond to climate change by providing basic services for a decent life for all. Socio-economic and anthropogenic factors including that of population-growth demographics, decisions on electricity, technology innovation and good governance are some of the drivers that influence the projected changes in greenhouse gas emissions and consequent climate change impacts. Our current understanding of these factors and the trends are summarised below:

(i) Demographics***.*** Fertility, mortality and migration are the key factors shaping the country's population trends. The general trend is that of an increasing population in the country by 2030-35 with economic growth, human migration, fertility and health services (HIV/AIDS prevention and treatment) being the driving factors (ISS, 2013; NPC, 2012). South Africa is also expected to have an evolving double disease burden in the ongoing transition from communicable to non-communicable diseases. This will be due to diseases extending their natural range, the emergence of new patterns as a result of climate change and extreme weather events; as well as an increase in deaths from non-communicable diseases - such as cardiovascular diseases, cancer, violence and injuries (ISS, 2013). At the provincial level, current scenarios indicate that by 2050 there will be a general increase in population in all provinces based on migration trends and using the residual analysis technique (ISS, 2013; NPC, 2012). Gauteng and the Western Cape are projected to have the highest increase in population by 2050, while there is relatively less increase expected in provinces such as the Eastern Cape, Free State, Mpumalanga, North West and Northern Cape.

(ii) Economic growth is one of the main drivers in combating unemployment and poverty in South Africa. The NDP has set targets in which the unemployment rate declines from 24.9% in 2012 to 6% by 2030, while the Gross Domestic Product (GDP) increases by an average rate of 5.4% per annum. The GDP growth rate in 2015 was 1.3%, mainly due to the slowdown in the mining and agricultural sectors. This rate is significantly lower than the average growth rate envisaged in the NDP. Other scenarios defined by organizations such as the Institute for Security Studies are premised on growth rates that are significantly lower than that envisioned in the NDP. These scenarios show a concerning trend of slow growth and underline the urgent need to stimulate economic activity and develop a more inclusive economy by addressing inequality, poverty and unemployment. Various other factors can affecting the country’s economy; including shifts in global economic and political power; power shortages, water shortages,[1] degree of investment in economic infrastructure, corruption, social cohesion and equity (Cilliers, 2015).

(iii) Natural resource use. The use of natural resources will depend on the chosen development trajectory and resource intensity of the South Africa economy. South Africa is regarded as a water-scarce country; however, projections suggest a continued increase in water demand. A continued increase in water demand coupled with projections for a drier and hotter future – with less precipitation in some areas – is a serious concern for the country’s future water security and immediate efforts should be put in place to adapt accordingly. South Africa produces two-thirds of Africa's electricity and 90% of this is generated in coal-fired power stations (DoE, 2016). Current scenarios which use data from the BP statistical review of world energy (2013) indicate a steady increase in energy demand in South Africa until 2030 (ISS, 2016). While there is an increase in the adoption of renewable energy, the continued reliance on coal and a large increase in nuclear power to add to the future baseload power - 65% coal, 20% nuclear and 15% renewables by 2030 (Integrated Resource Plan (IPR2), will allow South Africa to make significant progress in meeting its COP 21 commitments, but will require a significant capital investment. Natural resource shortages, particularly water, can have implications for the economy and society with impacts on the cost of food production and mobility of goods and people.

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[1] See S Hedden, **Parched prospects II: A revised long-term water supply and demand forecast for South Africa**, African Futures Paper no 16, Institute fore Security Studies, Pretoria, 22 March 2016, available at https://www.issafrica.org/publications/papers/parched-prospects-ii-a-revised-long-term-water-supply-and-demand-forecast-for-south-africa

(iv) Climate governance. In 1960 annual carbon emissions in South Africa were 26.7 Megatonnes and by 2010 this had increased to 125 Megatonnes. The country's carbon emissions from fossil fuels (especially coal) are likely to continue increasing until 2030 ('peak, pleateu, decline' or PPD trajectory that South Africa committed to UNFCCC in 2009, COP15) and these are defined in intended nationally-determined contribution (INDC) (UNFCCC, 2015; DEA, 2015j). The INDC projects indicate that between 2025 and 2030, emissions will be in a range between 398 to 614 Megatonnes carbon dioxide-equivalent. South Africa's greenhouse gas emissions are expected to peak then plateau for approximately a decade to 2035 and decline in absolute terms thereafter. This will require effective implementation of the full suite of policies and plans available at local, provincial and national levels to achieve this desired peak, plateau and decline trajectory.

(v) Cultural and social cohesion. Social cohesion goes across class, gender, race and ethnic divisions and is dependent upon the value systems within society. Social cohesion can be strengthened through education, religion, community and providing platforms for sharing the nation's arts and cultural productions and providing a unified action to respond to climate change (RSA, 2009a).

(vi) A key factor that can help to address poverty, inequality and unemployment in South Africa is improved governance, the combating of corruption and the establishment of a capable, developmental state able to play a socially transformative role.

Generating socio-economic scenarios[2] that take all of these considerations into account is challenging, due to the complexity of the associated systems and the need to structure interactions in their appropriate interdependent relationships. Since the future remains essentially unknown, the use of scenarios can give representations of possible futures that are useful to frame and inform policy choices. These efforts typically include a qualitative (or narrative) element associated with quantitative indicators. The UNDP Adaptation Policy Framework identified demographics, economic growth, natural resource-use, governance, policy and cultural cohesion to be the key drivers of socio-economic change (Malone and La Rovere, 2005). Globally, the majority of associated work has focused on the demographic and economic considerations with little or no work on the policy and cultural indicators due to data availability. Recent research on modelling socio-economic futures and development scenarios for South Africa has been carried out by the National Planning Commission and the Presidency's Policy Co-ordination and Advisory Services, as well as organisations such as the Institute for Security Studies (in partnership with the Frederick S. Pardee Center for International Futures) and global development organisations such as UNDP, World Bank and World Watch Institute. It is noteworthy that no socio-economic models for South Africa have yet incorporated the climate change futures to provide an integrated assessment of climate change. This is needed so that

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[2] Scenarios describe a comprehensive description of the future of human-climate system using qualitative and quantitative information.

climate change impacts can be explored in the overall context of **South Africa's capability to mitigate and adapt, and its shared responsibility in global climate governance.**

3.4.4 Framework for integrating socio-economic futures into climate adaptation planning

The IPCC has developed a set of Representative Concentration Pathways (RCPs) that explore alternative futures with different levels of global greenhouse gases. Table 0.4 summarizes key elements of the four RCP's. Climate modelling teams now utilise the RCPs as input into the model ensemble projections for future climate change.

Table 0.3: Representative Concentration pathways in the year 2100 (**Source: O'Neill, 2011**)

RCP 8.5	8.5 W/m^2	1350 ppm	Rising
RCP 6.0	6.0 W/m^2	850 ppm	Stabilizing
RCP 4.5	4.5 W/m^2	650 ppm	Stabilizing
RCP 2.6	2.6 W/m^2	450 ppm	Declining

The development of socio-economic scenarios that are consistent with the RCP pathways has also been done at a coarse international level through integrated assessment modelling, and there have been some analyses of impacts, adaptation and vulnerability based on existing emission scenarios (Nakićenović *et al.,* 2000). The development of the four new paths of radiative forcing (RCPs), the future social conditions, the climate change simulations (aligned to the RCPs) should be integrated to explore the alternative mixes of climate change mitigation, adaptation and impacts (O'Neill and Schweizer 2011), as depicted in Figure 3.35.

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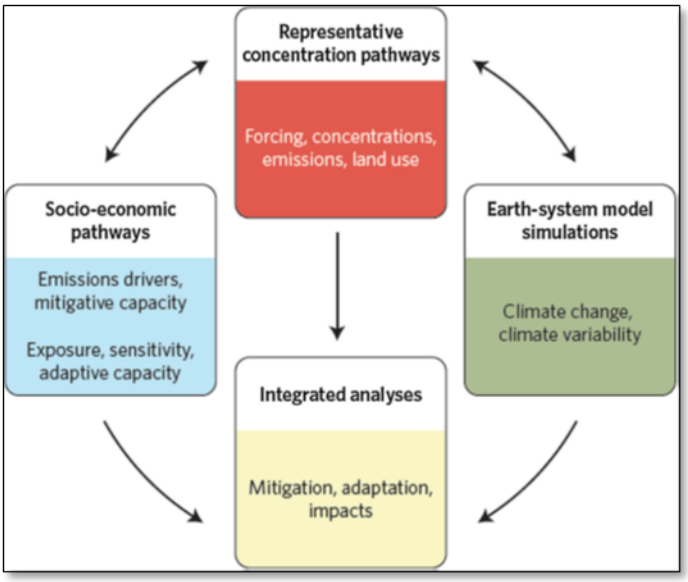


Figure 0.35: The parallel process conceptual diagram for the development of new, integrated scenarios of climate change (**Source: Moss *et al.,* 2010**)

The integration of socio-economic and climate scenarios are essential to investigate the degree to which adaptation and mitigation could reduce the projected impacts of climate change, as well as to estimate the cost of action versus the cost of no action. The scenarios can then also be used to inform boundary conditions for mitigation, to assess the cost-effectiveness of local mitigation measures which can include land-use planning at the local level and changes in regional energy systems (IPCC, 2012b).

The developed scenarios should provide both qualitative and quantitative descriptions of possible socio-economic and ecological futures that influence mitigation and adaptation, with the aim of improving decision-making and informing climate governance. The integrated scenarios would then bridge the gap between different disciplines regarding the level of climate change and its impacts on human development trends in relation to drivers of climate change, mitigation of greenhouse gas emissions and the capacity to adapt to climate change. The Shared Socio-economic Reference Pathways (SSPs) serve as defined scenarios to complement the RCPs (IPCC, 2012b) and consist of balancing the socio-economic challenges of mitigation and adaptation – see Figure 3.36 and Table 3.4. It is noteworthy that a globalised, highly-developed and eco-friendly world, with regional sustainable development would offer low mitigation and low adaptation challenges, but would require good governance, rapid technological development and dissemination and low population growth (SSP1 scenarios). The extreme alternative to this scenario would be the failure of efforts at both adaptation and mitigation characterised by a high population and poorly-established institutions and governance (SSP3 scenarios). In instances where mitigation and adaptation is not combined, shifts towards SSP4 and SSP5 may be experienced, with either high adaptation or mitigation challenges dominating these scenarios (Van Vuuren *et al.,* 2013).

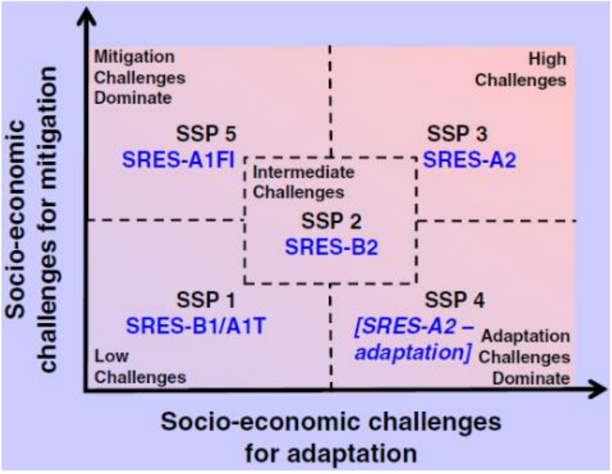
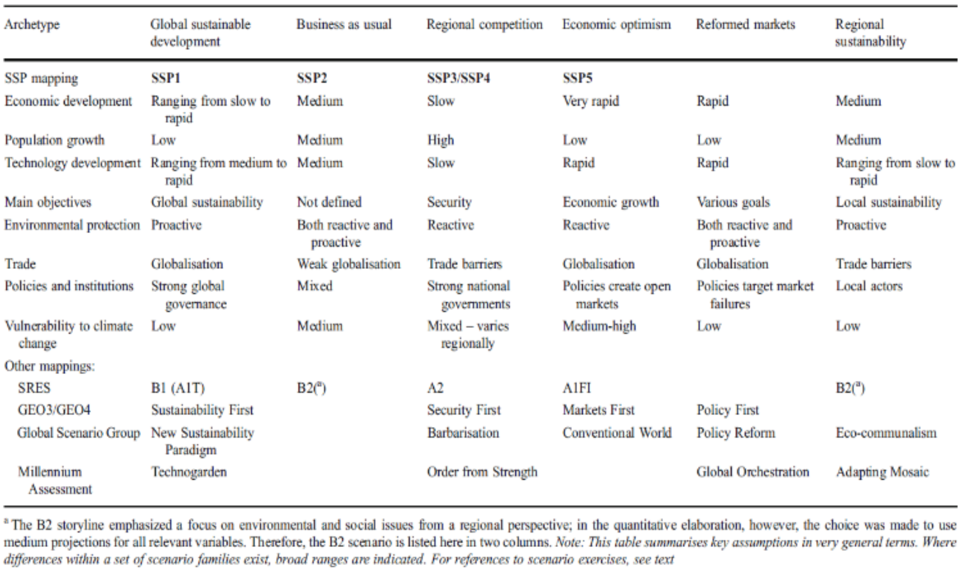


Figure 0.36: A suggested mapping of the Shared Socioeconomic Reference Pathways (SSPs) in terms of mitigation-adaptation (based on O'Neill *et al.,* 2013)

Table 0.4. Assumptions of scenarios of mitigation and adaptation (Van Vuuren *et al.,* 2013).



Archetype	Global sustainable development	Business as usual	Regional competition	Economic optimism	Reformed markets	Regional sustainability
SSP mapping	**SSP1**	**SSP2**	**SSP3/SSP4**	**SSP5**		
Economic development	Ranging from slow to rapid	Medium	Slow	Very rapid	Rapid	Medium
Population growth	Low	Medium	High	Low	Low	Medium
Technology development	Ranging from medium to rapid	Medium	Slow	Rapid	Rapid	Ranging from slow to rapid
Main objectives	Global sustainability	Not defined	Security	Economic growth	Various goals	Local sustainability
Environmental protection	Proactive	Both reactive and proactive	Reactive	Reactive	Both reactive and proactive	Proactive
Trade	Globalisation	Weak globalisation	Trade barriers	Globalisation	Globalisation	Trade barriers
Policies and institutions	Strong global governance	Mixed	Strong national governments	Policies create open markets	Policies target market failures	Local actors
Vulnerability to climate change	Low	Medium	Mixed – varies regionally	Medium-high	Low	Low
Other mappings:						
SRES	B1 (A1T)	B2([a])	A2	A1FI		B2([a])
GEO3/GEO4	Sustainability First		Security First	Markets First	Policy First	
Global Scenario Group	New Sustainability Paradigm		Barbarisation	Conventional World	Policy Reform	Eco-communalism
Millennium Assessment	Technogarden		Order from Strength		Global Orchestration	Adapting Mosaic

[a] The B2 storyline emphasized a focus on environmental and social issues from a regional perspective; in the quantitative elaboration, however, the choice was made to use medium projections for all relevant variables. Therefore, the B2 scenario is listed here in two columns. *Note: This table summarises key assumptions in very general terms. Where differences within a set of scenario families exist, broad ranges are indicated. For references to scenario exercises, see text*

The modelling of coupled socio-economic and climate change futures will therefore need to explore a range of scenarios that use the RCP and SSP as reference. The **modelling of climate change adaptation will depend on the prevailing mitigation** as well as the social and ecological vulnerability at a particular locality or region. A proposed framework to guide the modelling of adaptation to climate change should include socio-economic scenarios that integrate with climate change projections and reference mitigation commitments while also ensuring that they are:

- Relevant and appropriate for use at various levels by both the public and private sector in decision-making and in assessing the vulnerability to climate change;

- Reliable, and based on logical assumptions which do not over-estimate climate risks and is robust in terms of climate change impacts and risks, with clear boundaries of risk assessments;
- Based on established methodologies with transparency, open access of data, modelling and assumptions that can provide contextual guidance for interpretation
- Dynamic in order to account for internal feedback effects and enabling the forecasting over various periods of time (short-, medium- and long-term).

The premise of a socio-economic modelling framework is therefore a **dynamic coupled socio-ecological system**. Human systems can be conceived as classes of agents and larger structures within which those agents interact. The structures normally account for a variety of stocks (people, capital, natural resources, knowledge, culture, etc.) and the flows that change those stocks over time. Agents act on many of the flows, some of which are especially important in changing stock levels like births, economic production, or technological innovation. Over time, agents and the larger structures evolve in processes of mutual influence and determination. The costs of adaptation will need to be based on markets that have key stocks in the form of capital, labour pools and accumulated technological capability. In addition, non-market-based financial transfers among such agents with exchanges in a market system will need to be accounted for using social accounting matrices (SAM); and this is particularly relevant for South Africa with an informal second economy. Furthermore, governments interact with each other in larger inter-state systems that frame the pursuit of security and cooperative interaction like climate change agreements. Similarly, the human actor classes interact with each other and the broader environment and in doing so influence the prevailing practice, technological innovation and climate governance. These power relationships will need to be represented and accounted for in the action-reaction dynamics of the modelling. Understanding the stocks and flows in the model is vital to gain an insight into the system’s behaviours. Stocks are variables with levels that accumulate or decay over time. For example, the number of people living in a given country is a stock of population. Flows are time-specific values that either add to or take away from stocks, such as the number of births added to a population in a given year. Depending on the rates of births and deaths, population levels will grow, shrink, or equilibrate at a stable level.

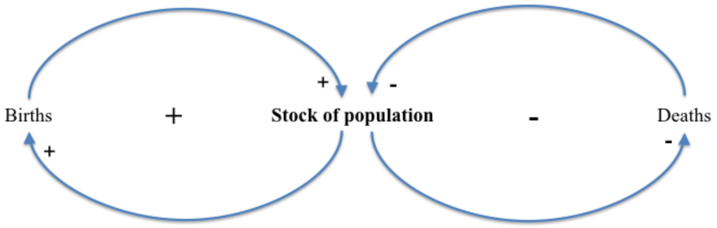


Figure 0.37: A causal loop diagram to represent the stock of population that depends on the birth and death rate amongst other factors.

There is, however, much that is missing from the above diagram, and a more nearly-complete understanding of population growth would require an analysis of the deeper drivers of each proximate driver of population, such as the effect that education has on the number of children families have.

A fully integrated modelling approach with socio-economic and climate change futures would include various stocks and flows within the following categories:

- Environmental Sustainability: Atmospheric carbon dioxide levels, world forest area, and fossil fuel usage
- Social/Political Change: Life expectancy, literacy rates, level of democracy, the status of women, shifts in values
- Demographic Futures: Population levels and growth, fertility, mortality, migration rates
- Food and Agriculture: Land use and production levels, calorie availability, and malnutrition rates
- Energy: Resource and production levels, demand patterns, the share of energy coming from renewables
- Economics: production by sector, consumption, trade patterns and structural change
- Global System: Country and regional power levels

It is proposed that the socio-economic modelling framework for climate change adaptation consists of modules that are inter-connected and can be accessed through a single graphical user-interface, similar to that of the International Futures forecasting system (www.pardee.du.edu); described below. This is an example of the components (or modules) that could be utilised for socio-economic futures modelling, together with some of the key characteristics that guide each system.

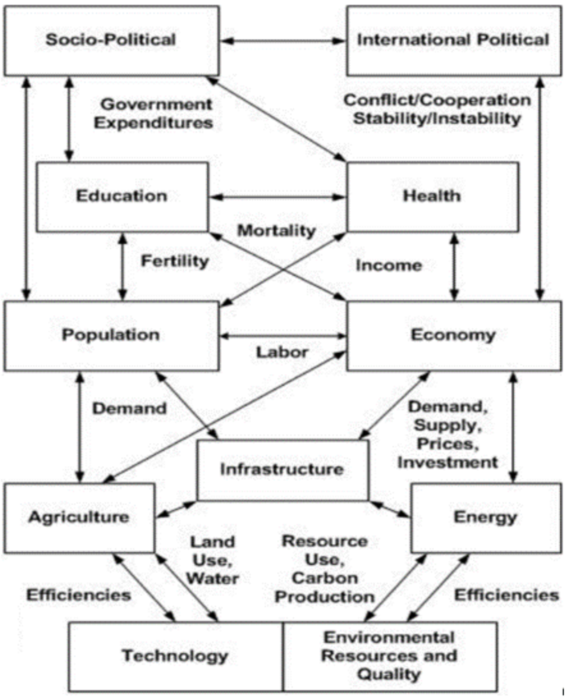


Figure 0.38: Proposed modules of the socio-economic adaptation modelling framework (**from IFS**).

The population module:

- represents 22 age-sex cohorts to age 100+ in a standard cohort-component structure (but computationally spreads the 5-year cohorts initially to 1-year cohorts and calculates change in 1-year time steps)
- calculates change in cohort-specific fertility of households, in response to income, income distribution, infant mortality (from the health model), education levels, and contraception use
- uses mortality calculations from the health model
- separately represents the evolution of HIV infection rates and deaths from AIDS
- computes average life expectancy at birth, literacy rate, and overall measures of human development (HDI)
- represents migration, which ties to flows of remittances.

The economic module:

- represents the economy in six sectors: agriculture, materials, energy, industry, services, and information/communications technology (ICT)
- computes and uses input-output matrices that change dynamically with development level
- is an equilibrium-seeking model that does not assume exact equilibrium will exist in any given year; rather it uses inventories as buffer stocks and to provide price signals so that the model chases equilibrium over time
- contains a Cobb-Douglas production function that (following insights of Solow and Romer) endogenously represents contributions to growth in multifactor productivity from human capital (education and health), social capital and governance, physical and natural capital (infrastructure and energy prices), knowledge development and diffusion (research and development [R&D] and economic integration with the outside world)
- uses a Linear Expenditure System to represent changing consumption patterns
- utilizes a "pooled" rather than bilateral trade approach for international trade, aid and foreign direct investment
- has been imbedded in a social accounting matrix (SAM) that ties economic production and consumption to representation of intra-actor financial flows.

The agricultural module:

- represents production, consumption and trade of crops and meat; it also captures ocean fish catch and aquaculture, but in less detail
- maintains land use in crop, grazing, forest, urban, and "other" categories
- represents demand for food, for livestock feed, and for industrial use of agricultural products
- is a partial equilibrium model in which food stocks buffer imbalances between production and consumption and determine price changes
- overrides the agricultural sector in the economic module unless the user chooses otherwise

The energy module:

- portrays production of six energy types: oil, gas, coal, nuclear, hydroelectric, and other renewable energy forms
- represents consumption and trade of energy in the aggregate
- represents known reserves and ultimate resources of fossil fuels
- portrays changing capital costs of each energy type with technological change as well as with draw-downs of resources
- is a partial equilibrium model in which energy stocks buffer imbalances between production and consumption and determine price changes
- overrides the energy sector in the economic module unless the user chooses otherwise.

The infrastructure module:

- forecasts physical extent of, and citizen access to road transportation, water and sanitation, electricity, and information and communications technology
- calculates the public and private financial costs of infrastructure construction and maintenance

The environmental module:

- tracks annual carbon dioxide emissions from fossil fuel use
- represents carbon sinks in oceans and forest land and models build-up of carbon dioxide in the atmosphere
- calculates global warming and links it to country-level changes in temperature and precipitation over time which, with the addition of carbon fertilization, impact agricultural yields
- represents indoor solid fuel use and its contribution to health-related variables

- forecasts outdoor urban air pollution and links with respiratory disease
- models fresh water usage as a percentage of total water availability

The education module:

- forecasts rates of intake and completion across formal education levels—primary, lower secondary, upper secondary and tertiary—for both sexes
- forecasts average years of education for the population as a whole
- captures educational attainment by age-sex cohort

The health module:

- accounts for major causes of disability and death across major World Health Organization categories
- measures the impact of health outcomes on the economy, through human capital's contribution to multi-factor productivity

The socio-political module:

- represents government finance, social conditions, and attitudes of individuals, and qualitative and quantitative indicators of governance

The international political module:

- traces changes in power balances across states and regions
- allows exploration of changes in the level of interstate threat, both as an index and probabilistic measure

The technology module:

- is distributed throughout the overall model
- allows changes in assumptions about rates of technological advance in agriculture, energy, and the broader economy
- is tied to the governmental spending model with respect to research and development (R&D) spending

The relationships between variables of the system are described mathematically, based on historical data and trends. A dynamic Computable General Equilibrium (CGE) modelling approach allows scenario analysis with the alteration of parameters (often including multipliers) that drive different variables within the model and the incorporation of stochastic elements can be used to assess impacts from extreme weather events on the economy (dynamic stochastic general equilibrium model). Through the identification and validation variables (stocks and flows) and their quantification, a system modelling approach can describe the forward and backward linkages, inter-connectedness between different elements, and the feedbacks that determine the overall system behaviour. This provides users of the model with the ability to change parameters and the initial conditions of the model in order to explore a range of uncertainty or to consider policy leverage. In addition, a scenario tree allows for a number of different interventions and allows users to frame uncertainty surrounding: initial conditions (How much oil is really out there?); technology growth rates (What happens if longevity increases?), agent behaviour (What happens if people save more and consume less?) and relationships between parameters (What happens if assumptions about elasticity of energy demand to its price are too low?).

3.4.5 Understanding climate impacts and costs

The LTAS report on economics of climate change adaptation (Report 6) illustrates the potential macro-economic impacts of future climate change on the South African economy with a dynamic computable general equilibrium (CGE) model to simulate the economy-wide impacts for the period 2010-2050. Three biophysical infrastructures critical for the country's economy are modelled water supply and water use (including urban, industrial and agriculture); (ii) roads; and (iii) coastal infrastructure. The scenarios indicate that at national level the economic impacts of climate change are minimal; however at sub-national level there is a higher variability with the most vulnerable communities likely to be the most severely impacted. At national level the impacts of climate change on the economy are minimal given the projected average annual economic growth rates, especially in the period before 2035 but the impacts may be more pronounced with time. Economic impacts are likely to be most significant at a sub-national level and for specific sectors affecting productivity such as agriculture and its agro-processing. This could enhance inequality and unemployment especially for regions that are dependent on agriculture which can result in increased rural-urban migration. Poverty and inequality in agriculture will affect mostly the unskilled workers who will not easily be absorbed into other economic sectors. Several areas of future research were identified to improve understanding on the impacts of climate change; such as estimating the anticipated impacts of extreme weather events and the associated adaptation costs for specific infrastructure (dams and bridges on other critical infrastructure such as energy, health and telecommunications), the human migrations and distributional shifts in wealth that will accompany climate change impacts, as well as new opportunities; such as possible areas that could provide hydroelectricity under the wetter climate change future scenarios in South Africa.

An integrated approach to modelling climate change impacts and socio-economic futures will enable estimates of the costs of various actions or responses. The climate governance costs wiIl need to be framed by the degree of mitigation compared to adaptation, of the appropriate scale (global, regional, national, and sub-national scales) and the degree of vulnerability. For example, in South Africa, coastal communities may face considerable risk of flooding and extreme weather events due climate change and will need considerable investments to enable them to adapt. At the same time, climate change and extreme heat and drought in the interior of the country could result in a decline in agricultural output and food shortages that would require different policy interventions. Understanding the economics of these adaptation options will require a spatial and temporal assessment of climate change and extreme weather events in South Africa, together with a spatial map of the socio-economic status and climate change vulnerability at appropriate scale. Based on a risk assessment of the climate change impacts to the profitability of various sectors of the economy, the socio-economic modelling will be able to assess the potential sectoral gains/losses arising from climate variability and climate change. This can be expressed as the gross value add (GVA) per sector (i.e. water, agriculture and forestry, human health, marine fisheries and biodiversity sectors defined by the LTAS) and the loss in GVA from climate change impacts assessed on the same basis as the costs required to adapt to climate change. When incorporated into the national system of accounts, the GVA loss from climate change can effectively inform government spending and climate change governance.

3.5 Development of a risk assessment methodology and vulnerability indices

3.5.1 Introduction

The concept of vulnerability, which broadly speaking refers to the “propensity or predisposition to be adversely affected” (Field *et al.,* 2014), was initially formed within the natural hazards research field (White & Haas, 1975). It has also gained increasing importance within the climate change research community. Extensive research and development in the field of vulnerability and vulnerability assessments has occurred over the last four decades (White & Haas, 1975; Blaikie *et al.,* 1994; Turner *et al.,* 2003). A vulnerability assessment refers to the process of identifying, quantifying and prioritising key risks and vulnerabilities of a system (such as a sector, locality or community). Climate change vulnerability assessments aim to capture the changing nature of risks and the variable capacity to cope with both risk and change over time (O’Brien *et al.,* 2009a). In the context of climate change adaptation, vulnerability assessments are often considered prerequisites for the construction of adaptation strategies and policies as they provide information on the circumstances that create risks, and the factors which would improve the resilience of the system to respond to those risks. However, limited evidence exists to link decisions that have resulted in reduced vulnerability to vulnerability assessment practice (Preston *et al.,* 2011).

The complexity involved in defining and measuring the various geographical, spatial, temporal and social dimensions of vulnerability has resulted in a multitude of methodologies for assessing and understanding vulnerability. As a consequence there is generally a lack of consensus regarding the appropriate frameworks and ‘best’ methodologies for assessing vulnerability (Preston, 2012). In South Africa, there is no standard approach or best practise guidelines for measuring vulnerability. This makes monitoring of vulnerability and the evaluation of adaptation measures considerably challenging, and precludes comparing different sectors or localities as well as assessing vulnerability over time (Preston, 2012). The demand for a more formal approach to vulnerability assessments brings with it a number of considerations that represent a number of challenges (see Box 0.1).

Box 0.1. Challenges associated with the development of a vulnerability assessment methodology

General challenges:

Systems under assessment are highly complex and dynamic. In many cases the interactions between biophysical and socio-economic dimensions are poorly understood and as such vulnerability assessments often do not include both biophysical and socio-economic determinants of vulnerability (Preston, 2012).

Vulnerability assessments often do not go beyond an academic exercise and this has ethical issues when engaging stakeholders and communities in vulnerability assessments. Paucity of reliable, readily available, and representative data for desired indicators of vulnerability. Any measure of vulnerability needs to capture the influence of processes operating on all relevant scales.

Climate specific challenges:

Any measures or indicators of vulnerability need to be capable of identifying both the current state and any future trend. There is a degree of uncertainty in scenarios of future states in climate as well as social and economic futures.

The development of one-size-fits all solution for assessing vulnerability to climate change is problematic as vulnerability is geographically and socially differentiated. A national scale assessment, for example, needs to take account of regional patterns of vulnerability within the country and the distribution of vulnerability within the national community (Adger *et al.,* 2004). Preston (2012:44) argues that the emphasis of vulnerability assessments “should be placed not on identifying or developing the ideal framework and methodology for assessment, but rather attempting to link information needs and objectives to the appropriate frameworks, methods and tools for assessment”.

This section of Chapter 3 initially set out to present a national vulnerability assessment framework and associated best practice guidelines that could be applied to various sectors and scales in South Africa. However, as illustrated by the literature review and the expert workshop opinions presented below, the development of a standard vulnerability assessment framework is neither feasible nor defensible.

Therefore this section intends to strengthen future vulnerability assessment work that is aimed at building South Africa's resilience to climate change by:

1. Outlining major theoretical and conceptual framings and common approaches that have proven successful in understanding vulnerability;
2. Building on insights and recommendations from South African vulnerability experts ;
3. Providing practical translations of theoretical and conceptual framing;
4. Presenting a best practice guideline for how to approach VAs, as well as highlighting practical tools available for evaluating the impacts, vulnerability and adaptation to climate change.

It is hoped that the understanding and guidelines provided in this section will assist in strengthening approaches to vulnerability assessments in South Africa, and thereby build a robust basis from which effective adaptation strategies and climate change policies can be developed. Due to concurrent time-lines these guidelines could not inform, in-full, the sector based reviews presented in Section 3.6 of this Chapter. The sector based reviews were based on the assessment of the three core components of vulnerability; exposure, sensitivity and adaptive capacity (see Section 3.6 and Appendix B31 for more details).

3.5.2 Understanding vulnerability to climate change

3.5.2.1 Framing of vulnerability by IPCC

Vulnerability to climate change is defined by the IPCC 3rd and 4th assessment reports (AR3 and AR4) as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (McCarthy *et al.,* 2001). This definition characterised vulnerability as a function of three components: exposure, sensitivity and adaptive capacity, which are influenced by a range of biophysical and socio-economic factors. Using this definition, a highly vulnerable system would be one that is very sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and for which the ability to adapt is severely constrained. Through the sensitivity and adaptive components, this framing takes into account that socio-economic systems can reduce or intensify climate change impacts.

In the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX, Field, 2012) and the IPCC Fifth Assessment Report (AR5), the understanding of vulnerability has shifted to a risk -based approach (Figure 0.39). Vulnerability is defined in AR5 as the "propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (Field *et al.,* 2014:5). Both the changes in the climate system and socio-economic processes, including adaptation and mitigation, are viewed as drivers of hazards, exposure, and vulnerability (Field *et al.,* 2014). In other words, current vulnerability to an existing climatic variability may not necessarily be the same as future vulnerability to climate change. This implies that vulnerability is inherently dynamic and recognises that both societal and environmental transformations are ongoing processes.

The current framing of vulnerability (Figure 0.39) is an improvement on AR4 as it recognises vulnerability as a complex and multidimensional concept where risks are the result of complex interactions among communities, ecosystems, and hazards arising from climate change. Climate change is not viewed as the risk but rather the interaction of climate changes with related hazards and evolving vulnerability and exposure of systems determine the changing level of risk (Field *et al.,* 2014; Oppenheimer *et al.,* 2014). Secondly, vulnerability is context and location specific and should be framed within social, economic, political, and cultural realities of those locations (Vogel & O'Brien, 2004). This implies that vulnerability is expressed differently at different scales, from individual to household, to the surrounding community and to the broader national scale (Cutter *et al.,* 2003).

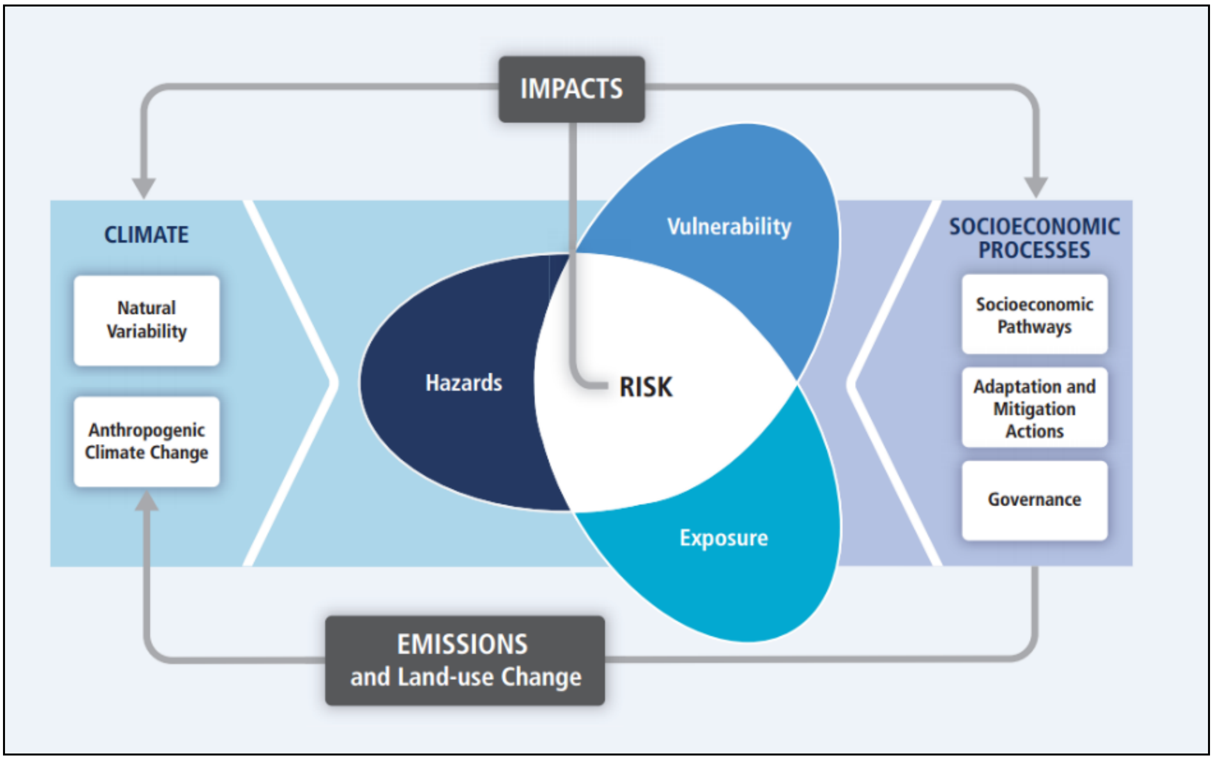


Figure 0.39: The IPCC AR5 vulnerability assessment framework.

3.5.2.2 Common approaches to vulnerability assessments

Vulnerability is a theoretical concept that is not readily measurable or observable, and which relates to consequences or outcomes (Hinkel, 2011). Vulnerability assessments have been widely used in many sectors, including disaster risk reduction research (see Box 3.2), food security studies and more recently climate change impact assessments (O'Brien *et al.,* 2009a). While a multitude of vulnerability frameworks have emerged, these tend to be conceptually broad and offer limited guidance on how they should be operationalised (Preston, 2011). Defining criteria for quantifying vulnerability has thus proven difficult, but several measures of vulnerability have been developed and applied. These include proxy or indicator-based approaches, model and GIS-based methodologies, participatory and multi-stressor approaches, with elements of the different approaches and methods often being used in combination.

The choice of approach in conducting a vulnerability assessment should be directly linked to the purpose of the assessment, be based on the spatial scale of the assessment (e.g. the national, provincial to local level) as well as the resources available (such as data, time, size of research team) (Patt, 2012). This does not however imply that a clear purpose, a predetermined spatial scale and reasonable resources at hand makes for a straight forward choice of methodology and ensures an outcome that is relevant to adaptation decision making. Often studies use a combination of bottom-up and top-down methods for a given case study in order to better understand/capture vulnerability (see Appendix B3 for definitions). Bottom-up or contextual based approaches consider climate variability and change to occur in the context of political, institutional, economic and social structures and changes which interact dynamically (Füssel, 2010). Top-down approaches, on the other hand, are a linear analysis of the projected climate change impacts on a particular exposure unit either biophysical or social, which is offset by adaptation measures.

Box 0.2. Disaster Risk Management in South Africa

The Disaster Management Act (Republic of South Africa, 2002) and the National Disaster Management Policy Framework (Republic of South Africa 2005) guide Disaster Risk Management (DRM) in the country. The Amendment Act now expands disaster management plans to include risk assessments, mapping of vulnerable areas and provides measures to reduce the risk of disaster through adaptation to climate change and developing of early warning mechanisms.

DRM is the responsibility of the National Disaster Management Centre (NDMC), whose mandate is to create the required institutional activities for integrated and coordinated disaster risk management, focusing on prevention and mitigation at all levels of government in order to enhance the resilience of communities and infrastructure to disaster risk. One of the priorities of the NDMC is the establishment of the National Disaster Management Information System (NDMIS), which includes risk and vulnerability profiling across the country in order to develop a National Indicative Risk Profile.

Indicator-based methodologies

Indicator-based assessments of vulnerability use a specific set or combination of proxy indicators in order to form an overall measure of vulnerability (see Box 3.3). An indicator is a function from observable variables (Hinkel, 2011). The indicator approach is a common methodology for the mapping of levels of vulnerability, as they produce measurable outputs across various spatial scales that can be easily used by policy makers. Furthermore, the indicator approach is valuable for monitoring trends and exploring the implementation of adaptation responses.

One of the key challenges of indicator-based assessments is the lack of reliable data, particularly socio-economic sources (such as data on human health), at the scale required for assessment (Adger *et al.,* 2004). Some critiques further say that indicators fail to capture the spatial and temporal heterogeneity of vulnerability, and are unable to convey uncertainty (Patt, 2012; Vincent, 2007). This is a result of the subjective nature of the selection of indicators and the difficulty in testing and validating the different metrics used as indicators. An example of this is the assessment of good governance, a key component of adaptive capacity, which is difficult to capture in an indicator (Vincent, 2007).

Box 0.3: Development of Social Vulnerability Index for South Africa using Census data

A social vulnerability index for South Africa was developed by Le Roux *et al.,* (2015). The index captures the drivers of social vulnerability, and identifies the most vulnerable communities in the country. The index was a composite of information on 14 variables (based on publically available data from StatsSA and IDPs) including: average household size; percentage of the population that is unemployed; percentage of the population living below the poverty line; percentage of the population living in rural areas; percentage of dwellings that are shacks; percentage of the population aged 25 with no education; percentage of the population that is disabled; percentage of households that are female headed; percentage of households using non-electric sources of energy for cooking; percentage households without telephone lines; percentage of households without a car; percentage of households without public water; and percentage of the population without SA citizenship. Figure 0.40 displays the social vulnerability index for South Africa (Le Roux *et al.,* 2015), emphasizing the most vulnerable communities in South Africa (red colours). The highly vulnerable areas include the former homelands of Eastern Cape, Kwazulu-Natal, Limpopo and North West provinces.

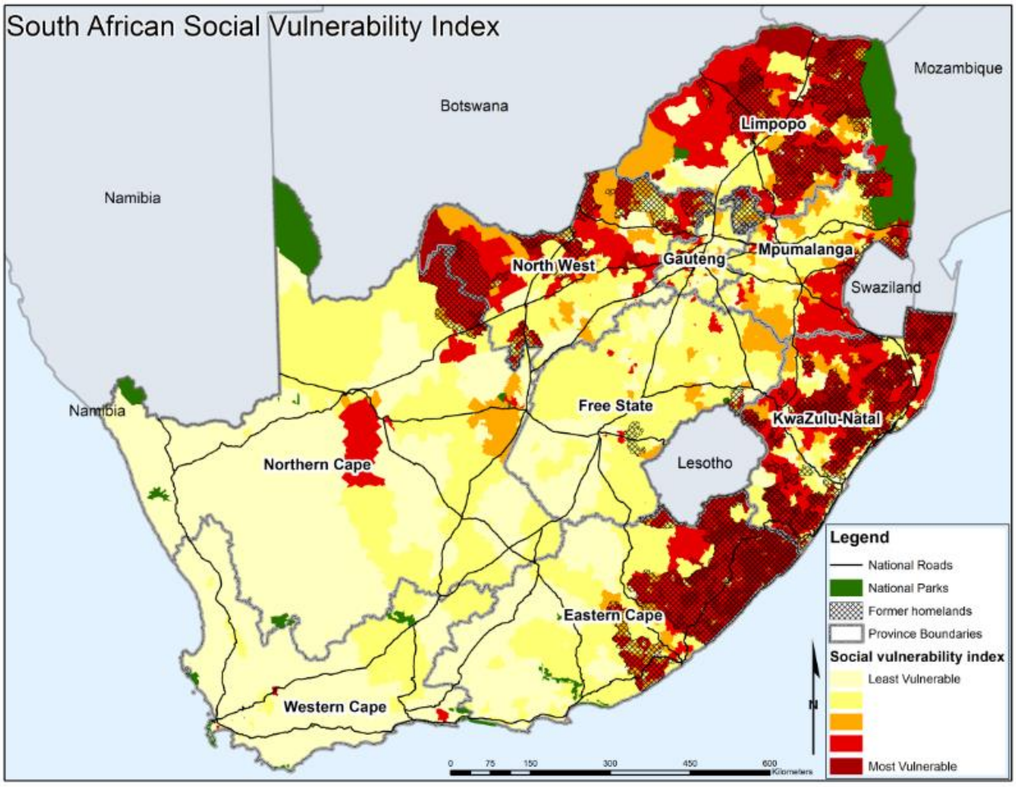


Figure 0.40: Social vulnerability index of South Africa (**Le Roux *et al.*, 2015**)

Box 0.4: Development of a Vulnerability Index for the Northern Cape Province through the assessment of social and biophysical vulnerability

The Department of Environment and Nature Conservation of the Northern Cape has produced a vulnerability index. The aim of the index is to assist local decision makers and managers in the rapid evaluation of vulnerability to climate change in the province. In the framework, vulnerability is an outcome of the interaction between social and ecological vulnerabilities and environmental risks and stresses arising from climate change. Biophysical vulnerability focuses on the exposure of ecological processes to climate change hazards, such as changes in temperature and intense rainfall. Social vulnerability focuses on aspects that limit the ability of communities to withstand or respond to adverse climate change impacts, such as poverty and inequality, marginalisation, food entitlements, access to insurance and housing quality.

Two main categories of climate change vulnerability have been considered to represent the overall climate change vulnerability for the province:

- Ecological vulnerability
- Socio-economic vulnerability

Under the ecological and socio-economic vulnerability categories, a set of sub-indicators were developed and used as proxies to represent the 3 core aspects of vulnerability:

- Exposure: e.g. change in temperature or rainfall (ecological) and % population living in least stable climate areas (socio-economic)
- Sensitivity: e.g. shift in biomes (ecological) and total direct dependence on natural resources as a % of the population (socio-economic)
- Adaptive capacity: e.g. % area of natural features supporting landscape resilience to climate change (ecological) and local Institutions supporting climate resilience (socio-economic)

The indicators were assessed on a scale of 1 to 5, with 1 representing the lowest and 5 the highest vulnerability. A crucial part of the vulnerability assessment process was local stakeholder engagement, and a clear understanding of the political processes. The vulnerability assessment methodology used in this study required robust socio-economic, ecological and climate data. The data used in the assessment was largely drawn from LTAS and the 2011 National Census (DENC, 2016).

Model and GIS-based methodologies

Measures of vulnerability are often visualised through mapping, as patterns can be identified and analysed through spatial analysis. Biophysical and socio-economic models are often used as a means to measure vulnerability. These commonly focus on a specific driver of change or sector, and apply statistical measures and mapping techniques to display vulnerability as well as measures of adaptive capacity and resilience (see and Box 3.5 for an example).

Several challenges have been identified with regards to spatial vulnerability mapping. Spatial representations of vulnerability are typically a snapshot of vulnerability, failing to encapsulate spatial and temporal drivers of structural inequalities (Tschakert *et al.,* 2013). While mapping of climate change vulnerability provides an insight into the vulnerability of place, and may have some value in identifying vulnerable places and people, they are not necessarily appropriate for decision making and policy development (Hinkel, 2011). Maps may create the impression that there is sufficient information on which to base decisions, and thus lead to stakeholders feeling over-confident (Preston *et al.,* 2011). As argued by Preston *et al.,* (2011), robust mapping assessments thus depend upon stakeholders being included into the assessment process.

Multi-stressor approach

Research in southern Africa has documented how local vulnerability (refer to Box 0.7 for summary of role of RVACs) is often the product of multiple stresses (Ziervogel & Calder, 2003; Casale *et al.,* 2010; O’Brien *et al.,* 2009b). Multiple stressors refer to a combination of biophysical and social factors that jointly determine the propensity and predisposition to be adversely affected (Field *et al.,* 2014). Many vulnerability frameworks (Turner *et al.,* 2003; Leichenko & O'Brien, 2008; Füssel, 2007; O’Brien *et al.,* 2009b) have recognised the importance of measuring multiple drivers and stressors in order to understand the multi-faceted nature and effects of vulnerability. These frameworks analyse multiple stressors to identify the intersection and interaction of stressors in different contexts. Multi-stressor approaches have the potential to contribute to the understanding of resilience by conceptualising the stresses and processes that lead to threshold changes, particularly those involved in the social and institutional dynamics of social-ecological systems. A challenge however exists in conceptualising exactly how different stressors interact and how they are perceived to interact in the future.

Participatory approaches

Participatory vulnerability assessments tend to focus on the affected communities or sectors, and use a wide range of tools for the collection and analysis of vulnerability such as cognitive mapping (Singh & Nair, 2014), interviews, surveys, vulnerability matrices, stakeholder engagement workshops and expert-based inputs. Participatory approaches are generally bottom-up processes that recognise multiple stressors beyond those of climate, including political, cultural, economic, and institutional drivers (Jones & Preston, 2011). These methodologies recognise the interaction of various exposures, sensitivities and adaptive capacities over time, assuming that vulnerability is a dynamic concept that changes over time (Smit & Wandel, 2006). Furthermore, the approach builds upon the understanding that sources of vulnerability function across different spatial scales from the national, provincial to local level. The methods and tools applied are often locations specific, as they need to be easy to understand, procedurally simple and culturally appropriate.

Participatory methodologies are closely linked with community-based vulnerability approaches and community based adaptation. Community-based approaches are a counter to the approaches that impose understanding and change from the outside, and instead emphasises how understanding and change should involve the full participation of communities and thus be developed from within (Ensor & Berger, 2009). While participatory based methods, including rural appraisal techniques and focus groups, are often used in data collection for vulnerability assessments, key points in the process, such as reflection, analysis and interpretation, tend to exclude the community participants (Fazey *et al.,* 2010). However, as argued by Tschakert *et al.,* (2013) vulnerability assessments can be enriched and invigorated through participatory approaches that allow communities to take part in the analysis and the process of reflection and iterative learning.

Box 0.5: eThekwini Safe Space Indicators

An indicator system was developed for eThekwini Municipality for monitoring progress towards sustainability outcomes. The system is based on the concept of 'safe space' that is defined by three largely independent axes (risk, human wellbeing and inclusive wealth). In terms of risk the system focused on the main drivers identified, namely; flooding resulting from extreme rainfall events, flooding resulting from high sea levels (a combination of storm surge and rising base levels due to climate change), and extreme heat and humidity events. **Figure 0.41** provides an example of the input data sets to assess risk of flooding (Pienaar & Scholes, 2015).

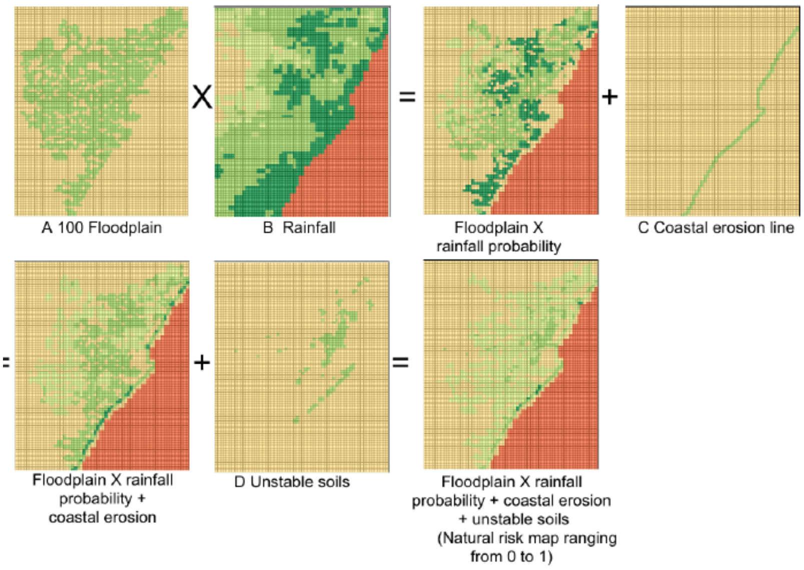


Figure 0.41: Example of calculating risk index for flooding based on set of input datasets (Pienaar & Scholes, 2015).

As for other approaches, participatory methods also have a number of challenges. This includes aspects such as identification of the appropriate target group, and ensuring that all voices are heard and equally included in the process. Depending on the extent to which the vulnerability assessment process allows engagements over longer periods of time and through continuous rather than one interaction, it might be challenging for those who are new to climate change to fully grasp the concepts and robustly reflect on climate change in the context of the system at hand. Language and translation of concepts poses another challenge, with complex concepts not always being easily translatable into multiple languages and common understanding of a concept thus not being a given. Lastly, participatory processes should ideally incorporate supporting data, including socio-economic and biophysical information, in order to ensure that the vulnerability assessment output is not purely based on the perceptions and understanding of participants.

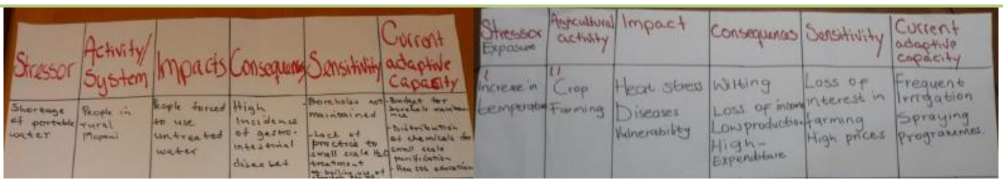
Box 0.6: A participatory-based vulnerability assessment for Greater Letaba and Greater Giyani Local Municipality

This vulnerability assessment was conducted by the South African National Biodiversity Institute (SANBI), in its role as National Implementing Entity (NIE) to the Adaptation Fund, together with Indigo development & change. The assessment formed part of the project development process for one of the South African Adaptation Fund projects, the Small Grants Facility Project. The overall aim of the assessment was to create insights that would make it possible to identify priority sectors for climate change adaptation responses for the Small Grants Facility Project. This was done through a participatory approach, focused on better understanding the local dynamics shaping livelihoods and sectors in Greater Letaba and Greater Giyani, and how climate change might impact these (Waagsaether, 2014).

The vulnerability assessment entailed six workshops, through which a total of over 100 people participated. Two of the workshops engaged Community Development Workers (CDW), whose perspectives were intended to provide insights into the local livelihoods context. The remaining four workshops were conducted with municipal officials working in a specific sector, more specifically water, agriculture, health and disaster management. The workshops focused on collectively exploring current stressors and challenges, as well climate change trends and possible impacts.

Given the different insights that were being sought, the processes in the workshops differed slightly between the CDW workshops and the sectoral workshops. The latter followed the following process (Figure 0.42):

- *Assessing vulnerability of sectoral systems/ activities to current stress* (*climatic/social/economic etc.*)
- *Assessing vulnerability of sectoral systems/ activities to future stress* (*climatic only*)
- *Identifying climate change adaptation responses*



Stressor	Activity/System	Impacts	Consequences	Sensitivity	Current adaptive Capacity
Shortage of portable water	People in rural Mopani	People forced to use untreated water	High incidence of gastro-intestinal diseases	Boreholes not maintained -Lack of practice to small scale H2O treatment eg boiling use of [illegible]	-Budget for borehole maintenance -Distribution of chemicals for small scale purification -Health education

Stressor Exposure	Agricultural activity	Impact	Consequences	Sensitivity	Current adaptive capacity
Increase in temperature	Crop Farming	Heat stress Diseases Vulnerability	Wilting Loss of income Low production High-Expenditure	Loss of interest in farming High prices	Frequent Irrigation Spraying Programmes.

Figure 0.42: Current sectoral vulnerability focus (left) and future climate change vulnerability focus (Right), resulting from step 1 and step 2 respectively of the sectoral workshop process

Box 0.7: South African Risk and Vulnerability Science Centres (RVAC)

In recognition of the unique challenges faced by the most vulnerable people in rural areas, the Department of Science and Technology funded the establishment of Regional Risk and Vulnerability Assessment Centres (RVAC) at rural universities in South Africa. The centres are strategically located at rural based universities including the University of Limpopo, University of Venda, Walter Sisulu University, University of Fort Hare and the University of Zululand (DST 2010). The aim of establishing the centres is to assist rural based universities by providing opportunities to enhance their capacity and capabilities in the areas of climate change environmental change. The centres should also provide risk assessment services to the local communities (Howard *et al.,* 2014).

3.5.3 Moving towards an improved understanding of vulnerability in South Africa

In order to understand the challenges and opportunities related to the role of vulnerability assessments in facilitating climate adaptation it is important to unpack some of the strengths and weaknesses of past VAs the country (refer to Box 0.8 for a summary).

Box 0.8: Summary of strengths and weaknesses of vulnerability assessment practice (after Preston, 2012: 49)

Strengths

Vulnerability assessments provide platforms upon which researchers and stakeholders can learn collectively

Frequent recognition of the role of biophysical and socio-economic determinants of vulnerability

Strong emphasis on assessment at the local scale

Assessment is flexible, with methods tailored to particular contexts and applications

Assessments are undertaken by teams of experts conveying credibility to assessment methods and outputs

Weaknesses
Lack of consistent methodology and comparability
Frequent lack of clarity regarding what is vulnerability and to what
Limited consideration of multi-scale determinants of vulnerability and their teleconnections
Inconsistent use of scenarios to represent future biophysical and socio-economic states
Limited consideration of adaptation/mitigation options to reduce vulnerability

3.5.3.1 The National Communications and the Long Term Adaptation Scenarios (LTAS)

A large body of constantly growing knowledge exists on sectoral climate change vulnerability in South Africa, as reflected in the Second National Communication (SNC) (DEA, 2011b) and the Long Term Adaptation Scenarios (DEA, 2013a) reports. There is a great expansion of information from the SNC to the much more detailed and in-depth LTAS reports.

While vulnerability is referred to consistently both through the SNC and the LTAS, neither have a consistent definition nor approach to vulnerability framing. This can be seen as a reflection of the lack of consistency in terms of definitions and framing of concepts applied in research and the wide variety of ways in which research has engaged with climate information. This makes it challenging to compile all under an umbrella approach, even within a single sector. Furthermore, the “status of knowledge” for the different sectors vary, with biodiversity, water and agriculture holding a large body of research, and climate change related research on health, human settlements and disaster risk in South Africa seemingly being sparser. This variable “status of knowledge,” as well as the variety of vulnerability assessment approaches, makes it challenging to combine and compare the findings from the different sectors. Furthermore, this variable “status of knowledge,” data availability and methods used makes it challenging to combine and compare the findings from the different sectors and provide an overall picture of the nature and magnitude of vulnerability in South Africa.

In the SNC the sectoral chapters have a “current vulnerability” section, however the majority do not define vulnerability, and tend to focus on impacts rather than a broader framing of the vulnerability context. Furthermore, the way in which the ‘current vulnerability’ sections and other chapters in the SNC are approached vary widely from sector to sector. In the LTAS there is a shift towards an impacts framing rather than a vulnerability framing, with all sectoral reports containing a climate change impacts rather than a vulnerability section. Vulnerability is still frequently mentioned, yet with limited attempts at defining the term. Only the health and the human settlements reports of the LTAS attempt to define and frame vulnerability more clearly. In these reports vulnerability is defined as:

Vulnerability = Hazard Exposure x Sensitivity – Adaptive Capacity

The sectoral chapters of the SNC and the sectoral reports of the LTAS are largely stand-alone products, with little or no cross-linkages. Efforts to make linkages are generally limited to a paragraph or two on cross-sectoral linkages, as found in the LTAS health report, or to a few paragraphs on how adaptation options in the sector at hand can assist in reducing vulnerability in other sectors, as in the LTAS biodiversity report. There thus seems to be a gap in bringing together all the vulnerabilities and impacts identified in the different sectors, and identifyingidentifying overlaps, linkages or potential cascading effects.

3.5.4 Guidelines for conducting vulnerability assessments in South Africa

As illustrated in the previous sections, there is no standard approach for measuring vulnerability, in South Africa or internationally. The view that there is no one-size fits all approach, given the diversity of aims and contexts for which vulnerability assessments (VAs) are conducted, was strongly supported through the findings from a VA expert workshop (see Appendix D3). The recommendations and views shared clearly illustrated the impossibility of developing *one* framework capable of encapsulating all assessments.

Recognising the challenges and limitations of a standardised methodology, the following section of the TNC refrains from presenting a standard framework for undertaking VAs. Instead the focus is on strengthening future vulnerability assessment work by: helping VA practitioners translate the conceptual and theoretical frameworks to a practical context; providing best practice guidelines for how to approach VAs; and by highlighting the main practical tools available for evaluating impacts, vulnerability and adaptation to climate change in South Africa.

3.5.5 Translating the theoretical elements to the practical context

As outlined in the IPCC VA framing, presented in Section 3.5.2.1., central vulnerability related elements include exposure, hazards, sensitivity and adaptive capacity and risks. In order to bridge the theoretical framing of the IPCC with the more practical thinking that is generally required for conducting VAs the section below will explain and unpack these elements in a practical context. This unpacking is aimed at assisting those who are relatively new to the concept of vulnerability, yet who are in some way involved in a VA process, or those who are generally struggling to convert the theoretical framing of vulnerability to VA practice.

In very simple terms ***exposure*** relates to a system, place or setting that could be affected. For example, the coastal city of Durban is exposed to sea level rise due to its location, while the inland, relatively high altitude city of Johannesburg is not. Another example would be tropical cyclones, for which Mozambique would be considered highly exposed, while South Africa is only slightly exposed and somewhere like Bulgaria not at all exposed. Here there is a link or overlap with the ***hazards*** element, which can be seen as the process or phenomenon to which someone or something is exposed. Hazards tend to refer to the climate-related stressors, in the form of the events (e.g. flooding) or trends (e.g. increasing temperatures) to which people or systems are exposed.

In many climate change related VA methodologies exposure only deals with climate related-stressors, such as the examples above or such as the extent to which an area is experiencing heavy rainfall or extremely hot days. Considering the multi-stressor reality of systems, places and people, exposure to non-climatic stressors, such as political and economic elements (such as corruption or global market price), are also important components that need to be considered.

Exposure can be explored with the present and/or the future in mind. In participatory methodologies it is quite common to start with developing an understanding of the current exposure before moving on to future exposure, informed by future climate change projections (see Box 0.9). In quantitative, indicator based methodologies this is often dealt with by seeing exposure only in terms of future change (see Box 0.9), i.e. the extent to which a system or area is expected to experience a change in the mean maximum temperature, the number of extremely warm days or in average rainfall. Future change assessed through indicator-based methodologies is rarely linked to projected changes in non-climatic stressors, such as political and economic change, other than indirectly through the emission scenarios that climate change projections are based on.

Box 0.9: Using climate change projections in vulnerability assessments

Choosing the single 'best' GCM or downscaled projection for a vulnerability assessment is problematic as future scenarios are all linked to the representation of physical and dynamical processes within that specific model. By using one model this may create the impression of a narrowly determined future, which may not fully span the range of potential future change.

The most suitable approach to be taken is to use the largest number of climate change projections as possible and that future change is expressed either as a narrative of potential future changes expressed as future scenarios (e.g. wetter and hotter) or as a summary statistic (e.g. percentiles) of the distribution of projected changes, with some measure or recognition of the spread of possible future climates also provided.

The degree of certainty in a finding, such as change in rainfall, is based on the consistency of evidence such as data, mechanistic understanding, models, theory and expert judgement and agreement between the different models.

Following on from exposure there is ***sensitivity***, which relates to the degree to which a system, community or sector is affected. For example, two households might be equally exposed to flooding, due to their location. However, one of those households might be more sensitive to the flooding if for example their housing structure is poorly built and easily washed away by flooding. Sensitivity is thus often related to aspects such as the state of infrastructure - whether roads are tarred or gravel, and elements of service delivery - whether people have access to proper sanitation facilitates and health services. Assessing sensitivity tends to also require consideration of the health and functioning of ecosystems. For example, a coastline with intact natural mangrove forest is generally less affected, and thus less sensitive, to a storm surge than a degraded coastline. Hence, aspects such as land and soil degradation, land use change and biodiversity loss are often included as sensitivity components. It needs to be noted that, the lines between sensitivity and adaptive capacity (outlined below) can sometimes be unclear, and that sensitivity components outlined above are in some cases included under adaptive capacity. In VAs sensitivity tends to be primarily based on current data, due to limited understanding and information on potential future sensitivity.

Adaptive capacity is an element of vulnerability that relates to the ability to adjust to change and take advantage of opportunities. It can be more intangible and harder to document or measure than aspects of exposure and sensitivity. As an example, say two families both lose their homes in a veld fire. The houses are very similar and located right next to each other. Hence, the households could in simple terms be considered to be equally sensitive and exposed to veld fires. However, when both houses burn down the one family has relatives that can take them in and accommodate them, while the other family does not have anyone who can take them in. These social networks, or lack thereof, are part of the soft aspects that constitute adaptive capacity. These soft aspects of adaptive capacity are often hard to get a handle on, and are not captured in the social databases, such as the Stats SA census data. Other adaptive capacity components that can be challenging to capture include aspects such as human capacity, which could be considered as people with the skills and knowledge and time available to develop and implement adaptation plans and measures.

In VAs adaptive capacity can also include other aspects; such as financial capacity, in terms of access and availability of funds; institutional capacity, in terms of relevant platforms, forums and committees; and the regulatory environment, in terms of relevant policies and regulatory frameworks. In some cases some of these components of adaptive capacity might be easier identified through participatory processes. For example, individuals working within the system at hand can identify the relevant institutions in the system, and explore where and how decisions are made to better understand the relevance of the institutions.

As is the case with sensitivity, adaptive capacity data in VAs tend to be based on current data, due to limited understanding and information on potential future adaptive capacity.

3.5.6 Bringing the theoretical elements together to understand vulnerability

To gain an overall understanding of the vulnerability of a system, community or sector to climate change necessitated to bring the elements above together. How this is done largely depends on the methodology, which is shaped by what the VA aims to achieve, whether it is for example to prioritise geographic locations for implementation or to understand how people in a specific location are vulnerable to climate change.

In indicator-based approaches the overall assessment of vulnerability typically involves averaging or weighting the scores of each indicator to determine an overall score for exposure, sensitivity and adaptive capacity. For example, Turpie & Visser (2013) calculate overall vulnerability to be the residual of exposure, sensitivity and adaptive capacity:

$$V = ((E + S) / 2 + (5 - A)) / 2$$

Where V= vulnerability, E = exposure, S = sensitivity and A= adaptive capacity

In some cases where VAs are based on participatory processes or literature review, the assessment does not include a scoring for exposure, sensitivity and adaptive capacity. Here the different elements are instead analysed through qualitative data analysis, potentially aided by qualitative data analysis software, in order to get an overall understanding of vulnerability. However, participatory processes can also include a form of scoring or rating process. This can be done by for example collectively discussing each exposure, and related sensitivity and adaptive capacity, in plenary and coming to a consensus on which are low, high or medium priority. Or it could entail participants identifying their priority concerns through a rank-based system such as stickers.

Prioritisation can also entail calculating or assessing ***risk***, the potential for consequences. One way of calculating risk is by estimating the likelihood of a consequence occurring and multiplying this with the expected magnitude of the consequences. For example, if looking at exposure to future climate change, estimating the likelihood of a consequence occurring would entail understanding of the confidence of climate change projections and of the relationship between the projected climate driver and the consequences. Then, estimating the magnitude of that consequence would entail unpacking potential economic, social and environmental consequences.

The concept of risks is often entangled in VAs in a variety of ways. Though clearly represented in the latest IPCC conceptual framing (see Figure 0.39), there is often a lack of clarity and a variety of interpretations for how it can practically be incorporated into VAs.

3.5.7 Best Practice Guidelines

Presented below is a set of best practice guidelines that should be considered when undertaking a vulnerability assessment. It is recognised that time and budgets do not always allow for the entirety of the below to be addressed.

It is best practice when:

- The VA **design is guided by the context** in which it will be used. Because there are a variety of possible VA outputs depending on the method applied, an initial consideration of how the information will be used is essential for the design of the process.
- The VA takes the entire coupled system into account, **considering climatic, biophysical, and social, economic and political components.**

- The design of the VA **process recognises that vulnerability is not static through time**, and, depending on how long it will be used for, might need to allow for new information to be incorporated over time.

The VA is based on **the latest science and conceptual framing**, and clearly defines the concepts as they are applied in the assessment. Thus for example applying the latest IPCC report projections (AR5) rather than those coming out of the previous IPCC report (AR4), and specifying clearly how adaptive capacity, exposure and sensitivity are defined, what aspects of each conceptual element are considered and why. Showing a clear linkage to the aim/purpose of the VA.

- The **realities of what the science can and cannot provide** is accounted for. For example, messages about future change must be framed around the extent to which they are scientifically defensible (i.e. temperature increase of between 1.5 to 2˚C versus wheat production in X area will decline).
- The VA **incorporates a variety of methods**, combining qualitative/quantitative, bottom-up/top-down, and thus balancing participatory input and objectivity. This might imply feeding impact modelling outputs (i.e. crop or hydrological modelling) or Stats SA data into a participatory process. Or it could mean complementing spatial indicator mapping that identifies vulnerable areas with a participatory process that further unpacks the understanding of the areas identified as vulnerable.
- Only **scale appropriate data** is included in the VA. There is a large range of data sources, and the data applied in the VA needs to be considered carefully in relation to the scale at which the assessment is conducted. For example, a map of South Africa based on Global Climate Model output is not likely to be an appropriate stand-alone resource for a VA at a local municipality scale. However, when utilising higher resolution data, the uncertainties introduced during the downscaling process should be considered in its application. Better understanding of the scale at which data can be applied defensibly may require consultation with whoever produced the data.

The VA **incorporates stakeholder participation**. While some level of understanding of a system's vulnerability can be developed through external exploration, there are intricacies of system, be it a small village or a provincial government, which are best known by the individuals that are operating within the system. The way in which stakeholders engage will depend on the method and context in which the VA will be used. For example, it might entail including stakeholders in the process of identifying and weighting vulnerability indicators, and/or working with stakeholders to identify elements of exposure, sensitivity and adaptive capacity.

  - The VA process **contributes to developing the capacity of relevant stakeholders**. Participation in the VA process in itself builds an improved understanding of the system at hand, in the context of a changing climate. This implies that the VA process itself can be considered as important as the output of the assessment.

- A VA that is conducted as a step towards developing climate change adaptation strategies and actions **incorporates the stakeholders that are responsible for developing and *implementing* the actions** in the process. This is to ensure the feasibility of the adaptation actions developed, and to ensure that those responsible for implementation understand *why* the actions have been developed.
- The limitations of the VA method applied are acknowledged and transparent.

3.5.8 Practical tools

There are a number of international (refer to Table in Appendix D4) as well as national tools that aim to assist governments and practitioners in evaluating the impacts, vulnerability and adaptation to climate change at the local, district, provincial and national scales.

3.5.8.1 Let's Respond Toolkit

The Let's Respond Toolkit (DEA et.al., 2012), which was developed in collaboration with the DEA, SALGA and COGTA and supported by Sustainable Energy Africa (SEA) and funded by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) has been designed to assist local government to integrate disaster risk reduction and climate change adaptation into Integrated Development Plans (IDPs). It is being applied in various district and local municipalities with support from among others SALGA, the DEA and NGOs. The Toolkit provides specific guidance on conducting vulnerability assessments at the local government scale. It advices that assessments are conducted through stakeholder workshops with the communities and local authorities and that the following factors will need to be identified and established:

- The existing stressors (economic, social, environmental) and climate conditions (climate variables and extreme weather events) affecting the sector or community;
- Existing measures to address climate conditions and their effectiveness;
- Trends and changes that are likely to have an impact in the future, for example, changes in local economy, population size, and political environment;
- Identify the major climate hazards and how future changes in climate may affect the sector/ community;
- Identify highly vulnerable sectors to these climatic changes;
- Identify the most vulnerable groups within the municipality and their location;
- Assess which aspects of people's livelihoods might be threatened because of changing climate conditions.

At present, DEA are working with 6 Provinces (LP, NW, MP, NC, GP, FS) to support district and local municipalities with building technical capacity and developing Climate Change Adaptation Response Plans as informed by the "Let's Respond toolkit "process and format. The approach is two-pronged and is informed by an introductory workshop that focuses on the:

1. Concepts and policy frameworks of Climate Change Mitigation, Adaptation and M&E;
2. Practical exercise of undertaking a vulnerability assessment process using historical events;
3. Rolling out the Let’s Respond toolkit phases in a practical manner relating it to the IDP process.

The other prong is working with a Service Provider to undertake municipal specific consultative vulnerability assessment and adaptation response plan that is further subjected to extensive stakeholder consultation internally and externally following the guidance of the Let’s Respond toolkit. The products of the process are:

- District Rapid Vulnerability Assessments reports with specific local context
- Sector/departmental specific adaptation response (measures) with local context
- Municipal Climate Change Adaptation Response/Action Plans
- Climate Change Adaptation responses that are mainstreamedmainstreamed into the municipal IDP as informed by the Let’s Respond toolkit.
- Transferred knowledge throughout the process so as to enhance implementation of the prioritised adaptation options through the consultative nature of the process and leading Climate Change Champions in each District and Local Municipality.

All District and Local Municipalities in LP, NW & MP have draft VAs and response plans still undergoing further stakeholder input process and are aiming for mainstreaming at the next IDP review process. FS, NC & GP Municipalities are in the process of undertaking Vulnerability Assessment process and will be having draft VAs and Adaptation Response Plans within the next year which will also be in time for the IDP review process. In the 2017/18 Financial year all Municipalities in KZN, WC and EC will be taken through the same process in addition to the work being undertaken by Provinces, SALGA and Municipalities.

3.5.8.2 South African Risk and Vulnerability Atlas (SARVA)

SARVA was designed with the aim of providing up to date information for key sectors in South Africa in order to support strategic decision making through the identification of risk and vulnerability (Archer *et al.,* 2010). SARVA provides open access to and visualisation of spatial and non-spatial data relevant to assessing the impacts of global change on human and natural systems through a centralised repository. The scope covers a range of themes, such as those relating to socioeconomics, climate/atmosphere, disaster management, agriculture, surface water, ground water, air quality/emissions, human settlements, biodiversity and coastal and marine systems. The soon-to-be launched South African Risk and Vulnerability Atlas Geospatial Analysis Platform (SARV-GAP) provides users with pre-defined maps and interpretations of key risk and vulnerability issues for global change in South Africa. Multiple stakeholders were involved in the development of SARVA as well as the SARV-GAP tool.

3.5.8.3 Climate Change Response Plan Toolkit

The Climate Change Response Plan Toolkit (www.climatechangesupport.org) is currently being developed through the Local Government Climate Change Support Program (LGCCS). The Toolkit includes 2 components:

- Vulnerability Assessment Tool includes a step-by-step guide on conducting vulnerability assessments and associated sector specific indicators, and
- Climate Change Response Plan Templates which can be used by local municipalities to develop their own plans

The toolkit provides information on district level vulnerability indicators such as the percentage households that are informal dwelling and the percentage households involved in agricultural activities in table and graph format. The sector specific vulnerability tool provides guidelines on how to conduct assessments for agriculture, biodiversity and environment, coastal and marine, human health, human settlements and water. The step-by-step guide; (1) Develop Climate Change Indicators, (2) Assess your Exposure to the Indicators, (3) Assess your Sensitivity to the Indicators, (4) Assess your Adaptive Capacity to the Indicators, and (5) Develop Response Plans for Priority Indicators.

3.6 Vulnerability and adaptation assessments of key socio-economic sectors

3.6.1 Introduction

The largest progress since the 2nd National Communication (SNC) is the development of the National Climate Change Response White Paper, the Long Term Adaptation Scenarios (LTAS) Research programme[3] (DEA 2013), and the Disaster Management Amendment Act No.16 of 2015. These seek to assess and quantify the climate change risks to South Africa and provide the bases and legal mandate for adaptive and migratory actions to reduce the country's contribution and exposure to climate change and related extreme events in varying sectors.

Building upon the work conducted in the LTAS, this component reviews and prioritises the most significant climate change risks and vulnerabilities for the following sectors; Agriculture and Forestry, Water Resources, Forestry, Terrestrial Ecosystems, Coastal Zone, Health, Urban and Rural Settlements, and Disaster Risk Management. The vulnerability assessment methodology presented in Section 3.5 of this chapter was used as a guide for each of the sectors. A five-step process was

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[3] The Long Term Adaptation Scenarios (LTAS) Flagship Research Program (2012-2014) was a multi-sectoral research program mandated by the South African National Climate Change Response White Paper (NCCR, para 8.8). The LTAS aims to develop national and sub-national adaptation scenarios for South Africa under plausible future climate conditions and development pathways.

followed (See Appendix D1) in each sector assessment in order to characterise the 3 core components of vulnerability; exposure, sensitivity and adaptive capacity.

While the assessment was conducted using a sectoral approach, the methodology attempted to also identify cross-sectoral issues that can be incorporated into an integrated overview. The review and prioritisation of the most significant sectoral climate change risks and vulnerabilities (both biophysical and social) was complemented through a literature review, including grey literature, of vulnerability work that has taken place in South Africa since the 2nd National Communication (2NC) to UNFCCC (DEA 2011). A review of the barriers to adaptation and information and data gaps are presented for each sector as well as the adaptation priorities. Furthermore, climate change may present specific opportunities to some sectors and assessment of these was included in the sector reviews below.

The assessments are focused on the national scale and, where possible, provincial level details are presented in order to demonstrate the spatial distributions of vulnerability across South Africa. Each assessment is based on the climate change projections and associated provincial narratives provided in Section 3.3.6 of this chapter.

3.6.2 Agriculture and forestry

3.6.2.1 Introduction

The South African agricultural sector is highly diverse in terms of its activities and socio-economic context. The primary agriculture sector contributes approximately 3% of the Gross Domestic Product (GDP) with many other significant secondary benefits to other industries. The entire value chain of agriculture is estimated to contribute approximately 12% to GDP and therefore represents a significant component of the economy. Agriculture, particularly high value crops such as fruit and wine is also a valuable earner of foreign exchange accounting for approximately 6% of the total export earnings for the country (Stats SA, 2015). The agriculture sector employs approximately 860,000 people (Stats SA, Q4 2015) and is critical in terms of national food security as well as supporting thousands of urban and rural households in terms of subsistence agriculture and small scale production. Some of the most vulnerable communities are directly dependent on agriculture for employment and subsistence and, this makes them some of the most vulnerable communities with regards to future climate change impacts in the country because of the direct impact of climate change on agriculture.

Agricultural production in South Africa ranges from the intensive production of horticultural crops, to large scale production of cereals, oil seeds, sugarcane, and tropical, subtropical and temperate fruit crops. Livestock production and its associated products constitute anywhere from 40% (Western Cape) to over 70% (i.e. Gauteng) of the provincial agricultural economy (Stats SA, 2007). Only 14% of the country however is currently considered potentially arable, with only one fifth of this land having high agricultural potential (Figure 0.43). Climate limitations are important in determining potential agricultural activities and suitability across the country. However, irrigation and conservation tillage practices can overcome rainfall constraints, in the high-value commercial agricultural sector and for smallholder farmers. Irrigation for agricultural production is estimated to consume in excess of 60% of South Africa's surface water resources, and a significant fraction of extracted groundwater. This makes the sector the primary water user in South Africa, and therefore a key focus in developing adaptation responses that involve water and consider food security and other socioeconomic implications. The agriculture and forestry sector is also critical in terms of climate change mitigation, particularly in terms of the potential impacts on national carbon sinks and carbon sequestration including both forests and land use impacts.

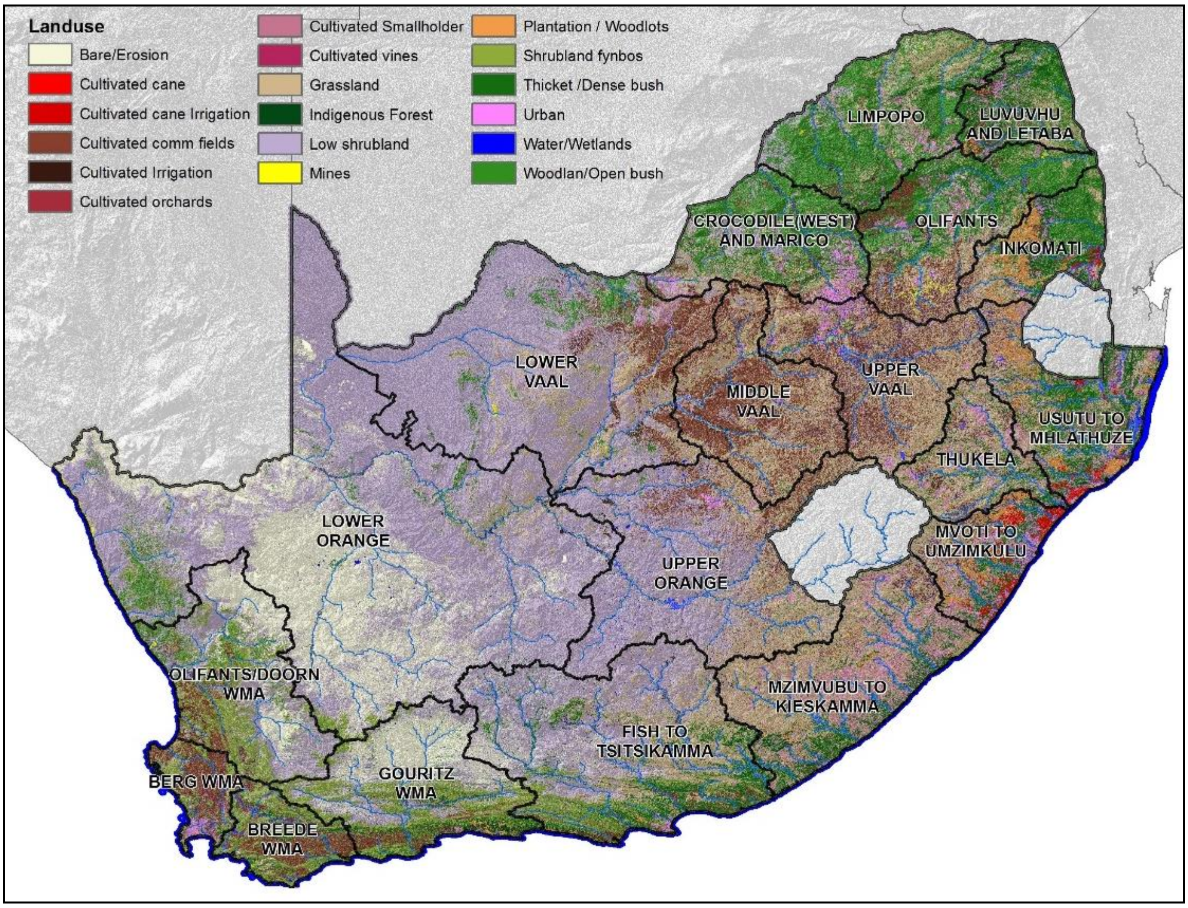

Figure 0.43: Map of currently cultivated areas in South Africa (**Source NLC, 2015**)

The agricultural sector is considered to be one of the most critical economic sectors in terms of potential impacts of climate change globally (IPCC, 2014) and in South Africa (DEA, 2011c; DEA, 2014c). Agriculture is impacted directly by changes in precipitation, temperature and evaporation. The impact of climate change, however, will be different for different crop types and in different parts of the country. This is due to differences in the response of different crop types to changes in climatic variables, but also differences in the spatial impacts of climate change relative to where the different crops are currently grown or will be grown in the future and the relative significance of these to the local economy.

Rain-fed agriculture is particularly sensitive to climate variability. For example an analysis of the sensitivity of agriculture production to historical changes in climate in South Africa (Blignaut *et al.,* 2009) found that a 1% decline in rainfall resulted in a decline in maize production of 1.16% and a decline in wheat production of 0.5%. While some crops may suffer from a reduction in precipitation, other crops such as sugarcane may benefit from both an increase in precipitation and an increase in temperature (Schulze, 2012). In all cases it is anticipated that future increases in temperature and evaporation will results in an increase in the irrigation demands across the country. Climate ch/ange is thought to also have an indirect impact on crop production through impacts on pests and diseases (Schulze, 2012).

3.6.2.1.1 Progress since the 2nd National Communication

Since the 2nd National Communication (DEA, 2011b) a number of further studies looking at climate change impacts on agricultural have been completed. In addition a consensus amongst climate scientists has been reached regarding climate narratives at a provincial level. Relevant studies include:

- Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (Porter *et al.,* 2014);
- Long Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa. Climate change Implications for the Agriculture and Forestry Sectors in South Africa (LTAS Phase 1, Technical Report No. 3 of 6, Department of Environmental Affairs, 2013);
- Biophysical Modelling in Support of Systematic Analysis of Climate Resilient Economic Development in South Africa (UNU-WIDER, LTAS Phase 2, Department of Environmental Affairs, National Treasury, and National Planning Commission, 2013);
- Adaptive Interventions in Agriculture to Reduce Vulnerability of Different Farming Systems to Climate Change in South Africa (WRC Project K4/1882; 2009 - 2014).
- The Development of a Climate Change Sector Plan for Agriculture, Forestry and Fisheries in South Africa (Department of Agriculture, Forestry and Fisheries, Update 2015);
- Climate Change Response Framework and Implementation Plan for the Agriculture Sector of the Western Cape Province (Western Cape Department of Agriculture and the Western Cape Department of Environmental Affairs and Development Planning, 2014; WCDOA, 2014);

Draft Climate Change Sector Plan for Agriculture, Forestry and Fisheries in South Africa

The draft Climate Change Sector Plan for Agriculture, Forestry and Fisheries (DEA, 2013b) was developed by the Department of the Agriculture Forestry and Fisheries (DAFF) in line with the National Disaster Management Framework of 2005 and in fulfilment of the requirements of the National Climate Change Response White Paper. The purpose of the sector plan was to implement a climate change-related plan of action to increase climate intelligence through awareness and knowledge of anthropogenic activities impacting the future, and to plan actions related to that. The basic approach of the sector plan is to transition to a system of climate smart agriculture in all aspects of the agriculture sector. Much of the technical aspect of the sector plan is based on the findings from LTAS and the “Atlas of Climate Change and the South African Agriculture Sector: A 2010 Perspective" (Schulze, 2010).

Climate Change Response Strategy and Implementation Plan for the Agriculture Sector of the Western Cape Province

The Western Cape Department of Agriculture (WC DoA) and the Western Cape Department of Environmental Affairs & Development Planning (WC DEADP) launched a collaborate study under the technical leadership of the University of Cape Town’s African Climate and Development Initiative (ACDI) entitled Smart Agriculture for Climate. In the Western Cape Province farmers and agri-businesses are already implementing responses to climate risks with the view that climate smart agricultural practices can meet the challenges of food security and sustainability, while ensuring continued profitability and growth opportunities. The Status Quo Report included an assessment of the risk and impacts of specific commodities and agro-climatic zones. The Status Quo Report was then used to develop a climate change response framework and an implementation plan focusing on four strategic focus areas (SFAs) as shown in Figure 0.44. The implementation plan also identified six priority programs for increasing the resilience of the agriculture sector to climate change in the Western Cape. The resulting implementation plan, named the SmartAgri Plan, sets the precedent for the development of climate change adaptation and response plans that should be applied to other provinces and sectors across South Africa.

Figure 0.44: Draft climate change response framework and strategic focus areas for the agricultural sector of the Western Cape (**WC DoA, 2016**)

Adaptive Interventions in Agriculture to Reduce Vulnerability of Different Farming Systems to Climate Change in South Africa

South Africa has a high-risk agro-hydrological environment which is likely to be exacerbated under conditions of climate change. The report provides an assessment of the vulnerability of different farming systems to climate change and evaluates alternative adaptation practices and techniques, both indigenous and science-based knowledge (Johnston *et al.,* 2016). This study is part of a Water Research Commission (WRC) research project looking in particular at improving water use efficiency.

Long Term Adaptation Scenarios (***LTAS***) ***Flagship Program***

The LTAS report on Agriculture and Forestry (DEA, 2013b) summarises various research studies on climate change impacts and vulnerabilities and recommended adaptation response options and research gaps for the agriculture and forestry sectors. There is a focus on detailing the results of various biophysical modelling studies that analyse future climate impacts, the themes include:

- Irrigation demand;
- Field and horticultural crop yields;
- Crop suitability;
- Agricultural pest species;

- Pasture crops;
- Animal production;
- Major forest genera; and,
- Farm labour.

The LTAS report concludes that many of the agricultural sub-sectors are sensitive to projected climate change. Much of the food production and food security which is at risk is linked to future projected water supply constraints, declines in water quality and competition for non-agricultural sectors. There is evidence that smallholder farmers are more vulnerable to climate change than commercial farmers due to limited access to resources. These vulnerabilities, however, vary significantly across the country and require further investigation in terms of specific impacts and opportunities to increase the resilience for climate change in the different agriculture sectors.

Biophysical Modelling in Support of Systematic Analysis of Climate Resilient Economic Development in South Africa

The United Nations University World Institute for Economic Development Research (UNU-WIDER) undertook a study of the potential impacts of climate change on the economy of South Africa (Cullis *et al.,* 2015). This study included an analysis of the potential impacts on key economic sectors including water, agriculture, transport and sea-level rise. The study was undertaken for National Treasury and the National Planning Commission (NPC), but was also incorporated into a report for the LTAS program on the potential economic impacts of climate change and consideration for potential adaptation options (LTAS Phase 2, Report 3, DEA, 2015a). This report concluded that the current highly developed and integrated bulk water planning and distribution system in South Africa provides a high level of resilience to future climate change impacts. The potential impacts on dry land agriculture are a significant risk to the national economy along with the potential impacts in the roads and transport sector. This study also looked at regional impacts in terms of individual water management areas (WMAs) and showed that these risks vary significantly between regions and this requires further analysis at a more local level in terms specific impacts and adaptation options, particularly with regards to the agriculture sector and the most agriculturally dependent areas.

3.6.2.2 Vulnerability to climate change

3.6.2.2.1 Current Risks

The agriculture and forestry sector in South Africa already experiences a variety of climate change vulnerabilities and risks. This is due to highly variable climatic conditions across the country, different agricultural systems, both smallholder and commercial, and diverse natural capital. An example of the current vulnerability of the agriculture sector is given in Box 3.10 in terms of the current drought crisis.

Box 0.10: South Africa's vulnerability to drought - 2015-2016 agricultural drought

South Africa experienced a strong El Niño which resulted in the worst drought nationwide since the 1930's (SAWS, 2016). An agricultural drought is a period of time (either months or years) when the moisture supply of a region falls to a level where crop and range production is severely impacted (Quiring & Papakryiakou, 2003). The agricultural sectors that have been most severely affected are maize, wheat and sugarcane along with beef and sheep production. The majority of maize (83%), wheat (53%) and sugarcane (73%) are produced under dryland conditions making them especially vulnerable to periods of drought (Agri-SA, 2016). The following provinces have been declared drought disaster areas:

Free State;

KwaZulu-Natal;

Limpopo;

Mpumalanga;

Northern Cape;

North West;

Western Cape (with areas of the Eastern Cape also affected).

The main climatic factors posing current risks to the agriculture sector in South Africa include high spatial and temporal variability of rainfall, and high evaporative demand. Other vulnerabilities include fire in the forestry sector, dependence on water as a scarce resource, soil that is susceptible to degradation, and expansion of urban areas. The factors include (DEA, 2013b).

- In South Africa those areas with lower rainfall experience the highest inter-annual variability in rainfall (Schulze, 2008). Rainfall variability presents an inherently high risk to climate change, especially in transitional zones of widely differing seasonality and annual rainfall volumes, such as the western Highveld. These transitional zones are sensitive and vulnerable to geographical shifts in climate (DEA, 2013b).
- In South Africa evaporative losses caused by high atmospheric demand, vary from 1 400 to 3 000 mm/ year (Schulze, 2008). Many parts of the country experience semiarid conditions due to unreliable rainfall and high evaporation (DEA, 2013b).
- Dependence on water is an important current vulnerability for both rain-fed and irrigated crops as well as for animal production. Irrigated agriculture is the largest single surface water user (approximately 60% of total available water) (DEA, 2013b).

- Agriculture’s vulnerability is intensified by soil potential constraints. Increasing temperatures reduces soil organic matter (Walker & Schulze, 2008) and adversely affects soil properties (Brevik, 2013) resulting in an increase in acid soils, depletion of soil nutrients, weakened soil structure, lower water-holding capacity and increased soil degredation (DEA, 2013b; DAFF, 2015a).
- Expanding urban areas, unsustainable land use, land reform, and increasing competition for agricultural land, resulting in land use change and poor economic decisions, which leads to land degradation. In addition degradation is intensified by bush encroachment and invasive alien plants (DEA, 2013b).
- Increased number of fires - This has a direct impact on the forestry sector, but is also a significant risk for the agriculture sector. In the Western Cape Status Quo Assessment, for example, the likely increase in fire risk was considered to be one of the most significant climate risks facing the sector (WC DoA & WC DEADP, 2014).

In addition to the biophysical and developmental risks identified above, the agriculture sector is also particularly sensitive to political and economic risks due to the importance of land reform in South Africa and its impact particularly in the rural areas as well as the impact of global chances in food prices and competition from other agriculture production areas, and inflation in critical input costs such as machinery and fertilizers. The agriculture sector is also particularly vulnerable to labour risks.

3.6.2.2.2 Future Risks

Future climate risks result primarily from direct climate related risks such as increasing temperatures and increased variability of rainfall and impact the production of different crop types (both dry land and irrigated agriculture), life stock production, impacts in the forestry sector and human impacts in terms of farm labourers. A short overview of some of these future climate risks in South Africa is given below.

Direct Climate Change Impacts and Associated Risks

The important future climate risks are those related to increases in temperature and rainfall changes. Water availability is critical for crop production, livestock and in the forestry sector, and future reductions and changes in precipitation is probably the greatest risk to the sector impacting both floods and droughts. Changes in temperature have multiple direct and indirect impacts for a variety of crop types. A summary of some of the future climate change risks are given below. These are derived primarily from information contained in the LTAS Report on the Agriculture and Forestry Sectors (DEA, 2013b).

Reference crop evaporation and increasing irrigation demand

The accurate estimation of evaporation from agricultural crops is particularly important for irrigation areas with the standard estimation method being the Penman-Monteith equation (McMahon *et al.,* 2013). An increase in crop evaporation by the intermediate future of around 5 –10% is projected. The consequence of this is higher evaporation from dams is increasing demand for irrigation water and reduced yields from dry-land crops (DEA, 2013b).

Soil water content and water logging

Soil water content determines when plant water stress sets in and in turn the timing of irrigation. For conditions of no soil water stress, the majority of South Africa is projected to experience more such days into the intermediate future apart from the southwest where the drying of soils is projected to result in crops experiencing more days with stress. In the intermediate future coastal areas in the Eastern Cape will experience less mild stress days but the remainder of the country will encounter an increase is the number of mild stress days. Plant water stress caused by waterlogging is projected to increase into the intermediate future, with the exception of the west coast with fewer waterlogged days (DEA, 2013b).

Wind and hail storms

Increasing frequency and intensity of storm events can have a direct impact on the agriculture sector particularly if these included high winds, heavy rain and hail. Hail damage in particular is considered to be a significant threat to the sector as a single storm can destroy an entire crop and do significant amount of damage to critical infrastructure, resulting in financial losses and insurance claims (NPC, 2012).

Positive chill units

An increase in temperature of 2°C in the intermediate future (2040-2070) will impact biennial plants, e.g. apples and pears, which require winter chilling (Grab and Craparo, 2011). Chilling is quantified by positive chill units, derived from hourly temperatures above or below critical thresholds (Schulze, 2010). Sensitivity studies report that a 2°C temperature increase results in positive chill unit reductions with median reductions in positive chill units of generally >30% into the intermediate future, with a high confidence in these projections (DEA, 2013b).

Sea Level Rise

While South Africa does not have large areas of low-lying agricultural land that would be directly impacted by future sea level rise, there are possible secondary risks associated with sea level rise such as salt water intrusion into groundwater aquifers used for irrigation in coastal areas (NPC, 2012).

Risks and vulnerabilities for farmers

Smallholder and commercial Farmers face many similar climate change risks particularly those relating to changes in temperature and precipitation (discussed in Section 3.6.2.2.2 on future risks), however the potential impact of these will be very different because of the differences in vulnerability and in the ability to adapt (i.e. adaptive capacity). Smallholder vulnerability to climate change is exacerbatedby the following:

- Finding means to finance and to use current and new technology and practices;
- Farming on communal land inhibits investment in on-farm infrastructure;
- Lack of access to markets;
- Limited access to extension services;
- Slow uptake of conservation farming techniques (DAFF, 2015a).

Many of the vulnerabilities for commercial farmers are related to access to water:

- Increasing demand for irrigation with competition for water with other sectors;
- Increased flooding of high value crops;
- Dependence on water sources external to the farm;
- Declining water quality from upstream and multi-purpose dams (DAFF, 2015a);
- Potential impacts on the supply change such as damage to main transport links (i.e. roads and railway) or reduced access to harbours due to increased high wind days;
- Additional costs for energy for irrigation and cooling of temperature sensitive export crops.

Crop Production Risks and Vulnerabilities

A summary of some the key climate change vulnerabilities for individual crop types are given below. These are based primarily on the summary of potential impacts given in the LTAS Agriculture Report (DEA, 2013b) and the Status Quo Assessment for Agriculture in the Western Cape (WC DoA, 2015). The majority of studies focused on a specific crop type with one exception being Cullis *et al.,* (2015) who undertook an analysis of potential climate change impact on crop yields for a wide range of crop types across South Africa and representing a wide range of possible climate change scenarios using empirical crop models. The analysis also considers the potential benefits of global mitigation efforts in terms of reducing the risk of potential climate change impacts by considering an unconstrained emissions scenario (UCE) representing business as usual as well as a level 1 stabilization scenario (L1S) corresponding to the results of significant global efforts to keep CO_2emissions below 450ppm.

Maize

Maize (*Zea mays L.*) is an important food crop in South Africa and researched studies have focused on vulnerability (Du Toit *et al.,* 2002), yields (Schulze *et al.,* 1995), and sustainability (Walker & Schulze, 2006; 2008). Maize yields have been simulated to be sensitive to both climate and CO_2 fertilisation, with doubled CO_2 counteracting much of the reduced productivity associated with a 2°C temperature rise, particularly in the Highveld (Walker and Schulze, 2008). More recently a review of various modelling studies suggested that rain fed maize yields could decline by an average of 18% (Zinyengere *et al.,* 2013). Estes *et al.,* (2013) found that yield could increase in marginal growing areas for maize but a reduction of up to 10% in the main commercial growing areas. Cullis *et al.,* (2015) found that while median impact on total maize yields for the UCE scenario is similar to that of the L1S scenario the risk of experiencing extremes (drought and flood) is reduced (Figure 0.45). This is a benefit for mitigation.

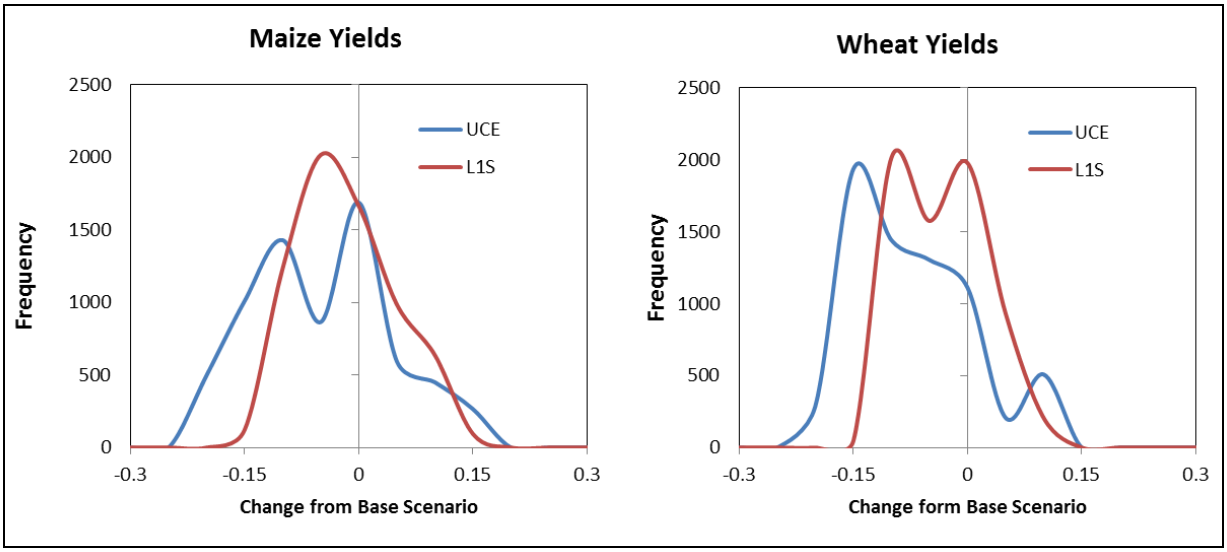

Figure 0.45: Potential climate change impacts on the average annual maize and wheat yields across South Africa by 2050 under two possible future mitigation scenarios: Unconstrained *Emissions* (**UCE**) **and Level 1 Stabilization** (**L1S**) (**Cullis *et al.,* 2015**).

Wheat

Wheat is generally a winter rainfall crop (DEA, 2013b). Simulations showed that winter wheat yields should increase slightly by 0.5-1.5 t/ha/season in the intermediate future in the main wheat growing Swartland and Rûens regions of the Western Cape Province (DEA, 2013b). Wallace (2013) looked at regionally specific climate change driven impacts on wheat in the Western Cape. Future yield responses were generally positive in the south and south-east of the province with smaller or negative median yield impacts projected in the western areas such as Swartland.

Sorghum

Sorghum (*Sorghum bicolour*) can tolerate erratic rainfall and is comparatively drought resistant (DEA, 2013b). New areas, presently climatically unsuitable for sorghum, are projected to be gained in the Free State and Eastern Cape in the intermediate future (Schulze 2010). It is projected that Sorghum yields will increase by 2–4 t/ha in parts of western KwaZulu-Natal, the inland areas of the Eastern Cape and the eastern Free State in the intermediate future (DEA, 2013b).

Soybeans

In the intermediate future climatically suitable areas for soybeans will change with areas lost to production in the east of KwaZulu-Natal and gains in the eastern Free Sate and inland Eastern Cape. It is projected that while major expansion of climatically suitable areas for soybean production might occur, there is also a likelihood that the area of actual production may become more concentrated (Schulze, 2010).

Sugarcane

Inland shifts in the climatically optimum growth areas for sugarcane may be expected in the intermediate future. In addition, the harvest-to-harvest cycle could reduce by 3–5 months (i.e. by 20–30%) by the intermediate future while yields are projected to increase by 5–15 t/ha along the coast and by up to 20–30 t/ha in the inland growing areas (Schulze, 2010). Sensitivity analyses have found that when a temperature increase of 2°C is coupled with simultaneous changes in rainfall, yields were modelled to decrease by about 7% for a 10% reduction in rainfall, and to increase by a similar percentage for a 10 % increase in rainfall. The climatically suitable areas for sugarcane will expand further inland in KwaZulu-Natal (Schulze, 2010; DAFF, 2013b).

The African sugarcane stalk borer (*Eldana saccharina*) is one of the most serious sugarcane pests. An increase in night-time temperatures in the intermediate future will increase the ability of the stalk borer to reproduce throughout the climatically suitable area for sugarcane by ~10% along the east coast to >30% further inland, with the frequency of infestations increasing. In addition, the expanded inland climatically suitable areas (in the intermediate future) for sugarcane will be vulnerable to African stalk borer infestations (Schulze, 2010). Higher temperatures will also increase the area exposed to the Spotted Sugarcane Stalk Borer (*Chilo sacchariphagus*) pest (DEA, 2013b).

Apples

Temperature increases are projected to cause a 28% reduction in climatically suitable areas for apple production by 2020, with suitable apple producing climates limited to the high-lying areas of the Koue Bokkeveld and Ceres by 2050 (Cartwright, 2002). This projection is consistent with observed trends of reduced export apple volumes partly ascribed to adverse climatic conditions. Midgley and Lötze (2011) found that future warming of 0.5, 1.0, 1.5 and 2.0°C in the warmer Grabouw-Villiersdorp region will reduce chill units by 9-17%, 19-34%, 29-48%, and 39-62%, respectively. In the colder Koue Bokkeveld region, similar warming will result in losses of 10-14%, 13-20%, 18-26%, and 24-32%. In the Koue Bokkeveld, total seasonal chill will remain sufficient for apples under all the warming scenarios tested.

The warming in the intermediate future influences the prevalence of pests and diseases. The number of life cycles per annum of the codling moth (which effects apples and pears) is over 30% greater than the present over the central areas of South Africa, 20–30% along the periphery of the country and 10–20% along the coast of KwaZulu-Natal (Schulze, 2010). Projections into the intermediate future indicate increases in the number of life cycles per annum of the oriental fruit moth (*Grapholita* *molesta*), by <1.2 in the southwest to ~1.5 life cycles along the east coast and parallel to the coast in the central north increasing to >2 additional life cycles, with high confidence in these projections (Schulze, 2010; DAFF, 2013b).

Pears

Risks associated with producing export-quality pears are related to cultivar specific sensitivities with producers likely to have to make changes in the cultivars grown over the next 30 years (DEA, 2013b). Simulations have shown that initial moderate warming (1-1.5°C) during the fruit growth period could lead to slight gains in the cooler Elgin region of the Western Cape, and slight losses in the warmer Ceres and Wolseley regions (Wand *et al.,* 2008), however, with continued warming (2-3°C) losses are estimated at between 5% and 20% depending on cultivar and region.

Tomatoes

Climate change will impact tomato production through the increase in frequency of drought and other weather extremes (Musvoto *et al.,* 2015). Limpopo Province is a major tomatoes producer and in the intermediate future temperatures are projected to become optimal for increasing the spatial distribution of the leafminer (agromyzid) pest (Tshiala, 2014) and the red spider mite (Tetranychidae) (Musvoto *et al.,* 2015).

Citrus

No published studies are available for the potential impacts of climate change on citrus growing under South African conditions (WC DoA, 2015). Citrus trees, however require water all year round, provided by a combination of rainfall and irrigation. Reduced availability of water in some critical growing areas such as around Citrusdal and Clanwilliam in the Olifants Catchment in the Western Cape maybe negatively impacted by climate change.

Rooibos tea

Rooibos tea production is vulnerable to reduced rainfall and lack of rainfall at critical times, with yields projected to decrease 40% during a drought year (Oettle, 2006). Numerous adaptation strategies are, however, used or known by farmers, including changes in ground preparation and tea harvesting times as well as wind erosion prevention and water conservation measures. Not all these measures are implemented, often due to lack of finances (DEA, 2013b). Climate change could result in significant reduction in the suitable growing areas for both wild and cultivated rooibos in the Northern and Western Cape (Lötter and le Maitre, 2014).

Viticulture

Research for the South African viticulture industry has focused on climate trends and influences at local scale on terroir and berry composition (WC DoA, 2015). Vink *et al.,* (2012) concluded that climate change will cause volatility in the soil and climate that classify different terroirs. Changes in the terroir units are significant as it is the diversity of the terror unit that defines most South African wines (WC DoA, 2015). It is difficult to establish the precise upper limits for temperature for each cultivar for growing high-quality wines, since there are examples where certain cultivars are still being produced successfully at temperatures above the estimated upper limit (WC DoA, 2015). However, reliable rainfall and access to irrigation will become a major constraint to the industry. If there is a shift in climatically suitable areas in the intermediate future the cost associated with moving the related infrastructure (such as cellars) is expensive and logistically problematic (DEA, 2013b).

Pasture grasses

Climate change is likely to impact the optimal growing areas for pasture grasses across South Africa including weeping lovegrass (*Eragrostis curvula*) and kikuyu (*Pennisetum clandestinum*) (Schultze, 2010). Changes in Kikuyu yield are more sensitive to simultaneous changes in rainfall and temperature than to temperature alone. Expansion of climatically suitable areas for weeping lovegrass and kikuyu are projected to occur into the intermediate future, but possibly the area of actual production may reduce (DEA, 2013b). Where pastures are currently irrigated these may come under pressure due to competing demands for water and increased variability in rainfall. Rain-fed pasture lands may also experience bush encroachment due to increasing levels of CO_2 (Bond and Midgley, 2012).

Climate change risks for the livestock sector

Livestock farming is the largest agricultural sector in South Africa. Livestock production includes cattle, sheep, chickens, pigs, game and goats (Musvoto *et al.,* 2015). Livestock production will be effected by climate change both directly, through heat stress and humidity (Archer van Garden, 2011; Nesamvuni *et al.,* 2012), and indirectly, through impact on feed (Musvoto *et al.,* 2015).

Broilers

The poultry industry contributed 22% of South Africa’s agricultural income in 2012 making it the largest single contributor to the agricultural sector. The broiler industry in South Africa is vulnerable to the effects of climate change, in particular the projected increases in temperature will cause changes in vectors of animal pests and diseases (Musvoto *et al.,* 2015). An increase in heat stress will impact on broiler development and a temperature rise of between 2.5–3°C will increase mortality rate. Poultry is reliant on maize for feed so the industry in sensitive to the climate change impacts on maize in the intermediate future (DEA, 2013b). Options to be considered by farmers would be reducing stocking density to reduce heat frequency, or improving ventilation, which implies a capital investment (DEA, 2013b; DAFF, 2015a).

Cattle and Pigs

Increased heat stress is one of the main direct impacts on pigs and both feedlot and dairy cattle in the intermediate future (Nesamvuni *et al.,* 2012). A reduction in stocking rate per housing for pigs would counteract heat stress (DEA, 2013b). Temperature thresholds for feedlot and dairy cattle are expected to be reached in the intermediate future. Projected scenarios will cause heat stress in the main milk producing areas of the country. High milk producing exotic dairy cow breeds have been cross-bred with heat-tolerant indigenous breeds to reduce heat stress effect and maintain milk production (DAFF, 2015a).

Sheep and Goats

Climate change is likely to impact sheep and goats through its effects on growth performance, animal health, forage and water resources (Rust and Rust, 2013). Climate change may have a potential benefit for sheep and goats due to reduced losses due to cold and wet weather after shearing (WC DoA, 2015).

Ostriches

Ostriches are one of the most heat tolerant farmed animals but excessively high temperatures will likely affect productivity particularly in the growth of younger birds. Fertility is also adversely affected by high ambient temperatures. In intensive ostrich production the feed is grown on farm with some of the supplementary feed being bought. The effect of climate change is indirect via the crops grown to feed the birds. The ability to provide affordable forage and feed to the ostrich industry will remain one of the biggest challenges of the industry (WC DoA, 2015).

Impacts on Forestry

In South Africa the majority of commercial plantations (1.273 million ha) occur in KwaZulu-Natal, Mpumalanga and the Eastern Cape provinces. (DAFF, 2010). The major species being:

- Pine (*Pinus patula*) 51 percent of total area;
- Eucalypts (*Eucalyptus grandis*) 40.5 percent of total area;
- Wattle (Acacia) and other species 8.5 percent of total area (Naidoo *et al.,* 2013).

Commercial forestry supplies inputs for a number of downstream industries and is an important strategic employer in rural areas where there is high unemployment (Naidoo *et al.,* 2013). The South African government has prioritised plantationexpansion in areas where it is appropriate to do so. The major constraint to any expansion is the competitionfor water and that any expansion in commercial forestry requires licensing (Lötter *et al.,* 2015). Commercial plantations are vulnerable to:

- Changes in temperature and rainfall regimes due to climate change will have an impact on the extent of land climatically suitable for specific species (Warburton and Schulze 2008; DEA 2013);
- Climate change influences on the survival and spread of insects and pathogens (DEA, 2013b);
- Eucalypts have been found not to benefit from the fertilisation effect on photosynthesis with elevated levels of CO2 but increased water use efficiency was observed (Booth, 2013);
- Plantations are vulnerable to fire caused by lightning strikes and climate change could increase the frequency of fires (Schulze, 2010) as a result of an increase in the high fire danger days.

Due to the long rotation of commercial plantationspecies the implementation of adaptation measures requires that planned responses are implemented well in advance of the impacts of climate change. These measures should be assimilated into sustainable forest management plans (Lötter *et al.,* 2015). Adaptation measures and management plans require an understanding of the effects of climate on plantations, the downstream industries and the communities that benefit from them (Kenan, 2015).

Farm labour and health impacts

Climate change is likely to impact on the agriculture and forestry sector through increasing heat stress and associated impact on the productivity of labour (Moustris *et al.,* 2010). In the intermediate future a combination of high levels of humidity, low wind speed and high temperature may result in discomfort and heat stroke defensive mechanisms of the human body (Becker *et al.,* 2003, DEA, 2013b).

3.6.2.3 Provincial Climate Change Risk Summaries for Agriculture

Climate change impacts on the agriculture and forestry sector will vary significantly across the country as a function of both the spatial variability in the potential climate change impacts, but also relative to the variability in different crop types and the existing adaptive capacity in different regions. Figure 3.46 illustrates the variation in the value of goods and services produced in agriculture and forestry across the country.

In addition to variability in crop types, the importance of agriculture to the provincial economy also varies i.e. in the Western Cape and Free State agriculture is a major part of the provincial economy (Figure 0.47). Over 60% of the agricultural households are located in Eastern Cape, Kwazulu-Natal and Limpopo. Livestock represents the largest part of agricultural economy in all of the provinces except the Western Cape (Stats SA, 2007). A summary of some of the critical provincial level climate change risks for the agriculture and forestry sector are described below.

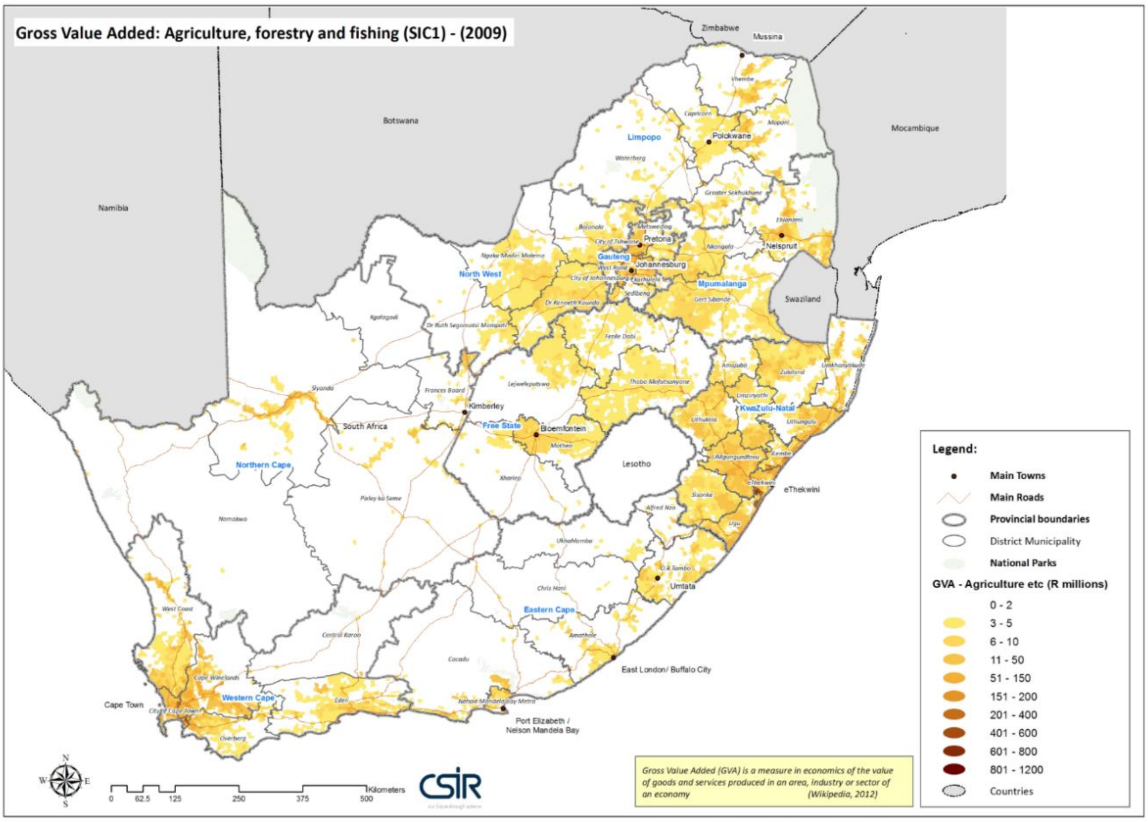

Figure 0.46: Gross value added: agriculture, forestry and fishing (**Naudé** ***et al.,*** **2007**)

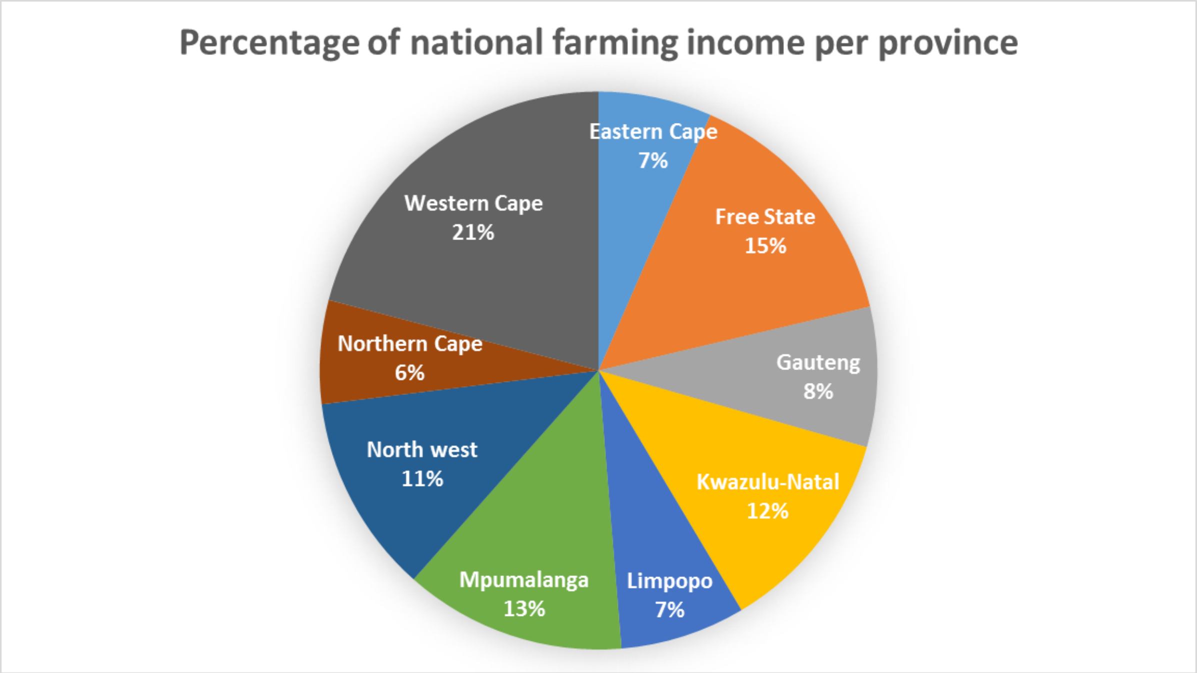

Figure 0.47: Percentage of farming income per province (**Stats SA, 2007**)

Eastern Cape

Livestock production, particularly sheep and beef farming (Musvoto *et al.,* 2015) and animal products constitute over 70% of the Eastern Cape's agricultural revenue; see Figure 0.48 (Stats SA, 2007). The province has a high percentage of smallholders particularly in the western part (Figure 0.49). A summary of the major impacts of climate change are:

- The total area suitable for commercial forestry plantations in Eastern Cape Province would increase e.g. by the intermediate future new climatically suitable areas for Pine (*Pinus patula*) are inland areas of the Eastern Cape with yields projected to increase by ~3 t/ha/annum (Schulze, 2010).
- Parts of the Eastern Cape not currently suitable for sorghum would become so in the intermediate future, with a projected increase in yield of 2-4 hectare/ha/annum (DEA, 2013b);
- Higher temperatures and increased evaporation would result in a higher irrigation demand;
- Without adaptation methods the increased soil evaporation under a warmer drier climate would negatively impact smallholder maize production (DEA, 2013b).

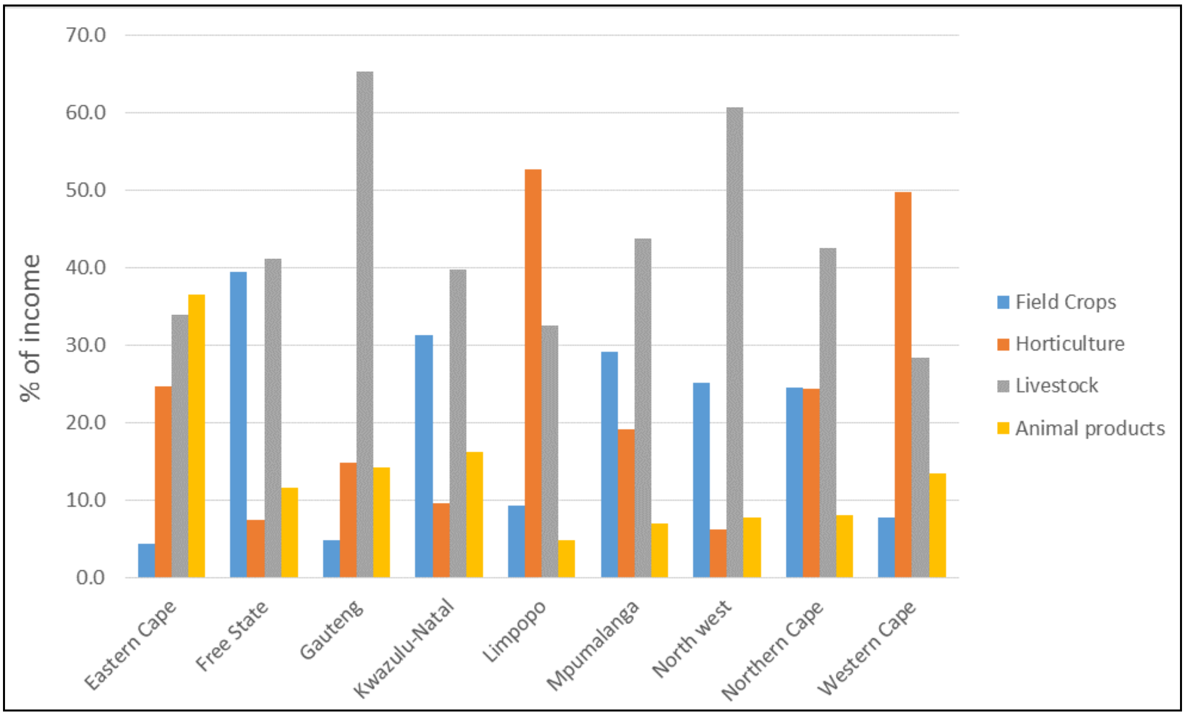

Figure 0.48: Percentage of provincial agricultural income per sub-sector (**Stats SA, 2007**)

Free State

The province is a major producer of grains such as maize and wheat along with sizeable production of sunflowers, soya, groundnuts and horticultural crops (Figure 0.50). Livestock production is also a major contributor to the provincial agricultural economy (Figure 0.48). An increase in temperature of

2°C would negatively increase maize yields and would counteract the benefit to the crop of elevated CO_2 levels (Walker and Schulze, 2008). Additional climate change impacts:

- Modelling studies have shown an increase in wheat yield of 0.5-1.5 t/ha/season under a warmer wetter intermediate future (DEA, 2013b);
- Areas suitable for sorghum expansion are likely to expand;
- Feedlot cattle are adversely affected by high temperatures, relative humidity, solar radiation, and low wind speeds. It is expected that temperature thresholds would be exceeded in the intermediate future (DEA, 2013b; DAFF, 2015a).

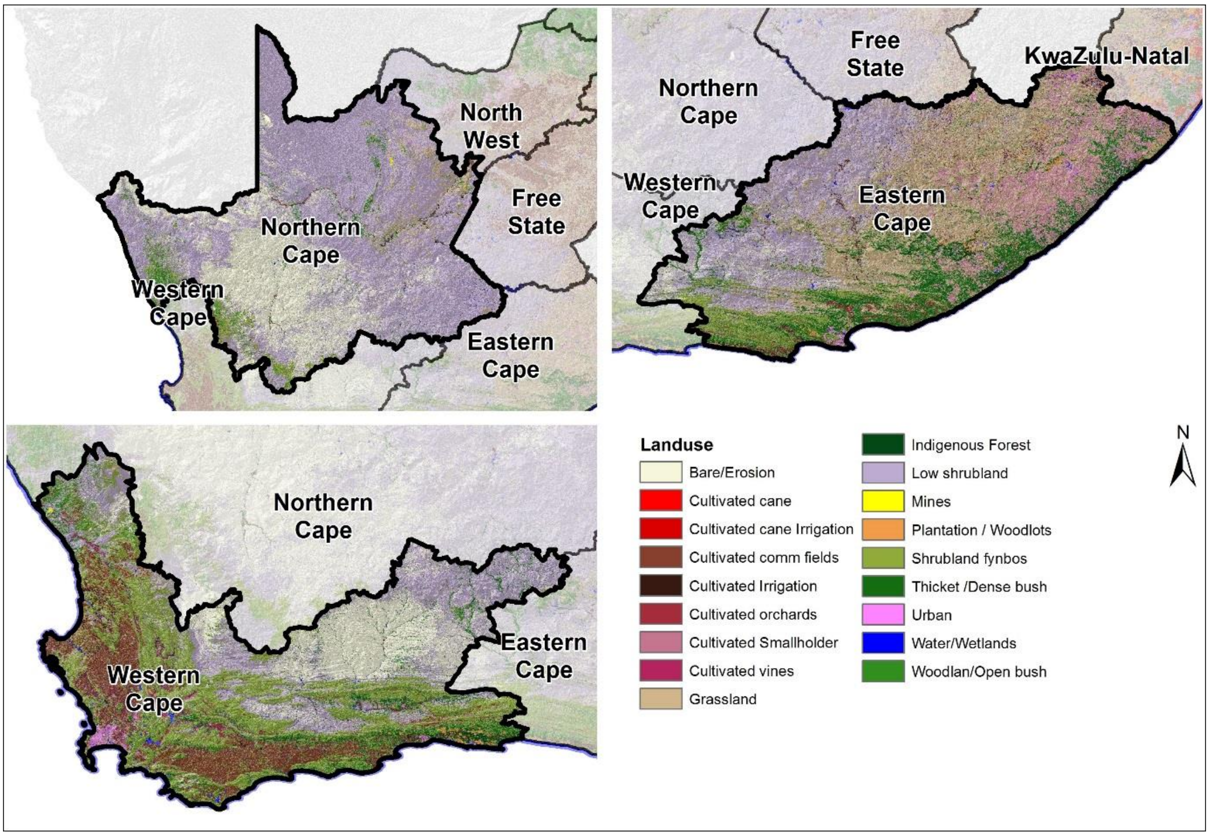

Figure 0.49: Land use for the Northern Cape, Eastern Cape and Western Cape (**NLC, 2015**)

Gauteng

In Gauteng there is a focus on high value horticultural crops such as flowers and vegetables along with substantial livestock production (Figure 3.48), (Stats SA, 2007). Gauteng contains large urban centres (Figure 0.51) and has a concentration of poultry and pig farms which supply these urban hubs (Musvoto *et al.,* 2015). The higher temperatures will impact livestock and increase evaporative soil loss. Even with the warmer wetter climate future the irrigation demand will be higher as crops will experience a greater water deficit. Although the dry years in the intermediate future may be less frequent than currently experienced but when they do occur they will have impacts on agriculture due to the 2°C higher temperatures (DEA, 2013b).

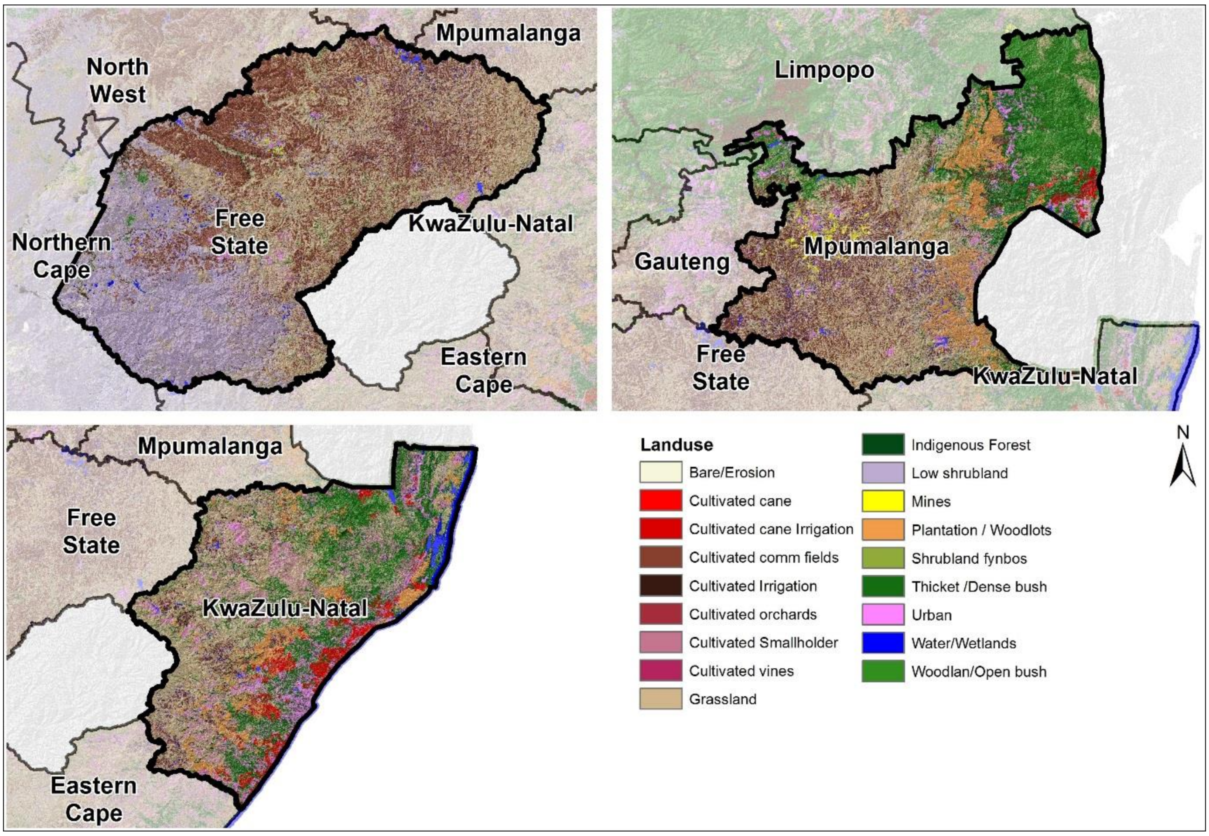

Figure 0.50: Land use for the Free State, Mpumalanga and KwaZulu-Natal (**NLC, 2015**)

KwaZulu-Natal

In KwaZulu-Natal there are a number of climates which are determined by elevation and proximity to the coast. This allows a range of commercial crops such as maize, soya, sugarcane, bananas, pineapples and large areas of smallholder maize (Figure 0.50). There is significant livestock production in the province (Figure 0.48) in addition to the dairy farming in the KwaZulu-Natal midlands. There has been the successful uptake of conservation agriculture by commercial farmers growing maize under irrigation particularly in the Bergville area of the province. In addition successful pilot studies of conservation agriculture and rainwater harvesting by smallholders are underway (Kosgei *et al.,* 2007). The main climate change impacts are summarised below:

- A large number of smallholder maize farmers will be impacted by the higher temperatures (Walker and Schulze, 2006);
- The total area suitable for commercial forestry plantations in KwaZulu-Natal would increase over the eastern seaboard and adjacent areas (DEA, 2013b);

- The number of life cycles of the codling moth to increase by 10-20% (Schulze, 2010);
- Increased number of dry spells would increase irrigation demand, however, under a warmer drier future they would be less water available for irrigation (DEA, 2013b).

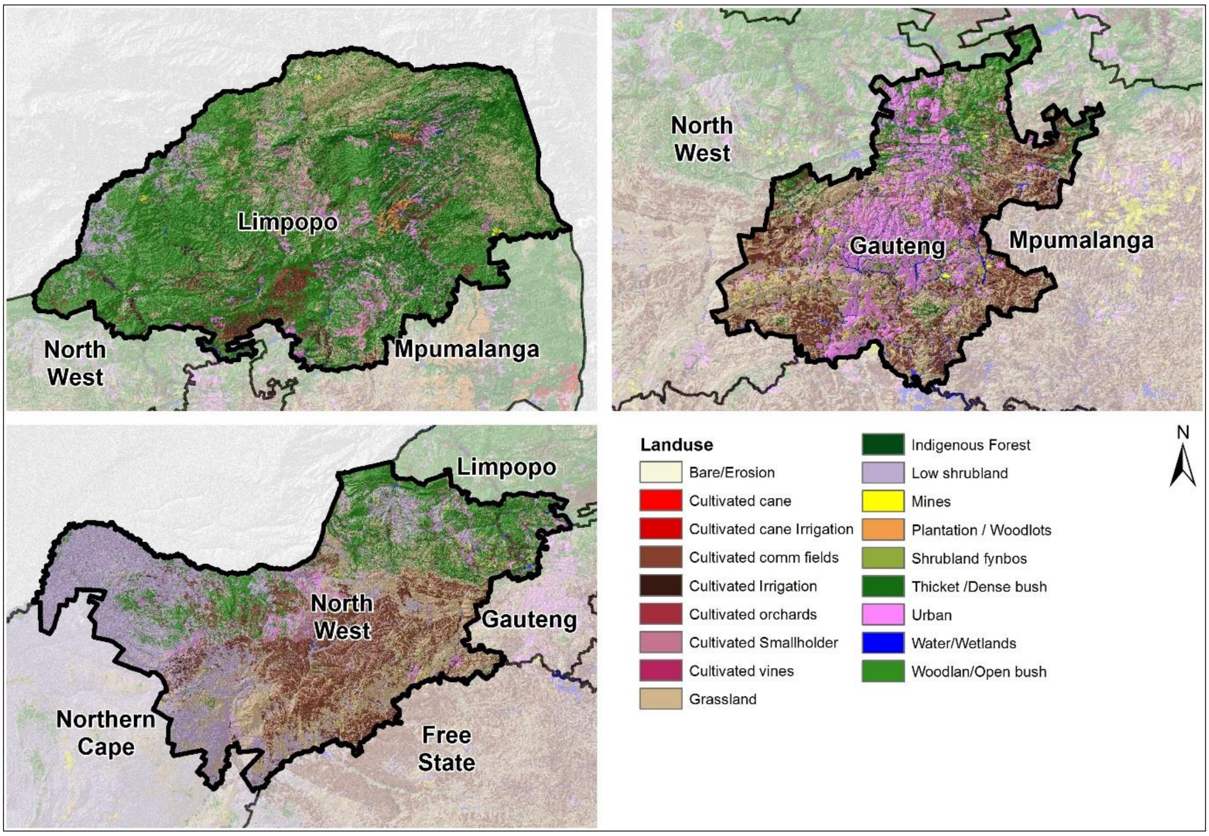

Figure 0.51: Land use for the Limpopo, Gauteng and North West (**NLC, 2015**)

Limpopo

The important crops include sunflowers, vegetables, citrus and nuts, there is also a large number of smallholder maize farmers (Figure 3.51), with livestock production also being economically important (Figure 3.48) (Stats SA, 2007). The higher temperatures will impact livestock and increase evaporative soil loss. A summary of the major climate change impacts for the intermediate future are:

- The large number of smallholder maize farmers will be impacted by the higher temperatures;
- The climate is expected to become unsuitable for Pines (*Pinus patula*) (DEA, 2013b);
- Higher temperatures will increase the spatial distribution of pests (Schulze, 2010);
- Higher temperatures will increase the water deficit experienced by crops and impact livestock (DAFF, 2015a).

Mpumalanga

The province is a summer rainfall area and its major crops include maize, sunflowers, soya, sugarcane (Figure 3.50), bananas, oranges and nuts along with significant amounts of animal production (Figure 0.48) and forestry. A summary of the major climate change impacts for the intermediate future:

- The total area suitable for commercial forestry plantations in Mpumalanga would increase (Schulze, 2010);
- Increased frequency and duration of hot summer spells with impacts likely on the developmental stages of important crops and possible heat stress for workers (DEA, 2013b);
- Increased number of dry spells would increase irrigation demand, however, under a warmer drier future there could be less water available for irrigation (DEA 2013).

Northern Cape

Livestock production is a significant part of the economy in the Northern Cape (Figure 0.48). Where rainfall is sufficient, rain-fed crops such as maize, wheat, groundnuts, lucerne and barley are grown. Table and wine grapes are grown when there is access to water for irrigation e.g. in close proximity to the Orange River (Figure 0.49). In the case of heat stress (for both farm labour and the impact on cattle), Nesamvuni *et al.,* (2012) and Archer van Garderen (2011) show that heat stress probabilities are likely to increase in the future and that the Northern Cape Province, particularly the parts bordering Namibia and Botswana, is an area of concern. The increase in hot spells will have significant impacts on any dry land crops and will increase the water requirements of existing crops. If sufficient water can be made available from the Orange River, climate change could however result in increased crop yields.

North West

The North West province is a major producer of maize on commercial farms with other crops such as sunflowers, groundnuts and vegetables grown (Figure 0.51). Livestock production encompasses a major part of the agricultural activity in the province (Figure 0.48). The increasing temperatures are a major concern for livestock production and human health. The increase in temperature would negatively increase maize yields and would counteract the benefit to the crop of elevated CO_2 levels (Walker and Schulze, 2008).

Western Cape

Agriculture is a major part of the provincial economy (Figure 0.46), the major crops grown include winter wheat, barley, potatoes, oranges, lemons, apples, pears, peaches, table grapes, wine grapes, flowers and rooibos (Figure 0.49) with livestock production and animal production comprising of approximately 40% of the agricultural income (Figure 3.48). A summary of the major climate change *impacts for the province:*

- Projected reduced runoff in areas important for the deciduous fruit industry in the Western Cape will negatively affect the production of horticultural crops (WC DoA, 2015);
- Future temperature increases are projected to cause a reduction of the area suitable for apple production due to a reduction in chill units (Cartwright, 2002);
- A warmer wetter future shows winter wheat yields to increase slightly by 0.5-1.5 t/ha/season in the intermediate future in the main wheat growing Swartland and Rûens regions of the Western Cape (DEA, 2013b).

The majority of the wheat production in the Western Cape is under Conservation Agriculture with the adoption rate estimated to be 60-70% (WC DoA, 2015).

3.6.2.3.1 Cross-cutting impacts

A number of potential cross-cutting impacts of climate change on the agriculture and forestry sector have been identified and some of these are described below as they relate to these other sectors.

Human settlements

Urban expansion is using up valuable high potential agricultural land which can never be recovered. This highlights the importance of integrated planning in adaptation studies with agriculture, mining and municipalities needing to be planned conjunctively, specifically with regard to water quantity and quality (DAFF, 2015a). Potential impacts of climate change in the agriculture sector also have significance for human settlements in terms of possible increases in food prices and associated risks for food security.

Water resources

Agriculture is the largest single surface water user in the country. Dependence on water represents a significant current vulnerability for almost all agricultural activities. There is evidence that smallholder dryland farmers are more vulnerable to climate change than commercial farmers, while large-scale irrigated production is probably least vulnerable to climate change, conditional upon sufficient water supply for irrigation being available (DEA, 2013b). Adaptation plans would benefit by considering water curtailments to irrigators in times of drought, in the light of food security and conditional upon irrigators using water efficiently. The socio-economic implications of water use trade-off scenarios under plausible future climates need to be investigated to inform key decisions on development and adaptation planning in order to reduce impacts on the most vulnerable communities and groups (DAFF, 2015a).

Disaster risk management

In the intermediate future farmers are likely to experience the following climate related hazards:

- Likely increases in the risk of floods and droughts due to more variable rainfall;
- High intensity thunderstorms with increases in surface runoff, erosion and mudslides;

- Potential increased frequency and intensity of hail storms or wind storm damages;
- More frequent and hotter fires, often started by lightning, with loss of grazing and other crops;
- Anticipated increases in pest and disease infestations;
- Water borne diseases – increased outbreaks of insects as a result of warmer water and possibly lower flows in the dry season (DAFF, 2015a).

Terrestrial ecosystems

Alien invasive species

Alien invasive plants use considerable amounts of water which is then not utilisable to downstream users (Kotzé *et al.,* 2010), with the water reduction in some primary catchments is as high as 8%. There are extensive riparian invasions by eucalypts and wattles along perennial rivers such as the middle and lower sections of the Orange River and the lower Vaal River (Le Maitre *et al.,* 2013). In riparian zones where water availability is greater, the invading tree water-use can be up 1.5–2.0 times that of the same species in dryland areas (Le Maitre *et al.,* 2015). Improved conditions for alien species invasions may emerge with climate change due to increasing CO_2 concentrations and where riparian vegetation becomes more stressed by lower future flows or changes in channel erosion. Already farmers in the Western Cape perceive a marked growth in riparian aliens. Adaptation measures in this regard will need to include policies on clearance (WC DoA, 2014).

National Terrestrial Carbon Sinks Assessment

The National Terrestrial Carbon Sinks Assessment (DEA, 2015b) is a first of its kind for South Africa and was commissioned following a directive from the National Climate Change Response Policy (DEA, 2011a). Given this, the aim was to assess the national carbon sinks in relation to afforestation, forest restoration, wetlands, agricultural practices and urban greening. The results show that land use changes often as a result of agriculture and forestry developments can have a significant impact on climate change mitigation and the possible sequestration of carbon to offset greenhouse gas emissions at a national level (DEA, 2014k; DEA, 2015b). In addition, improved soil conservation is a critical in terms of mitigation.

3.6.2.3.2 Adaptive capacity

Climate change problems are superimposed upon the many other challenges and stressors that the South African agriculture sector already faces such as environmental degradation, disease outbreaks, and higher input costs. To a certain extent, farming communities already adapt and cope with a variable climate (DEA, 2013b). Managing an uncertain future climate involves understanding vulnerability and reducing the associated risks (Andersson *et al.,* 2009).

A vulnerability study on the farming sector (Gbetibouo and Ringler, 2009) found that nationally farmers have a medium-level exposure risk to climate change coupled with medium to high-levels of social vulnerability. At a provincial level the Western Cape will contend with high exposure to extreme events through climate change. As a result they will experience economic losses but, the adaptive capacity of this province is high due to its greater wealth, comparatively high percentage of commercial farmers, well developed infrastructure, and access to resources (Figure 0.52). For Limpopo Province, KwaZulu-Natal and the Eastern Cape, even moderate climate changes will disrupt the livelihoods of the large number of smallholder farmers. Most of the smallholder arable land in theses provinces is rain-fed and consequently the increased rainfall variability from climate change would threaten the livelihoods of people who depend on rain-fed agriculture (Johnston *et al.,* 2013).

Web-based tools are already available to help farmers adapt to climate variability and to promote efficient use of water in irrigation e.g. Fruitlook (Western Cape Department of Agriculture see Box 3.11), WeatherWeb (The South African Sugarcane Research Institute (SASRI)).

Box 0.11: FruitLook

FruitLook (http://www.fruitlook.co.za/) is a web based tool funded by the Western Cape Department of Agriculture to promote water efficiency in the wine and fruit sub-sector and is considered to be a significant opportunity for building adaptive capacity. Fruitlook provides weekly updates for parameters of:

- Growth (biomass production, leaf area index, vegetation index);
- Moisture (actual evapotranspiration, evapotranspiration deficit, water use efficiency);
- Minerals (nitrogen in leaf, nitrogen in upper leaf layer).

Knowledge of these parameters can assist farmers in understanding the consequences of management decisions and can not only improve resource efficiency, but result in significant financial savings. On FruitLook, wine and fruit farmers can register their irrigation blocks and analyse the growth of the crop and the soil water status both temporally and spatially during the growth season. FruitLook can help farmers to explain yield variation between fields and to implement effective irrigation scheduling.

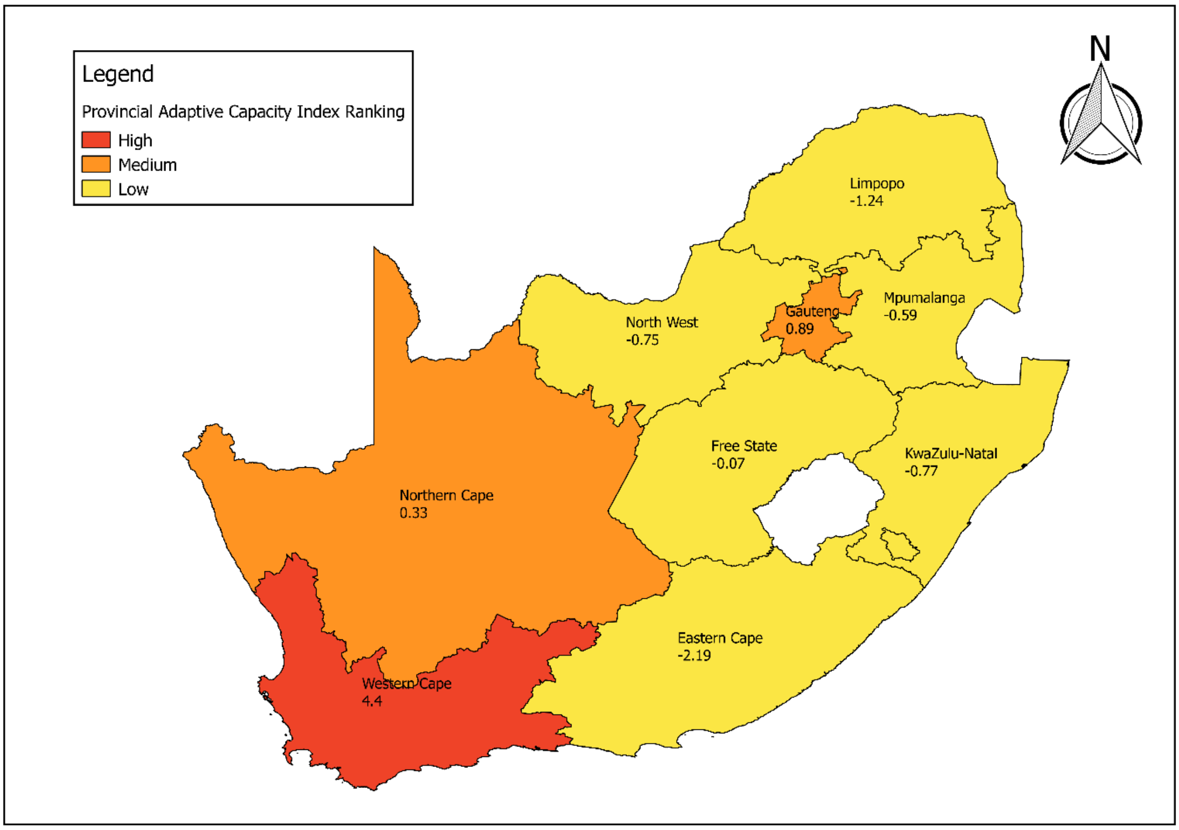

Figure 0.52: Adaptive capacity index at a provincial level (after Gbetibouo and Ringler, 2009)

Box 0.12: Working for Wetlands

In South Africa's Second National Communication (2011) a recommended adaptation option was wetland conservation and in general an improvement in natural resource management. Wetlands in the South African context perform vital ecosystems functions and provide a wide range of agricultural goods and services in supporting livelihoods in many rural communities. Working for Wetlands is a government programme managed by the Natural Resource Management Programmes of the Department of Environmental Affairs, and is a joint initiative with the Departments of Water and Sanitation (DWS), and Agriculture and Forestry and Fisheries (DAFF). In this way the programme is an expression of the overlapping wetland-related mandates of the three parent departments, and besides giving effect to a range of policy objectives, it also honours South Africa's commitments under several international agreements, especially the Ramsar Convention on Wetlands.

The programme is mandated to protect pristine wetlands, promote their wise-use and rehabilitate those that are damaged throughout South Africa, with an emphasis on complying with the principles of the Expanded Public Works Programme (DEA, 2012) and using only local Small, Medium and Micro Enterprises (SMME's). The Expanded Public Works Programme seeks to draw significant numbers of unemployed people into the productive sector of the economy, gaining skills while they work and increasing their capacity to earn an income. The Working for Wetlands

Programme was established in 2002 and in the 11 years since 2004 has invested over R765 million in wetland rehabilitation and has been involved in over 980 wetlands, thereby improving or securing the health of over 70 000 hectares of wetland environment. The Working for Wetlands Programme is ongoing. Other significant programs with a similar potential impact for climate change adaptation in multiple sectors include the Working for Water and Working on Fire program which is looking to reduce the potential for fire risk particularly under a warmer climate (DEA, 2012).

3.6.2.4 Balancing opportunities and threats

3.6.2.4.1 Barriers to adaptation

There are a number of potential barriers to adaptation in the agriculture and forestry sector. Selections of some of these potential barriers that have been identified are listed below:

- Lack of co-ordination with related sectors (e.g. water, land development, land reform);
- Poor maintenance and reduced functioning of particularly small scale irrigation schemes (van Averbeke *et al.,* 2011);
- Reduced number of agriculture extension services and extension support (DAFF, 2015a);
- Reduced monitoring and availability of critical and relevant climate change information;
- Policy implementation (i.e. implementation of the Climate Change Sector Plan for Agriculture, Forestry and Fisheries, (DAFF, 2015b));
- Limited access and affordability of insurance cover for increasing risk of disasters;
- Limited flexibility for autonomous adaptation through for example temporary trading of water use allocations and strict limitations imposed by regulatory bodies and some markets;
- Conservation Agriculture is seen as key to mitigation strategy but there has been slow uptake of the technology nationally, particularly by smallholder farmers, possibly due to a lack of training and capacity building. The exceptions to this are wheat farmers in the Western Cape (WC DoA, 2016) and sugar and maize famers in KwaZulu-Natal (BFAP, 2007).

3.6.2.4.2 Key evidence gaps

A number of critical research and data gaps have been identified in the LTAS Report on Agriculture and Forestry (DEA, 2013b) and the IPCC report on climate risk and vulnerability. These include *inter alia*:

- **Livestock animal health:** Changes in rainfall and temperature will potentially increase costs and management (i.e. increasing temperatures will affect the broiler industry). Research is required into how climate change will affect ectoparasites as major vectors;
- **Changing pest/disease/weed distributions:** Research needs to focus on improving understanding on the changes in the distribution of plant and animal diseases, whether pest infestations will increase, and into effective control of infestations. In addition further understanding is required on increased costs of weed control due to alien invasive plants increasing in abundance.
- **Plant breeding:** More drought/heat resistant varieties of crops i.e. varieties of apples and pears that require lower positive chill units.
- **Plant needs:** Revised estimates of crop water requirements, soil pH and fertiliser requirements of crops under intermediate future climates (DEA, 2013b).
- **Impacts of adaptation:** Future studies should examine the impact of adaptation measures when employed in the current climate (IPCC, 2014).
- **Forestry:** Research into biophysical responses of plantations to elevated CO_2 levels is required. Rising CO_2 levels could be incorporated into tree process models and this output can be combined with landscape models (Kennan, 2015).
- **Conservation agriculture uptake:** Research into the decision making process of both commercial and smallholder farmers to increase understanding on why the adoption of conservation agriculture has so far been limited and into what type of institutional support is required. Using case studies such as the current drought may assist in this.

3.6.2.4.3 Opportunities

The Agriculture sector has traditionally been known for being highly adaptive. Climate change does also present some opportunities for the agriculture and forestry sector. These relate particularly to the increased fertilization effect due to high concentrations of CO_2 as well as possible changes in precipitation that could enhance crop yields in certain parts of the country. These specific opportunities will need to be explored further as well as the potential benefit that comes with opportunities for additional financing through global climate funds and the added benefits that improved adaptation in the agriculture sector has in other sectors. For example improved water use efficiency and associated benefits of conservation agriculture for reducing sediment and erosion risks as well as enhancing biodiversity and other ecosystems goods and services provided through improved natural resource management. There is an opportunity for improvement in livelihoods of resource poor smallholder famers if improved natural resource management is combined with the sustainable development process.

On a continental and global scale it is also important to note that climate change will have very different impacts in different locations. This could present an opportunity in terms of changing production areas for certain crops, but requires South Africa to consider the potential impacts of climate change in a broader context and to look for opportunities to rather import crops from neighbouring African countries (as well as recent imports of poultry from the USA) that may experience increasing precipitation and associated improved crop production efficiencies. This has the potential to make certain limited resources such as water and land available for more productive uses as well as strengthening ties with neighbouring countries. In this regard it will be critical to debate and consider differences between "food security" and food "sovereignty" and to ensure climate change adaptation is considered in a more holistic way. It will also be important to consider potential impacts of climate change in other crop producing regions of the globe to identify opportunities where South Africa should focus in terms of future production markets.

3.6.2.5 Adaptation priorities

A number of adaption priorities have been identified for the agriculture and forestry sector in South Africa. Adaptation priorities identified LTAS (DEA 2013) and SmartAgri (WC DoA, 2016) include:

- Mainstreaming Climate Smart Agriculture and forestry;
- Improved water use efficiency and management;
- Improved soil conservation and catchment management;
- Improved monitoring, knowledge and decision support systems;
- Further development of new crop varieties, such as the utilisation of drought resistant crop varieties.

3.6.2.5.1 Climate Smart Agriculture

Climate Smart Agriculture (CSA) is similar to Conservation Agriculture (CA) and is considered critical for improved resilience and sustainable production in the agriculture sector globally and in South Africa.

CSA encompasses three main themes in order to achieve food security and development, they are:

- Sustainability - sustainably increasing agricultural productivity;
- Adaptation - building resilience to climate change;
- Mitigation - reducing and/or removing greenhouse gases (FAO, 2010).

CSA includes established methods such as CA (which includes reduced or no till, crop residue management; crop rotation and intercropping), and innovation such as early warning systems (Jirata *et al.,* 2016). The improved water and land management associated with conservation agriculture provides the foundation for CSA. Central to CA is the maintenance of a permanent or semi-permanent soil cover, either mulch or a nitrogen fixing intercrop, which protects the soil from the sun, rain and wind and provides inputs to soil biota (Knowler and Bradshaw, 2006). Minimal mechanical soil disturbance is also practised in order to prevent erosion and soil loss and to maintain soil moisture. In terms of pastures, knowledge of carrying capacity is important to prevent overgrazing and degradation of farmland which would enhance climate change impacts.

In addition to the on-farm methods that can be utilised, CSA principles can also be applied in the planning process (DAFF, 2011). In view of the spatial variation of both vulnerability and adaptive capacity at a provincial level, policies should be modified to subnational conditions i.e. the more vulnerable provinces have a high number of smallholder farmers, 62% of agricultural households are located in Limpopo, KwaZulu Natal, and the Eastern Cape (Stats SA, 2011). A suggested approach is to integrated climate change adaptation measures with sustainable development strategies e.g. in the provinces with a high number of smallholder farmers, policy measures that support improved management of soil and water resources should be introduced with policies that encourage agricultural intensification and diversification (Gbetibouo and Ringler, 2009). It is essential that land reform programs are joined with effective environmental management (Hoffman, 2014).

3.6.2.5.2 Climate Smart Forestry

Similar to CSA there are several adaptation measures that can be implemented in order to build resilience in the forestry sector as part of improved Climate Smart Forestry. These include (DEA, 2015c):

- Planning: Landscape level plans should be developed and implemented with other sectors such as biodiversity and water resources to ensure environmental sustainability;
- Research: There is a need specifically for mitigation and adaptation research in South African conditions with a focus on how plantations respond to elevated levels of CO_2 and temperature increase;
- Tree selection: Cognisance of shifts in geographic suitability of key species is required to optimise site-species matching. The introduction of new tree species is essential to improve productivity quality, health and timber value. New varieties also have the potential to build tree resilience to diseases, pests and environmental stresses (DEA, 2015c).

3.6.2.5.3 Improved water use efficiency and management

During the next decades South African will experience changes in rainfall patterns. The consequences of rainfall changes will be freshwater shortages or flooding resulting in negative impacts on agricultural production. An important adaptation strategy is to improve water availability through sustainable water management and increase water use efficiencies. Possible adaptation options for water use include:

- Water and nutrient conservation technologies such as improving irrigation efficiency, water recycling, rainwater harvesting, and the artificial recharge of aquifers;

- Increased surface water storage where appropriate (i.e. in some regions increased storage could just result in storing more hot air) and conditional upon maintaining environmental flows;
- Maintenance of ecological corridors and critical ecosystems such as catchment areas, wetlands and riparian banks to improve water quality, water reliability and reduced flooding risks;
- Mainstreaming CSA and CA maintains moisture in the soil for longer periods than conventional agriculture and reduces input costs;
- Improved monitoring of groundwater and consideration for conjunctive use. Farmers will need to re-evaluate groundwater recharge rates for boreholes to remain sustainable;
- Conversion to drip irrigation because of its high water use efficiency where it is beneficial for the soil (not sandy) and crop, and where finances allow (DEA, 2013b);
- Improved operation and maintenance of critical water supply infrastructure.

3.6.2.5.4 Restoration of degraded landscapes

There are many areas of South Africa that have become degraded some of them due to unsustainable agriculture and farming practices. It is critical that these areas are restored for increased landscape productivity, social ecological resilience and soil carbon sequestration (WC DoA, 2016). These degraded landscapes should be identified and appropriate remedial action developed. This could include the rehabilitation of erosion gullies and dongas, the restoration of areas impacted by overgrazing, the rehabilitation of wetlands and the removal of invasive alien plants. These activities could open up new areas for cultivation as well as providing additional ecosystem goods and services to protect and improve the climate resilience of surrounding agriculture land, water supply systems, and biodiversity.

3.6.2.5.5 Improved monitoring and decision support systems

Greater confidence should be developed in seasonal and short term forecasts which will enable farmers to implement the appropriate measures to either minimise the effect of adverse conditions or maximise the benefits from favourable forecasts (DEA, 2011c). The South African Weather Service (SAWS) and Agricultural Research Council, (ARC) which maintains the agricultural weather stations network, are currently providing short-term climate warnings by means of mobile phones. Climate information on a daily basis is imperative for farming processes such as irrigation scheduling, timing of fertiliser applications, in-field traffic control, cultivar and variety selection, timing of planting and harvesting, and response farming (DEA, 2013b). Decision support tools, such as Fruitlook should be developed and promoted to assist farmers in adapting to extreme temperatures and droughts and to improve water efficiency.

3.6.2.5.6 Development of new crop varieties

Moisture deficits are a huge challenge to crop production. With warmer future climates new crop varieties are required that are modified to have improved drought tolerance and have enhanced water use efficiency. According to the DEA (2011) there has been progress in developing new varieties of potatoes, sweet potatoes, soybeans, indigenous vegetables, maize and wheat. These efforts should be continued and in particular focused on making these new crop varieties available to small scale farmers.

3.6.2.5.7 Improved knowledge and communication

To reduce vulnerability in the agriculture sector it is important to increase awareness and disseminate information as widely as possible on the impacts and adaptation options. This is particularly pertinent to increase the uptake of CSA and CA techniques as many within the farming community are either not aware of climate change and its impacts, or regard climate change as normal climate variability. As part of the knowledge dissemination there should be an expanded extension service to provide advice on how to adapt to climate change (DEA, 2013b). The identification and sharing of case studies, particularly in the face of particular climate disasters such as the current drought, are important as this will raise awareness of the benefits for example of adopting CSA.

3.6.2.5.8 Priority Adaptation Projects for Agriculture

The Western Cape Department of Agriculture has identified six priority projects to catalyse the early adoption of important climate response interventions with high impact resulting from the SmartAgri project to develop a climate change adaptation framework and implementation plan. These priority projects were the result of extensive stakeholder engagement and identified a large number of specific climate change response actions. These projects were selected because they are practical and have multiple benefits in addition to improved climate resilience. Priority projects include:

- Conservation Agriculture for all commodities and farming systems
- Restored ecological infrastructure for increased landscape productivity, socio-ecological resilience and soil carbon sequestration
- Collaborative integrated catchment management for improved water security (quality and quantity) and job creation
- Energy efficiency and renewable energy case studies to inspire the transition to low-carbon agriculture
- Climate-proofing the growth of agri-processing in the Western Cape
- An integrated knowledge system for climate smart agricultural extension

While these priority projects were identified for the Western Cape, they would also be relevant for application at national level as well as in other provinces. A similar process to SmartAgri can be undertaken in other provinces and resulting in a similar set of priority projects.

3.6.3 Coastal Zone

3.6.3.1 Introduction

Numerous long-term changes in physical forcing have been observed at a global, synoptic (basin), regional and local scales as a result of climate and other anthropogenic-induced changes. Impacts of these on biological processes supporting fish and fisheries production in both marine and freshwater ecosystems in coastal zones have been noted and may be used as proxies for further estimating global climate change impacts. Some of these physical factors mentioned earlier, include atmospheric circulation, intensity and variability patterns, ocean stratification, currents and mixing, hydrological cycles and seasonal patterns. The following effects of climate change relevant to coastal environments and fisheries where appropriate, were considered:

- Modification of terrestrial climatic and hydrologic processes;
- Change in coastal and oceanic circulation processes;
- Ocean acidification;
- Sea Surface Temperature
- Sea Level Rise
- *Increase* in sea storminess; and
- Wind Systems

3.6.3.2 Vulnerability to climate change

Many physical or biological systems are able to adapt naturally to change, and if this happens in a resilient environment, are less likely to be vulnerable to impacts of climate change. However, many natural systems are likely to be vulnerable to certain climate change impacts and unable to adapt rapidly or adequately enough.

Since all exploit natural resources whose abundance, distribution, behaviour and productivity are affected by their environment, every sector of the South African marine fishing industry is vulnerable to a greater or lesser extent to changes in the marine environment brought about by climate change. In the analysis of the vulnerability of marine fisheries off the coastal zone and marine aquaculture, attempts were made to index the sensitivity of fisheries to climatically-induced changes in the resources, the socio-economic impact of potential changes in the fishery and the ability of the fisheries to adapt to such changes. These indices were combined into a Vulnerability Index (VI) for each of South Africa's twenty-one fisheries and for the marine aquaculture sector, which allowed comparison between the fisheries. The small-scale and commercial small-boat fisheries for linefish (including shore-based net-fisheries) and the fishery for small pelagic fish were found to be the most vulnerable to climate-induced changes.

3.6.3.2.1 *Oceanic circulation processes*

Large-scale coastal currents determine, to a large degree, coastal climate, which in turn will impact on coastal dynamics. The coastal ocean encompasses harbours, bays, lagoons, open coastlines, and the shelf seas, where a myriad of processes occur on a broad range of temporal and spatial scales with complex interactions. It is at the coast where human influences on the ocean are most concentrated: including waste disposal, construction, transportation, agriculture, commercial and small-scale fishing, aquaculture, recreation, mineral and biological exploitation, to name a few. Further, where the fishing sector is concerned, on top of the large-scale climatically-induced changes in resources which will affect all sectors of the industry, small-scale fishers are particularly vulnerable to local variations in abundance and distribution because of the limited geographic range of their operations. The problem is exacerbated in fisheries where the concession areas are very small, making these fisheries highly vulnerable to local weather effects.

Oceanic motion mediates all these interactions at several scales with seasonal, decadal and longer timescale variability. The ocean circulation around Southern Africa affecting South Africa's coastal zone is characterized by two large-scale ocean current systems: (1) the greater Agulhas Current system, and (2) the Benguela Upwelling system. Changes in the currents' behaviours (e.g. speed, average positions) will impact not only on the properties and circulation of the coastal zone, but will also impact on the coastal flora and fauna (including estuarine species).

The Southern African regional ocean can be divided into five distinct sub-regions (Figure 0.53), each region displaying specifically different flow dynamics, and each contributing in a different manner towards the marine and coastal environment, its resources and ecosystem, regional weather and global climate (Lutjeharms, 2006).

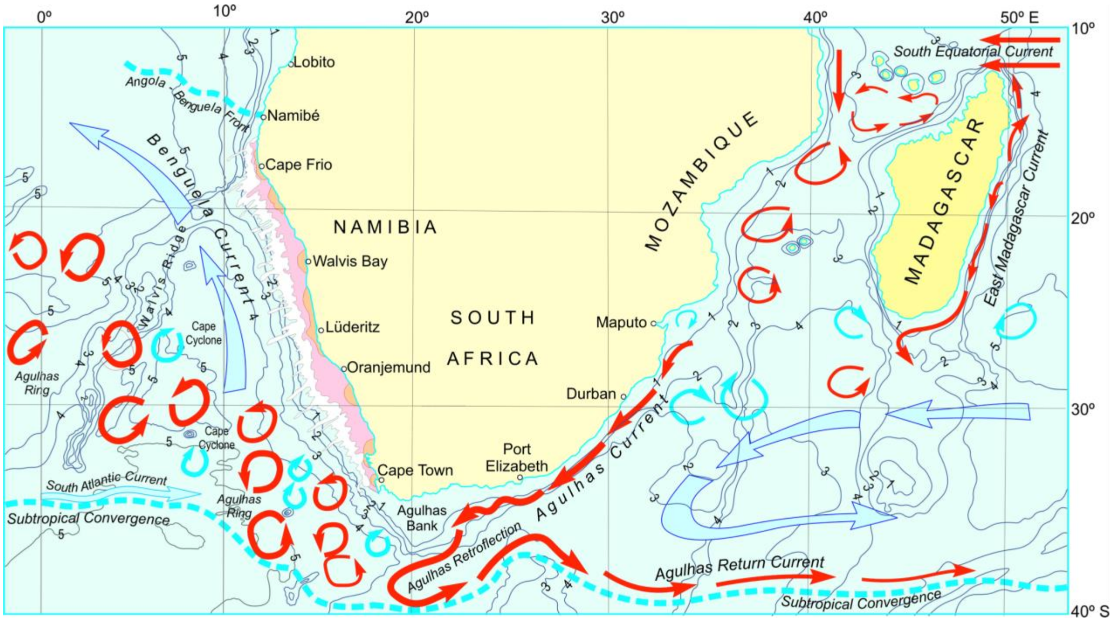

Figure 0.53: Schematic of the ocean circulation in greater Agulhas Current system from Ansorge and Lutjeharms (2007).

These regions include (1) the source regions of the Agulhas Current – namely the Mozambique Channel, the East Madagascar Current flowing along the east coast and south of Madagascar, (2) the northern and (3) the southern Agulhas Current, which have distinctly different characteristics, (4) the Agulhas retroflection, a region of intense turbulence and variability, and (5) the Benguela Upwelling System, one of the world’s four major upwelling systems. In the context of coastal climate change the Agulhas Return Current and the Southern Ocean are not discussed in great detail here, although they form part of the oceanic systems as a whole.

Sources of the greater Agulhas Current system

The greater Agulhas Current system is one of the most energetic current systems in the world playing a fundamental role in the marine environment, its resources and ecosystem, regional weather and global climate (Lutjeharms, 2006). The Agulhas Current forms part of the South-West Indian Ocean circulation, flowing polewards along the southeastern coast of Southern Africa from 27ºS, near Richards Bay, to 40ºS, approximately 600 km south of Cape Agulhas (Gordon, 1985; Stramma and Lutjeharms, 1997).

The Agulhas Current is thought to have two main sources, the South Equatorial Current (SEC), and recirculation from the South-West Indian Ocean sub-gyre, which supplies the greater part: 40 Sv of a total 60 Sv in the upper 1000 m (Stramma and Lutjeharms, 1997). Therefore, long-term changes of the circulation in the Indian Ocean may eventually affect the total volume of water transported polewards in the Agulhas Current.

Indeed, analyses of current measurements derived from satellite observations (Backeberg *et al.,* 2012) suggest that the South Equatorial Current is intensifying in response to increasing trade winds over the tropical Indian Ocean. Particularly north of Madagascar a strong increase in the currents is evident, which in turn affects the flow through the Mozambique Channel, a major source of water and variability for the Agulhas Current. The flow in the Mozambique Channel as it is known today, is dominated by southward moving anti-clockwise rotating eddies (Sætre and da Silva, 1984; Biastoch and Krauss, 1999; and de Ruijter *et al.,* 2002). The formation of eddies in the Mozambique Channel is related to variations of the South Equatorial Current (Backeberg and Reason, 2010). The effect of the intensified South Equatorial Current is reflected in the Mozambique Channel as a doubling of the eddy propagation speeds through the channel (Backeberg *et al.,* 2012). The southern branch of the East Madagascar Current has also intensified, with larger and faster moving eddies moving towards the northern Agulhas Current.

The eddies and variation of the circulation south of Madagascar have been documented to be important contributors to the Agulhas system (Siedler *et al.,* 2009). Increasing eddy properties (amplitudes, radii and westward propagation velocities) south of Madagascar imply increased volume transported towards the Agulhas system. The satellite derived ocean currents imply that the circulation in the South-West Indian Ocean has intensified, and via the flow through the Mozambique Channel and south of Madagascar, these signals travel towards the Agulhas Current affecting its strength and variations.

The northern Agulhas Current and Natal Pulses

The northern Agulhas Current between Port Edward (30°S) and Port Elizabeth (34°S), is characterized by very strong and stable flow conditions. It can be found in close proximity to the shore for approximately 80% of the time (Grundlingh, 1983) with its edge generally within 20-50km from the coast (Bryden *et al.,* 2005; Goschen 1990; Rouault and Penven, 2011). It transports large volumes of warm water southward (on average about 70 million m^3/sec) and can be associated with current velocities of up to 4 knots.

The position of the Agulhas Current varies predominantly due to the irregular passage of offshore clockwise circulating meanders (Rouault and Penven, 2011). Some of these large-amplitude cyclonic meanders (also referred to as “Natal Pulses” due to their region of origin) can force the current’s core up to 200 km offshore (Krug *et al.,* 2014). Natal Pulses can occur up to 4 times per year (Krug *et al.,* 2014, Beal *et al.,* 2015) with on average 1.6 Natal Pulse per year progressing to the southern Agulhas Current region (Rouault and Penven, 2011). Natal Pulses have long residence times (Krug *et al.,* 2014). They strongly impact the coastal and shelf regions where they drive localized upwelling (Bryden *et al.,* 2005) and participate in the dispersion and transport of pollutant or fish larvae through associated processes such as such current intrusions, meanders, filaments or water plumes.

The satellite derived long term trends in the Agulhas Current are complex, owing to the highly chaotic nature of the current and the many processes the impact it. Backeberg *et al.,* (2012) report that in the northern Agulhas Current, an increase in the mean flow component of the Agulhas Current is evident, which is linked to larger and faster moving eddies arriving at the current. The Agulhas Current intensifies in response to larger and faster eddies due to a transfer of momentum from the eddies to the current through complex non-linear interactions. It is unclear how an intensified northern Agulhas Current impacts the formation of Natal Pulses.

It is interesting to note, that only the northern Agulhas Current, north of about Coffee Bay, experiences an intensification of the mean current. To the south of Coffee Bay, the current appears to be slowing down, but meandering more.

Southern Agulhas Current

Contrary to the northern Agulhas Current, the flow in the southern regions displays characteristics more typical of western boundary currents. With a separation of the continental shelf from the coast near Algoa Bay, the current begins to exhibit numerous meanders, plumes and eddies (Lutjeharms *et al.,* 1989).

As noted, the southern Agulhas Current appears to be slowing down, while exhibiting increase variability (Backeberg *et al.,* 2012), which occur in the form of meanders and eddies. These changing characteristics of the Agulhas Current may impact shelf edge upwelling, which occurs along the inshore edge of the Agulhas Current (Goschen and Schumann, 1994; Martin and Fleming, 1988) upstream of a persistent upwelling cell near Port Alfred (Schumann, 1987).

Furthermore, upwelling events near Port Alfread co-occur with offshore migrations of the Agulhas Current (Goschen and Schumann, 1988), suggesting that the Agulhas Current location (partially) drives the upwelling variability. Long-term changes in the strength and position of the Agulhas Current, such as those suggested by Backeberg *et al.,* (2012), will affect the inshore upwelling cells as well as the shelf edge upwelling, which in turn may impact the coastal ecology.

Studies have shown that intensified upwelling events impact bird feeding numbers. In addition to the ecological impact, changing sea surface temperatures influence the overlying atmosphere (Jury, 1994; Jury and Walker, 1988; Jury *et al.,* 1993), which in turn affects the rainfall over the adjacent coastal zone (Jury *et al.,* 1993). It is noteworthy that the vegetation cover near Port Alfred exhibits some of the greatest variability in southern Africa (Rouault *et al.,* 1995).

The Agulhas Bank is a wide and relatively shallow (±200m deep) region within the southern Agulhas Current, extending from Port Elizabeth to Cape Town and approximately 300km south in a roughly triangular form. On average, the Agulhas Current trajectory follows the outer edge of the Agulhas Bank south-westwards.

There is a strong contrast between the shallow, well-stratified waters over the Agulhas Bank and the deep and turbulent flows of the Agulhas Current, which creates a range of hydrographic habitats that become especially evident in the distributions of organisms (Lutjeharms, 2006). Furthermore, the disparity in sea surface temperatures and heat content between the two contrasting waters in turn has a substantial impact on the overlying atmosphere affecting local weather.

The effects of the changing Agulhas Current on the circulation over the Agulhas Bank are not well understood, nor studied. Close to the coast, winds play an important role in determining the ocean temperatures through wind driven upwelling.

Rouault *et al.,* (2010) reports a cooling trend along South Africa's South Coast and in the Port Elizabeth/Port Alfred region associated with an increase in upwelling-favourable easterly winds, suggesting that the cooling trends are both due to an intensification of the Agulhas Current as well as increased upwelling favourable winds.

Agulhas Retroflection and Leakage

With the southern termination of the Agulhas Bank, approximately 600km south of Cape Agulhas, the current continues on its southwesterly path, developing oscillations of increasing amplitude until it eventually retroflects near 40ºS and between 16ºE and 20ºE. The Agulhas Retroflection exhibits some of the highest levels of mesoscale variability in the world's ocean (Lutjeharms and van Ballegooyen, 1988; Garzoli *et al.,* 1996). The retroflection loop may have a diameter of up 340 km, and shedding of anti-clockwise retroflection eddies, or "Agulhas Rings", occurs here at irregular intervals (Lutjeharms and van Ballegooyen, 1988).

The Agulhas retroflection is an important region in the global ocean. It is at this juncture, where the transport of warm, salty waters from the Indian to the Atlantic Ocean occurs, the process is known as the Agulhas Leakage.

It is thought that the Agulhas leakage plays a key role in determining global climate (Beal *et al.,* 2011), and its variability may affect the Atlantic Meridional Overturning Circulation (AMOC) strength (Weijer *et al.,* 2002) and hence the onset of glaciations in the northern hemisphere (Bard and Rickard, 2009; Peeters *et al.,* 2004).

A number of mechanisms contribute to the total Agulhas leakage: Agulhas Rings, cyclonic eddies, filaments, coastal jets and direct fluxes (de Ruijter *et al.,* 1999; Gordon, 1986). Agulhas Rings are large anti-cyclonic vortices, which occur due to the intermittent occlusion of the Agulhas Retroflection loop at the southern extension of the Agulhas Current. Each year between 4 to 8 Agulhas Rings of varying sizes (200 to 400 km in diameter) are pinched off and advected north-westward into the south eastern Atlantic Ocean along the west coast of South Africa. Natal Pulses also influence the leakage of warm and salty Agulhas Current water into the Atlantic. In particular, they have been linked to the formation of Agulhas Rings (van Leeuwen and de Ruijter, 2000) and to Early Retroflections (Lutjeharms and van Ballegooyen,1988; Rouault *et al.,* 2010). Early Retroflections are rare occurrences when the Agulhas Current retroflects upstream of its usual location and which are associated with momentary interruption of the Agulhas Leakage.

In response to anthropogenic influences, the Southern Hemisphere westerly winds are increasing in intensity and moving polewards, causing an increasingly positive phase of the Southern Annular Mode (SAM) (Cai, 2006). Model simulations of the region have suggested changes in the Southern Hemisphere westerly winds and an increasingly positive SAM phase, the Agulhas leakage has increased by 25%, supplying more salt to the AMOC potentially offsetting the North Atlantic freshening (Biastoch *et al.,* 2008).

Changes in Agulhas Leakage through Early Retroflection or changes in the shedding frequency or properties of Agulhas Rings would therefore impact on the dynamical and hydrographic properties of the Benguela marine ecosystem and its coastal climate. Increased or decreased air/sea interactions as a result of water masses modification could also lead to wetter/dryer climates thus impacting on river run-off and estuarine dynamics.

Benguela Upwelling System

The Benguela Upwelling System on the west coast of South Africa extends northward from the southern tip of Africa to Angola (Shannon, 1985). The upwelling system is driven predominantly by southerly and southeasterly winds (Hagen *et al.,* 2001; Risien *et al.,* 2004) that are affected by the high pressure system over the South Atlantic, which includes sub-tropical storms, or low pressure systems, crossing the South Atlantic Ocean and moving over the southern Benguela as well as by the the low pressure system over southern Africa (Shannon and Nelson, 1996; Risien *et al.,* 2004). In addition to this, seasonal trade winds also influence the dynamics of the upwelling (Shannon, 1985;

Chavez and Messié, 2009). The Benguela Upwelling System is rich in pelagic fish biomass and important for coastal fisheries (Bakun *et al.,* 2010), and climate change related long term impacts on the upwelling have significant and far reaching socio-economic implications.

The Benguela is unique among upwelling systems, in that its southern boundary is bordered by the Agulhas Current, a strong warm, highly dynamics ocean current. The juxtaposition of the two allows for the dynamics of the Benguela Upwelling System to interact with, for example, Agulhas Rings. Previous studies have shown that most of the water masses and energy input into the Benguela ecosystem originate from the Agulhas Current (Gordon 1987, Matano and Beier 2003), and it has been suggested that Agulhas Rings can remove significant amounts of water from the upwelling front region. This would have a profound effect on the biota of the upwelling regime, including recruitment for anchovy (Duncombe *et al.,* 1992). It has furthermore been suggested that Agulhas Rings are the primary mechanism by which low oxygen waters are removed from the slope (Gordon *et al.,* 1995). Thus, changes in the Agulhas Current have direct implications for the Benguela Upwelling system, although these remain to be quantified.

Bakun (1990) put forward a hypothesis stating that as a consequence of rising greenhouse gas concentrations, the surface temperature over the continents would warm faster than the oceans. This would lead to a strengthening of the continental lows and oceanic highs, which in turn would enhance the land–sea pressure gradient causing a strengthening of alongshore winds and thereby enhancing upwelling. A warming ocean surface, would feed back positively by introducing more humidity in an otherwise dry atmosphere over land, reinforcing the greenhouse gas effect (Bakun, 1990). The observational record of south-western Africa surface temperatures over land does indicate that there has been a more rapid increase over land compared to the oceans since 1980. In agreement to Bakun’s hypothesis, Rouault *et al.,* (2010) found decreasing trends in coastal SSTs in the Benguela System from 1985–2009, associated with increasing upwelling-favourable south-easterly winds. However, the robustness of the upwelling trends in the Benguela Upwelling System remain unclear (Bakun *et al.,* 2010). This is thought to be due to the influence of ENSO on atmospheric humidity in Benguela, combined with a number of successive strong ENSO events that may have suppressed the long-term intensification signal.

It has been suggested that larger scale climate modes of variability, such as ENSO, impact the interannual variability of upwelling by modulating local conditions. These include variations of low stratospheric winds (Hagen *et al.,* 2001); the St. Helena Island Climate Index (HIX) (Hagen *et al.,* 2005); and the Antarctic Oscillation (AAO), (Jones and Widmann, 2004). Moreover, the impact of El Niño–Southern Oscillation (ENSO) could be of major importance and play an even stronger than the one of the AAO (Rouault *et al.,* 2010; Dufois and Rouault, 2012). El Niño tend to weaken while La Niña events tend to strengthen upwelling. It is thought that this is related to an equatorward shift in the high pressure over the southern Atlantic which leads to weaker upwelling-favourable trades winds (and vice versa for La Niña events) (Dufois and Rouault, 2012).

The primary hazards to (physical) South African (SA) coastal infrastructure related to the sea are[4] direct wave impacts, coastal flooding and inundation, and erosion and under-scouring (Theron *et al.,* 2010). Rises in sea level, combined with rises in SST and an increase in storms and extreme events such as cyclones in the tropical Indian Ocean, have the potential to inundate harbours, marine aquaculture farms and fish processing plants close to the shoreline. Focussing on the abiotic hazards to infrastructure and developments in the SA coastal zone, one finds that the main metocean drivers are thus waves, seawater levels, winds (to a lesser extent in most of SA) and currents (in much fewer instances).

The degree to which a specific site is exposed to prevailing ocean swells determines the wave energy impacting on the shoreline. This is largely dependent on the site location, coast configuration, topography and bathymetry. To quantify the hazard or assess the vulnerability to coastal flooding/inundation, direct wave impacts, extreme water levels and wave runup, it is necessary to determine the maximum point that storm waves can reach (wave runup), in other words the height to which a wave would run up the beach slope. Primary components of this are the following:

- Determining extreme offshore wave climate (present and future).
- Deriving resultant inshore wave conditions.
- Calculating extreme seawater levels (e.g. components).
- Modelling wave run-up levels.

Together with a few other coastal parameters (e.g. erosion/accretion, climate change scenarios, etc.), this is a critical step in determining “vulnerable” coastal locations (a component of integrated coastal management strategy, mainly for safety and to protect property from abiotic physical coastal/marine processes/”impacts”). In conjunction with other integrated coastal management considerations (wind sediment transport, public access, environmental criteria, heritage, etc.), this also determines the coastal setback line (as required by the Integrated Coastal Management Act). Adequate information on the inshore wave climate (1 and 2 above) and coastal flooding elevations (3 and 4 above) will have much wider integrated coastal management use (e.g. planning and response), leading to, for example, appropriate coastal adaptation measures (for e.g. protection, resilience and sustainability of goods and services).

Shoreline ’stability’ or the probability of erosion (and/or under-scouring of structures) is affected by many drivers, processes and activities, some of which are natural and some of which are due to anthropogenic actions. Most of these variables are listed and “typed/classified” in the following diagram depicted in **Error! Reference source not found.** For more detail on observed sea level rise and projected changes in storminess around the South African coast (refer to Work package 1 and 2).

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[4] Note that other abiotic coastal/marine hazards to consider are low-probability hazards: tsunamis, undersea slope failures, and so forth. There are also biotic hazards/vulnerability, for example harmful algal blooms and pollution (e.g. oil spills, outfalls, etc.)

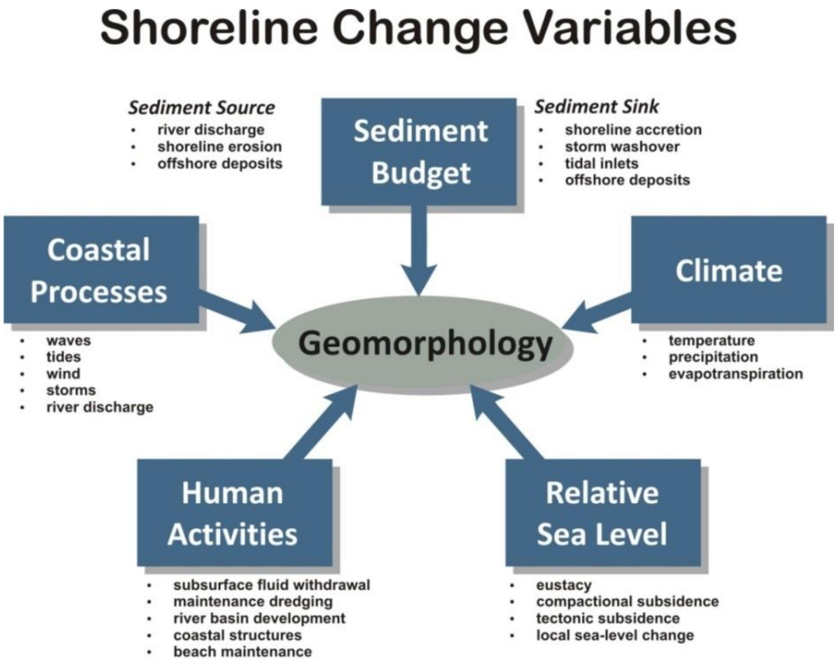


Figure 0.54: Drivers, processes and activities affecting shoreline "stability" or erosion

The problem with SLR is not just the vertical rise (described in work package 1) but also its interaction with changing storm intensities and wind fields to produce sea conditions that will progressively overwhelm existing infrastructure (e.g. Battjes, 2003; Houghton, 2005). This is a particularly important risk in the case of the highly exposed South African coastline and a subject that up to now has been little explored (Theron, 2007). Although we are not at this time able to reliably estimate changes in storm patterns, windiness, wave energy or direction, the increase in storm activity and severity will probably be the most visible impact and the first to be noticed (refer to work package 2). For example, higher sea levels will require smaller storm events to overtop existing storm protection measures (see **Figure 0.55** below for an example of an existing problem area).

Figure 0.55: An existing coastal flooding problem (**Table Bay, South Africa**)**, likely to worsen due to climate change** (**Photo: L van der Merwe**)

It is concluded that the best estimate (or ‘central estimate/mid scenario’) of SLR by 2100 is around 1 m, with a plausible worst-case scenario of 2 m and a best-case scenario (low estimate) of 0.5 m (Theron *et al.,* 2012). The corresponding best estimate (mid-scenario) projections for 2030 and 2050 are 0.15 m and 0.35 m, respectively.

Each South African city is faced with a variety of coastal vulnerabilities. According to the ICM act the 100 m distance from the coastline represents the urban coastline and the 1000m distance represents the rural line. From Table 0.5 the percentage of the population of each of the listed coastal cities are given with regards to the ICM act’s coastal lines. Looking at the population percentages in this manner does not reveal any clear threats. When the topography is taken into account, e.g. through the 20m contour line, the vulnerability of the various cities becomes clear. The lower lying cities, such as Saldanha and Cape Town, are thus much more threatened by SLR than elevated cities such as East London and Durban. It should be noted that this table only serves as an example of topography influenced vulnerability to SLR and the true vulnerability of each city has to take into account all the drives of relative coastal SL change and coastline types.

Table 0.5: Relative vulnerability of South African coastal cities to SLR.

City	100m buffer line population percentage	1000m buffer line population number percentage	20m contour line population percentage
Saldanha	8.29%	38.07%	43.25%
Cape Town	0.43%	4.62%	27.59%
Port Elizabeth	0.02%	2.61%	12.12%
East London	0.04%	4.48%	1.28%
Durban	0.32%	6.86%	6.35%
Richards Bay	0%	0.55%	16.44%

In **Figure 0.56Error! Reference source not found.** two examples are provided that illustrated the relative areas lying below the 20 m contour line and thus illustrating the topography and population density influencing SLR vulnerability.

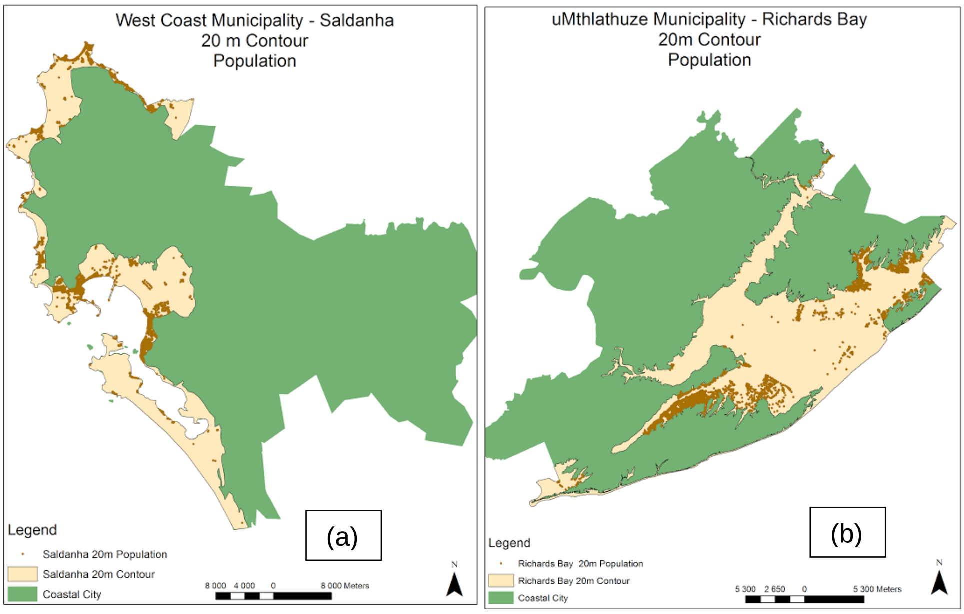


Figure 0.56: The shaded areas represent the coastal population within (**a**) **the Saldanha municipal district and** (**b**) **Richards Bay municipal district under the 20 m contour line. The brown dots represent the population per household**

3.6.3.3 Sea Surface Temperature (from the DAFF CCAMP, 2016)

The average sea surface temperatures of the global oceans have increased since the beginning of the 20th century and between 1950 and 2009, the average sea surface temperature of the Indian and

Atlantic Oceans (both of which border South Africa) has increased by 0.65°C and 0.41°C respectively. A warming ocean is also likely to lead to declines in dissolved oxygen through reduced solubility and increased stratification that will reduce ventilation of the ocean interior. The combination of higher ocean temperatures and declining pH and oxygen concentrations will pose a significant threat to marine species of importance to fisheries and marine aquaculture, and to ecosystem functioning.

The IPCC 5th Assessment Report (AR5) concluded that there is high confidence that warming and acidification will continue in the future over most, and possibly all, of the ocean environment, but that the rates will vary from region to region. IPCC forecasts make use of different scenarios (Representative Concentration Pathways or RCPs), which describe different possible climate futures, depending on the quantity of greenhouse gases emissions in the coming years. The mean sea surface temperature is forecast to increase from 2000 to 2050 by between approximately 0.7 and 1.5ºC and by between 0.7 and 4.0ºC from 2000 to 2100, depending on which RCP is used for forecasting. IPCC AR5 also reported that the rapid physical and chemical changes in the oceans have already had impacts on the distribution and abundance of marine biota and ecosystems, with a general trend of marine organisms moving to higher latitudes as the sea temperatures in those regions increase. Similarly, increasing acidification and de-oxygenation of the oceans will lead to decreased survival, calcification, growth, development and abundance of some marine organisms.

A recent study of changes in sea surface temperatures between 1950 and1999 by Hobday and Pecl identified an area of ocean to the south and east of South Africa, approximately equivalent to the position of the southern Benguela ecosystem, and another area in the Mozambique Channel that extends into South Africa's EEZ in the north east of the country as having experienced warming at rates during that period that puts them within the top 10% of areas globally. The authors referred to the top 10% of areas globally as 'hotspots". The 10% threshold was equívalent to an increase of 1.48º C per 100 years. There is little information on expected changes in ocean conditions at a regional scale for the areas around South Africa, but in a recent study, Popova *et al.,* (2016) investigated likely changes in some of the 'hotspot' areas identified in the Hobday and Pecl study, including the South African hotspot. That investigation used the high resolution Nucleus for European Modelling of the Ocean (NEMO) framework, with a horizontal resolution of approximately 1/4º and 75 depth strata. The forecasts were forced by scenario RCP 8.5. RCP 8.5 is the most extreme of the RCP scenarios, and could therefore be expected to give the most pessimistic results, but it is the only RCP which includes the high resolution necessary for the regional analyses. The model forecast an increase of approximately 3ºC for the ocean area around South Africa. This was the lowest increase in the six areas examined in the study but, based on IPCC assessments, would still pose moderate to high risk of negative impacts on the local area. The model forecast that there would be substantial shifts in and intensification of the dominant currents off the coast of South Africa but the study did not attempt to forecast the direct impacts of these expected changes. The model projections indicated that acidification is unlikely to be a threat to ecosystem processes in the oceans around South Africa by 2099; a view which is however open to question.

Overall, these global results and those for the local region give strong evidence that warming of the oceans around South Africa will continue for the remainder of this century and will be sufficient to have marked impacts on the distribution and abundance of species important to the national marine fishery and marine aquaculture sectors.

3.6.3.3.1 Ocean acidification

Fossil fuel burning and anthropogenic land-use changes have caused the global atmospheric CO_2 concentrations to rise from approximately 280 parts per million (ppm) in the pre-industrial era (Joos and Saphni, 2008) to about ppm in 2013 (Dlugokencky and Tans, 2014; Le Quéré *et al.,* 2015). The oceans have absorbed approximately 30% of these total anthropogenic carbon dioxide emissions from the atmosphere (Canadell *et al.,* 2007). When seawater absorbs anthropogenic CO_2 from the atmosphere, chemical reactions occur that reduce the pH of seawater, the concentration of carbonate ion, and the saturation states of the biominerals aragonite and calcite in a process called "ocean acidification" (Feely *et al.,* 2010). pH is a measure of acidity, with lower values indicating a higher concentration of hydrogen (H^+) ions and a more acidic liquid. Ocean acidification refers to anthropogenic CO_2-induced reduction in pH and carbonate saturation (generally express as the saturation state of aragonite - Ω_{arag}) (Feely *et al.,* 2010; Gruber *et al.,* 2012). Future predictions indicate that with increasing atmospheric CO_2 concentrations, pH will generally decrease across the ocean surface, while the effect is expected to be amplified in bottom waters of the ocean. Over the past 250 years, the average pH of the ocean surface waters has decreased by about 0.1 which translates into a 30% increase in "acidity") (Feely *et al.,* 2010). By the end of this century, average surface ocean pH is predicted to decrease between 0.14 to 0.32 pH units under the most conservative and worst emission pathway scenarios respectively (IPCC AR5, Feely *et al.,* 2004, 2009; Doney *et al.,* 2009).

An important mechanism by which these low pH bottom waters are introduced to coastal (and estuarine) environments is upwelling. Typical of upwelling systems, the Benguela CS along South Africa's west coast has naturally lower pH currently ranging between 7.60 and 8.25, depending on the season (Figure 0.57); Gregor, 2012). This system is predicted to have a pH of between 7.8 and 7.5 by the year 2100 and an even lower pH (7.3 to 6.7) by the year 2300 (Caldiera and Wicket, 2005). As a result of climate-driven speeding up the South Atlantic Sub-tropical gyre (Saenko *et al.,* 2005; Roemich 2007) upwelling in the Beguela CS is going to become more intense which may extend the persistence of lower pH and Ω_{arag} saturation.

Many catchments and estuaries in SA are either acidic or neutral with no real change in the buffering effect of seawater on low pH freshwater inflow. In turn, evidence points towards land-use practices increasing pH in some naturally acidic systems thus allowing settlement and colonization by oysters and other calcifying invertebrate species previously excluded. Ironically, poor water quality in SA estuaries may offer some invertebrates refuge from ocean acidification. However, most of these are introduced, alien invasive species such as the Pacific oyster *Crassostrea gigas*.

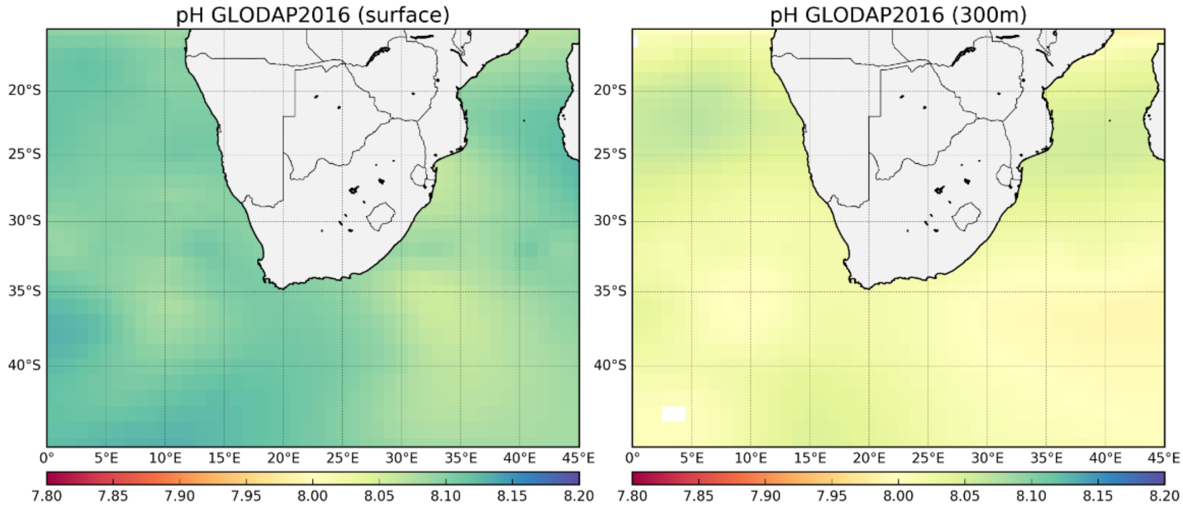


Figure 0.57: Regional In situ pH climatology in surface water (left) and depth of 250m (right) mapped from 1o x 1o GLODAPv2 dataset using Data-Interpolating Variational Analysis mapping method (Lauvset *et al.,* 2016)

Figure 0.57 shows the climatological pH conditions in the surface (left panel) and at 300m depth (right panel) below the surface. The difference between average pH in the surface around Southern Africa (pH ~ 8.1) and 300m the mean pH is roughly 8.0 highlight the gradient between surface and subsurface upwelling source waters. Similarly, a marked difference between aragonite saturation states between the subsurface and subsurface (300m) is observed in **Error! Reference source not found.**. Under the anticipated increasing upwelling conditions in the future, surface waters around South Africa is expected to experience more frequent occurrence of low pH waters which is undersaturated with respect to aragonite.

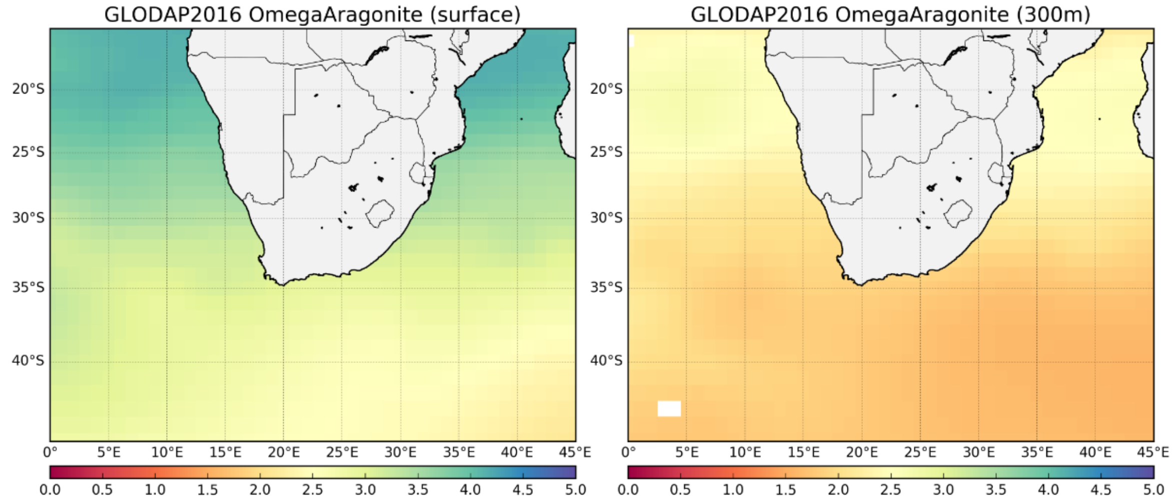


Figure 0.58: Regional climatology of saturation states of aragonite in the surface (left) and at 300m depth (right) mapped from 1o x 1o GLODAPv2 dataset using Data-Interpolating Variational Analysis mapping method (Lauvset *et al.,* 2016)

Predicting the response of individual organisms to high CO_2 and associated low pH, in data sparse regions of Southern Africa is complicated. Global biogeochemical climate models and data analysis predict that the Benguela Upwelling System will experience corrosive and irreversible consequences of ocean acidification within the 21st century and that, through changes in the Agulhas Current and local upwelling, the East Coast will not escape these effects. (There are in fact signs that the Benguela Upwelling System may already be under strain from effects related to ocean acidification, which appears to be most severe in the inshore region of the Namaqualand Coast). Generally indications from recent work indicate, foraminifera, molluscs, and echinoderms respond with reduced rates of calcification and sometimes dissolution of skeletal structures. Also reduced fertilization rates and early development stress are observed in sea urchins and molluscs and copepods (Table 1 in Fabry *et al.,* 2008). Important is to note that natural variability in pH should be taken into account when effects of ocean acidification are considered. In certain areas, natural variability may fluctuate in ranges much larger than the rate at which anthropogenic CO_2 is decreasing pH in the ocean. Also natural fluctuation in pH may play a large role in the development of resilience in marine populations. For instance, a comparison between two indigenous mussel species (*Aulacomya ater* and *Choromytilus meridionalis*), and two invasive species (*Mytilus galloprovincialis* and *Semimytilus algosus*), found on the West Coast of South Africa, under low pH conditions (pH 7.5) and mean conditions (8.0), showed that native species are better adapted to low pH treatments with little changes in shell dissolution and growth rates (Emanuel, 2013).

Another example, is the coastal waters near Hermanus where diurnal fluctuations of pH range from 7.7 to 8.2 (Lucas and Lester, Sancor newsletter, 2015), due to recent proliferation of kelp beds. These have implications for abalone (*Haliotus midae*) farming, where early indications show juvenile abalone (3 month old) show effects of shell dissolution within 48 hrs of exposure to pH = 7.5 (Lucas, 2014, pers. comm.).

Effects on fish include slow development, delayed metamorphosis of larvae and physical and chemical changes in bone structure. Delayed metamorphosis can result in delayed settlement or even recruitment failure when the recruitment window is relatively short. Malformation of otoliths or fish ear bones has been shown to cause increased cortisol levels, stress levels and compromised immune systems as well as a switch from sound to visual stimuli in the Sciaenidae (drums) and other soniferous (sound producing) fish (Browning *et al.,* 2012).

In the Benguella region, pH in shallow waters can decrease to levels as low as 6.6 for several days, during upwelling events along the West Coast, hypoxic conditions associated with organic matter decay (Knapp *et al.,* 2015 and references therein). The authors have shown that long term exposure of West Coast rock lobster (*Jasus lalandi*) to low pH condition (pH = 7.3, for 28 weeks) trigger a physiological response which allows organisms to fully compensate for extracellular acidosis by adjusting cellular bicarbonate concentrations (Knapp *et al.,* 2015). This highlights the resilience of local species to the highly dynamic nature of the upwelling region. The abovementioned studies, although promising, are still in early stages of understanding ecosystem vulnerability to the long term predicted climate change scenarios and further investigation remains essential.

The saturation states of biominerals aragonite and calcite, directly affects the ability of $CaCO_3$ secreting organisms, such as coccolithophores, pteropods, mollusks and corals to produce their exoscelletons (Doney *et al.,* 2009). The saturation state of calcium carbonate mineral phases is defined by $\Omega = [Ca^{2+}][CO_3^{2-}]/K'_{sp}$, where K_{sp} is the apparent solubility product of calcium carbonate, which varies with temperature, salinity and pressure (Mucci, 1983). A value of $\Omega = 1$ indicates saturation, and $\Omega > 1$ are favourable for calcification, whereas dissolution are favored when $\Omega < 1$, and provides a useful indicator of a chemical threshold, albeit not a strict criterion, biomineralization or dissolution. In fact, it has been shown that some calcifying organisms require ambient seawater conditions well above saturation while others can generate or maintain calcified structures in undersaturated conditions at a bioenergetics cost (Feely *et al.,* 2009).

The majority of surface water are supersaturated with respect to calcium carbonate (e.g., $\Omega = 2 – 4$, and 4 – 6 for aragonite and calcite respectively). Oceanic water below the thermocline (deeper than 1000m) is saturated in $CaCO_3$ due remineralization and the effect of pressure effect on its solubility. Stratification of the water column results in a ‘saturation horizon’ at a certain depth, which is regionally dynamic and influenced by general circulation. The Sub-Tropical Atlantic Ocean (15^{o}S – 50^{o}S), becomes undersaturated with respect to aragonite between 400m and 1000m, while the calcite saturation horizon lies between 3000 – 3500m (Chung, 2004). In the Indian and Pacific oceans, shallower aragonite and calcite saturation horizons are observed (100 – 1000m) due to older water which has accumulated more CO_2, from respiration and transport pathways of deep ocean circulation.

Globally the aragonite saturation state from preindustrial to present has decreased below the envelope of natural variability (Hauri *et al.,* 2013). The aragonite saturation horizons in all ocean basins have shallower by varying amounts between 50 – 200m over the previous 250 years due to anthropogenic addition of CO_2 to the ocean (Feely *et al.,* 2004; Orr *et al.,* 2005). Over the next 20 to 30 years the aragonite saturation state will decrease below the present envelope of variability, causing near-permanent under-saturation in subsurface waters (Hauri *et al.,* 2013).

3.6.3.3.2 Increase in sea storminess

The Fourth Assessment Report of the IPCC predicts an increasing frequency and intensity of extreme weather events in the 21st Century (IPCC 2007). The frequency and magnitude of severe weather events such as tropical cyclones, hailstorms, droughts and floods appears to be on the increase globally (IPCC 2007). In South Africa, increases in either intensity or frequency, or changes in seasonal storm intensity have been reported at a local scale albeit on a very short time-scale (Guastella and Rossouw 2012, Harris 2010).

Preliminary findings indicate that there may be long-term trends in regional metocean climates, while sea level rise alone will greatly increase the impacts associated with extreme sea-storm events (Theron 2007). The regional variation in the global wave climate was demonstrated by Mori *et al.,* (2010), who, in simulating future trends, predicted that mean wave height might generally increase in the regions of the mid-latitudes (both hemispheres) and the Antarctic ocean, while decreasing towards the equator. Wang *et al.,* (2004), Komar and Allan (2008) and Ruggierio *et al.,* (2010) provide further evidence of a general wave height increase and increasing storm intensities in the Northern hemisphere. Such changes in the regional metocean climates are expected to have significant impacts on local coastal areas. It is therefore important to also investigate possible future climatic changes off the southern African coastline as well as the expected associated impacts. As can be anticipated, a more severe wave climate (or related oceanic wind climate) will result in more storm erosion, potentially more coastal sediment transport, and greater coastal impacts.

Preliminary analyses (Rossouw and Theron 2009) found that the annual mean significant wave height (Hm0) for the wave data collected off Richards Bay and Cape Town indicate no real progressive increase. This may appear to contradict the findings of the IPCC, as presented in PIANC (2008), but the South African results may reflect a regional aspect of the impact of climate change. Although the averages appear to remain constant, there seems to be some change in the individual storms. For example, considering the peaks of individual storms off Cape Town during the more extreme winter period (June to August), an increase of about 0.5 m over 14 years is observed. This result may be indicative of a significant increase in the "storminess" over the next few decades. It is also worth noting that the opposite occurs during summer: there has been a general decrease over the last 14 years with regard to individual storms off Cape Town. However, it must be noted that the South African wave record is too short to make any firm conclusions at present. To some extent it could be said that the preliminary "trend" indicated by the South African wave data is supported by the model predictions of Mori *et al.,* (2010), which appear to show an increase in wave height for the South African coast of roughly 6% for extreme events (Theron *et al.,* 2010).

All coastal fisheries are susceptible to increased storminess, small-scale artisanal ones even more so. A general increase in wind strength, and in the frequency and strength of storms and extreme weather events will make it more dangerous and difficult to catch fish, and will also reduce the number of days on which the boats are able to go to sea. Fishers who operate from the shore or from small boats launched from and landed at relatively unprotected harbours, will be the most seriously affected. There is evidence of this having already happened with analysis of South Africa's National Marine Linefish System (NMLS) data suggesting a significant decrease in the number of suitable sea-days corresponding with an increase in storminess over the past two decades (Augustyn *et al.,* 2017).

Wave climate and conditions are determined by ocean winds (velocity, duration, fetch, occurrence, decay, etc.). Predicted values for potential changes in oceanic wind regimes off southern African are lacking. In view of this shortcoming and to enable an assessment of the potential impacts of stronger winds, a relatively modest increase of 10% could be assumed. Thus, a modest 10% increase in wind speed, means a 12% increase in wind stress, a 26% increase in wave height, and as much as an 80% increase in wave power (Theron 2007). This means that a modest 10% increase in wind speed could also result in a potentially significant increase in coastal sediment transport rates and consequently impact on estuarine mouth regimes.

3.6.3.4 Wind System

The south-easterly wind blowing parallel to the north/south- aligned west coast of southern Africa induces large scale coastal upwelling – the offshore displacement of surface waters and their replacement at the coast by cold, nutrient-rich waters from depth. Referred to as the Benguela Upwelling System, this is one of the largest eastern boundary upwelling systems in the world, and the injection of nutrients makes it a region of particularly high primary, secondary and fish production

Apart from seasonal synoptic effects, several large-scale modes of variability subject to climate change influence the functioning of the Benguela Upwelling System south of the Lüderitz region in Namibia, known as the southern Benguela. The most important are *El Niño* Southern Oscillations (ENSOs) in the south-eastern Pacific, the Antarctic Oscillation (AAO) otherwise called the Southern Annular Mode (SAM), and large-scale modulations of the high-pressure subtropical anticyclone. Variations in ENSOs and in the SAM are the most important source of large-scale climate variability in the tropics and middle and high latitudes in the Southern Hemisphere. It has been shown that during austral summer, *El Niño* events lead to a weakening of upwelling-favourable southeasterly winds and consequently warmer than average SSTs in the southern Benguela. While there has been no obvious trend in the frequency or intensity of ENSOs in recent decades (although they are predicted to intensify), there have been decadal-scale changes in the SAM which have resulted in a southward shift in synoptic wind systems to the south of the continent. This has in turn caused an increase in upwelling-favourable south-easterly winds, evident in a general reduction in SST in the Cape Peninsula upwelling region in late summer over the past few decades. The increase in upwelling is confirmed by satellite-derived wind data which show that since the early 1990s there has been an increase in both the intensity and variability of upwelling along the West and South Coasts, particularly between Cape Columbine and Cape Agulhas. The cooling within this upwelling zone runs counter to the broader scale warming which has been observed in the region, and which is expected, following global trends, to increase (Reference for this section: Augustyn *et al*., 2017).

3.6.3.5 Adaptation priorities

Adaptation to climate change implies a range of measures by which to essentially cope with and even try to overcome the challenges of, and vulnerabilities to, climate change impacts. By definition adaptation includes initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected *climate change* effects. Various types of adaptation exist, e.g. *anticipatory* and *reactive, private* and *public*, and *autonomous* and *planned* (IPCC, 2007). When considering marine living resources, generic differences in the adaptive capacity of the various sectors within the South African marine fishing industry — the large-scale industrial, small-boat commercial, small-scale, recreational and marine aquaculture sectors— are considered in the latest report by DAFF (DAFF, 2016). Of these, the large-scale industrial and recreational fishers are seen as the most adaptable and the small-scale fishers the least adaptable. In the report, possible adaptation measures for the fisheries rated as being most vulnerable to climate change are identified. For **linefish**, the measures include targeting other species, improving catching efficiency, putting catches to better use, moving to larger vessels and introducing specific management measures to alleviate fishing pressure on species most threatened by climate change. The measures suggested for the **small pelagic** fishery include better use of present resources, developing fisheries for alternative pelagic species and mesopelagic fish, moving to alternative catching methods and larger vessels, and allowing for increased variability in abundance and availability in management strategies. The adaptation measures suggested for the **marine aquaculture** sector are somewhat longer term, since the threats facing this sector do not appear to require such urgent action. They range from protecting existing farms from increased storm activity and rising sea level to controlling the in-farm environment more effectively and switching to or developing more climate-resilient farmed species. Better and longer-range prediction of Harmful Algal Blooms (HABs) and other harmful events and trends such as ocean acidification are also proposed as an adaptation measure.

When it comes to mitigating the climate change effects associated with SLR and increased storminess there are a few generally agreed upon strategies. To protect a particular coastline, the coastal processes have to be well understood. If the incorrect protection measure is enforced addressing the wrong driver of the coastal problem experienced, the problem will only get worse. Generally two types of coastal erosion can be distinguished:

- *Episodic* erosion and
- Structural erosion.

Episodic erosion is generally associated with coastal erosion occurring during a severe storm. This type of erosion occurs over the time span of hours and in large volumes. The sediments removed from the coastline are usually not lost to the littoral system and can be returned to the coastline under calmer wave conditions (usually summer). If a particular coastline has an intact dune system the brunt of the erosion occurs on the fore dunes.

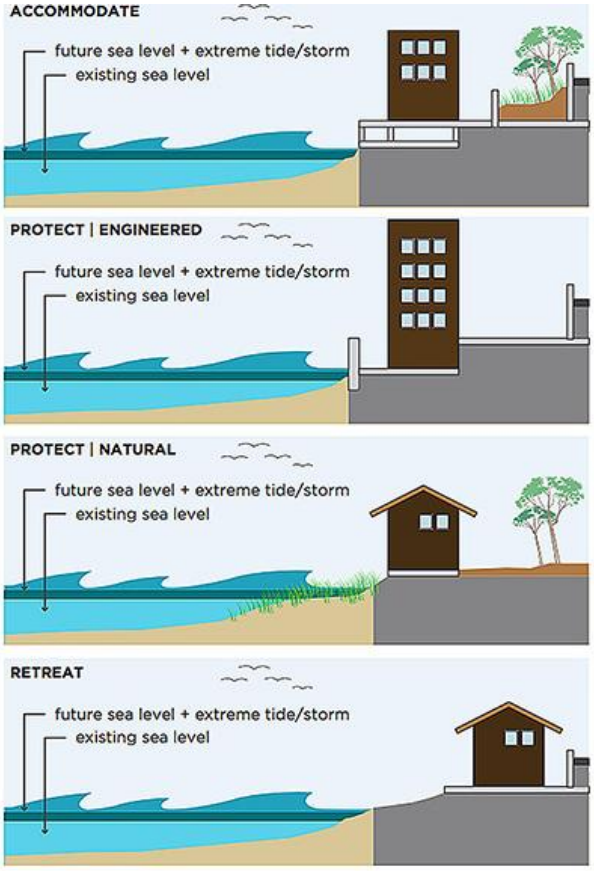


Figure 0.59: Schematic illustration of mitigation and adaptation measures in response to SLR (**Campbell & Wilson, 2016**)

Structural erosion on the other hand is the long-term, steady erosion of a particular coastline. The main driver of this erosion type is usually a longshore current that traverses up and down the coastline. If the nett amount of sediment entering a particular stretch of coastline is less than the amount exiting the section, structural erosion will occur. Utilising protection measures that does not alter or inhibit the longshore transport of sediments will thus not solve the erosion problems caused by structural erosion. In **Table 0.6** a summary is provided of various types of interventions that could be considered given various natural coastal systems. Within **Error! Reference source not found.** the protection measures should also be subdivided into soft (natural) and hard (engineered) protection. Generally soft interventions are preferred above hard interventions (depending on the problem faced). A successful example of a soft protection measures can be found in the Dutch Sand engine where an entire new peninsula we created from dredged sediments. This Sand engine now provided much needed sand naturally to the surrounding beaches utilising the naturally occurring longshore currents. Due to the fact that only on big intervention was made and that frequent maintenance is not required, local wildlife is now also returning to this stretch of coastline close to Den Hague in the Netherlands.

Table 0.6: The impact of rising sea levels on coastal areas and and societal adaptive measures. The measures are classified as: [P] - Protective, [A] - Adaptive, `and [R] - Retreat measures. Adapted from (**Bollmann, 2010**).

Effects of sea-level rise on natural coastal systems		**Possible protective/adaptive measures**	**Relative costs**
1. Flooding of low-lying areas and resultant damage	a) Storm tides b) Backwater in estuaries	1. Dykes and flood barriers [P] 2. Artificial dwelling mounds, flood-proof building (standards) [A] 3. Identification of risk zones [A/R] 4. Adapted land-use and landscape planning [A/R]	1. Very high (construction, maintenance) 2. Medium to high 3. Very low (one - off) 4. Medium (recurrent)
2. Loss of or changes to coastal wetlands		5. Adapted land development planning [A/R] 6. Dyke relocation [A/R] 7. Foreshore reclamation [P/A] 8. Beach nourishment, sediment protection [P]	5. Low to medium (ongoing) 6. Very high (one - off) 7. High (recurrent) 8. Medium/low (ongoing)
3. Direct and indirect morphological changes, particularly erosion of beaches and bluffs		9. Construction of groynes, bank protection, sea walls [P] 10. Beach nourishment, dune protection [P] 11. Underwater reefs, breakwaters [P] 12. Development - free zones [R]	9. Medium to high (construction) 10. Medium/low (ongoing) 11. Medium to high (construction) 12. Low to high (one - off)
4. Intrusion of saltwater	a) into surface water b) into ground water	13. Dams and tide gates to prevent influx of saltwater [P] 14. Adapted / reduced withdrawal of water [A/R] 15. Pumping in of freshwater [P] 16. Adapted withdrawal of water [A/R]	13. High (construction, maintenance) 14. Low (ongoing) 15. Medium (recurrent) 16. Low (permanent)

Effects of sea-level rise on natural coastal systems	Possible protective/adaptive measures	Relative costs
5. Higher (ground)water levels and limited soil drainage	17. Soil/land drainage improvement [P] 18. Construction of pumping stations [P] 19. Altered land use [A] 20. Designation of flood areas/ high risk areas [A/R]	17. High (ongoing) 18. Very high (construction, maintenance) 19. Low (permanent) 20. Very low (recurrent)

3.6.4 Estuarine Environments

3.6.4.1 Introduction

Estuaries are transition zones linking land, sea and freshwater ecosystem processes and functions (Gillanders *et al.,* 2011). Their processes and patterns are temporally and spatially complex driven by the interaction between saline and freshwater at a range of scales. While relatively small in area, they are highly productive systems and are an integral part of the coastal system, supporting a host of ecosystem services to society.

Southern African estuaries are highly variable in size, shape, degree of marine/riverine influence and catchment characteristics (Reddering 1988). The estuaries of the region also represent highly variable habitats in which conditions such as mouth state, water depth, salinity, temperature, turbidity and dissolved oxygen concentrations can fluctuate rapidly, both temporally and spatially (Day 1981). South African estuaries' role as fish and prawn nursery grounds and important feeding areas for migrant birds is of particular importance as they contain much of the only sheltered habitat along the southern Africa coastline, due to its highly exposed linear nature (Beckley, 1984).

On a global-scale, South Africa's nearly 300 estuaries are relatively small (70%< 50 ha), with limited tidal flows (Cooper 2001, Van Niekerk *et al.,* 2013). Owing to strong wave action and high sediment availability, more than 90% of the estuaries have restricted inlets, with more than 75% closing for varying periods of time when a sandbar forms across the mouth (Cooper 2001). Estuary response to climate change processes will vary according to estuarine type. For example, large and small estuaries respond differently to flow reduction, with large estuaries (associated with high tidal flows) being less sensitive in comparison with small systems, which are highly dependent on river inflow to maintain their natural mouth state regime. This section aims to assess expected ecosystem response in South African estuaries to the key climate change impacts.

3.6.4.1.1 Approach

This section reviews the potential impacts of climate change on South African estuaries. We investigate oceanic and climatic processes that may affect South African estuaries, before discussing the likely effects Climate Change will have on key estuarine processes and associated biotic responses. Conclusions are supported by observed data or derived from known responses to related anthropogenic pressures, e.g. flow modification as a result of catchment development. Some of the potential differences associated with the various coastal regions and types of estuaries are highlighted, including an acknowledgement that climate change is not the only variable likely to have an impact on these systems.

South Africa's coast spans three biogeographical regions (or climatic zones), namely the cool temperate west coast, warm temperate south and east coast and subtropical east coast (Emanuel *et al.,* 1992, Turpie *et al.,* 2000, Harrison 2002,. Transition zones between the biogeographical regions are shaped by oceanographic and climatic features such as currents, bathymetry and, terrestrial runoff respectively. Therefore, these transitional zones vary according to El niño - La niña events and related wet-dry cycles (Dieppois *et al.,* 2015). Rainfall patterns across the bioregions are characterised by high variability (Schulze and Lynch 2007, Schulze and Maharaj 2007, Lynch 2004, Davies and Day, 1998). The annual runoff of South African rivers is highly variable and unpredictable in comparison with the larger European and North American rivers, fluctuating between floods and extremely low to zero river inflow (Poff and Ward 1989; Dettinger and Diaz 2000; Jones *et al.,* 2014).

For this assessment South Africa's estuaries, therefore, were subdivided into six regions (Table 0.7) along the coast that were relatively homogenous with respect to rainfall and catchment characteristics, coastal topography, beach slope, the dominant mouth position when closed, and estuary size. Table 0.7 also provides a brief summary of the location and general characteristics relating to estuaries.

Table 0.7: Regions along the South African coast used in climate change response assessment for estuaries, as well as key physical features of each region

COASTAL REGION	KWAZULU NATAL	WILD COAST	EASTERN CAPE	SOUTHERN CAPE	WESTERN CAPE	WEST COAST
Biogeographical zones	Sub-Tropical	Transition between sub-tropical and warm temperate	Warm temperate	Warm temperate	Transition between Cool and warm temperate	Cool temperate
Estuaries in region	Kosi to Zolwane (74 estuaries)	Great Kei – Umtamvuna (85 estuaries)	Swartkops to Cwili (58 estuaries)	Papenkuils to Duiwenhoks (37 estuaries)	Breede to Buffels (Wes) (20 estuaries)	Krom - Orange (17 estuaries)
Rainfall seasonality	Mid to late summer, Early summer in larger catchments	Late summer rainfall	Late summer to All year	All year, peaks in spring and autumn. Very late summer in larger catchments	Predominantly winter	Winter (Orange mid to late summer)
Mean annual precipitation (mm)	600 – 1200	400 - 800	200 – 800	200 - 800	200 – 600 (mountain catchments >1000)	200 - <100
Dominant catchment size	Numerous small catchments	Numerous small catchments	Small catchments interspersed with large catchments	Small to large catchments	Small to large catchment	Three very large catchments rest small catchments
Coastal topography	Steeply incised, Coastal plain in northern parts	Steeply incised	Vary from steeply incised to coastal plain	Vary from steeply incised to coastal plain	Vary from steeply incised to coastal plain	Coastal plain
Dominant closed mouth position	Mostly perched	Mostly not perched	Mostly not perched	Mostly not perched	Mostly not perched	Mostly perched
Estuary sizes (%):						
Small: < 100 ha	87.8%	89.4%	81.0%	67.6%	70.0%	64.7%
Medium : 100-500 ha	4.1%	10.6%	17.2%	21.6%	15.0%	17.6%
Large: >500 ha	8.1%	-	1.7%	10.8%	15.0%	17.6%

For this assessment South Africa's estuaries were subdivided into six coastal regions that were relative homogenous with respects to rainfall and catchment characteristics, coastal topography, beach slope, the dominant mouth position when closed, and estuary size. These regions were assessed to evaluate how Climate Change related-stressors potentially could affect ecosystem processes and condition based on their sensitivity to each stressor. A change rating (low=largely similar, medium= some change from present, high = significant change is expected) was then applied to indicate were the most change is projected to occur in the near- and mid-future. The following effects of climate change relevant to estuarine environments were considered (Gillanders *et al.,* 2011, Day *et al.,* 2008; Day *et al.,* 2011):

- Change in oceanic circulation processes;
- Modification of terrestrial climatic and hydrologic processes;
- Ocean acidification;
- Sea Level Rise; and
- Increase in sea storminess.

The alarming implications the extreme far-future scenarios were not considered here as much work is still need on how stream flow reduction will be impacted on in more detail. This will be the work of future studies.

3.6.4.1.2 Progress since the 2nd National Communication

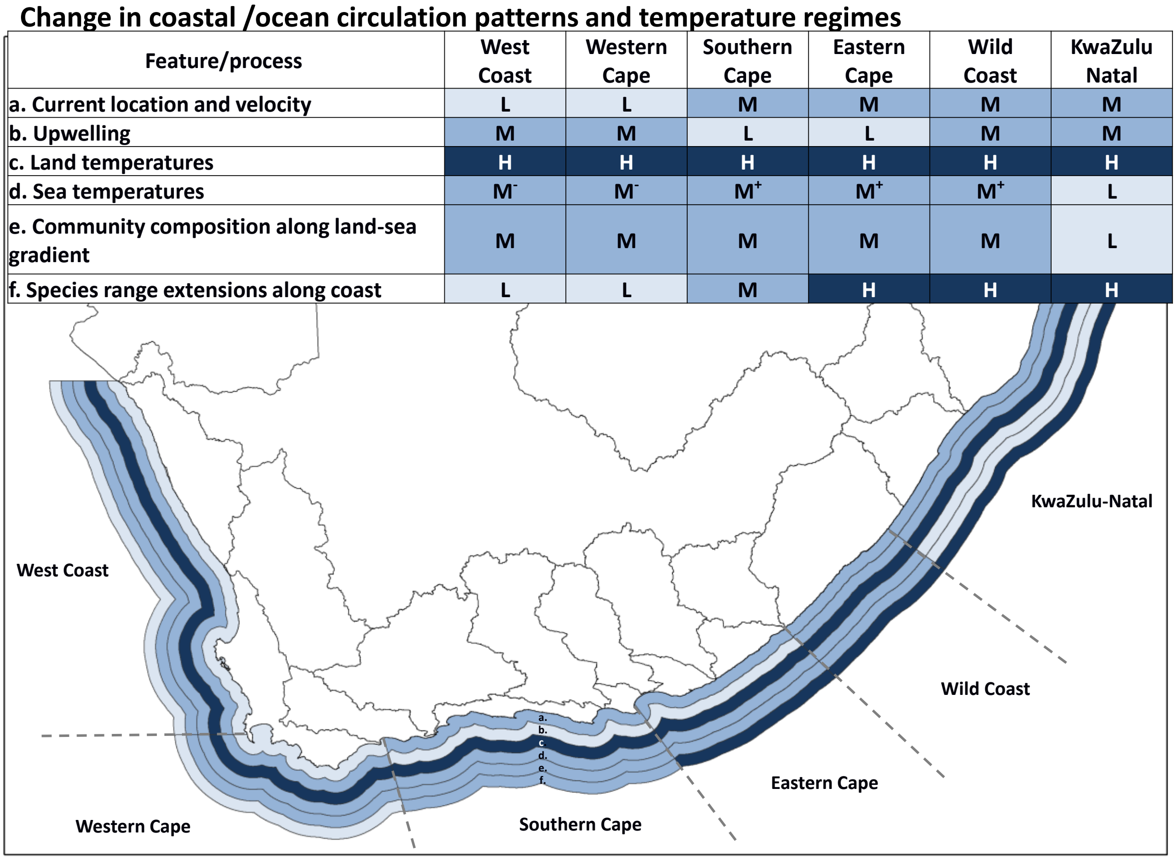
Estuaries were not assessed in detail in the 2de National Communication. Some emphasis was placed on their vulnerability in the *Long-Term Adaptation Scenarios Flagship Research Programme* (*LTAS*) *for South Africa: Climate Change Implications for Marine Fisheries* (Hermes *et al.,* 2013). This assessment draws from the National Biodiversity Assessment 2011 (Van Niekerk and Turpie 2012), the LTAS, and regional scale freshwater flow requirement studies (e.g. Mvoti to Mzimkulu Water Management Area) to predict the vulnerability of South Africa's estuaries on a regional scale.

3.6.4.2 Vulnerability to climate change

3.6.4.2.1 Change in coastal and ocean circulation and temperature regimes

The projected change in maximum atmospheric temperatures over southern Africa shows that for all seasons, the largest temperature rise is projected to occur over the western interior, with the strongest warming projected to occur during winter (Figure 0.60). However, the coastal areas are projected to warm at a slower rate than areas over the interior, due to the moderating effect of the ocean. By the end of the 21st century, South Africa is projected to have warmed by about 3 to 4° C compared to the early 1960s. Projected temperature increases in the average global surface atmosphere range from a low scenario of 1ºC to 3ºC, with a potential upper range of 6ºC by 2100.

Rouault *et al.,* (2009) showed that the sub-tropical eastern coast of South Africa is warming (max. 0.5 ºC per decade). Some localised areas, such as the South African west and south coasts, are cooling seasonally (max. - 0.5° C per decade) (Rouault *et al.,* 2010, Lima and Wethey 2012), with cooling in the cool-temperate regions being particularly apparent from January to May (Lima and Wethey 2012) (refer to Section 3.6.3 on Coastal Zone for more information).



Change in coastal /ocean circulation patterns and temperature regimes

Feature/process	West Coast	Western Cape	Southern Cape	Eastern Cape	Wild Coast	KwaZulu Natal
a. Current location and velocity	L	L	M	M	M	M
b. Upwelling	M	M	L	L	M	M
c. Land temperatures	H	H	H	H	H	H
d. Sea temperatures	M^-	M^-	M^+	M^+	M^+	L
e. Community composition along land-sea gradient	M	M	M	M	M	L
f. Species range extensions along coast	L	L	M	H	H	H

Figure 0.60: Regional summary of changes in ocean circulation patterns and shifts in temperature regimes and the influence on the community structure, abundance and distribution of estuarine species. Vulnerability is indicated as high/medium/low shifts from west to east with potential change a. to f. depicted by moving outward from the coast.

Shallow-water aquatic systems, such as South Africa's estuaries will exhibit greater increases in temperature than deeper coastal and marine waters (Rijnsdorp *et al.,* 2009, James *et al.,* 2013). Besides direct temperature changes, changes in the thermal gradients along latitudinal gradients and hence changes in the location of biogeographical boundaries are also likely (Potts *et al.,* 2015). Bioregions may also contract or expand under the influence of ocean processes; warmer temperatures on South Africa's east coast seeing expansion of the subtropical bioregion south-westwards compacting the warm temperate region against the cooling southern Benguela and expansion of cool-temperate waters and species to the east (Blamey *et al.,* 2015. Whitfield *et al.,* 2016). The Cunene Estuary on the northern border of Namibia is the northern limit of some temperate estuary-associated fish distributions (e.g. Cape silverside *Atherina breviceps* and white steenbras

Lithognathus lithognathus) and the southernmost limit of some equatorial species (e.g. Senegal sleeper *Eleotris senegalensis* and West African freshwater goby *Awaous lateristriga*) (van Niekerk *et al.,* 2008). This suggests that the Cunene may be the southernmost boundary of the overlap of Guinea and Benguela Current Large Marine Ecosystem fauna. According to Whitfield *et al.,* (2016) coastal warming could result in the southward shift of both the cool temperate and equatorial limits for estuary-associated species to the Orange Estuary on Namibia's southern border with South Africa. Temperature changes can also influence water circulation patterns such as stratification within an estuary (Kennedy *et al.,* 2002).

Temperature influences the biology of organisms (mortality, reproduction, growth, and behaviour). Temperature can also influence interactions among organisms for example predator prey, parasite-host relationships and competition for resources. Species are adapted to, and distributed within, specific environmental temperature ranges (Harrison and Whitfield, 2006, Maree *et al.,* 2000, Elliot 2002). Many organisms are more stressed near their species range boundaries (Sorte and Hoffman 2004). As temperature changes, the geographical distribution of species, depending on their tolerances or preferences, may contract or expand, leading to new and unpredictable species interactions (Murawski 1993, Harley *et al.,* 2006, Clark 2006, Perry *et al.,* 2005, USEPA 2009). Areas of cooling may, however, limit the ability of species to shift their distribution resulting in a decrease in the range of certain species in South Africa. Ultimately, the present species, community and assemblage composition of many South African estuaries may change (James *et al.,* 2013).

Estuaries are characterized by fluctuations in salinity, temperature, dissolved oxygen and pH with only a few species adapted to cope with the fluctuating environment. Of the 1800 coastal fish species found in South Africa, fewer than 100 species are regularly recorded in estuaries (Whitfield 1998). Many species of fish in estuaries are tolerant of extreme temperatures. Despite the tolerance of estuarine-associated species to extreme temperatures in estuaries, changes in the distribution and abundance of marine species in estuaries is likely to be linked to coastal temperatures as a result of spawning and larval development taking place in the marine environment within the appropriate temperate regime for each species. For fish species, thermal windows are narrow in the early life stages (eggs and larvae) and then widen in juveniles and young adults (Pörtner and Peck 2010).

In recent years a number of estuarine-associated subtropical species such as spotted grunter *Pomadasys commersonnii*, checked goby *Redigobius dewaali* and blacktip kingfish *Caranx heberi* as well as some tropical reef species such as coachman *Heniochus diphreutes*, have extended their range 200 to 1000 km south to the permanently open Breede Estuary (Lamberth *et al.,* 2011 COP). James *et al.,* (2008b) and Mbande *et al.,* (2005) highlight the increased occurrence of tropical fish species in estuaries along the East Coast of South Africa (e.g. East Kleinemonde and Mngazana). Of the six tropical species recorded in the East Kleinemonde Estuary, longarm mullet *Valamugil cunnesius* and robust mullet *Valamugil robustus*, have been recorded consistently in the estuary every year after 2002, and are found in both summer and winter indicating that water temperatures are continually within the tolerance range of these species (James *et al.,* 2008a). Although changes in the numbers of tropical fish species have been recorded in this estuary the numbers of temperate species have not declined, resulting in an increase in species richness. In time, there is the possibility of a decline in the number of temperate species in temperate systems (James *et al.,* 2013). In the Mngazana Estuary the proportion of tropical species recorded in winter increased from 1975 to 2002. Higher average temperatures would favour tropical species during winter, while limiting the northward penetration of certain temperate species (Mbande *et al.,* 2005). Range expansion of spotted grunter *Pomadasy commersonnii* into the warm-cool temperate bioregion transition zone has culminated in stock separation, loss of return migration and the establishment of a spawning population in its new range (Lamberth *et al.,* 2013). Ironically, the parent population is overexploited and has collapsed (Spawner Biomass < 25% of unfished levels) whereas the new population is currently well above equilibrium (Lamberth *et al.,* 2013, Winker *et al.,* 2015).

There are numerous once-off records of tropical fish species recorded in other warm-temperate estuaries along the South African coast, some only recorded in summer and others persisting throughout the year (Whitfield *et al.,* 2016). Overwintering of tropical estuarine-associated marine species in temperate South African estuaries is possible, due to the similarity in water temperature ranges in estuaries throughout the country (Whitfield *et al.,* 2016). Figueira *et al.,* (2009) and Figueira & Booth (2010) examined the performance of tropical fish species as they recruited into temperate environments along the southeast coast of Australia, and concluded that for the majority of tropical fish species overwinter survival is the ultimate bottleneck for population establishment, with the ability of some tropical species to survive at temperate latitudes determined by the frequency of survivable winters.

High levels of exploitation in South African waters lead to range-contraction of the tropical bull shark *Carcharinus leucas* in the 1980s whence it all but disappeared from temperate estuaries (McCord and Lamberth 2009). The recent re-expansion of this species into cooler temperate waters can be attributed to a decade of extended drought and unavailability of St Lucia Estuary and other important pupping and nursery habitats on the subtropical coast of South Africa. This illustrates the assertion that in some cases range expansion may be driven by loss of habitat or increasing physiological stress in the animal's original range, not by suitable conditions developing elsewhere ((McCord and Lamberth 2009, Whitfield *et al.,* 2016).

Species that are unable to migrate, or compete with other species for resources, may face local or global extinction. Although higher temperatures might not result in the extinction of a species throughout its range, the species may be eliminated from part of its range. Communities do not shift their distribution as a unit. Movement into newly suitable habitats depends on: 1) the number of adults available in the original habitat and their ability to bear young; 2) an adequate number of potential colonisers; 3) the ability of potential colonizers to move into new habitats; 4) the survival of an adequate number of individuals in the new habitat to ensure genetic diversity to meet challenges and to produce succeeding generations (Kennedy *et al.,* 2002). Thus the loss of species from an estuary that has become too warm may reduce species diversity in that estuary in the short term, with recovery depending on the mobility of new colonizers, their ability to tolerate higher temperatures and their tolerance of higher salinities in the marine environment. Warming is likely to result in new mixes of foundation species, predators, prey and competitors with an overall change in population, community assemblage and trophic structure (USEPA 2009, James *et al.,* 2013). For example, fishes with the most temperature-sensitive distributions include many key prey species of non-shifting predators (Perry *et al.,* 2005).

Mobile organisms, or those with mobile eggs and larvae, can quickly colonise new habitats, whilst relatively immobile or sessile ones will disperse more slowly. The degree of dispersal depends on the behavioural characteristics and duration of different life-history stages. Altered freshwater flow, high fishing pressure, and anomalous events such as extended droughts and unseasonal floods have culminated in genetic bottlenecking and a collapse in the effective population size of the estuary-dependent dusky kob *Argyrosomus japonicus* throughout its South African range (Mirimin *et al.,* 2015). Further, there's evidence that *Argyrosomus japonicus* males are hybridising with silver kob *A. inodorus* females which are at similar levels of depletion (Mirimin *et al.,* 2014; 2016). Low effective population sizes of both species has the few remaining but relatively large *A. japonicus* males outcompeting the equally few but smaller *A. inodorus* males (Mirimin *et al.,* 2014; 2016).

Changes in temperature will also affect coastal vegetation with more subtropical species moving further south most notably the invasion of salt marsh habitats by mangrove species (Steinke 1999, Adam 2002, Gilman *et al.,* 2008). Mangroves typically have a subtropical to tropical distribution and are excellent indicators of global warming, particularly in southern Africa where they occur at one of the most southerly distributions in the world (Whitfield *et al.,* 2016). Although mangroves have been introduced into estuaries as far south as East London, as temperatures increase it is thought that mangroves will naturally colonize permanently open estuaries to the south of East London and result in competition with intertidal salt marsh habitats (Whitfield *et al.,* 2016). If there is a contraction of salt marshes in the current warm temperate region due to global warming, there is little opportunity for these plants to expand southwards due to the shape of the subcontinent which has an east-west orientation in this biogeographic region (Whitfield *et al.,* 2016). The expansion and contraction of mangroves are also potentially governed by the occurrence of frost (de Lange and de Lange, 1994). If the frost region is predicted to expand this will curb the possible occurrence of mangroves further south. This said, in the absence of frost, white mangrove *Avicennia marina* in New Zealand occurs further south than 34°S (Cape Town).

There are a number of mangrove-associated invertebrates that reach their southern-most distribution on the African continent in the Eastern Cape Province (Whitfield *et al.,* 2016). For example, two species of tropical fiddler crabs *Uca annulipes* and *U. urvillei*, are found in the salt marshes in the warm temperate Kariega Estuary (Hodgson 1987). Until recently, the Kariega Estuary was regarded as the southernmost range of distribution for *Uca* in southern Africa. However, the recent discovery of *U. annulipes* in the Knysna Estuary constitutes a new southernmost limit for the genus (Peer *et al.,* 2016). Similarly, the mangrove snail *Cerithidea decollate*, which is also common in parts of the middle reaches of the Kariega Estuary (Hodgson 1987), is expected to proliferate should mangrove habitat establish in this system. This species has also been recorded in some warm temperate estuaries along the southern Cape coast, including the Knysna system where at high tide the snail climbs the rush *Juncus kraussii* (Hodgson and Dickens 2012) instead of mangrove trunks as it does in the main part of its range (Whitfield *et al.,* 2016).

Overall, the large numbers of shallow, small temporarily open/closed estuaries (TOCEs) that characterise the South African coast are likely to be very sensitive to terrestrial temperature increases predicted under far-future climate change predictions. Bigger, permanently open estuaries on the other hand, will be more likely to respond to shifts in coastal temperature due to changes in ocean currents and upwelling conditions, whilst the influence of terrestrial heating will be mostly confined to the upper reaches where river processes dominate. This means that South African estuaries will be subjected to changes in the coastal temperature gradient and along a land-sea gradient (Wooldridge and Dyzel 2012).

Biogeochemical fluxes (***DO and nutrients***)

Estuaries are influenced by coastal biogeochemical processes to varying degrees. With marine processes having a much greater effect on permanently open, marine dominated estuaries, compared to TOCEs or fluvially-dominated systems. In terms of biogeochemical shifts linked to ocean circulation, it is expected that estuaries adjacent to upwelling systems will be most affected. Tidally-driven advection can increase nutrient availability in estuaries as a result of more intense upwelling. In South Africa this phenomenon will mostly affect the permanently open estuaries along the west coast and Western Cape regions (i.e. systems adjacent to the Benguela system) such as the Great Berg and Olifants estuaries. In the case of the Great Berg Estuary (situated within St Helena Bay) more frequent upwelling induced “black tides” and advection of anoxic waters (e.g. Lamberth *et al.,* 2010) may pose additional risk.

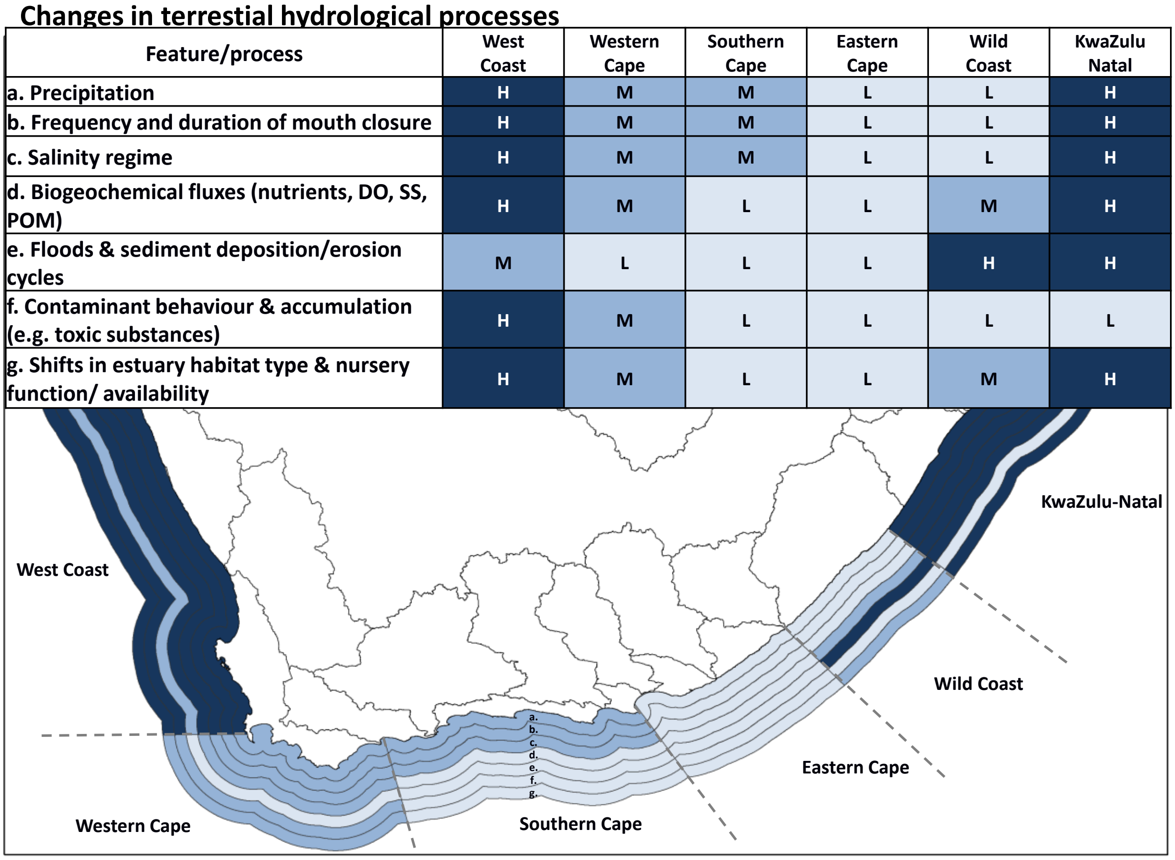
Most aquatic organisms extract oxygen from the water-body they live in. The effect of higher temperatures and less oxygen could be to constrict the available habitat for certain species. Pörtner and Knust (2007) identified the oxygen limitation of thermal tolerance as a major driver of change in warming oceans. The metabolic rate of species increases as temperatures increase and they therefore need more oxygen. But warm water holds less oxygen and so their growth is limited. Although there is variation in oxygen limits between species and even within life history stages, fishes have generally evolved to respire optimally within a narrow range of temperatures (Pörtner and Peck 2010, Potts *et al.,* 2015). For migratory species, particularly those at boundary of their distribution, they are likely to respond to oxygen limitation by changing their distribution (Potts *et al.,* 2015). Estuarine-associated species, may change their distribution while in the coastal environment and will either be resilient to oxygen limitation (e.g. *Pomadasys commersonnii*) or may move rapidly to avoid unfavorable temperatures, if they normally follow a thermal window in the estuary (e.g. *Argyrosomus japonicus*). (Potts *et al.,* 2015). Potts *et al.,* (2015) suggest that catadromous species using estuaries will be affected by the influence of oxygen limitation through all phases of their life history, with spawning adults being the most greatly affected. Warming temperatures in the coastal environment may alter their migratory patterns as individuals seek optimal temperatures to maintain their significant respiratory requirements during the migration (Potts *et al.,* 2015).

3.6.4.2.2 Modification terrestrial climatic and hydrologic processes

Climate change in southern Africa will alter precipitation patterns which will affect the quality, rate, magnitude and timing of freshwater runoff to estuaries and will exacerbate existing human modifications of river inflows (refer to WP1, WP2, Alber 2002; USEPA 2009). Along the subtropical and warm temperate biogeographical region the combination of generally wetter conditions and heavy precipitation events would result in more runoff being generated. The decrease in rainfall in the cool temperate bioregion, with related possibility of a slight increase in inter-annual variability, would result in a decrease in flows and an increase in flow variability, as changes in precipitation are amplified in the hydrological cycle (Hewitson & Crane 2006; Engelbrecht *et al.,* 2009; 2011; Lumsden *et al.,* 2009). The exception to this is the Orange River which drains more than half of the country and with most of the catchment falling in the summer rainfall area. The frequency and magnitude of large flood events are expected to increase in this system as are the intensity and duration of drought or zero-flow periods. The impact of these changes on marine and estuarine habitats and biota are likely to be severe as this catchment provides more than 75 % of the flow into the sea on the west coast.

Freshwater inflow patterns

Estuarine functioning is strongly influenced by the magnitude and timing of freshwater runoff (Meynecke *et al.,* 2006). Changes in runoff ultimately drive changes in: the frequency and duration of mouth closure; the extent of seawater intrusion; decrease/increase in biogeochemical fluxes; and the sediment and organic deposition/erosion cycles, and the behaviour of contaminants (Figure 0.61). It will also affect related human adaptation strategies to reduce risk, e.g. increase impoundment and land use change, which will increase the rate of change in primary inputs (flow, sediment and nutrients) to estuaries and the coast.



Changes in terrestial hydrological processes

Feature/process	West Coast	Western Cape	Southern Cape	Eastern Cape	Wild Coast	KwaZulu Natal
a. Precipitation	H	M	M	L	L	H
b. Frequency and duration of mouth closure	H	M	M	L	L	H
c. Salinity regime	H	M	M	L	L	H
d. Biogeochemical fluxes (nutrients, DO, SS, POM)	H	M	L	L	M	H
e. Floods & sediment deposition/erosion cycles	M	L	L	L	H	H
f. Contaminant behaviour & accumulation (e.g. toxic substances)	H	M	L	L	L	L
g. Shifts in estuary habitat type & nursery function/ availability	H	M	L	L	M	H

Figure 0.61: Regional summary of the consequences of changes in precipitation on key estuarine processes – mouth state, salinity regime, nutrient fluxes, floods and sediment depositional cycles, contaminant behaviour, habitat type and nursery function. Vulnerability is indicated as high/medium/low shifts from west to east with potential change a. to g. depicted by moving outward from the coast.

In addition to long-term climate change processes, South African estuaries are also subjected to global change vectors such as freshwater abstraction, agricultural return flow and discharges. These local pressures can either amplify or moderate the impact of climate change. For example, along the West Coast the projected long-term reduction in runoff will amplify the impact of present high levels of abstraction (e.g. Olifants or Great Berg).

The majority of South African estuaries are under flow reduction pressure, with less than 8% estimated to receive higher than natural runoff. About 3% of the estuaries are under severe flow reduction pressure, i.e. less than 50% of natural flow remaining. An additional 11 % of estuaries in South Africa are under a moderate degree of flow reduction pressure with between 50 to 75% of natural flow remaining. While 3% of systems received between 150 to 250 % of the natural MAR as a result of catchment diversions or waste water discharges. **Error! Reference source not found.** indicates estuaries that are under severe flow modification in red.

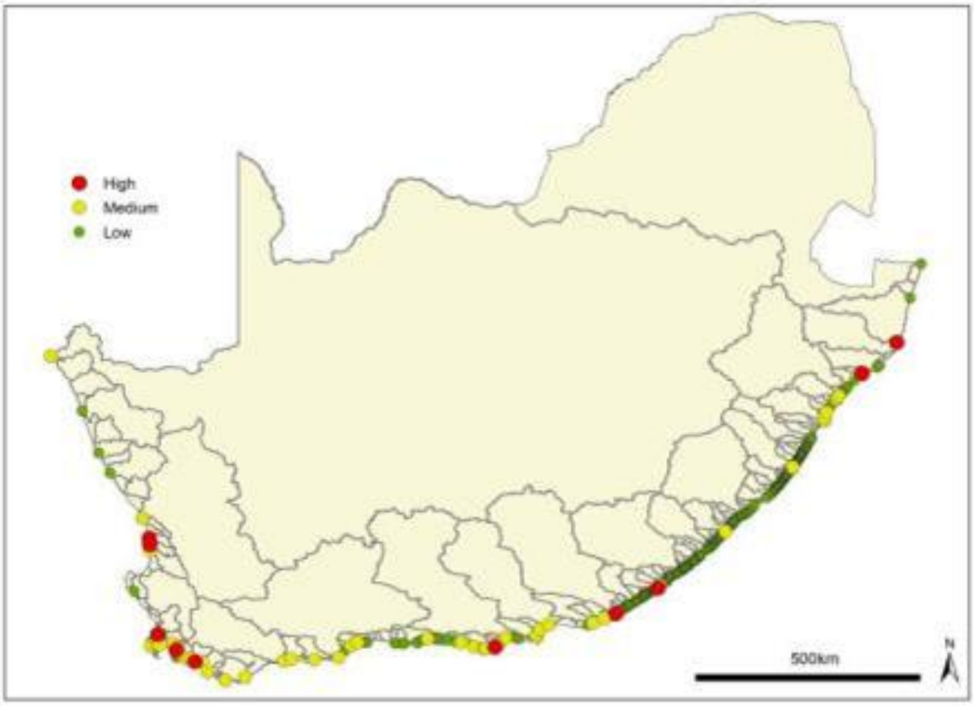


Figure 0.62: Degree of pressure on freshwater flow to the estuaries of South Africa

In principle, all estuaries are sensitive to changes in river inflow. This is especially true of the relatively small South African estuaries which depend on river inflow to offset high wave energy along a relatively straight coast (Cooper 2001, Van Niekerk and Turpie, 2012).

River flow into South African estuaries plays a major role in attracting the postlarvae of estuary-associated marine fish species into these systems (James *et al.,* 2008c) and any reduction in flow associated with climate change would be expected to have concomitant impacts on fish cohort strengths (Whitfield *et al.,* 2016).

Frequency and duration of mouth closure

TOCEs become isolated from the sea by the formation of a sand berm across the mouth during periods of low or no river inflow. Such estuaries stay closed until their basins fill up and their berms are breached by increased river flow (Van Niekerk *et al.,* 2014). A major consequence of stream flow modification (reduction or increase in flow) is, therefore, a change in the frequency and duration of estuary mouth closure in TOCEs (Whitfield *et al.,* 2008). While TOCEs are the most likely to show sensitivity to flow modification, in extreme cases fresh water reduction can cause permanent mouth closure or significant flow increase prevent mouth closure from occurring. Permanently or predominantly open estuaries may also experience closure and switch to being TOCE systems (Van Niekerk *et al.,* 2014).

The consequences of these physical changes for the biota can be severe. For example the mudprawn *Upogebia africana* has an obligatory marine phase of development during the larval stages. Estuary mouth closure, particularly for extended periods (e.g. >1 year), disrupts the life cycle and can result in local extinction of the mudprawn (Wooldridge and Loubser 1996). Some demersal zooplankton species exhibit tidally-phased migratory behaviour (Schlacher and Wooldridge 1995). Mouth closure removes the tidal signal and thereby disrupts the life cycles of these organisms. Extended mouth closure coupled with dilution or evaporation can lead to hypo or hypersalinity respectively with impacts on biota linked to their salinity preferences or tolerances. Reproduction may be interrupted in species that breed in estuaries e.g. *Callichirus kraussi* or mass mortalities may result in species unable to escape intolerable conditions in a system (Whitfield *et al.,* 2006).

Prolonged closed phases in TOCEs result in a low recruitment potential for juvenile marine fish and effectively prevent the emigration of adults back to sea (Vorwerk *et al.,* 2003). During extended closed phases, fish populations may also decrease considerably due to predation (by other fishes, birds and mammals). For example, predation by piscivorous birds (cormorants, darter and heron) reduced the size of the Cape stumpnose *Rhabdosargus holubi* population in the West Kleinemonde Estuary by 80% (1971) and 20% (1972) respectively over a six to seven month period (Blaber 1973). In severe cases the number of fish will be so greatly reduced by predation that, should the mouth eventually open, their numbers will be so low as to make an insignificant addition to the adult population in the open sea. Alternatively the fishes may simply die in the estuary without ever having had the opportunity to breed. In the East Kleinemonde Estuary, the timing of mouth opening, rather than duration and frequency, had a significant effect on fish species composition (James *et al.,* 2008b) as well as the abundance of individual marine species (James *et al.,* 2008b) and consequently changes in the frequency of mouth closure may have a profound effect on the fish communities of this and other similar types of estuaries (James *et al.,* 2013).

In the case of birds, mouth closure will lead to a loss of tidal action which, in turn, will adversely affect the quantity and availability of intertidal benthic organisms to waders that forage mainly on intertidal mudflats (Whitfield *et al.,* 2008). Many of these waders are Palaearctic migrants; therefore mouth closure can have an international impact on the populations of such birds. Other effects of reduced stream flow include the loss of shallow water habitats, favoured by herons, flamingos and other wading birds, and the loss of islands, which provide roosts and breeding sites safe from terrestrial predators.

If climate change results in the closure of certain permanently open estuaries due to reduced catchment run-off then eelgrass, which provides important nursery habitat for fish and invertebrates in estuaries, could disappear from these systems (Whitfield *et al.,* 2016).

Overall, increased mouth closure results in loss of connectivity with the marine environment and adjacent estuaries and increased population isolation. This in turn increases the probability of speciation under extreme climate or global change scenarios.

Changes in the extent of seawater intrusion

Reduction of fluvial flow into estuaries may have a range of effects on the salinity regime. The degree to which seawater will enter an estuary is dependent on river inflow and the bathymetry of the system, i.e. seawater penetration is often constrained by river inflow in the shallow, constricted upper reaches of SA systems, but penetration and mixing with relative ease into the deeper middle reaches (while the lower reaches are generally dominated by tidal flows). Often it is thus the middle reaches of an estuary that shows the most sensitivity to changes in flow (river and tidal) as they can shift from a more brackish character to a more fresh (increase flow) or marine (increase sea level or decrease flow) state. For example, in large systems flow reduction may initially result in a reduction in the extent of the estuarine mixed zone i.e. that section of an estuary with salinity between 20 and 10. Further reduction in stream flow can result in the complete elimination of this mixed zone so that, effectively, the system functionally becomes an arm of the sea e.g. the Kromme Estuary (Snow *et al.,* 2000; Wooldridge and Callahan 2000; Strydom and Whitfield 2000; Bate and Adams 2000). If there is no inflow at all a reverse salinity gradient may develop, where the salinity at the head of the estuary may exceed that of seawater e.g. the Kariega Estuary (Bate *et al.,* 2002; Whitfield & Paterson 2003).

In addition to supporting a resident estuarine fish assemblage, estuaries are important nursery, refuge and feeding areas for numerous marine fish species (Elliot *et al.,* 2007). Reduced freshwater inflow may reduce the (primary) productivity of an estuary, thereby reducing the food available to juvenile fishes (Strydom and Whitfield 2000). This will have an adverse effect on fish recruitment, growth, survival and production or recruitment into the adult population (Dolbeth *et al.,* 2010). Reduced freshwater inflow also alters the distribution and abundance of marine, estuarine and freshwater species due to changes in salinity (Gillson 2011) and loss of nursery habitats (Whitfield and Cowley 2010). Reduction in stream flow in TOCEs may lead, paradoxically, to a reduction in salinity in many small systems. Reduction in inflow can lead to mouth closure and, provided that the river inflow still exceeds evaporation and seepage losses, a progressive freshening of the estuary until such time as rising water levels lead to a breaching of the berm closing the mouth, e.g. Groot Brak. The impact is an almost complete loss of the marine species with only a few estuarine and freshwater species remaining (Whitfield 2005). Mass mortalities of marine fish species have been recorded in the Bot when salinities declined to 2-3, temperature was less than 18°C and fish were unable to escape into the sea (Bennett 1985).

Increased stream flow will also reduce, or prevent salinity penetration into an estuary. In a very small system, or if there is a significant increase in river flow, an estuary with a full salinity gradient may be turned into a fresh water dominated system, with a related reduction in water residence times and associated primary production. Extreme river flooding can result in a temporary decrease in both species diversity and abundance, due to a rapid decline in salinity, loss of nursery habitats and loss of estuarine resident species and pelagic fishes to the marine environment (Grange *et al.,* 2000).

Biogeochemical fluxes (***suspended solids, nutrients, POM, dissolved oxygen***)

The biogeochemistry in estuaries is strongly influenced by river inflow (coastal fluxes being the other vector). However, in situ hydrodynamic processes (e.g. mixing, flushing, residence time and stratification) and biogeochemical processes (e.g. flocculation, remineralisation and primary production) also strongly influence biogeochemistry (e.g. Taljaard *et al.,* 2009). Important biogeochemical fluxes in estuaries that may be affected by climate change, include suspended solids (or turbidity), particulate organic matter (POM), nutrients (e.g. dissolved inorganic N and P), and dissolved oxygen (DO).

Suspended solids (SS) in estuaries are controlled by numerous factors influenced by climate change such as river inflow, *in situ* biological processes and re-suspension of settled particles (Gillanders *et al.,* 2011). Within the South African context modification in river inflow is considered most important. River inflow usually introduces SS to estuaries during high flow events (e.g. floods), especially in highly erodible catchments. Therefore, it is postulated that estuaries situated in regions where runoff is projected to decrease (mainly the West Coast and Western Cape) will become generally less turbid, while systems where an increase in extreme events is expected will become generally more turbid (mainly KZN and, to some extent the Wild coast region). This, in turn, may affect important factors such as light attenuation (e.g. linked to primary production) and visibility (e.g. predator-prey relationships), that will decrease in systems becoming more turbid and increase in the less turbid systems. Similar responses can be expected for the transitional waters (i.e. coastal water masses just outside river/estuary catchments that display strong estuarine characteristics, e.g. nearshore areas off the Thukela, Umzimvubu and Orange estuaries).

Factors controlling particulate organic matter (POM) are more complex, as it is not only affected by input from the river, but also in situ biological processes (e.g. primary production, leave litter, die-off) and anthropogenic input (e.g. wastewater discharges and contaminated runoff). However, in terms of climate change effects, changes in river runoff are viewed to be a key factor. In this regard POM is expected to follow a similar response as described for SS that is river inflow usually introduces significant amounts of POM to estuaries/transitional waters during high flow events (e.g. floods). Therefore systems situated in regions where a decrease in floods is projected (Western Cape and West coast regions) will generally receive less catchment-derived POM, while areas where extreme events are expected to increase catchment-derived POM may become higher compared with present (mainly KZN and, to some extent the Wild coast region).

Nutrients (e.g. inorganic N and P) in estuaries are naturally derived from upwelling (see ocean circulation processes), river inflow, as well as *in situ* processes (e.g. remineralisation and primary production) (e.g. De Villiers and Thiart, 2007; Taljaard *et al.,* 2009; Gallender *et al.,* 2011). However, anthropogenic sources (e.g. wastewater and industrial discharges, contaminated stormwater and agriculture return-flow) have greatly modified the nutrient input and dynamics in these systems. In many instances aquatic ecosystems are no longer able to assimilate nutrient loads resulting, for example, in eutrophication. A recent assessment on South African estuaries (Van Niekerk *et al.,* 2013) concluded that wastewater discharges and agricultural return flow are the major anthropogenic sources impacting on water quality, primarily through nutrient enrichment. Figure 0.63 provides an indication of the extent to which these land-based anthropogenic sources have modified the nutrient dynamics in South African systems.

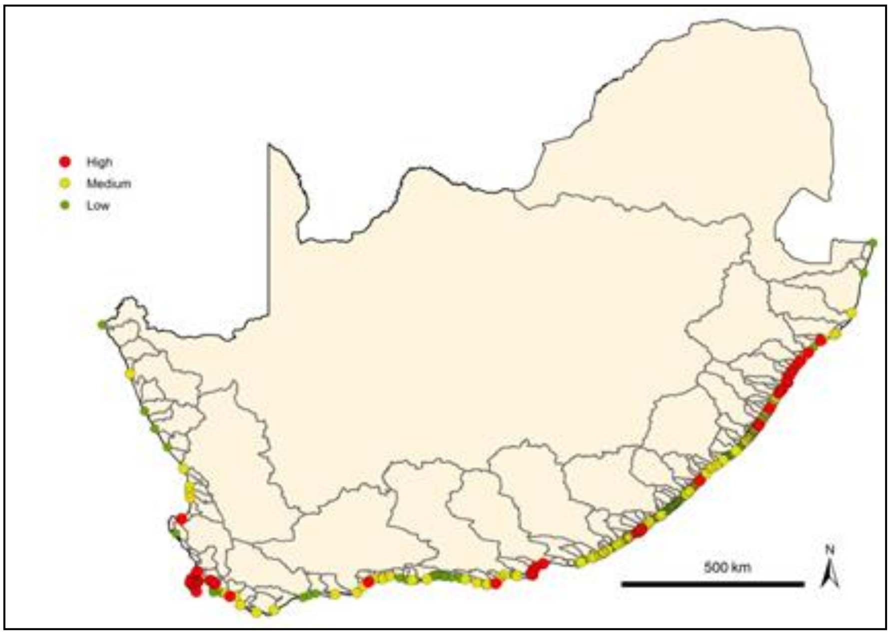


Figure 0.63: Overview of the modification in nutrient dynamics in South Africa's estuaries as a result of existing land-based anthropogenic sources (**mostly wastewater discharges and agricultural return flows**)

Of note is the clustering of highly impacted systems around the urban centres such as Cape Town, Port Elizabeth and Durban, mostly associated with wastewater discharges (and contaminated stormwater runoff). The medium levels of impacts visible in the more rural areas between the urban nodes are mostly associated with agricultural return flows (e.g. fertilizing). Therefore, it is important to understand that any influence on nutrient dynamics, driven by climate change, will be super-imposed on the existing effect of land-based anthropogenic sources.

One of the main climate-change related effects on nutrients will be changes in freshwater flow patterns (river inflow). Nutrients input primarily derived from diffuse sources in the catchment (e.g. agricultural runoff) primarily show seasonal nutrient concentration profiles coincident with river runoff, that is, concentrations are highest during high flows typical of river flows derived from major agricultural areas (De Villiers and Thiart, 2007; Howarth *et al.,* 2000). However, point sources (e.g. municipal wastewater) resulted in nutrient concentration profiles that are either not related to runoff, or that is inversely related to runoff. Thus, in estuaries where point sources are the dominant anthropogenic input (e.g. in urban nodes), high river flows may in fact decrease nutrient concentrations through dilution. Adding to these complexities is, for example, the effects on nutrient processing and leaching from agricultural areas associated with change in atmospheric temperature and rainfall (e.g. changes evapotranspiration) (Bouraoui *et al.,* 2002; Jeppesen *et al.,* 2009; Jeppesen *et al.,* 2011).

Another important consideration is residence time, as influenced by the frequency and duration of mouth closure in TOCEs. In systems where land-based anthropogenic and/or climate-change effects will increase nutrients concentrations, greater retention (residence) will allow for more effective utilisation through biological processes (e.g. primary production). Increased residence time will also favour in situ regeneration (e.g. through remineralisation) of nutrients depending on organic matter stocks to fuel such processes (Taljaard *et al.,* 2009).

Dissolved oxygen (DO) levels in estuaries are influenced by numerous factors, including temperature, salinity, nutrient/organic loading, residence time and stratification. The effect of increased nutrients (e.g. N and P) is primarily related to enhanced algal/plant growth directly influencing DO through photosynthesis (increasing levels) and respiration (decreasing levels). Accumulation of algal biomass and microbial degradation of organic matter can cause consistent decreases in DO levels, contributing towards hypoxia/anoxia (Gillander *et al.,* 2011). Increased atmospheric temperature also can increase primary production and remineralisation rates with ripple effects into the intensity of change in DO (Justic *et al.,* 2007). Warming will also reduce the oxygen solubility in estuarine waters (Doney *et al.,* 2012; Keeling *et al.,* 2010).

Important to note is that low DO levels or hypoxia can occur naturally, especially in deeper estuarine systems where vertical stratification of the water column limits water–atmosphere gas exchange because mixing is inhibited (Hassell *et al.,* 2008). However, anthropogenic loading of nutrients can drastically increase the extent and frequency of hypoxia/anoxia. Shallow estuaries are usually well-mixed, rapidly equilibrating with atmospheric oxygen. However, shallow systems are much more vulnerable to large diurnal variations in DO where they can shift from net autotrophic (releasing DO) to net heterotrophic (using DO) within 24 hours depending on the intensity of nutrient loading (Baumann *et al.,* 2015). Extended residence times within estuaries are likely to exacerbate the intensity of organic matter remineralization and its effects on DO dynamics (Wallace *et al.,* 2014; O’Boyle *et al.,* 2013).

Given the positive relationship between nutrient enrichment and DO, Figure 0.63 also provides a good indication of altered DO dynamics. Especially the smaller, TOCEs in the urban nodes have been heavily impacted, i.e. receiving high nutrient and organic waste loads and increased residence time. Climate change driven changes in DO dynamics will be super-imposed on the existing effects of land-based anthropogenic inputs. Mortalities of fish in estuaries when near-zero DO values persisted for several days have been recorded in the Sezela and Tongati estuaries in KwaZulu-Natal (Whitfield 1995).

The expected effects of climate change on DO will differ across the six regions. However, common across the regions will be the effect of increased atmospheric temperatures possibly increasing primary production and remineralisation rates with rippling into DO dynamics. For example diurnal variations and hypoxia/anoxia will intensify especially during periods when estuaries close (increased residence time). In KZN residence time is viewed as the most important climate-driven factor given the nature of most of these systems (i.e. small and shallow temporarily open/closed estuaries). The increased river inflow will increase mouth openings, thus reducing residence time. As a result the effects of nutrient enrichment on DO levels will be less persistent, i.e. these systems will flush more often. However the large lake systems in this region (e.g. Kosi Bay) comprising naturally deep, highly resident water bodies, will not benefit from this mechanism and can become enriched over time with predicted higher river inflow. For the Wild Coast only a small increase in runoff is predicted. Also characterised by small, temporarily open/closed estuaries, the effect on DO dynamics is expected to be similar to that for KZN albeit dampened. Only small shifts in river runoff is predicted for the Eastern Cape and Southern Cape regions. Climate change, therefore, is not expected to have a large effect on nutrient dynamics compared with the KZN and Wild coast regions. A significant decrease in runoff is projected for the Western Cape and West coast regions. Here, the smaller temporarily open/closed urban estuaries (especially in the Western Cape region), highly enriched by wastewater inputs is mostly at risk because of increased closure increasing residence time.

Estuarine resident taxa are most susceptible to degradation of estuaries as they are entirely dependent on estuaries. Excessively low numbers of either estuarine resident taxa or estuarine-dependent marine taxa is usually indicative of disturbance within a system (Harrison and Whitfield 2004). In the Sezela Estuary in KwaZulu-Natal, which was subject to chronic industrial pollution in the 1980s, a maximum of two estuarine resident fish species were recorded in the system between 1984 and 1986. Subsequent improvements in water quality resulted in an increase in the number of estuarine resident fish species recorded to a maximum of 16 species in 2001 (Harrison and Whitfield 2004).

Sediment dynamics and organic accumulation

Floods in estuaries scour sediment deposited during periods of lower flow. This accumulated sediment is both catchment derived and brought in from the sea by flood tides. Soil erosion in catchments poses a major threat to estuaries, particularly those in KZN and those in the former Ciskei and Transkei regions of the Eastern Cape Province (Morant and Quinn 1999). The potential denuding of vegetation in arid catchments (i.e. increasing the erodibility of soils) coupled with an increase in the frequency of high intensity rain events due to climate change will lead to a significant increase in the deposition of sediment in estuaries.

It is foreseen that the potential water shortage predicted under near- and far-future climate change scenarios, especially in the Western Cape, would lead to the need to build more dams to secure water supplies to urban areas and agriculture. Major dams have the effect of capturing minor (annual) flood peaks entirely and attenuating major flood peaks. The degree to which this will occurs depends on the ratio of dam volume to MAR, the level in the dam preceding the flood, and the size of the flood. Therefore, if floods are reduced in intensity and frequency, sediment deposition and accumulation occurs and estuaries are reduced in water volume and surface area. Numerous small farm dams as well as barrages and weirs, collectively also have a major impact on the variability and duration of stream flow and consequently on estuaries. Instead of being available as stream flow the water is stored and subjected to consumption and losses, including evaporation and seepage. Higher temperatures, with the related increase in evaporation due to climate change, will not only increase the need to build more farm dams but also will exacerbate the impact of existing dams on the aquatic environment. Therefore catchments that are heavily utilised may see a general reduction in floods and associated sediment transport, e.g. Mgeni and Great Brak.

Contaminant behaviour and accumulation (***e.g. toxic substances***)

The impacts of climate change on contaminant (e.g. metals, poly-aromatic hydrocarbons, pesticides, herbicides and pathogens) behaviour and accumulation in the environment is becoming an increasing concern (Schiebek *et al.,* 2007). These contaminants are introduced through an array of human activities released into systems via rivers, wastewater discharges diffuse runoff and atmospheric deposition. The concerns in terms of climate change specifically resolve around changes in chemical behaviour (e.g. associated with changes in temperature, pH and DO), as well as the remobilisation and flushing of such contaminants. For example, changes in pH and DO may result in accumulated contaminants becoming bio-available with ripple effects into estuarine biota. Many toxic substances, such as metal and persistent organic pollutants, tend to adsorb onto fine sediment particles and POM, which can then settle from the water column through flocculation or weakening turbulence. During periods of high flow, such contaminants can then either be re-suspended or flushed.

The chemical responses of contaminants to changes in temperature, pH and DO in estuaries are largely dependent on the type of contaminant, as well as the inter-dependency between the responses. For this assessment, it can best be postulated that areas subject to significant shifts in the above will be most vulnerable to climate change related effects.

The re-suspension and flushing of settled contaminants from estuarine systems, is largely influenced by high river flows and extreme events.

3.6.4.2.3 Ocean acidification

Ocean acidification refers to anthropogenic CO_2-induced reduction in pH and carbonate saturation (generally expressed as the saturation state of aragonite - Ωarag) (Feely *et al.,* 2010; Gruber *et al.,* 2012). Whilst pH will generally decrease across the ocean, the effect is expected to be amplified in bottom waters of the ocean, with upwelling introducing these low pH bottom waters to coastal and estuarine environments. Upwelling in the Beguela system is predicted to become more intense which may extend the persistence of lower pH and Ω_{arag} saturation (Saenko *et al.,* 2005; Roemich 2007). The pH of surface waters may decrease by 0.3-0.4 units by 2100 under the influence of rising atmospheric CO_2 levels (Caldeira and Wickett 2003). Systems along upwelling coast will be more at risk (Figure 0.64). Important is to note that natural variability in pH should be taken into account when effects of ocean acidification are considered. Natural fluctuation in pH may play a large role in the development of resilience in marine populations. On the other hand, it may combine with the effects of ocean acidification to produce even more extreme events resulting in even greater impact on the biota (Hoffman *et al.,* 2011). The reduction in pH that accompanies elevated CO_2 concentrations may have profound implications for coastal and marine ecosystems (Harley *et al.,* 2006, James and Hermes 2011).

Naturally, pH levels in estuaries are influenced by river inflow (e.g. influenced by catchment geology and vegetation), coastal upwelling and *in situ* processes such as primary production and remineralisation (Freely *et al.,* 2010). pH in river inflow generally is lower compared with surface coastal waters, but the hydrological and geological regimes as well as vegetation in the catchment plays a determining role (Aufdenkampe *et al.,* 2011). In South Africa, pristine rivers draining the Table Mountain group with fynbos plants have naturally low pH values (pH<6), for example the black water systems of the Western Cape region (Midgley and Schafer, 1992). However, as a result of anthropogenic interference (e.g. riparian clearing, agricultural return flow and other inappropriate land-use practices), many of these weakly buffered systems have lost their strong acidic character, where pH levels can exceed that of coastal waters (Lamberth, unpublished data). Vegetation types are also important *in situ* factors influencing pH (Wallace *et al.,* 2014). For example, salt marshes support high levels of microbial metabolism. As such, high correlation between DO and pH and extreme acidification has been observed in these habitat types (Baumann *et al.,* 2015). Conversely, seagrass-dominated estuaries are often net autotrophic, buffering acidification in the water column (Hendriks *et al.,* 2014).

Ocean acidification

Feature/process	West Coast	Western Cape	Southern Cape	Eastern Cape	Wild Coast	KwaZulu Natal
a. Decrease in pH	M	M	L	L	L	L
b. Calcifying organisms require more energy to maintain dissolving exoskeleton	M	M	L	L	L	L

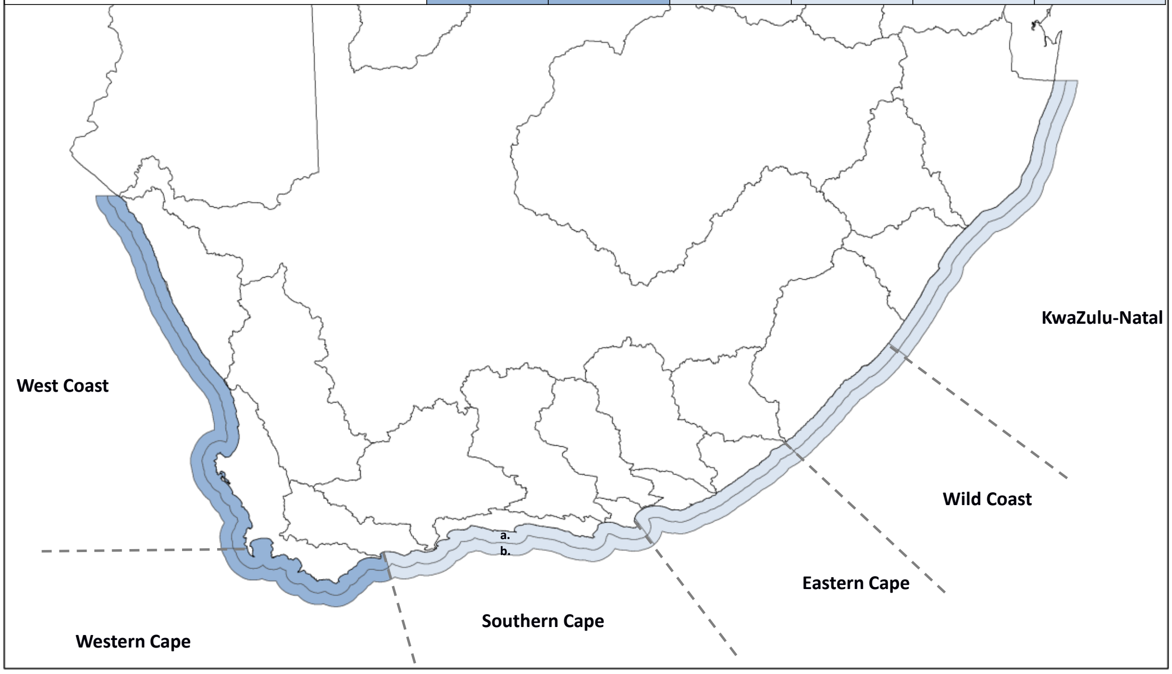


Figure 0.64: Regional summary of the vulnerability to ocean acidification and the possible consequences on calcifying species. Vulnerability is indicated as high/medium/low shifts from west to east with potential change a. to b. depicted by moving outward from the coast

However, land-based anthropogenic sources have drastically increased nutrient loading into estuaries causing excessive primary production which subsequently accumulates as organic matter (Van Niekerk *et al.,* 2013). This organic matter fuels remineralisation that not only influences DO levels but also pH. During respiration and remineralisation CO_2 is produced resulting in a lowering of pH (Wallace *et al.,* 2014). Deeper, stratified systems are more vulnerable to the effects of remineralisation compared with shallower, well-mixed systems. However, shallower systems are much more vulnerable to large diurnal variations in pH where they can shift from net autotrophic (increasing pH) to net heterotrophic (lowering pH) within 24 hours depending on the intensity of nutrient loading (Baumann *et al.,* 2015). Extended residence times within estuaries are likely to exacerbate remineralisation and the lowering of pH (Wallace *et al.,* 2014; O'Boyle *et al.,* 2013). Most at risk are the smaller, temporarily open/closed systems in the urban nodes (Cape Town, Port Elizabeth and Durban) and to a lesser extent rural catchment receiving agricultural runoff (Figure 0.64).

Currently the low pH and Ω_{arag} observed in many estuaries are still associated with land-derived anthropogenic pressures, with ocean acidification only making a minor contribution in marine dominated systems subject to upwelling (Freely *et al.,* 2010). However, by the end of this century, ocean acidification may become the dominant process in such systems as the acidification process continues, especially systems in the West Coast and Western Cape regions situated along the Benguela upwelling system. In the smaller, temporarily open/closed estuaries of these regions, reduced runoff and longer closure main further intensify the effects of land-derived pressure owning to longer residence time. In the KZN region, and to a lesser extent the Wild Coast region, increased flows and more frequent openings in the small temporarily open/closed estuaries, may reduce the existing effects of land-based enrichment through more regular flushing.

The resulting decrease in pH will affect all calcifying organisms, as structures made of calcium carbonate would start to dissolve requiring more metabolic energy for an organism to maintain its exoskeleton. Estuarine organisms that may be affected include coralline algae, echinoderms, crustaceans and molluscs (USEPA 2009, James *et al.,* 2013).

Acidification affects organisms in two ways: through reduced pH and increased CO^2 (hypercapnia, Wood *et al.,* 2008). Research on various organisms has shown that acidification causes a great diversity of responses and it is therefore difficult to generalise predictions (Vézina & Hoegh-Guldberg, 2008). Ocean acidification influences physiological processes and behaviours in many organisms by reducing gas exchange (Fabry *et al.,* 2008, Pelejero et.al. 2010), lowering metabolic rates and growth (Bibby et.al. 2007, Fabry *et al.,* 2008, Guinotte & Fabry 2008, Vézina & Hoegh-Guldberg 2008, Doney *et al.,* 2009) and disrupts defensive responses and behaviours (Bibby et.al. 2007, de la Haye 2012). In addition, in some calcifiers, rates of calcification are reduced (Gattuso *et al.,* 1999; Riebesell *et al.,* 2000; Gazeau *et al.,* 2007) and even shells dissolved (Feely *et al.,* 2004; Arnold *et al.,* 2009; Bibby *et al.,* 2008). Calcifiers residing in cold water habitats such as upwelling systems are at a higher risk to ocean acidification and decreased seawater carbonate saturation, as their environment is only just supersaturated with respect to the carbonate phases they excrete (Andersson *et al.,* 2008). The extent of these potential impacts will depend on the organisms' ability to adjust their acid–base balance as well as their ability to increase their calcification rates, while the ability to withstand or adapt to these changes over long periods of time would clearly be beneficial (Fabry *et al.,* 2008). Doney *et al.,* (2007) predict that the effects of ocean acidification will be felt more severely in coastal waters as the combined effects of nutrient enrichment; pollution, overfishing and climate change will make it even more difficult for organisms to adapt or counter changes in ocean chemistry. Acidification will likely impact various life stages differently as CO_2 tolerance varies between life stages of organisms (Pörtner, 2008). Generally, for fish species the egg and juvenile phases are more sensitive to elevated CO_2 compared to the larval and adult stages (Ishimatsu *et al.,* 2004). Increases in CO_2 levels may lead to hypercapnia (elevated CO_2 partial pressure) and acidosis in the blood and tissues of fishes (Pörtner *et al.,* 2004).

Ocean acidification will not only have a direct impact, but will possibly indirectly influence the ability of organisms to deal with local phenomena. Estuary-dependent species with a pelagic life-history stage will be particularly vulnerable. Slower growth and delayed metamorphosis of fish and invertebrate larvae may result in recruitment failure if these animals miss the brief recruitment window typical of most temporarily open-closed systems along the South African coastline. In some fish species, slow development and changes in the physical and chemical structure of otoliths (and other bone structure) may alter sensory perceptions and their ability to communicate, avoid danger or detect prey (Potts *et al.,* 2015). Otolith malformation led to atypical behaviour such as reliance on visual rather than sound stimuli, as well as to increased cortisol levels, stress levels and suppressed immune systems in the Sciaenid *Sciaenops ocellatus* (Browning *et al.,* 2012). However, not all species will react in the same way to ocean acidification and an understanding of the process driving the different responses by fish is critical for future prediction (Potts *et al.,* 2015).

Anomalous to the above in South African estuaries is the alkalinisation of acidic blackwater catchments brought about by riparian clearing, agricultural return flow and other bad land-use practices some estuarine pH levels exceeding that of marine inflow (Lamberth unpublished). Abrupt changes and increases in pH and other environmental extremes raise the susceptibility of fish and invertebrates to disease (Huchzermeyer and Van der Waal 2012). The invasive potential of these pathogens and their vectors also increases (Conn, 2014). Further, the invasive potential of alien species e.g. oysters may also increase.

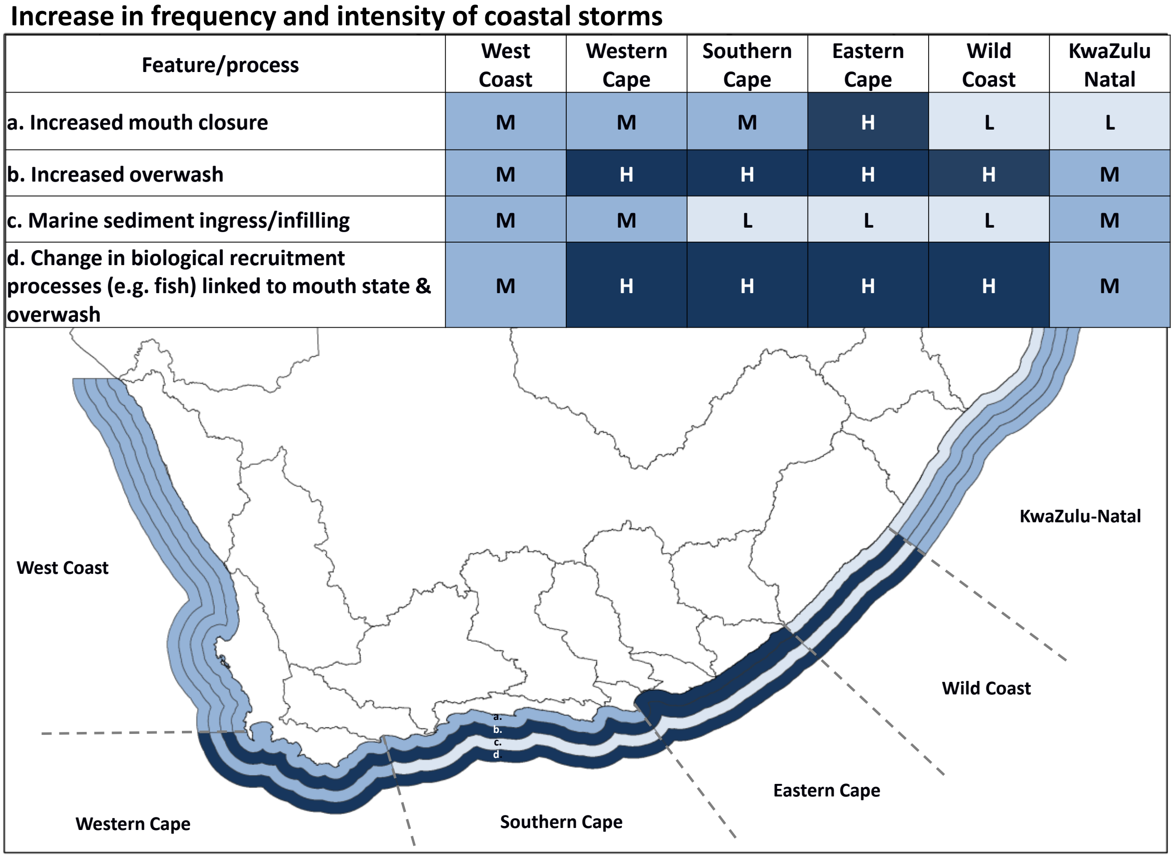
While, many species have enough physiological plasticity to cope with acidification but many may not be able to cope with the two extremes of acidity and alkalinity in the marine and estuarine environment.

3.6.4.2.4 Increased sea storminess

The Fourth Assessment Report of the IPCC predicts an increasing frequency and intensity of extreme weather events in the 21st Century (IPCC 2007). The frequency and magnitude of severe weather events such as tropical cyclones, droughts and floods appears to be on the increase globally (IPCC 2007). In South Africa, increases in either intensity or frequency, or changes in seasonal storm intensity have been reported at a local scale albeit on a very short time-scale (Guastella and Rossouw 2012, Harris 2010). Preliminary analyses (Rossouw and Theron 2009) found that while the annual mean significant wave height (Hm_0) off Richards Bay and Cape Town show no increase, there seems to be some change in the individual storms, e.g. the peaks of individual storms off Cape Town during the more extreme winter period (June to August) with an observed increase of ~0.5 m over 14 years. This may be indicative of a significant increase in the “storminess” over the next few decades. The observed data also indicate a general decrease during summer for the same period.

A number of small to medium sized estuaries (e.g. Great Brak) show great sensitivity to increased wave action. In general, large storms at sea generate the wave conditions that will close such estuaries, unless there is significant river flow to maintain the open mouth condition. An increase in storminess due to climate change would therefore increase the occurrence of mouth closure and transport more marine sediment into an estuary than at present. Estuaries along an exposed, sediment rich coastline (e.g. parts of KwaZulu-Natal) would be more likely to close than estuaries that are fairly protected, or those located on sediment starved coastlines (e.g Transkei and Tsitsikamma coastlines) (**Error! Reference source not found.**).

A substantial rise in sea level (especially in sediment starved catchments) would have major implications for estuarine salt marshes and mangroves, as the rate of sedimentation would not be able to keep up with the rate of sea level rise (James *et al.,* 2013). This would result in a loss of essential estuarine habitat (such as mangroves and salt marsh), which will ultimately affect estuarine fish and invertebrates.



Increase in frequency and intensity of coastal storms

Feature/process	West Coast	Western Cape	Southern Cape	Eastern Cape	Wild Coast	KwaZulu Natal
a. Increased mouth closure	M	M	M	H	L	L
b. Increased overwash	M	H	H	H	H	M
c. Marine sediment ingress/infilling	M	M	L	L	L	M
d. Change in biological recruitment processes (e.g. fish) linked to mouth state & overwash	M	H	H	H	H	M

Figure 0.65: Regional summary of the consequences of increase frequency and intensity of coastal storms on estuary mouth state, overwash and marine sediment processes. Vulnerability is indicated as high/medium/low shifts from west to east with potential change a. to d. depicted by moving outward from the coast

Increased wind speeds have resulted in a significant decline in sea-days for the commercial line fishery on the southern Cape coast (Kerwath, Lamberth in prep). In an attempt to maintain fishing effort and catch rates, fishers are likely to build larger vessels or find calmer waters elsewhere. In the absence of sheltered bays on the South African coastline, there’s likely to be displacement of fishing effort from an increasingly stormy sea into calmer estuarine waters. This has already happened in the Bot Estuary and with the gillnet fishery in the Langebaan MPA with the resultant overexploitation and user conflict.

3.6.4.2.5 Sea level rise

Recent calibrated observations from satellites, are that global sea level rise over approximately the last decade has been 3.3+/- 0.4 mm.yr^{-1} (Rahmstorf *et al.,* 2007). The IPCC AR5 SPM 2013 (IPCC, 2013) concludes that anthropogenic warming and sea level rise will continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations are stabilised. South African tide gauge records show substantial agreement with global trends (Theron 2007). South African sea level rise rates are approximately: west coast +1.9 mm.yr^{-1}, south coast +1.5 mm.yr^{-1}, and east coast +2.7 mm.yr^{-1} (Mather 2008, Mather *et al.,* 2009). Based on the above findings it is concluded that the best estimate (or 'central estimate/mid scenario') of sea level rise by 2100 is around 1 m, with a plausible worst-case scenario of 2 m and a best-case scenario (low estimate) of 0.5 m. The corresponding best estimate (mid-scenario) projections for 2030 and 2050 are 0.15 m and 0.35 m, respectively (Theron *et al.,* 2012).

Sea level rise can either counteract the reduction in runoff to an estuary or exacerbate the effect depending on the size of the estuary, the sediment availability, and the wave energy near or at its mouth. In the case of small, temporarily open/closed estuaries sea level rise could assist in maintaining open mouth condition through increasing the tidal prism, if the system is sheltered from wave action and/or little sediment is available near its mouth. Alternatively, sea level rise could merely reset the level at which an estuary closes to the same relative height above mean sea-level, without significantly affecting the amount or duration of mouth closures. However, an increase in storminess might actually increase the frequency and or duration of the mouth closure due to increased marine sediment transport into the mouth area during sea storms. In the case of permanently open estuaries, sea level rise may lead to an increase in saline penetration (especially in the middle reaches) and require additional freshwater to maintain the same salinity gradient as at present, i.e. it may be necessary to increase ecological flow requirements to maintain present ecological production levels.

Sea level rise (between +0.5 and +2.0 m MSL)

Feature/process	West Coast	Western Cape	Southern Cape	Eastern Cape	Wild Coast	KwaZulu Natal
a. Increase salinity penetration	H	M	M	M	M	L
b. Increased tidal flushing/prism	H	H	H	M	L	H
c. Changes in the frequency and duration of mouth closure	H	H	H	M	L	H
d. Changes in habitat (e.g. plants) & nursery function/ availability	H	H	H	M	M	H

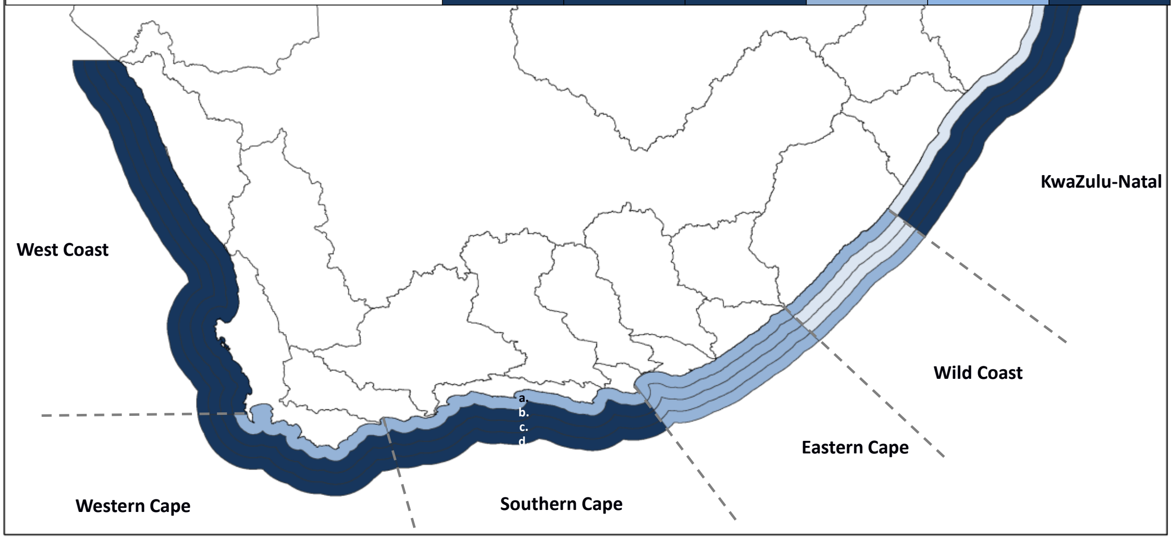


Figure 0.66: Regional summary of the consequences of sea level rise on key estuarine processes – salinity distribution, tidal flushing and mouth state. Vulnerability is indicated as high/medium/low shifts from west to east with potential change a. to g. depicted by moving outward from the coast

Climate change and sea level rise will increase the pressures on management agencies to implement assisted (and often premature) breaching as increasingly properties will be below the level of the sand berm near the mouth (see Figure 0.66). The response of humans to sea-level rise may take the form of actions damaging to estuaries and estuarine biota, such as armouring the coastline with berms or dykes that will prevent biological systems from adjusting naturally (e.g. by inland retreat of wetlands). An example of an impact on the biophysical processes is the loss of salt marsh and mangroves leading to a decrease in estuarine habitat and food supply. An indirect impact is an increase in turbidity as sediment is no longer trapped by the fringing vegetation around an estuary. This, in turn, reduces light penetration thus causing a decrease in primary production by microalgae, whilst filter and“tactile” feeders will benefit at the expense of “visual” feeders (e.g. estuarine round herring *Gilchristella aestuaria* vs Cape silverside *Atherina breviceps*). Furthermore, some mangrove and salt marsh systems may not be able to keep pace with more rapid levels of sea-level rise. Mangroves may outcompete saltmarshes in subtropical areas in response to rising sea levels (Adams 2002).

3.6.4.3 Balancing opportunities and threats

3.6.4.3.1 Barriers to adaptation

Accelerated climate change is one of many pressures acting on estuaries and should be viewed as an additional form of anthropogenic stress and not a separate pressure in an already stressed ecosystem. In turn, climate change can accelerate ecosystem change in estuaries and other ecosystems. It is necessary to understand the potential amplification of variability that climate change may have on existing freshwater resources and its use, together with the potential impact on estuarine and marine production, as well as the harvesting of resources in the marine and estuarine environments. It is thus necessary to integrate climate change and non-climate change threats. Climate change should be seen as a catalyst to fast-track freshwater resource issues that need addressing, e.g. ecological water allocations (Day and Moore, 2009).

3.6.4.3.2 Key evidence gaps

The ability to predict the response of estuaries to climate change and to plan mitigation and adaptation strategies is still hindered by a lack of good prediction tools and the lack of a fundamental understanding of many of the effects of climate variability on the physical, chemical and biological characteristics of the aquatic domain (Meyer *et al.,* 1999). We are limited by the availability of both data (e.g. long-term flow data, temperature data, mouth conditions, wave height, species data) and models (e.g. flow changes, linking hydrological regimes to ecosystem processes and large-scale ocean current changes). At the same time, this uncertainty around forecasting change should not be seen as an impossible obstacle to understanding and developing adaptive mechanisms to reduce the effects of climate change on estuarine resources. Accurate forecasting is not obligatory to begin the process of adapting to climate change as major trends are often obvious enough for meaningful actions to be planned and implemented.

3.6.4.3.3 Opportunities

Stressed ecosystems have a lower resilience to change. By increasing or maintaining the resilience of estuaries, the ability of a system to recover after, for example an exceptional flood or drought, is enhanced. The resilience of an estuary is influenced by the intactness of its catchment and estuarine functional zone. The processes underpinning goods and services, such as the assimilation and cycling of nutrients in estuaries, also needs to be protected if resilience is to be maintained. For example, developments within the estuarine functional zone will reduce the resilience of the system to extreme flooding, as little lateral movement would be possible. A way to ensure resilience is the determination and implementation of the Estuarine Ecological Water Requirements (Reserve) and the protection and / or rehabilitation of the estuarine functional zone. Healthy estuaries equate to estuaries resilient to change (van Niekerk and Turpie 2012).

3.6.4.4 Adaptation priorities

The interaction between Climate Change stressors, estuarine processes and associated biotic response are complex. With multiple interactions which can both amplify and moderate responses. A summary of these complex interactions is provided in Table 0.8.

Table 0.8:The impact of Climate Change stressors and their associated on critical estuarine processes and variables features they impact on, which in turn drivers a range of key biotic responses. (**POM = Particulate Organic Matter, SS = Suspended Solids**).

CLIMATE CHANGE STRESSOR					**KEY ESTUARINE PROCESSES/ VARIABLES**	**KEY BIOTIC RESPONSES**								
Ocean circulation	**Climatic and hydrologic**	**Ocean acidification**	**Sea level rise**	**Storminess**		**Structure/ habitat forming**	**Eutrophication**	**Primary production**	**Range contraction/**	**Recruitment**	**Nursery function**	**Community composition**	**Behavioural responses**	**Local Extinctions**
	●				**Runoff**			●		●				
	●		●	●	**Mouth State**	●		●		●	●	●	●	●
	●		•	•	**Salinity**	●	●				●	●		•
●	●			•	**Nutrients (N&P)**	•	●	●			●	●		
●	●				**Temperature**	•		•	●	•	•	•	●	●
•	●	●			**Oxygen**						●	●	●	●
●	●	●			**pH**						●	●	●	●
	●		●	●	**Sediment dynamics & organic accumulation**	●	●	•			•	●		
					POM and SS	•					•			
	●				**Toxin**		●				●	●		●

This analysis shows that KZN and West Coast estuaries will be the most influenced by Climate Change from a structural and functional perspective. This is contrary to the current monitoring programmes which focus on biotic responses in the biogeographic transition zones (e.g. Transkei and western Southern Cape).

In summary, the impacts of Climate Change on estuaries include: 1) Changes in precipitation and associated runoff with the following consequences for estuaries: a) Modifications in the extent of saline water intrusion; b) Shifts in the frequency and duration of estuary mouth closure; c) Decrease or increase in nutrients fluxes; and d) Changes in the magnitude and frequency of floods and related sediment deposition/erosion cyclese) Changes in the dilution and or flushing of pollutants; 2) Rising temperatures from both the land and sea impacting on estuarine processes and biotic distribution; 3) Sea level rise and related impact on salinity and mouth state; 4) Changes in ocean circulation patterns; and 5) Increase in frequency and intensity of coastal storms also impacting on salinity and mouth state.

In the case of KwaZulu-Natal the major driver of change is increased runoff into the numerous small, perched temporarily open/closed estuaries, which will result in more open mouth conditions, a decrease in retention time and a related decrease in primary productivity and nursery function. This is best illustrated by the fact that estuary volume of these small perched systems shrinks by 50 - 90% when open to the sea. In contrast, West Coast estuaries will be negatively impacted as a result of reduction in runoff, related decrease in nutrient supply and an increase in sea level rise. This in turn will increase salinity penetration in permanently open estuaries and increase mouth closure in temporarily open ones. Similar to KwaZulu-Natal, West Coast estuaries will experience a decline in primary production and loss of nursery function.

Although Wild Coast, Eastern and Southern Cape estuaries will show some shifts in mouth states, nutrient supply, salinity distribution and ultimately production (e.g. fisheries), the most obvious impacts of Climate Change along these coastal regions will be the change in temperature (nearshore and land), associated species range expansions or contractions and changes in community structure. The bimodal rainfall zone of the Southern Cape is projected to show an increase in the frequency and magnitude of large floods as well as the duration and intensity of droughts. This region is characterised by medium to small catchments wherein bimodal rainfall ameliorates flow variability and confers a degree of stability on estuarine habitats. An increase in the magnitude of floods can cause deeper scouring of mouth regions, thereby increasing tidal amplitude and exposure of subtidal habitats and communities.

The effect of sea level rise, and related increase in tidal prisms, will be less apparent along the KwaZulu-Natal coastline, where with the exception of estuarine lakes and bays, the majority of estuaries are perched whilst it will be more apparent along the southern and Western Cape coast with their more extended coastal floodplains.

The far-future scenarios under both the high and low mitigations pathways, holds sever consequences for South Africa’s estuaries. Their relative small size and low runoff make them extremely vulnerable to climatic and hydrological climate change stressors - stream flow reduction, temperature increases and associated evaporation. All the coastal regions will be subjected to extreme change under these projections. Under the far-future scenarios estuary mouth closure will become prevalent along the entire coastline with some systems not connecting to the coast on decadal scales (e.g. Verloren, Uilkraals). The occurrence of hyper-salinity (>35) will become ubiquitous in most permanently open systems and a large number of open systems may close in the future (e.g. Olifants, Great Fish, Keurbooms, Kosi estuaries). Some smaller estuaries may dry out in their entirety, similar to Holgat and Brak on the west coast, while the estuarine lakes are likely to show extreme shifts in open water openwater area on decadal scales (St Lucia, Bot, Swartvlei). Thus, while trajectory is clear, much research still needs to be done to establish the extent to which individual systems will respond to such drastic change – making extreme prediction without more rigorous investigations will only be interpreted as alarmist.

It is essential that climate change, and the projected effects thereof, be integrated into current plans and policies dealing with management and governance of estuaries, specifically, the water and coastal management sectors. Current planning tools need to focus on integration of the synergistic effects of global change. In addition, adaptation includes adjusting to situations, developing coping strategies and impact responses. Adaptation may be behavioural or involve mitigation such as engineering solutions. This requires an adaptive management approach which is supported by monitoring and frequent review.

3.6.5 Human Health

3.6.5.1 Introduction

Human health is a key component of the South African Constitution (Act 108 of 1996) Section 24 of the Act is written as follows (RSA, 1996):

‘Everyone has the right to (a) an environment that is not harmful to their health or well-being; (b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that – (i) prevent pollution and ecological degradation; (ii) promote conservation; and (iii) secure ecologically sustainable development and use of natural resources while promoting justifiable econo.mic and social development.’

Human health has been a key component of the Millennium Development Goals (MDGs) which were set following the Millennium Summit of the United Nations in 2000 (StatsSA, 2013) and subsequently adopted by the Johannesburg Plan of Implementation of the World Summit on Sustainable Development (WSSD) on 26 August to 4 September 2002 (UN, 2002). Through the MDGs it has been widely acknowledged that health and sustainable development are interrelated. Many, though not all, are strongly linked to the current health status of the country. Almost all the MDG goals relate to health, either directly or indirectly. South Africa’s achievements of the various goals have been summarised in Table 0.9. The main concern about health in South Africa is that the country has a quadruple burden of disease with i) maternal and child health, ii) HIV and TB, iii) trauma and violence and iv) non-communicable diseases all contributing greatly to the national burden of disease (Sherry, 2015).

The mission of the Department of Health is '*to improve health status through the prevention of illnesses and the promotion of healthy lifestyles, and to consistently improve the health care delivery system by focusing on access, equity, efficiency, quality and sustainability.'* (*https://nationalgovernment.co.za/units/view/16/Department-Health*)

Although the National Department of Health has the over-arching responsibility for the health of the citizens of South Africa, many other departments and sectors also contribute, either directly or indirectly. For example, municipalities contribute through service delivery, e.g. through the management of sewage treatment works. Other national departments such as Department of Education, Water Affairs, Social Development, Human Settlements etc. all contribute to human health as indicated by the SDGs. Natural disasters may have health implications through injuries directly related to the disaster, as well as pollution of the environment following the disaster, and would require involvement of a variety of stakeholders at different levels. This may include the South African Weather Service, Disaster Management, and all levels of government.

It is complicated because roles are across levels of govt and sectors, and then take a few examples; i.e. service delivery is whatever, and natural disasters would include health, SAWS, disaster mgt, all levels of gov't etc.

Table 0.9: South Africa's achievements for each of the Millennium Development Goals

MDG	Status in South Africa
Goal 1 **To eradicate extreme poverty and hunger**	**The target for the proportion of the population living on <$1/day was achieved already in 2011 in South Africa. The proportion of people who suffered from hunger was halved from the baseline figure by 2011 (MDG Country Report, 2013).**
Goal 2 **To promote universal primary education**	**Target not met for South Africa. the proportion of learners starting Grade 1 and finishes primary school and the literacy rate did not reach the goal of 100% (MDG Country Report, 2013).**
Goal 3 **To promote gender equality and empower women**	**Target not met for South Africa The gender parity index (GPI) in percentage of net enrolment ratio in primary education did not reach the goal of 1:1 for South Africa (WHO, 2016a; UN, 2009).**
Goal 4 **To reduce child mortality**	**In South Africa the goal of 18 per 1000 live births for infant mortality rate was not achieved (32.8 in 2013). The goal of 20 per 1000 live births for under 5 mortality rate was not achieved (43.9 in 2013). Life expectancy at birth was 60 in 2013, thus not achieving the goal of 70 (WHO, 2016a).**
Goal 5 **Improve maternal health**	**Target for South Africa not met. There was only a 7% reduction in maternal mortality ratio by 2013 (WHO, 2016a).**
Goal 6 **To combat HIV/AIDS, malaria and other diseases**	**Goal was partially achieved. The South African target was to have halted and begun to reverse the spread of HIV/AIDS, TB and malaria by 2015. The target of the death rate associated with TB and malaria was achieved (MDG Country Report, 2013) There was a 1.2% reduction in the incidence of HIV (WHO, 2016a).**
Goal 7 **Ensure environmental sustainability**	**There were mixed results for this goal (StatsSA, 2013). The target for the proportion of the population using improved drinking water was achieved, but not for improved sanitation (WHO, 2016a; StatsSA, 2013).**

3.6.5.1.1 Progress since the 2nd National Communication

With the target date for achieving the MDG passed, the Department of Health in South Africa have set 10 new goals (Sustainable Development Goals (SDGs)) in their Strategic Plan 2014/15 to 2018/19 (DOH, 2014a). The goals directly related to health are to: i) raise life expectancy; ii) improve tuberculosis (TB prevention and cure; iii) reduce maternal, infant and child mortality and iv) reduce prevalence of non-communicable diseases (DOH, 2014a).

Climate change and health is also covered in the Report on the South African Country Situational Analysis and Needs Assessment for the Preparation of National Plans of Joint Action for Implementation of the Libreville Declaration on Health and Environment in Africa (SANA) (DOH&DEA, 2013). The SANA assessed the full complement of environmental health determinants, the drivers that determine their associated risk levels and the management of these risks, as well as the national legislative environment, the technical and institutional capacities, and the inter-sectoral cooperation mechanisms and available resources. A key finding from the SANA was that South Africa does have many environmental and health policies and programmes in place. However, it was found that there is a lack of formal and supported inter-sectoral linkages between health and the environment (DOH&DEA, 2013).

South Africa does have environmental and health policies, programmes and surveillance mechanisms in place, many of which do address climate change and health explicitly (DOH&DEA, 2013; Garland, 2014). The South African Environmental Health Policy includes climate change and environmental degradation as factors that may adversely affect health. Subsequent to this, the Department of Health has released the National Climate Change and Health Adaptation Plan (2014-2019) (NCCHAP; DOH, 2014) that provides more details of adaptation needs and considerations for the health sector. The guiding principles of the NCCHAP are prevention; community participation; inter-sectoral cooperation and collaboration; synergies between climate change adaptation and other public health initiatives; equity; evidence-based planning. Climate change is mentioned as one of the greatest challenges to human development (DOH, 2013).

There are also sector or health risk-specific policy updates since South Africa's Second National Communication. For example, the existing ambient air quality standards for benzene and PM_{10} (particulate matter with aerodynamic diameter ≤ 10μm) became stricter in January 2015 as per the original Air Quality Act (RSA, 2009b). In addition, $PM_{2.5}$ (particulate matter with aerodynamic diameter ≤ 2.5μm) was added as a criteria pollutant in 2012, with scheduled lowering of the regulated threshold starting in 1 January 2016, and 1 January 2030 (RSA, 2012). For mental health, the National Development Plan has identified the need to improve and grow the network of professionals to treat and support those experiencing psychosocial problems (SAHR, 2016). The Mental Health Policy Framework and Strategic Plan (adopted in 2013) also showed the intent of government to integrate mental health in the South African health system (SAHR, 2016).

3.6.5.2 Vulnerability to climate change

The Intergovernmental Panel on Climate Change, in the Fifth Assessment Report, stated that there is very high confidence that "…health of human populations is sensitive to shifts in weather patterns and other aspects of climate change" (Smith *et al.,* 713: 2014). The linkages between health and climate variables are however, highly complex. On a global scale, it is likely that climate change has already contributed to ill health; however this contribution is not well-quantified (Smith *et al.,* 2014). In South Africa, the linkages between climate, including climate variability, and health are not well-quantified (Myers *et al.,* 2011a; DEA, 2013c). However, many of the current health risks do have a linkage to climate, and thus may be impacted by climate change.

Climate can impact health either through direct exposures (e.g. floods, increases in temperature), or through indirectly exposures (e.g. changes in climate impact distribution of disease vectors), as well as through disruption in society or the economy (e.g. changes in climate impact on food distribution) (Smith *et al.,* 2014). In addition to climate drivers, there are modifying factors that can influence the impact that climate has on human health.

3.6.5.2.1 Current risks

Burden of disease

As mentioned in the introduction of this sector, the main current concern with regard to health in South Africa is that the country has a quadruple burden of disease (SAHR, 2015). A potential increase in communicable diseases related to climate change, such as cholera and other water-borne diseases pose a risk. The same is true for vector borne diseases, such as malaria and plague, where the distribution of these vectors may be extended due to the impact of climate change (Zhou *et al.,* 2008, CIEH, 2008). However, the burden due to non-communicable diseases that are on the increase in South Africa (DOH, 2013) may also render people more vulnerable to the impact of climate change, because existing diseases cause people to be more susceptible to exposure to hazards (including climate change). For example, people with cardiovascular diseases will be more susceptible to the effects of heat and air pollution, two factors envisaged to increase due to climate change.

From the risk factors identified as specific to South Africa, it is evident that at least childhood undernutrition and unsafe water may be further impacted by climate change. Childhood undernutrition will be exacerbated by food insecurity due to the impact of climate change on agriculture and the quality of water as a result of a future decrease in rainfall in some regions.

Figure 0.67 below highlights the changes in ranking of burden of diseases in South Africa between 1990 and 2013; this ranking is based on Years Lived with Disability (YLD) (per 1000, all ages, non-age standardized) due to the leading cause of disease (SAHR, 2016). The large increase in the contribution of HIV/AIDs to YLD is clear in Figure 6.53, as is the wide-range of diseases that contribute to YLDs in South Africa. The risk factors that have been identified as those factors attributing most to the Disability Adjusted Life years (DALYs5) in South Africa, were the following: unsafe sex; body mass index; alcohol use, blood pressure; fasting plasma glucose; childhood under nutrition; smoking; unsafe water; intimate partner violence; sub-optimal breastfeeding (SAHR, 2015).

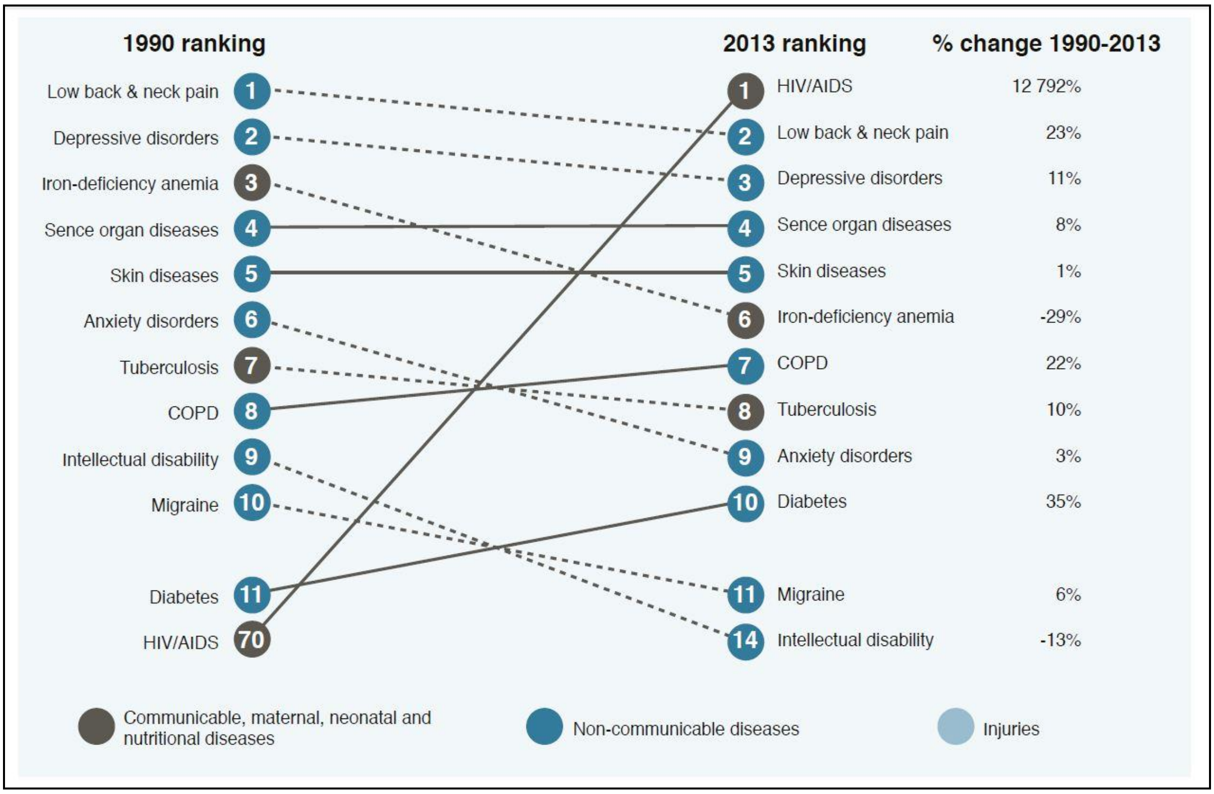


Figure 0.67: Leading causes of years lived with disability in South Africa for 1990 and 2013, and percent change (**1990-2013**) (**taken from SAHR, 2016**)

3.6.5.2.2 Future risks

The South African National Department of Health National Climate Change and Health Adaptation Plan (NCCHAP) provided an overview of selected health and environment risks from climate change (DOH, 2014), and the Long Term Adaptation Scenarios (LTAS) assessment provided greater detail on those risks for South Africa (DEA, 2013c).

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[5] One DALY is the loss of one year of healthy life due to premature mortality or living with a disability.

Table 0.10 below lists the environmental health risks considered in the NCCHAP and LTAS. Health risks indicated in bold were selected for more detailed assessment. Some of the risks may be regarded as modifying factors and have been labelled as such. This is not an exhaustive list of modifying factors for the sectors; however, modifying factors per risk discussed in this assessment are provided in the sections below. Both, public and occupational health, have the potential to be impacted by a changing climate. Occupational health impacts include those of outdoor workers. The percentage of the South African workforce that work outdoors is not known; however, in 2014, the agriculture sector alone employed ~700 000 workers (DAFF, 2014).

Table 0.10: Selected environmental and health risks in South Africa as highlighted in NCCHAP and LTAS (DOH, 2014, DEA, 2013c)

Environmental Health Risks	Category	Example
Heat stress	Climate-sensitive	Increases temperature can have direct impact on public and occupational health
Natural disasters	Climate-sensitive	Natural disasters (e.g. floods, drought, fires) can have immediate and long-term impacts on health
Housing and settlements	Modifying factors	Housing, infrastructure and service delivery can be a modifying factor for many health risks (e.g. clean water supply can mitigate water-borne diseases, improved thermal comfort in houses can mitigate heat stress, etc.).
Communicable Diseases	Climate sensitive and modifying factor	Some communicable diseases (e.g. cholera) are climate sensitive; others can be pre-existing conditions that may make people more vulnerable to climate-sensitive diseases.
Exposure to air pollution and respiratory disease	Climate-sensitive	Ambient air pollution levels are climate-sensitive; changes in climate factors (e.g. temperature, relative humidity, rainfall) can impact pollutant emissions, transport and deposition.
Non-communicable Diseases	Modifying factor	For many climate-sensitive health risks, pre-existing condition can make a person more vulnerable (e.g. pre-existing cardiovascular disease have been found to make people more vulnerable to heat stress)
Vector and rodent-borne diseases	Climate-sensitive	Changes in rainfall and temperature may impact the geographical range of vectors
Food insecurity, hunger and malnutrition	Climate-sensitive	Agricultural and fisheries sectors are climate-sensitive, which can have an impact on malnutrition.
Mental illness	Modifying factor and potential for climate sensitivity	Adverse situations, such as natural disasters create a conducive environment for the occurrence of mental health problems

Heat stress

International studies have found strong relationships between increasing temperatures and increasing rates in mortality (Kovats and Hajat, 2008; Azhar *et al.,* 2014; Burkart *et al.,* 2014). It is not well-known the impact that high temperatures currently have on public health in South Africa, as there are no published studies quantifying the health linkage nor the health relationship to temperature. Despite the evidence for an increase in the number of hotter days and nights there has been very little research conducted on how the impacts of heat affect human health (DEAT, 2011; DEA, 2013c).

A recent study by Garland *et al.,* (2015) investigated the risk to human health over Africa from increasing apparent temperatures (AT) (i.e. an index that accounts for temperature, relative humidity and wind speed) assuming the low-mitigation (i.e. A2) scenario from IPPC Fourth Assessment report (Nakićenović and Swart, 2000). In this study, AT_{max} ≥ 27°C, were considered to be a "hot day" where health may be at risk from high apparent temperatures. This threshold was based on studies in the United States of America, as there is no local information on thresholds (NWS, 2016). The modelled average number of "hot days" per year in South Africa from this study (Figure 0.68A) in the current climate (1961-1990) range from very few (green) to up to 170.

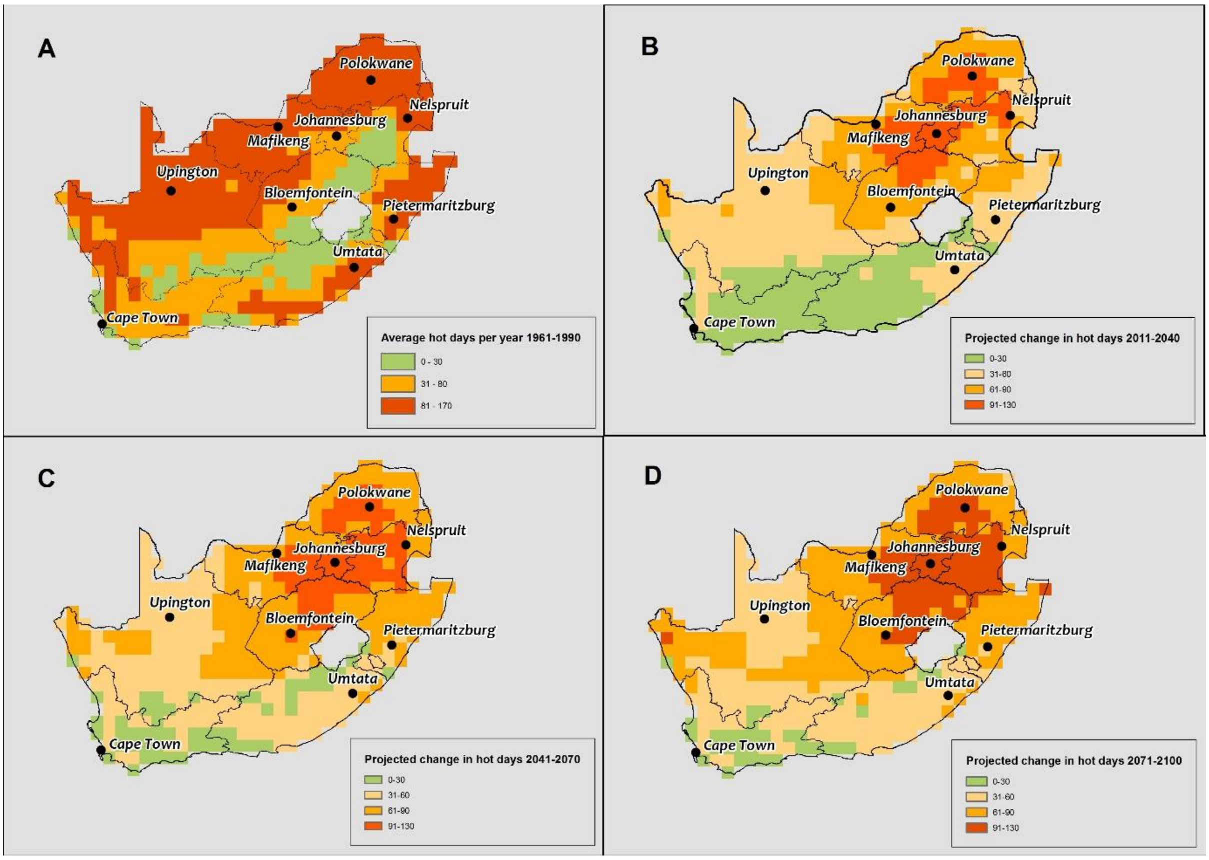

Figure 0.68: CCAM model derived a) average number of "hot days" per year in present climate, b) projected change in average number of "hot days" per year in 2011-2040 compared to 1961-1990, c) projected change in average number of "hot days" per year in 2041-2070

The projected changes in the average number of “hot days” per year for 2011-2040 (Figure 0.68B), 2041-2070 (Figure 0.68C) and 2071-2100 (Figure 0.68D) show an increase in number of “hot days” across the country. The areas with the greatest increases are in north-east South Africa. In Johannesburg, it was projected that the average “hot days” per year increase from <50 days per year to over five months of the year by the end of the century; these increases are large and may lead to large negative health impacts. However, currently, the temperature threshold where health will be impacted by heat among South African populations is not known, nor is the vulnerability of populations to increasing temperatures (Garland *et al.,* 2015).

International literature has found that in general, vulnerability to heat stress is largely determined by social, economic and environmental factors. Environmental factors include air pollution, high density build environment, lack of open spaces and minimal tree cover, and the urban heat island effect (DEA, 2013c; Kovats and Hajat, 2008). Social and economic factors include: dependence and access to social services, personal wealth, occupational status, education, type of housing and occupancy ratio (Cutter *et al.,* 2003). Housing is a modifying factor when considering the thermal comfort of a dwelling. Scovronick and Armstrong (2012) explored how housing type could modify the relationship between temperature and mortality, using the Eastern Cape and Western Cape Provinces as case studies. They found that housing protected more against the cold than the heat, and that wealthier houses would give the most protection. Among low-income housing, the difference was small, however formal and traditional houses were found to provide more protection than informal houses (Scovronick and Armstrong, 2012). The very old, very young, poor, those with pre-existing conditions, and socially isolated individuals are most vulnerable to the adverse health impacts of climate change (Frumkin *et al.,* 2008; Kovats and Hajat, 2008).

3.6.5.2.3 Vector-borne and rodent-borne diseases

Malaria

Currently, local malaria transmission only occurs in KwaZulu-Natal, Mpumalanga and Limpopo, though imported cases have been reported at health facilities in other provinces (SAHR, 2016). The most prevalent parasite is *Plasmodium falciparum*, accounting for ~95% of all malaria cases in South Africa (Coleman *et al.,* 2008; DOH, 2007; Maharaj *et al.,* 2012). Malaria cases in South Africa dropped from 64,622 cases (in 2000) to 9,866 (in 2011), and then increased again to 13 925 in 2013 (HST, 2015). The number of malaria-related deaths decreased by 81% (from 458 to 89) between 2000 and 2011, and increased again to 136 in 2015 (HST, 2015). The goal of DoH has been to eliminate malaria by 2015 (DEA, 2013c). However, this did not consider non-locally transmitted (or imported) cases, which constitute the majority of cases currently in South Africa (DEA, 2013c).

Malaria is sensitive to climate factors, though the relationship is complex and vector-specific, and thus malaria models are needed to understand the potential magnitude of impact (Smith *et al.,* 2014; Alonso *et al.,* 2011). Most of the projected future spread of malaria will be on the edges of the current malaria areas, for example areas where it is currently too cold for transmission. These regions do include South Africa (DEA, 2013c). In general, temperature, rainfall and relative humidity are key climate drivers for malaria. These factors need to be at optimal ranges, at the same time, for malaria transmission to occur. As the modelled risk varies across malaria models used in studies, research is on-going (Caminade *et al.,* 2014). In addition, many non-climate factors impact on malaria transmission, such as level of drug resistance, HIV infection, and land-use change (DEA, 2013c). Thus, while it is possible to model the climate suitability of regions to malaria transmission, the potential risk is also extremely sensitive to non-climate factors.

3.6.5.2.4 Other vector-borne and rodent-borne diseases

In South Africa, research on vectors of diseases is critical because there is a lack of knowledge about vectors themselves; as well as the impact climate change may have on these vectors (DEA, 2013c). The increasing rodent infestations in especially urban areas, is also a risk. In the NCCHAP it was noted that 54% of residents of low socio-economic suburbs in Johannesburg identified rodents as a major problem in their homes. Recently (16 March 2016) the rodent infestation in urban areas was again highlighted when it was reported that antibodies to *Yersinia pestis* bacteria was found in a rat in an informal settlement in the Gauteng province, indicating recent contact between the animal and the organism (NICD, 2016). *Yersinia pestis* may cause the bacterial infection known as plague, which is transmitted by fleas associated with rats. The last outbreak of the plague in South Africa was in 1982 in the Eastern Cape when 13 cases and one death were reported (NICD, 2016). It is suggested that the reproductive potential of rodents is increased mainly under higher temperatures but also under wetter conditions (CIEH, 2008).

Climate change may enlarge areas of vector borne diseases (DEA, 2011b). In addition to malaria, Rift Valley fever and schistosomiasis were mentioned as diseases that may require special initiatives (DEA, 2011b). Rift Valley fever is a viral disease affecting humans and domesticated animals and transmission is by biting insects such as mosquitos. Schistosomiasis is caused by a parasitic trematode flatworm, intermediately hosted by fresh water snails that release larva which penetrates the skin of humans exposed to the contaminated water (EB, 2015).

There is a persistently high rate of schistosomiasis in Africa with an estimated 163 million people in sub-Saharan African infected in 2012 (SAHR, 2015). A study in China showed that an increase in temperature may cause the spread of schistosomiasis into areas where it was not found before as well as the possible increase in transmission intensity in areas where it exists. The influence of precipitation on this spread was not studied, but could possibly exacerbate it (Zhou *et al.,* 2008).

The use of pesticides in controlling vectors as mentioned in LTAS (2013) was also discussed in NCCHAP. Concerns include the possible increase in vector and rodent-borne diseases, and the consequent increase in the use of pesticides to control these vectors and rodents. Increased poisonings due to pesticide use and storage also pose a significant risk.

Malnutrition

The so called “nutrition transition” currently observed in many countries, is also evident in South Africa (SAHR, 2016). Nutrition change is characterised by a change in diet from a diet rich in grains, vegetables and fruit with minimal animal products to a diet rich in processed food, animal products, sugar, salt and fat. This latter type of diet is tasty and high in energy, but poor in nutrients and is generally known as the “western diet” (SAHR, 2016). To ensure enough essential nutrients in the diet, it is important to eat a variety of food. Dietary diversity may be used as an indicator of food security and quality of nutrition as a low diversity is associated with conditions such as underweight, stunting and even cardiovascular risk (Shisana *et al.,* 2013).

In 2011, malnutrition was ranked the fifth leading underlying cause of death for the age group 0–14 years in South Africa (StatsSA, 2012). In the age group one month to eleven months, as well as in the group one to four years, malnutrition was the third leading underlying cause of death, while HIV/AIDS was ranked 10th (StatsSA, 2012). The provinces where malnutrition was ranked highest (4th) were the Free State, North West and Limpopo, while in the Western Cape it was ranked lowest (9th) compared with the other provinces (StatsSA, 2012).

The case fatality rate for severe malnutrition is determined as a percentage of the number of deaths from the condition divided by the number of cases. In South Africa the case fatality rate of severe malnutrition in children below the age of 5 years was 11.6% during 2014/15 (DHB, 2015). This figure is above the Department of Health’s target of <5% in 2018/19 (DOH, 2014).

The 2014 General Household Survey in South Africa showed the percentage of people (adults and children) that experienced hunger due to a lack of food in the household, decreased from 29.3% in 2002 to 13.1% in 2014 (StatsSA, 2015). The percentage of households vulnerable to hunger also decreased, from 23.8% in 2002 to 11.4% in 2014 (StasSA, 2015).

In the Global Burden of Disease study (2013), child and maternal malnutrition was one of the risk factors identified. The indicators for this risk factor were among others, underweight, wasting, and stunting. If children are classified as “stunted”, it means they are below the median height for their age (reflecting chronic undernutrition), wasting means they are below the median weight for their height (reflecting acute undernutrition) and underweight is determined by their weight-for age ratio. The primary reason for stunting is poor nutrition, repeated infections, and inadequate feeding practices during the first 1000 days (WHO 2015).

The incidence of severe malnutrition in children below the age of 5 years in South Africa was 4.5 per 1000 during 2014 (SAHR, 2016). This incidence ranged from 1.9/1000 in Gauteng province to 8.7/1000 in the Free State province (SAHR, 2016). Table 0.11 below highlights the South African statistics for the prevalence of stunting, wasting and underweight children across multiple studies. In addition, the averages for the African Region and global averages are given for comparison sake. According to the indicators for nutritional status of children (stunting, wasting and underweight), while there are discrepancies across studies, in general, South Africa is in a better position than the WHO African region, and compared to global averages.

Table 0.11 Prevalence of stunting, wasting and underweight in South Africa from different studies. The prevalence in the African Region and globally are highlighted at the bottom for comparison sake

Study	Year of assessment	Age range	Prevalence			
			Stunting	Wasting	Underweight	Reference
SANHANES	2012	0-14 yrs	15.4%	2.9%	5.8%	Shisana *et al.,* 2013
World Food Programme	2014	None specified	33%	5%	9%	WFP, 2016
SANHANES	2012	<5 yrs	21.5%	2.6%	2.6%	Shisana *et al.,* 2013
WHO	2007-2014	<5 yrs	23.9%	4.7%	8.7%	WHO, 2015a
WHO: African Region Figures	2007-2014	<5 yrs	39.4%	10.2%	24.9%	WHO, 2015a
WHO: Global Figures	2007-2014	<5 yrs	24.5%	7.7%	15.0%	WHO, 2015a

Food security

Although South Africa as a country may have adequate food supply, it does not guarantee food security at every household level in the country (Shisana *et al.,* 2013). The SANHANES study (South African Health and Nutritional and Examination Survey) was conducted due to the need for data on illnesses and their risk factors in South Africa, and to act as a baseline for the health and nutritional status of the population, as this was the first comprehensive study addressing these issues. Food security was defined as: “a condition that exists when all people, at all times, have physical, social and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life” (Shisana *et al.,* 2013 p 145). The study’s findings on food security and malnutrition in children are highlighted in Box 3.13.

Box 3.13: South African Health and Nutritional and Examination Survey

Food security in the SANHANES study was measured by an internationally recognised index, the CCHIP index, based on the Community Childhood Hunger Identification Project (CCHIP). According to the CCHIP index, a score of five or more positive responses to eight questions indicated a shortage of food in the specific household, thus household members were considered to be “hungry”, while a score of zero indicated a food secure household. The results showed the following:

45.6% of the households in the study were food secure, 28.3% were at risk and 26.0% were food insecure (thus experienced hunger). Those classified as food insecure were mostly in urban informal and rural formal areas (Shisana *et al.,* 2013).

The Western Cape scored the best (57.9%) for households being food secure followed by the Northern Cape (56.5%), Gauteng (56.0%) and Mpumalanga (55.0%). The Eastern Cape scored the lowest (31.4%) (Shisana *et al.,* 2013).

The Global Hunger Index (GHI) (based on insufficient energy intake, child underweight and child morbidity), for South Africa was at 5.8, considered to be moderate, in the same order of magnitude than China (5.1) and much lower than most other African countries.

The average score for dietary diversity in South Africa was 4.2, which is a slight improvement on the results of the previous survey (4.02) in 2009 (Shisana *et al.,* 2013). Rural informal areas had the lowest score and urban formal areas the highest. The Western Cape (4.6) and Gauteng (4.9) had the highest diversity score of the provinces while North West (3.3) and Limpopo (3.2) had the lowest

Food systems will be negatively impacted by climate change, leading to compromised food availability, access and utilisation which will have significant consequences on food insecurity in the region (DEA, 2013c). According to the IPCC (2007:13), “agricultural production, including access to food, in many African countries and regions is expected to be severely compromised by climate variability and change”. If temperatures continue to rise, the price of food will escalate, leaving vulnerable households with limited access to nutritious foods, increasing the risk of malnutrition in South Africa (DEA, 2013c). According to DEA (2013), food insecurity, hunger and malnutrition are significant contributors to the cumulative negative impacts of climate change.

The impact of the 2015/16 El Nino on weather conditions in South Africa was significant with a severe drought that led to water shortages and it is envisaged that the consequences of this drought will have an effect throughout the current year (NICD, 2016). This includes a significant reduction in food supply that will also lead to the need to import food (WFP, 2016). The water shortages and drought also led to live stock being in a poor condition in many areas (WFP, 2016) and even to loss of livestock. The price of white maize for July 2016 is already at a record high in South Africa and in some areas maize prices are more than double the average of the past five years (WFP, 2016). The food price inflation was already at 5% in 2015 (WFP, 2016) and this is expected to increase further.

Water-borne diseases

According to the South African Medical Association (SAMA), fast-rising temperatures and changing rainfall/humidity patterns will inevitably lead to a surge in vector-borne and water related diseases, especially in Sub-Saharan Africa (SAMA, 2015). Five South African provinces have already been declared drought disaster areas in 2015/2016. Direct and indirect consequences of climate change will result in increases in compromised drinking water, increases in malaria, dysentery, cholera and dengue, increased food insecurity and an increase in extreme weather events. It has been shown that growth of the bacterium Vibrio cholera is affected by water salinity, water temperature and changes in rainfall patterns (SAHR, 2016). South Africa is thus at risk of further cholera outbreaks. However, no cases of Vibrio cholerae O1 were detected between 2012 and the end of 2015, except for two cases reported in Gauteng, serotype Ogawa (NICD, 2013, 2015).

As stated in the National Climate Change and Health adaptation plan, diarrhoeal related diseases are important in South Africa, (DOH, 2011). The diarrhoea incidence of children under 5 years (per 1000) have been decreasing (from 112.4 in 2010 to 90.3 in 2012) (HST, 2015). The incidence of diarrhoea with dehydration (per 1000) has also gradually decreased from 2009 (21.1) to 11.3 in 2014 (HST, 2015). Figures from StatsSA suggest that only approximately one-third of deaths from diarrhoea and pneumonia in children are being recorded in the DHIS. This suggests that poor access to health facilities for severely ill children remains an important determinant of child mortality in South Africa (DHB, 2015).

Severe storms, resulting in floods and landslides, can also affect access to safe water and sanitation (SAHR, 2016). The Blue Drop Report 2014 (released in early 2016) reported that the National Blue Drop score (which measures the performance of individual potable water suppliers) has “improved substantially” since 2009; but also that the “drop in performance in general in 2014 is perturbing and water services authorities and their providers need to regain the progress made in 2012” (SAHR, 2016). During this survey, only 44 Blue Drops (indicating excellence) were awarded to 20 of the 152 Water Service Authorities. Overall, it was claimed that 60% of the water supplied daily was supplied with Blue Drop excellence.

There has however not been an updated report on waste water treatment (the Green Drop report) (SAHR, 2016). According to the General Household Survey (2014), 79.5% of households nationally had access to “improved sanitation” (i.e. a flush toilet connected to a public sewerage system or septic tank, or a pit toilet with a ventilation pipe) in 2014, with only 4.9% of households having no sanitation or relying on the bucket system. This figure was however still high in the Northern Cape

(9.1%), Eastern Cape (8.5%), Free State (7.9%) and Mpumalanga (7.1%) (SAHR, 2016). Table 0.12 shows the related figures for different provinces.

Table 0.12: Statistics, per province, related to availability and quality of clean water in South Africa

	EC	FS	GP	KZN	LP	MP	NC	NW	WC	SA	Ref
Drinking Water System (Blue Drop) Performance Rating (SAHR, 2016)											
2012	82.1	73.6	98.1	92.1	79.4	60.9	68.2	78.7	94.2	87.6	Blue Drop 2012
2014	72.0	75.0	92.0	86.0	62.0	69.0	68.0	63.0	89.0	79.6	Blue Drop 2014
Percentage of households with access to piped water											
2013 GHS	80.5	95.9	95.9	86.2	77.5	86.7	96.1	88.3	98.7	89.9	Stats SA GHS 2013
2014 GHS	78.5	95.3	96.4	86.5	79.6	87.1	95.8	87.2	98.9	90.0	Stats SA GHS 2014
Population using safely managed sanitation services (%)											
2013 GHS	71.2	83.3	90.2	73.9	50.0	62.7	81.7	70.0	94.8	77.9	Stats SA GHS 2013
2014 GHS	78.1	83.8	90.9	75.7	54.0	64.3	83.7	66.7	94.6	79.5	Stats SA GHS 2014

Cholera, while not currently a problem in South Africa, has been an area of study for modelling water-borne diseases (DEA, 2013c). In the LTAS report, cholera was highlighted as an example of water-borne diseases. South Africa is also affected by cholera outbreaks in neighbouring countries like Mozambique and Zimbabwe. Modelling of cholera, should thus focus on different spatial and temporal scales (DEA, 2013c). For South Africa some of the most important environmental data needed to model the climate suitability for cholera will include rainfall, accumulated rainfall, pH, ultraviolet (UV) light, and algal blooms (DEA, 2013c). Non-climate data such as water access, sanitation, urbanisation and infrastructure need to be considered as they may contribute to transmission of cholera (DEA, 2013c).

Health impacts from exposure to air pollution

The World Health Organization has identified air pollution as the “contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere” (WHO, 2016b). Anthropogenic emissions from activities such as fossil fuel combustion, mining, traffic, solid waste disposal, biomass burning, domestic fuel combustion and dust disturbance or wind-blown dust are key sources of air pollution in South Africa and subsequently have an impact on human health (DEA, 2013c).

The most common health impacts resulting from air pollution in South Africa currently include acute respiratory infection, chronic respiratory diseases, tuberculosis and other respiratory diseases (Makri and Stilianakis, 2008). A national perspective suggests that indoor air pollution and urban air pollution are ranked fifteenth and seventeenth, respectively, as risk factors causing the national burden of disease. The associated air pollution health effects (namely tuberculosis and lower respiratory tract infections) were ranked third and sixth, respectively, in terms of disease prevalence in South Africa (MRC, 2008). For South Africa, the Medical Research Council (MRC) estimated that solid fuel burning caused 0.5% of all deaths (about 3000) in the country in 2000, and contributed 25% to the burden of disease from lower respiratory illness in children below 5 years of age (Norman *et al.,* 2007). It was also estimated that 0.9% of all deaths (about 4600) in South Africa in 2000 could be attributed to outdoor (ambient) air pollution (Norman et. al., 2007a).

Ambient air pollution concentrations are regulated in South Africa for the following criteria pollutants, particulate matter (PM), sulphur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), benzene (C_6H_6), lead (Pb) and nitrogen dioxide (NO_2). Atmospheric chemical processes and the transportation of pollutants have the potential to be modified as meteorological factors such as temperature, precipitation, wind speed and direction and clouds are affected (Kinney, 2008). Ground-level ozone and particulate matter are two of the significant health-related pollutants in South Africa (Silva *et al.,* 2013).

The linkages and feedbacks that exist between climate change and air quality are complex, and are extremely important in the context of public health. Air quality is heavily influenced by the weather and is therefore sensitive to climate change. In addition, particulate matter and ozone are recognised as climate forcing agents for the role that they play in their interactions with solar and terrestrial radiation (UNEP SLCP study).

Ozone and particulate matter are two pollutants that are of greatest concern when it comes to these linkages and human health (Jacob *et al.,* 2009). The formation of ozone in the troposphere requires the existence of nitrogen oxides and volatile organic compounds and occurs in the presence of sunlight. Higher temperatures and more sunlight are likely to increase the anthropogenic emissions of ozone precursors and in doing so, will facilitate greater ozone formation. Given that the photochemical production of ozone occurs in the presence of sunlight, the highest concentrations are reached at midday during summer and spring (Doherty *et al.,* 2013). Global studies have further shown that although concentrations of ground-level ozone are slowly starting to decrease in developed countries, there has been an exponential increase in the levels originating from developing countries (Lei *et al.,* 2012). Stringent standards to regulate the high emissions in developed countries and larger volumes of anthropogenic emissions generated in developing countries can account for this change (Lei *et al.,* 2012).

The seasonal variation of particulate matter and thus its residence times and atmospheric sinks is complex and further dependent on the location of the source. Particulate matter is removed most effectively from the atmosphere through precipitation and therefore generally has a residence time ranging from a few days to a few weeks in the boundary layer and the troposphere, respectively (Jacob *et al.,* 2009). Changes in the climate and consequently changes in the weather and atmospheric chemistry and dynamics, therefore effects the removal of particulate matter from the atmosphere, which could potentially be detrimental to human health. Particulate matter, specifically $PM_{2.5}$, has significant health implications due to its small particle size which causes respiratory illnesses and impacts on lung function (Fang *et al.,* 2013; WHO, 2006).

While there are no specific studies on the linkages between air quality and climate change in South Africa, it is likely that there will be an impact on human health as there is international evidence to suggest that air quality and climate change are in fact linked. With the climate changing at an accelerated rate, it is challenging to project the future impacts on air quality and because of this uncertainty, further research needs to be conducted to better understand the implications for air quality and consequently human health (Tai *et al.,* 2012).

There are also a number of non-climatic factors associated with air pollution that play a key role in human health in South Africa. Some of these factors include poverty, rapid urbanization, lack of access to basic services such as electricity, lack of education and socio-economic status. In low-income settlements, residents tend to burn dirtier solid fuels to provide for their energy needs if they do not have access to electricity. The situation is further exacerbated by the influx of people into low-income settlements in urban areas, in search of employment opportunities (DEA, 2013c). National electrification programmes have assisted in accelerating the wide-spread roll-out of electricity to a large proportion of households in low-income settlements in South Africa. There has been a steady increase in the number of households connected to the national electricity grid in recent years, with 77.1% in 2002 to 82.7% in 2011 to 86% in 2014 (Stats SA, 2012; Stats SA, 2015). This has subsequently led to a considerable reduction in residents' exposure to indoor air pollution and in turn, to the associated acute respiratory illnesses. The increased percentage of households connected to the main electricity supply does however also have climate change implications in that larger volumes of coal are being consumed at the power stations to generate the additional required electricity supply (DoH, 2014). Although there has been a significant increase in the number of informal houses connected to the national electricity grid, studies have shown that a large portion of these households continue to use solid fuels such as wood, coal and crop waste for their energy needs, for reasons relating to poverty. Household appliances that are powered by electricity tend to be unaffordable to people living in low-income settlements and as a result, these people continue to make use of these fuels (Pereira *et al.,* 2011, Matsika *et al.,* 2013).

Mental ill health

Although climate change and weather events do not directly cause mental health problems (Berry *et al.,* 2008), climate change and weather events may, through adverse situations such as heat waves, floods, veld fires, droughts, snow, and mudslides, create a conducive environment for mental health problems to occur (Berry *et al.,* 2008 in DEA, 2013c). This is also likely to result in or exacerbate the disruption of the social and biophysical life support systems (Doherty and Clayton, 2011 in DEA, 2013c).

Findings from the 2003 South African Stress and Health (SASH) study indicated a relatively high prevalence of mental disorders in South Africa, including a 12-month prevalence of 16.5% and a lifetime prevalence of 30.3% for depression and anxiety disorder, which are most common in the adult South African population (Stein *et al.,* 2009; SAHR, 2016). High rates of substance abuse were also reported (SAHR, 2016). The study further found that 75% of people with a mental disorder do not receive mental health services (SAHR, 2016).

An association has been found between acute climate events such as high temperatures and heat waves and diminished mental capacity (such as absent-mindedness) and increased hospital admissions (Hansen *et al.,* 2008; Dapi *et al.,* 2010 in DEA, 2013c). These conditions are exacerbated by mind-altering substances such as alcohol (Hansen *et al.,* 2008). Although not well-researched, sub-acute extreme weather events (e.g. prolonged drought) may cause environmental distress, and a disturbed sense of place (Myer, 2002; Berry *et al.,* 2008 in DEA, 2013c). These symptoms may be aggravated by other climate change-related issues such as loss of livelihoods, loss of shelter, disruption of family structure and social networks, and displacement and migration of populations. This may directly lead to and/or exacerbate mental health problems such as anxiety, apathy, helplessness, depression and chronic psychological distress (Myers, 2002; Berry *et al.,* 2008; *in* DEA, 2013c). Although mental health is a pervasive phenomenon, the poorest are often most affected (Fritze *et al.,* 2008; Doherty and Clayton, 2011 in DEA, 2013c). The impacts can be local as well as affecting people far away from the place where the disaster occurred (Dunn *et al.,* 2008 in DEA, 2013c).

The impact of and responses to climate change and weather events on mental health may be affected by several factors such as cultural background and perceptions of risk (APA, 2009; Willox *et al.,* 2013 in DEA, 2013c). As a result, the mental health impacts of climate change reflect significant variability among individuals, communities, and populations (APA, 2009). These factors need to be considered in addressing mental health problems in the context of climate change (APA, 2009). There is no integrative research policy guideline or framework addressing both the direct and indirect mental health effects of climate change (Berry *et al.,* 2008; Fritze *et al.,* 2008 in DEA, 2013c).

3.6.5.2.5 Cross-cutting impacts

The key current and future risks for the health sector in South Africa that have climate sensitivities are discussed above. However, there is a lack of research on the potential impact of climate change on health, and thus the impacts across risks cannot be quantified, nor can the potential magnitude of impact be compared across risks. The impact of modifying factors and other non-climate factors are also significant.

The impact to human health from climate change will have linkages across many sectors, due in part that the health impacts may not be a direct response to a change in climate variables, but rather an indirect response. Table 0.13 (environmental exposure aspects) and Table 0.14 (modifying factors) gives examples of cross-sectoral linkages to the health sector in South Africa. These were highlighted in the LTAS report. The potential environmental exposure aspects are those that are directly impacted by climate variables, and the modifying factors are those aspects that can modulate the resultant impact of climate on health. Descriptive examples are provided in the table for each aspect. It is clear that in order to mitigate the health impacts from climate change, inter-sectoral collaboration is a necessity.

Table 0.13: Summary of cross-sectoral linkages for environmental exposure aspects

Environmental Exposure Aspects	Environmental Example
Water	Water quality is directly linked to water-borne diseases
Air Pollution	Exposure to air pollution may exacerbate respiratory illnesses
Agriculture	Decrease in food supply may lead to increase in malnutrition
Natural Disasters	Flood, droughts and fires have health impacts
Ecosystems and Land-use	Land-use can impact vector distribution
Fisheries	Decrease in food supply may lead to increase in malnutrition

Table 0.14: Summary of cross-sectoral linkages for modifying factors

Modifying factors	Modifying factors Example
Human settlements and built environment	Thermal comfort of housing can impact heat stress (Maller and Strengers, 2011)
Natural disasters reduction and response	Early warning systems can impact magnitude of health effects from natural disasters
Education	Education about water pollution can mitigate water-borne diseases
Service Delivery	Continuous supply of clean water can mitigate water-borne diseases
Public Health System	Public health system with adequate resources can mitigate health impacts
Occupational Health System	Exposure and health impact of increasing temperature temperatures on outdoor worker can be mitigated through implementation of occupational heat-health plans

3.6.5.2.6 Adaptive capacity

There has not been another census since the 2011 Second Communication (StatsSA, 2011). A census survey will indicate the growth in the proportion of sensitive people to climate change in terms of age and socio-economic conditions. In terms of other factors that do make people more vulnerable, it is known that the prevalence of non-communicable diseases is increasing and these existing diseases may render people more susceptible to the effects of climate change as mentioned earlier.

In their 2015 annual report, the World Bank stressed the importance of “healthy and productive ecosystems” as the backbone of development, as these systems not only provide the air, water and soil, but also acts as a buffer against climate change (World Bank, 2015, p 20). It is envisaged that the demand for food in sub-Saharan Africa will increase by about 60% in the next fifteen years (World Bank, 2015). At the same time, it is projected that if the temperature increases more than 2˚C due to climate change, a reduction in crop yield of up to 20%, is possible in the poorest regions (World Bank, 2015). Thus, in general, the health sector in South Africa is currently facing a wide-variety of challenges that may be exacerbated by climate change. Human health impacts due to climate change may put an extra burden on the public health system. It is therefore important to act pro-actively and implement the necessary changes and improvements in the system (Mayosi *et al.,* 2012).

International goals, such as the Sustainable Development Goals (SDGs) would have impact on climate change and health. For example, in order to improve integrated water resource management and to strengthen adaptation strategies to climate change, the objectives below were stated, which would have an impact on the potential risk to water-borne diseases:

- Universal access to safe drinking water and improved sanitation;
- Improved water quality and wastewater management;
- Water-use efficiency; (Hemson, 2016).

In general, there are many policies covering climate and health linkages that could be leveraged to develop adaptation strategies for the sector, balancing opportunities and threats.

3.6.5.3 Barriers to adaptation and key evidence gaps

There are a number of barriers to adaptation for the health sector in South Africa. These can include issues such as a lack of institutional capacity in terms of staff and expertise, limited understanding and expertise in climate related issues, financial and economic constraints and poor communication and co-ordination between government departments and the public (Ziervogel *et al.,* 2014). As noted in the SANA, there is a lack of formal and supported inter-sectoral linkages between health and the environment (DOH&DEA, 2013), which would be a barrier to adaptation in the sector (Gary *et al.,* 2013).

An important barrier is the lack of data on climate-health linkages, and vulnerability and risk of communities to climate change (DEA; 2013; DOH&DEA, 2013; Gary *et al.,* 2013, Vogel, 2013). Without such data and linkages, it is not possible to begin to estimate the potential magnitude of climate change on human health in South Africa. Indeed, an important recommendation of the LTAS report was that a quantitative vulnerability and risk assessment for the health sector should be performed; this would help to identify the most important health risks, as well as begin to identify the most vulnerable populations or communities. Adaptation strategies can then be tailored to region or communities based upon their risks and vulnerability (Gary *et al.,* 2013; Ziervogel *et al.,* 2014).

The key research needs for mitigating negative health impacts from climate change were outlined in Myers *et al.,* (2011b) and are summarized in Table 0.15 below. In general, these tasks are consecutive as they build upon the evidence and knowledge gained; in South Africa, there are gaps across research tasks.

Table 0.15: Research tasks for adapting to climate change in the health sector (**taken from Myers *et al.,*** (**2011b**)**, based on framework in McMichael, 2010**)

Research Task	**Examples of studies needed**
Clarify relationships between climate variation and health outcomes	Incidence of heat-related illness in outdoor workers in plantation agriculture
Estimate, statistically, current burden of disease attributable to climate change	Use available secondary data to perform a comparative risk assessment of the burden of disease from climate change
Seek evidence of actual current health impacts	Perform a study of deaths from diarrhea among children under 5 yrs old in climate to climate variables, and climate variability
Develop scenario-based modelling to project future risk (**including handling complexity and uncertainty**)	Use scenario planning methods for high-level modelling and prediction of likely futures. These can include changes in climate factors and non-climate factors.
Estimate health co-benefits of actions to avert/reduce further environmental change	Estimate the health co-benefits of public transport systems (e.g. improvements in air pollution, more exercise)
Evaluate health-protecting actions	Evaluate the result of introducing a drought-resistant crop on rural malnutrition
Monitor for unintended consequences of adaptation	Study effects of a new drought-resistant strain of crops on whether unintentional effects such as more (or different) chemical hazards to workers emerge

3.6.5.3.1 Opportunities

For human health, no opportunities in terms of climate change could be identified from the literature searched, other than that highlighted by Willems (2012). He suggested that the climate change crisis must be used by all involved to form partnerships not only in addressing the challenges of climate change but also in living and working together, dependent on each other, in an unbiased, manner.

3.6.5.3.2 Adaptation priorities

Most of the adaptation measures in South Africa focus on reducing vulnerability to present day climate exposure, there is a need to also focus on the medium to long term changes in climate (Ziervogel *et al.,* 2014). It is expected that the largest health risks from climate change will be in communities and populations that are currently most impacted by climate-related diseases, and thus it is important to address these needs with flexible policies, programmes and systems to protect health now and into the future (Smith *et al.,* 2014; Garland, 2014). Prioritization of adaptation options for identified key health risks can be assessed through a framework proposed by Ebi and Burton (2008) that screens adaptation options by factors such as, technical feasibility, environmental acceptability, economic efficiency, degree of effectiveness, social and legal acceptability and compatibility, and the available human and financial capacity in the assessed area. However, this prioritization can only occur after the key risks and vulnerabilities have been quantified.

To ensure that the implementation of adaptation measures is going to achieve the desired outcomes, both in the present and future, basic public health systems and services (providing clean water, sanitation and primary healthcare) should be prioritised, disaster preparedness and response needs to be increased, raising awareness and education on climate change and the impacts it has or likely to have in the future needs to be communicated to communities and poverty alleviation needs to be emphasized and addressed (Gary *et al.,* 2013; Wright *et al.,* 2014).

3.6.6 Terrestrial ecosystems

3.6.6.1 Introduction

This review integrates the key findings on vulnerability of terrestrial ecosystems to climate change as documented in the Long Term Adaptation Scenarios (LTAS), the National Biodiversity Assessment Report (NBA), Climate Change Adaptation Plan for South African Biome (DEA, 2015c) and Strategic Framework and Over-arching Implementation Plan for Ecosystem-based Adaptation (DEA, in preparation). According to findings from theses assessments, climate change will have a variety of impacts on South Africa’s terrestrial ecosystems with evidence suggesting alterations in existing habitats as well as species distribution (DEA, 2013d; DEA, 2015c).

South Africa has a wealth of terrestrial biodiversity critical to its national heritage, supporting livelihoods and economic development (DEA, 2015c). South Africa is home to three of the thirty-four internationally recognisedbiodiversity ‘hotspots’ which are the Cape Floristic Kingdom, the Succulent Karoo and the Maputoland Pondoland Albany region. These ‘hotspots’ contain high concentrations of endemic plant and animal species, in areas most threatened by human activity. South Africa’s biodiversity is exposed to significant risks and the National Biodiversity Assessment (Driver et. al, 2012) found that 40% of terrestrial ecosystems are under threat and only 6.5% were reported in the Second National Communication (SNC) to have been afforded formal protection (DEA, 2011b).

The terrestrial ecosystems are delineated into nine biomes: Grassland, Fynbos, Succulent Karoo, Albany Thicket, Savanna, Nama Karoo, Desert, Forest and the Indian Ocean Coastal Belt. These biomes provide crucial ecosystem services such as soil production, water flow regulation, pollination, and natural fodder for dry-land livestock grazing. The Climate Change Adaptation Plan for South African Biomes (DEA, 2015c) states that these biomes and the ecosystems services they provide are under severe threat from the effects of climate change and non-climatic drivers such as land-use change and invasions by alien species.

The future risks to the terrestrial ecosystems of the nine provinces in South Africa are assessed in this review by making use of provincial climate narratives 3.5.5 of the chapter. The adaptive capacity of the terrestrial ecosystems is assessed to determine their resilience and that of their inhabitants to climate change.

3.6.6.1.1 Progress since the Second National Communication

Since the reporting of the SNC, there has been considerable progress in both knowledge around impacts of climate change on terrestrial biodiversity and development of frameworks, adaptations plans and policy(Figure 0.69).

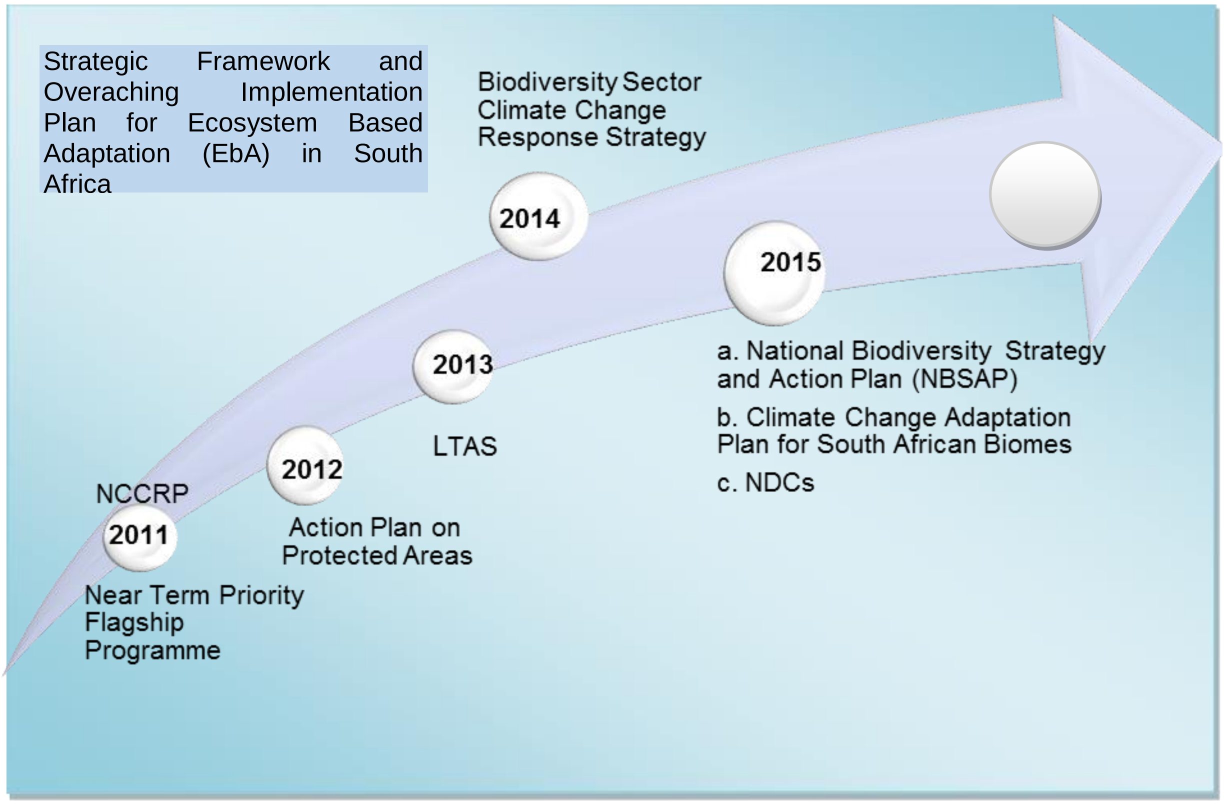

Figure 0.69: Timeline of National Climate Change Policy and Framework relevant to the terrestrial ecosystems

National Action Plan for Protected Areas

The National Action Plan for Protected Areas was submitted to the Convention on Biological Diversity in 2012. The implementation plan has set action targets that indicate how much of each ecosystem should be included in protected areas and help to focus protected area expansion on the least protected ecosystems. This Action Plan outlines South Africa’s 20 year target of increasing land-based protected areas from 6, 5% to 12%. Figure 0.70 provides an overview of the current protected areas across South Africa and the status of ecosystems according to four classes of endangerment.

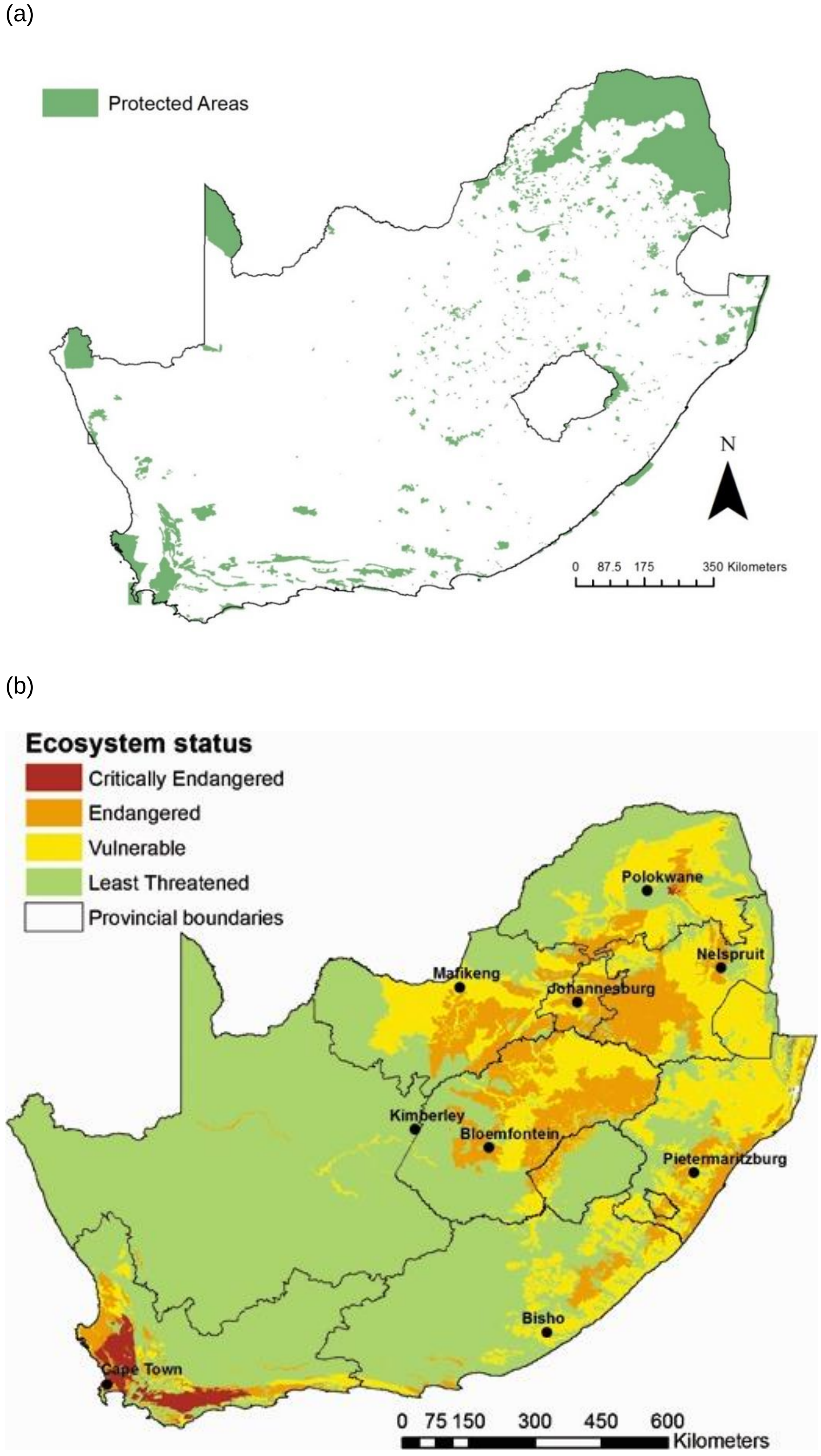

Figure 0.70: (**a**) **Map of the Conservation Areas and Protected Areas** (**PACA**)**. Data source: DEA Protected Areas Database and** (**b**) **Map of Ecosystem Status** (**NBA, 2012**)

National Climate Change Response Policy

The National Climate Change Response Policy (NCCRP) addresses the management of invasive alien species through Near Term Priority Flagship Programmes. One of these Priority Flagship Programmes is the Expanded Public Works Programme (Working for Water and Working on Fire). The Working for Water under the Expanded Public Works Programme is a significant programme with the objective to manage and control alien species invasion.

Long Term Adaptation Scenario Programme

The LTAS Biodiversity Report has prioritized action to be taken, based on the vulnerability for both climate change and land-use (DEA, 2013d). The species approach was undertaken in LTAS to model climate change impacts on 623 bird species to gain an understanding of the potential range shifts of a taxon with highly mobile individuals (DEA, 2011c). The LTAS species approach used birds for two reasons (i) birds are potential indicators of climate responses and (ii)birds are the focus of a national monitoring effort that engages thousands of amateur and professional bird watchers which has been used to build a significant database of changing bird distributions across South Africa.

Climate Change Adaptation Plans for South African Biomes

The aim of the Climate Change Adaptation Plans for South African Biomes DEA, 2015c) was to “identify and prioritise adaptation actions which apply to the broad South African landscape covering ecosystems which occur within it, the species which make up those ecosystems, ecosystem services, and various cultural and economic activities which take place in and depend on those landscapes” (CSIR, 2015). The draft progress report on the implementation of climate change adaptation plans for SA biomes demonstrates the progress in terms of implementing the adaptation options. Key gaps identified are draft is that there is still a lack of monitoring and evaluation on the effectiveness of the adaptation options at biome level as well a lack of awareness and outreach on the impacts of climate change on biodiversity and ecosystems.

Ecosystem Based Adaptation Strategy

The Ecosystem Based Adaptation (EbA) strategy aims to integrate the sustainable use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change (https://www.environment.gov.za/sites/default/files/docs/nas2016.pdf). The EbA Strategy is currently being implemented and is is guided by a vision that seeks to align the work on EbA to the overall objective of the NCCRP. Therefore, the afore-mentioned vision indicates that “Ecosystem-based adaptation (EbA) is implemented as part of South Africa’s overall climate change adaptation strategy in support of a long-term, just transition to a climate-resilient economy and society. The strategy will achieve its mandate through four priority areas covering coordination and communication; research; strengtheningof priority sectors and EBA flagship projects as outlined in

Figure 0.71 as laid out in the 2015 National Biodiversity Strategy and Action Plan (https://www.environment.gov.za/sites/default/files/docs/nas2016.pdf).

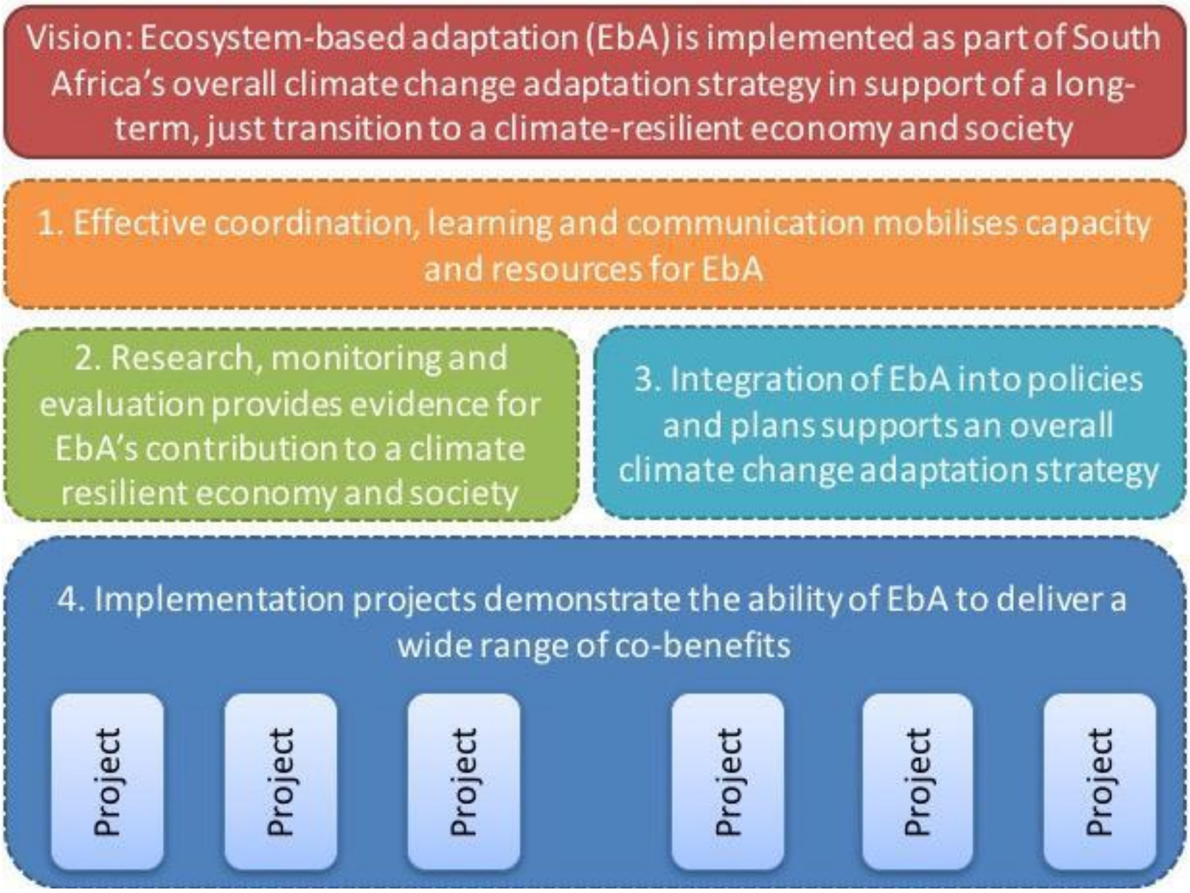

Figure 0.71: Overview of the EbA Strategy (**DEA and SANBI, 2016**)

Biodiversity Sector Climate Change Response StrategyHealthy ecosystems are critical to human well-being and the quality of life. In order to provide guidance on the development of national adaptation biomes response to climate change and its potential impacts, the framework was developed (DEA 2014). The policy framework mandate is to address climate change response of both biodiversity and ecosystem resource and their interaction with natural resources.

3.6.6.2 Vulnerability to climate change

3.6.6.2.1 Invasive alien species and bush encroachment

Expansion of invasive plants could reduce the integrity of all South African biomes by reducing indigenous plant and animal species. Through the Working on Fire program substantial progress has been made in controlling and managing bush encroachment. In other areas of the country there has been other mitigation measures applied in managing bush encroachment, as illustrated in the case study (Box 0.14: Bush Encroachment Mitigation: Molopo Savanna).

Box 0.14: Bush Encroachment Mitigation: Molopo Savanna

The Molopo Savanna is located in the bush encroachment mitigation study undertaken at Molopo within the Northern Cape and North West Provinces. Bush encroachment greatly affects rangeland productivity. The Molopo Savanna was 40-45% encroached and as result there was 82% decline in forage productivity and 80% decline in grazing capacity (Picture 2). Three of three mitigation actions were implemented to reduce the cover. Over a period of 4 years the Molopo Savanna had regenerated with a co-existence of grass and woody plants (Pictures 2 and 3).

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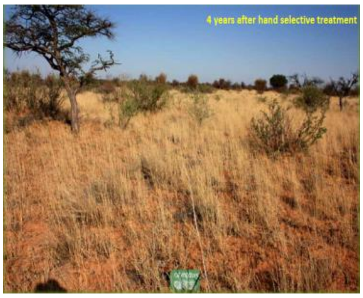


3.6.6.2.2 *Species based approach to assess impacts climate change*

The bird species richness modelled under current climate conditions in Southern Africa is highest in association with the high altitude regions of the Drakensberg and eastern coastal escarpment. The projected species range change reflects a slightly greater concentration of species in the high altitude regions, and lower concentrations in more arid regions. Overall, the modelled loss of richness is lower than projected in earlier studies on animal species.

The range shift projections for bird species in South Africa indicate a low risk for significant bird range shifts that result in species losses is presented in Figure 0.72. As a result of predominantly climate change associated temperature and rainfall changes in a few key areas the risk is high where high potential rates of species richness loss is projected (DEA, 2013d). The Kgalagadi Tranfrontier conservation, central region area is known to be an area at risk of potential aridification and desert biome expansion and has high potential rates of loss in birds' species richness projected. On the northern region of KwaZulu-Natal Province, towards the north-eastern boundary of South Africa there is greater risk projected for loss of bird species richness, along the border with Mozambique and the Limpopo basin (DEA, 2013d).

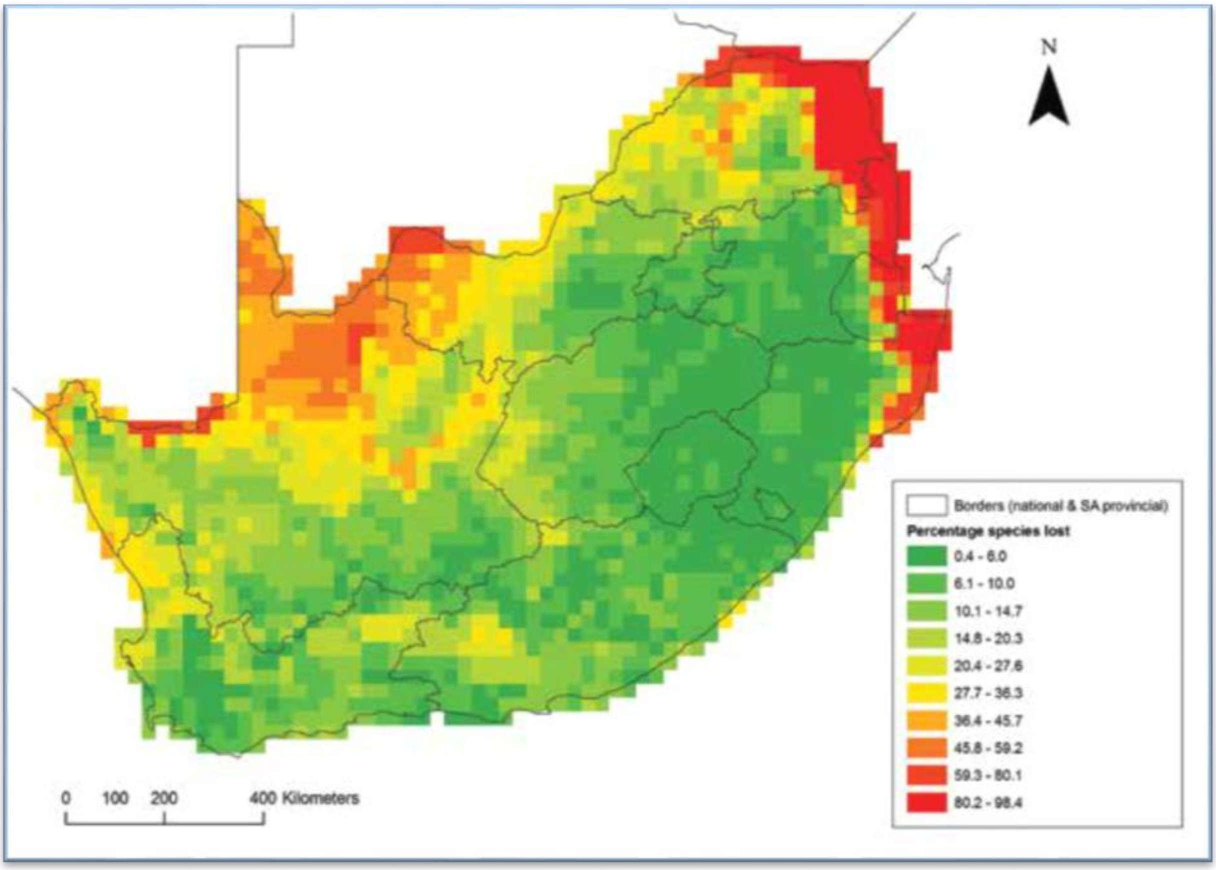


Figure 0.72: Projections of bird species richness loss for South Africa under future climatic scenarios to approximately 2050 (**DEA, 2013d**)

3.6.6.2.3 Future risks

Biome envelope modelling approach to assess impacts of climate change

Each of the nine biomes in South Africa has a specific climate envelope or a particular environment controlled by rainfall and temperature which is ideal for the biome to thrive. The changes in both temperature and rainfall as a result of climate change will influence the areas where the biomes will continue to thrive and as a result, the area suitable for one biome might become more suited to another, putting stress on the ecosystem and its inhabitants. In a situation where these climatic changes occur over long periods of time, the biomes are able to adapt and shift in response, but if the changes are accerelated, occuring over shorter periods of time, as a result of climate change for instance, the biome and the species might not be able to adapt of shift, resulting in species being lost. This is a big threat especially in biomes that are already degraded or fragmented (DEA, 2013d ; Driver *et al.,* 2012).

The Phase 1 of the LTAS Biodiversity Report categorised Terrestrial Ecosystems (biomes and species) vulnerability to climate change impacts and land use change, taking into consideration both climatic and non-climatic factors. When combining the threats of land-use and climate change, the

Grassland, Indian Ocean Coastal Belt, Fynbos, Forest, Nama Karoo and Succulent Karoo biomes were identified as the most vulnerable to both climatic and non-climatic threats and in need of strong protection, restoration and/or research to ensure adaptation benefits for vulnerable communities under future climate conditions.

The summary of the findings of the LTAS indicate that significant change and loss of habitat is projected for the grassland biome, due to climate change. This is likely to be related to the high altitude location of the biome and its susceptibility to warming effects, as well as the possible increase in tree cover due to a longer growing season and CO_2 fertilisation. The savanna biome, on the other hand, is projected to expand with its geographic range partly replacing grassland. However, an increase in woody cover could shift the structure of some areas of the savannah biome towards woodland and even forest.

This will increase the opportunities for bush encroachment and the invasion of woody plants (alien and indigenous) into the grassland biome with major implications for the delivery of ecosystem goods and services to people, notably water delivery from highland catchments and grazing. Such shifts have extremely important implications for conservation and ecosystem services delivery, as well as ecosystem processes such as wildfire. Figure 0.73 shows the projections of biome shifts under low, medium and high risk climate scenarios to approximately 2050 (DEA, 2013d).

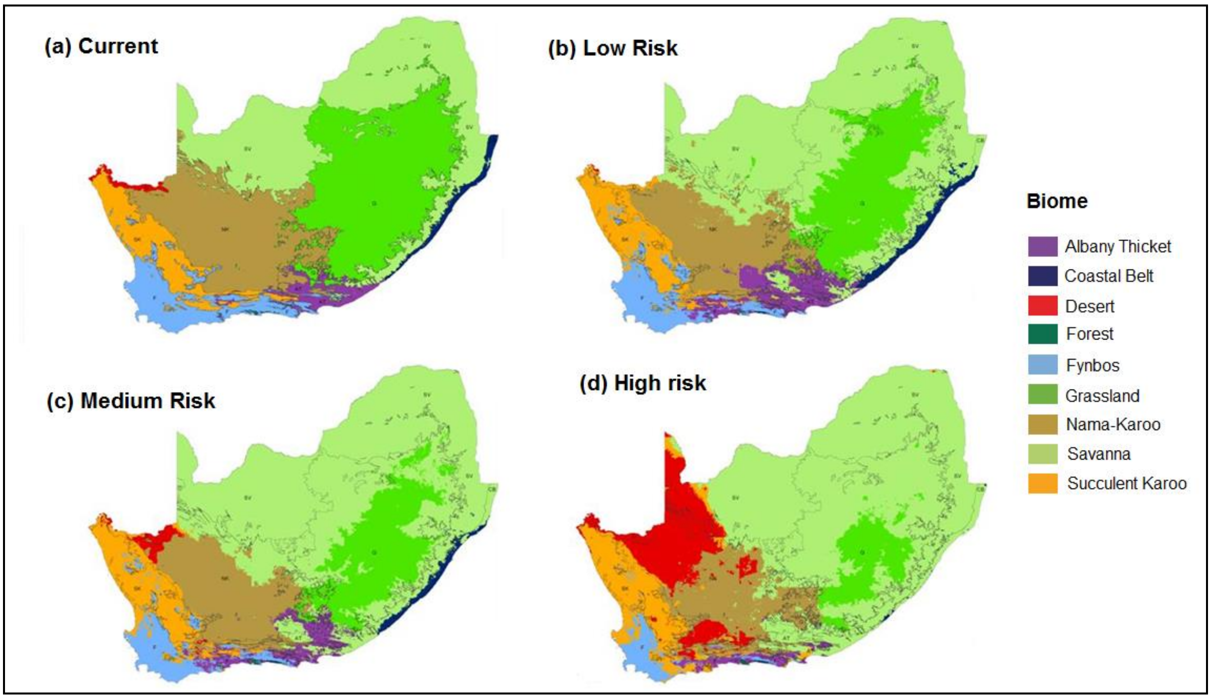


Figure 0.73: Predictions of biome climate envelopes under difference climate scenarios by 2050 as described by Driver *et al.,* (2012). The future scenario is based on 15 downscaled global circulation models and the A2 emissions scenario

The Desert Biome

The desert biome is located in the Northern Cape Province only, with a small area located on the border of the province with Namibia. The area is characterised as semi-arid to arid with an average rainfall of 70mm per year. Rainfall is mainly received through infrequent rainfall events, the passage of rare winter cold fronts and occasional convective rainfall events during the summer. In terms of temperature, the province experiences average summer daytime temperatures of over 32°C, and the province is generally 2°C hotter than the rest of the country with at least 30% of the days in January exceeding 36°C. The night temperatures drop to below 0°C on occasion. The western coastline is subjected to coastal fog which is a source of water in this arid environment.

The hotter and drier climate projected for the Northern Cape Province will favour the desert biome, with the biomes expected to increase in extent over time. The reduced rainfall, especially the rainfall associated with the cold fronts along the west coast will favour the desert biome. The Desert Biome climate envelope is likely to expand greatly under both futures, and will encroach on current areas of both the Succulent Karoo Biome and large parts of the northern Nama Karoo Biome. The same trend is noted under the climate scenarios from the Long Term Adaptation Scenarios, which modelled changes in the climate envelop under high, medium and low risk scenarios of climate change. Under the high risk scenarios, the desert biome is expected to expand into central southern areas of the Northern Cape and a small part of the Eastern Cape on the border with the Western Cape as well as northern areas of the Western Cape Province.

Nama Karoo Biome

The Nama Karoo biome is located in four provinces in South Africa, namely; Northern Cape, Western Cape, Eastern Cape and a small part in the Free State province. The largest area of the biome is found in the Northern Cape Province which is one of the driest provinces in the country. The Nama Karoo is located in the arid areas inside the country with rainfall in this biome varying from 60 – 400 mm per year. Rainfall in the biome is erratic. The biome is also located in areas of high temperatures reaching as high as 30°C and temperature drops to 0°C.

The climate areas across all the four provinces where the Nama Karoo is located will experience increases in temperature and reduction in rainfall, which will affect the climate envelope for the Nama Karoo. The climate envelope found in large areas currently representative of the Nama Karoo Biome is likely to resemble arid Savanna Biome under the high mitigation/low-risk and intermediate scenarios, and a Desert Biome climate envelope under the low mitigation/high-risk scenario. The extent of the Nama Karoo in the Northern Cape will be pushed down to the central southern area while the biome will extend in the Eastern and Western Cape Provinces. Some areas in the Free State will be replaced by the arid savannah in the south west of the province. Under the high risk scenario in LTAS, this biome will completely disappear in the Free State Province.

Succulent Karoo Biome

The Succulent-Karoo biome is found mainly in the Northern and Western Cape Provinces mainly along the west coast and small parts of the Eastern Cape Province. This biome receives winter rainfall and which is characterised by low but fairly reliable rainfall and average summer temperatures of 16°C. The biome experiences high aridity in the summer months and occurs above 100 meters above sea-level.

The Succulent Karoo biome is a coastal biome and is expected to thrive under the cold west coast conditions and will remain constant across the current areas of occurrence. The biome will experience minimal changes in the extent of its climate envelope. The Succulent Karoo biome might replace the Fynbos biome in the parts of the Western and Eastern Cape while the desert biome will replace the Succulent Karoo in the Northern Cape.

Grassland Biome

The Grassland Biome occurs in the central interior of the country, occupying most of the Free State Province and parts of other provinces such as North West, Gauteng, Mpumalanga, KwaZulu-Natal, Eastern Cape and small parts of the Western and Northern Cape. The biome is characterised by summer rain with as much as 400 to 1200 mm per year received with the temperature ranging between frost-free to snowy winters. This biome is not well protected and is one of the most threatened, mainly as a result of land use change.

The projected wetter and drier cycles as well as the anticipated increases in temperatures in the interior of the country, regardless of what province it is, will negatively impact the grassland biome. The areas of the biome found at high altitudes are the worst affected, and will experience the most loss. According to the LTAS scenarios, the grassland biome will shrink in all provinces especially under the high mitigation scenario. Similar trends of decrease in the biome across the provinces are projected.

Forest Biome

The indigenous Forest Biome occupies the smallest areas (4%) and is located on the southern coast plains and at high altitude areas of the Western Cape, Eastern Cape and along the Kwa-Zulu Natal Province coastline. The areas where the biome is located are protected from fire and are frost free and the areas receive mean annual rainfall of 525 mm of winter rainfall and more than 725 mm in the summer months.

The projected changes in rainfall along the Eastern Cape coastline as a result of additionally, increased ocean temperatures in the warm Agulhas current will produce intense local convective storm systems, resulting in more intense heavy rainfall events in the coastal plains and mountains. The higher temperatures expected in the province will result in increased evaporation, which will in turn result in increased dryness. A hotter and drier climate is not ideal for the forest biome and is expected to drastically reduce in extent as a result of the increased dryness and reduced rainfall. The increased dryness will result in decreased moisture which is essential for the optimum growth of the biome.

Albany Thicket Biome

The Albany Thicket Biome is mainly located in the Eastern Cape Province with very small patches found in the Western Cape. The biome is primarily found in areas where the rainfall is between 200mm and 1050mm per year and it is located along the river valleys and where there are no fires. Parts of the biome are located within the Baviaanskloof Nature Reserve resulting in this biome being well protected.

The Albany Thicket forest is dependent on winter conditions associated with the cold fronts that will continue to occur in the Eastern Cape, despite expected changes in the frequency and duration of the cold fronts. According to the LTAS scenarios, the Albany Thicket biome will persist under the low-risk and intermediate climate scenarios, but may be replaced by Nama Karoo and Savanna conditions under the high-risk scenario.

Fynbos Biome

The Fynbos Biome is located in the Western Cape Province with small patches found in the Eastern and Northern Cape Provinces. The rainfall averages between 210mm in lowlands and up to 800mm in the mountains. Fire is a critical part of the ecosystem essential for the management of the biome.

The northern and eastern areas of the Fynbos Biome are likely to experience climate stress due to increased temperatures and extreme events such as very hot days and high fire danger days that increase the frequency and intensity of wildfires. The climate envelopes in these areas might become more like the Succulent Karoo and Albany thicket biomes under all LTAS climate scenarios. However, the main Fynbos areas located in the mountains areas will likely be least affected by changes in climate and will remain within their climate envelope.

Savanna Biome

The Savanna Biome is the largest biome in the country and is found in all the provinces with the exception of the Western Cape. The biome is acknowledged to be one of the most resilient to changes in the climate because of the diversity found in its flora and fauna. The climate envelope for the biome ranges from semi-arid areas to coastal lowlands. The biome receives an average rainfall of between 50mm and 750mm per year. The biome is reasonably protected in some areas but poorly protected in others.

The diversity found within this biome may be attributed to the reason why the biome is resilient to change in the climate. The climate envelope suitable for Savanna Biome is likely to expand significantly in the future, and specific savanna species are likely to benefit. The increases in temperature expected across the country as well as increases in the hot spells in provinces such as the Free State and Mpumalanga will result in a drier and hotter climate suitable for savanna biome. The reduction in rainfall and the contribution of increases in evaporation, resulting in drier climate will also continue to favour the Savanna, with the arid savanna expected to gain in extent, especially in areas where the biome borders the Grasslands, Nama Karoo and the Coastal belt.

Coastal Belt Biome

The Coastal Belt Biome, also known as the Indian Ocean coastal belt is found along the eastern coastline, along the KwaZulu-Natal and Eastern Cape. This biome receives rain all year long with an average of between 819mm and 1272mm and temperatures between 19°C and 22°C. The biome experiences hot to very hot summer, with mild winters, and is moderately well protected.

The Indian Ocean Coastal Belt is the third most threatened biome and it is expected that large areas of this biome will be replaced by the savanna biome. The heavy dependence of the climate envelope on water puts it at risk, especially the increases in temperature that will increase dryness, despite the projected increases in rainfall for the two provinces. However, in areas where the moist conditions are expected to continue, the biome might increase in extent. According the LTAS projections, the changes in the climate envelopes for the coastal biome will result in drastic reduction of the biome.

The changes in the climate envelopes for all the biomes in the country will be dictated by changes in rainfall and temperature, whereby increases or decreases will either benefit or disadvantage the current biome extents. This will have far reaching impacts on the ecosystem services provided by these biomes, including the role of the biomes in helping communities to be climate resilient and adapt to climate change.

3.6.6.2.4 Cross-cutting impacts

Climate change impacts on one biome can have impacts on various sectors of the economy of South Africa. Table 0.16 provides a summary of vulnerability of each biome to key climatic changes as well as the cross cutting sectors that are impacted. The biomes presented are only those that have been identified and categorised by the LTAS to require the highest, high and medium action plan.

Table 0.16: Climate risks for each of the biomes assessed, priority action and crosscutting sectors impacted (adapted from DEA, 2013d and DEA, 2015c)

Priority Action	Biome	Climate risk	Cross-sector impacts
Highest	Grassland	Increased temperature and CO_2 will result in the invasion of savanna-like biome. Condition and major shrinkage of the spatial area of the biome Increased. Fire intensity and likely mega fires Increased temperature may limit livestock, and in particular dairy cattle More intense rainfall especially if coupled with overgrazing will intensify erosion	Agriculture
	Indian Ocean Coastal Belt	Potential invasion of savanna type vegetation Change in the proportion of forest versus grassland, linked to changes in fire regime and climate Extreme high temperatures will make domestic livestock raising unviable	Nature based Tourism
High	Fynbos	Increased intensity and frequency of fires and more “out-of-season” fires Alien invasive species, especially grasses in lowland ecosystems Habitat transformation/fragmentation, particularly on the lowlands through agriculture and urbanisation	Tourism Water Agriculture
	Forest	Extreme high temperatures may increase destructive fires Heat intolerant Afrotemperate forests most at risk from temperature increase All forest types vulnerable to decreasing rainfall, with swamp forest and other water-table depth forest systems being vulnerable to changes in groundwater recharge	Biodiversity based economy (e.g. Medicinal plants)
Medium	Nama Karoo and Desert	High temperatures exceeding comfort thresholds for most species of livestock, including wildlife management. High temperatures coupled with certain rainfall thresholds linked to increased pests and pathogens in particular areas Possibly higher frequency of extreme rainfall events implications for all sectors, including disaster management	Ecotourism Agriculture Water
	Succulent Karoo	Extreme high temperatures will place constraints on livestock productivity Higher temperatures could result in the range contraction of succulent plant species Reduced rainfall and increased drought frequency could result in a reduction in forage quality and quantity	Tourism Primary Livelihood (grazing) Biodiversity based economy (e.g. game farming)
	Savanna	Extremely high temperatures will make domestic livestock challenging and may lead to a sudden switch to other nature based ventures More summer rain and rising CO_2 will lead to an increase in bush encroachment and expansion of the savannah into grassland and Indian Ocean Coastal Belt biomes Rising CO_2 will also lead to high risk of alien woody plant invasion particularly in highly degraded rangelands	Tourism Water Game farming
	Albany Thicket	Extreme high temperatures will make domestic livestock raising unviable More summer rain and rising CO_2 will cause encroachment of savanna-like condition in the northeast More intense rainfall will cause soil capping, flash flooding, erosion and poor recharge	Agriculture

3.6.6.2.5 Adaptive Capacity

The anticipated changes in climate and the resulting impacts that have been identified for the different biomes will not only affect the provision of ecosystem services, but will also compromise the adaptive capacity or resilience of the biomes and their inhabitants to climate change. Biomes need to provide a buffer for communities affected by climate change and other stressors.

Adaptive capacity will also allow ecosystems to take advantage of the opportunities presented by climate change, and is a dynamic process, influenced by natural, social and economic factors, as well as social and institutional networks (UNEP, 2011). Adaptive capacity or the resilience of an ecosystem will allow the system to absorb the anticipated changes, re-organise itself so as to retain its characteristics and ecological function (Driver *et al.,* 2012). Understanding the potential resilience or adaptive capacity of ecosystems to climate change, as well as the importance of the ecosystems in assisting communities to cope with and respond to climate change is essential for planning purposes. The areas where biome climate envelopes are expected to remain unchanged or retain their composition and structure in the face of climate change, provide opportunities for new and existing conservation of these biomes. Figure 0.74 shows the areas of biome stability and changes in their envelopes under various scenarios, throughout South Africa.

Areas of biome stability (dark green areas) as modelled under the different LTAS scenarios are predicted to stay within their current climate envelopes and are likely to maintain a stable ecological composition and structure. The white areas however indicate areas where biomes are most at risk of change in composition and structure in the face of climate change (Driver *et al.,* 2012). The areas of biome stability coincide with the biomes that will be less affected by climate change, such as the savannah, parts of the Nama and the Succulent Karoo and smaller parts of Grasslands. The areas of biome stability will support the resilience of natural ecosystems to adapt naturally to climate change. In these areas, the biomes will continue to provide a myriad of ecosystem services as well as assist communities to cope with the adverse impacts of climate change (Driver *et al.,* 2012).

The future implications for these losses are severe especially for the livelihoods and economic sectors dependent on the ecosystem functions and services. These sectors will be severely affected by the increases in temperature and increased water insecurity across the country resulting in a decline in overall human wellbeing. Therefore, adaptation responses to these changes need to take into account the multi stressors affecting terrestrial ecosystems over and above climate change. The areas of biome stability are expected to contribute immensely to the resilience of biomes confronted by climate change. The factors presented in Table 0.17 are considered to be critical for supporting the resilience of terrestrial ecosystems to climate change provided they remain intact and retain their ecological function and ecological infrastructure (Driver *et al.,* 2012).

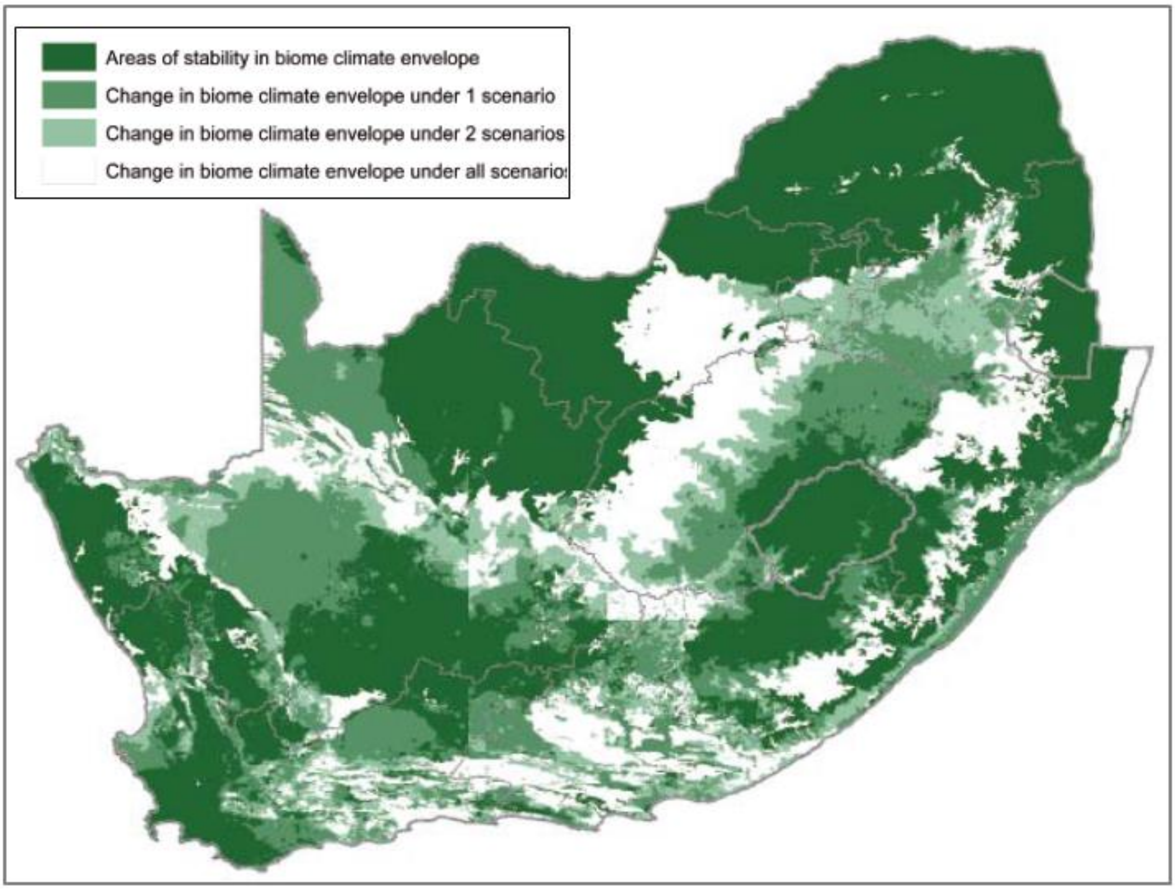


Figure 0.74: Areas of biome stability in the face of climate change, under a range of climate scenarios, according to niche modelling results using statistically downscaled future climate scenarios only (**Driver *et al.,* 2012**)

Table 0.17: Factors that will contribute to the adaptive capacity of terrestrial ecosystems to climate change **(**Driver *et al.,* 2012**)**

River corridors and buffers of natural riparian vegetation provide important connectivity in the environment, allowing ecosystems and species to respond to climate change.
Intact coastal ecosystems provide vital connectivity in the landscape to enable ecosystems and species to respond to climate change.
Maintaining these areas is imperative so as to enable species and ecosystems to speedily adapt to changing climate. These are areas where the shortest possible movements are needed for a species or ecosystem to remain within its acceptable climate envelope. These areas coincide largely with the country's high water yield sub-catchments, which are responsible for the majority of South Africa's water supply.
These areas have comparatively high numbers of biomes, vegetation groups or vegetation types (diverse set of habitats, landscapes and microclimates) occurring in close proximity and are essential to support biodiversity adaptation capacity
Areas that containing exceptionally high diversity of species, many of them endemic. Species in these areas have survived changes in climate in the past and are essential for supporting biodiversity adaptation capacity.
These areas are inclined to be wetter and cooler than the surrounding environment and epitomise key shorter term refugia which enables species to persist in regions, (such as most of South Africa) that are expected to become warmer and drier.
These areas contain existing protected areas and large areas identified as priorities for protected area expansion, to meet biodiversity targets for terrestrial and freshwater ecosystems

3.6.6.3 Balancing opportunities and threats

3.6.6.3.1 Barriers to Adaptation

The effective implementation of the biodiversity sector plans and other frameworks is a challenge that creates a barrier to adaptation. This is as a result of limited capacity to carry out effective land-use planning particularly at sub-national level and decision making. Thus the implementation of national and provisional climate change adaptation strategies is mostly dependent on increasing human capacity and financial resources at local, provincial and national government (Peterson and Holness, 2011).

3.6.6.3.2 Key Evidence Gaps

Ecosystem Management- Invasive Alien Species

The LTAS on Biodiversity (DEA, 2013d) has identified gaps in the understanding of the rates of spread of invasive species. Working for water as an initiative on ecosystem management to address invasive species, is not fully adequate in addressing such a complex problem (Richardson and Van Wilgen, 2004; *van Wilgen, 2012*). Thus in determining effective measures and solutions van Wilgen suggests that research is required to guide interventions such as:

- Development of early detection means of invasive alien species.
- Approaches to quantify impacts of invasive alien species based on sound ecological understanding.
- Strategies to deal with significant conflict of interest that arise when invasive species also provide benefits in other areas.

Expansion and Monitoring - Protected Areas Expansion

The pace and scale of implementation of the set target to increase the protection of terrestrial ecosystems areas from 6.5% to 12% by 2020 to contribute to climate change adaptation needs to be increased (Peterson and Holness, 2011). In addition, the development of the monitoring and evaluation programme that has measurable criteria to assess the success of restoration, protected areas extent (DEA, 2014f) and better land use planning will be critical to track progress on the implementation of these targets (Peterson and Holness , 2011). The 5th World Parks Congress Report in 2014 highlighted that South Africa has 124 Important Bird Areas (IBA) covering over 14 million hectares of habitat, with only 41% of the total land surface covered by our IBA being legally protected (DEA, 2014f).

Continuous technical support- Workplace Capacity Building

The South African report on ecosystem-based planning for climate change has indicated that in order to overcome the barriers to adaptation, the biodiversity sector needs to support users and implementers of Biodiversity Sector Plans and provide continuous workplace based support (Peterson and Holness, 2011).

3.6.6.3.3 Opportunities

Significant opportunities exist in the implementation of the limate Change Adaptation Plan for South African Biomes"and the Ecosystem Based Adaptation Strategic Framework and overaching implementation planincluding different responses for different biomes and actions that have benefits beyond adaptation, such as linkages to national development planning and priorities. For instance, in the case of grassland, adaptation opportunities may include adjustment of land proportions, and optimisation of protected areas, which are recommendations under a variety of scenarios, including climate change. In the case of the desert biome, education, outreach and extension are considered critical given the need to balance competing requirements for water, and require up to date information and extension/advice to do so.

In addition, evidence-based information at the local scale on the impacts of climate change on biomes is essential to guide land-use management and policy decisions; that will be guided by knowledge on exactly how the projected climate-driven changes are likely to manifest in the context of the complex range of land-use activities. Currently, some of the local scale information does not conform to the projected impacts by climate envelope modelling; and this often results in challenges in the development of biome specific adaptation measures at local level. According to Midgley *et al.,* (2012), key best practices that must be undertaken in Ecosystem Based Adaptation include:

- Stakeholders involvement in adaptive planning and implementation
- Development of locally contextualised adaptation measures
- Linking to national, provincial and local scale ‘enabling’ frameworks
- Considering adaptation within the broader landscape
- Ensuring safeguarding against risks and costs
- Financial sustainability a key consideration from the start
- Development of monitoring and evaluation.
- Tracking of cost effectiveness and resilience outcomes.
- Establishment of learning networks and communities of practice.

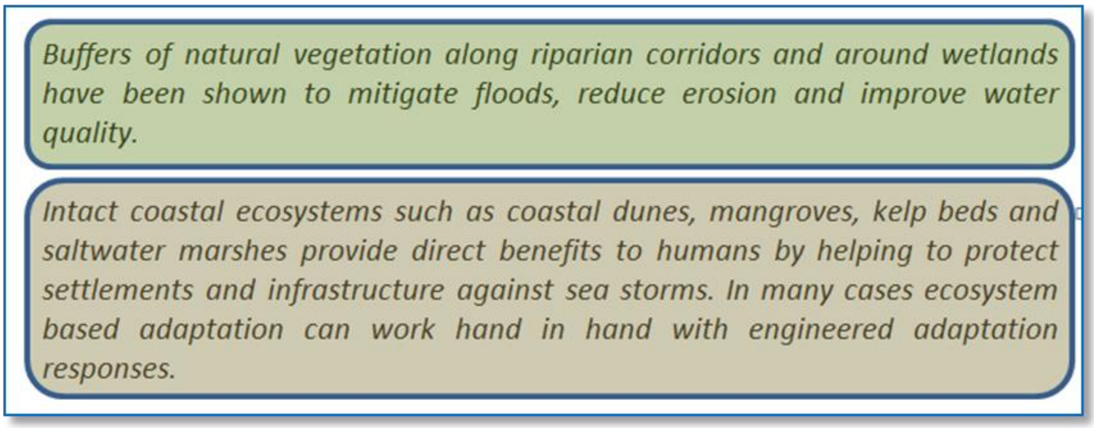
3.6.6.4 Adaptation Priorities

3.6.6.4.1 Ecosystem Based Adaptation (EbA)

The approach of utilising healthy and intact ecosystems as cost-effective and convenient responses to the impacts of changes in climate and variability; has recently emerged as a critical factor for adapting to climate change and referred to as ecosystem based adaptation (EbA). Ecosystem based adaptation is defined by the Convention of Biological Diversity (CBD) as “the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change”. This approach is also supported by the National Climate Change Response Policy. The Biodiversity Sector Climate Change Response Strategy (2014) is instrumental in identifying opportunities for climate change response using EbA for sustainable livelihoods, (https://www.environment.gov.za/sites/default/files/docs/nas2016.pdf; Driver *et al.,* 2012). This will benefit rural poor communities that are directly dependent on natural resources for their livelihood and given the fact that EbA measures are cost effective and more accessible to the communities in need (https://www.environment.gov.za/sites/default/files/docs/nas2016.pdf).

The approach of using EbA, promotes the maintenance and integrity of ecosystems through the management, conservation as well as restoration of ecosystems rather than relying on engineered solutions that are expensive and some might have negative impacts on the environment. In many cases EbA approaches may be used to complement engineered solutions. Other tools that can be used for EbA, maintenance will include environmental impacts assessments, land use planning, and the expansion of current protected areas. Working with the private sector such as agriculture, mining and forestry is encouraged to reduce the carbon foot print. EbA is particularly effective for coping with or adapting to extreme events such as floods and storms (Driver *et al.,* 2012). Figure 3.75 provides examples of Ecosystem based Adaptation measures that can be introduced to promote and protect the integrity of ecosystems.

The process of maintaining and restoring ecological infrastructure for EbA has other societal benefits which include the creation of employment and the contribution to livelihoods in rural and poor communities across the country. Cases or areas where the ecosystems require rehabilitation are where land use or other factors have affected the integrity of the system and therefore an intervention is required, such as the clearing of alien invasive species along rivers to increase water supply and allowing the ecosystem to recover on its own (Driver *et al.,* 2012).



Buffers of natural vegetation along riparian corridors and around wetlands have been shown to mitigate floods, reduce erosion and improve water quality.

Intact coastal ecosystems such as coastal dunes, mangroves, kelp beds and saltwater marshes provide direct benefits to humans by helping to protect settlements and infrastructure against sea storms. In many cases ecosystem based adaptation can work hand in hand with engineered adaptation responses.

Figure 0.75: Examples of Ecosystem Based Adaptation Measures

Areas of natural habitat that support functional stable landscapes and the continued provision of ecosystems services in the long term. Figure0.76 will contribute to the ecosystem based adaptation and conservation, benefitting both the ecosystems and the communities that dependent on them (Driver *et al.,* 2012). The areas which provide the optimum benefit and value for the communities are still to be identified from those mapped in Figure0.76. The biodiversity of South Africa is still relatively intact compared to many developed countries, thus the country is better able to take advantage of the opportunities offered by our ecosystems through the implementation of EbA (Driver *et al.,* 2012). The Ecosystem based Adaptation strategy is expected to benefit and address three outcomes namely, socio-economic, climate change adaptation and biodiversity conservation. To ensure that all the outcomes of EBA are met, the Biodiversity Sector Climate Change Response Strategy (2014), the Climate Change Adaptation Plan for South African Biomes (2015), and the revised National Biodiversity Strategy and Action Plan (NBSAP) (2015) acknowledge the importance of EbA and an implementation plan for the achievement of the EbA set targets by the year 2020(SANBI, 2016).

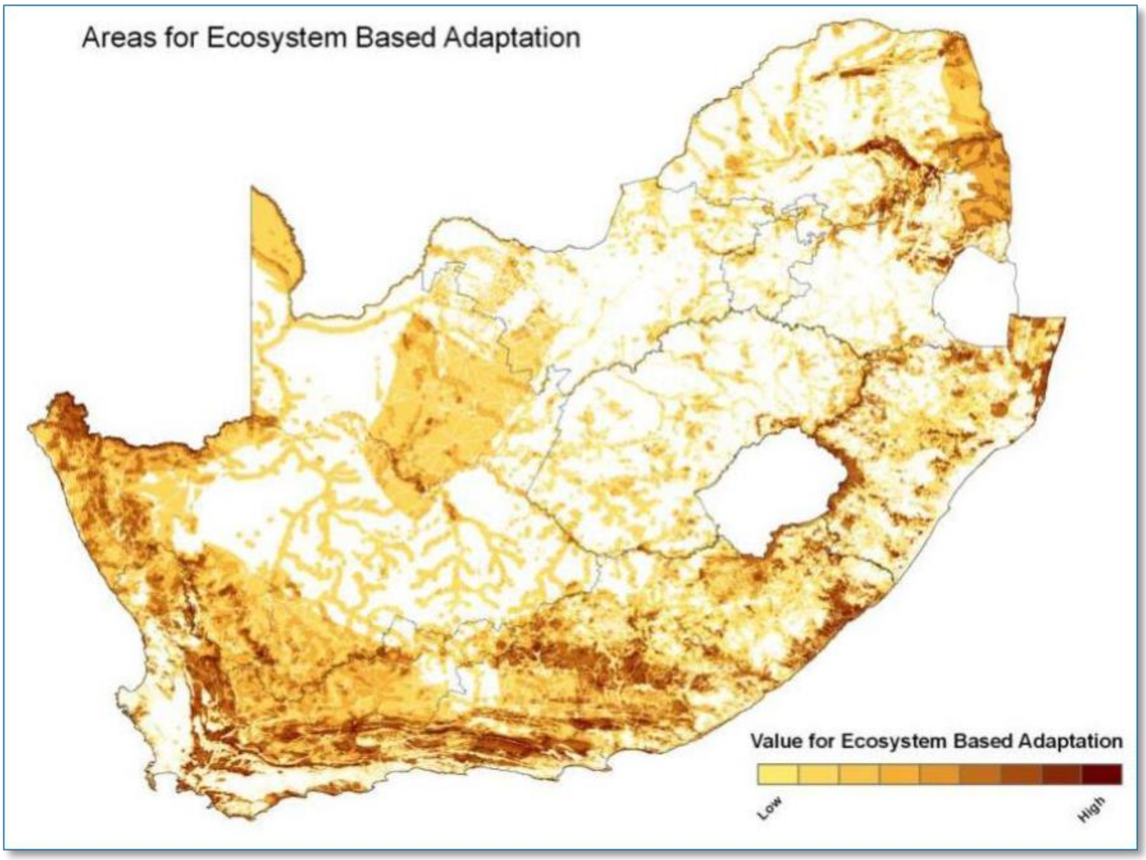


Figure0.76: Areas of natural habitat that support functional stable landscapes and continued provision of ecosystems services in the long term (**Driver *et al.,* 2012**).

The NBSAP acknowledges the critical role of biodiversity management for the achievement of EbA. Co-benefits need to be achieved through a coordinated approach and that will assist in achieving the expected multiple-benefits of helping people to adapt to climate change within the context of sustainable development. The following are four key focus areas that have been identified as being essential for the achievement of EbA outcomes (DEA and SANBI, 2016) include

1. Effective coordination, learning and communication mobilises capacity and resources. This is necessary to best mobilise resources and enhance capacity for EbA in a way that supports sustainability, replication and upscaling. Demonstrating EbA as a valid and cost-effective adaptation option as part of the overall adaptation strategy.
2. Research, monitoring and evaluation provide evidence for EbA‟s contribution to a climate resilient economy and society. This is required to address knowledge gaps, ensure that implementation of the Strategy and projects contribute to the knowledge base, and support policy-relevant research.
3. Integration of EbA into policies, plans and decision-making to supports an overall climate change adaptation strategy in order to effect systemic changes that deliver benefits at scale. Thus, requiring the integrating of EbA into relevant polices and plans of a range of sectors.

4. Implementation projects demonstrate the ability of EbA to deliver a wide range of co-benefits including action to be taken from the start in order to help natural resources and people to adapt to climate change, enabling learning environment through doing and assist in profiling successes, lessons learned and practice of EbA

The EbA Strategy comprises of two interrelated components, the *Strategic Framework* and the *Overarching Implementation Plan*. Together they provide a roadmapfor the next five years from 2016/2017 to 2020/2021 financcial years (DEA and SANBI, 2016) While the EbA will be funded by some of the current sources of funding from DEA and SANBI, additional funding may be sought, if required (SANBI, 2016). Apart from the financial resources, institutional measures have been put in place that will facilitate the delivery of EbA outcomes and co-benefits in such a way that EbA activities will be aligned with the existing programmes. This will allow the alignment of financial, human and other resources with on-going activities (DEA and SANBI, 2016).

The institutional arrangements that have been set for the implementation of the EbA strategy include setting up a coordination committee and elements of implementation need to be integrated in the business plans and performance agreements of institutions such as SANBI and DEA as well as other essential institutions. The EbA committee will coordinate and raise funds for the implementation of the EbA strategy. Finally, a community of practise will be set up to offer support for the strategy. The implementation of the EbA strategy is already partly in action, as highlighted by the institutional measures already in existence.

Mainstreaming terrestrial ecosystems adaptation into existing policies through integrating adaptation issues into ongoing policy processes, such as a the National Development Plan, the National Spatial Biodiversity Assessment, the National Protected Areas Expansion Strategy, Biome Adaptation Plan and Ecosystem based Adaptation, as well as the Expanded Public Works Programmes (e.g. working for Water, Fires, Wetlands, Ecosystems, Energy, etc.) are key aspects of adaptation and that are currently implemented by the Department of Environmental Affairs and other relevant departments.

To increase the resilience of biodiversity and ecosystem service delivery under future climate conditions, synergies could be developed during adaptation planning and implementation between biodiversity, poverty reduction and development objectives. Specifically, the potential of biodiversity and ecological infrastructure to achieve sector-specific adaptation and development outcomes/benefits would need to be mainstreamed into adaptation, development and poverty reduction processes and strategies at both national and local levels. Coordination across sectors (including the land use planning sectors) would be essential in this mainstreaming process. Key elements would be to include stakeholder engagement with implementation focusing at local level through prioritising low-cost approaches with multiple benefits; integrating adaptation and mitigation responses; and making use of indigenous knowledge.

It is critical to acknowledge that Ecosystem-based Adaptation and expansion of protected areas using climate-resilient approaches offer two adaptation response options for the biodiversity sector that are appropriate for achieving increases in the climate resilience of biodiversity and maintaining and/or enhancing ecosystem service delivery. However, these two approaches should be adapted as necessary to build the resilience of ecological infrastructure to support economic sectors and livelihood activities.

3.6.6.4.2 Biome-level priorities

There is a consistent message of significant change and loss of habitat for the grassland biome as a result of the expansion of woody savannah areas under future climate scenarios. The grassland biome is crucial for providing water for drinking and other economic and livelihood activities in South Africa. Furthermore, it is an area that is likely to increase in importance as a habitat for bird diversity. Therefore prioritising adaptation responses in this biome will be critical to prevent reductions in bird species richness, maintain water supply from highland catchments, maintain grazing services for local communities and manage ecosystem processes such as wildfire. Furthermore, integrating vulnerability assessment data with spatial data related to ecosystem services (in particular water-related services) as well as user-specific vulnerability data should be prioritised for this sector and inform planning and decision making.

Authorities need to also prioritise mainstreaming the potential of biodiversity and ecological infrastructure to provide adaptation and development benefits across sectors through effective implementation of EbA strategy to build resilience of vulnerable biomes, ecosystems and local communities to climate change. Lastly, effective monitoring and evaluation of the implementation of biodiversity related policies should be prioritised to track progress and inform investment decisions that will support the implementation of these policies.Key adaptation options for each of the biomes are shown below.

Table 0.18: Top climate-related adaptation options (**DEA, 2015c**)

Biome	Adaptation Priority
Albany Thicket	• Switch to wildlifeand biodiversitybased land uses • Restore previously degraded areas • Reduce stress from over-browsing of thickets
Desert and Nama Karoo	• Switch to ecotourism and wildlife management, using appropriately informed management, with sufficient advice and support • Restoration of degraded areas, preferably using a multiple benefits approach, with support for in situ conservation
Forest	• Fire and alien plant management and remove stress from over-utilisation of forests • Spatial planning (often linked to the biomes in which forests are imbedded) • Maintain ecosystems in which the forest is embedded and control invasions of the forest edges • Restore forest margins and degraded forest areas, including the use of invasive alien species stands to allow for forest species recruitment
Fynbos	• Maintaining effective land management through water-supply and support effective management of private land • Implement the existing biome-wide and municipal conservation plans, including expanding existing reserve systems, and purchasing high biodiversity value land, especially in the lowlands • Partnerships between agricultural and conservation sector to find more effective ways of managing landscapes for biodiversity and ecosystem services, including: controlling invasive alien species; public and private sector involvement and Biodiversity Stewardship Programme
Grassland	• Fire management • Alien plant management • Spatial planning to minimise fragmentation • Protecting against overharvesting and over grazing
Indian Ocean Coastal Belt	• Integrated spatial planning, including strategic conservation and protection of corridors. Reduce land transformation. • Switch to wildlife- and biodiversity-based land uses • Restore previously degraded areas and improve irrigation efficiency • Manage fire
Savanna	• Switch to wildlife- and biodiversity-based land uses • Manage encroaching biomass (both indigenous and alien) for bioenergy generation/charcoal production • Identification of Critical Biodiversity Areas for expansion of protected area network
Succulent Karoo	• Supporting emerging farmers through the development of economically viable SMMEs • Restoration of previously degraded areas including mined areas • Mainstream biodiversity best practises into livestock grazing and ostrich farming • Support informal conservation initiatives • Improved water use efficiency and better coordination between water users.

3.6.7 Urban and rural settlements

3.6.7.1 Introduction

Human settlements in South Africa face significant immediate and critical challenges even before the likely impacts and risks associated with climate change are considered (DEA, 2013a; Linkd Environmental Services, 2013). Some of the current challenges include migration, urbanisation, poor spatial planning resulting from the legacy of apartheid, inequality, poverty, service provision complexities, limited local government capacity, and increased strain on aging infrastructure and reduced capacity for critical operations and maintenance of key infrastructure.

Historically climate change research has focused on climate science and the associated biophysical impacts; whereas vulnerability assessments have tended to focus on rural areas and communities that are most directly impacted by climate change. In recent years, however there has been increased focus on assessing the potential climate change impacts and vulnerabilities of urban areas and cities (e.g. Bulkeley and Betsill, 2013; eThekwini Municipality, 2011; ICLEI, 2012; Roberts and O'Donoghue, 2013), particularly with regards to the potential for increasing disaster risk. The importance of incorporating climate change into normal development planning has been recognized as critical in terms of achieving broader development objectives through sustainable and climate compatible development (DEA, 2013a). Human settlements are characterized by different types of settlements that have different challenges and vulnerabilities with regard to climate change (DEA, 2013a; 2014e), (Table 0.19).

Table 0.19: Vulnerability of different settlement types to climate change (DEA, 2013a; 2014e)

	Vulnerability to climate change
Urban settlements: A complex spatial mix of social classes and growth patterns	• Affluent residential areas or suburbs which often attracted individuals with higher income and greater personal capacity and resilience to climate change. • Gap, Low cost, and social housing areas which tend to have a greater diversity in terms of ethnicity and social status. These households may have greater social vulnerability and reduced adaptive capacity. • Informal settlements develop in an unplanned and at times illegal manner as a result of unsustainable rural/urban migration. Provision of basic services is limited in these areas, and the dense communities have a higher vulnerability to all hazards that will become even greater due to climate change.
Rural settlements: Located outside of the urban and peri-urban areas primarily depend on agriculture, and tourism.	The population in these areas are the most vulnerable to climate change due to likely impacts in the agriculture sector and limited alternative incomes that result in low adaptive capacity
Coastal settlements: Either urban or rural are situated along the coastline	These areas are subject to similar challenges and development objectives for both urban and rural areas but have added vulnerabilities due to sea level rise, storm surges, salt water intrusion and other impacts to marine and estuary environments.

3.6.7.1.1 Progress since the 2nd National Communication

Since the Second National Communication in 2011 (DEA, 2011b), significant additional research into climate change risks and vulnerabilities for human settlements, as well as the establishment of global networks aimed at building climate change resilience, has resulted in an improved understanding of climate risks for human settlements. This progress has capacitated and motivated a number of provinces, local and district municipalities to develop specific climate change response strategies. These strategies include a more detailed analysis of particular localised climate change risks and vulnerabilities.

National Climate Change Response White Paper

The National Climate Change Response White Paper (NCCR 2011) expands further from the SNC regarding the challenges to existing infrastructure and service delivery which may increases climate change vulnerability in human settlements (Table 0.20).

Table 0.20: The NCCR strategies to reduce the vulnerability for rural and urban areas

Urban Areas	Rural Areas
Promoting building of climate resilient infrastructure.	Diversifying rural livelihoods to strengthen resilience.
Improving climate resilience of low-cost housing.	R&D appropriate agricultural technologies promoting soil and water conservation.
Encouraging water-sensitive urban design (**WSUD**).	Developing and introducing drought resistant crops and livestock.
Using down-scaled climate projections to provide effective information and assessment tools for land-use planning and urban design.	Adoption of agricultural practices conserving eco-systems and building climate change resilience.

Long Term Adaptation Scenarios (***LTAS***) ***Research Program***

The LTAS made a number of recommendations with regards to more downscaled climate information and integration into current design standards and infrastructure planning, recommendations for improvements with regards to housing development, and greater consideration for developing ecological infrastructure to either complement or as an alternative to traditional physical based infrastructure solutions.

The LTAS, like other climate change adaptation strategies, however also recognised that development is the best form of adaptation as it reduces vulnerability, provided that this is done with climate change in mind so as to prevent possible maladaptation.

Global Networks to support adaptation for human settlements

Since the publication of the SNC there have been many developments in terms of global networks to support adaptation and sustainable development for human settlements. These include the signing of the Durban Adaptation Charter (DAC, nd) and the formation of the C40 and 100 Resilient Cities programs of which many South African cities and local municipalities are now contributing members (C40Cities, 2017; RSA, n.d.).

Spatial temporal evidence for planning in South Africa (***stepSA***) ***website***

The CSIR (Council for Scientific and Industrial Research) has developed stepSA as a support tool to disseminate research informing the sustainable development in cities, towns and settlements. It is geared to be used by sectoral decision makers and practitioners for planning processes. The information obtainable through the portal has direct implications for human settlements with indicators such as settlement density, population growth, migration trends and climate data. These tools provide the stockholders “the capability to view and compare development dynamics within and between cities, towns and rural settlements across South Africa.” Which “has made a major contribution towards understanding the challenges and opportunities associated with an increasingly city and town based population.”[6]

Disaster Management Amendment Act No.16 of 2015

There is a strong link between the impacts of climate changes for both Disaster Management and Human Settlements. The amendment to Disaster Management Amendment Act No.16 of 2015 has implications for reducing the risk and vulnerabilities and applying effective sustainable spatial development of human settlements. An example of successful implementation of this integrated approach is presented by eThekwini Municipality which has taken significant steps towards raising the strategic profile of the disaster management function in the development planning process and integrating climate change with the citywide risk assessment process (ICLEI, 2012). The applicability of disaster management planning is elaborated on further in Section 3.5.

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[6] stepSA, Functional City, Town and Settlement Typology

Box 0.15: Integrating Disaster Management and Climate Change Response: eThekwini Municipality's Municipal Climate Protection Program (**MCPP**) (**ICLEI, 2012, p. 6**)

eThekwini Municipality's Municipal Climate Protection Program (MCPP), initiated in 2004, seeks to mainstream climate change adaptation in the general city planning and development framework. This approach attempts to harmonize local urban responses to climate change with key development priorities. Following an initial assessment of local climate change impacts, the Headline Climate Change Adaptation Strategy (HCCAS) was prepared in 2006. Furthermore, in 2009 sector-specific adaptation plans were developed and piloted in three high risk sectors: health, water and disaster management. This lead to the development of an institutional partnership between the Disaster Management Unit and the Environmental Planning and Climate Protection Department (EPCPD). With the EPCPD position in the city's Development Planning and Management Unit, the improved link to strategic planning has allowed disaster management to increase its influence. The partnership has influenced both strategic and sector-based response planning for climate change as well as mobilizing resources.

The key principles for eThekwini's success are:

Political will and buy-in

An institutional design which embeds disaster management in policy formulation as a core constituent of a city's strategic planning team.

Development of new institutional partnerships.

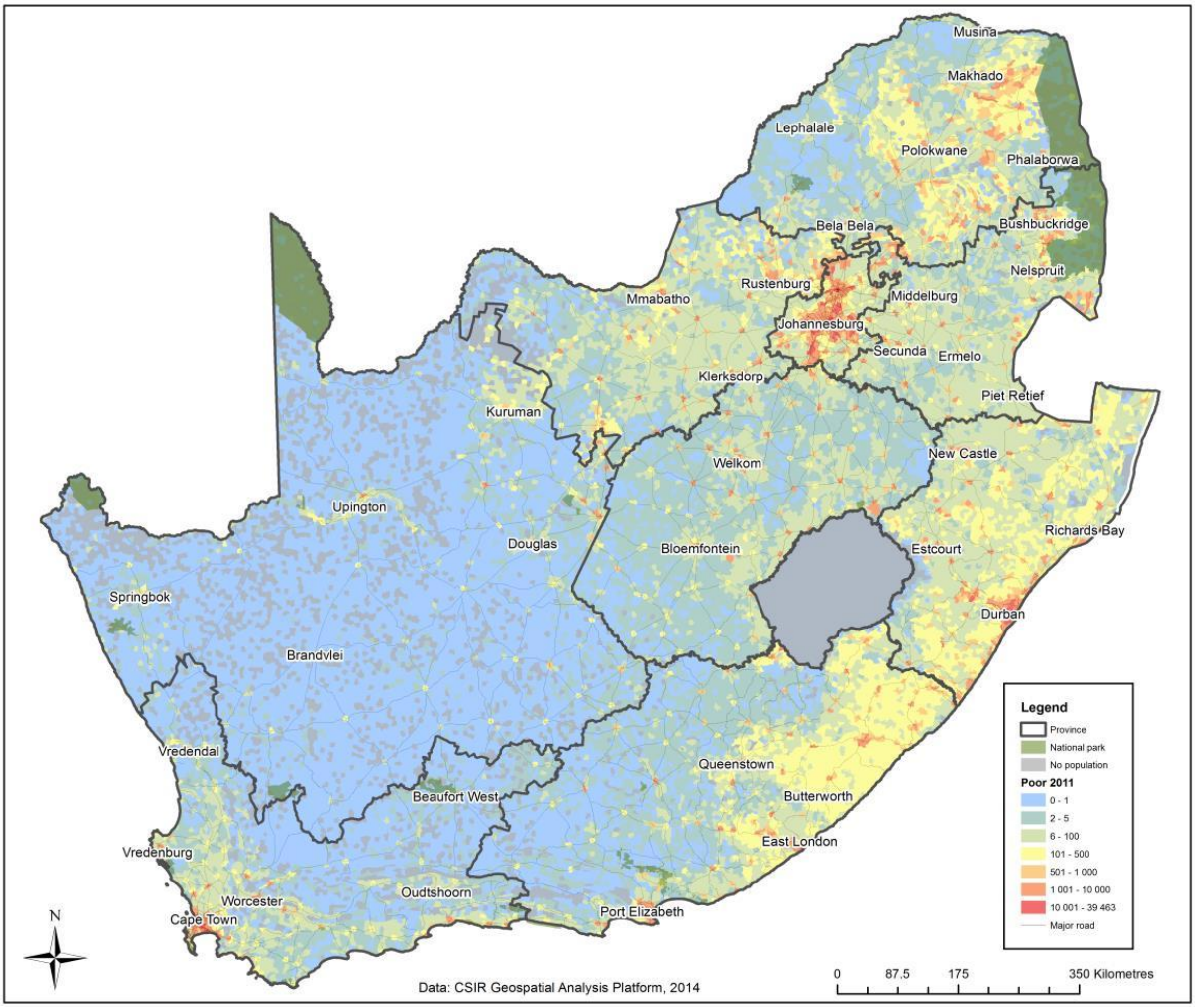
Overcoming basic institutional and resource challenges which delay appropriate disaster management planning.

A strong focus on ecosystem based adaptation, a key tool for improving the adaptive capacity of cities, especially in the Global South.

Evidence-led adaptation strategies need to be appropriate to the specific urban contexts and continually refined through piloting studies, monitoring and evaluation. The 'learning by doing' principle adopted by the eThekwini Municipality is a robust approach for the development of local urban adaptation strategies.

3.6.7.2 Vulnerability to Climate Change

The current vulnerability of human settlements are determined by access to basic services, the type of dwelling, health and age, economic factors, land tenure status and social grants (DEA, 2013a). Additionally, political and economic ideologies are considered to be the root causes of vulnerability as they influence the distribution and allocation of resources (van Huyssteen, *et al.,* 2013). In this regard, the long term implications of apartheid era planning in South Africa which created fragmented urban communities and increased vulnerabilities will be experienced both by the current generations as well as future generations (Figure 0.77).



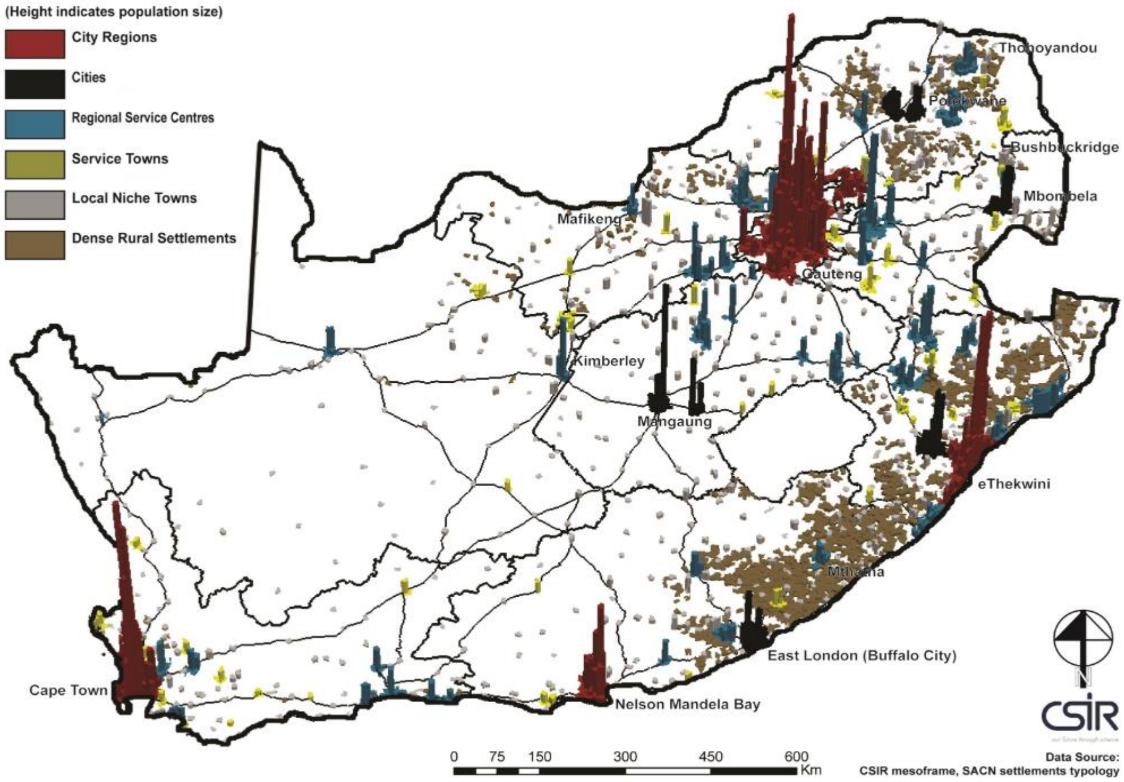
Data: CSIR Geospatial Analysis Platform, 2014

Figure 0.77: National Vulnerability (**CSIR**)

Future risk will be subject to many of the present challenges but will be compounded by climate changes expected to increase exposure to both temperature and precipitation hazards, and water and heat related stresses. Adaptation strategies to reduce the risk must be effective not only for the current communities but also for the households in the future. Uncertainty inherent in climate modelling as well as the regarding emission pathway will require adaptation strategies that are applicable and resilient against a wide range of potential climate futures. The discord between much needed economic development of a resource rich country and the moral responsibility to mitigate climate change through the reduction of atmospheric emissions creates a scenario where one goal may be prioritised at the expense of the other. Each path will have implications to household vulnerability in the future.

3.6.7.2.1 Current risks

The 2011 census reports a population of approximately 52 million people in South Africa (estimated at 55 million in 2015) (StatsSA, 2011). Of those 77.82% live in cities and towns, including high density settlements this number is 89.56%, accounting for 90.02% of the national economy while only utilising 11.49% of the national land area. The majority of those living in urban areas (42%) reside in the four major city regions of Gauteng, Cape Town, eThekwini and Nelson Mandela Bay (Figure 3.78). The significant urban densification of economic activity provides opportunities for those moving to the urban areas, the population density however increases the vulnerability, particularly for those living in informal settlements where services are more limited. The people living in rural areas account for 10.44% (Table 0.21). Integrated development planning is essential for both urban and rural areas but should assist the most vulnerable communities with priority. Proxies for area vulnerability are given by household size, inhabitant age, dependency ratios and income levels (Figure 0.79). The largest average number of household inhabitants and the most vulnerable population occurs in the rural areas (5.55), second are the informal settlements (4.68). The expected annual increase in household size is dominated by informal areas (8.85%). Urban migration has increased the average age of inhabitants in the rural areas to 46.6 years (over 4 years higher than all other areas). Vulnerability correlates to the level of unemployment, which is dominated by the informal and peri-urban areas with 35.9% and 37.5% respectively. Migration to urban areas has skewed the dependency ratio toward highest vulnerability in the rural areas (81%). Lastly higher per capita income will increase the coping capacity of the population and this is exhibited strongly in the urban areas in which the population earns at least 1/3 more per month than the other areas.



Data Source:
CSIR mesoframe, SACN settlements typology

Figure 0.78: City, Town and settlement typology

Table 0.21: Comparative analyses of population and economic activity in South Africa (**Van Huyssteen** ***et al.*****, 2013**)

Functional Settlement Type (CSIR/SACN 2013v2)	**Area_Km**	**% of National Area**	**Population 2011**	**% of National Population**	**Service Economy (Service Sector GVA (xR1000))**	**Economic Activity (*Total GVA (xR1000))**	**Contribu-tion to Formal Nat Econ Activity**
CityRegions	20 575	1.65%	21 856 192	42.22%	758 652	1 185 948	56.77%
Cities	8 225	0.66%	3 876 064	7.49%	102 574	178 276	8.53%
TOTAL CITIES	**28 800**	**2.30%**	**25 732 256**	**49.70%**	**861 226**	**1 364 224**	**65.30%**
Regional Centres	18 079	1.45%	7 313 730	14.13%	141 580	229 697	10.99%
ServiceTowns	7 232	0.58%	2 720 372	5.25%	47 847	87 232	4.18%
TOTAL MAJOR TOWNS	**25 311**	**2.02%**	**10 034 102**	**19.38%**	**189 427**	**316 929**	**15.17%**
Local or Niche Towns	29 756	2.38%	4 327 891	8.36%	69 102	121 169	5.80%
Rural Nodes in High density areas	928	0.07%	191 123	0.37%	2 537	4 850	0.23%
TOTAL SMALL TOWNS	**30 684**	**2.45%**	**4 519 014**	**8.73%**	**71 639**	**126 019**	**6.03%**
High Density Settlements	59 276	4.74%	6 081 912	11.75%	40 074	73 587	3.52%
Sparse Rural Areas	1 070 931	85.66%	3 036 010	5.86%	51 830	184 994	8.86%
Dense Rural Areas	35 258	2.82%	2 366 803	4.57%	13 921	23 351	1.12%
TOTAL REST OF SA	**1 165 465**	**93.22%**	**11 484 725**	**22.18%**	**105 826**	**281 932**	**13.50%**
NATIONAL TOTALS	**1250260**	100.00%	**51770097**	100%	**1228117**	**2089104**	100%

2011 Population in cities & towns

77.82%

2011 Population in cities,towns & Settlements

89.56%

** GVA Total excludes Construction sector*

SOURCE: CSIR GAP 2013 based on StatsSA Census 1996,2001,2011; SACN/CSIR Settlement Typology 2013v2, CSIR TAT (Temporal Analyses Tool) 2013

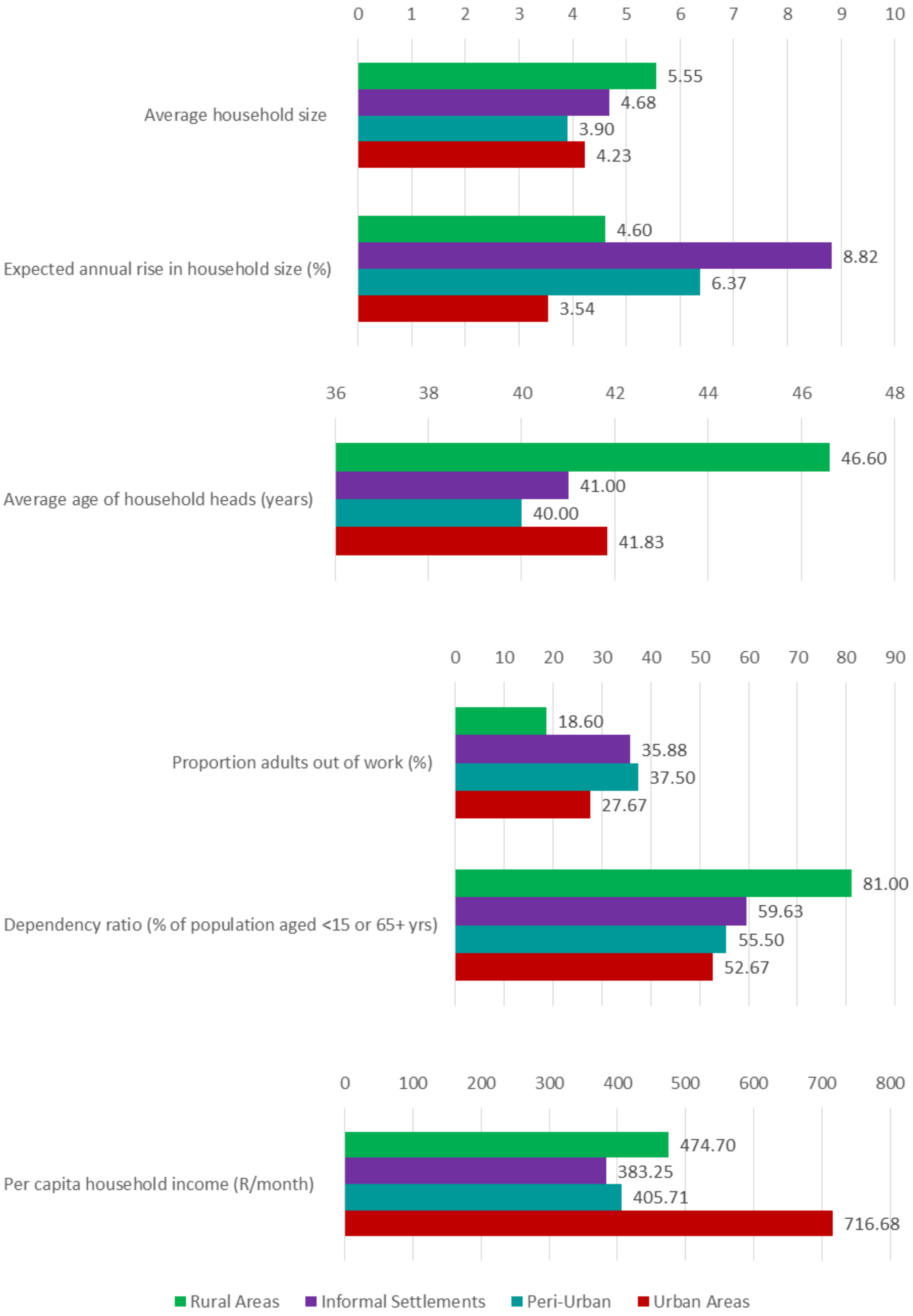


Figure 0.79: Demographic information per area type (**Stats SA, 2011**)

The LTAS identified both current direct climate risks for human settlements as well as current social drivers of vulnerability for human settlements in South Africa.

Urban settlements

Many urban settlements are currently stressed to meet the needs of the population. Ecological and resource limits are stretched due to poor urban management (NDP; RSA, 2011a) and may lead to water stress, food insecurity and power shortages. Additionally, urban settlements adapt slowly to environmental changes making them particularly vulnerable to climate change (RSA, 2011a).

Variability in precipitation places stress on water resources and the reliability of water supply. Growing water demand places pressure on water supply systems (DEA, 2013e; RSA, 2011a). Declining water and air quality pose serious challenges for human health (DEA, 2013e). Urban settlements have many impermeable surfaces which increase runoff, floods and downstream impacts (DEA, 2013e).

Exposed infrastructure poses challenges for urban, urban-coastal and peri-urban settlements (DEA, 2012; DEA, 2013a; DEA, 2014e). Extreme weather events and groundwater changes can damage infrastructure. Urban settlements depend heavily on private and public transport which makes them susceptible to impacts resulting from damaged transportation infrastructure due to extreme events (DEA, 2013a).

In some urban areas people have been evicted from climate-vulnerable areas such as low lying areas prone to flooding in order to reduce their vulnerability however it is difficult to prevent those people from returning or preventing new people from settling into these areas without addressing the underlying drivers such as land availability and the proximity to employment opportunities.

Informal Settlements

Unplanned informal settlements lack extensive infrastructure, use unsuitable construction materials, expand into more exposed areas and have inadequate service provision. These areas are disproportionately affected by air and water pollution risks (DEA, 2013a), susceptible to floods and fire (RSA, 2011a) and lack capacity, resources, funds and insurance to repair damages that occur from weather events. Population density in these areas as well as at unplanned expanding urban/rural interface areas is also usually high. The cost of providing services to such settlements is also high due to uncoordinated and dispersed settlement patterns, poor access and distance from existing bulk infrastructure services.

The illegal and uncoordinated occupation of some areas removes the option for enhancing local institutional capacity and these areas often do not have the support of government. The threat of loss in these areas extends to livelihoods and loss of life, rather than simply financial losses as for formal urban areas (IPCC 2007).

Rural settlements

Rural communities are already highly vulnerable to the current climate variability and in particular extreme weather events and variable water supply. A high reliance on agriculture (commercial and subsistence) exposes these areas directly to the impacts of current annual variability in rainfall and water scarcity which adversely affects crop yield and quality (DEA, 2013a; DEA, 2013b; Linkd Environmental Services, 2013).

Rural settlements are also impacted by environmental degradation, soil loss, extreme weather events, pests, bush encroachment and veld fires that impact directly on agriculture and food security (DEA, 2013b; Linked Environmental Services, 2013). These existing pressures may force unsustainable land use practices, and further land and environmental degradation though deforestation and overgrazing.

The isolated nature of rural settlements and dispersed services also increases the risk exposure for rural communities. Furthermore rural areas tend to have limited transport access points, inadequate road maintenance rendering them susceptible to seasonal floods and erosion from high rainfall intensity (DEA, 2013a). Livelihoods and wellbeing are subject to this vulnerability as transport disruption threatens access to markets and limits service access, such as police, fire services and ambulances (DEA, 2013a). Disaster response is also pressured as a consequence of the remote location and limited resources of rural settlements but will also be subject to the same vulnerability in ability to administer response and recovery in rural settlements (DEA, 2013a).

Coastal settlements

Coastal settlements are subject to the same vulnerabilities as both urban and rural settlements. They however face additional risks due to coastal proximity such as storm surges, salt water intrusion and red tides. These all have the potential to impact directly and indirectly community livelihoods, marine fishery industry (commercial and subsistence), tourism and environmental health. These sectors are often the basis for many local coastal settlement economies (DEA, 2013a; DEA, 2014e).

This could have knock on effects felt though food stress and tourism (Mather and Stretch, 2012). Further impacts to estuary ecosystems are occurring through increase silt deposition. Coastal erosion is already resulting in rocky shorelines developing where previously established sandy shorelines occurred (Mather and Stretch, 2012). Coastal settlements face financial vulnerability due to loss of real estate, decreased value of beachfront properties, decreased tourism revenue and damaged infrastructure (DEA, 2013a; DEA, 2014e).

3.6.7.2.2 Future risks

Historical measures for design and construction thresholds, spatial development planning need to move toward risk adaptation and measures required for a future climate (DEA, 2013a). Extreme events that historically occurred with a periodicity of one in fifty years will likely occur with greater frequency and design specification should shift relative to the shifted baseline climate.

To ensure a no-regret state of development, infrastructure and planning should be designed to withstand worst-case climate scenarios hostile to human settlements (DEA, 2013a). Impacts to human settlements associated with climate changes will become more prevalent and livelihoods are further threatened though resource availability and environmental capacity (Linkd Environmental Services, 2013).

Urban settlements

The climate changes projected in the future will have significant impacts on resource availability for urban settlements. Projected increased temperatures and evaporation coupled with enhanced urban heat island effect pressures existing settlement capacity (DEA, 2013a; DEA, 2014e). Further stress will be placed on water and food security, energy, water treatment, fuel supply, transportation, and health (DEA, 2013a).

Impacts to livelihood security in rural areas will likely drive increased urbanisation, migration, immigration and conflict (potentially xenophobia) will rise due to increased pressure on labour markets (leading to higher rates of unemployment), government resources and service delivery (DEA, 2013a; DEA, 2014e). Population growth increases water demand, power, heating and cooling demand, and already limited service provision. Meeting these needs will become increasingly difficult in future (DEA, 2013a).

There will be an increased energy demand for cooling particularly in inland regions of the country, but there may also be a related decreased demand for energy associated with heating (DEA, 2013a). Uncertainty in the projections and the unpredictability of the climate system will hamper the ability of Eskom to forecast and match electricity generation with variable and changing demand. Disruptions to water and electricity supply will become more widespread consequently reducing small, medium and large scale industrial productivity (DEA, 2013a).

Climate change will alter the thermal constraints and precipitation for which the built environment is designed and measured. The changing in the baseline climate will necessitate changes to existing building codes and design standards (DEA, 2013a).

These enhanced climate extremes experienced in the urban areas are further exacerbated by the influx of people predominantly into the four major urban areas (Figure 0.80). While there is increased pressure on service delivery for the urban area as a whole, this population increase is mostly focused on the informal areas of these urban areas, thereby increasing the already high vulnerability of the inhabitants.

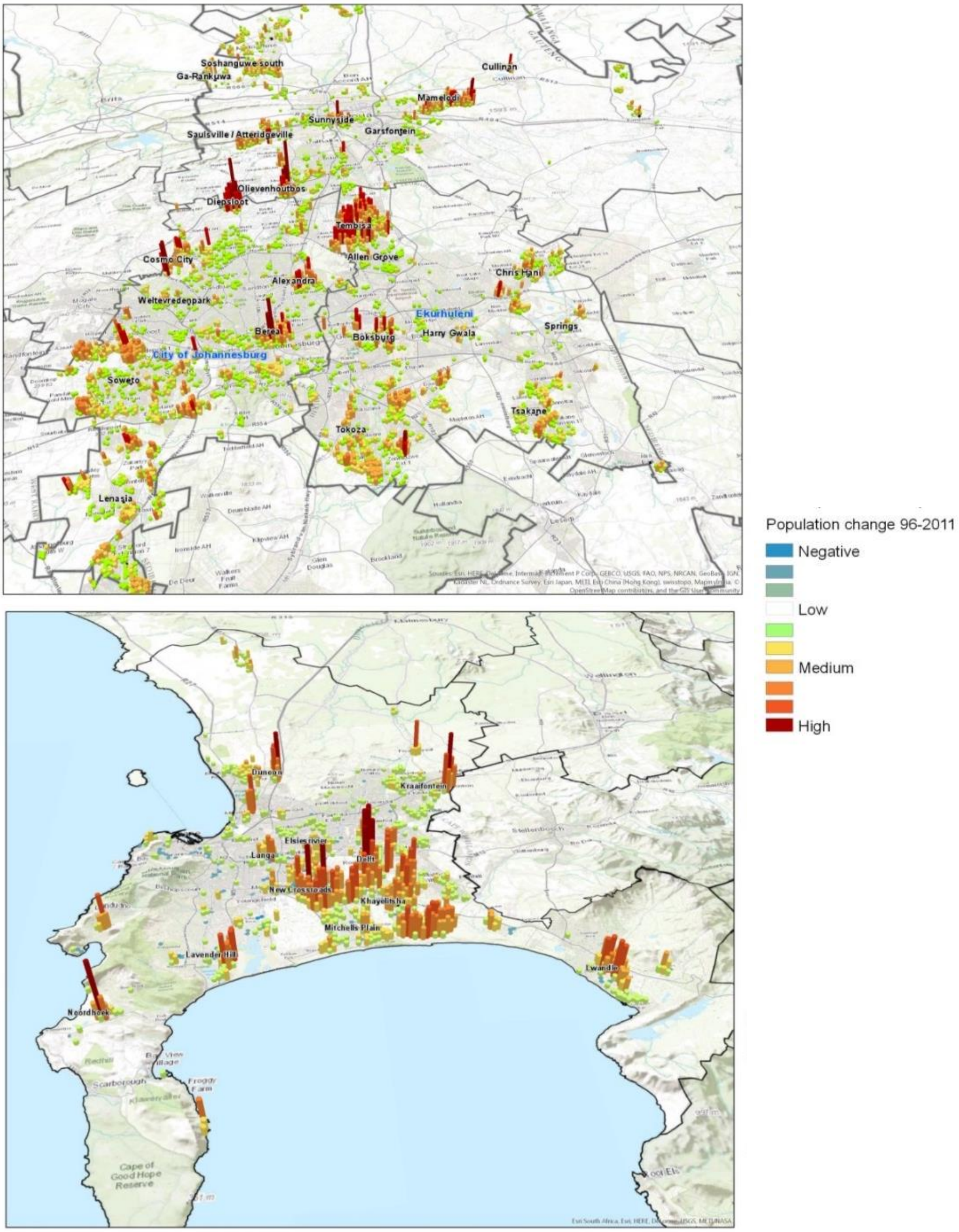
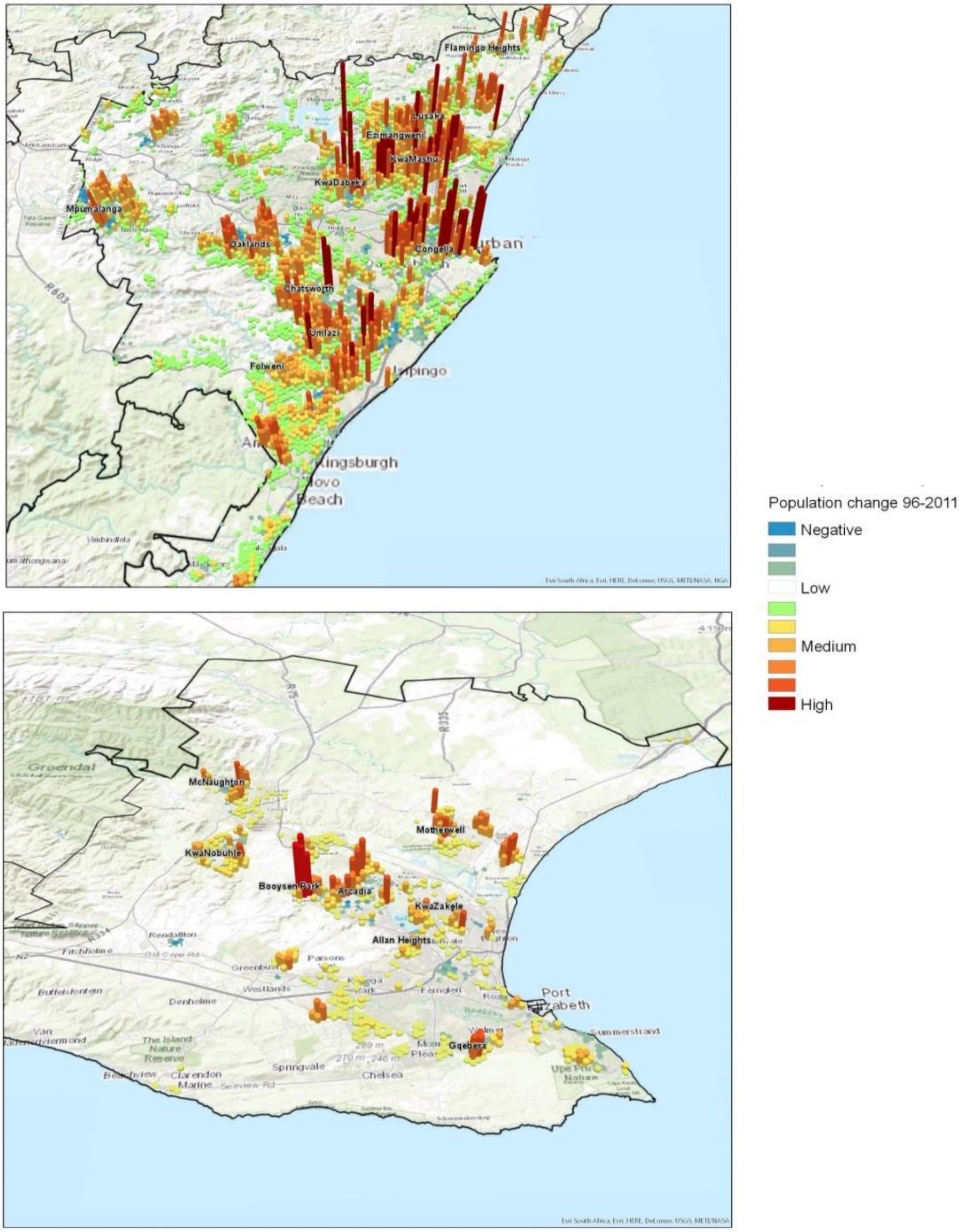


Figure 0.80: Change in population from 1996 - 2010 for the four major metropolitan areas of Gauteng (1st panel), Cape Town (2nd panel), eThekwini (3rd panel) and Nelson Mandela Bay (4th panel)



(cont): **Change in population from 1996 - 2010 for the four major metropolitian areas of Gauteng** (**1st panel**), **Cape Town** (**2nd panel**), **eThekwini** (**3rd panel**) **and Nelson Mandela Bay** (**4th panel**)

Rural settlements

Climate changes are and will continue to impact growing seasons which are becoming shorter, more variable with decreasing yields for both commercial and subsistence farmers (DEA, 2013a; DEA, 2013b; Linked Environmental Services, 2013). This variability threatens food and livelihood security for rural settlements in particular and drives migration to urban areas (DEA, 2013b). Malnutrition as a consequence of food insecurity impacts the health of the rural population and affects the ability of communities to remain productive in both farming and rural livelihood activities (DEA, 2013b). Furthermore heat stress, malnutrition and disease also impacts livestock health. Livestock numbers could decline resulting in reduced yield and production (DEA, 2012; DEA, 2013b) threatening food and livelihood security further.

Informal Settlements

Projected impacts to the urban areas such as food and water insecurity and further pressure on service delivery are exacerbated in the informal settlement areas where communities are of a higher density and generally decreased personal capacity (DEA, 2013a; DEA, 2014e). This increased risk exposure will amplify the impacts associated with climate change. The effects of increasing rural/urban migration will be felt primarily in informal settlements as those moving will lack the capacity and not have sufficient resources to enter the more established formalised settlements. Informal settlements that have developed in an unplanned nature and with substandard construction materials will be particularly vulnerability to more extreme climate changes such as projected increased heatwaves, precipitation intensity and floods (DEA, 2013a).

Coastal settlements

Climate change will result in sea-level rise and potential coastal inundation, land loss and salt water intrusion in the coastal settlements (DEA, 2013a; DEA, 2014e). Additionally there are risks associated with increased severe storms, erosion, tidal influence and flooding that further impacts coastal settlements through the loss of property and damage to infrastructure (DEA, 2013a; DEA, 2014e Taylor and Peter, 2014). There are also indirect impacts in the coastal areas through the decline in marine fisheries and tourism revenue.

Climate change impacts are estimated to reduce the value of South African fisheries by approximately 18% with potential shifts in fish stocks impacting particularly on smaller coastal settlements and artisanal fishing communities. These impacts on marine diversity affect livelihoods and coastal economies (DEA, 2013f; DEA, 2014e). Extreme weather also endangers fishing boats (DEA, 2013f). Small fishing ports may need to upgrade their infrastructure in order to be more resilient to climate hazards. Shipping movements will be affected causing expensive delays and changes in global trade.

Although South Africa is not considered to be particularly vulnerable to the impacts of sea level rise, as compared to other countries such as Bangladesh or Mozambique (Dasgupta *et al.,* 2007), there are specific local municipalities along the coast that have a relatively significant amount of land that is considered to be at risk from possible sea level rise and increased storm surges (i.e. below 5.5 m above mean sea level), (DEA, 2015d). This does not include the possible additional impacts in terms of sea water intrusion into coastal aquifers that may impact some coastal communities and existing farming areas.

Assessing the national impacts to the coastal environment suggests an inundation of 279.8 square kilometres (GIS analysis estimated at 2,130 km^2 - Figure 0.81 of land due to a 1m sea level rise scenario. This area is currently less than 5.5m above sea level, however the cumulative impacts of sea level rise and the increased wave swash will render significant areas unsuitable for human settlements.

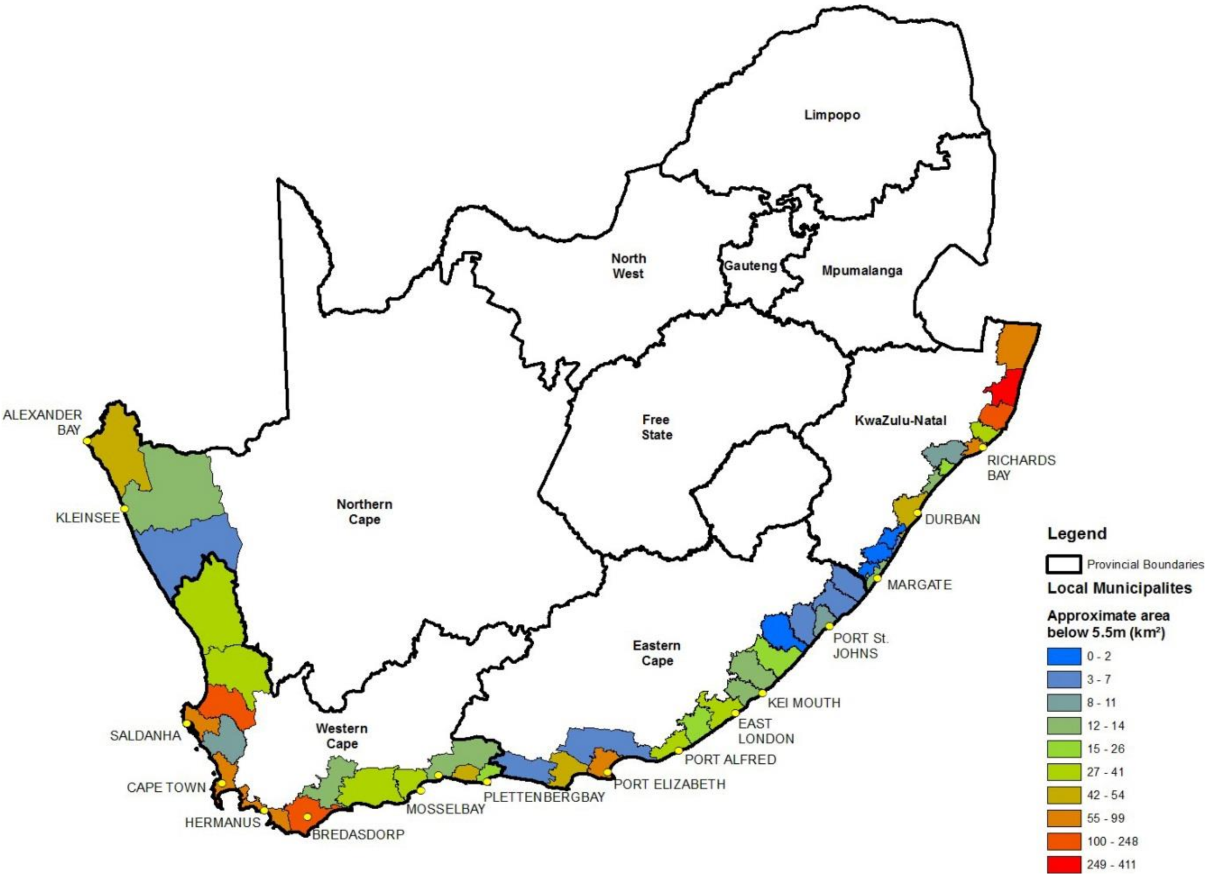


Figure 0.81: Exposure to eustatic sea-level rise across South Africa's local Municipalities based on extent of land under 5.5 metres (**Source: Peter Wilson, Aurecon Group, 2014**)

This impact would have significant financial sectoral implications for human settlements in terms of infrastructure and property assets (Table 0.22).

Table 0.22: Summary of National Sea-level rise costs 2010-2100 under two scenarios (2010 prices)

	Low (**0.5m eustatic rise and swash up to 5.0 metres by 2100**)	**High** (**1m eustatic rise and swash up to 5,5 metres by 2100**)
Public Infrastructure	R11,3bn	R20,7bn
Real Estate and Private Assets	R154.4bn	R273.1bn
Tourism	R45.9bn	R91.8bn
TOTAL	R211,5bn	R385,5bn

The impact of sea level rise is likely to be felt more at a local level for individual cities rather than at a national level. For example, without any adaptation responses to sea level rise the beachfront at Durban will experience increased risk to infrastructure and developments such as Ushaka Marine World (Mather and Stretch, 2012) and specific parts of Cape Town will also see an increasing risk due to sea level rise (Cartwright, 2008). Theron and Rossouw (n.d.) however note that in South Africa, few coastal settlements are vulnerable to sea level rise due to the coastal topography and existing infrastructure such as sea walls. The coastlines of Port Elizabeth, Mossel Bay, Southern Cape coast, Saldanha Bay, Table Bay, Northern False Bay and the KwaZulu-Natal Coast have been identified as the most vulnerable coastal settlements (Theron and Rossouw, n.d.) with some agricultural areas such as the West Coast at greatest risk from salt water intrusion into groundwater supply.

3.6.7.2.3 Cross-cutting impacts

Economy

The development of human settlements is impacted by macro-economic factors such as unemployment, costs of building, inflation, income, access to credit and financial environments (DHS, 2016.). Building costs and businesses are impacted by increasing scarcity of raw materials. The cost of living for individuals will increase and consequently living standards will be forced to decrease. Weather events damage assets, equipment and fixed capital consequently impacting mining, manufacturing and construction industries. Increasing climate risks such as damage to infrastructure and assets by extreme weather events and ill health results in higher insurance prices and increased investment costs. Economic losses can result from decreased tourism, workday loss from ill health and decreased productivity. Climate change has changed the way the world views economic growth, because countries are held responsible for their carbon emissions they are constantly exploring cleaner sources of energy (KZN PDP, 2011).

A review of the potential impact of climate change on the economy of South Africa noted that the greatest risk was from impacts to dry-land agriculture and transport infrastructure (DEA, 2015a; Cullis *et al.,* 2015). Consideration of the economic impacts in different parts of the country noted that it was in particular the rural areas that were most at risk form the potential economic impacts of climate change.

Health

Climate change alters the range and breeding season of disease vectors and can result in increased spread of diseases. Malaria is more common in rural areas (particularly to the north eastern part of RSA) whereas dengue fever and bilharzia is more common in urban areas, especially informal settlements because of poor water and waste systems. Increased temperature results in temperature inversions which trap pollution causing dry eyes, headaches, nasal congestion, fatigue, nausea, and respiratory problems. Urban residents are more prone to temperature related illnesses due to the enhanced heat island effect. Water-borne diseases will become more prevalent due to decreased water quality, damaged water and sanitation infrastructure. Human health and mortality is affected by disaster response and emergency services already under strain (DEA, 2013c).

Food security

Health goes hand in hand with food security. Climate change directly affects the production and distribution of food and reduced access to affordable nutritious food will increase diet-related health problems such as malnutrition or obesity (Ruwoldt, 2013). Urban food security relies on linkages with rural areas, and the associated impacts on the agriculture sector at local and global levels that impact on prices.

Water Supply

Future water supplies are considered to be one of the greatest climate risks for human settlements (IPCC, 2012a). South Africa, however already has a well-developed and highly integrated bulk water distribution system that has been design to address the existing high spatial and temporal variability in water supply. For the major metropolitan areas, this existing water supply infrastructure is considered to provide a reasonably high level of resilience in terms of future water supply provided that it continues to be managed correctly and planned accordingly (Cullis *et al.,* 2015). Of greater concern are the smaller cities and towns that are dependent on only a single source or do not have the capacity to efficiently manage and maintain existing and future water supply infrastructure (DWA, 2013). Increased variability in rainfall is also likely to have a greater impact on dry-land agriculture and hence on the potential economics of rural settlements (Cullis *et al.,* 2015). The link between water and energy (i.e. the water-energy nexus) also needs to be considered with regards to climate vulnerabilities for human settlements and possible adaptation options.

Embracing the concepts of water sensitive urban design (WSUD) will be critical in terms of reducing climate change vulnerabilities for human settlements in terms of increased resilience for future water supply, but also in terms of reducing the risk from flooding and treatment of waste water which benefits water quality as well as reducing the energy requirements with benefits for climate change mitigation.

3.6.7.2.4 Adaptive capacity

Societal vulnerablity will be greatly reduced through the building of adaptive capacity, which currently is poor in South Africa (Theron and Rossouw, n.d.). Building adaptive capacity in the most socially and climatically vulnerable settlements, such as informal settlements, peri-urban interfaces and rural settlements should be a priority where small intervention in resilience will yield greatest decrease in vulnerability. Areas of established formalised capacity and development, such as urban centres will derive only limited benefit from building adaptive capacity (DEA, 2013a; DEA, 2014h). Income and assets are critical to adaptive capacity, thus the unemployed will have greater vulnerability and more likely to experience the negative impacts of climate change (DEA, 2013 DEA, 2014h).

Policy developments

In order to guide local scale adaptation strategies and mediate between competing strategies of particular settlements and individual sectors, a strong policy framework at national and provincial level is necessary. However, national and provincial policy must be feasible at the local level and local government needs capacity, authority and co-ordinated mandates to address challenges in improving human settlements.

National level

The NCCR White Paper suggests that urban settlements promote urban densification, increase the resilience of low-cost housing and the implementation of WSUD. It also suggests that rural settlements support small-scale farming that conserves ecosystems, make use of drought resistant crops, conserve soil and water and empower local communities. Coastal settlements are advised to take sea level rise into account when developing new areas and to protect natural ecosystems. Climate change is addressed in the National Development Plan (NDP) acknowledging South Africa’s vulnerability and identifying climate change response as key to achieving national objectives and long term sustainable development.

Provincial level

Climate change impacts all spheres and levels of government and highlights the importance of enhanced coordination and policy alignment (Table 0.23).

Institutional arrangements and capacity

In order to effectively address the needs of human settlements, government institutions need to be capacitated with authority and co-ordination aligned to national and provincial level policies and plans. They also need to address specific climate change risks and adaptation in a locally relevant context, see example in

Box 0.16: Changing perceptions of climate mitigation among competing priorities: the case of Durban, South Africa (Aylett, 2011)

. National and provincial governments must support local authorities (LA) to assist them in incorporating the impacts of climate change into the delivery of services, planning and decisions on land use. Furthermore national or provincial government strategies are implemented over a longer time frame and larger scale than LAs.

Large scale climate change impacts breach the bounds of a single local municipality and have national or provincial implications for human settlements, particularly for food and water security and migration. Adaptations regarding food and water security need to be coordinated by provincial, national and regional actors because food and water security depends on large decentralized networks on regional or global scales as well as linking urban and rural areas. Adaptations involving migration also require provincial, national and regional coordination. Migration may be reduced by national governments that increase adaptation in rural settlements.

Local municipalities are responsible for planning and managing land use on a smaller scale and generally with shorter planning horizons while making use of a local spatial development framework and operating within provincial and national frameworks (Eastern Cape Planning Commission, 2014). However local spatial development frameworks are often not strategically aligned, particularly in the rural areas because of lack of capacity, resources and unacknowledged authority to make decisions resulting in insufficient service delivery at the local level (Bourne *et al.,* 2012; DEA, 2013a; DEA, 2014h) and poor coverage of rural and communal areas (Eastern Cape Planning Commission, 2014). Critical sectors such as environment, sustainable resource usage and commonage in rural settlements do not receive the necessary attention (Bourne *et al.,* 2012). Furthermore governance arrangements in some rural areas may lack clearly demarcated traditional and local authorities or may not be implemented in a democratic and equitable manner (DEA, 2013a; DEA, 2014h).

Municipalities are responsible for delivering bulk infrastructure services for electricity, sanitation, water, waste water treatment and reticulation systems (Free State Planning Commission, 2013). Yet the additional pressures resulting from climate change impacts at local level may exacerbate institutional weakness in addressing climate change adaptation, particularly when given a narrow mandate or is seen as a separate issue from development and service delivery (DEA, 2013). However with good institutional arrangements and mandates, an opportunity for synergy can arise if adaptation objectives are combined with the resources necessary to support sustainable and climate compatible development. This allows adaptation to be mainstreamed into infrastructure, spatial and economic policies (DEA, 2013a; DEA, 2014h).

The local government has mandates and the institutional arrangements to directly intervene in issues regarding physical infrastructure. However, they often lack the capacity to meet adaptation and mitigation needed in infrastructure projects requirements. Non-governmental intervention such as autonomous adaptation in these projects is not viable as it relies on strong independent institutions (DEA, 2013a; DEA, 2014h).

The institutional capacity to manage risks in urban settlements is constrained largely due to much of the urban growth taking place outside of strategic planning objectives. Therefore service delivery and land use management is problematic in these unplanned areas (van Huyssteen *et al.,* 2013). Such inadequate or inappropriate planning exacerbates the vulnerability of human settlements to both current variability and future climate change (Oranje and van Huyssteen, 2011).

Combining autonomous (spontaneous reflex) and planned adaptation with an aligned collaborative intervention between government, communities and households will significantly increases adaptive capacity. Each level will require different types of adaptation; government presents strategic framework and capacity while communities and households grapple with precise vulnerabilities and climate related risks on the ground. Households and communities can even promote adaptation in areas where governments lack the capacity. Furthermore with risk-pooling, information sharing, saving schemes and some infrastructure upgrading they can partially fill the gap in adaptation.

Table 0.23: Examples of provincial policy and plans aligned to climate change adaptation

Province	Details
Limpopo Local Development Plan	Indicates a clear provincial commitment towards climate resilience in line with the NDP 2030 and strives to develop sustainable human settlements and improved quality of household life, as captured in outcome 8 of the LDP.(LPG, 2015)
The Mpumalanga Local area plan and implementation plan (**LAP**)	Encourages sustainable development and climate change resilience to make sure that environmental resources are protected and used sustainably. LAP needs to contribute to the development of integrated human settlements (Royal Haskoning DHV, 2014)
The Kwa-Zulu Natal Provincial Growth and Development Strategy (**PGDS**)	Indicates a clear provincial commitment towards climate resilience and the need to develop human settlements as set out in the strategic goals.
The North West Provincial Development Plan (**PDP**)	Focuses on addressing the entrenched spatial patterns that increase social inequality and economic inefficiency, ensuring that housing delivery restructures towns and cities and the strengthening of livelihoods of the communities, among others.(NWPC, 2013)
The Western Cape Vision 2030 Provincial Development Plan (**PDP**)	Includes an integrated framework for human development and seeks to improve the quality of human settlements, as captured in one of the strategic objectives. It seeks to 'shift the focus from state-driven quantitative housing delivery to a system where people make their own decisions, build their own houses and transform spatial patterns to create vibrant and liveable communities.
Western Cape Government Climate Change Action Plan	A strategic framework and implementation for addressing the risks of climate change in the agricultural sector.

Box 0.16: Changing perceptions of climate mitigation among competing priorities: the case of Durban, South Africa (Aylett, 2011)

Durban currently experiences crisis relating to food, energy and extreme weather events. Durban represents the impacts that climate change could have on coastal settlements in developing countries. The issues that Durban faces highlight the institutional barriers to effective mitigation that are evident in municipalities. However, Durban has actively engaged in generating municipal mitigation plans, institutional restructuring and integrating climate change policy through different municipal departments. International funding, support for local leaders and partnerships were key in order to initiate climate change programmes in Durban. Thus, Durban is seen as an example of how climate change initiatives and mitigation can take place in a city with many competing development priorities and poor leadership from municipal politicians.

Socio-economics

South Africa's socioeconomic profile is characterised by inequalities evident across income, age, racial groups and space in many cases resulting from the legacy of apartheid and influenced by topography and several other socioeconomic factors (van Huyssteen *et al.,* 2013). Risks are generally higher in areas with existing development pressures and vulnerability (van Huyssteen *et al.,* 2013). Various changes in the socio-economic conditions of South Africa have influenced the relative risk and vulnerabilities across the country since the SNC (DEA, 2011b).

Between 2011 and 2014 South Africa's population increased from 51.5 million to 53.7 million (GHS, 2014). The largest proportion of population increase was in Gauteng (6.51%) and the Western Cape (5.85%). The lowest was in the Free State (0.51%) as shown in Table 0.24. The number of households in South Africa also increased from 14.1 million in 2011 to 15.6 million in 2014 (GHS, 2014). At the time of the 2011 census 77.6% of households were living in formal dwellings and 13.6% in informal dwellings (Stats SA, 2011), see Table 0.25. There is an increase in the number of households (nationally 10.08%) in all provinces with Gauteng and Mpumalanga Province exhibiting the largest increases with 12.81% and 11.13% respectively; Eastern Cape with the lowest increase of 5.94%. As of the 2011 census the divide between formalised to informal dwellings at household level was also 77.6% to 13.6%, see Figure 0.82. Over time, migration from rural areas to the cities of people which tend to have lower capacity and would therefore be forced to settle in informal dwellings will shift the ratio further toward the informal and more vulnerable side. It should also be noted that population and dwelling counts in informal areas are problematic and estimation may therefore incorrect and therefore change the ratio.

Table 0.24: Number of individuals per province, 2011-2014 (Taken from GHS, 2014)

Province	**Total population (Thousands)**				**% change 2011 to 2014**
	2011	**2012**	**2013**	**2014**	
WC	5792	5904	6017	6131	5.85
EC	6554	6586	6620	6656	1.56
NC	1143	1153	1163	1173	2.62
FS	2744	2749	2753	2758	0.51
KZN	10237	10346	10457	10571	3.26
NW	3497	3547	3598	3650	4.38
GP	12202	12464	12728	12996	6.51
MP	4022	4075	4128	4182	3.98
LP	5388	5452	5518	5585	3.66
RSA	51580	52275	52982	53701	4.11

Table 0.25: Number of households per province, 2011-2014 (GHS, 2014)

Province	**Number of households (Thousands)**				**% change 2011 to 2014**
	2011	**2012**	**2013**	**2014**	
WC	1571	1619	1669	1720	9.48
EC	1600	1631	1663	1695	5.94
NC	289	296	304	312	7.96
FS	823	843	863	883	7.29
KZN	2428	2504	2583	2663	9.68
NW	1071	1105	1140	1177	9.90
GP	3990	4153	4323	4501	12.81
MP	1051	1088	1127	1168	11.13
LP	1350	1392	1436	1483	9.85
RSA	14173	14631	15107	15602	10.08

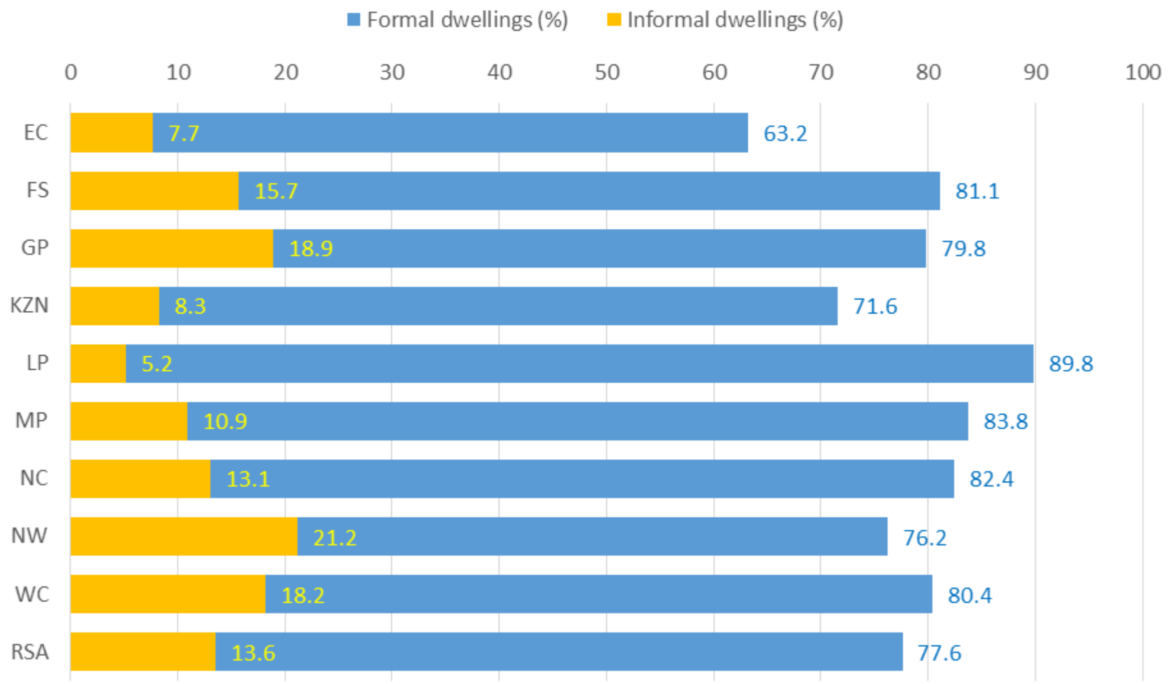


Figure 0.82: Households living in formal and informal dwellings (**Stats SA, 2011**)

Populations at higher risk include those with low or zero income. People earning between R0 and R3200 (67%) and between R3200 and R6400 (71%) stay in formal owned or rented accommodation. Therefore approximately 33% of people earning between R0 and R3200 and 29% earning between R3200 and R6400 live in an informal shelter, a backyard dwelling, traditional dwelling or other shelter (Figure 0.83). These people, already subject to heightened economic vulnerability, are highly exposed to potential climate change impacts and are the least capacitated to cope with the adverse impacts of climate change.

The provision of basic housing reduces climate change vulnerabilities but is also considered critical in terms of social development. Based on the annual national housing delivery it can be seen that housing delivery has slowed between 2011 and 2014 (Figure 0.84). The average national housing delivery was 241 616 between 2005 and 2010. While additional families and individuals in proper housing will decrease exposure to climate risk, the increase in general population highlights the need to maintain or increase the provision of basic housing to the most vulnerable communities.

Adaptive capacity is enhanced through the provision of housing. The Department of Human Settlements estimated that in 2014 there were just over 11,000 housing delivery projects underway (Figure 0.86) decreasing the susceptibility of the occupants to the hazards associated with a changing climate. Following 2010 there has been a decline in the number of serviced sites and housing units completed and delivered across South Africa (Figure 0.85). In the context of an increasing population the number of sites completed needs to be maintained or increase and not decreased if exposure to climate risks are to be reduced.

Presently there are a large number of housing projects at various stages of completion (Figure 0.86). Mpumalanga province has the highest number completed projects followed by the Western Cape, Free State and the Eastern Cape. Gauteng, being the most densely populated province has the most housing projects either runner or moving slowly. The Northern Cape and the North West Province have the lowest number of total housing projects.

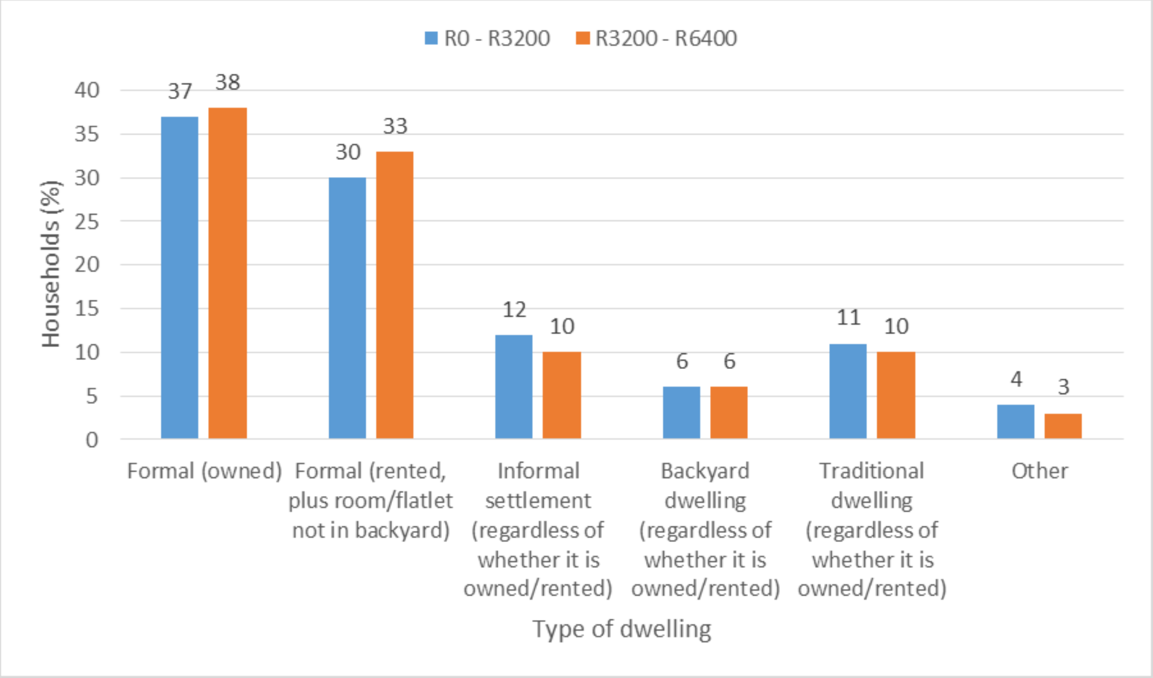


Figure 0.83: Housing circumstances of households earning below R6400 (**Stats SA, 2011**)

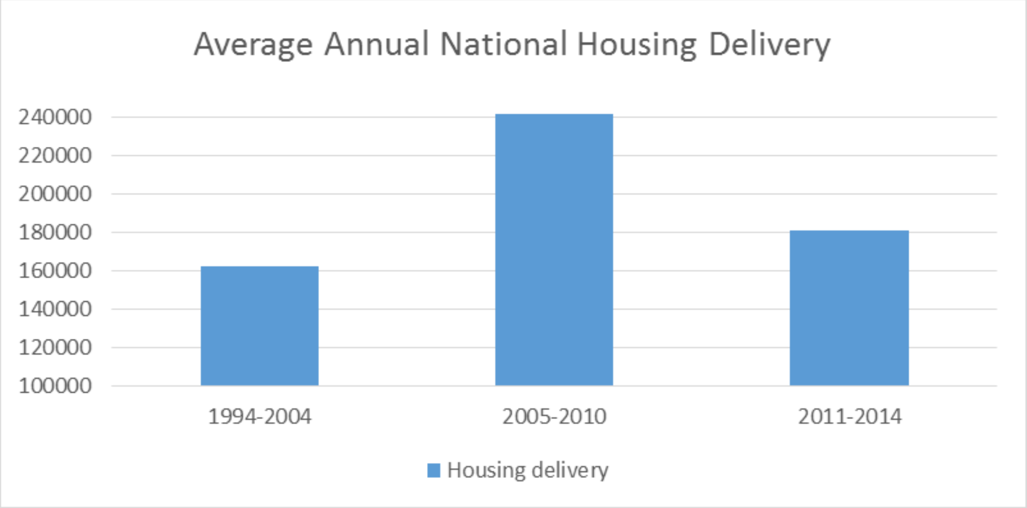


Figure 0.84: Housing Delivery Trends for South Africa (**Department of Human Settlements**)

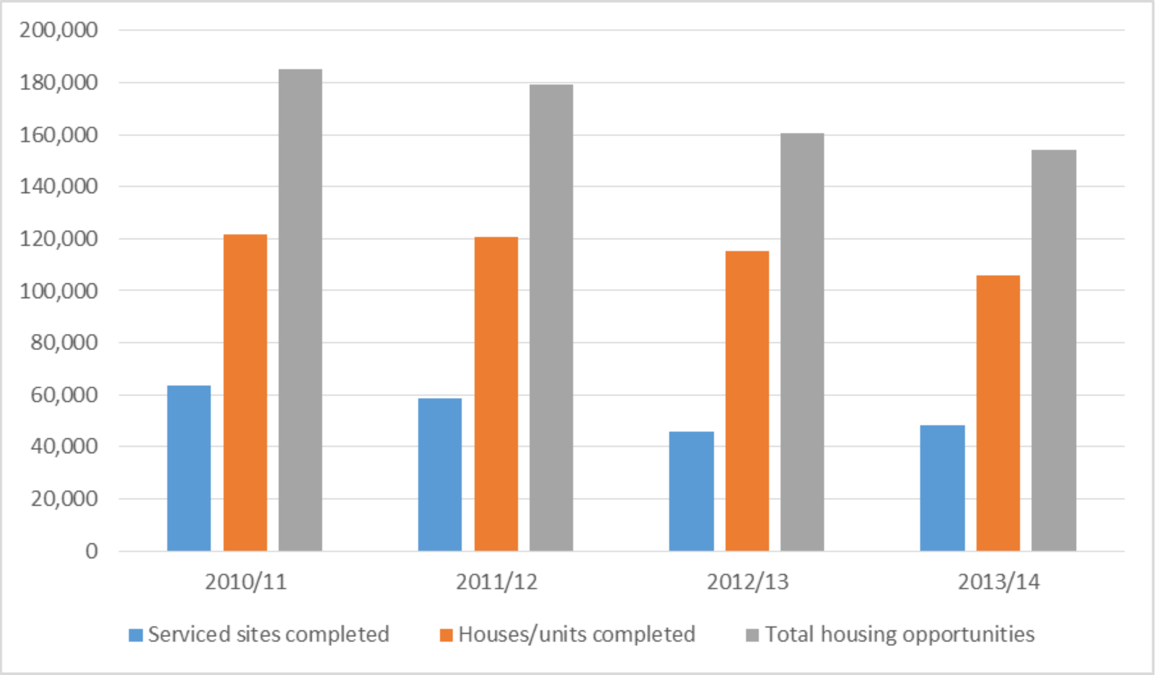


Figure 0.85: Housing delivery since 2010/2011 (**Department of Human Settlements**)

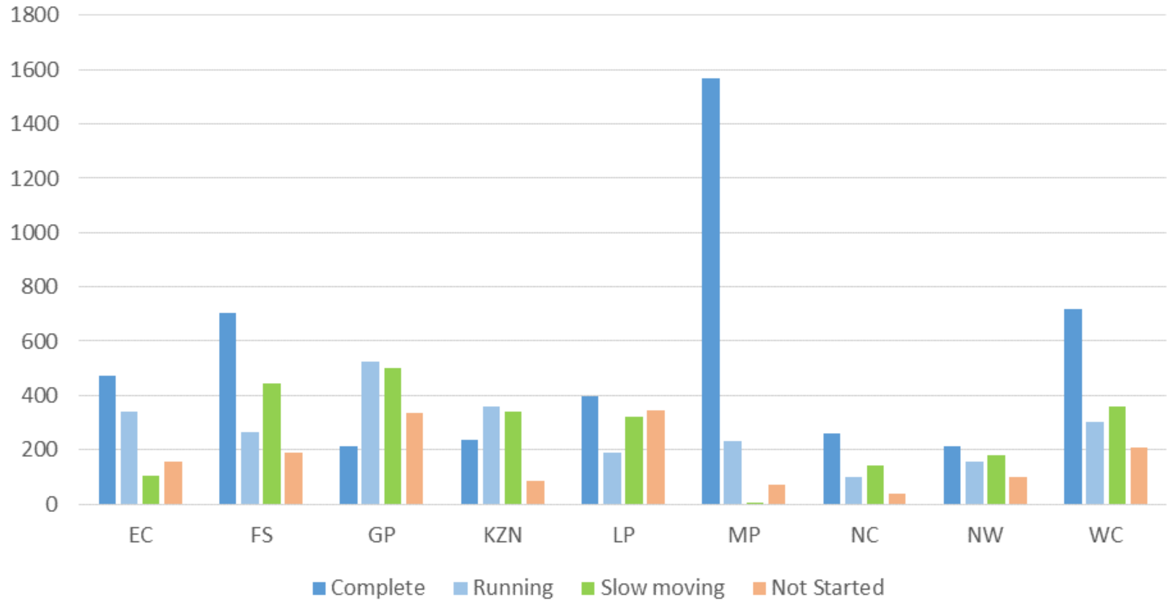


Figure 0.86: Housing projects underway (**Department of Human Settlements, 2014**)

Programmes, Organisations and initiatives

A number of programs, organizations and initiatives have been implemented or have made significant progress since 2011 in order to develop climate change resilience and adaptive capacity related to human settlements globally and in South Africa. These include global networks as well as a number of national and provincial level programmes, that although not necessarily directly aimed at reducing climate change risk and vulnerabilities are making significant progress in this regard through the provision of housing and support for urban upgrading and sustainable development.

Global networks

Since the publication of the SNC there have been many developments in terms of global networks to support adaptation and sustainable development for human settlements. These include the signing of the ICLEI Local Governments for Sustainability, the Durban Adaptation Charter (DAC, n.d.) and the formation of the C40 and 100 Resilient Cities programs of which many South African cities and local municipalities are now contributing members (C40Cities, 2017). These are described briefly below:

- *ICLEI Local Governments for Sustainability* helps its members to make their cities and regions sustainable, low carbon, resilient, ecomobile, biodiverse, resource-efficient and productive with a green economy and smart infrastructure.
- *C40 Cities Climate Leadership Group* includes Cape Town, Durban, Johannesburg and Tshwane. C40 addresses climate change while driving urban action that decreases climate risks and greenhouse gas emissions and creates economic opportunities while also improving the health and wellbeing of urban residents (C40Cities, 2017).
- *100 resilient cities network* is signed by Durban as the only South African city to the network founded by the Rockefeller Foundation. Durban, which is the poorest metropolitan area in South Africa, has become a global leader in climate change adaptation and copes with limited resources and a wide range of environmental, economic and social challenges.
- *The Durban Adaptation Charter* (*DAC, n.d.*) which has 114 signatories representing 950 local governments from 27 different countries was initiated at the United Nations Framework Convention on Climate Change (UNFCCC) in December 2011 in order to encourage local governments to take action against climate change, to assist in increasing the capacity of communities and reducing their vulnerability.

3.6.7.3 Balancing opportunities and threats

3.6.7.3.1 Barriers to adaptation

Limited funds and capacity are considered to be significant barriers to adaptation to climate change for human settlements in South Africa. National, provincial and local level authorities also often have to respond to more immediate and pressing challenges. Climate change, with a slow and hard to define onset is considered to be a long term problem and is allocated minimal priority. This is demonstrated by the emission reduction programmes in the eThekwini Municipality receiving secondary priority to adaptation and other more immediate development issues (Aylett, 2011).

Some mitigation and adaptation options, such as decentralized energy and water supply systems also present a financial risk to local authorities given the current financial systems where much of their revenue is raised from levies on basic services such as energy, water and waste removal. Identifying alternative financing systems is therefore critical to support adaptation and sustainable development. The current system of municipal finance also tends to favour the development of large physical infrastructure projects. Mechanisms do not readily exist to provide financing for alternative options. An example of an alternative option to physical infrastructure is investing in ecological infrastructure that is more sustainable, promotes climate resilience and supports improved ecological functioning and job creation. Cartwright *et al.,* (2016) provide some interesting examples for alternative funding of ecological infrastructure that could also support sustainable development of human settlements

Ziervogel *et al.,* (2014) noted that a number of institutional barriers for addressing climate change have also been identified in South Africa. These include: the lack of capacity (numbers of people and expertise), limited understanding of and expertize in tackling climate-related issues. There is also low staff retention within government departments and the positioning of climate change as an environmental issue rather than as a development issue. This is manifest in conservative financial management practices, poor communication and coordination between departments, and between different levels of government particularly from national or provincial to local level.

Maladaptation or improper resource allocation could also result due to a lack of coordination policies. For example, the competing demand for water between irrigation agriculture stressed due to rainfall changes, increased evaporation and temperatures over the provision to urban communities and industrial sectors. This requires careful strategic consideration and assessment of potential trade-offs between demands that are competing in a climate of greater water variability.

Additional research into climate change risks and vulnerabilities for human settlements, as well as the establishment of global networks aimed at building climate change resilience, has resulted in an improved understanding of climate risks for human settlements since the SNC yet further research is needed on the localised scale. The potential adaptation options and recommendations set out in the National Climate Change Response (NCCR) and the LTAS report are presently not being implemented and pose a barrier for further progress towards resilience. Identifying and addressing these barriers to adaptation should be given a higher priority.

3.6.7.3.2 Key evidence gaps

The LTAS Report (DEA, 2015a) noted that adaptation research is often focused on interpreting the implications of climate change in terms of bio-physical impacts on infrastructure and the economy. As priorities shift from mitigation to adaptation planning and action, the need for decision-oriented research at a local community scale is becoming more evident (Wise *et al.,* 2014). More research is needed to understand and demonstrate where effective ecosystem based approaches are being used on livelihoods of the communities, particularly in rural areas. Behavioural change and social cohesion are critical to community-based adaptation in both urban and rural settings and therefore a focus on mind-set and responsibility changes is need for community driven adaptation and mitigation solutions. This is also being advocated at a global level in terms of “bottom-up” approaches such as “decision scaling", "robust decision-making" and "adaptation pathways" as an alternative to the traditional top-down approach to climate change (Matthews *et al.,* 2015).

A recent review of the LTAS program (Ziervogel *et al.,* 2015) also identified a number of key knowledge gaps in part due to a lack of climate scenario products; under-synthesized and potentially contradictory climate information, incomplete impacts modelling approaches and inadequate process understanding and associated impacts. This confusion will lead to contradicting strategies and variable priorities for the adaptation of settlements at a high level. This confusion is also transferred down to the local intervention level with local decision makers uncertain on how to apply existing climate information in their decision making process for improving the resilience of human settlements. Thus, there is a need to develop approaches that support robust and clear assessments. These need to be resilient and able to exhibit an adaptive decision framework taking account of uncertainty and reducing lock-in to particular future scenarios (Weaver *et al.,* 2013). This also shows that climate change projections need to be downscaled to the local scale for relevance (DEA, 2013a).

Urban settlements

Research that helps in understanding the environmental vulnerabilities of informal settlements is needed in order to direct local government plans (DEA, 2013a). Research beyond major urban centres is also required to examine the challenges faced by municipalities (Pasquini *et al.,* 2015).

Informal settlements

In addition to research needed in urban settlements, the path and scales of vulnerability need assessment to better cater for the high exposed residence of informal settlements.

Rural settlements

Further research in rural communities is needed to guide policies relating to tenure reform and land restitution. Local level climate projections are needed to assess agricultural vulnerabilities. Seasonal forecast information needs to be more user friendly and gain wider dissemination amongst rural communities.

Coastal settlements

There is a major research gap in information regarding the effects of a combination of sea level rise and severe sea storms (Mather and Stretch, 2012). There is also little data on coastal erosion and changes in shorelines (Mather and Stretch, 2012). Both of these need to be addressed to increase the resilience of coastal settlements.

3.6.7.3.3 Opportunities

In many areas where development, infrastructure and provision of services has not yet formalised, there are opportunities to plan and design human settlements with lower ecological and carbon footprints than already established cities. This would allow for them to focus on competitiveness and capacity for sustainable population growth rather than requiring a growth strategy reliant on intensive carbon and resource utilisation (Taylor and Peter, 2014). This is validated by Cartwright (2015a) who notes that the current state of under-development in African cities could provide an opportunity to respond to the challenges of climate change by integrating climate change into traditional development planning and financing requirements.

This can be done through the development of appropriate technologies, financing, and institutional arrangements (Cartwright, 2015a; Cartwright *et al.,* 2015b). One such development avenue is carbon offset projects which will increase sustainable development benefits particularly to rural settlements by providing the opportunity to channel funds into rural development projects (EDF, 2015). Thus creating jobs, decreasing land degradation, restoring landscapes and protecting biodiversity.

Interventions for increasing climate adaptation often co-inside with sustainable development planning best practice. In the water sector for example, support for improved WCDM is enhanced when considering the uncertainty associated with climate change impacts on future water supply (Cullis *et al.,* 2011).

eThekweni Municipality provides a novel approach to an alternative analysis of adaptation options under uncertainty and resource constraints (Cartwright *et al.,* 2013). The benefit-cost ratios and total benefits for each of a set of intervention clusters under future climate scenarios is modelled. Taking into account planning and interventions time frames, it highlights how the most efficient interventions across all futures tend to be socio-institutional and display cross sectional benefits.

3.6.7.4 Adaptation priorities

It is estimated that if South Africa does not adapt to climate change impacts, it could cost the country approximately 1.5% of GDP by 2050 (KwaZulu-Natal Provincial Planning Commission, 2011). Adaptation therefore is essential and should benefit multiple sectors and societies where possible with responses tailored to fit locations and particular circumstances (Mather and Stretch, 2012).

While the annual impact on GDP and GDP growth was found to be relatively low as a percentage, the net present value (NPV) of the cumulative impact on GDP by 2050 is highly variable, ranging from losses of R 930 billion to gains of R 310 billion (real 2007 Rand), and 96% of the climates scenarios show overall losses (DEA, 2015a). These losses result primarily from the potential impacts on dry-land agriculture and on roads. The median loss in NPV under the unconstrained emissions (UCE) or “hotter” scenario is approximately R259 billion by 2050. At more than 10% of 2007 GDP, this is sizeable and should motivate for action in terms of both mitigation and consideration and funding of potential adaptation scenarios (DEA, 2015a).

Taylor and Peter (2014) recognise that greenhouse gas emissions per capita in African cities is significantly less than in developed countries, therefore focus should be towards adaptation to current and future climate variability. Where possible, there should be an emphasis on climate compatible development at the settlement scale within cities in order to improve living and working conditions as well as safety, security and wellbeing. It should also be noted that informal growth is permanent and developing appropriate adaptation responses for African cities is also critical.

The incorporation of disaster risk management principles into low cost housing and informal settlement upgrades through construction standards and policy, while adhering to national, provincial and local strategies will boost human settlement risk reduction. Strategic planning and development of infrastructure, services and institutions as a high priority is vital for reducing vulnerability, particularly in informal settlements and better adaptation (Linkd, 2013; UN-Habitat, 2011). The provision of clean water, sanitation, electricity, drainage, tenure, emergency services, healthcare, schools and transport should be a priority for human settlements (UN-Habitat, 2011).

In order to reduce pressure on labour markets created by urbanisation and immigration, stronger social protection must be put in place, rural and urban economies must be built, living standards must be raised (DEA, 2013a) and rural communities need to be developed (Linkd Environmental Services, 2013). Raising living standards through social protection and economic growth reduces the impoverishing effects of increased food, water and energy prices as well as increasing adaptive capacity by minimizing social vulnerabilities (DEA, 2013a).

Improved water resources management will be critical in terms of reducing future climate change risks and supporting future social and economic development (DEA, 2013a). This is applicable both in terms of improved urban planning and design based on the principals of WSUD, but also in terms of improved water use efficiency in the agriculture and energy sector, as well as protection of catchments, wetlands, riparian banks and estuaries that provide basic water services and reduce the risk of flooding and water quality risks for human settlements.

Alternative adaptation measures such as mainstreaming ecological and ecosystem based adaptation including wetland and river management and restoration into the planning of human settlements should be considered. Water demand from cities needs to be reduced by implementing usage restrictions and higher tariffs and water must be used sustainably. Maintenance and repairs must be prioritised. Awareness campaigns and incentives to reduce water use must be promoted.

Regulations promoting efficiency should be implemented e.g. low-flow requirements for toilets. Supply-side adaptations include harvesting rainwater, recycling, exploiting new aquifers, using seawater for certain uses such as for swimming pools and desalinating seawater for general use. Increased runoff resulting from the development of human settlements should also be limited to reduce the risk of flooding and to maintain groundwater recharge (DEA, 2013a).

Climate change will impact on food prices and security. Contingencies are essential to ensure food security for all. The urban poor can be protected from changes in food markets by producing food domestically. Governments need to intervene in food markets through the use of subsidies or tax reductions. Food aid can assist with providing food security to communities. Consumption by middle and high end consumers is often high and wasteful and needs to be reduced (DEA, 2015e).

There are multiple benefits from the development of the green economy for human settlements. Government need to support this through the development of policies that decouple development from natural resource consumption, carbon emissions and natural assets destruction and support long term sustainability.

Adaptation in informal settlements and the provision of housing is vital. Community-based adaptation should be implemented in informal settlement upgrades, rural housing subsidies and tenure reform. Ecosystem-based adaptation needs to be incorporated into overall adaptation policies. Local government needs to address spatial inequalities. Mostly informal settlements and poor rural communities experience backlogs in service provision but even settlements that have well established infrastructure face breakdowns in service provision. In order to reduce the vulnerability and increase the resilience of these settlements to climate change, services, water, electricity and waste collection must be put in place (DEA, 2013a).

In general it can be concluded that, despite not always having a direct impact from climate change, addressing the current risks and vulnerabilities of human settlements could potentially result in some of the best returns in terms of reducing climate vulnerabilities. This is because the areas of human settlements are directly linked to human wellbeing, they are the epi-centres of social and economic development, and they are intimately linked to most other sectors. This means that efforts to address climate change vulnerability with regards to human settlements will by implication require implementation of adaptation options in other sectors.

There are however still many barriers to adaptation for human settlements that need to be addressed. This will require a change in urban planning and in particular changes to the current system of municipal financing, investments in physical and ecological infrastructure and current design standards. If these barriers can be addressed by the time of the fourth national communication it may be possible to conclude that South Africa has truly established resilient human settlements.

3.6.8 Disaster risk management

3.6.8.1 Introduction

Climate-related disasters have come to dominate the disaster risk landscape to the point where they now account for upwards of 80% of reported disasters worldwide (CRED, 2015). Under climate change it is expect that there will be a significant increase in the risk of disasters not only due to increases in extreme weather events, but also due to increasing population growth, poor land use practices, and generally an increasing number of people living in high risk areas particularly in Africa.

The National Climate Change Response (NCCR) White Paper highlights disaster management as a key area of development for the country, due to the expected increase in extreme climatic events. This commitment is illustrated by the fact that the national government’s investment in disaster risk reduction and emergency response has risen from US$ 0.02 bn. to US$ 0.7 bn. between 2010 and 2015, as part of the total increase of investment in adaptation which rose from US$ 1.64 bn. to US$ 2.31 bn. (South Africa, 2015).

As the relationship between climate change and disaster risk become increasingly clear to both the public and private sector, actions are being seen on all levels. Smart (policy) choices and informed decision making will be and are already delivering economic, environmental and social benefits locally and internationally, motivating more resilient and sustainable solutions in achieving everyday objectives.

The South African policy context has positioned the country to take a leading role in this regard, with the progressive national disaster management regulatory framework and incremental cross sectoral support for practical disaster, risk and emergency management of which climate change response is acknowledged as a critical factor.

3.6.8.1.1 Progress since the 2nd National Communication

Over the coming years/decades the international community will be guided by three significant undertakings with regards to disaster risk management which came into effect in 2015, namely the Sendai Framework for Disaster Risk Reduction 2015-2030, the Sustainable Development Goals, and the Conference of Parties (COP) 21 Agreement. Of most immediate relevance to the field of Disaster Risk Reduction is the Sendai Framework for Disaster Risk Reduction 2015-2030 (see Box 0.17: Sendai Framework for Disaster Risk Reduction 2015-2030 3.17).

Box 0.17: Sendai Framework for Disaster Risk Reduction 2015-2030

In March 2015, the Third United Nations World Conference on Disaster Risk Reduction (WCDRR) adopted the Sendai Framework for Disaster Risk Reduction 2015-2030, which was later endorsed by the UN General Assembly in its 69th session. The Sendai Framework provides the basis for a risk-informed and resilient future. The Sendai Framework specifically addresses climate change and climate action, providing measures, guiding principles and means of implementation. Sendai outcomes are a significant milestone in international cooperation for building resilience to climate-related disasters. The Sendai Framework establishes the significance of ensuring credible links on the post-2015 agenda including the sustainable development goals, financing for development, climate change and disaster risk reduction and the calls for enhanced coherence across policies, institutions, indicators, reporting and measurement systems for implementation (UNISDR, 2015a).

South Africa’s National Disaster Management Centre (NDMC) will play a key role in implementing the Sendai Framework (Nel, 2015).

South Africa has made significant progress on various levels with regards to acknowledging the reciprocal relationship between climate change and disaster risk and facilitating greater integration between climate change science, impacts and response and disaster risk management, including the establishment of some of Africa’s most advanced early warning systems (EWS). These include the Advanced Fire Information System (AFIS), the South African Weather Service’s (SAWS) Multi Hazard EWS (MHEWS), and the South African Flash Flood Guidance System (SAFFG) (DEA, 2014d; DEA, 2015d). The information originating from these systems are disseminated to all spheres of government for inclusion in local EWS.

One of the most significant developments in terms of the sectoral policy context since the SNC has been the Disaster Management Amendment Act (DMAA) No.16 of 2015. See Section 6.6 of the Human Settlements Chapter for more information on the DMAA.

Capacity Building

As referenced by South Africa's final progress report on the implementation of the Hyogo Framework for Action (Sethusha, 2015), on a national level, gradual progress has been made on integrating climate change concerns into our understanding of disaster risk. Although the majority of progress relates to institutional commitments, tangible achievements have also been realized. This includes the establishment of a Directorate for Disaster Management and Climate Change aimed at facilitating the integration of climate change mitigation and adaptation disaster management in departmental operations.

Another significant initiative has been the establishment and continued development of the South African Risk and Vulnerability Atlas (SARVA) and the setup of Risk and Vulnerability Science Centres (RVSC), (see Section 3.5 on tools for vulnerability assessments).

Long Term Adaptation Scenarios (*LTAS*) *Flagship Program*

The LTAS report on perspectives for disaster risk reduction and management in South Africa (DEA, 2015d). A precautionary principal is therefore recommended, particularly with regards to potential low cost or "no-regrets" adaptation options such as increasing the size of culverts for storm water design, improved monitoring and improvements to land use planning that take into account possible increasing risks from flooding and possible sea level rise or increases in storm surges. Best practice with regards to improved land use planning, biodiversity protection and water use efficiency and consideration for a diversity of water supply options, as well as improved agriculture efficiency and reduced vulnerability through improved housing and services delivery is also recommended (DEA, 2015d).

3.6.8.2 Vulnerability to Climate Change

Climate change will pose additional challenges for disaster risk management and the appropriate allocation of resources for disaster risk reduction. The frequency of extreme events as well as their spatial variability is likely to increase (see Section 3.6 of this chapter), which will alter and likely increase the number of communities located in hazard zones. The increased exposure combined with high levels of vulnerability particularly with regards to poorer communities will likely contribute to an increase in the overall levels of disaster risk.

Climate change will make it increasingly difficult to anticipate, evaluate, and communicate the variables that contribute to disaster risk. High degrees of uncertainty will make it less reliable to use the past as a precedent for the future, making development planning and allocation of resources increasingly complicated. This will have significant implications for the social and economic development of the country. Climate change could potentially prove a significant obstacle to maintaining and improving overall well-being, as responding to its impacts may continually demand resources to be redirected away from investments aimed at development.

3.6.8.2.1 Current risks

In the context of disaster risk the priority hazards currently facing South Africa are floods, drought and wild-fires (Figure 0.87). All of which can be either directly or indirectly exacerbated by climate change. Other disaster risks include lighting strikes, heat waves, hail damage, wind storms and sea level rise as well as possible increases in health related disasters, increased migration, and possible war and conflict, that could be exacerbated by future uncertainties including climate change.

Over the last two decades there have been 52 climate-related disaster declared in South Africa (EM_DAT, 2016). The key factor is not the increase in the occurrence of hazard events but rather a significant increase in human vulnerability as an ever-growing number of people are exposed to disaster risk. The main risk drivers include population growth, urbanization, the large portion of the population residing in informal settlements, and high levels of poverty and inequality (UNISDR, 2015).

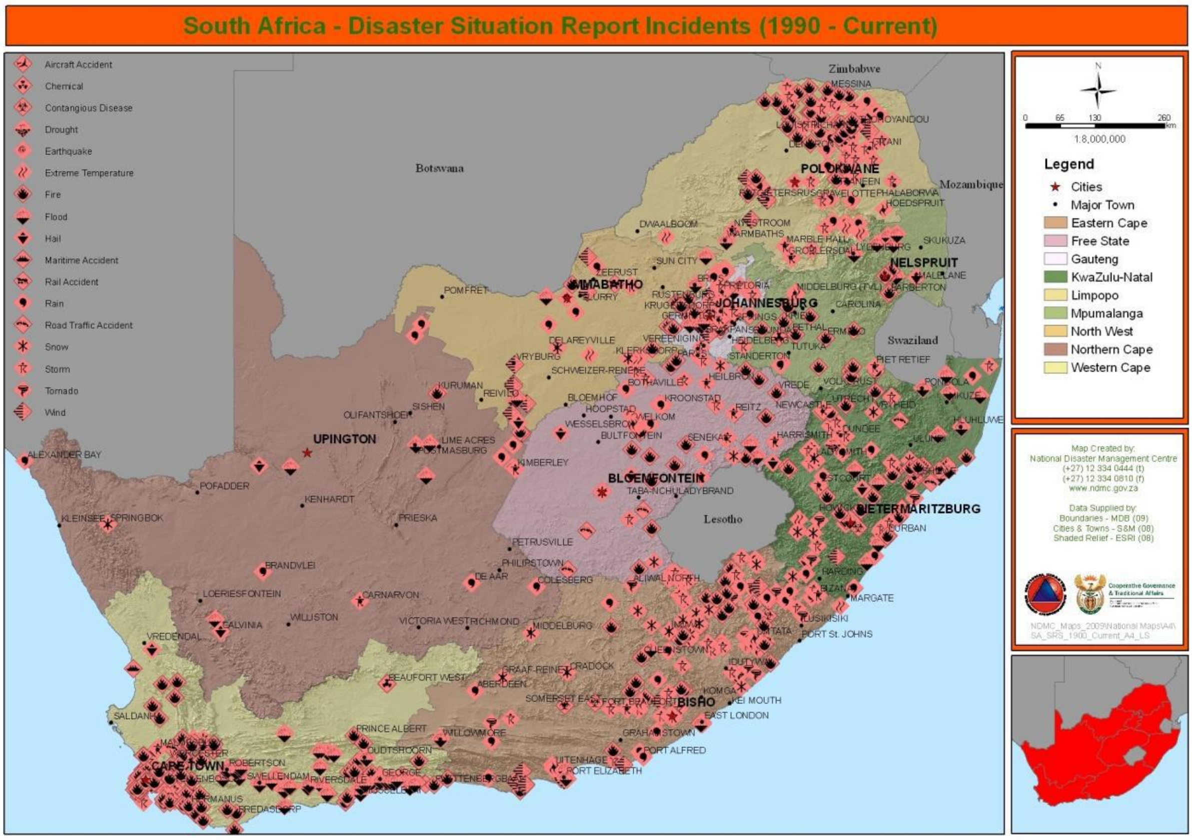


Figure 0.87: National Disaster Management Centre (**NDMC**) **disaster situation report showing the extreme events incidents that have occurred across the country from 1990 to date** (**DEA, 2015d**) (**http://gisportal.ndmc.gov.za/StaticMaps.aspx**).

Drought

The term drought may refer to meteorological drought (below average precipitation), hydrological drought (low river flows and water levels in rivers, lakes and groundwater), agricultural drought (low soil moisture), and environmental drought (a combination of the above) (IPCC, 2012a). Drought can also be caused, or at least impacted by human actions such as a failure to maintain or operate critical systems such as water supply infrastructure resulting in what is called a social or operational drought. This is particularly a concern in areas of reduced operational capacity.

Drought impacts stem from a combination of factors. Increasing rainfall variability is one aspect, but how this affects communities depends upon how well people, the economy and the environment can adapt. Various factors may undermine people’s ability to withstand reduced water availability (a meteorological drought) and to prevent it from developing into agricultural and hydrological drought with social, economic and environmental impacts (UNDP, 2012). A summary of some of the root causes driving and sustaining drought risk in the South African context includes:

- Population growth;

- Poverty and inequality;
- Lack of awareness and education on drought;
- Inadequate water resource management;
- Environmental degradation;
- Health status (e.g., HIV/Aids, nutritional status, etc);
- Harmful traditional practices (e.g., overgrazing).

Flooding

Flooding events are primarily a natural occurrence, attributed to South Africa's already highly variable rainfall. Such events may then be exacerbated by dam and infrastructure failures related to inadequate design and maintenance, particularly in the case of storm water infrastructure in urban areas, as well as poor land use planning and a lack of early warning systems. It is generally acknowledged that the South Africa's history of land use planning, largely developed under Apartheid has resulted in a significant increase in the risk and vulnerability of poorer communities particularly with regards to the location of informal settlements in high risk areas. In rural areas degradation of the natural environment, particularly with regards to overgrazing and poor land use management practices, has also resulted in an increase in the flooding risk as well as increased soil loss and sedimentation.

Wild-fire

Fire risk is strongly linked to weather and climate conditions, with factors such as wind and temperature being critical aspects of fire activity (CSIR, 2010). While climatic variables and natural causes play a significant role, human activity remains a main risk factor. Humans drive fire risk through activities such as land clearing and inadequate environmental and land management and the increased spread of invasive alien plants (IAPs) particularly pine, eucalyptus and wattles.

Recent years have seen a marked increase in veldfire risk across South Africa due to poor forestry practices, cyclical changes in weather patterns, altered population densities and distribution continued spread of alien invasive plants constrained fire management resources (CSIR, 2010). Fortunately, some positive progress has been made in reducing fire risk particularly through the establishment of Working on Fire and the increasing distribution of Fire Protection Associations as well as continuing efforts to remove and control IAPs through the Working for Water Program of DEA.

3.6.8.2.2 Future risks

The possibility of increased disaster risk is considered to be one of the most concerning and potentially costly impacts of future climate change in South Africa (DEA, 2015f; DEA, 2015g).

Understanding these risks and identifying key areas of concern will be critical for developing suitable and sustainable adaptation policies and scenarios.

It is clear that climate change will be modifying hazard levels and exacerbates disaster risks in some locations and sectors of the country (see Section 3.4 of this chapter). The LTAS program provides initial quantitative estimates of future risks related to extreme events, based on provisional models of potential impacts under a range of possible climate futures. This informs adaptation scenarios for disaster risk reduction including droughts, floods, sediment and sea level rise that complements other studies in the LTAS Flagship program (DEA, 2015f; DEA, 2015g).

Droughts

The causal factors of drought are many and include both natural and anthropogenic factors such as changes in land use and land cover, in efficient water use and management of critical infrastructure. As a result, vulnerability to drought must be contextualized since a number of human and ecological systems having adapted to natural variabilities in rainfall and water availability (DEA, 2014b).Climate change projections show a significant increase in the frequency, duration and severity of droughts events in South Africa during the second half of the 21st century, with specific reference to the south Western Cape (DEA, 2015b). In contrast, summer rainfall catchments such as the Sabie River, although less severe, will be experiencing increased drought risk from the beginning of 21st century.

Climate change impacts related to meteorological droughts appears to be manifesting over a longer time horizon compared to more acute impacts of hydrological droughts, with the winter rainfall regions experiencing impacts in the second half of the century. This is an important factor when considering impacts. Crop yields can be severely affected by a single drought year, but can recover quickly if the drought is broken even by a single good year. Water resources systems however respond much more slowly and it will take a number of years for the impacts of droughts to be felt particularly with regards to groundwater impacts (DEA, 2015b).

In South Africa there has already been many years of development of a highly integrated bulk water distribution system designed to ensure reliability of future water supply in the face of an already high spatial and temporal variability in rainfall and a disconnect between areas of water resource availability and demand. This results in South Africa having the most number of registered large dams in Africa and large number of inter-basin water transfer schemes. This highly developed bulk water distribution system provides some resilience to future climate change impacts, particularly with regards to the large demand centres such as Gauteng, the Vaal System and the Western Cape Water Supply System (Cullis *et al.,* 2015). Of greatest concern are the smaller water supply systems and standalone schemes that are often dependent on a single water resource with limited storage capacity or systems that are inefficient, or not adequately managed or maintained (DWA, 2013).

Dry-land agriculture and the associated communities are considered to be the most vulnerable to increasing drought risk due to future climate change because of the direct dependence on rainfall and the impact that even small changes in the timing and intensity of rainfall can have on the success of a particular crop (DEA, 2015d).

Flooding

The risk of flooding is also likely to increase in the future due to a combination of increasing climate risks as well as other socio-economic pressures resulting in changing land use and more people living in high risk areas. Possible future risks in terms of increased precipitation and flooding include (IPCC, 2014, DEA, 2014d):

- Large numbers of people exposed to flood events in urban areas, particularly in low-income informal settlements;
- Death, injury, and disruption of human security, especially among children, elderly, and disabled persons;
- Interaction of increasing frequency of intense precipitation, urbanization, and limits of insurance;
- Burden of risk management shifted from the state to those at risk leading to greater inequality,
- Eroded assets due to infrastructure damage, abandonment of urban districts;
- Creation of high risk / high poverty spatial traps; and limited ability to cope and adapt due to marginalization, high poverty, and culturally imposed gender roles;
- Overwhelmed, aging, poorly maintained, and inadequate urban drainage infrastructure; and
- Increased demands on governmental attention to disaster risk reduction.

More detailed analyses of specific risks to individual areas and critical infrastructures are necessary to prioritize action, taking into account local hydraulic and physical characteristics and areas of specific risk. A starting point would be for individual municipalities and state agencies such as DWS, SANRAL or ESKOM to identify which areas or key infrastructure are considered to be most critical and then to assess the specific local hydraulic conditions and evaluate adaptation options for future climate change and other future uncertainties.

Sea-level rise

There are risks associated with increased severe storms, erosion, tidal influence and flooding impacts coastal settlements through the loss of property and damage to infrastructure (DEA, 2013a; Taylor and Peter, 2014). Studies on sea-level rise have identified Saldanha Bay, Table Bay, northern False Bay, Mossel Bay to Nature’s Valley, Port Elizabeth and the developed areas along the KZN coast as being the most vulnerable to the effects of sea level rise (Blake, 2010).

There are also potential indirect impacts on the coastal areas that may manifest through the decline in production levels of marine fisheries and tourism revenue. These impacts are likely to be felt at a local level for individual cities. For example, without any adaptation responses to sea level rise the beachfront at Durban will result in significant damages to infrastructure and developments such as Ushaka Marine World (Mather and Stretch, 2012) and specific parts of Cape Town will see an increasing risk due to sea level rise (Cartwright, 2008) .

Although South Africa is not considered to be particularly vulnerable to the impacts of sea level rise, as compared to other countries such as Bangladesh or Mozambique (Dasgupta *et al.,* 2007), there are specific local municipalities along the coast that have a relatively significant amount of land that is considered to be at risk from possible sea level rise and increased storm surges (DEA, 2015d). This does not include the possible additional impacts in terms of sea water intrusion into coastal aquifers that may impact some coastal communities and existing farming areas.

Wild-fire

Wild-fire risk is shaped by factors such as temperature, soil and atmosphere moisture and wind. All these factors can be linked to climate variability and climate change. As humans manage fire in most parts of the world, the resulting changes in fire occurrence patterns will also be contingent on human activity, government policies, and institutional development (CSIR, 2010). Although our choices regarding land use and firefighting tactics will play a role in increasing or reducing risks, observed and projected changes in climate are expected to increase the area at risk of wild-fire across South Africa. Bush encroachment and the increasing spread of invasive alien plants (IAPs), facilitated by increasing CO_2 in the atmosphere is also likely to increase the risks from fires in certain parts of the country. The potential for initiation of veld fires may also be increased due to increased risk of lightning strikes.

3.6.8.2.3 Cross-cutting risks

Changes in the disaster risk patterns related to climate will have various cross sectoral implications with specific linkages to water and food security, health and human settlements. The nature of climate change and disaster risk is inherently cross-cutting, and highlights the importance of integrating solutions for poverty reduction, gender equality, disaster risk reduction and climate change to ensure lasting solutions to global vulnerabilities and achieving sustainable development. Accordingly, multi-sectoral collaboration is needed in assessing risk and developing and implementing adaptation and resilience building plans.

The key cross-cutting risks arising from the interdependency between climate change and disaster management, in South Africa, will include the following sectors:

Water resources and hydrology

The frequency of floods and droughts is anticipated to increase and this will bringmajor challenges connected to water security, and thus posing social, economic and environmental risks. Agriculture accounts for the majority of water withdrawal. Water is needed to generate energy and at the same time energy is needed to provide water to homes and industries. Water also provides crucial ecosystem services, and a lack of sanitation and safe drinking water services will pose a major public health threat and risk of disaster.

Agriculture

The increased frequency of natural disaster will have direct and potentially long-term impacts on the agricultural sector, livelihood sustainability and food security. The agricultural sector will be challenged to move towards resilient food systems that are more efficient and productive, preserve the natural resource base and ecosystem services, and able to withstand risks, shocks and long-term climate variability (UN, 2015).

Health

The National Department of Health has acknowledged the potential health impacts of climate change in the National Climate Change and Health Adaptation Plan (2012). The plan highlights nine key risks which includes natural disasters. Human health and mortality will be affected by disaster response and emergency services (DEA, 2013c).

Terrestrial ecosystems and biodiversity

Disasters have the potential to both reveal underlying environmental problems and contribute to worsening them. Apart from the fact that ecosystems are affected by disasters, it should also be noted that protecting ecosystem services contributes to risk reduction. Environmental degradation, settlement patterns, livelihood choices and behaviour can all contribute to increased disaster risk, which in turn adversely affects human development and contributes to further environmental degradation

Rural and urban livelihoods

Disasters are one of the many threats to reducing poverty, impacting livelihoods through the damage and/or destruction of assets on which livelihoods depend, and the losses derived from the loss of income. Accordingly the livelihood impacts are likely to result from disaster impacts on the various sectors. In light of the expected increase in climate-related hazards effective risk reduction will become imperative in protecting the livelihoods of the most vulnerable.

Economy

The altered disaster risk patterns associated with climate change will have to be recognized in highly exposed areas of the country. An increase in the frequency of disaster events has the potential to cause significant short and long-term economic impacts, compromising growth and development in terms of tourism, commerce and industry. While disasters may exert significant budgetary pressures, effective economic transformation has the potential to increase resilience to the shocks likely to emanate from climate related hazards. Insurance companies in particular are concerned about the possible economic impacts of the increasing risk of disasters due to climate change and in many cases are taking the lead in terms of providing support for adaptation options in particular with regards to reducing the flooding risk.

Infrastructure

A lack of development and appropriate infrastructure is a contributing factor to increasing the disaster risk for South Africa and other African Cities and reducing poverty and inequality is critical to reducing social vulnerability. Good development with regards to infrastructure, services and institutions will be critical in reducing climate induce disaster risks. (UN-Habitat, 2011). Safe and resilient infrastructure are important to deliver basic services to the population. This will require them being constructed and maintained to adequate minimum standards. However, many current design codes and standards are based on historical climate information and will need to be updated taking into account possible future climates and uncertainty.

3.6.8.2.4 Adaptive capacity

The expressions “disaster risk reduction” and “climate change adaptation” represent policy goals, one concerned with an ongoing problem (disasters) and the other with an emerging issue (climate change) (UNSIDR, 2009, p. 2). Another shared feature between the two disciplines is that they are often dependent on the implementation of specific adaptation policies through other linked sectors.

South Africa’s progress in the field of disaster management provides a foundation of adaptive capacity for adaptation policies to be built on. Adaptation has clear linkages to practices of disaster risk management designed to tackle existing risks of extreme weather events and the South African policy context is well positioned to support the mutually beneficial objectives to the two disciplines.

Risk reduction and mainstreaming adaptation and risk into development activities are important policy goals for responding to climate change and increasing risk of disasters. The implementation of these changes will often require fairly radical shifts in thinking and new institutional architecture (Uitto & Shaw, 2015). Typically with extreme weather events the focus, particularly in developing countries, is on the recovery from a disaster rather than vulnerability reduction before the event (i.e. reactive), and this system is reinforced by the investment policies of donors. This system is beginning to change with integrated disaster risk management and the acceptance that the timeframe of focus for risk reduction needs to also consider pre-event vulnerability reduction (i.e. proactive). For this to occur, different institutions need to be involved at various stages. The multi-sectoral nature of climate change and disasters means that effective implementation can only be achieved when disaster management institutions are integrated with other relevant government institutions at all levels of administration within a country.

The initial groundwork has been laid down by the legal requirement, mandating each government department to establish disaster management units in addition to their participation national advisory forum on natural disasters. As a result, the legislative support for the integration of disaster risk reduction and climate change adaptation appears to be very good, particularly considering recent amendments in the DMAA.

However, it often means that people are charged with disaster management responsibilities even if it is not their core area of competency or focus of work.

Whilst the reorientation of existing disaster management frameworks can be problematic as barriers will remain, the generation of practical climate change and disaster risk information is increasing. This has been achieved through the growing number of vulnerability and risk assessments being completed, and having this information has been shown to be correlated with the number of lives saved and general quality of response after a disaster (Uitto & Shaw, 2015). Information sharing is dependent on understanding of the importance of that information, knowing to whom to disseminate it, and how. Individuals act as key hubs within a network, and thus play a large gate-keeping role for the communication information on risk.

Public servants working in the field of disaster management do not always have the required knowledge and skills and this, together with the norms of professional culture, play a key role in how information is disseminated, shared and used. As well as including administrative structures, it is also important to create institutional frameworks that allow for participation of other relevant stakeholders. NGOs, for example, have a long history of providing emergency humanitarian assistance after disasters, and longer term reconstruction.

South Africa has actively embraced the change in paradigm from disaster response to longer term integrated disaster risk management. The recent introduction of legislation, its amendment and progressive policy framework now means that, at least on paper, South Africa has one of the most advanced institutional disaster management frameworks in the world for supporting climate change response.

3.6.8.3 Balancing opportunities and threats

3.6.8.3.1 Barriers to adaptation

South Africa has disaster management legislation considered one of the most advanced institutional frameworks in the world. Each level of government (national, provincial, local) is mandated to provide and implement for disaster risk reduction and response and recovery. The Disaster Management Act (2002), the National Disaster Management Policy Framework (2005) and Disaster Management Amendment Act No. 16 (2015) requires a focus on disaster prevention and mitigation and decentralization of disaster risk reduction tasks. Furthermore it mandates the compliance of disaster risk reduction into development planning and uptake by stakeholders. The functions of disaster monitoring and documenting, resource mobilization, coordinating the response and maintaining a stakeholder database falls to the National Disaster Management Centre (NDMC). While the legislation is robust and comprehensive, the implementation on the ground has been challenging.

The current reporting structure related to natural disasters in South Africa does not include a detailed account of the cross-cutting impacts, and in general, there is insufficient reporting on disaster events. Information on natural disasters is usually gathered by disaster relief organizations mainly using estimates. This includes multiple sources such as the National Disaster Management Centre of South Africa, the Global Risk Data Platform and the South African Weather and Disaster Observation Service. However, these sources do not report on the all the direct and indirect impacts arising from natural disasters and often not in a consistent manner.

A primary issue impeding implementation is a general lack of compliance on an institutional and community level. This may be related to transformational changes required to achieve disaster risk reduction goals. The risk drivers of a particular area may be linked to cultural beliefs and behaviors, specific economic factors and prevailing patterns of social cohesion societal cohesion. Transformation may however have ethical implications or be in conflict with equity and ethical dimensions of a particular society and put sustainable development in the presence of climate change at odds with context specific societal development objectives. This highlights the need for complementing scientific knowledge with traditional, indigenous and local knowledge and practices to strengthen the development and implementation of policies, strategies, plans and programmes. Addressing the issue will also require a concerted effort to improve all stakeholder understanding of disaster risk reduction and climate change adaptation.

Disaster risk reduction is still often seen as a low(er) priority activity due to the presence of a short term and reactive rather than proactive attitude to disaster risk reduction. This results in it often being poorly funded or incentivized at the local level. The lack of commitment to disaster risk reduction activities in national, provincial and local line departments will continue to impede the mainstreaming of risk reduction into development processes. More effective integration between disaster risk reduction and climate change adaptation and development will require clear definitions of roles and responsibilities particularly at local municipality level.

3.6.8.3.2 Key evidence gaps

From a technical perspective a lot of work has been undertaken on sectoral impacts of climate change, but integrated assessment across different sectors is limited within South Africa (Ziervogel *et al.,* 2015). As with broader disaster risk studies, a cross-sectional approach will garner important information and highlight linkages between sectors (such as agriculture and water resources) from several sources with different approaches and priorities. Without understanding and appreciating these linkages the baseline for adaptation priorities will be insufficient and the adaptation response in general and disaster management in particular will fail to effectively address the impact of an event in the context of climate change or climate variability.

Adaptation studies in South Africa do not sufficiently reflect or account for potential uncertainties or envelopes of change within the projected climate and the associated impacts. Adaptation priorities must also take cognizance of varying political and economic conditions regionally. Furthermore, short term consequences of adaptation responses to climate changes fall short of assessing the impacts in the medium and far future in a changed climate. Ziervogel *et al.,* (2014) gives the example of formal and informal urbanization increasing densification, but there is no vulnerability and impact assessment of the increased population concentration in the context of climate changes and changing extreme weather event frequency.

Furthermore, information on climate change risks and vulnerabilities at a local level remains limited particularly with regards to the potential increasing risk of disasters. For example provisional modelling of the possible increase in flooding risks to dams, bridges and powerline crossings undertaken in the LTAS (DEA, 2015d) was very limited in scope and although it did consider the whole of the country it only considered a small selection of regionally downscaled climate models. The analysis did not take into account any of the specific local conditions such as individual bridge details including the current condition, local hydraulic controls, or possible impacts of upstream and downstream development on the possible flood frequencies of flood magnitudes. There is a great need to undertake more detailed analysis of potential changing risks at a local level (i.e. individual municipality, community, or individual structures level). This requires engagement with decision makers to identify existing risks and thresholds for decision making using a process such as "decision scaling" as well as consideration of alternative scenarios in support of "robust decision making" (Matthews *et al.,* 2015). The process will have to be supported collaborative research and proven case studies on developing decision frameworks focused on robust, resilient and adaptive approaches to disaster risk reduction and climate change that are able to account for uncertainty and not address a singular potential climate scenario. With the inherent variability and uncertainty, this poses a significant risk to 'climate-resilient development' as highlighted in the NCRR (2011).

3.6.8.3.3 Opportunities

At a high level, the legislation, roles and responsibilities needed to strengthen disaster risk reduction, as a measure of climate change adaptation, is not only mandated but addressed at national, provincial and local levels. The limited implementation of policies at national and local level can be traced to a lack of understanding of the principles and linkages between DRR and climate change. Increasing capacity of officials is required and as this is done, there is an opportunity to improve the structural interface and co-ordination between all levels of government. The National Disaster Management Centre (NDMC) should be considered as the custodian of both DRR and climate change adaptation due to the correlative link between them. This would allow for integrated climate-resilient development strategies to be more clearly established and supporting a proactive stance by Government.

Once national stakeholders are actively engaged, it is expected to filter through to provincial and local level more effectively and improve the application disaster risk reduction as part of strategic development objectives. The effective mainstreaming of disaster risk as part of Government's overarching support to climate change adaptation as critical to sustainable social and economic development has the potential to generate a variety of cross-cutting benefits related to resilient development. At the local level, climate change can be used to motivate local municipalities and stakeholders to map the community vulnerability to let weather related hazards inform local planning and support development objectives. This will allow municipalities to take advantage of the potential co-benefits that will arise from integrating risk reduction into existing development related spending. Potential benefits range from more resilient livelihoods to improved service delivery and improved environmental health.

When considering possible adaptation options for disaster risk reduction it is important to rather take a more holistic management approach that recognizes the root causes of risks when aiming to strengthen resilience. An example of this is the Dutch "room for the river concept" which recognizes the increasing risk from both climate and land use change and considers new approaches to land use planning and risk management rather than building higher and longer dykes which are becoming prohibitively expensive and insufficient to deal with increasing risk (De Boer, *et al.,* 2013). This approach recognizes the importance of natural systems such as catchments, wetlands and riparian flood plans and looks to enhance aspects of the system having additional benefits for local communities.

3.6.8.4 Adaptation priorities

The LTAS report on Early Warning Systems and Disaster Risk Reduction and Management (DEA, 2015f) presents the following recommendations with regards to adaptation priorities for improved policy for disaster risk reduction and management:

- Mainstream disaster risk reduction (not simply disaster response) into policy and planning for all sectors and levels of government.
- Support the continued shift from a reactive to a proactive approach to disaster management.
- Improve collaboration between DRM and climate change adaptation line departments at all levels of national, provincial and local government.
- Improve DRR-M coordination within and between government departments.
- Improve delineation of roles and responsibilities around DRR-M, emphasising the importance of DRR within all sectors and levels of government.
- Support the establishment of DRR-M structures, including forums and nodes, at all levels.
- Strengthen institutional capacity to respond to EWS information at all levels and especially support local level engagement in collating and sharing information.
- Provide adequate funding and technical support for DRR-M at all levels:
    - Provide additional support to assist local government with post disaster costing and reporting, as well as with initiatives such as acquiring finance to support risk reduction.

    - Further support local municipalities in efforts to map community vulnerability to all weather-related hazards and to integrate this into local planning.
    - Build capacity in relevant institutions to understand the principles of DRR-M, including continued and enhanced development of standardised guidelines and operational procedures.
    - Encourage efforts to provide appropriate reports on the costs of the damages caused by disasters at all levels.
- Undertake robust needs assessments and gap analyses at all levels.
- Acknowledge the role of healthy ecosystems and ecological infrastructure in reducing the impacts of climate change and integrate into DRR-M planning.
- Continue development of EWS to ensure timeous and effective dissemination of practical information to all populations groups. The roll out of EWS in vulnerable areas is critical and can be undertaken in partnership civil society with the support of government and NGOs.

The LTAS Report on provincial modelling results for droughts, floods, sea level rise and sedimentation (DEA, 2015d) makes a number of recommendations with respect to reducing the risk associated with each of these different climate change risks. These include recommendations for both policy and planning as well as hard and soft infrastructure to reduce and mitigate the increasing risks from disasters that would be equally applicable even without the likely impacts of climate change.

The recommendations for adaptation options given in the LTAS Report (DEA, 2015f) show a number of cross-cutting issues for mitigation of increasing drought, floods and sediment loads that are applicable across a range of climate futures and therefore represent no-regrets options that should be implemented. These include (DEA, 2015f, p. 52):

- Continuous monitoring and drought/flood early warning systems.
- Improved land care, catchment management and water sensitive urban design, etc.
- Enforcement of zoning practices to reduce the number of people in flood-risk areas that take into account possible climate change impacts.
- Routine maintenance and correct operation of existing infrastructure.
- Integrated design and planning that takes into account climate change risk.
- Improved safety nets, including access to insurance and diversification of livelihoods that increase the resilience of particularly vulnerable groups.

These no-regrets options tend to be institutional in nature rather than requiring hard engineering solutions. In specific cases adaptation should consider engineering solutions (both soft and hard), but unlike changes in land care and catchment management or climate change mitigation, these solutions tend to address the symptoms and not the cause of increased disaster risks. It is important therefore that adaptation addresses all aspects of the risk equation, including improved resilience and capacity which is dependent on appropriate social and economic development.

Under a drying future (either nationally or in specific regions of the country) adaptation should include a review of the resilience of existing water supply systems with a particular focus on improved integration and diversification of the current stand-alone water resources systems. Future food security and food sovereignty also require an increased integration and diversification at a national and regional (SADC-wide) scale and be considered as potential adaptation options.

Under a wetting future, adaptation options need to include a review of current flood risk and engineering design standards, changes to urban flood retention and flood mitigation works, focus on water sensitive design of municipal infrastructure and changes to the operating rules of large dams with an increased flood control role. The later requires consideration of the trade-off with increasing drought risks.

For sea-level rise the most appropriate adaptation option is managed retreat through the demarcation and enforcement of coastal set-back lines that incorporate future sea level rise and storm surges. In certain situations hard engineering solutions could be considered, but care must be taken that these solutions do not simply move the problem on to somewhere else where the impacts may be just as significant, if not more substantial. Internationally there is now a growing recognition of the multiple benefits offered by soft or ecological engineering solutions to not only increasing flood risk, but also potential sea level rise impacts. These should also be explored and considered for implementation where appropriate in South Africa.

3.6.8.4.1 Research gaps

The lack of research on various aspects of climate change can be considered an adaptation barrier. The Human health sector identifies a variety of health related research gaps as a barrier, while Urban and rural settlements specifically highlights the lack of relevant research at a local scale.

3.6.8.4.2 Poor or inappropriate maintenance of infrastructure

Infrastructure challenges can speak to aspects such as financial constraints, human capacity and competing priorities, and can to some extent be considered a symptom rather than a causal barrier. In the Agriculture and forestry sector challenges with irrigation infrastructure are however highlighted as a barrier to adaptation, particularly in relation to small scale irrigation schemes. In the Water sector general water service infrastructure is considered to pose a threat to the effective functioning of South African water institutions, and is thereby deemed a potential barrier to adaptation.

3.6.8.4.3 Different local contexts, ethical implications and the lack of integration of different knowledge systems

For Disaster risk management a multifaceted barrier is noted in relation to addressing risk drivers that are interconnected with cultural beliefs, behaviour and economic factors, and the ethical implications of possible adaptation responses. This leads to an emphasis of the importance of improving all stakeholders’ understanding of disaster risk reduction and climate change adaptation, and the incorporation of a variety of knowledge systems in this understanding.

Barriers do not necessarily act in isolation, and while generic categories are provided here the way in which adaptation barriers manifest is context specific (IPCC, 2014: 908). The way in which adaptation barriers are outlined and unpacked here is relatively simplistic, and does not reflect the breadth of most recent definitions and understanding of the IPCC.

Given the relatively limited and diverse approaches to sectoral unpacking of adaptation barriers in previous chapters, there seems to be a need for further exploration to develop a better understanding of South African adaptation barriers. Furthermore, there is a need to make a shift, from a focus on *if* barriers to adaptation exist and *which* they are, towards an approach that analysis *why* and *how* identified barriers emerge (Biesbroek, 2013). Table 0.26 gives a summary of cross-sectoral linkages for modifying factors.

Table 0.26: Summary of cross-sectoral linkages for modifying factors

	Agriculture	Coastal zone	Estuarine environment	Human health	Terrestrial ecosystems	Urban and rural settlements	Disaster Risk Management	Water
Lack of or insufficient co-ordination and/or communication	■			■		■	■	■
A non-conducive institutional environment and/or regulatory environment	■							■
Climate change being seen as a low priority and/or being treated as a separate environmental issue			■			■	■	
Financial and economic constraints or limitations of the current financial system	■			■	■	■	■	

	Agriculture	Coastal zone	Estuarine environment	Human health	Terrestrial ecosystems	Urban and rural settlements	Disaster Risk Management	Water
Lack of or insufficient human and institutional capacity	■			■	■	■		■
Lack of understanding and expertise				■		■		
Lack of or insufficient training and capacity building	■						■	
Lack of or insufficient data, information and M&E	■			■			■	
Research gaps				■		■		
Poor or inappropriate maintenance of infrastructure	■							■
Different local contexts, ethical implications and the lack of integration of different knowledge systems							■	

3.6.9 *Water resources*

3.6.9.1 Introduction

South Africa experiences extreme rainfall fluctuations. Consequently, the management of its water resources involves catchment and river systems management, water storage, water abstraction and return-flow management. In order to manage the variability of surface water runoff and to supply water to locations of economic activity, South Africa has built comprehensive water resources infrastructure that includes 794 large dams (i.e. dams with a wall height ≥15m, or a wall height between 5 and 15m and a storage capacity exceeding 3 million m^3). Their combined storage capacity is in the order of 31 billion m^3. More than two thirds of the country's mean annual runoff (MAR), is stored in these dams.

South Africa has a reliable yield, (at 98% assurance of supply), of only about 15 billion m^3 a^{-1}, comprising 68% surface water, 13% groundwater, 13% return flows and 6% from alternative sources, such as desalination. Of the estimated at 49 billion m^3 a^{-1} MAR, only about 10.24 billion m^3 a^{-1} is available at the required 98% assurance. Recent estimates indicate that the potential, reliable, groundwater yield could be over 5 billion m^3 a^{-1}. Furthermore, return flows from irrigation, urban domestic uses and bulk industrial and mining effluents could offer re-use opportunities of up to 1.9 billion m^3 a^{-1}.

Current usage is estimated to be between 15 and 16 billion m^3 a^{-1}, roughly split between agriculture (62%), municipal (27%), mining (3%), industry (3%), energy (2%) and afforestation (3%). An estimated 9.5 billion m^3 a^{-1} is required to satisfy the total ecological reserve requirement. Rivers, lakes, wetlands and estuaries are some of the key ecosystems requiring protection. The human reserve is required to satisfy basic human needs by securing a basic water supply, for people who are, or who will, in the reasonably near future, be: (i) relying upon; (ii) taking water from; or (iii) being supplied from, the relevant water resource.

The current basic domestic water use component, (or 25 litres/person/day), translates to 490 million m^3 a^{-1} or 11% of the total domestic water use of 4.5 billion m^3 a^{-1}. Many rural settlements still have insufficient water resources to meet their basic water demands and further groundwater and surface water resource developments are necessary. Due to ineffective metering and billing, consumption in urban and rural areas could rise to over 7 billion m^3 a^{-1} resulting in an increase in total water use of close on 20 billion m^3 a^{-1}.

Water is unevenly distributed across the country and not always available where needed. To overcome this it is necessary to transfer water from areas where there is surplus water available to areas of need. An example is the Lesotho Highlands Water Scheme which supplies water to Gauteng's Vaal Water Management Area through transfer from Katse and Mohale Dams in Lesotho. There are 29 inter-basin and inter-river system transfer schemes with a total transfer capacity of 7 billion m^3 a^{-1}. Phase 2 of the Lesotho Highlands Water Project, which was recently given the go-ahead, will transfer an additional 465 million m^3 a^{-1} to South Africa.

Responsibility for the treatment and distribution of water and sanitation is allocated to the statutory water services authorities (municipalities or groupings thereof) and the water boards. However, arrangements differ from place to place. An institutional reform and realignment process is underway in the Department of Water and Sanitation, with the view to restructure the water boards into regional water utilities (RWUs), so as to improve efficiency.

Current water usage already exceeds reliable yield and this translates into fairly large water restrictions during a drought year like the one the country is experiencing. Additional water resources need to be developed in order to provide for increased domestic water requirements. In future some Water Management Areas will need to develop additional local water resource bulk infrastructure.

Comprehensive water resource assessments (reconciliation studies), primary tool for strategic water resource planning to the 2030 time horizon, in 13 key demand/economic areas, have been completed along with other water resource assessments, (the so-called All Towns Studies), in 905 towns. From these assessments, which do not make provision for climate change, it was found that 28% of the towns have inadequate water resources and are in need of urgent attention. Water resource actions were identified and water conservation and demand management (WC/WDM), was identified as a key requirement, yet 50% of towns do not currently implement WC/WDM. Moerover, furture reconciliation studies must include climate change.

From these assessments it was found that 28% of the towns have inadequate water resources and are in need of urgent attention. Water resource actions were identified and water conservation and demand management (WC/WDM), was identified as a key requirement, yet 50% of towns do not currently implement WC/WDM. There are no provisions for climate change in the water resources reconciliation studies, the primary tool for strategic water resource planning to at least 2030.

3.6.9.1.1 Progress since the 2nd National Communication

Unlike other sectors that use political boundaries, assessment of the water sector is done using hydrological boundary. Political and hydrological boundaries seldom overlap each other (Figure 0.88)

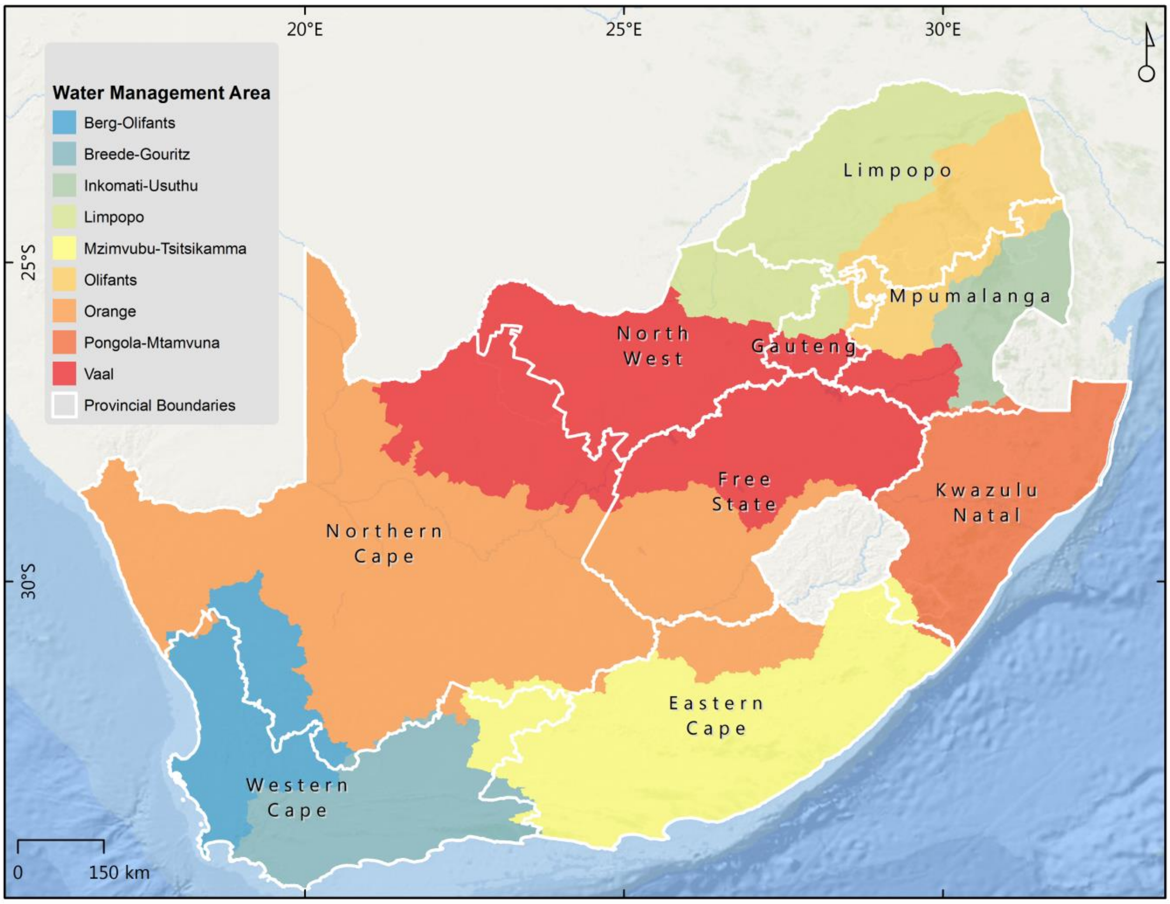


Figure 0.88: Provincial versus hydrological boundaries over South Africa

A number of studies have assessed the impacts of climate change on water resources for specific areas of South Africa; only few studies have assessed its impacts at national scale (Shulze, 2012, Cullis *et al.,* 2015). The country water resources and hydrological processes are routinely assessed using two hydrological models, namely the Agricultural Catchments Research Unit (ACRU) and the Pitman models. The ACRU model which works at the sub-daily scale and the quinery drainage basin scale is particularly relevant for understanding the impacts of extreme events and the fine scale impact of climate change on a number of sectors. The Pitman model which works at the monthly scale and the quaternary drainage basin scale is useful for cross-sectoral integrated assessment (DEA, 2013a).

Schulze (2012) uses output from General Circulation Models (GCMs) from the IPCC's Fourth Assessment Report (IPCC, 2007) to make projections, at the quinery drainage basin scale, of possible changes to the South African water sector associated with anticipated global climate change.

Cullis *et al.,* (2015), uses outputs from all GCMs in the form of hybrid frequency distributions (HFD) developed by the MIT Global Change Group (Schlosser *et al.,* 2012) to make projections, at the quaternary drainage basin scale, of possible changes to the South African water sector associated with anticipated global climate change. Cullis *et al.,* (2015) used the Pitman model (Pitman 1973) to assess at a monthly time scale the impact of climate change on water resources; and a national configuration of the Water Resources Yield Model (WRYM) to assess the impact of climate change on water supply. Henceforth, the understanding of the impact of climate change on the water sector now goes beyond the hydrology.

3.6.9.2 Vulnerability to climate change

3.6.9.2.1 Water Quantity

South Africa already suffers from high-risk hydrology, with high levels of variability in rainfall from year to year, resulting in frequent floods and droughts. As a water scarce country, the river systems and aquifers are highly used and developed, and many are already highly degraded. In addition to this scenario, there is extreme inequality in access to water for productive purposes, arising out of the apartheid legacy. While this is the picture at a national level, closer examination allows the division of the country into six distinct climatic zones, each of which will be impacted differently by climate change.

The key water related vulnerabilities under climate change have been determined through overlaying climate modelling on development scenarios for each of the zones. While the various climate change models agree that there will be significant temperature increases across South Africa in the medium to longer term, when it comes to changes in rainfall, the models provide different results in certain climate change zones. However, there are general trends which are described below. It is important to note that the results below are derived from a relatively wet scenario. Results from other modelling processes such as those used by the CSIR give much drier scenarios.

Northern Interior (***Zone 1: Limpopo, Olifants and Inkomati***)

Projected changes in rainfall in this region show a great deal of spread and uncertainty as the region falls between areas projected to get wetter (central and eastern South Africa) and areas projected to get drier (Zimbabwe and Botswana). Projections indicate general drying (but with possible slight wetting) depending on their representation of the regional climate gradient, so this is an area of significant uncertainty.

Zone 1 contains irrigated agriculture, power and mining, urban and forestry, with dryland on the Highveld. It therefore has high water requirements and under climate change will see increasing demand. However, population and economic growth within this zone will have a greater impact on increasing water demand.

Key climate change impacts:

- Likely reduction in rainfall, particularly in the summer rainfall period;
- Significant increased temperatures, and thus evaporation;
- Increase in water demand from agriculture;

- Increase in demand for power generation;
- Increase in domestic demand.

East Coast (***Zone 2: Pongola-Umzimkulu***)

Projected changes in rainfall along the east coast show strong agreement on wetter conditions due to increased moisture availability, increased heating and resultant instability, and increased advection of moisture from the South Indian anti-cyclone. Increased atmospheric moisture will likely result in increased rainfall intensity with increased frequency of extreme events and flooding. Zone 2 is a water-rich zone but is susceptible to rainfall variability and increases in extreme events, especially flooding, as there is a high occurrence of rain-fed agriculture and subsistence farming.

Key climate change impacts:

- Likely increase in summer rainfall, with increased large events (storms);
- Moderate increase in temperatures due to proximity to ocean.

Central Interior (***Zone 3: The Vaal system***)

Climate models suggest some possibility of either wetter or dryer conditions, depending upon the strength of the heat low and Indian Ocean high pressure advecting moisture into the region. The likely increase in moisture would produce both more rainfall and more intense convective rainfall systems leading to a possible increase in extreme events. However, regional rainfall is complex and adds a great deal of complexity and uncertainty to the projections. The Vaal system has two extremes, the portion of Gauteng, and the vast expanses of the Free State. Similarly to zone 1, there are a number of important activities including mining, industrial and domestic demand.

Key climate change impacts:

- Highly uncertain future rainfall, with possible wetting or drying during the summer months;
- Likely increase in storm activity and large rainfall events;
- Significant increase in temperatures;
- Increase in water demand from agriculture;
- Increase in demand for power generation;
- Increase in domestic demand.

West Coast and North Western Interior (***Zone 4: The Orange system***)

With very dry conditions dominating the western parts of this area, projected absolute changes in rainfall are small and have large uncertainties, while temperature increases are expected to be significant. Some suggestion of increased summer rainfall in the eastern high water yield inland areas would be a result of increased moisture availability and a possibly more intense heat, but this is highly uncertain with reduction of summer rainfall also being possible. Rainfall shifts along the coast are uncertain, although the likely change is expected to be relatively small in either direction. Zone 4 is water-scarce with reliance on intensive irrigation and groundwater use. Furthermore, mining in the area contributes to salinity issues.

Key climate change impacts:

- Uncertainty of rainfall patterns in the eastern parts, but with likely increased storm activity;
- Likely drying in the arid western and coastal areas;
- Significant increase in temperature expected;
- Increase in water demand from agriculture;
- Already a water scarce zone in the west, but is projected to become drier.

Southern Cape (***Zone 5: Mzimvubu-Tsitsikamma***)

Projected changes in rainfall suggest an increase, most likely due to increased moisture availability for both inland convective rainfall as well as coastal orographic rainfall. However, there is considerable uncertainty in the implications for rainfall in this complex interface zone, particularly in the south-western parts of the area. It has a large rural population with a high level of subsistence farming. It also has untapped water resources yield potential.

Key climate change impacts:

- Uncertainty in rainfall impacts in year round rainfall area, although likely drying in the west;
- Likely increases in the summer rainfall in the western parts;
- Moderate temperature increases;
- Extreme events such as flooding might have an impact on the large rural population.

South Western Cape (***Zone 6: Breede-Gouritz and Berg Olifants***)

A play-off between the southerly shift in the mid-latitudes resulting in drier conditions, and a moister atmosphere producing more orographic rainfall results in a great deal of uncertainty as to the future of rainfall and water availability in this region. A shift to wetter conditions in the mountains and drier conditions in the lower coastal plains is expected, but the confidence of these predictions is currently low. Zone 6 has a large urban population as well as strong commercial agriculture.

Key climate change impacts:

- Uncertain climate impacts on winter rainfall, but likely increase in orographic activity;
- Possibly spread of rainfall beyond the historical winter rainfall period;
- Moderate temperature increases compared to the rest of the country;
- Increase in extreme events will affect vulnerable communities;
- An increase in the demand for water for agriculture and domestic use.

3.6.9.2.2 Water Quality

The consequences of climate change on water quality are poorly understood and only beginning to be studied. This stems from the relatively scanty water quality monitoring network of the country. Nevertheless, there is evidence of deteriorating water quality of South Africa's major river systems, water storage reservoirs and ground water resources – the core water supply systems that underpin social and economic development in South Africa.

The country already faces an enormous task in dealing with the problems posed by key water quality issues such as acid mine drainage, eutrophication (or nutrient enrichment) and salinisation, coupled to the apparent ineffectiveness of many institutions to treat domestic sewage and industrial effluent to levels that are safe for discharge to rivers and streams.

Higher water temperatures will alter water-gas equilibria and increase the rates of microbial processes; these will in turn accelerate nitrification, denitrification, respiration and methanogenesis (the generation of methane by anaerobic bacteria). Floods and droughts will also modify water quality by direct effects of dilution or concentration of dissolved substances. Even if these facts are often inferred, few scientific works have been published until recently on the impacts of climate change on water quality modification. Moreover, climate change is not the only factor affecting water quality. Land use evolution, deforestation, urban spreading and area waterproofing may also contribute to water quality degradation. More often, water pollution is directly linked to human activities of urban, industrial or agricultural origin, and climate change could lead to degradation in surface water quality as an indirect consequence of these activities.

Northern Interior (***Zone 1: Limpopo, Olifants and Inkomati***)

If there is no or very little change in the hydrological drivers for climate change then current water quality trends would probably continue. Water quality in the Mokolo River is still good but it is deteriorating as a result of intensive agricultural activities and in future, water quality is expected to deteriorate further as a result of the exploitation of coal reserves in the Lephelala area (acid mine drainage impacts) as well as informal settlements (microbial contamination), urban areas (organic loads, nutrients), and industrial developments (salinity, trace metals) associated with new mining and power generation activities in the area. The water quality impacts would probably be similar to those experienced in the coal mining areas of the upper Olifants River (Witbank, Middelburg area). Intensive agricultural developments (agro-chemicals, salinity) in the Letaba, Luvuvhu, middle and lower Olifants rivers, are also contributing to the slow deterioration in water quality. Elevated nutrient concentrations and eutrophication would probably continue or increase due to increased urbanisation and the growth in effluents from wastewater treatment works serving the towns in this zone. Very few WWTW's meet effluent standards and problems associated with nutrient enrichment, microbial pollution, and elevated organic loads, will continue until operational problems at the WWTW's have been resolved. A number of the coal mines in the upper Olifants River are reaching their end of economic lives and mine workings will start filling up and ultimately start decanting into surface waters. This will probably aggravate acid mine drainage problems in the Olifants River. The impacts associated with mining (acid mine drainage), intensive irrigation agriculture (agro-chemicals, nutrients, salinity), and urbanisation and dense settlements (organic loads, microbial pollution) in the Crocodile River and lower Komati River will probably continue.

Key climate change impacts:

- Water quality would continue to deteriorate due to man-made impacts;
- A moderate increase in water temperature would affect biological and microbiological processes.

East Coast (***Zone 2: Pongola-Umzimkulu***)

Water quality in the Pongola River may improve slightly as flow increase in the river, diluting agricultural return flows from Pongola Irrigation Scheme (salinity, nutrients). An increase in rainfall intensity will probably lead to more erosion of topsoil in communal lands and areas where overgrazing is common leading to higher suspended sediment loads in rivers, and sediment deposition in river channels and in receiving dams. Acid mine drainage problems may increase in the coal mining areas in the upper Mfolozi system, upper Mkuze River, and upper Thukela River. However, an increase in floods (dilution) would probably mitigate some of the impacts and one could probably expect wider seasonal fluctuations in quality than experienced under current conditions. More frequent floods may also alleviate the hypersaline conditions that develop in Lake St. Lucia during extended dry periods. Wetter conditions will probably promote the spread of waterborne diseases such as cholera through the mobilisation of pollutants from the catchment surfaces, and warmer air and water temperatures would create more favourable conditions for disease intermediates such as mosquitoes (e.g. malaria) and snails (e.g. bilharzia and liver fluke). Malaria and bilharzia could therefore spread to areas where they don't occur at present. Pesticide residues may also increase in waters as malaria control programmes are extended to reduce the spread of the disease. Eutrophication problems in reservoirs would probably also increase due to continued poor performance of WWTW's and enhanced washoff and leaching of nutrients from agricultural lands. Water quality in the southern regions of this zone (Mzimkhulu and Mkomazi) is regarded as good and, with the exception of microbial water quality and sediment, is expected to remain good under wetter conditions.

Key climate change impacts:

- The spatial distribution and severity of tropical water-borne diseases would probably increase;
- Sedimentation of dams and rivers would increase due to increase in rainfall and erosion;

- Eutrophication problems in the Mgeni River would probably increase in severity and duration due to more favourable climatic conditions.

Central Interior (***Zone 3: The Vaal system***)

The Central interior is characterised by extensive urbanisation, mining and industrial developments as well as large water infrastructure including dams and interbasin transfers into the upper Vaal system. Slightly wetter conditions, higher rainfall intensities and increased frequency of flooding would probably have a negative impact on water quality. Higher rainfall intensities would probably mobilise larger amounts of pollutants during summer rain storms and, although there might be some dilution during flooding to mitigate the impacts, the total pollutant load to receiving rivers and dams would probably increase. Flooding and more intense rainstorms would probably lead to more frequent failure of the sewerage infrastructure (damage to pipe infrastructure, and surcharging sewers), posing a health risk to downstream users and affecting aquatic ecosystems through wider fluctuations in dissolved oxygen concentrations. A higher frequency of intense rainfall events may also result in more frequent failures at WWTW's resulting in sludge overflows into effluent streams, some biological processes not operating as designed, and more frequent failure to meet effluent standards. Nutrient enrichment of rivers and reservoirs would probably increase as a result of elevated nutrient loads but the impacts on algal growth may be mitigated if the water residence times in reservoirs are reduced. If the winter temperatures become milder, more frequent winter algal blooms may occur posing a risk to water treatment works and downstream water users. Wetter conditions would also result in an increase in the volume of urban stormwater runoff. This would probably increase the sediment, pathogen, organic and nutrient loads to receiving water bodies with negative impacts on downstream users and aquatic ecosystems. The volumes of poor quality mine water contaminated with salts, sulphates and dissolved metals would probably increase due to the wetter conditions and increased infiltration into groundwater compartments. More intense rainstorms would probably lead to more erosion in agricultural areas leading to higher sediment deposition in receiving rivers and reservoirs. The eutrophication problems in the middle Vaal River would probably not improve because it is related to the nutrient load, salinity, underwater light climate, and milder water temperatures. The spatial extent and density of invasive aquatic weeds (e.g. water hyacinth and water lettuce) would probably increase as a result of plants being distributed wider by increased flows and favourable air temperatures.

Key climate change impacts:

- The severity of present day water quality problems would probably increase due to increased washoff of pollutants, increased urbanisation, and failure of aging wastewater infrastructure
- Acid mine drainage problems would probably increase in response to elevated rainfall and water infiltration into underground compartments

West Coast and North Western Interior (***Zone 4: The Orange system***)

A slight increase in rainfall would probably result in slightly more erosion and elevated sediment loads to rivers and reservoirs. Sediment loads are already high in rivers like the Caledon and Modder rivers and a slight increase in rainfall would probably not have a significant impact on the current status. Eutrophication related water quality problems in the lower Orange River will probably continue and even increase slightly as nutrient rich inflows from the Vaal River system increase, and as sunlight and water temperatures become even more favourable for algal growth. If rainfall increase slightly then the washoff of agrochemicals from large irrigation schemes may also increase slightly along with the impacts on aquatic ecosystems. The outbreaks of pest blackflies (Simulium chutteri) are related to flow regulation in the lower Vaal and Orange and the population will probably not be changed significantly by a change in water temperature in those areas. Flow will probably be regulated more as water transfers in the upper Orange/Senque increase which would create more favourable conditions for pest blackflies.

Key climate change impacts:

- Eutrophication problems in the lower Orange River would probably increase in duration and severity.

Southern Cape (***Zone 5: Mzimvubu-Tsitsikamma***)

An increase in rainfall in the Southern Cape would probably result in an increase in erosion and sediment loads to rivers and reservoirs. In rural areas with limited sanitation there might be an increase in water borne diseases such as cholera and dysentery. Increased rainfall may aggravate salinity problems in rivers like the Fish and the Sundays rivers where the baseflow is very saline. The washoff of litter and other pollutants from dense settlements around urban areas would probably increase as a result of increased rainfall and stormwater runoff. This would have a negative impact on the microbial quality of receiving water bodies, especially in areas around Grahamstown, Port Elizabeth, Uitenhage and East London. Increased rainfall would also lead to an increase in the washoff of agrochemicals from large irrigation projects along the Langkloof Valley, Gamtoos, and the Orange Fish government water scheme. Increased rainfall would also increase the organic load to rivers and streams in areas of intensive dairy farming and dairy processing industries such as around George, Riversdal, and Kareedouw.

Key climate change impacts:

- The spatial extent and severity of waterborne diseases would probably increase as a result of increased rainfall and washoff of pollutants;
- Salinity problems in Fish River would probably increase.

South Western Cape (***Zone 6: Breede-Gouritz and Berg Olifants***)

If rainfall increases in the mountain regions of the Western Cape, there would probably be little impact on the water quality in the headwaters of rivers. As much of this water is already impounded in water supply dams, the water quality in those dams would probably remain good. Drier conditions in the coastal plains would however aggravate a number of water quality problems already experienced, and may alleviate some other problems. In terms of urban runoff, lower rainfall would probably result in less runoff and a lower pollution load. However, the impacts of grey water disposal in dense settlements with low levels of sanitation services would be more prominent as less stream flow would be available to dilute the polluted inflow. Pollutants would also accumulate for longer on the catchment surface and could result in a higher pollution peak when it is washed off early in the rainfall season. Areas of the Swartland have naturally saline soils and lower rainfall, and therefore lower baseflow, may alleviate some of the salinity problems in tributaries of the Berg River. In rivers like the Olifants River where irrigation return flows add a significant salt load to the middle and lower Olifants River, a reduction in rainfall could aggravate the salinity problem in future due to less dilution. The same would probably happen in the lower Breede River. Nutrient enrichment from WWTW discharges in the mainstem Berg and Breede River would probably continue but it would probably be aggravated by lower streamflow in the rivers. Lower rainfall may reduce the impacts of agrochemicals in some areas. However, in areas where irrigation return flow is the main pathway for the transport of residues into rivers and streams, higher in-stream concentrations may be experienced as a result of evaporation. Lower rainfall in dairy areas such as the Bonnievale area may reduce the organic load to rivers and streams. An increase in storage to deal with the drier climate would lead to further flow regulation in rivers and probably lower flows in rivers. The result would be that there was less water available for dilution of wastewater discharges and runoff from urban areas.

Key climate change impacts:

- Water quality problems (nutrient enrichment) caused by point source discharges would probably be aggravated due to lower dilution in rivers;
- Water quality problems caused by non-point source discharges (salinity, pathogens) may remain unchanged or improve slightly due to drier conditions;
- Impacts of irrigation return flows on water quality in the lower reaches of the Olifants, Berg and Breede rivers, may increase due to lower dilution in these rivers.

3.6.9.2.3 Groundwater

The country Utilisable Groundwater Exploitation Potential (the total volume of available, renewable groundwater in South Africa is about 10 343 million m^3 a^{-1} (or 7 500 million m^3 a^{-1} under drought conditions). Up-to-date figures for groundwater use in South Africa are hard to obtain. Thus, it is estimated that we use between 2 000 and 4 000 million m^3 a^{-1} of this groundwater. Thus, there is the potential to considerably increase groundwater supplies in South Africa.

Understanding of the impact of climate changes on groundwater in South Africa is limited and further research need to be conducted on various aspects of groundwater (quality and quantity) to quantify the impact on groundwater and on the communities that are dependent on groundwater.

The replenishment of groundwater is controlled by long-term climatic conditions. Since rainfall is the main source of recharge to aquifers, climate change may have a considerable impact on groundwater resources. Under predicted climate change conditions, groundwater has to be used and managed in a sustainable way in order to maintain its buffering and contingency supply capabilities, as well as maintain adequate water quality for human consumption. Artificial recharge, groundwater data collection and groundwater research all form part of the strategy for meeting climate change.

3.6.9.2.4 Cross-cutting impacts

Climate change stands to have significant impacts on a range of sectors, including agriculture, business and industry, energy and fisheries. Provision of potable water supply, groundwater pumping, treatment of sewage, household cooling, transport, and communication all require reliable sources of power supply. These systems are also of fundamental importance in adapting to climate change. Water is the cross-cutting transmitter of climate change impacts on each of these sectors. Water is at the centre of the web linking food security, trade and energy. Climate change adds an additional dimension of human livelihoods to create what is often referred to as the water-food-energy nexus. South Africa is already a water scarce country with climate change adding additional stress to the system.

3.6.9.2.5 Adaptive capacity

While the extended system of national and international water transfer schemes and dams gives South Africa a relatively extensive adaptive capacity, the benefits of these technical solutions are limited. Firstly, overall river runoff will decrease, leading to a reduced amount of water available for capture, storage and transfer. Secondly, demand will increase because of population growth and economic development. Lastly, there is a paucity of suitable sites and financial resources for realising large-scale water infrastructure projects. These considerations suggest that the adaptive capacity of the water sector can be further increased by improved water governance. This includes a switch from supply to demand management and the possible redistribution of water rights in the face of limited resources.

Spatial differentiation of extreme events in different regions of the country calls for a flexible, polycentric and decentralised approach to water governance. The CMA concept includes these features, and when fully functional, they will increase the adaptive capacity and resilience of South African water governance. Catchment management agencies (CMAs) are statutory bodies established in one of the 9 defined hydrological boundaries called water management area (WMA). CMAs coordinate functions of other institutions involved in water related matters within WMAs.

3.6.9.3 Balancing opportunities and threats

3.6.9.3.1 Barriers to adaptation

South Africa is experiencing severe capacity challenges that impede the successful implementation of its water policy, legislation and various strategies. This translates into the slow establishment of CMAs, difficulties in several local authorities in discharging their water related duties, shortage of technical staff in DWS national and regional offices. The water services sector is highly criticised for the inappropriate maintenance of its water services infrastructures. This poses a threat to the effective functioning of water institutions in South Africa.

Despite the government's vision for a comprehensive formalised system of water governance, water management in South Africa, and in particular in rural South Africa, tends towards plural legal systems. The complex set of institutional relationships that govern the water sector, involve a myriad of organisations fulfilling different roles and functions. Hence, problems and challenges experienced in the sector are in part a consequence of these multiple institutional layers and the associated risks of performance failure by any one party. Their effective alignment and good intergovernmental relations will be a critical part of ensuring effective adaptation to climate change across the water value chain. Furthermore, the water related policies and legislation are not always aligned.

Customary water management structures are not mentioned at all in the National Water Act. Nonetheless, the Traditional Leadership and Governance Framework Act (Act No. 41 of 2003) makes provision for traditional leadership to promote sustainable water resource management and requires national and provincial government to provide for their involvement (through legislation and other means).

3.6.9.3.2 Key evidence gaps

The country's national water monitoring networks are continually shrinking. Every year, less rainfall and flow gauges are operational. The present monitoring networks have to be optimised and aligned with the Country's strategic and management requirements.

Large amount of uncertainties remains in the climate change modelling and scenarios. There is a need to continue to model water parameters but to include the monitoring of soil moisture, wind speed and water temperate and make this information freely available to research organisations and institutes.

There is a research gap in groundwater recharge and how climate change will affect groundwater. Further research is required in the area of water quality, examining the multi-layered effects climate change has on water resources.

3.6.9.3.3 Opportunities

Although hampered by the disappearance of rainfall and flow gauges, the national surveys of South Africa's national water resources, WR90 to WR2012, provide the cornerstone of baseline national water resources assessment and planning for South Africa as required in the National Water Act and the National Water Resource Strategy. The nationwide programme to develop water reconciliation strategies for all towns, villages and clusters of villages across the country, provides current and future water requirements of settlements, the water resource, and hence the current and future water balance. Thus, the current scenario on which future climate scenarios can built on is already set up for the country.

In addition, several strategies have been and are being developed:

- The National Water Resources Strategy 2 (DWS, 2013) ensures that national water resources are protected, used, developed, conserved, managed and controlled in an efficient and sustainable manner towards achieving South Africa's development priorities in an equitable manner over the next five to 10 years.
- The Long Term Adaptation Scenarios (DEA, 2013a) develops national and sub-national adaptation scenarios for South Africa under plausible future climate conditions and development pathways. It therefore assists relevant sectors to develop their adaptation strategies.
- The Climate Change Response Strategy (DWS, 2011) provides guidance on adaptation to the water-related impacts of climate change and to maximise any beneficial impacts. The strategy includes the approach to be taken to climate and water adaptation, as well as measures and actions, where possible, focusing on actions that support both adaptation and mitigation.

3.6.9.4 Adaptation priorities

Adapting effectively to climate change in the water sector not only requires that water is at the heart of national climate change adaptation strategies, but also that existing national water policies, plans and funds mainstream climate change adaptation. The current strategy focuses on the implementation of both “no regret” and “low-regret” measures and sets out a series of actions to be implemented within a defined time period, recognising that climate change adaptation is an issue of water governance, infrastructure development and water management.

3.6.9.4.1 Water governance

One of the key elements of responding to climate change is ensuring that the institutions responsible for water management and governance are able to adapt timeously and effectively to changing climatic conditions. This requires that the policy and legislation support adaptive approaches, and that management institutions, such as municipalities, CMAs, international bodies and DWS are designed and operate as adaptive, learning institutions. It also requires that the monitoring and information systems underpinning the work of these organisations be appropriately designed.

To ensure good water governance it is critical that not only should all stakeholders have open channels of communication, but also climate adaptive financing needs to be part of the water investment framework to ensure adaptive measures are implemented.

The transformation towards water management along hydrological boundaries improves the fit between the governance regime and water resources but, as previously alluded, creates a number of problems of fit, interplay and scale that needs to be resolved.

3.6.9.4.2 Infrastructure development, operation and maintenance

South Africa has a relatively robust set of water infrastructure due to the already high variability in climate. Climate change exacerbates this variability, and potentially increases the frequencies of extreme events thus reducing the natural recovery time between events. The safety and resilience of existing infrastructure in the face of potential changes in rainfall intensity and flooding is needed.

The planning horizon for infrastructure is long term, and requires more planning time than build time. For this, we need to ensure we have several options planned to deal with the high level of uncertainty with regards to climate change.

There are a wide range of potential climate change impacts on water supply and sanitation, including flood damage to infrastructure which may interrupt supply, result in contaminated water supply or result in contamination of water resources from flooded or damaged sanitation and waste water treatment systems. The vulnerability of different systems varies depending on the technology, management systems and human capacity in the system.

Systems that provide water to large populations from a single water resource are extremely vulnerable to climate change, particularly in areas in which the potential for significant droughts is likely to increase. Systems, which provide water from multiple sources, spread the risk and are more resilient as a result.

Small water schemes run by households or communities are highly vulnerable due to lack of financial capacity and weak management and technical capacity. Rural community managed systems are particularly at risk.

Groundwater needs to be protected, and its use and maintenance adapted to climate change. Preventing groundwater degradation and unwise exploitation will prove more cost-effective than trying to clean up and restore mismanaged aquifers. In addition, South Africa, as a water scarce country, has to investigate all possible sources of water. In water scarce areas, alternate water sources are already being investigated such as rainwater harvesting, desalination and re-use. In some regions, these systems have been implemented to augment the current water supply from traditional sources.

Flood protection measures should include insuring adequate provision and maintenance of drainage infrastructure. This includes storm water drainage infrastructure and ensuring it is regularly cleaned and free from blockages and debris.

A critical issue is the decline in the number of rainfall gauging stations in the country which has made the detection of climate change trends in observed flow records difficult. A robust monitoring network, identifies trends, provides better real-time system management and assist with the correct adaptation strategies.

3.6.9.4.3 Water management

Data collection needs to be standardised, using the same parameters, needs to be centrally collected and stored. Furthermore, climate scientist and researchers should have easy access to the information in order to update climate modelling and conduct vulnerability assessments.

The most widely applied method in climate change modelling is to use outputs from the General Circulation Models (GCMs) which enable the simulation of most of the key features of climate on a global scale downscaled to a catchment level. The challenge with the GCM's when downscaled to catchments in South Africa, is that they provide differing results, some indicating wetter futures, while others predict drier futures, especially in the intermediate future. Unfortunately this only increases the uncertainty of South Africa's possible climate futures. However, all the models agree on the temperature, which is due to increase. A second modelling approach uses fundamental physical modelling to project future climate. The two different modelling techniques produce different results. There is a need to better align the two processes to reduce some of the uncertainty in the modelling process.

Potential climate change adds one more layer of uncertainty to the already challenged water sector. Whilst scientists' ability to project long term changes remains imperfect, in many areas we know enough to prioritise risks and put adaptation measures in place.

3.6.10 Synthesis

3.6.10.1 Cross-cutting issues across sectors

The defining characteristic of complex dynamic systems is that they are made up of large numbers of interacting, interdependent components. These interactions are often non-linear: their causes and effects are not proportional to each other. Small changes in one sector or region can sometimes have very large effects. For this reason, the behaviour of these systems is very difficult to predict. A high degree of uncertainty can correspond to a high degree of risk. Crosscutting risks can thus be defined as 'risks that can trigger unexpected large-scale changes of a system, or imply uncontrollable large-scale threats to it' (Helbing, 2012, p. 261). A variety of additional cross-sectoral interdependencies may influence overall risk levels. These complex interdependencies are difficult to outline and Figure 0.89 and Table 0.27 are an attempt at characterising these.

Figure 0.89: Summary of cross-sectoral linkages for environmental exposure aspects

Table 0.27: Summary of cross-sectoral linkages for modifying factors

Modifying factors	Modifying Example
Human settlements and built environment	Thermal comfort of housing can impact heat stress (Maller and Strengers, 2011)
Natural disasters reduction and response	Early warning systems can impact magnitude of health effects from natural disasters
Education	Education about water pollution can mitigate water-borne diseases
Service Delivery	Continuous supply of clean water can mitigate water-borne diseases
Public Health System	A well resourced public health system can mitigate health impacts
Occupational Health System	Exposure and health impact of increasing temperature temperatures on outdoor worker can be mitigated through implementation of occupational heat-health plans

3.6.10.2 Summarising barriers to adaptation

The implicit assumption of a barrier is that it presents a hindrance, something that needs to be overcome. In the context of adaptation, it tends to refer to something that increases the chances of failure, reducing the chances of successful adaptation (Biesbroek, 2013). While recognising that in recent international literature the term has to some extent evolved into two different yet complimentary terms, adaptation constraints[7] and adaptation limits[8], the term adaptation barrier is applied here as

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[7] "A factor or process that makes adaptation planning and implementation more difficult" (IPCC, 2014:906)

the more recent terms have not yet been absorbed in the literature assessed. This section collates the various sector specific barriers identified in the previous sectors sections, and groups them into 11 categories in order to give an overall sense of the current perceptions of South African adaptation barriers:

3.6.10.2.1 Lack of or insufficient co-ordination and/or communication

Given the cross-cutting nature of climate risks, responses necessarily involve a wide range of actors and thus require alignment of policies, plans and activities, clear allocation of responsibilities and consistent reporting – all of which can be considered important aspects of good co-ordination and communication. The lack thereof can thus be perceived as an adaptation barrier, as in the Agricultural sector where the lack of co-ordination with related sectors such as water, land development and land reform, is highlighted as a possible barrier. For Human health poor communication and coordination between government departments and the public is emphasised. The lack of policy coordination and alignment is also recognised for Urban and rural settlements as well as for the Water sector. In Disaster Risk Management inconsistent reporting on natural disasters, as well as the lack of clearly defined roles and responsibilities, are identified as further barriers.

3.6.10.2.2 A non-conducive institutional environment and/or regulatory environment

Climate change adaptation may require for example increased cross-sectoral coordination and flexibility or transformation in terms of the way in which things are done. The current institutional and regulatory environment is not necessarily conducive for such, as is highlighted for the South African water sector were the complex institutional relationships, and the myriad of organisations fulfilling different roles and functions pose possible barriers. In the Agricultural sector a slightly different barrier is highlighted, the strict limitations imposed by regulatory bodies and markets can limit the flexibility for autonomous adaptation, such as temporary trading of water use allocations.

3.6.10.2.3 Climate change being seen as a low priority and/or being treated as a separate environmental issue

There is still a tendency for climate change being boxed as an environmental issue, thus preventing broader engagement around the related issues. More immediate or seemingly pressing issues also tend to get priority, particularly in the developing country setting where government actors generally have a large number of immediate pressures. In the Disaster risk management sector historical emphasis on short term and reactive responses to disaster means that disaster risk reduction tends to be considered a low(er) priority. In the Estuarine environment and the Urban and rural settlement sectors it is noted that climate change is often seen as a separate or environmental issue, rather than

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[8] "Is more restrictive in that it means there are no adaptation options that can be implemented over a given time horizon to achieve one or more management objectives, maintain values, or sustain natural systems" (IPCC, 2014:906)

a development issue or an issue that should be integrated and addressed together with other non-climate issues.

3.6.10.2.4 Financial and economic constraints or limitations of the current financial system

The lack of access to financial capital, larger scale macroeconomic aspects that relate to for example economic development and globalization trends, and the ways in which financing frameworks operate can act as barriers to adaptation actions. For a number of South African sectors finance and economics related barriers were highlighted. This includes a general lack of financial resources for implementation, especially at the local level. It includes the limited access and affordability of insurance cover in relation to Agriculture and forestry, and a challenge stemming from the fact that government is reliant on revenue from resource consumption and basic services including energy, water and waste removal.

3.6.10.2.5 Lack of or insufficient human and institutional capacity

The lack of capacity can include the general lack of staff and expertise, as well as shortage of technical staff specifically. This has implications in terms of the ability of sectors to carry out planning, as well as the implementation of policies, plans and frameworks. Capacity issues are identified here as a barrier experienced in a number of sectors, including Agriculture and forestry, Human Health, Terrestrial ecosystems, Urban and rural settlements and Water.

3.6.10.2.6 Lack of understanding and expertise

While a particular understanding and expertise may exist, it can be found lacking in the spaces where it is required for implementation of adaptation. For both the Human health sector and the Urban and rural settlements sector limited understanding of climate change and related expertise are identified as barriers to climate change adaptation. In disaster risk management the lack of compliance on an institutional and community level is seen as a primary issue impeding implementation, and is partially attributed to the lack of stakeholder understanding of the linkages between disaster risk reduction and climate change adaptation.

3.6.10.2.7 Lack of or insufficient training and capacity building

Climate change adaptation may for example require application of new technology or new implementation frameworks, or the need for people previously not engaged with issues of climate to start building an understanding of how climate interacts with their lives or with their line of work. Insufficient training and capacity building is identified as potentially causing a slow uptake of conservation agriculture, a climate change adaptation response strategy that is commonly identified in the agricultural sector.

3.6.10.2.8 Lack of or insufficient data, information and M&E

Systematically monitoring progress through time and consistent collection of a variety of data and information supports the evidence base for research and action. In the South African context the lack of data on climate-health linkages, reduced monitoring and availability of climate change information for Agriculture and Forestry and insufficient reporting on disaster events are highlighted.

3.6.10.2.9 Research gaps

The lack of research on various aspects of climate change can be considered an adaptation barrier. The Human health sector identifies a variety of health related research gaps as a barrier, while Urban and rural settlements specifically highlights the lack of relevant research at a local scale.

3.6.10.2.10 Poor or inappropriate maintenance of infrastructure

Infrastructure challenges can speak to aspects such as financial constraints, human capacity and competing priorities, and can to some extent be considered a symptom rather than a causal barrier. In the Agriculture and forestry sector challenges with irrigation infrastructure are however highlighted as a barrier to adaptation, particularly in relation to small scale irrigation schemes. In the Water sector general water service infrastructure is considered to pose a threat to the effective functioning of South African water institutions, and is thereby deemed a potential barrier to adaptation.

3.6.10.2.11 Different local contexts, ethical implications and the lack of integration of different knowledge systems

For Disaster risk management a multifaceted barrier is noted in relation to addressing risk drivers that are interconnected with cultural beliefs, behaviour and economic factors, and the ethical implications of possible adaptation responses. This leads to an emphasis of the importance of improving all stakeholders’ understanding of disaster risk reduction and climate change adaptation, and the incorporation of a variety of knowledge systems in this understanding.

Barriers do not necessarily act in isolation, and while generic categories are provided here the way in which adaptation barriers manifest is context specific (IPCC, 2014: 908). The way in which adaptation barriers are outlined and unpacked here is relatively simplistic, and does not reflect the breadth of most recent definitions and understanding of the IPCC.

Given the relatively limited and diverse approaches to sectoral unpacking of adaptation barriers in previous chapters, there seems to be a need for further exploration to develop a better understanding of South African adaptation barriers. Furthermore, there is a need to make a shift, from a focus on *if* barriers to adaptation exist and *which* they are, towards an approach that analysis *why* and *how* identified barriers emerge (Biesbroek, 2013).

3.6.10.3 Key evidence gaps

Consideration of the current evidence gaps provide guidance for the future allocation of resources and research focus, and indicates progress that can be made towards the 4th South African National Communication. While the individual sector chapters outline sector specific gaps, the section below collates these gaps into themes to summarise the type of evidence gaps that are emerging across the sectors. The evidence gaps highlighted for the sectors are largely related to various aspects of research, with some emphasis on data and monitoring.

Data gaps on are only briefly mentioned, with the Urban and rural settlements sector highlighting lack of data on coastal erosion and changes in the shoreline, and the Coastal zone sector highlighting the lack of aspects such as long-term flow data and temperature data. These data gaps are closely linked to **monitoring** aspects, for which the Water resources sector identifies a gap in terms of national water monitoring and monitoring of soil moisture, wind speed and water temperatures.

A commonly cited research gap relates to the **impacts or effects of climate variability or change**. These are largely related to biophysical aspects in Agriculture, including climate change impacts on vectors, soil pH and fertiliser requirements for crops, as well as the impacts of climate change on various aspects of the aquatic domain addressed by the Coastal zone sector. For Urban and rural settlements a gap in terms of the combined impacts of sea level rise and severe storms on coastal settlements is emphasised, while the Water resources sector highlights the need for further research on the multi-layered impacts of climate change on water resources.

Gaps in terms of **risk and vulnerability assessments** are highlighted for Urban and rural settlements and Disaster risk management, often in relation to **the local scale**. The former identifies a gap in terms of understanding of the environmental vulnerabilities of informal settlements, needed to direct local government plans, as well as the need to have a closer look at the path and scales of vulnerability in order to better cater for the high exposed residence of informal settlements. The Disaster risk management sector highlights the lack of vulnerability assessments that consider increased population concentrations in the context of climate change, in the context of formal and informal urbanization increasing densification. The Disaster risk management sector also identifies a gap in terms of information related to local level climate change risk and vulnerability, and the increasing risk of disasters at the municipal, community and individual scale.

Climate science related gaps are highlighted in relation to Disaster risk management and Urban and rural settlements, and span from the lack of climate scenario products, to local scale projections, to more user-friendly seasonal forecasts. The lack of adequate **impacts modelling** is also identified, with the Coastal zone sector highlighting limited availability of models that link hydrological regimes to ecosystem processes and large scale ocean current changes, and the Urban and rural settlements sector emphasising how impacts modelling approaches are currently incomplete. For the Human health sector a gap is identified in terms of the need develop scenario-based modelling to project future health related risk, with the inclusion of both climatic and non-climatic factors. The Disaster risk management sector highlights the need to expand the scope of the provisional modelling work conducted as part of the LTAS in relation to the possible increase in flooding risk and related impacts on dams, bridges and powerline crossings.

Decision-oriented research is another gap identified in sectors. In the agricultural sector, the need for research into the decision making process of smallholder and commercial farmers in relation to the limited uptake of conservation agriculture is highlighted. For Urban and rural settlements there is emphasis on the need for more evident decision-oriented research at the local community scale, noting how bottom-up approaches such as robust decision making, decision scaling and adaptation pathways are being advocated globally. Engagement with decision makers through processes such as robust decision making and decision scaling is also highlighted as a gap in the context of Disaster risk management, with emphasis on the need for case studies on developing decision frameworks.

The Human health sector outlines a number of very specific research gaps, many of which are focused on **understanding current health issues** and links to climate: clarify relationships between climate variation and health outcomes; estimate, statistically, current burden of disease attributable to climate change; seek evidence of actual current health impacts; estimate health co-benefits of actions to avert/reduce further environmental change; and evaluate health-protecting actions.

Lastly, there is some emphasis on **research that will guide specific interventions**, with the Terrestrial ecosystems sector highlighting the need for research that can guide the development of early detection means of invasive aliens and strategies to deal with conflict of interested related to invasive aliens. The Urban and rural settlements sector identifies the need for further evidence to demonstrate where effective ecosystem based approaches are practiced, particularly in the rural context

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3.7 Towards a National Adaptation Plan

3.7.1 Introduction

The National Climate Change Response Policy (NCCRP) recognised the need for the country to implement adaptation actions in order to respond to climate change. This would specifically involve changes to policy and process responses that need to be taken so that the country is able to best moderate or benefit from climate change.

South Africa will finalise its National Climate Change Adaptation Strategy by 2017 that will be used as the National Adaptation Pan (NAP) for the country which will prioritize the key activities to co-ordinate and prioritise the country's climate change adaptation needs.

This Chapter reports on the progress made by South Africa in the adaptation space since the SNC. More specifically the chapter discusses South Africa's readiness to effectively develop, implement, monitor and improve (through continuous learning) effective climate change interventions. This review is critical for taking stock as well as providing direction to the NAS. To be successful the NAS needs to build on, and where necessary, add value to measures that are already planned or underway.

3.7.2 Progress toward the development of the National Adaptation Strategy

The National Development Plan (NDP) for South Africa provides a long-term perspective to guide the country's development trajectory such that poverty is eliminated and inequalities are reduced by 2030 (NPC, 2012; RSA, 2011b). Government sectoral plans therefore have to ensure long-term alignment with the NDP to ensure that the planning and implementation outcomes can be achieved. Furthermore, the NDP states that climate change is already having an impact on South Africa with marked temperature increases, rainfall variations and rising sea levels. The NDP therefore recognises that policy needs to quickly and effectively respond to ensuring the natural environment is protected from the effects of climate change (NPC, 2012).

Since the inception of the NCCRP South Africa has undertaken significant steps toward addressing climate change adaptation across key socio-economic sectors, however, there remain policy and knowledge gaps that highlight the future needs that the country should aspire to respond to. As a developmental state, South Africa has also embarked on tackling the root causes of poverty and inequality and has recognised that climate aspirations are likely to have an unsuccessful/slow rate of implementation if not understood in the context of poverty and equality (RSA, 2011b).

As such, when the country developed its Nationally Determined Contributions (NDC) in 2015, the adaptation goals were developed taking cognisance of the NDP sectoral goals and timelines. The NDP with respect to climate change (NPC, 2012) specifically states that by the year 2020 annual data on climate impacts should feed into the assessment, reporting, policy and regulatory process and that by this time plans to strengthen the states capacity would start to pay off, with rigorous skills development interventions active across the country. It is further envisaged in the NDP that by 2020 that resilience planning would be integrated into all planning processes in the country. The NDP further proposes that by the period of 2025-2030 the investments in climate resilient infrastructure made in the previous decade would start to bear fruit and that South Africa would be well capacitated to comfortably manage its policy, regulatory and support functions, and report to the national and international arenas as appropriate.

Based on these points of departure from the NDP and the climate change response needs as outlined in the NCCRP, the overarching adaptation aspiration of the South Africa’s NDCs is to place the availability and vulnerability of natural resources and the vulnerability of the South African population to climate change at the centre of the NDP initiatives (CSIR, 2015).

These goals seek to prioritise South Africa’s adaptation needs and to ensure that decision-makers are provided with information relevant to potential climate change impacts at an appropriate scale. Furthermore, given the country’s developmental trajectory, there is a need to ensure that climate change is mainstreamed into planning and policies. For example, the need to increase exports in the agriculture and agro-processing industries in the context of economic growth is outlined in the NDP. The intention is to create 643 000 direct jobs and 326 000 indirect jobs in the agriculture, agro-processing and related sectors by 2030 as a means of creating an inclusive economy. As such there is a need to ensure that these expectations are considered within the context of expected climate impacts on this sector and that appropriate interventions can be implemented to meet these goals (CSIR, 2015).

The focus on generating information on vulnerability and adaptation needs, as well as the integrating climate change considerations into policy further highlights that it is essential to have processes in place such that policies on climate change adaptation become institutionalised and that there is institutional capacity for implementation (CSIR, 2015). The NDC further recognises the need to track the implementation of adaptation actions through the development of a reporting system that can be used to report on the progress made.

The country has acknowledged that these institutional, research and financial gaps exist and the aspirational goals for adaptation as outlined in the NDC will be a key to effectively addressing these barriers. Of particular importance in this process is the development of the NAS which has begun in 2016 concurrent to the National Climate Change Act. The NAS outlines the key strategic goals and outcomes that are needed to respond to climate change, in terms of adaptation, emphasising the interlinkages between climate change resilience and development goals. Using the NCCRP and NDCs as a basis, the NAS outlines the vision and strategic goals, with strategic outcomes for the period of 2017-2025 outlined and the strategic interventions that need to be implemented to achieve these outcomes expanded on (https://www.environment.gov.za/sites/default/files/docs/nas2016.pdf).

The information presented in this chapter, demonstrates the extent of climate change knowledge that has been developed in the country. Specifically through the LTAS processes, significant knowledge of climate change projections, and potential climate change impacts have been developed. Further to this, in response to the adaptation needs outlined in the NCCRP, numerous sectoral and government adaptation plans have been developed. The progress that has been made toward providing a basis for achieving the country's aspirational adaptation goals is discussed in the following sections.

3.7.3 Progress with Mainstreaming Climate Change into Policies and Planning

From the aspirational goals listed above it is evident that the country aims to manage the impending climate change impacts through interventions that build and sustain South Africa's social, economic and environmental resilience and emergency response capacity (DEA, 2014g). The NCCRP stated that for the immediate future, sectors that need particular attention from an adaptation perspective are water, agriculture and forestry, health, biodiversity and human settlements (RSA, 2011a). Potential adverse impacts of climate change on food production, food and water security, and human health as outlined in Section 3.6 are significant policy concerns in South Africa. The incorporation of climate change considerations into sectoral plans and policies is therefore recognised in the NDC.

To effectively mainstream climate-resilient development, all government sectors have to ensure that all policies, strategies, legislation, regulations and plans are in alignment with the NCCRP (RSA, 2011a). All national departments are further mandated to develop sector specific climate change adaptation plans. The sectoral responses and related adaptation plans are critical in supporting the country's NDCs in achieving the goals of the NDP and NCCRP.

3.7.4 Sector Plans of National Departments

This section presents an overview of sectoral plans that have been developed since the Second National Communication (SNC). The particular focus of this review is to highlight how national departments have envisaged and planned for responding to climate change.

3.7.4.1 Water

The NCCRP (RSA, 2011a), highlights that climate change will adversely impact on the availability and distribution of rainfall and therefore water resources throughout the year. As such the NCCRP identified a number of adaptation needs within the water sector in response to climate change. In particular, it highlights that implementing the best catchment and water management practices will help to ensure the greatest degree of water security and resource protection under changing climatic conditions. This will entail investment in water conservation and water demand management and exploring new and unused resources, particularly groundwater, re-use of effluent, and desalination. It is further recognised in the NCCRP that these efforts toward water security have to be supported by water related research, and appropriate resources and governmental support. The plan also specifically speaks of the need to ensure that climate change considerations are incorporated into the short-medium and long-term water planning processes across relevant sectors such as agriculture, industry, economic development, health, science and technology (RSA, 2011a).

To date, significant progress has been made with regard to including climate change considerations in the water sector’s plans and strategies. The Water for Growth and Development Framework 2030 provides a medium to long-term perspective on managing water resources in the country. This framework states that all scenario planning responses must consider climate change to ensure that measures are implemented timeously (DWAF, 2009). The core objective of how the country aims to ensure water for an equitable and sustainable future is outlined in the second National Water Resources Strategy of 2013 (commonly referred to as“NWRS2”). The NWRS2 has dedicated a chapter to climate change, in which it seeks to address the core issues raised for water in the NCCRP.

Furthermore, a Climate Change Adaptation Strategy for Water has been developed that aligns with the NWRS2, and specifically highlights the importance of monitoring and assessing the implementation of the NWRS2. The Climate Adaptation Strategy for Water (DWS, 2016) outlines a number of strategic adaptation actions for addressing climate change impacts. The options range from planning for new dams to developing new groundwater sources. The strategy further highlights the need to improve flood warning systems and to ensure that water allocation is sufficiently flexible to cope with climate change. Importantly, the strategy also highlights the needs to protect water allocations to poor and marginalised communities, particularly under drought conditions. The strategy further outlines timelines and responsibilities for achieving these adaptation actions (DWS, 2016).

3.7.4.2 Agriculture, forestry and fisheries

The potential adverse implications of climate change on food production, agricultural livelihoods and food security were highlighted as significant national policy concerns in the NCCRP (RSA, 2011a) and SNC (DEA, 2011b). Climate-resilient responses in these sectors should promote food security, conserve soil quality and structure, contribute to biodiversity and contribute to empowerment goals. Priorities to build climate resilience in the agriculture and forestry sector included the integration of climate-smart agriculture into climate-resilient rural development planning, development of long-term scenarios, use of early warning systems, improving food security, and increased integration into other sectors (e.g. water sector, rural development) (RSA, 2011a; DEA, 2014d; DAFF, 2012b).

The Department of Agriculture, Forestry and Fisheries (DAFF) has been proactive in initiating sector-related climate change strategies and scenarios to promote awareness of climate change, to advocate sustainable practices which aimed to contribute the least to greenhouse gas emissions, conserve the sectors natural environments and mitigate the effects of climate change as much as possible (DAFF, 2012b).

The Integrated Growth and Development Plan (IGDP) for the Department of Agriculture Forestry and Fisheries (DAFF, 2012; DAFF, 2012c) describes the current realities and challenges of the agriculture, forestry and fisheries sector and outlines the goals, objectives and interventions that need to be made to as part of their long-term strategy to address key national issues. The agriculture, forestry and fisheries sector each impact on climate change and/or the other sectors. Selected interventions proposed in the IGDP (DAFF, 2012a; DAFF, 2012c) include developing a water demand management strategy for Agriculture, Forestry and Fisheries, an Integrated Climate Change Strategy and a National Food Policy.

The IDGP (DAFF, 2012a) identified the need to develop both adaptation and mitigation strategies for the sector. Adaptation strategies in the agricultural sector would include diversification in crop and livestock production (varieties and breeds), income diversification, and changing seasonal migration (e.g. for livestock farmers). However, since the adaptive capacities of the poor may be most constrained, public policies to support adaptation by poor producers, on the grounds of human rights, economic development and environmental sustainability are favoured. The most effective adaptation options will require substantial public and private investments in irrigation, support of stress-tolerant crop varieties and animal breeds, and support to improve roads and marketing infrastructure for small famers. Water-efficient production technologies and rainwater harvesting for smallholder production will be essential in South Africa.

According to the interventions required for the fisheries sector in DAFF’s IGDP, strong decadal variability implies a need for adaptive management strategies to be used at five- to ten-year intervals as productivity and distribution of resources change (DAFF, 2012a; DAFF, 2012c). The interactions between the impacts of unsustainable fishing and climate change need be considered in tandem and not as separate issues.

In 2013, DAFF developed a draft Climate Change Sector Plan for Agriculture, Forestry and Fisheries (CCSPAFF) (DAFF, 2013a) in compliance with the NCCRP (RSA, 2011a) and in support of disaster risk management. The Climate Change Adaptation and Mitigation Plan (CCAMP) (DAFF, 2015c) was developed using outputs from the CCSPAFF, NCCRP and other research projects on climate change which include the Agricultural Greenhouse Gas Inventory and the "Atlas of Climate Change and the South African Agricultural Sector: A 2010 Perspective" (Schulze, 2010) (also see DEA, 2014k; DEA, 2014l). The CCAMP addresses the agriculture and forestry sector, but not the fisheries sector.

In the forestry and natural resources management programme in DAFF’s Strategic Plan for 2015/16-2019/2020, one of the strategic objectives is to ensure adaptation to climate change through implementation of effective prescribed frameworks. This involves the implementation of a Climate Change Mitigation and Adaptation Plan to improve adaptability and productivity of livestock and plant species by 2019/20 (implement Climate Change Plan through the biogas production integrated crop-livestock system) (DAFF, 2015c).

3.7.4.3 Health

The NCCRP stated that many of the health challenges currently experienced in the country are likely to be compounded within a changing climate. Climate change and its impacts are likely to place an additional strain on South Africa's health care system, highlighting the need to integrate climate change considerations into health sector plans. The NDP emphasises the need to promote the health and well-being of all South Africans and to provide affordable access to quality health care by 2030. The National Department of Health Strategic Plan (NDHSP, 2014) sets out the strategic goals for the period of 2014-2019 in light of supporting these NDP priorities. These strategic goals aim to improve the quality of care and human capacity within the health care system. A further goal is to ensure that norms and standards are implemented to track these improvements.

As the country strides to improve the health and well-being of all its citizens, the concern is that climate change could have negative effects in this regard. Specifically, natural disasters like floods could result in the contamination of water supplies and displacement of communities. Adaptation within the health sector has to not only consider the direct impacts of climate change through factors such as heat stress, but also climate change impacts of the key socio-economic sectors (water, biodiversity, agriculture), which will also have impacts on human health.

A climate change adaptation plan has been drafted for the health sector for the period of 2014-2019 (DoH, 2014), and focuses on nine health and environmental risks that include heat stress, natural disasters, housing and settlements, communicable diseases, exposure to air pollution and respiratory diseases, non-communicable diseases, vector and rodent borne disease, food insecurity and mental ill health.

The main goals of the plan are to conduct vulnerability assessments, improve on the monitoring and surveillance of key indicators, and improve inter-sectoral partnerships through a National Climate Change and Health Steering committee. The plan further seeks to prioritise research and development to understand potential impacts of climate change on health and manage and implement appropriate interventions. These goals further include the development of indicator datasets to monitor the implementation of such actions. Specifically, the Department of Health, plans on establishing a series of model projects on adaptation actions in high-risk areas, which could be scaled up for implementation to other areas of the country. The proposed National Climate Change and Health Adaptation Steering Committee may play an important role in identifying climate change and health protection opportunities.

The plan also seeks to improve health systems readiness to climate change. In the case of natural disasters for example, the plan highlights the impacts of weather-related disasters on human life, stating that between the period 1980 and 2010, such disasters have resulted in 1969 deaths, and affected 18 456 835 people. In this example, as the effects of extreme weather events on health are difficult to quantify due to under-reporting, the plan recognised the need to improve reporting and information systems. The public health sector is presently embarking on a robust, transversal strategy to better prepare itself for disasters, but with the main thrust on reducing the effects of a disastrous event. The strategy spans all facets of the health system, and ensures that both risk reduction measures as well as response systems are in place in each district with the objective of ensuring service continuity during adverse events.

The plan further highlights the need for inter-sectoral action for climate change and health that must be aligned to the principle of ill health prevention. The plan asserts that health departments should build the capacities required to engage and negotiate across sectors in the interests of public health. The need to assess and strengthen the Health System Readiness Capacity within hospitals and health facilities is also needed. Such assessments will need to have a particular focus on assessing the capacity to prevent casualties and other acute health impacts or disease outbreaks resulting from extreme weather events, and emergency response services. For provinces that are sharing borders with other countries, there is also a need to assess health system readiness and effectiveness to health needs of climate change refugees or migrants (DoH, 2014). It is expected that the implementation programme for this climate change adaptation plan will focus on short, medium and long-term implications for public health.

3.7.4.4 Biodiversity

The NCCRP (RSA, 2011a) outlined projected impacts of climate change on South Africa’s key biodiversity assets along with recommendations on how to meet the challenges through integration of climate change into the management of biodiversity and ecosystem services. Approaches suggested in the NCCRP included the need for increase institutional support to biodiversity management and research institutions; expansion of protected area network (in line with the National Protected Area Expansion Strategy (RSA, 2010)); prioritisation of climate change research into marine and terrestrial and ecosystem services; expansion of existing gene bank to conserve critically endangered species; and prioritisation of impact assessments and planning to include full-range of possible climate outcomes.

The National Biodiversity Strategy and Action Plan (NBSAP) was updated in 2015 (RSA, 2015) and identifies the priorities for biodiversity management in South Africa for the period 2015-2025, aligning these with the priorities and targets in the global agenda, as well as national development imperatives. The vision of the updated NBSAP is to “Conserve, manage and sustainably use biodiversity to ensure equitable benefits to the people of South Africa, now and in the future” (RSA, 2015). The report on ‘Climate Change Adaptation Plans for South Africa’s Biomes’ (DEA, 2015c) builds on work conducted as part of the LTAS programme (DEA, 2013a) and presented potential adaptation responses to guide current and future decision makers in protecting South Africa’s natural ecosystems and biodiversity in the face of climate change. One of the priorities of the updated NBSAP is to ensure that new tools are developed to support planning and decision-making, and that both new and existing tools are implemented and maintained. Integration of climate change considerations, from both a spatial and land use compatibility perspective, needs to be considered in the development and maintenance of these tools. A number of biome-based adaptation plans have been developed, and a target by 2019 is the implementation of the Land Degradation National Action Plan and Biodiversity Climate Change Adaptation Plans for nine biomes (RSA, 2015).

3.7.4.5 Human Settlements

Due to diverse nature of settlements in South Africa these settlements can be considered as being as urban, rural and coastal settlements. As such each of these settlements has their own set of developmental challenges, potential to be impacted by climate change and thus adaptation needs and responses that are required.

3.7.4.5.1 Rural settlements

The NCCRP states that over 39% of South Africans live in rural areas, with a large proportion of the impoverished people living on communal farming areas (RSA, 2011b). Climate change is likely to have impacts on food production and spatial planning and land distribution and thus affect rural settlements.

A significant focus for the Department of Rural Development and Land Reform was therefore on the integration of climate change responses into the Comprehensive Rural Development Programme (CRDP). The CRDP is the key strategy in the department’s campaign to reduce poverty, malnutrition, unemployment and shortage of infrastructure in rural South Africa. It is reported that under the CRDP, during 2012, 2 447 household food gardens were established and that 39 331 rainwater harvesting tanks were distributed to households, among other initiatives carried out in rural communities (RSA, 2014).

The Climate Change Adaptation Sector Plan for Rural Human Settlements (LES, 2013) was developed to support the creation of sustainable livelihoods that are resilient to climate change. The plan specifically calls for access to climate resilient services and infrastructure in rural areas to be promoted through climate resilient rural housing programmes that include rainwater harvesting, solar water heaters and off-grid/mini grid electrification, environmentally-friendly and socially acceptable sanitation solutions (RSA, 2013a). In terms of the financial obstacles to electrification in rural areas, full use should be made of current opportunities afforded by commercial renewable energy projects which are required to have a social investment component in terms of existing regulations (DOH&DEA, 2013). There is an opportunity to invest in long term research on more effective ways to supports rural household climate resilience by undertaking research to develop and identify technological and social innovation opportunities in rural human settlements, particularly with respect to environmentally and socially sustainable models for delivering housing, basic services and infrastructure to under-serviced rural human settlements (DOH&DEA, 2013).

3.7.4.5.2 Urban Settlements

The majority of the country’s population live in urban areas with challenges with respect to energy and water provision likely to be compounded by climate change. Climate change may exacerbate the problems caused by poor urban management and increase the vulnerability of informal settlements

(RSA, 2011b). It is recognised that national policy is required to coordinate strategies and mediate between the competing adaptation needs of particular settlements. As such the NCCRP recognises that there is a need for building of climate resilient infrastructure, water and energy sensitive urban design, and consideration of ecosystem services when planning for development. The Spatial Planning and Land Use Management Act, No. 16 of 2013 (SPLUMA) provides a framework to guide spatial planning and land-use management in country and requires the incorporation of environment requirements, such as climate change.

3.7.4.5.3 Coastal Settlements

Many South African cities are built along the coastline. Flooding and coastal erosion result in the loss of coastal infrastructure (including breakwaters, roads and public amenities), habitat and ecosystem goods and services (RSA, 2011a). Predicted rises in sea level may further exacerbate these impacts with climate change expected to increase both the frequency and intensity of storms that are associated with sea level rise. As such the country's coastline will become increasingly vulnerable to storm surges, coastal erosion, sea-level rise and extreme weather events (RSA, 2011a). Coastal settlement development plans should take into account the potential impact of sea-level rise and intense weather events, such as storm surges, on infrastructure development and investment in coastal areas, particularly in terms of the location of the high-water mark and coastal set-back lines that demarcate the areas in which development is prohibited or controlled (RSA, 2011a). The NCCRP states the country will need to review and amend the legislation to deal with adjustments of coastal set-back lines that affect the status of existing public and private infrastructure.

The National Environmental Management: Integrated Coastal Management Act (Act No. 24 of 2008) (ICM Act). The ICM Act identifies the need to consider the potential for increase in the number and severity of natural disasters and the need for preventative measures with respect to adjusting or determining the coastal protection zone. The ICM was amended with changes reflected in the National Environmental Management: Integrated Coastal Management Amendment Act of 2014. The amendments clarify definitions, and also extend the powers of MECs to issue coastal protection notices. Climate change is not directly incorporated into the Environmental Impact Assessment (EIA) legislation in the country and there is no legal mandate to ensure that EIAs consider climate change. However, according to the National Environmental Management Integrated Coastal Management Act, 2008 (Act No.24 of 2008) estuary management planning must consider the predicted impacts of climate change and potential disasters, so as to minimize the potential detrimental impacts of predicted climate change through a precautionary approach to development in and around estuaries and with regard to the utilization of estuarine habitat and resources.

Furthermore, Integrated Coastal Management Act (Act No.24 of 2008) has been amended with respect to the coastal protection zone. This protection zone aims to manage, regulate and restrict the use of land that is adjacent to coastal public property. As such it has been amended to increase the surface area of flood prone areas as a consequence of climate change. The Integrated Coastal Management Act 24 of 2008 further requires that coastal provinces and municipalities develop management programmes that allow for potential climate change impacts to be taken into account in all coastal planning and management.

Nine key priorities for coastal management are identified in the coastal management programme that sets out a series of goals and associated management objectives, aimed at coastal management efforts that should be addressed at a national level (DEA, 2014e). The priorities and national management objectives are seen as emphasising the commitment, such as implementing integrated coastal management in South Africa over the next five years (2013-2017). The priorities include the need for effective planning for coastal vulnerability to global change (including climate change) to ensure that all planning within the coastal zone addresses coastal vulnerability (DEA, 2014e).

3.7.4.5.4 Disaster Risk Management

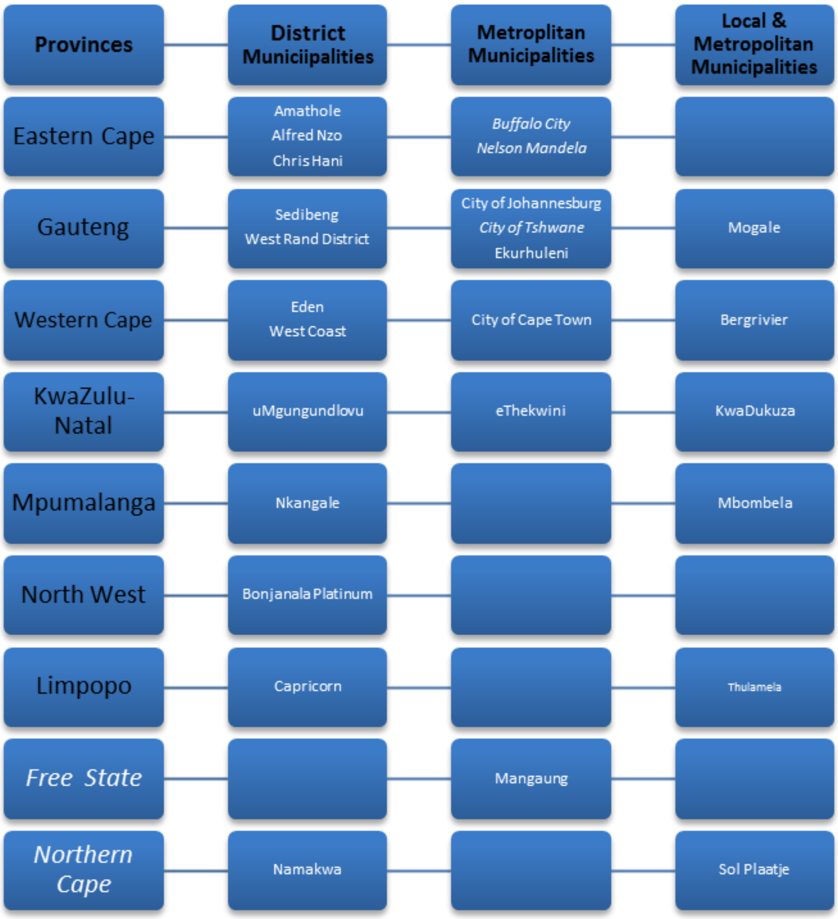
NCCRP states that the potential an increased number of extreme weather events under a changing climate will require disaster management systems to be strengthened. To do so effectively there is a need to facilitate increased use of seasonal climate forecasts and to ensure that municipalities are well equipped to use this information in their response planning (RSA, 2011a). As the increase in extreme events is likely to place an additional strain on those communities and municipalities who lack resources and are already vulnerable, there is also a need to develop mechanisms to assist these communities to recover. The Disaster Management Act 2002, Act No 57 of 2002, was therefore amended through the Disaster Management Amendment Act No.16 of 2015. As a result of these amendments each organ of state (national, provincial and local) is required to develop a disaster management plan that include adaptation responses and the development of early warning systems to reduce the risks of disasters.

3.7.5 Provincial and Local Adaptation Plans

The NCCRP (2011) clearly mandates the development of dedicated provincial climate change strategies, while requiring local municipalities to integrate climate change into municipal planning tools. The importance of provincial and local government planning is echoed in one of the aspirational goals of the NDC, where it is noted that climate considerations also need to be taken into account in sub-national policy frameworks. All nine provinces have made progress towards this end since the SNC, with a number of district, local and metropolitan municipalities following suite. This section is concerned with providing an overview of these strategies and plans, emphasising how they are focusing efforts to address climate vulnerability through adaptation actions and related efforts.

Dedicated provincial climate change strategies and plans are currently at different stages of development (Figure 0.90). Some provinces have finalised their strategies (Gauteng, Western Cape), some have draft strategies (North West, KwaZulu-Natal, Eastern Cape) or initial adaptation strategy documents (Limpopo, Mpumalanga, North West) (Urban Earth, 2016). Two provinces (Northern Cape, Free State) are in the process of developing their strategies, having developed climate change projections, vulnerability assessments and climate change status quo reports (Urban Earth, 2016). The seven strategies and adaptation documents that are finalised or in a draft state are outlined in more detail in section 3.3.7.1 through 3.3.7.7

This includes both drafts and finalized plans, however cursive means that a plan or strategy is in process but the draft is not accessible. Based on information found in: NAS draft provincial report & DEA's First Annual Climate Change Response Report.



Provinces	District Municiipalities	Metroplitan Municipalities	Local & Metropolitan Municipalities
Eastern Cape	Amathole Alfred Nzo Chris Hani	*Buffalo City* *Nelson Mandela*	
Gauteng	Sedibeng West Rand District	City of Johannesburg *City of Tshwane* Ekurhuleni	Mogale
Western Cape	Eden West Coast	City of Cape Town	Bergrivier
KwaZulu-Natal	uMgungundlovu	eThekwini	KwaDukuza
Mpumalanga	Nkangale		Mbombela
North West	Bonjanala Platinum		
Limpopo	Capricorn		Thulamela
Free State		Mangaung	
Northern Cape	Namakwa		Sol Plaatje

Figure 0.90: Overview of provincial and municipal climate change plans or strategies.

3.7.5.1 Eastern Cape

The draft Eastern Cape Climate Change Response Strategy is the oldest of the strategies, dating back to 2011. The Strategy was under development when the National Climate Change Response Green Paper (2010), which preceded the NCCRP, was released.

Climate change is set to impact the broader social economic context of the Eastern Cape. This will have implications for local planning and implementation, including the Provincial Industrial Development Strategy (PIDS) and the Provincial Growth and Development Plan (PGDP) and its programmes (CES, 2011). The strategy outlines the relevance of climate change to these plans and programmes, highlighting the need for plans, programmes, initiatives and infrastructure development to include climate change risks and impacts, and for subsequent adaptation measures.

A risk and vulnerability assessment considers climate change manifestations and 2nd and 3rd order impacts in the Eastern Cape. The impacts that were identified as extremely significant were grouped into the following adaptation categories: coastal infrastructure and livelihoods; responses to increased risk of wildfires; flood management; the effects of increased temperatures on human lives; food security; and water scarcity planning. For each category one or several adaptation programmes were proposed. The plan also identified a number of mitigation programmes. A variety of details were outlined for each of the programmes, including aspects such as the programme custodian, location, objectives, targets, key stakeholders and activities.

3.7.5.2 Gauteng

Published in 2012, the draft Gauteng Climate Change Response Strategy and Action Plan takes its lead from the NCCRP. The plan has a large focus on mitigation interventions, but also outlines climate change adaptation challenges and subsequent responses. The responses are developed for categories that are directly aligned with the NCCRP priority sectors, and include water, agriculture and food security, urban development and infrastructure, natural resources and biodiversity, health and disaster management. A number of cross-cutting responses are also developed, linked to governance, research, public awareness, training and education, and monitoring and evaluation.

However, the plan notes that from this large number of proposed responses a multi-departmental committee is required to identify priority responses. It further highlights that an investment plan, as well as comprehensive projects and plans developed and budgeted by departments, municipalities and organizations, are still required.

3.7.5.3 Western Cape

Western Cape’s Climate Change Response Strategy (WCG, 2014) builds on a provincial strategy and action plans from 2008. Following the approach taken by the NCCRP the province’s response strategy takes a two-pronged approach, considering both mitigation and adaptation. Seeking opportunities to combine the development of climate resilience, the creation of jobs and economic growth, a low carbon development trajectory and ecosystem enhancement, the strategy will guide the implementation of innovative projects (WCG, 2014; WCDOA, 2016).

Clearly acknowledging the linkages between climate resilience and the economy, communities and natural systems, the province outlines the following climate change adaptation outcomes (WCG, 2014:2):

- “well-managed natural systems that reduce climate vulnerability and improve resilience to climate change impacts;
- significantly increased climate resilience and coping capacity within communities which reduces climate-related vulnerabilities;
- an actively adaptive and climate change resilient economy which unlocks new markets and economic growth opportunities arising out of climate change.”

Based on the urgency of action, nine select focus areas for mitigation and adaptation action were identified in the plan. While outlined through a different framing, these focus areas are largely aligned with the NCCRP priority sectors. Those directly relevant to adaptation include the built environment, water security and efficiency, biodiversity and ecosystem goods and services, coastal and estuary management, food security and healthy communities. For each select focus area, a number of priority areas were identified, for example, farming practices that are in harmony with nature and can improve the resilience and adaptive capacity of informal settlements.

To execute the province's climate response strategy the next step is to develop an implementation framework, which will list and prioritise programmes and activities for implementation for each of the focus areas above. Cross-cutting programmes, including communication, job creation and capacity building, and partnerships will support the implementation of the strategy.

3.7.5.4 KwaZulu-Natal

KwaZulu-Natal's draft Climate Change Action Plan was released in June 2014, and aimed to minimise or eliminate the risks related to the impacts of climate change through a number of proposed actions and measures. The plan considered both mitigation of and adaptation to climate change effects, and outlined measures to be taken to address each of the two.

The proposed adaptation measures were preceded by a qualitative description of the vulnerability of each of the major sectors, based on a vulnerability assessment from 2009. Between three and nine proposed adaptation options, as well as the responsible entity, was outlined for each of the following categories: natural systems, water resources, fire regimes and forestry, agriculture, health, marine and coastal zone, and municipality and planning. These include actions such as expanding rainwater harvesting and storage, shifts in crop calendars and investigating possible revisions to flood line estimations.

The plan itself states that a proper climate change plan is still required, informed by the outputs from an energy audit and carbon foot-print and a climate vulnerability study.

3.7.5.5 Mpumalanga

Mpumalanga's adaptation strategies document was developed in 2015 as part of the Climate Support Programme. Solely focused on adaptation, its ultimate aim was to suggest strategies that could be applied by the province to develop adaptation responses in vulnerable sectors.

The document outlined a number of recommendations for climate adaptation measures for each of the following nine target-sectors: agriculture; forestry; livelihoods and settlements (Rural and urban); ecosystems (terrestrial and aquatic); tourism; water supply; human health; disaster management; and extractives. The target-sectors are very much aligned with the NCCRP priority sectors, with the addition of tourism and extractives. These target-sectors were identified in a preceding vulnerability assessment process in Mpumalanga. The process involved experts and relevant sector officials, who, in addition to those sectors identified as vulnerable to climate change, chose to add sectors deemed important to the province.

Climate change adaptation measures identified in the document include aspects such as: revisiting site classification models for forestry; improving building practices and strengthening monitoring; and identifying suitable buffers around protected areas so as not to negatively impact on tourism reserves. While this document answers the question of “what do we do,” the next step will be to look at how to do it. This will require the development of a climate change adaptation implementation plan, which includes accountability mechanisms, budgetary allocations, timelines and responsibilities. The document notes that relevant sector departments need to take responsibility of this process.

3.7.5.6 North West

The North West’s adaptation strategies document was developed in 2015 as part of the Climate Support Programme. The document thus follows the exact same process as that outlined above for Mpumalanga, though resulting in a slightly different set of target-sectors: agriculture; rural livelihoods and settlements; terrestrial ecosystems; water resources; extractives; and disaster management. For these, province-appropriate climate change adaptation measures were identified, many of which are similar to those outlined for Mpumalanga.

The process going forward for the North West is exactly as that for Mpumalanga, in terms of relevant sector departments taking responsibility for the development of a climate change adaptation implementation plan.

3.7.5.7 Limpopo

Limpopo’s adaptation strategies document was developed in 2015 as part of the Climate Support Programme. The document thus follows the exact same process as that outlined above for the North West, though resulting in a slightly different set of target-sectors: agriculture; livelihoods and settlements – rural and urban; ecosystems - terrestrial and aquatic; water supply; and human health. For these, province appropriate climate change adaptation measures were identified, many of which are similar to those outlined for Mpumalanga and the North West.

The process going forward for Limpopo is as that for Mpumalanga and the North West, in terms of relevant sector departments taking responsibility for the development of a climate change adaptation implementation plan.

3.7.6 Municipal Adaptation Planning

The NCCRP highlights the crucial role that local government will need to play in building climate resilience through the planning human settlements and urban development; the provision of municipal infrastructure and services; water and energy demand management; and local disaster response, amongst others (RSA, 2011a).

While not required by the NCCRP in 2014, the South African Local Governance Association (SALGA) outlined a mandate for municipalities to formulate climate change response strategies (SALGA, 2014). As such a number of local governments have also developed climate change plans and strategies.

As highlighted in a recent report from the DEA (2016), 10 out of just over 40 District Municipalities, 6 out of over 220 Local Municipalities and 8 out of 8 Metropolitan Municipalities have developed or are in the process of developing strategies. Due to the diverse planning needs of municipalities a full review for comparative purposes is not included in this review.

3.7.7 Monitoring and Evaluation

It is critical to measure and monitor climate change responses so that decisions can be based on accurate, current and complete information to reduce risk and ensure that interventions are effective. The needs of the monitoring and evaluation (M&E) system for the country is outlined in the NCCRP that specifically calls for the monitoring of climate change impacts and the establishment of an M&E system for gathering information and reporting progress on the implementation of adaptation and mitigation actions. To this end the country has embarked on developing an M&E system for mitigation and adaptation aimed at providing an evidence base of the impact of climate change in South Africa and the associated responses.

The aim of the adaptation component of the M&E system developed by the Department of Environmental Affairs (DEA) is to track the country's transition to a climate resilient society (DEA, 2015). It is therefore built upon the work that is being undertaken with respect to climate information; climate risks, impacts and vulnerability; and climate resilience response measures which form the three key building blocks of the structured approach proposed for a M&E system adaptive capacity and response measures (DEA, 2015i). The indicators for understanding the progress made toward the transition to a climate resilient South Africa are based on the number of policies/plans and strategies that integrate climate change; the number of stakeholder platforms on climate change adaptation related activities; the number of monitoring systems and networks to monitor climate and atmospheric parameters and the number of monitoring systems and the number of monitoring systems and networks to monitor climate change impacts. This type of information facilitates tracking progress in the implementation of climate resilient responses and assessing the effectiveness of such responses in enhancing adaptive capacity and addressing climate change vulnerability.

Among the challenges associated with tracking the transition to a climate resilient society is that the effectiveness of adaptation responses may not be evident for many decades. This coupled with the long timescales associated with climate change and its impacts, along with the multi-sectoral and multi-stakeholder nature of adaptation, make it challenging to track the transition to a climate resilient society. The difficulties in trying to attribute cause and effect and the lack of agreed metrics for adaptation are also acknowledged as challenges to M&E for adaptation (DEA, 2015i). However, the system will serve to provide a useful platform for gathering information and reporting progress on the implementation of actions that will ultimately assist in understanding how the country's vulnerability and adaptive capacity is changing**.**

3.7.8 Implementation of Climate Change Projects

The initiation of the National Climate Change Response Database (NCCRD) in 2009 provides an important resource to the M&E system discussed above. Adaptation activities are emerging across the South African landscape. Project-based responses are developed and implemented by a variety of actors, ranging from the private sector and parastatals to Non-Governmental Organisations (NGOs) and local government. The NCCRD was developed by the DEA as a means to provide easy access to this landscape[9]. The database came as a response to the scattered nature of information on implementation of climate change interventions, recognised as a non-conducive setting for an "efficient, effective, integrated and cohesive climate change response" in South Africa (Dlamini, no date: slide 6). The database thus provides the natural source of information for this review, aimed at providing a sense of South Africa's adaptation implementation landscape in the years since the SNC.

While not claiming to provide an exhaustive overview of South African adaptation projects, the NCCRD is understood to be the largest existing South African database for adaptation projects. However, as noted by the DEA, gathering of information held by a large number of stakeholders is extremely time and labour intensive, with information at times difficult to find and with some information holders suspicious of the intention of the database (Dlamini, no date). An update of the database was underway at the time of this review (in the first few months of 2016. While updating information in the database is an ongoing process, the majority of the 125 adaptation projects listed have been implemented over the last 4-5 years[10].

The NCCRD provides an overview of three types of projects, Adaptation, Mitigation and Research projects. For each project it provides a number of set categories of information, including description, funding organisation, host organisation and project start and end year[11]. A list of all adaptation projects was downloaded from the database[12], and amended[13], resulting in a list of 125 projects. Analysis of the 125 projects included categorisation of implementing agents, funders and the focus of the projects, as well as mapping the geographic spread of the projects.

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[9] http://nccrd.environment.gov.za/deat/

[10] A total of 23 of the projects were deemed to be operational at the time of the review, of which ten were scheduled for completion in 2016, five were scheduled for completion in 2017 and the completion of the remaining eight were spread relatively evenly between 2018/19/20. Just over half of the projects, 75, had already been completed, with a large portion of these, 24 projects, completed in 2015, and approximately ten projects were completed each year from 2011 through 2014. Insufficient data meant that it was not possible to get clarity on 27 of the projects.

[11] Note that not all the projects provide information for each category, and these cases are recorded in the analysis as "not specified."

[12] The list of projects was downloaded from the database 05 April 2016.

[13] The database download presents projects that have a number of different geographical implementation areas as separate projects, with one project per implementation area. These were reorganised to each represent *one* project, with multiple implementation areas.

Government, in the form of national and provincial governments and district, local and metropolitan municipalities, are the implementers of around half of the 125 projects (

Table 0.28). Out of the government actors the metropolitan municipalities are the major implementers, responsible for approximately half of the 64 government implemented projects. As was highlighted in Section 3.7.5 all eight South African metropolitan municipalities have a climate change plan or strategy either completed or in process and research has found evidence of adaptation being integrated into the plans and practices of metros (Ziervogel *et al.,* 2014). South African metros can thus to some extent be seen as being at the forefront of adaptation planning and implementation, likely in part due to their governments being better capacitated.

Implementers that are more indirectly government actors are included in the Parastatals & National institutes/ councils/ agencies/ foundations category, and which include for example ESKOM, the South African National Biodiversity Institute (SANBI) and the National Agricultural Marketing Council (Table 0.29). Following on from government and government-related actors, South African NGOs are the most dominant, with international and regional actors almost negligible. Only two of the projects in the database are implemented by university based groups, which is not surprising considering that universities are generally focused on research rather than on implementing actions.

Table 0.28: Project Implementers and Funders

Project Implementers[14]			**Project Funders**[15]	
National Government	**12**		National Government	**14**
Provincial Government	**12**		Provincial Government	**10**
District Municipalities	**5**		District Municipalities	**1**
Local Municipalities	**2**		Local Municipalities	**0**
Metropolitan Municipalities	**33**		Metropolitan Municipalities	**34**
National institutes/councils/agencies/ foundations & parastatals	**17**		National institutes & parastatals	**3**
South African Non-Governmental Organisations (NGOs)	**21**		South African trusts, funds and Non-Governmental Organisations (NGOs)	**10**
University based groups	**2**		Private sector	**5**
Private sector	**5**		Foreign Governments & Development Agencies	**4**
International NGO/ agency/ networks	**6**		International trusts, funds, agencies, institutions and NGOs	**39**
Regional networks, initiatives & institutes	**6**		Regional programmes & initiatives	**3**
Not specified	**5**		Not specified	**8**

Overall, the projects presented in the database are largely South African led in terms of implementation, with a minor part played by international actors. However, international actors play a greater role play a greater role in terms of funding. International trusts, funds, agencies, institutions and NGOs fund the largest number of projects, with South African Trusts, Funds and NGOs playing a minor role. South African government actors still play a central role when it comes to funding, with metropolitan municipalities again the most dominant. However, as many projects list several funders without reference to the proportion contributed by each, it was difficult to get a more detailed understanding on the proportion of funding provided by the different actors.

Metropolitan municipalities dominated comprised Half of the projects being implemented were in metropolitan municipalities in Tshwane, Cape Town or eThekwini. Hence, the Western Cape (45), followed by Gauteng (25) and KwaZulu-Natal (25), have the most projects being implemented in their province. The Northern Cape has a relatively high number of projects (16), followed by 12 projects in Eastern Cape. The remaining provinces, Limpopo and Mpumalanga have comparatively few projects,

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[14] Note that one project has more than one implementer, hence the numbers presented here total to more than the 125 projects presented.

[15] Note that many projects have more than one funder, and so the numbers here total to a lot more than the 125 projects presented.

with the Free State and North West having only two and one project/s respectively. As illustrated in Figure 0.90. Section 3.7.5 the North West and the Free State also display the least climate change strategies and plans of all the provinces, indicating that both planning and implementation in the two provinces may be lagging behind that in other South African provinces.

The NCCRP clearly identifies water, agriculture and forestry, health, biodiversity, human settlements and disaster risk management as the sectors that require particular attention for the immediate future. While sectoral planning is well underway at the national level, as outlined in Section 3.7.3, this project review provides an opportunity to reflect on the extent to which general adaptation projects map to these sectors. The projects were thus categorised according to the NCCRP priority sectors, with the addition of a coastal zone and a cross-sectoral category, based on the project descriptions provided.

As illustrated in Table 0.29 close to half the projects relate to the Terrestrial ecosystems sector. Included in the terrestrial ecosystem sector are projects focused on: sustainable land-use management; wildlife, biodiversity, soil and water conservation; restoration; alien clearing; rehabilitation; stewardship; biodiversity corridors; protected areas; ecological resilience; and ecosystem-based adaptation. A large number of these also have linkages and cross-benefits with other sectors, for example alien clearing can link to water resources and restoration to disaster risk management. However, the projects were largely framed around the natural systems, and were thus categorised accordingly. Further research is required in order to fully understand this large weighting towards terrestrial ecosystems projects. Though it can be theorised that the no-regrets nature of such projects, whatever the extent of future climate change, as well as the strong and long standing South African conservation movement could be playing a role.

The cross-sectoral category holds the second largest number of projects. While not a sector as such, this category was included for projects that did not speak to any sector, but rather address aspects such as general policy dialogue, partnerships, collaborations and information sharing, training, sharing of tools and strategizing climate change responses. These can generally be considered to be enabling projects, focused on planning and capacity and knowledge building.

While it is the category with the third most projects, the agriculture and forestry sector features an unexpectedly low number of projects. Agriculture is a priority sector in all of the provincial plans, and could be expected to feature more prominently given its central role in food security and given the large number of South African subsistence farmers. Water resources, urban and rural settlements and DRM, and the coastal zone have fewer projects, with the health sector having the least number of projects. While analysis of a broader range of projects and a more up to date database is required to fully understand the landscape, there are indications that South African adaptation projects are thus not well spread across the country’s priority sectors.

Table 0.29: Sectoral focus of projects[16]

Agriculture & Forestry[17]	Terrestrial ecosystems	Water Resources	Urban and Rural settlements & DRM	Coastal zone	Health & CC	Cross-sectoral	Not clear
19	51	9	9	12	2	31	4

Box 0.17: Example from a Provincial database

The Western Cape has developed a provincial database for climate change projects, the Western Cape Climate Change Database (WCCCD)18. This database provides an up to date snapshot of projects at a provincial scale19. It can be considered as the 'known status quo,' in that it does not claim to have an exhaustive overview of all current projects.

The database includes a total of 32 adaptation projects, of which just over a third are implemented by government. As opposed to what was found in the national project review, international as well as private sector actors play a larger role than South African NGOs in implementing projects in the Western Cape. In terms of funding it is somewhat hard to get an overview, with only half of the projects presented in the database identifying their funder. However, from the remaining half, government and international actors and foreign governments are found to fund a relatively similar amount of projects, with South African trusts, funds and NGOs playing a negligible role.

The geographic spread of projects mirror what was found in the national project review, with half of the total projects being implemented in a big metropolitan municipality, the City of Cape Town20. However, a large number of the projects listed (10) do not specify the municipality in which it is being implemented, but are instead reported as being either provincial or national projects.

In terms of the project focus the spread is different to that at the national level. Agriculture & forestry, terrestrial ecosystems, urban and rural settlements & DRM and cross-sectoral each have six or seven projects, while the coastal zone, water resources and health & climate change have three, two and one respectively.

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[16] Note that for several projects more than one sector has been ticked, and so the numbers here total to more than the 125 projects presented.

[17] Projects focusing on fisheries were also included here.

[18] Contact the Frances van der Merwe at the Western Cape Government to add projects to the WCCCD: Frances.vanderMerwe@westerncape.gov.za

[19] The database was updated very recently, 2015/2016.

[20] Importantly, the two databases have not been cross-checked, and are likely to contain a large number of the same projects.

This review, aimed at providing a sense of South Africa's adaptation implementation landscape in the years since the SNC, has provided some key insights. It showed the prominent role of the South African government, and particularly metropolitan municipalities, in implementing and, to some extent funding, adaptation projects. The geographic spread of projects further showed how a large proportion of adaptation projects take place in the provinces where South Africa's biggest metros are located, with provinces like the Free State and North West provinces having a negligible number of projects in comparison. Finally, the review illustrated a disproportionately large emphasis on terrestrial ecosystems projects, as compared to projects in the other sectors.

A centralised platform such as the NCCRD makes a review of climate change adaptation projects possible, and has the potential to play a valuable role in tracking the implementation of adaptation activities through time. As such, the drive that took place in 2012 and 2013 to populate the database can be considered as important progress for the South African adaptation landscape since the last National Communication, and the database updating phase was underway during the writing of this review. The importance of ensuring that as many projects as possible are included is critical, as this information can play an important role in understanding how the South African adaptation landscape evolves. The willingness of stakeholders to contribute information is thus central, as is the way in which information is collated. For example, it is important to ensure that those populating the database have a common understanding of the categories provided, so that, for example, categorisation of projects to a specific sector (host sector) happens in a consistent manner.

3.7.9 Climate Adaptation Financing

Central to the adaptation planning and implementation process is the issue of finance, the provision of funding. As highlighted in the NCCRP (2011), South Africa will need domestic resources to be complemented by international resources in order to build a climate-resilient society. This will require a range of actions, ranging from mobilisation to coordination to new market-based instruments to financial reforms. This section aims to firstly provide a brief overview of adaptation finance in South Africa by reporting on the progress made since the SNC in terms of overarching governance and mechanisms for climate finance, and by outlining the main national and international sources of adaptation finance. The past investments toward climate change adaptation in the last five years are presented in Section 7.5.2.

3.7.9.1 Funding sources

In 2011 the NCCRP called for the development of a climate finance strategy and architecture, as well as a climate finance coordination mechanism. The Development Bank of Southern Africa (DBSA) conducted investigations on behalf of the DEA in this regard, looking at the most effective setup and structure of a climate finance coordination mechanism. DBSA developed the prototype presented in Figure 0.91, and proposed a more South Africa-driven investment programme aimed at growing ownership and increased integration (Montmasson-Clair, 2012).

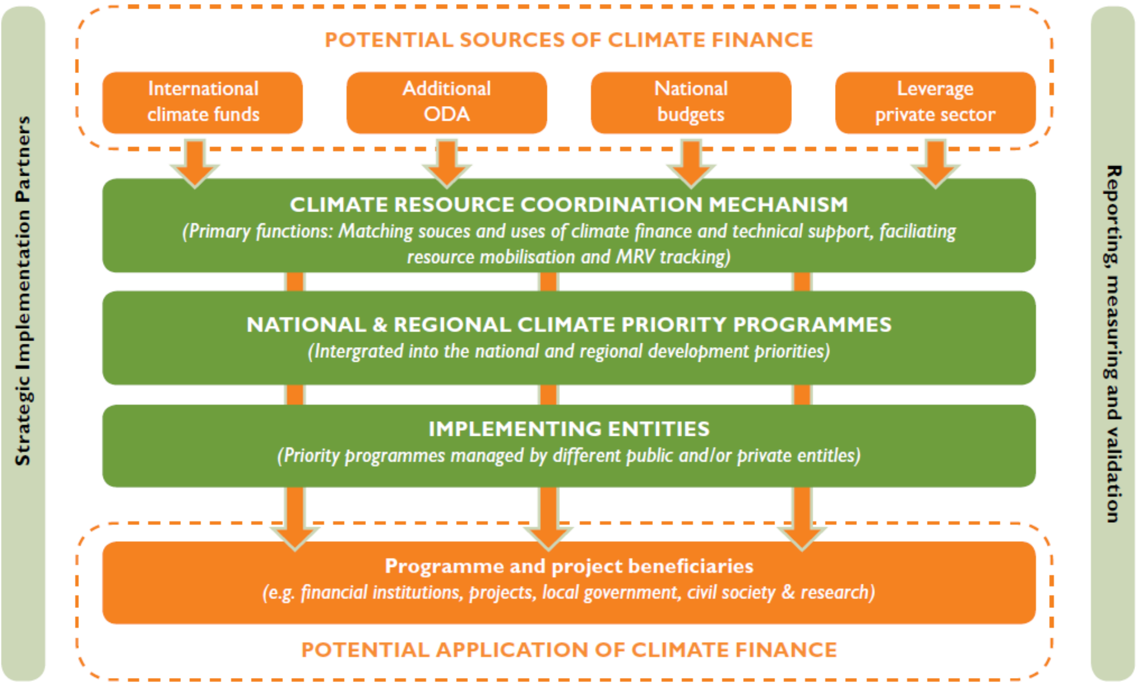

Figure 0.91: Prototype for climate co-ordination for South Africa (RSA, 2011b)

Potential sources of climate finance, as outlined in Figure 0.91, include international climate funds, additional official development assistance, national budgets and private sector. As illustrated in recent global figures, which show that in 2014 only 17% of public climate finance went to adaptation (Buchner *et al.,* 2015), mitigation tends to dominate. This is set to shift with the 2015 Paris agreement as pledges were made to move towards a more equal focus towards mitigation and adaptation.

In South Africa, a number of international and national funds have, to varying degrees, been funding adaptation action over the past 4-5 years. The majority of these have become operational in South Africa in the years since the SNC and are briefly discussed here.

The Global Environmental Fund (***GEF***), established in the 1990s, is the financial mechanism for a number of conventions, including the UN Convention on Biological Diversity and the UNFCCC. Climate change adaptation is a minor part of that, and the majority of GEF-funded climate change related projects in South Africa so far have been mitigation related.

The Adaptation Fund (***AF***) came about in the 2000s and is dedicated to funding climate adaptation and resilience activities. Funding can be accessed through accredited Implementing Entities, including Multilateral Implementing Entities such as the African Development Bank, UNDP and UNEP (UNDP-UNEP, 2011). A South African National Implementing Entity (NIE), the South African National Biodiversity Institute (SANBI) was accredited in 2011. The SANBI NIE issued a call for project concepts towards the end of 2013, which following a long multi-step selection and concept and proposal development process, led to the approval of two South African projects in October 2014. These two projects, the uMngeni Resilience project and the Small Grants Facility project, have a total of $10 million from the AF, and are currently in the implementation stage.

More recently, ***the Green Climate Fund*** (***GCF***) was formally established in 2010, and over time, is committed towards a 50:50 balance between adaptation and mitigation investments. The GCF provides a variety of financial instruments beyond grants, including equity, subordinated debt and concessional loans. As with the AF, access to the GCF financial instruments requires accreditation. Accreditations have been awarded since 2015, and the first South African entity to be accredited to access GEF funds was the Development Bank of South Africa (DBSA) in March 2016. Two other South African entities are currently waiting for the final accreditation, Nedbank and SANBI. As opposed to the AF, where the NIE’s access to funding is capped at $10 million, the GCF has no such caps and single projects can be up to the size of $250 million. The GCF is thus has the potential to bring large amounts of climate finance into South Africa over the next few years. It is still too early to say to what extent this will be adaptation focused, but at least one of the entities, SANBI, will be focused on projects that are either a combination of adaptation and mitigation projects or that are solely adaptation.

South Africa has also set up national arrangements for finance, one of which is the ***South African Green Fund***, whose inception was confirmed early in 2012. The Fund is managed by DBSA, on behalf of DEA, who initially set aside R 800 million for the establishment of the Fund. Aiming to catalyse the transition towards a green economy, the Fund offers financial support in the form of grants, loans and equity. Since 2012 the Fund has concluded several public requests for proposals, funding projects within the following funding windows: green cities and towns; low carbon economy;

and environmental and natural resource management. While not explicit, adaptation aspects are entangled in the last and, to some extent, first of the three funding windows.

The Drylands Fund is another South African initiative, formally constituted in 2011. It came about following South Africa's ratification of the United Nations Convention to Combat Desertification (UNCCD), and was established as a mechanism to house, manage and utilize contributions to fund the country's UNCCD National Action Programme. While not directly a climate finance mechanism as such, the Fund's focus on sustainable land use management and people living in areas vulnerable to environmental degradation implies that actions financed through the Drylands Fund tend to implicitly also address climate related vulnerabilities. Initially housed within the DBSA, this fund has in more recent times moved to SANBI, and a strategy for the way forward for the fund is currently in process.

3.7.9.2 Investments in adaptation for the period 2010-2015

The NDC provides an overview of past investments made from 2010-2015, that were based on annual reports on expenditure of different departments of the South African government. In the approach undertaken to estimate these investments as part of the NDC, activities that met the criteria or definitions of adaptation technologies, or were regarded as technology transfer for the adaptation sector were considered (CSIR, 2015).

In the water sector, for example, the country has invested in numerous projects to make the water sector more resilient through investments into new desalination plans, and the development of bulk water supply infrastructure and maintenance thereof, and the development of new water storage facilities. In the past five years significant investment has also been made in terms of operational climate monitoring and operation climate prediction under the foresight of the South African Weather Services (SAWS) (CSIR, 2016). In addition to these investments during this five year period it was found that various programmes have been undertaken that are relevant to climate change adaptation in this sector. These include the Environmental Protection and Infrastructure Programme, that created 99 548 work opportunities 2012/13, while 13 613 were created in the first half of 2013/14. Working for water (WfW), Working on fire (WoF) and The Working for Wetlands programme. Such programmes have not only supported the rehabilitation, protection and sustainable use of natural resources but also provided for employment and training of men and women from marginalised communities. The DBSA as the implementing agent for the Green Fund in 2013/2014 further approved 22 projects in South Africa (CSIR, 2015).

It has been estimated that the capacity for domestic investment into climate change adaptation increased from US$ 0.26 million to US$ 1.1 million from 2011 to 2015. The implementation investment increased from $US 0.71 bn $ US 1.88 bn from 2010 to 2015. The breakdown of per year for some of these key investments is shown below in Table 0.30

Table 0.30: Summary of investments made in adaptation in South Africa (CSIR, 2015)

Years	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
US$ Million						
Environmental Protection	84 955.8	54 279.7	113 623.9	84 889.6	81 738.3	88 006.8
WfW and WoF	62 496.7	88 944.3	110 758.4	144 621.0	15 0645.4	183 175.3
Green fund	0	0	8 877.4	2 5000.0	2 5000.0	3 000.0

Based on the existing investments that the country has made, the investments that will be needed in the future for adaptation was estimated and included in the country's NDC. These investments were scaled up with the range[21] 5% - 15% increase per annum to the years 2020, 2025 and 2030, with the total investments increase to R 29.5 bn - R 46.5 bn, R 37.6 bn – R 93.5 bn and R 48.0 bn – R 188.0 bn respectively (CSIR, 2015).

3.7.10 Reflecting on the Capacity to Adapt

This section reports on South Africa's existing capacity to adapt to climate change. More specifically the discussion below is intended to evaluate South Africa's capacity to develop appropriate climate change adaptation strategies and to translate these strategies into adaptation action. This assessment is based on a review of post-2011 studies and reports that have undertaken some form of analysis of South Africa's existing capacity to adapt to climate change. The assessment considered the key determinants of adaptive capacity that include an enabling regulative environment, adequate financial resources, human capacity, access and availability of relevant climate change related research and information, as well as the institutional capacity for cross-sector integration and stakeholder coordination.

For the purposes of this report, the focus was confined to the three spheres of government (national, provincial and local), and does not include an assessment of the adaptive capacity of other key actors such as the private sector or civil society. The critical role that these actors play in contributing to the country's ability to respond effective to climate change is however acknowledged.[22] The key determinants of adaptive capacity are discussed below.

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[21] The range represents uncertainty in the estimates

[22] Both, civil society and the private sector are proactively engaging with the topic of climate change and started to respond through innovative measures aimed at increasing South Africa's resilience to climate change. NGOs, for example, have been instrumental in capacitating local government through targeted skills development interventions. Representatives from the private sector have started to establish public–private partnerships aimed at building greater resilience at the landscape level.

3.7.10.1 The regulatory environment

Climate change adaptation policies and regulatory frameworks are important for mainstreaming climate change considerations/responses into all spheres of government, and for identifying roles and responsibilities. An enabling regulative environment is furthermore an important prerequisite for providing guidance to adaptation planning and creating enabling conditions for adaptation interventions within the public as well as private sector.

Sector specific climate change adaptation strategies have been developed for water; agriculture, forestry and fisheries, health, biodiversity (biomes) and human settlements ,and substantial progress has been made with regard to the development of provincial climate change response strategies. While the development of provincial climate change response strategies is an important step towards understanding and responding to current and future climate change impacts, the SARAs Report (2015) highlights that the capacity to develop and implement such strategies at the provincial level remains limited. In particular the lack of competencies to support or conduct vulnerability assessments and climate risks analyses were emphasised. This problem links back to skills and knowledge deficit in the provincial departments (See human capacity as well as research & information below.)

At local government-level, climate change response strategies exist for all metropolitan municipalities or are in draft form (DEA, 2016a). All have also several targets and key performance indicators for climate change adaptation in their Integrated Development Plans (IDPs). Ten district municipalities have climate change response strategies, these include Chris Hani, uMgungundlovu, Amathole, Alfred Nzo, West Coast, Eden, Capricorn, Bojanala, Namakwa and Nkangala (DEA, 2016a). Some of these municipalities make reference to climate change considerations through the mentioning of the establishment of climate change forums, research, options for financing the strategy etc. Six local municipalities have climate change response strategies, three of which have performance indicators for climate change in their IDPs (DEA, 2016a).

Overall the integration of climate change considerations into municipal development planning tools such as the IDPs and Spatial Development Plans (SDPs) remains limited and requires more attention and strategic assistance from provincial government (DEA, 2016a, Ziervogel *et al.,* 2014).

3.7.10.2 Financial resources

Access to and availability of financial resources dedicated to climate change adaptation planning (e.g. for the development of impact and/or vulnerability assessments) and for the implementation of specific adaptation actions and programs are key determinants of adaptive capacity.

It has been reported in the SARAs Report (2015) that no funding is provided to provincial environmental departments for climate change adaptation planning and development. The report highlights that in particular Limpopo, the Northern Cape, Gauteng, the Free State and Mpumalanga have found it challenging to finance adaptation initiatives. The Western Cape is currently the only province that has a budg*et al.,* located for the provisions of climate change response initiatives through its environmental department (SARAs Report, 2015). However, according to the NAS provincial chapter the funding remains minimal. Several provinces have been able to secure funds through the Green Fund (e.g. the Eastern Cape and KwaZulu-Natal) and some are in the process of developing strategies for accessing international funding options (Urban Earth, 2016). The Western Cape and Gauteng have started to investigate potential climate change response funding options such as green and climate bonds, commercial finance through debt and equity, municipal revenue sources or a carbon tax (Urban Earth, 2016).

The SARAs Report (2015) states that fiscal mechanisms and incentives that would motivate municipalities to mainstream climate change responses are currently missing. According to the DEA M&E Annual report municipalities receive financial support from SALGA, DEA and civil society for mainstreaming climate change adaptation into municipalities (DEA, 2016b). While some of the larger metropolitan municipalities and one district municipality[23] have been able to secure international funding for initiating adaptation activities, small municipalities have almost no direct financial resources for implementation of climate change activities available (Ziervogel *et al.,* 2014). Due to the fact that climate change continues to be framed as an environmental issue rather than a developmental challenge, climate change related responsibilities at the municipal level continue to be referred to as unfunded mandates creating an additional burden for municipalities (Ziervogel *et al.,* 2014; DEA 2016).

3.7.10.3 Human capacity

The importance of having people with the necessary awareness, skills and knowledge available to develop climate change responses, mainstream and implement climate change adaptation interventions, and access larger networks and partnerships is recognised in the NCCRP.

It is recognised that outside the existing national and provincial climate change units/ directorates there is almost no personnel with formal training on climate change (including adaptation) (SARAs Report 2015). This presents an obstacle to mainstreaming climate change considerations into the day-to-day activities of the different departments. It further hampers the ability to access and interpret available climate information, and to develop, prioritize and execute appropriate adaptation interventions. Chapter 5, Section 5.3.3 describes approaches to strengthen climate change education, training and social learning in South Africa and provides an action plan with specific action areas, priority actions and recommendations on who could be involved in each action area.

In addition to sufficient knowledge on climate change and climate change adaptation, government officials responsible for the implementation of concrete adaptation measures need to be equipped with the necessary skills that allow them to make robust decisions in light of uncertainties and with long term climate change in mind. Hence, in particular, learning, systems thinking and

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[23] The uMgungundlovu District Municipality has been able to secure $ 7.5 million for the implementation of the "Building resilience in the Greater uMngeni Catchment, South Africa" Project from the Adaptation Fund.

experimentation needs to be fostered and further enhanced by monitoring and evaluating techniques and systems that help to assess the impact of specific adaptation interventions.

Several studies (Pasquini *et al.,* 2015, DEA, 2016b) have also highlighted the important role that climate change awareness plays for the development of leadership in form of climate change adaptation champions in administrative and political positions. These champions are a vital for getting the necessary buy-in from their home departments, pioneering innovative initiatives, creating collaborative partnerships with the private sector and civil society as well as for connecting to exiting knowledge networks.

3.7.10.4 Research and information

South Africa benefits from having a well-established earth system research program and climate science expertise which is situated across a number of universities and national research institutions (Ziervogel *et al.,* 2014). This expertise has allowed for the development of region and sector-specific climate change scenarios and climate impact assessments, leading to a better understanding of projected climate change impacts. Yet it needs to be noted that a major constraint to climate change impact modelling in South Africa is the lack of a robust national system that provides spatially extensive climate data (Ziervogel *et al.,* 2014). Of particular concern is that national data for hydrology are becoming difficult and costly to obtain (Ziervogel *et al.,* 2014). Another key constraint is that expertise and advice from the science community continues to be sought in an ad hoc manner.

At the national level, sectoral planning has been able to build upon detailed impact modelling and the output from processes such as LTAS. However, at a provincial level it is reported that some provinces require guidance in terms of how to access climate change information relevant for their specific province (SARAs Report, 2015).

At local level, in comparison to district and local municipalities, metropolitan municipalities tend to be better equipped to access and interpret climate related data. Metropolitan municipalities (such as the City of Cape Town) have a strong knowledge base (made up of various universities and consultancies) within or in close proximity to their municipal boundaries (Pasquini *et al.,* 2015). The collaboration goes beyond information provision (free and paid), and extends into various fora and initiatives that foster long-term partnerships and lead to knowledge sharing and capacity building. These forms of partnerships are critical for mainstreaming climate change information into the local scale planning, and therefore need to be extended to local and district municipalities. Provincial and national government should also provide information on existing channels that municipalities can utilize to access relevant climate change data and information.

3.7.10.5 Institutional capacity

At a national level, dedicated departmental climate change units exist in the DAFF, DWS, DST (DEA 2016). Their role is to assist other relevant departmental units on issues of climate change and to mainstream climate change considerations into strategic long term planning.

Key structures for coordinating climate change issues at the national level are the Intergovernmental Committee on Climate Change and the National Committee on Climate Change (DEA 2016).

At a provincial level, currently only the Western Cape Province has a dedicated climate change unit which is situated under the environmental department (DEA 2016). Yet as already discussed in the human capacity section climate change units are critical for capacity building at the municipal level (including technical support). They are also important support structures for other departments and can facilitate better cross-sector integration.

Other important mechanisms for cross-sectoral integration are the provincial climate change forums and strategic working groups. These bring together representatives from various departments and meet at a regular basis to discuss climate change related topics as well as the progress on specific interventions prioritized in the climate change response plans and strategies.

The Eastern Cape, KwaZulu-Natal, Gauteng, the Northern Cape and the Western Cape have established climate change foras (DEA 2016). Whereas in some provinces these fora and working groups are situated with senior management and therefore have influence on strategic decision making processes, other fora lack this influence or are no longer functional (DEA 2016). To improve the coordination and alignment across the three spheres of government more effort needs to be made to share the outcomes of the work of the provincial fora with the fora at national and municipal level. At a local level it was found that the City of Cape Town and eThekwini have dedicated climate change units as well as climate change committees/forums.

3.7.10.6 South Africa’s capacity to adapt

Since the SNC, South Africa has made noticeable progress in creating an enabling environment for climate change adaptation through the development of sector and location specific climate change response plans and strategies. This has been aided by a growing body of climate change research and the establishment of structures and platforms intended to create the necessary institutional capacity for mainstreaming climate change considerations into all spheres of government and for facilitating cross-sectoral integration.

It is essential that if South Africa wants to successfully translate existing and forthcoming climate change response strategies and plans into adaptation action greater attention needs to be paid to strengthening its existing adaptive capacity. All three spheres of government require more resources (in terms of finances, human capacity, access to information and research) and institutional capacities (cross-sectoral climate specific fora and working groups, partnerships and learning possibilities). New skills sets and dedicated climate change personnel are particular important for addressing long term climate change. Until now little practical experience for implementing interventions related to long term climate change exists (with the exception of some interventions focusing on topics such as sea level rise) (Ziervogel *et al.,* 2014). However this will be critical for taking advantage of arising opportunities and for moving South Africa into a climate resilient future. Local governments, who have the primary responsibility for planning and management at the urban and local scale, need to be given more support.

While this capacity assessment tried to identify some of the major constraints that currently prevent South Africa to reach its full potential in the adaptation space, it needs to be noted that strong differences between the provinces as well as among the municipalities exists in terms of available capacities. A more nuanced and systematic investigation needs to be conducted in order to get a better understanding of how the adaptive capacity of specific provinces and municipalities could be strengthened.

3.7.11 Concluding remarks

The review presented in this section of the chapter highlights that an enabling environment for climate change governance has been created at the national and to a certain extent at the provincial level through the establishment of sectoral and provincial climate change response strategies respectively. Whilst the country has made progress, there are still gaps that exist around financial resources, capacity and research. Specifically, dedicated financial resources for climate change adaptation planning and implementation are needed at a provincial and local government level, with guidance needed on how to access international and national funds available to them. Other critical knowledge gaps highlighted in previous studies (e.g. Ziervogel *et al.,* 2014) relate to the need for cross-sectoral approaches and integrated assessments. These are vital for creating a better understanding cross-sectoral linkages and regional/landscape vulnerabilities, and for developing adaptation measures that are of benefit to various sectors and communities.

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Appendix B1

B1.1 On the quality of weather station data in South Africa

Error! Reference source not found.B.1a and B.1b below describe the availability of station records of daily rainfall across the country from 1960 to 2012, as well as the percentage of stations with valid (e.g. quality-confirmed) data through time. It shows how station density increased consistently from the start of the 20th century and peaked in the 1980s, after which it began to decline quite drastically. The result is that for analysis spanning several decades, there are relatively few stations available that consistently have data available through the whole period.

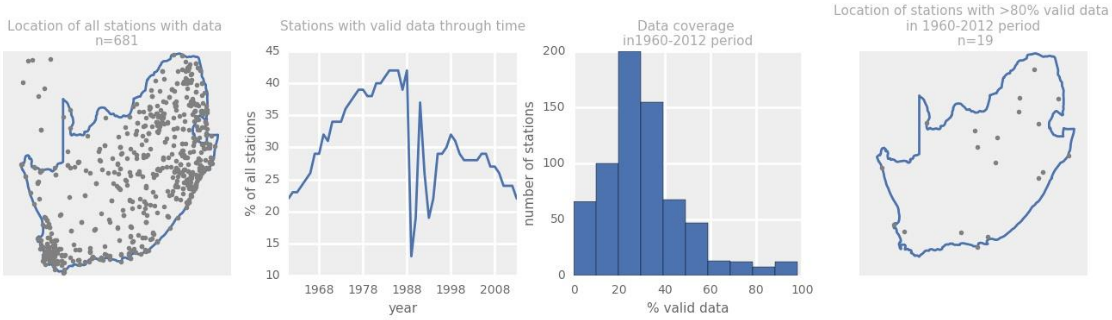


Figure B.1a: Analysis of station data availability for temperature observations (**maximum daily temperature**) **across South Africa for the period 1960-2012**

MacKellar *et al.,* (2014) used the period 1960 to 2010 to calculate trends in various climate statistics. This work presented here considers the slightly longer period of 1960 to 2015.

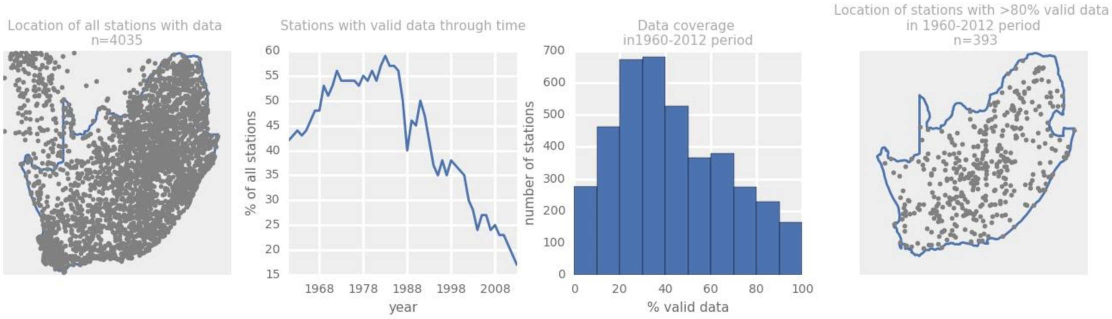


Figure B.1b: Analysis of station data availability for rainfall observations across South Africa in 1960-2012

B1.2 Homogenised near-surface temperature time series data

Given the challenges that natural climate variability and heterogeneity in station data pose to the analysis of climate trends over South Africa, the South African Weather Service (SAWS) has in recent years initiated a project to increase the period over which a reliable analysis of temperature trends over South Africa can be obtained. The length of period was initially determined by the minimum number of stations to be deemed sufficient to define temperature variability over South Africa to a reasonable degree. Guidelines developed by Vose and Menne (2004) and Jones and Trewin (2002), translated to the surface area of South Africa, recommends a network of a minimum of 20 stations to provide an adequate idea of the countrywide historical trends in the climate. However, South Africa exhibits a relatively complex climate across its surface area compared to the cases considered by Vose and Menne (2004) and Jones and Trewin (2002), and it may be argued that more than 20 stations are required. Consequently, the earliest decade that could be selected to obtain an adequate number of stations (almost 30) with time series up to the present, but which would require a homogenisation procedure, was the 1930s.

The complete approach, methodology and results can be found in Kruger and Nxumalo (2016), but briefly summarized below. The homogenisation procedure utilized is called the RHtestsv4, developed under the auspices of the WMO ETCCDI. Assessments of the quality, completeness and, thereafter, the homogenisation process, produced a set of time series for 27 climate stations. The locations of these stations are presented in Figure B.2. It is noted that after the mentioned procedures not all stations had reliable data available back to initial selected date of 1931, but could still be deemed to reflect the general trends for the 1931 to 2015 period. Further station details, including the period of validity of analysis for each station, are presented in Table 3B.1.

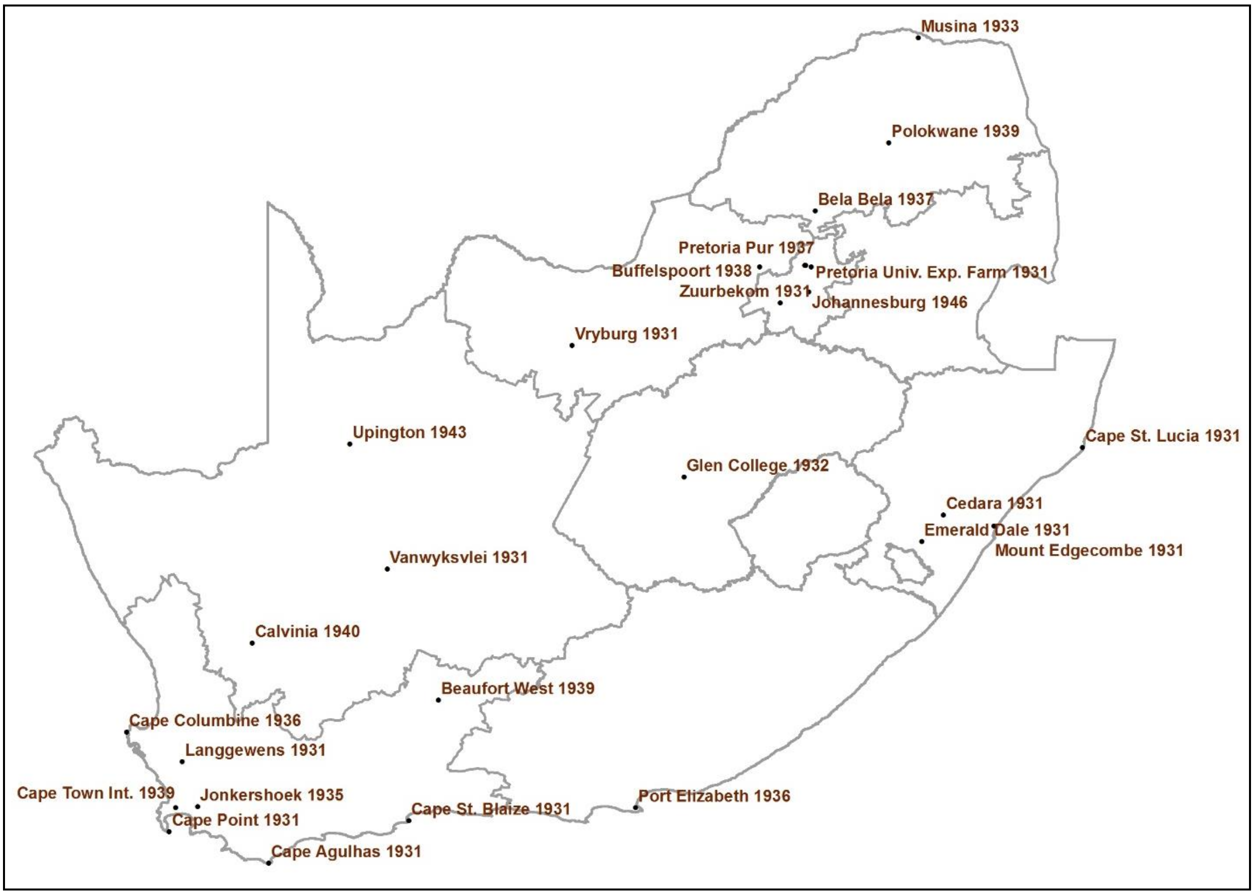


Figure B.2: Climate stations utilized in the homogeneous surface temperature trend analysis of SAWS, with starting dates of analysis (**Kruger and Nxumalo, 2016**)

Table B.1: Long-term climate stations used in the analysis of temperature trends for the period 1931-2015 (**Kruger and Nxumalo, 2016**)

Climate Station	**Approximate Latitude** (°)	**Approximate Longitude** (°)	**Approximate height** (**m**)	**Start year**
Cape Agulhas	-34.83	20.02	8	1931
Cape Point	-34.35	18.50	208 – 227	1931
Cape St. Blaize	-34.18	22.15	60 – 76	1931
Cape Town International	-33.98	18.60	42 – 46	1939
Jonkershoek	-33.97	18.93	244 – 350	1935
Port Elizabeth	-33.98	25.60	59 – 60	1936
Langgewens	-33.28	18.70	175	1931
Cape Columbine	-32.83	17.85	63	1936
Beaufort West	-32.35	22.60	857 – 902	1939
Calvinia	-31.48	19.77	975 – 980	1940
Vanwyksvlei	-30.35	21.82	962	1931
Emerald Dale	-29.93	29.95	1189	1931

Climate Station	**Approximate Latitude (°)**	**Approximate Longitude (°)**	**Approximate height (m)**	**Start year**
Cedara	-29.53	30.28	1076	1931
Mount Edgecombe	-29.70	31.05	91	1931
Glen College	-28.95	26.33	1304	1932
Upington	-28.45	21.25	793 – 841	1943
Cape St. Lucia	-28.50	32.40	3 – 107	1931
Vryburg	-26.95	24.63	1234	1931
Zuurbekom	-26.30	27.80	1578	1931
Johannesburg	-26.13	28.23	1676 – 1695	1946
Buffelspoort	-25.75	27.48	1230	1938
Pretoria Pur	-25.73	28.17	1286	1937
Pretoria	-25.73	28.18	1300 – 1330	1939
Pretoria University Exp. Farm	-25.75	28.27	1372	1931
Bela Bela	-24.90	28.33	1143	1937
Polokwane	-23.87	29.45	1230 – 1311	1939
Musina	-22.27	29.90	525	1933

B1.3 Rainfall time series data

The 1921-2015 rainfall trend analysis presented in the TNC is based on the time series of 60 individual rainfall stations of SAWS. These stations were selected on the basis of having the most complete record in each of the 94 SAWS homogeneous rainfall districts. In addition the selected stations, presented in Table 3B2, have at most 10% of the data record missing over the analysis period. It should be noted that this data availability was based on the availability of daily rainfall totals, which excludes rainfall accumulations, a common occurrence in the case of voluntary rainfall stations (especially those in remote areas such as plantations). While some data comparisons were done among neighbouring rainfall stations, no formal homogenisation process was applied. The latter process requires a relatively dense network of stations with long-term records, which in most regions in South Africa does not exist.

Table 3B2: Long-term climate stations used in the analysis of rainfall trends for the period 1921-2015.

Rainfall station	**Applicable SAWS rainfall district number**	**Approximate Latitude** (°)	**Approximate Longitude** (°)
STEINKOPF	1	-29.27	17.74
NIEUWOUDTVILLE SAPD	2	-31.37	19.12
PIKETBERG-SAPD	3	-32.91	18.75
VRUGBAAR	4	-33.63	19.04
REENEN	5	-32.11	19.51
CALITZDORP – POL	8	-33.53	21.69
PRINCE ALBERT – TNK	9	-33.22	22.03
ROOIRIVIER	10	-33.55	22.82
STEYTLERVILLE – MAG	12	-33.33	24.34
MERWEVILLE – POL	16	-32.66	21.52
RONDAWEL	17	-33.20	22.66
SAAIFONTEIN	19	-31.72	21.88
KAMFERSKRAAL	20	-32.24	23.05
KENDREW ESTATES	21	-32.52	24.48
ALBERTVALE-FRM	22	-32.74	26.01
DURBAN - BOTANICAL GARDENS	25	-29.85	31.01
GINGINDHLOVU	26	-29.03	31.57
EXWELL PARK	27	-32.21	27.10

Rainfall station	**Applicable SAWS rainfall district number**	**Approximate Latitude** (°)	**Approximate Longitude** (°)
NKOBONGO	28	-31.87	28.04
CEDARA	30	-29.54	30.27
MAHLABATINI	31	-28.24	31.46
SKUKUZA	33	-24.99	31.59
CARNARVON - POL	38	-30.97	22.13
RICHMOND C/K - TNK	39	-31.42	23.94
TAFELBERG HALL	41	-31.56	25.19
DORDRECHT CLARKS SIDING	42	-31.41	27.12
MOORSIDE	44	-28.40	29.61
TAFELKOPPIES	46	-26.88	30.62
ALKMAAR	47	-25.45	30.82
HANGLIP	50	-23.02	29.92
THORNLEA	52	-28.63	21.52
MARYDALE - POL	53	-29.41	22.11
LEKKERVLEI	54	-31.05	23.60
GRAPEVALE	55	-31.15	25.23
BURGERSDORP - POL	56	-31.00	26.33
MIDDELPLAATS	57	-30.45	26.87
WARDEN SKOOLSTRAAT	60	-27.85	28.96
DE EMIGRATIE	62	-26.77	30.10
KALKFONTEIN	64	-23.90	29.58
NIEKERKSHOOP - POL	68	-29.33	22.84
REDDERSBURG - POL	70	-29.65	26.17
CYFERFONTEIN	71	-29.80	26.52
WESTMINSTER ESTATE	72	-29.16	27.17
DRIEFONTEIN	73	-27.44	28.00
JOHANNESBURG-ZOOLOGICAL GARDNS	74	-26.17	28.04
WITBANK STREHLA	75	-26.21	28.91
NYLSVLEY	76	-24.65	28.67
VILLA NORA-POL	77	-23.53	28.13
HOPKINS	79	-27.71	22.70
EUREKA	81	-29.08	24.48
MASELSPOORT DAM	82	-29.03	26.41
VENTERSBURG - MAG	83	-28.09	27.14
OTTOSDAL - POL	84	-26.81	26.00
SWARTRUGGENS - POL	85	-25.65	26.69

Rainfall station	**Applicable SAWS rainfall district number**	**Approximate Latitude** (°)	**Approximate Longitude** (°)
RANKINS PASS-POL	86	-24.53	27.91
VRYBURG PALMYRA	89	-26.27	24.18
VRYBURG WELGELEVEN	90	-26.76	24.58
SLURRY	92	-25.81	25.85
TUSCANY	93	-25.24	26.18
RIETFONTEIN SAPS	94	-26.74	20.03

B1.4 Testing for statistical significance

For the extended LTAS (2013) analysis presented in the TNC, temporal trends in climate statistics were assessed using the Mann-Kendall Tau statistic (Mann, 1945; Helsel & Hirsch, 1992), and the associated test for its statistical significance. Mann-Kendall Tau and its significance level express the strength of a monotonic trend, but do not reflect trend magnitude in the measured variable units (or in other words its slope). In order to provide the latter, Theil-Sen (Theil, 1950; Sen, 1968) slope was calculated. Theil-Sen slope is a linear (uniform) slope that is compatible with the assumptions of Mann-Kendall test.

The adopted trend indices (Tau and Theil-Sen slope) are more robust than the traditional linear trend in that they are not sensitive to outliers in data, are less sensitive to the exact shape of the trend, and their uncertainty is not influenced by whether the data distribution follows or not the normal distribution. The adopted indices are, therefore, ultimately more powerful in distinguishing spurious from real trends.

An additional aspect considered in trends analysis is the presence of serial correlation in data. Climate data, due to the nature of underlying climate processes often display temporal persistence, even at inter-annual time scale. The presence of such persistence (or serial correlation) does not affect the magnitude of an eventual trend, but affects strongly its significance (increases it if there is a positive serial correlation in data, and decreases it if the correlation is negative). Tests for the presence of serial correlation in climate data were carried using Durbin-Watson statistic (Durbin and Watson, 1950). It appears that, for example in rainfall, there is a significant serial correlation during the peak rainy season months, both in the summer and winter rainfall zone. On the annual basis, virtually all analysed stations display significant positive autocorrelation for total annual rainfall and first order temperature indices.

The procedure of stationary bootstrapping (block bootstrapping with randomized block length) (Effron and Tibshirani, 1993; Wilks, 2011) was used to calculate significance levels of trends accounting for autocorrelation in data. Since this procedure does not affect attained significance levels when data are not serially correlated, it was applied to all station data, not just these that displayed serial correlation. The trend significance was calculated for each index/station as a percentile of distribution of Tau obtained from a 1000 block-bootstrap re-samplings of data. The significance of the trend was expressed as a two-tailed p-value. While interpreting the results, a p- value of 0.05 was considered as a threshold of significance.

For the extended SAWS trend analysis, the determination of trend significance was based on the statistical test employed by the WMO ETCCDI RClimDex software, which was employed in the index calculations. The statistical significance of the linear trends of the indices was evaluated by the *t*-test at the 5% level.

B1.5 Supporting results on the analysis of temperature trends over South Africa

B1.5.1 Average temperature

SAWS reports on an annual basis the results of the long-term trends in the annual mean temperatures of a group of South African climate stations to the *Annual State of the Climate* reports, published on an annual basis by the *Bulletin of the American Meteorological Society*. Figure B.3 presents the latest results, for the period 1951 – 2015, utilizing stations of which at least 80 % had sufficient data for a particular year, throughout the period. It is shown that, for these particular stations, the trend in annual mean temperatures is approximately 1.4°C per century. The year 2015 was by far the hottest, reflecting the general global situation in 2015, which the WMO declared the hottest year ever since the instrumental measurement era began.

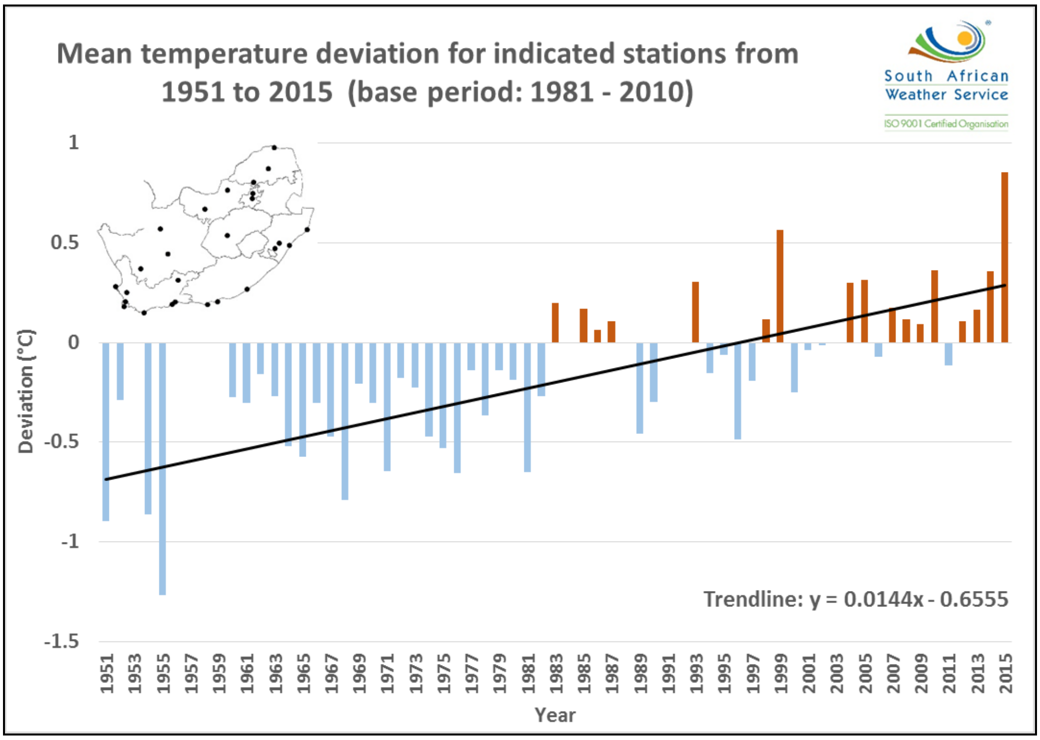
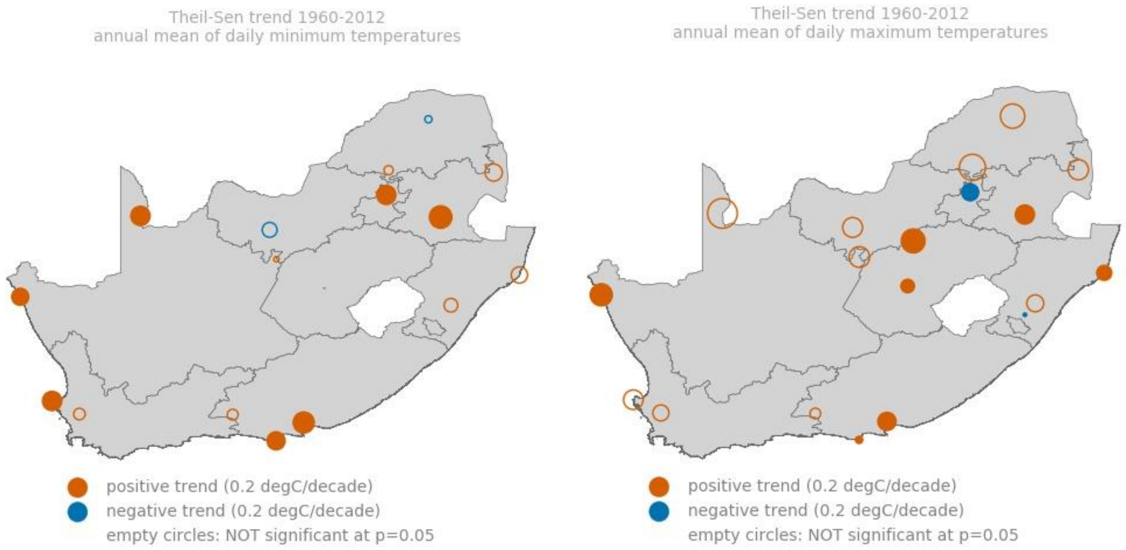


Figure B.3: Annual mean temperature anomalies for 26 climate stations, with positions indicated in the map, in °C, for the period 1951 – 2015 (**State of the Climate 2015, 2016**)

B1.5.2 Minimum and maximum temperature

The trend analysis performed for the period 1951-2015 on the extended LTAS (2013) data set is largely consistent with that obtained for the homogeneous station data of SAWS (Section 3.2.2.2) and is presented in Figure B.4). Exceptions are the relatively large trends in minimum temperature recorded over the central interior, negative trends in minimum temperature recorded over Gauteng, and insignificant trends in minimum and maximum temperatures recorded over Limpopo. It is possible that these inconsistencies in the analysis may be attributed by the heterogeneous nature of the time-series analyzed.



Theil-Sen trend 1960-2012
annual mean of daily minimum temperatures

Theil-Sen trend 1960-2012
annual mean of daily maximum temperatures

Figure B.4: Theil-Sen trends in annual mean of daily maximum and daily minimum temperatures, in the 1960-2015 period (symbols scale by area)

B1.6 Supporting results on the analysis of rainfall trends over South Africa

B1.6.1 Rainfall totals

In the analysis of the extended LTAS data set for 1960-2015, the positive trends in rainfall over the central interior extends westwards to the Western Cape, with statistical significant trends identified over much larger areas than in the SAWS analysis for 1921-2015 (Figure B.5). These differences may be partially attributable to the shorter period of analysis , which is more susceptible to impacts of decadal variability on the trends identified.

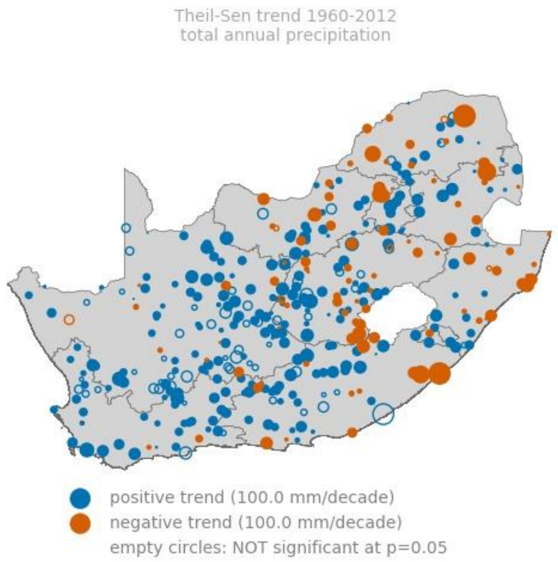


Figure B.5: Theil-Sen trends in total annual rainfall, in the 1960-2015 period

B1.6.2 Extreme rainfall events

Figures 3.B.6 and 3.B.7 show changes in the magnitude of the 95th and 99th percentile of daily rainfall events, respectively, as calculated for the extended LTAS (2013) data set for the period 1960-2015. The observed trends are mostly positive across the country, consistent with the SAWS analysis presented in Figures 3.9 and Figures 3.10 for related metrics.

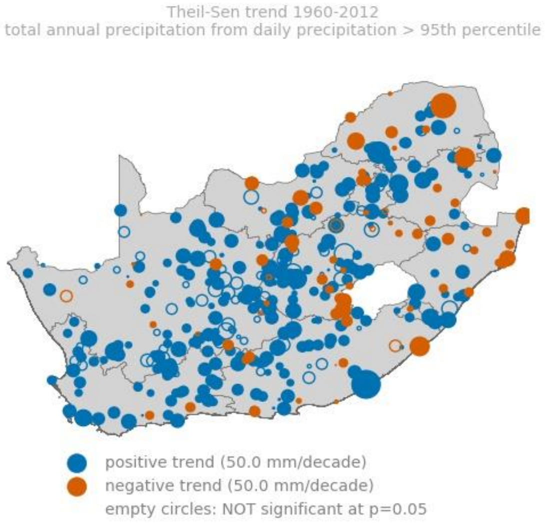


Figure 3.B.6: Theil-Sen trends in 95th percentile of annual precipitation

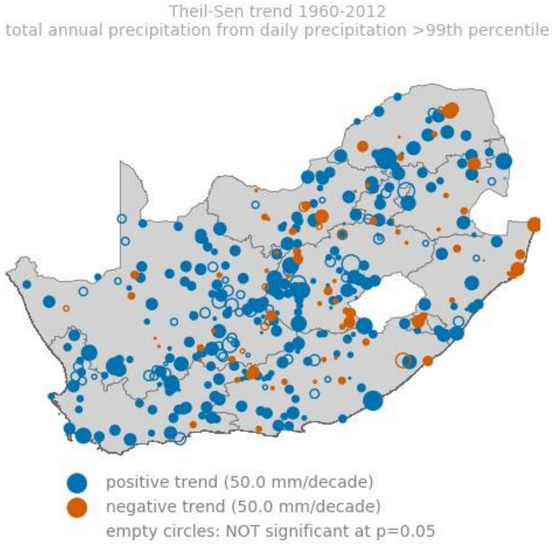


Figure 3.B.7: Theil-Sen trends in 99th percentile of annual precipitation

Analysis of the extended LTAS (2013) data set (Figure B.8) is indicative of wide-spread positive trends, consistent with the analysis of the longer time-series SAWS data (Figure 3.11).

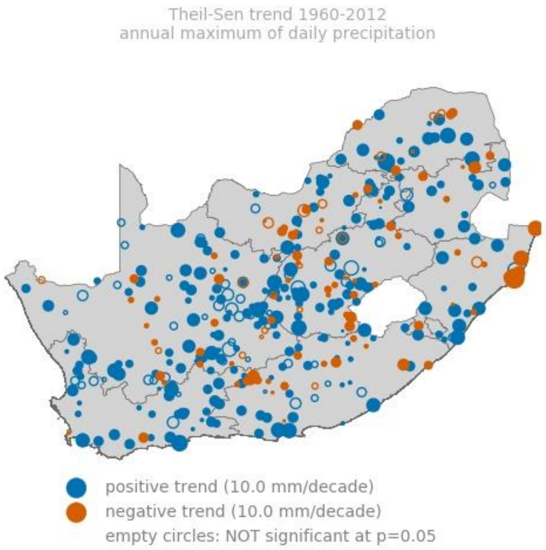


Figure B.8: Theil-Sen trends in the annual maximum of daily precipitation over the 1960-2015 period

Figure B.9, based on the extended LTAS (2013) analysis, provides confirmation of the average amounts of rainfall calculated on days with precipitation only have been increasing across the western and central parts of South Africa, consistent with the analysis of the SAWS data (Figure 3.16).

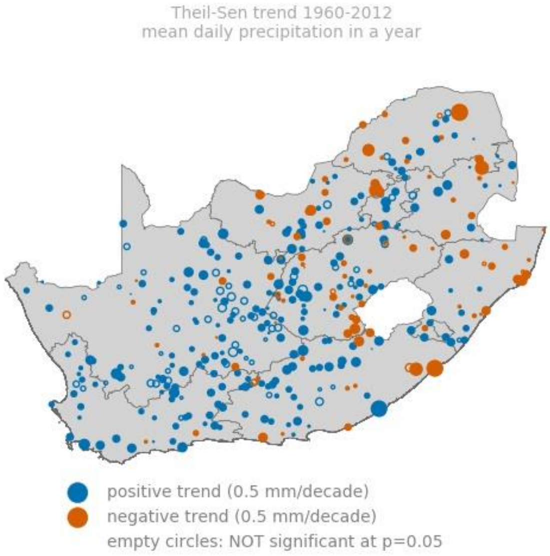


Figure B.9: Theil-Sen trends in the annual mean of daily precipitation over the 1960-2015 period

Appendix B2

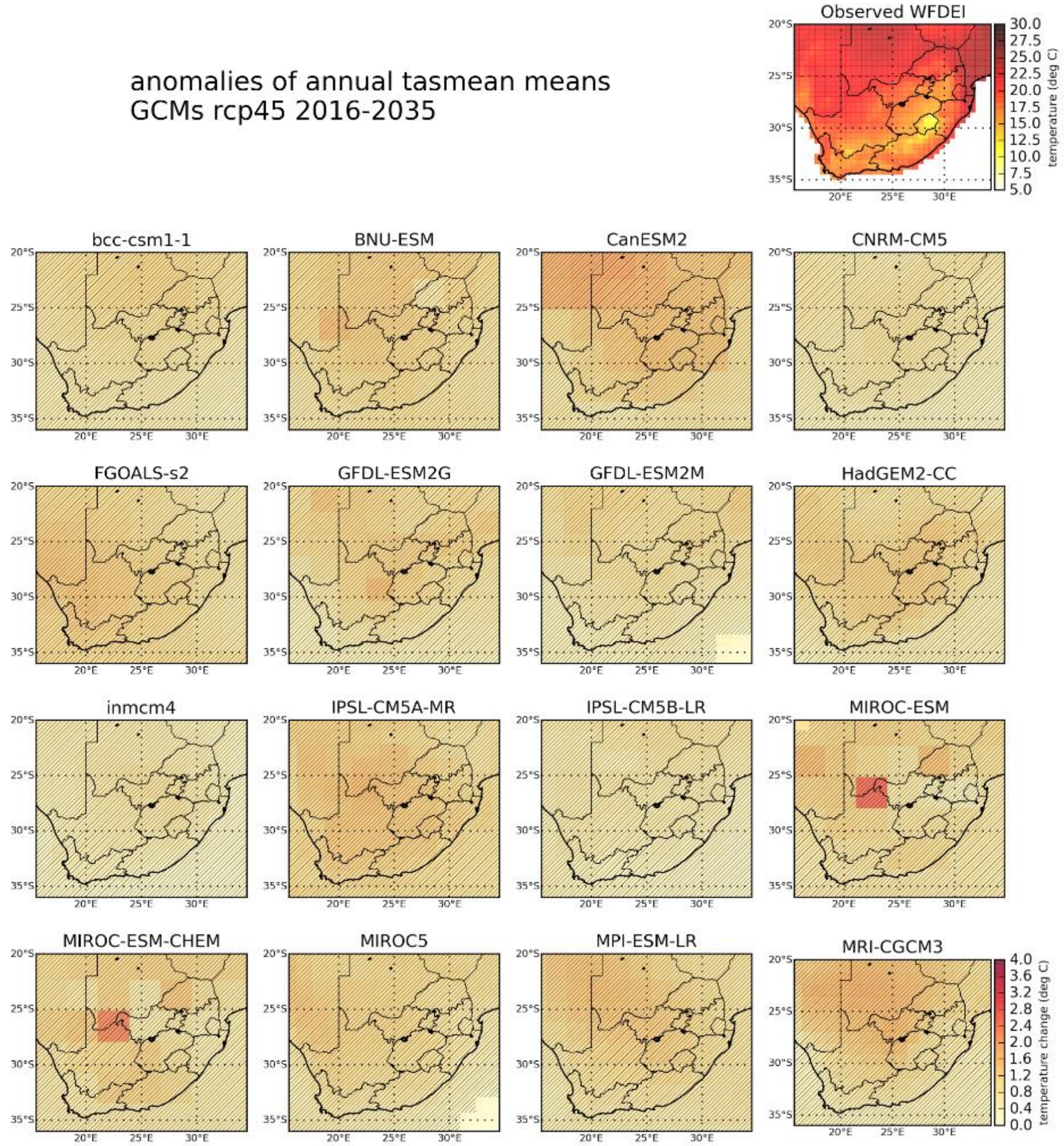


Figure B.10a: GCM projected changes of annual mean temperature under the RCP 4.5 pathway for the 2016-2035 period.

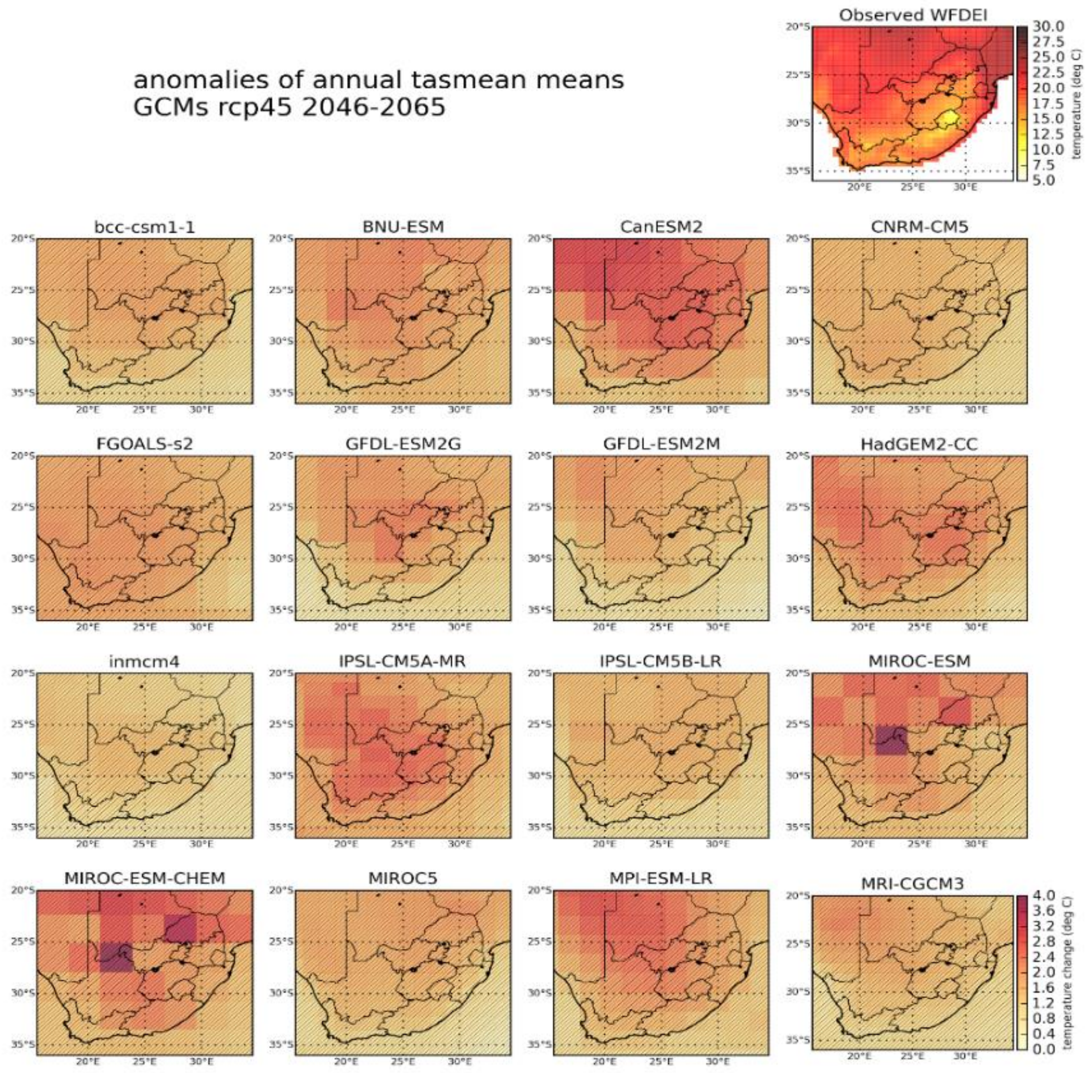


Figure B.10b: GCM projected changes of annual mean temperature under the RCP 4.5 pathway for the 2046-2065 period

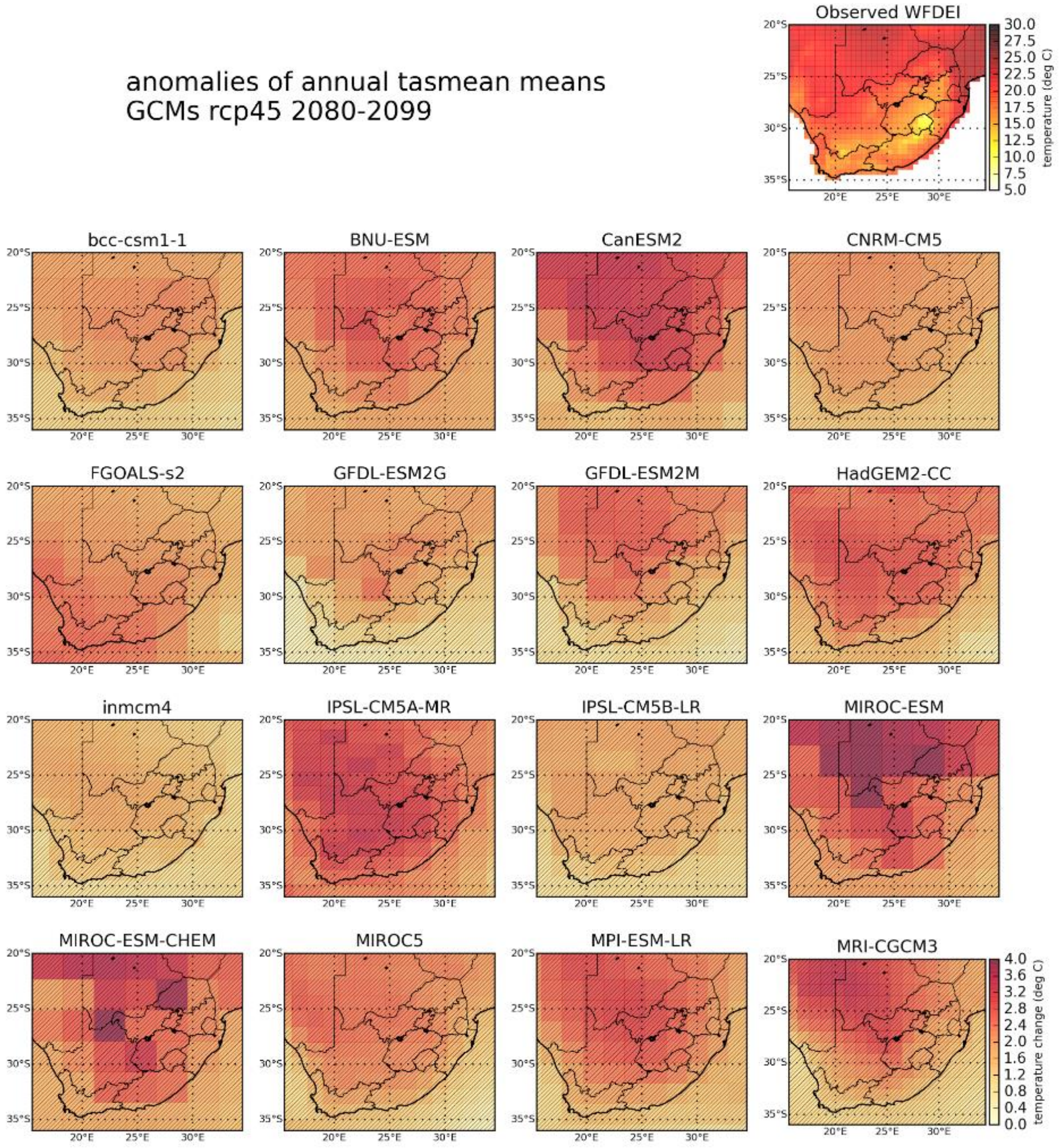


Figure B.10c: GCM projected changes of annual mean temperature under the RCP 4.5 pathway for the 2080-2099 period.

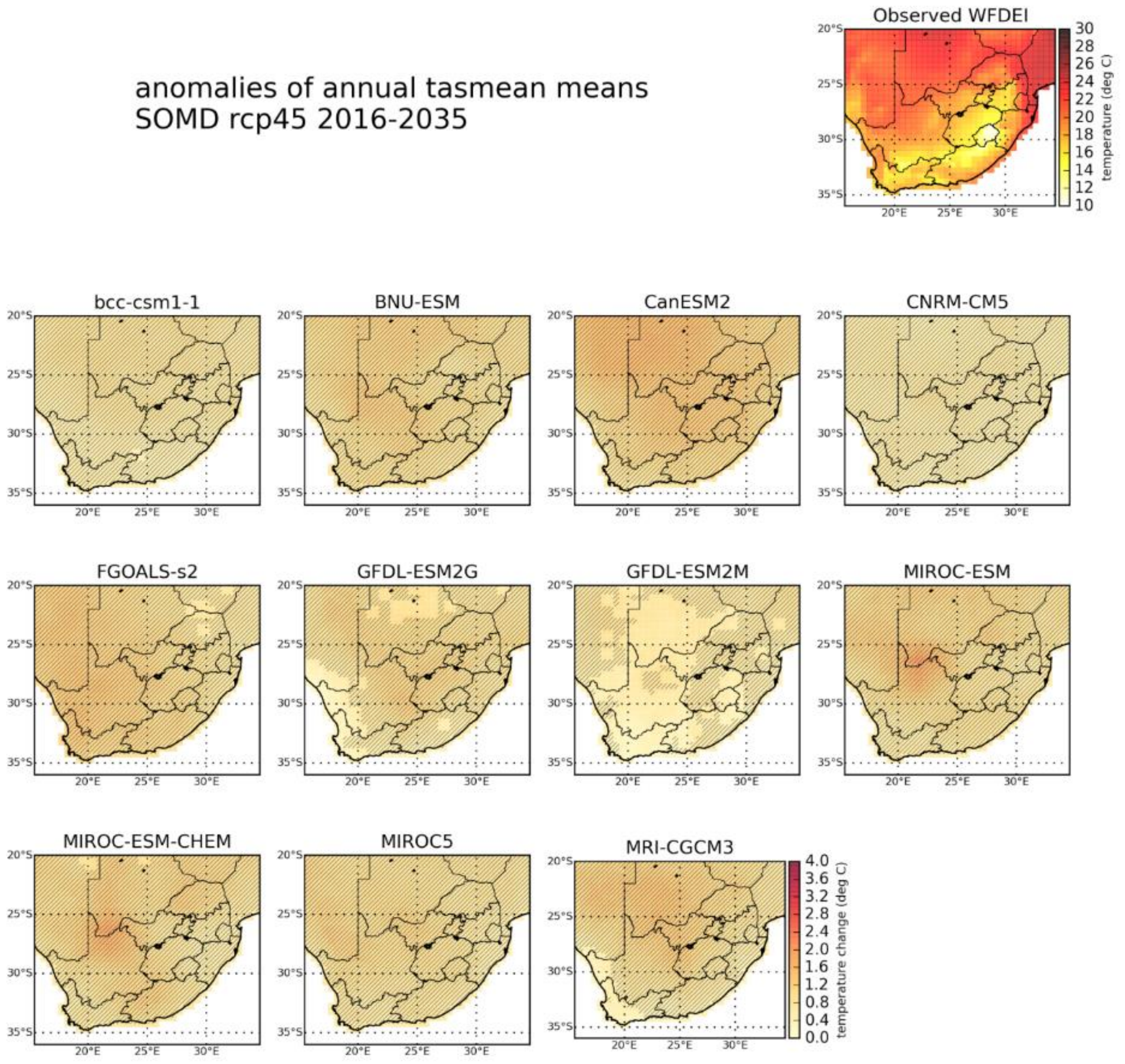


Figure B.11a: Statistically downscaled projected changes in annual mean temperature under RCP 4.5 for the 2016-2035 period

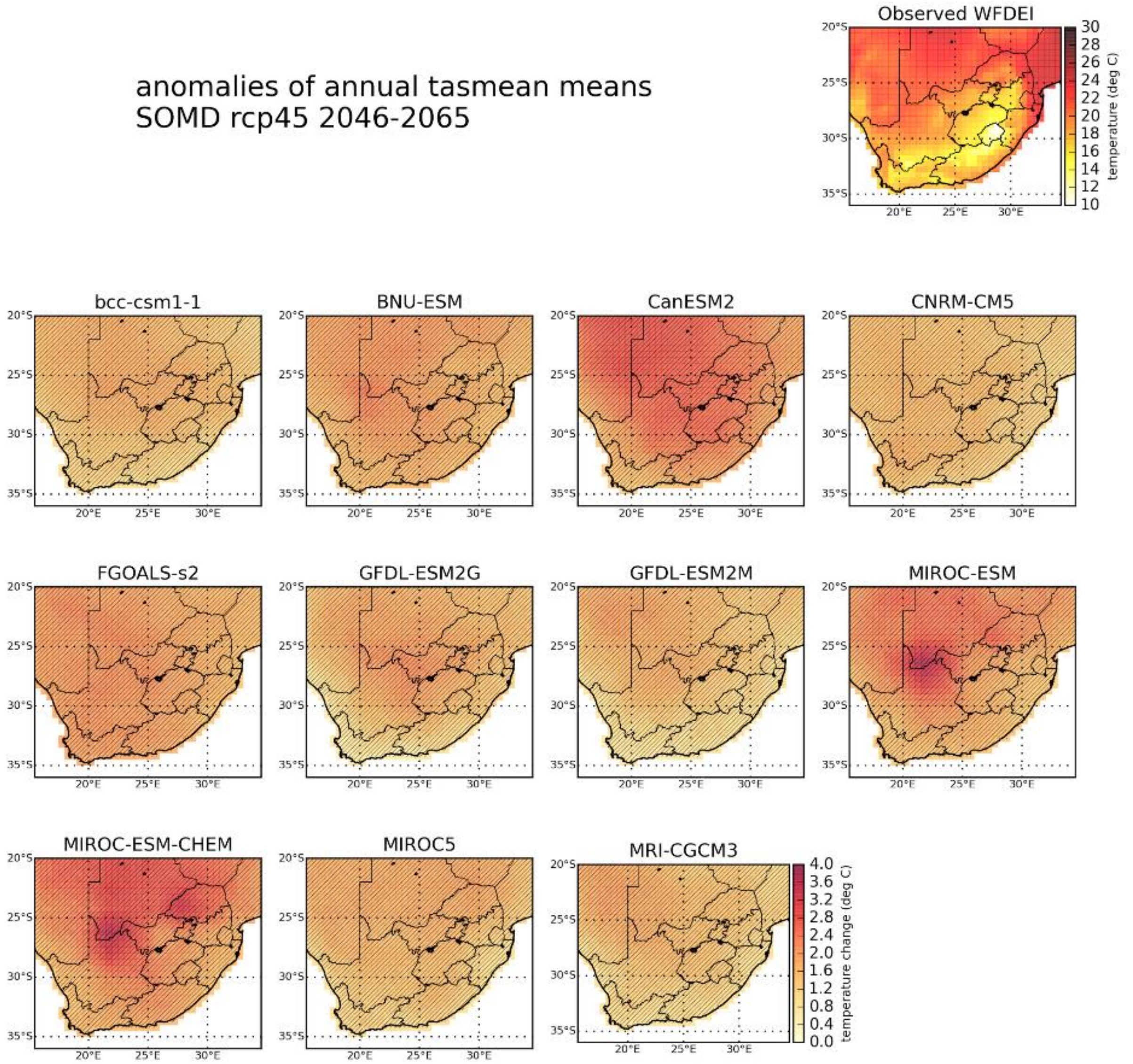


Figure B.11b: Statistically downscaled projected changes in annual mean temperature under RCP 4.5 for the 2046-2065 period.

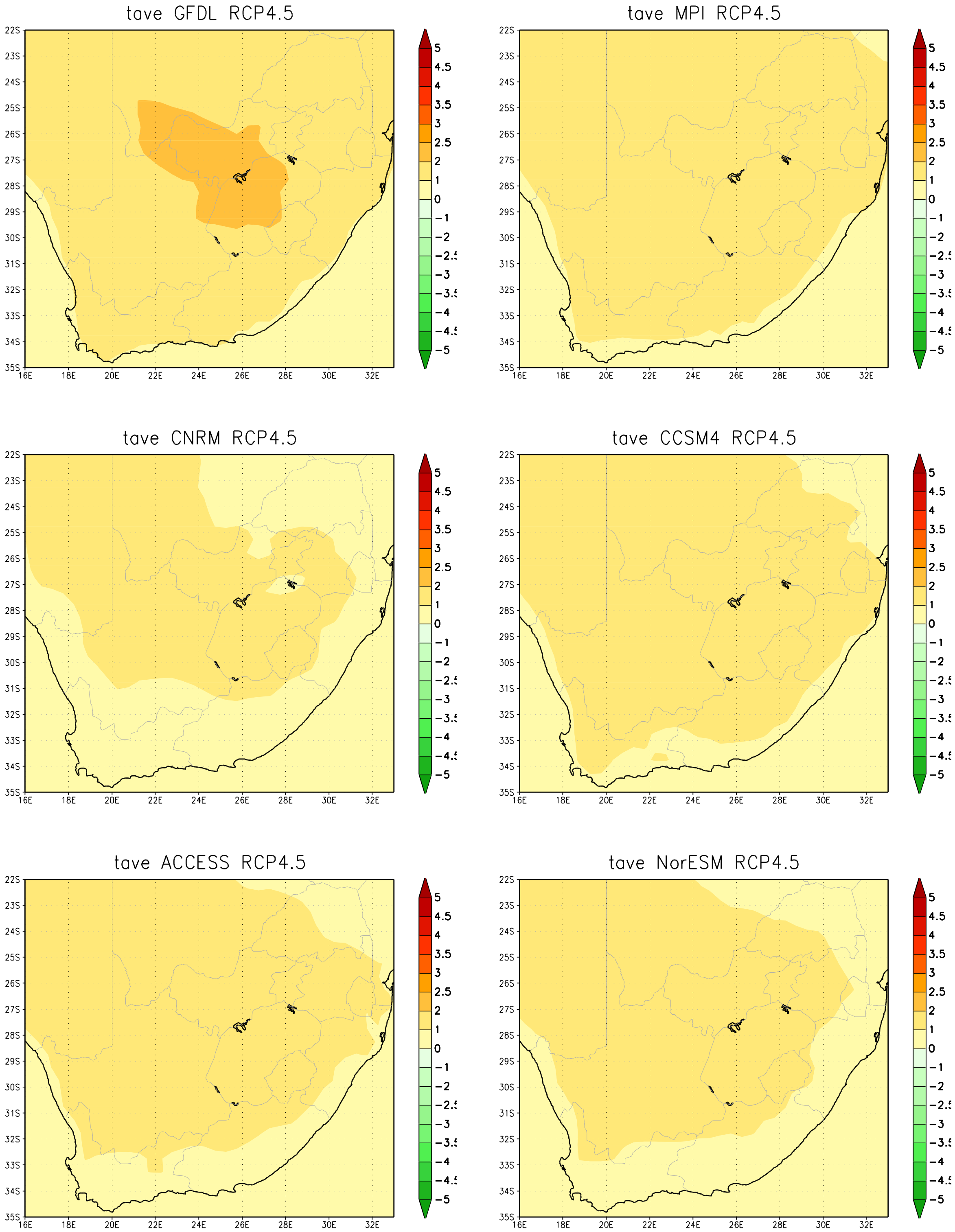


Figure B.12a: CCAM dynamically downscaled projected changes in annual mean temperature under RCP 4.5 for the 2016-2035 period.

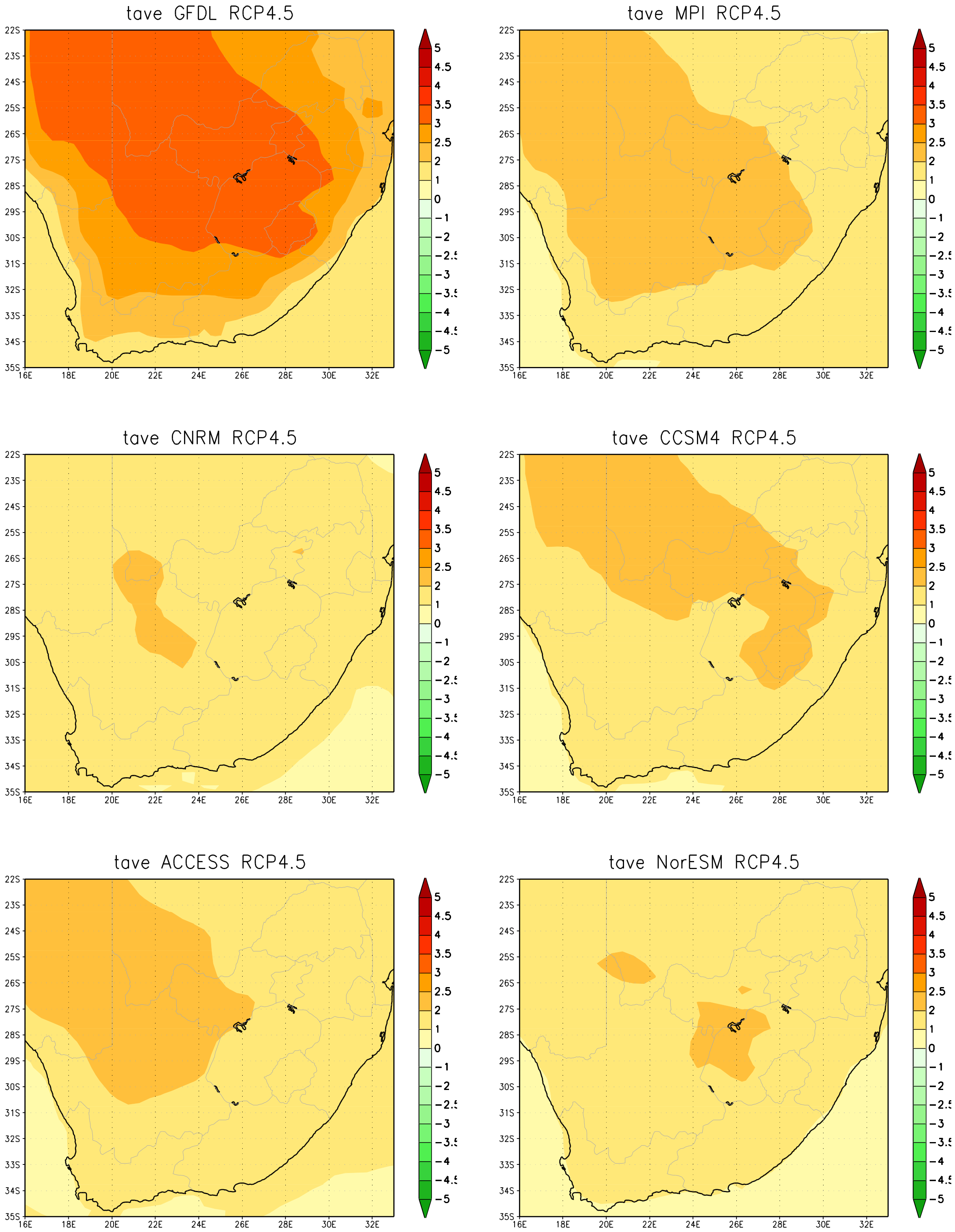


Figure B.12b: CCAM dynamically downscaled projected changes in annual mean temperature under RCP 4.5 for the 2046-2065 period.

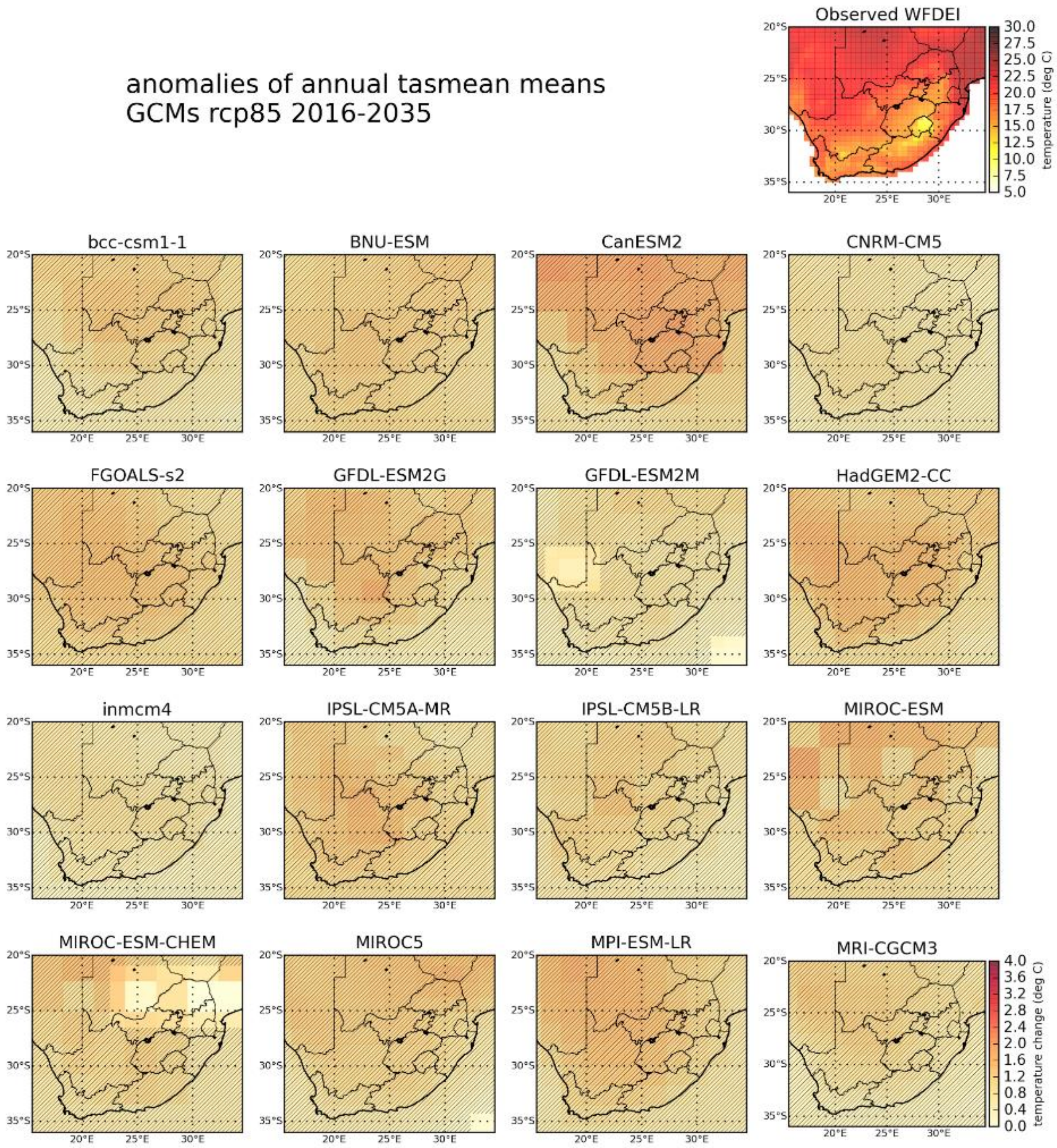


Figure B.13a: GCM-projected changes of annual mean temperature under the RCP 8.5 pathway for the 2016-2035 period.

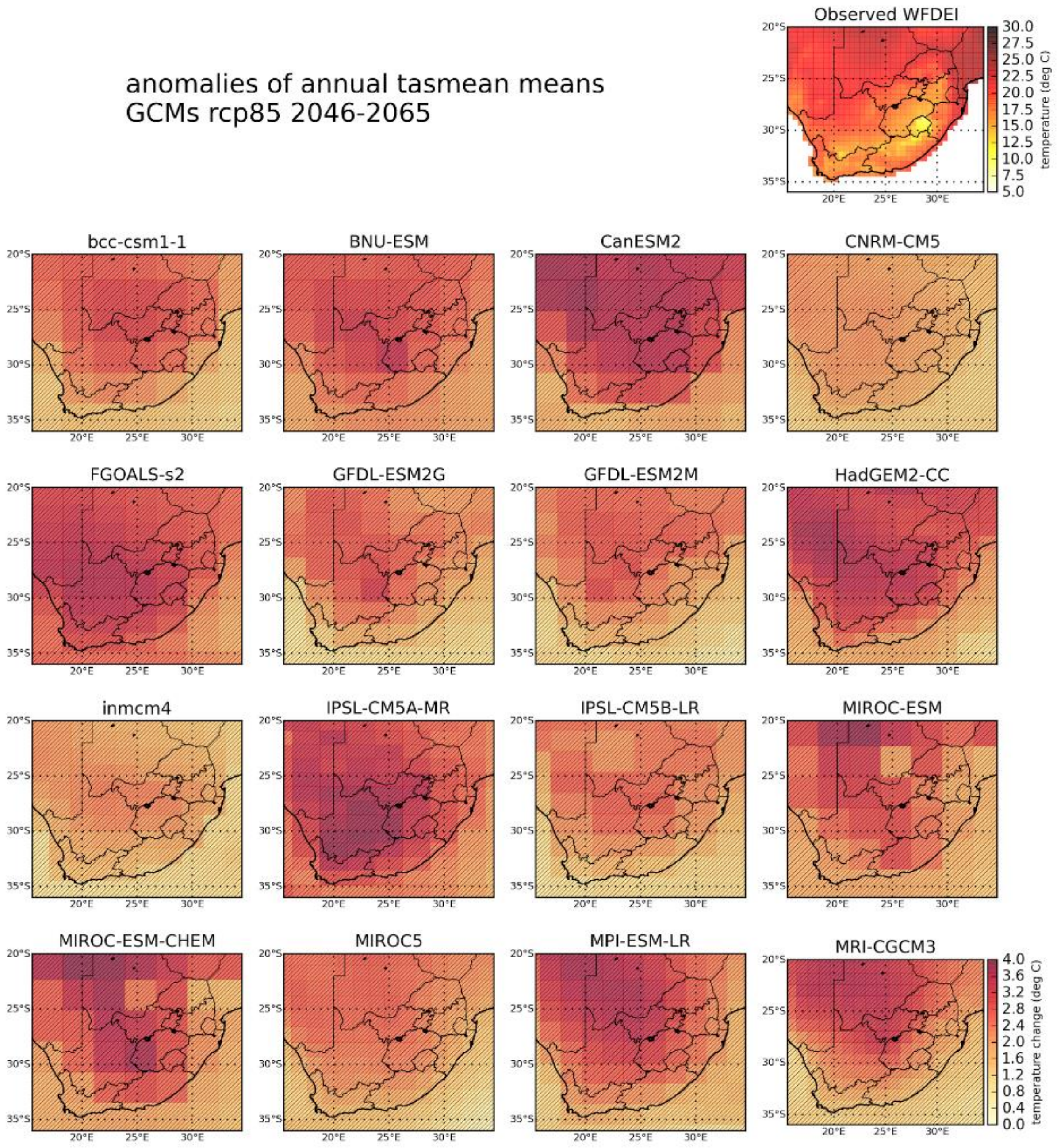


Figure B.13b: GCM-projected changes of annual mean temperature under the RCP 8.5 pathway for the 2040-2060 period.

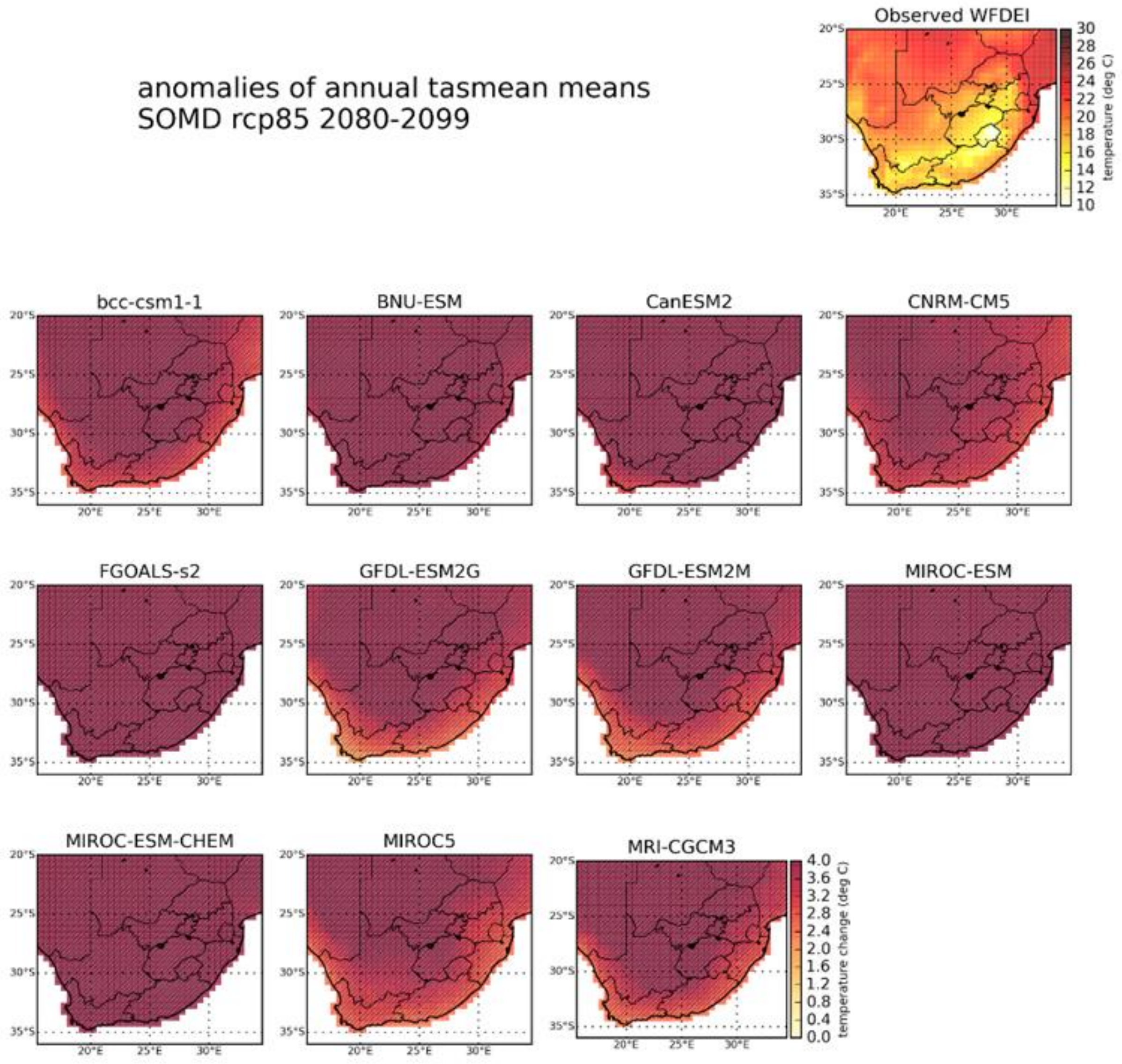


Figure B.13c: GCM-projected changes of annual mean temperature under the RCP 8.5 pathway for the 2080-2099 period.

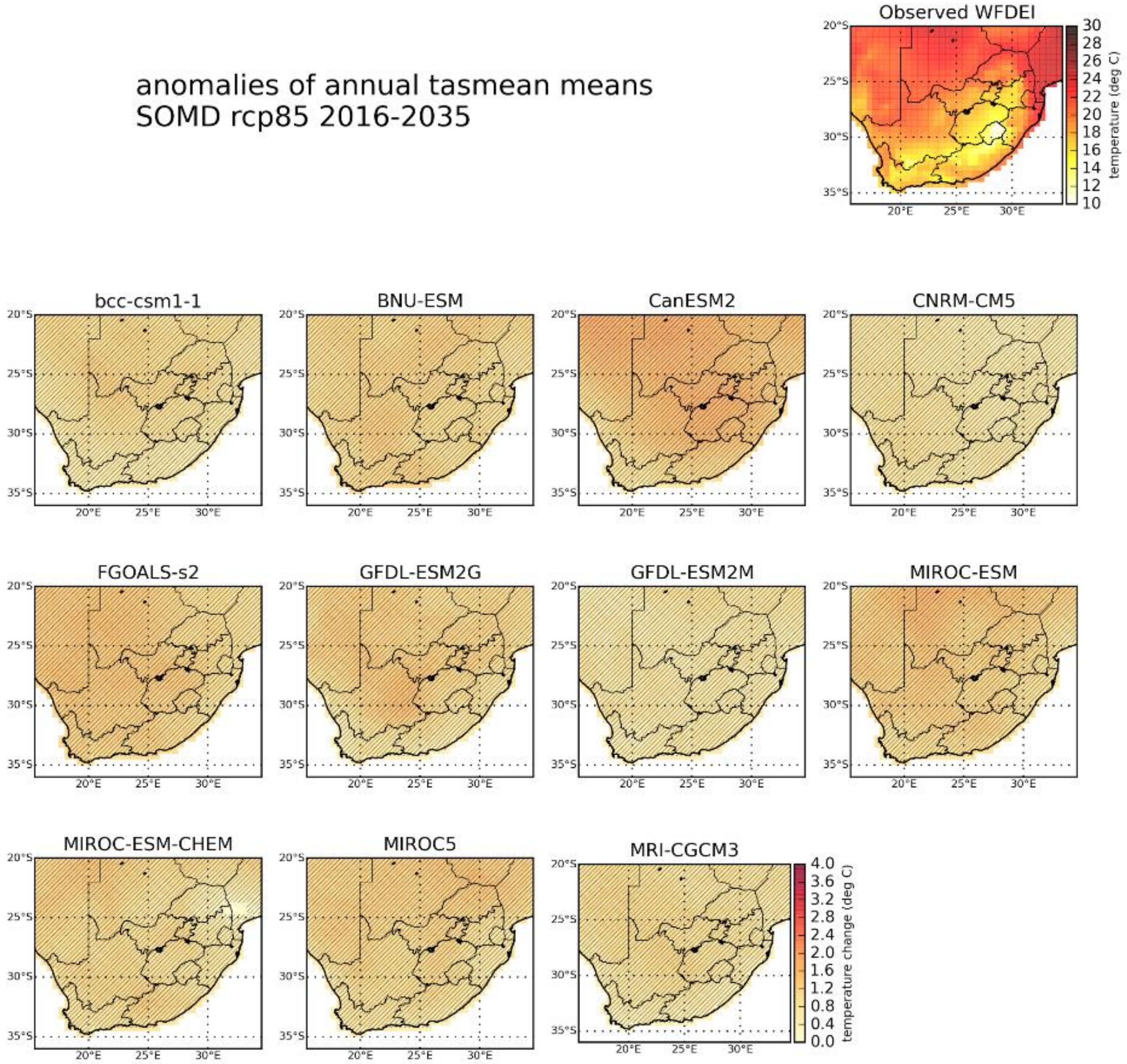


Figure B.14a: Downscaled projected changes in annual mean temperature under RCP 8.5 for the 2016-2035 period

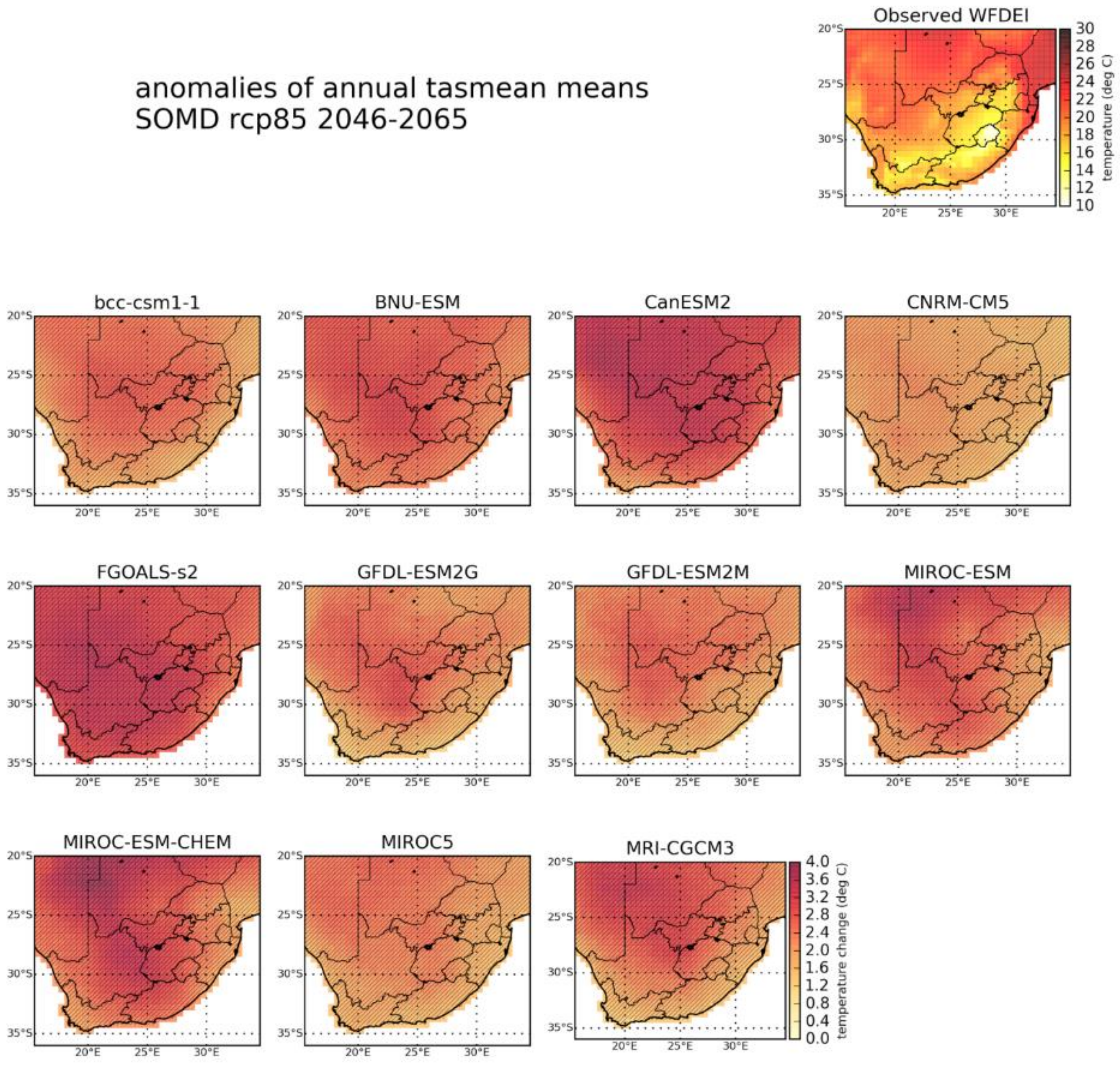


Figure B.14b: Downscaled projected changes in annual mean temperature under RCP 8.5 for the 2046-2065 period.

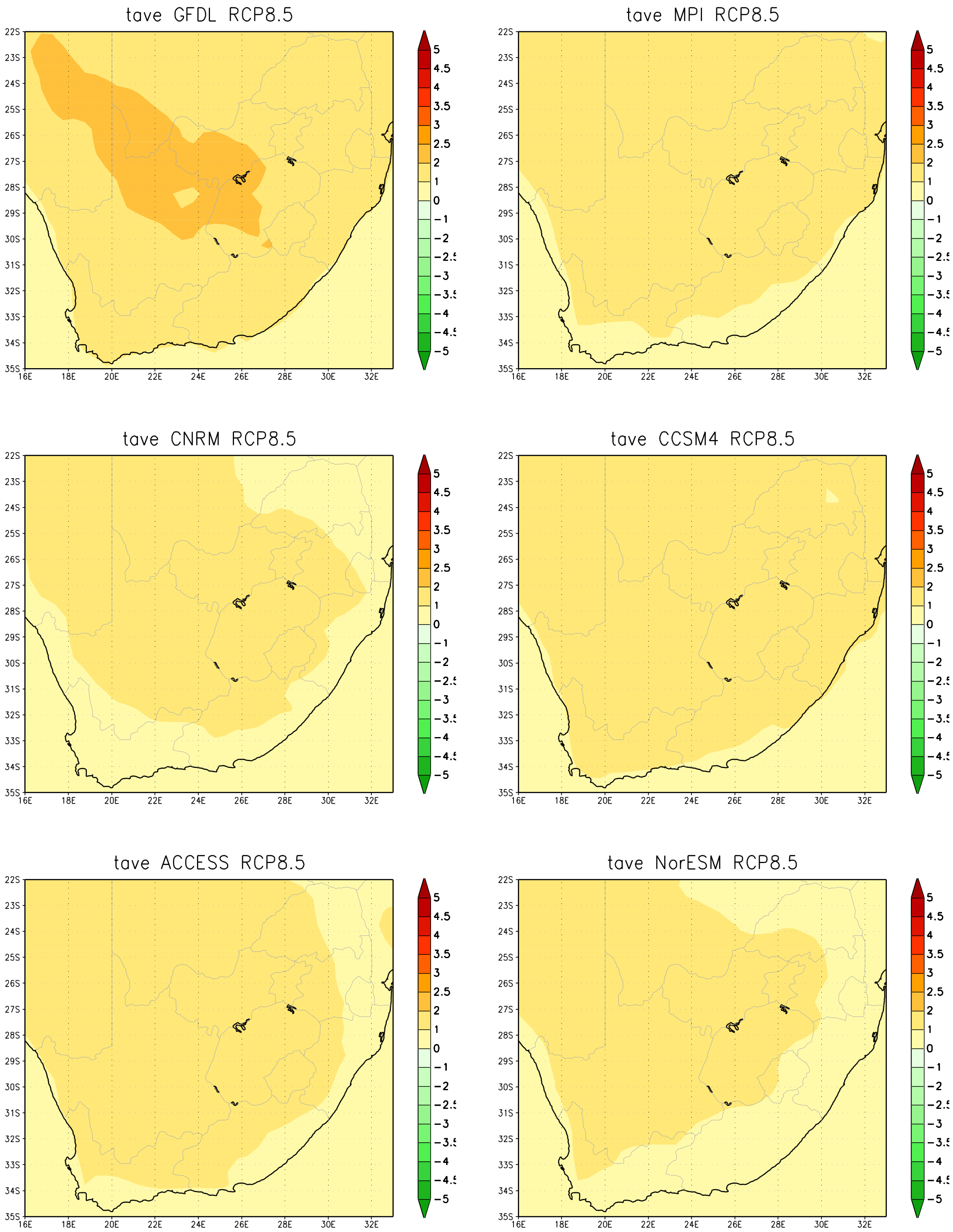


Figure B.15a: CCAM dynamically downscaled projected changes in annual mean temperature under RCP 8.5 for the 2016-2035 period.

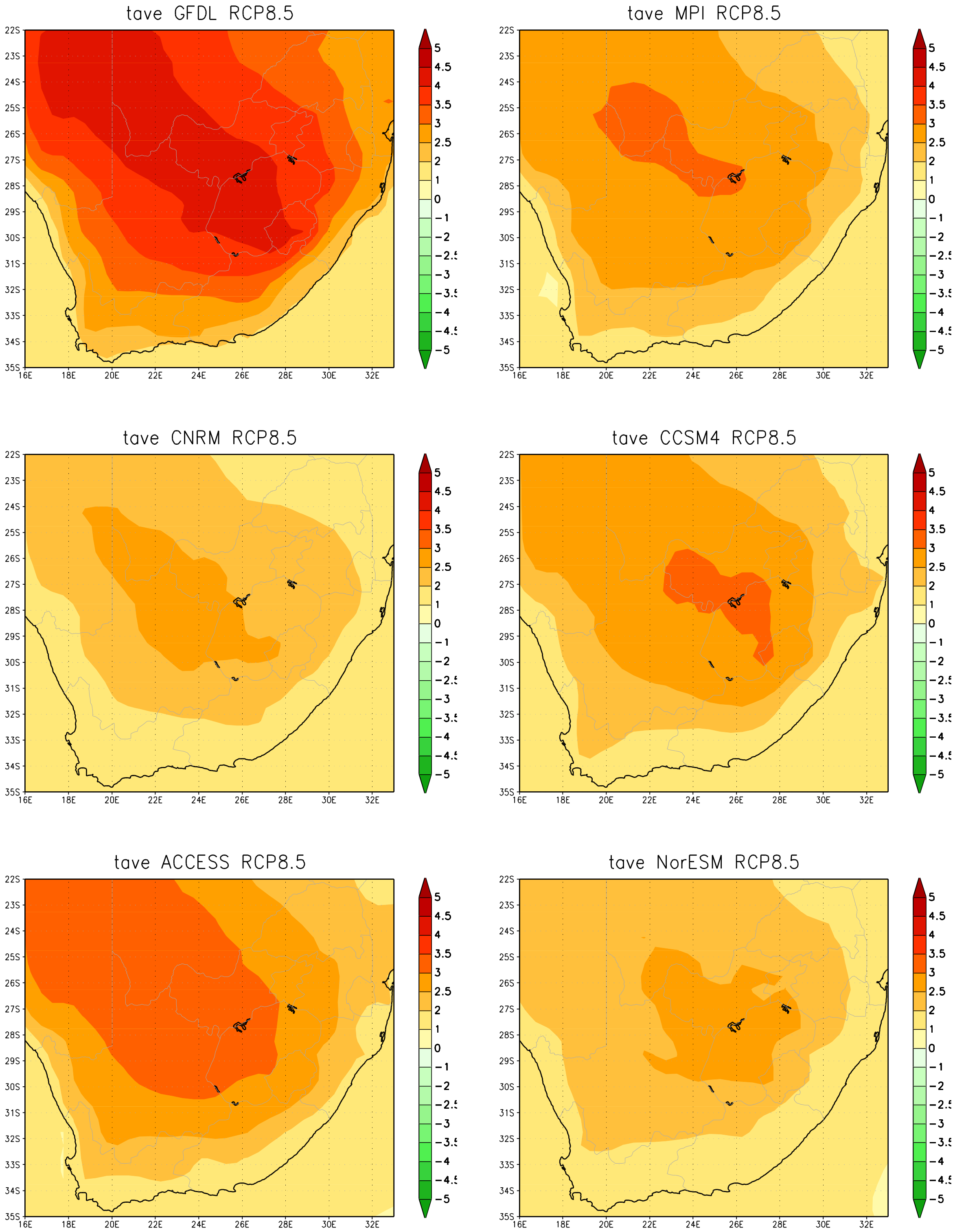


Figure B.15b: CCAM dynamically downscaled projected changes in annual mean temperature under RCP 8.5 for the 2046-2065 period.

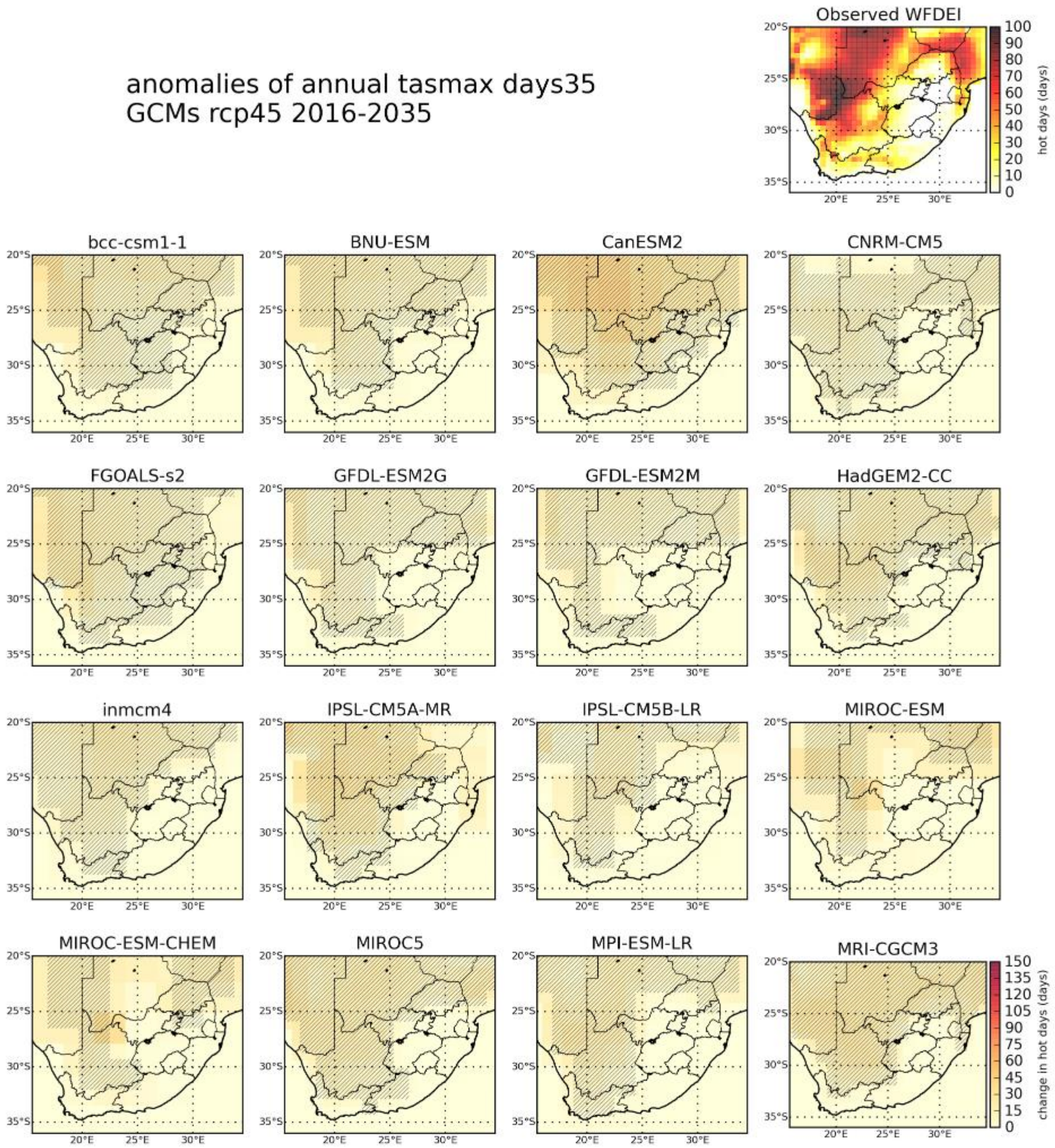


Figure B.16a: GCM-projected changes in the number of very hot days under RCP4.5 for the 2016-2035 period.

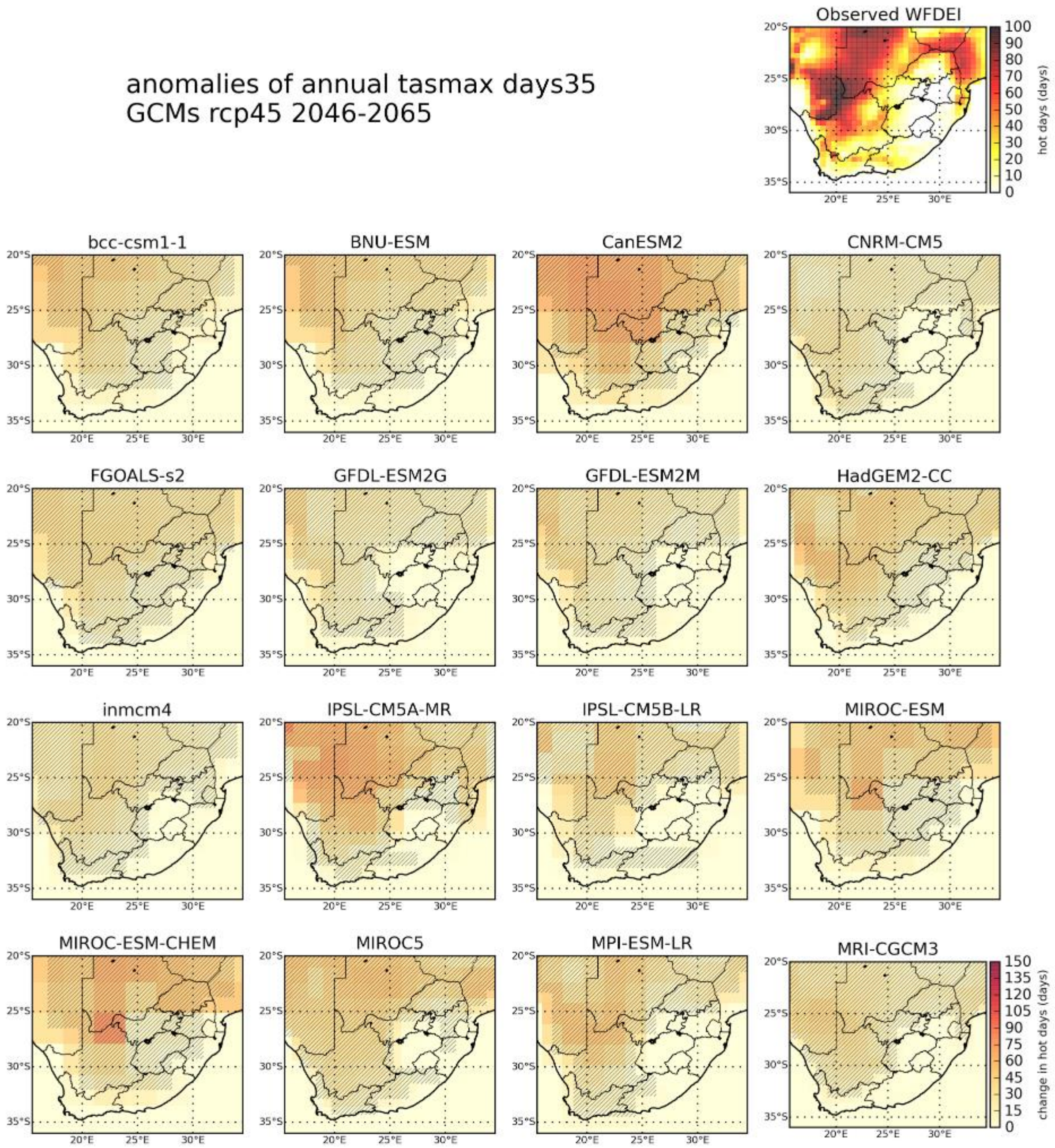


Figure B.16b: GCM-projected changes in the number of very hot days under RCP4.5 for the 2046-2065 period.

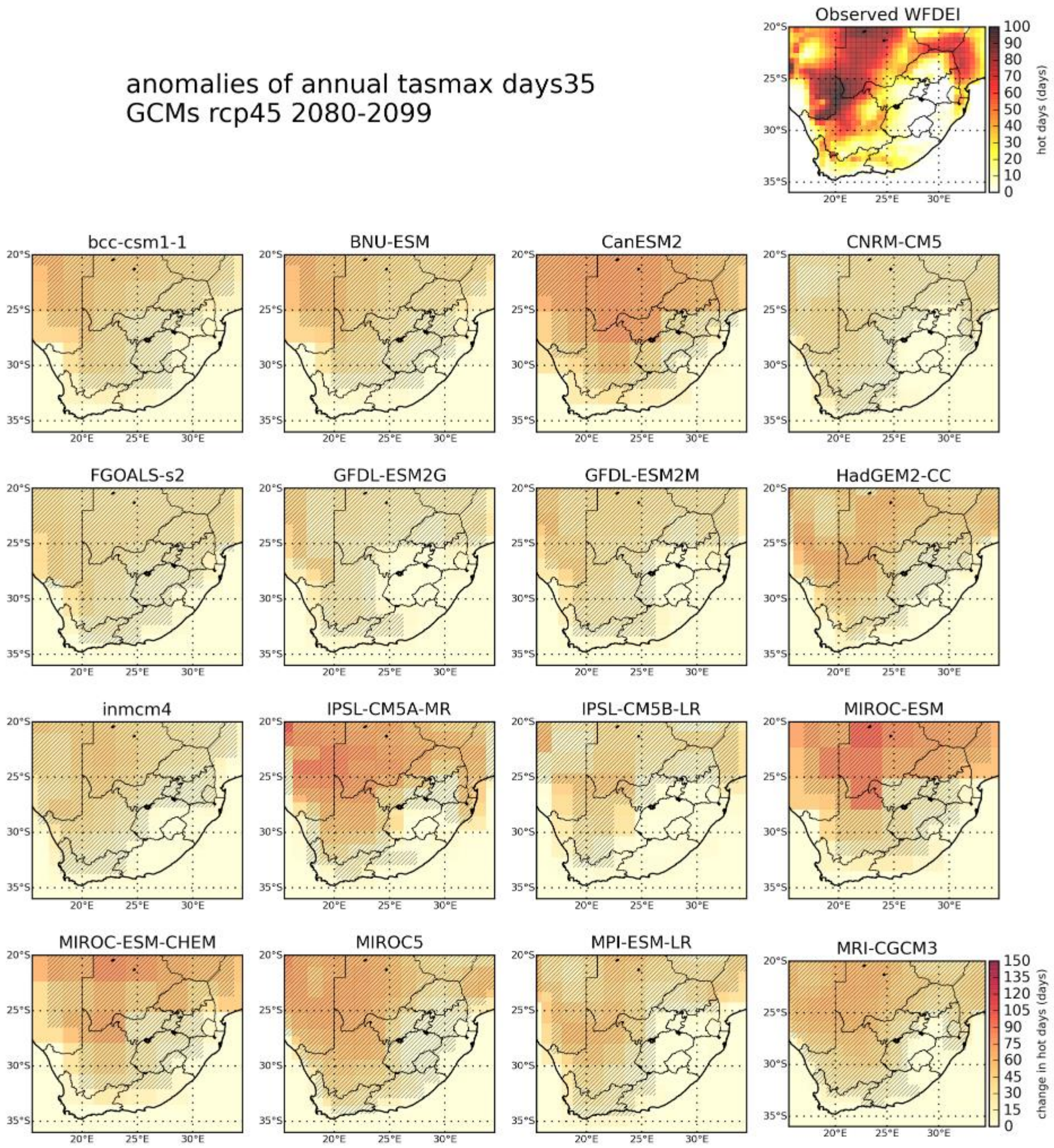


Figure B.16c: GCM-projected changes in the number of very hot days under RCP4.5 for the 2080-2099 period.

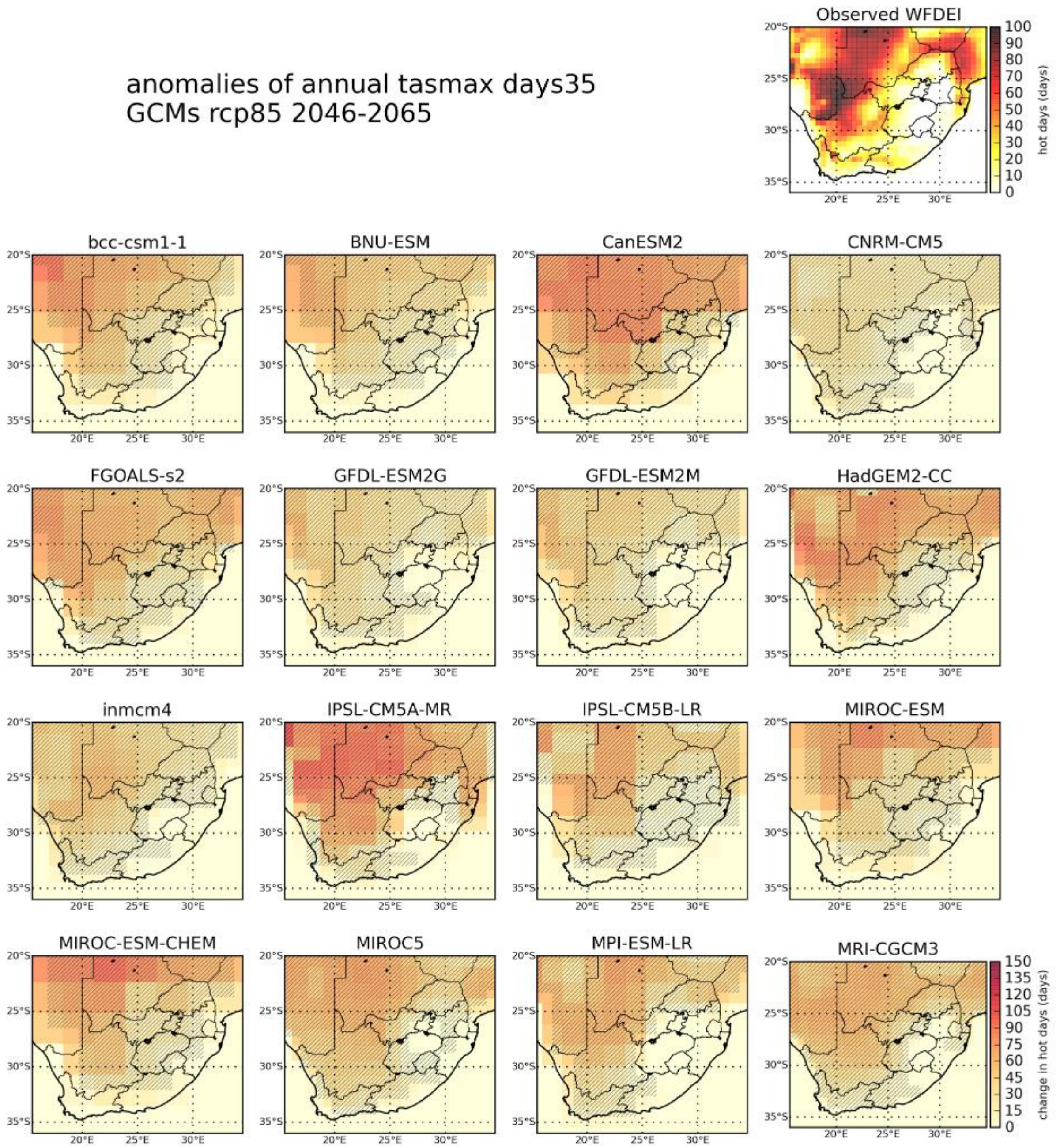


Figure B.17a: Statistically downscaled changes in the number of very hot days under RCP4.5 for the 2016-2035 period.

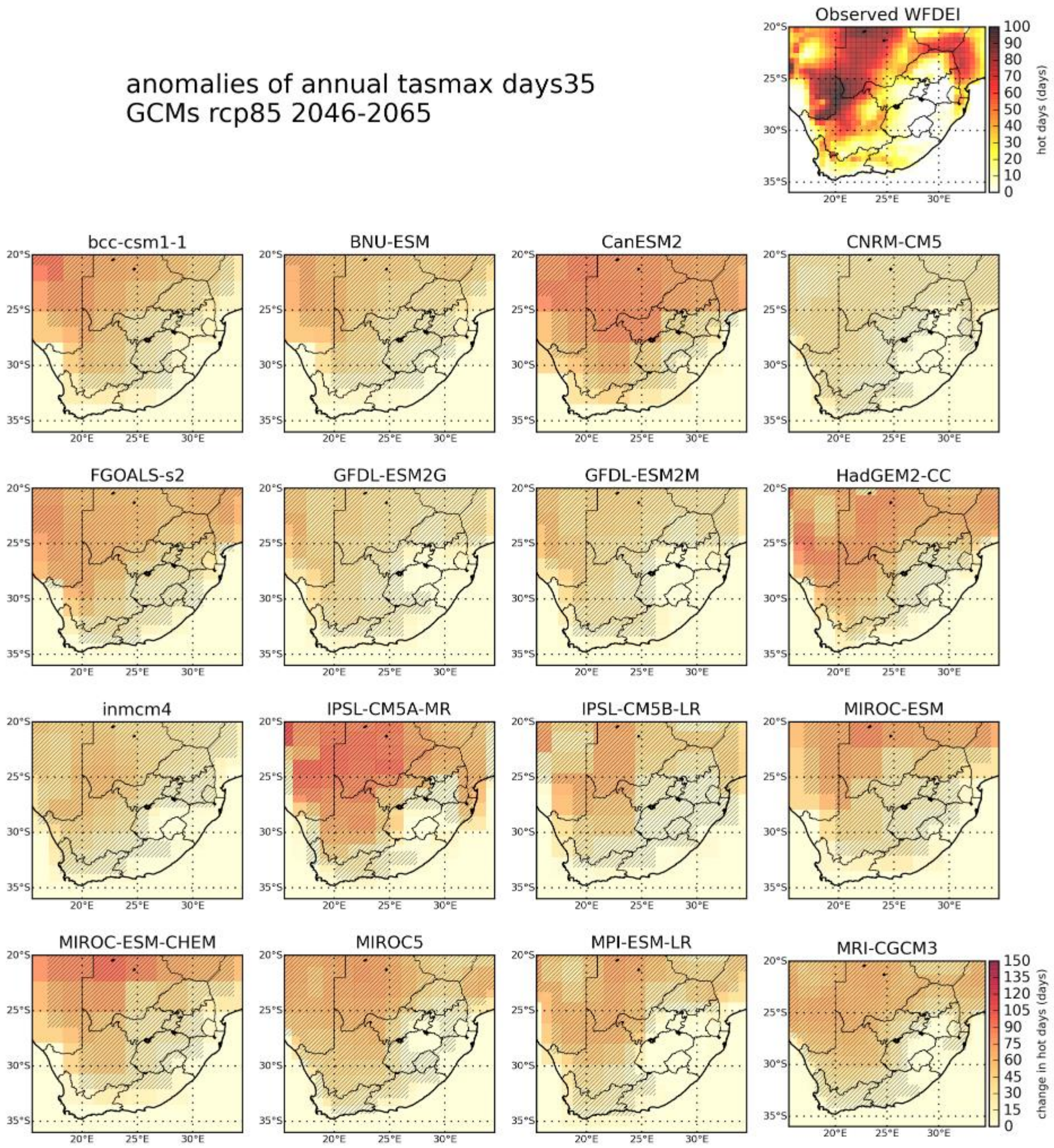


Figure B.17b: Statistically downscaled changes in the number of very hot days under RCP4.5 for the 2046-2065 period.

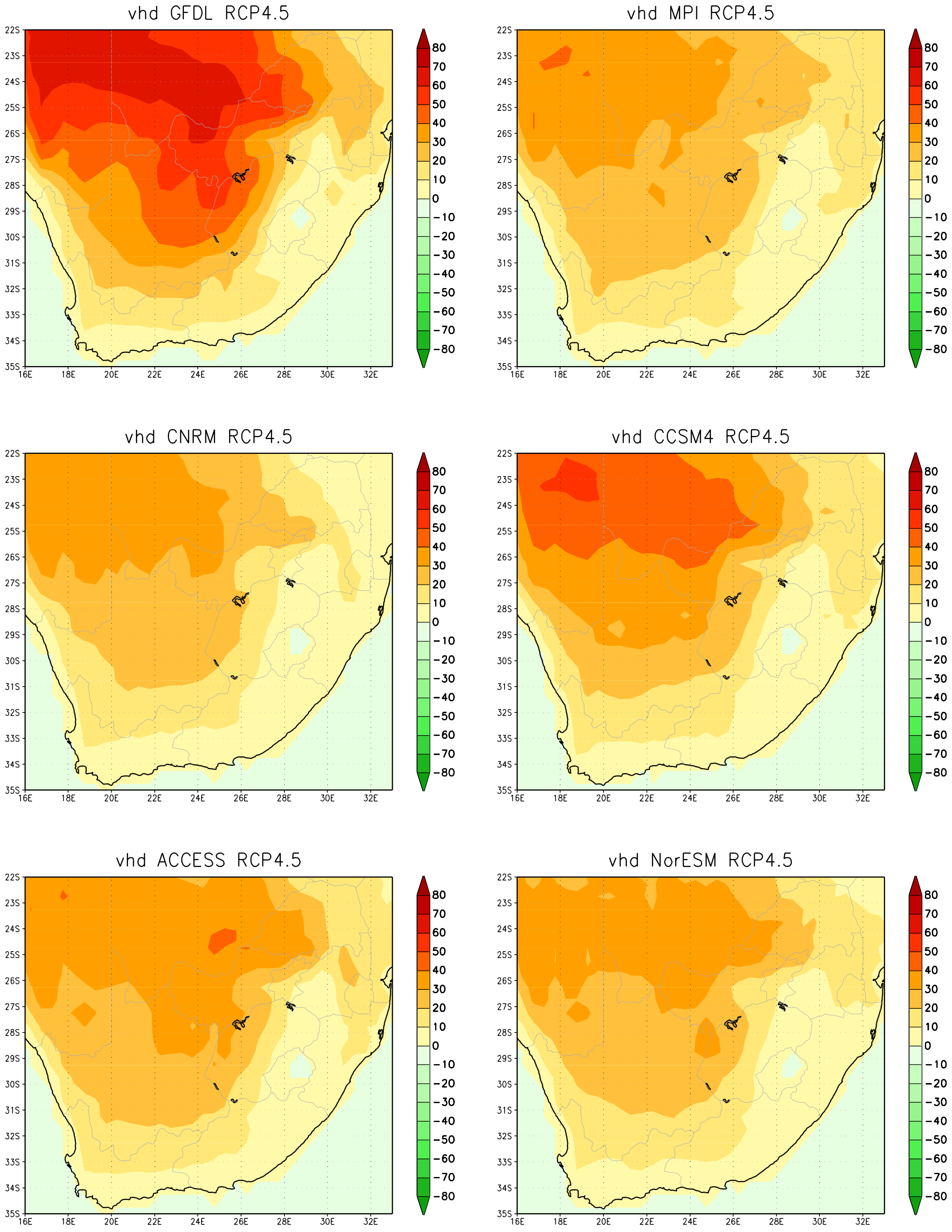
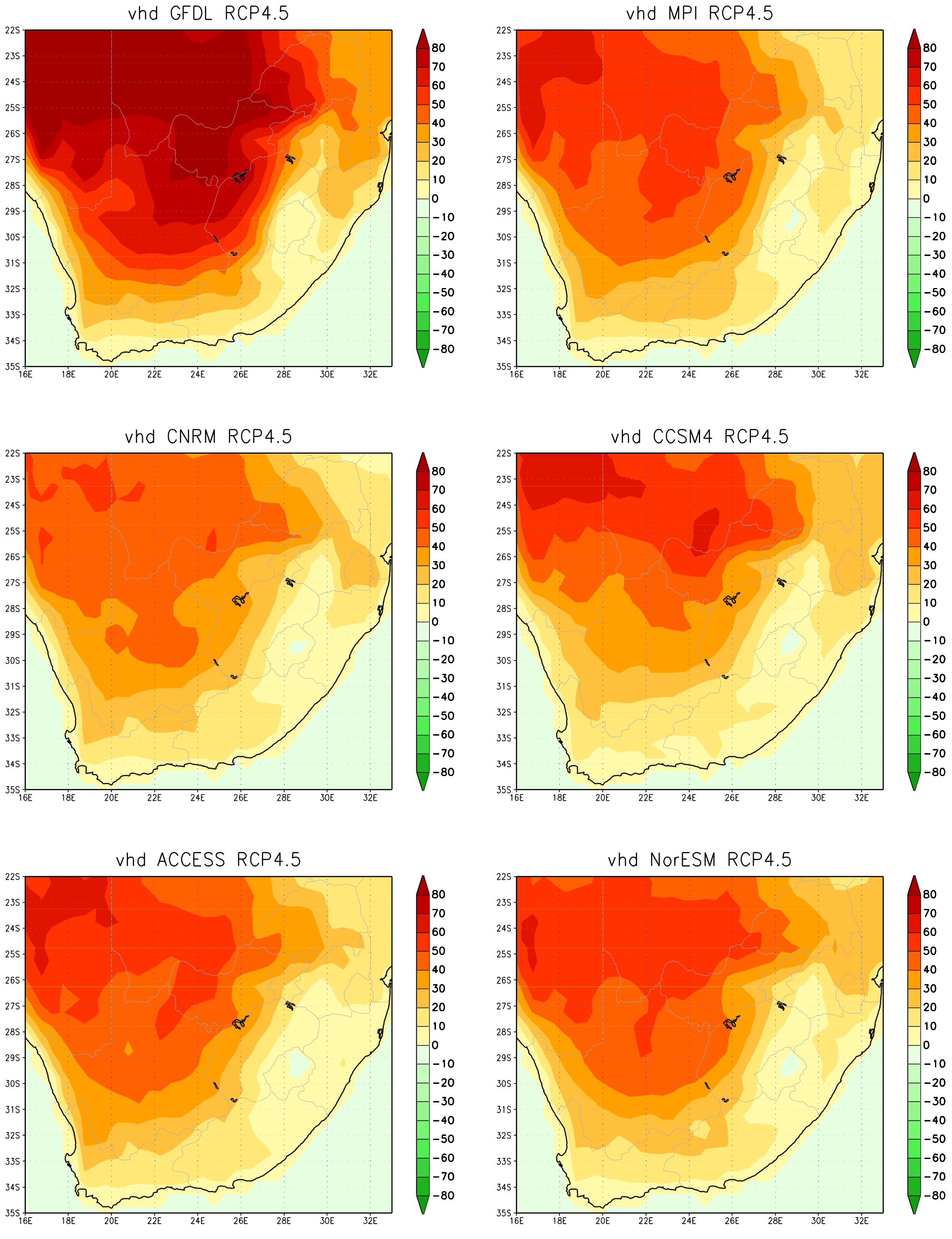


Figure B.18a: Dynamically downscaled changes in the number of very hot days under RCP4.5 for the 2016-2035 period.



vhd GFDL RCP4.5

vhd MPI RCP4.5

vhd CNRM RCP4.5

vhd CCSM4 RCP4.5

vhd ACCESS RCP4.5

vhd NorESM RCP4.5

Figure B.18b: Dynamically downscaled changes in the number of very hot days under RCP4.5 for the 2046-2065 period.

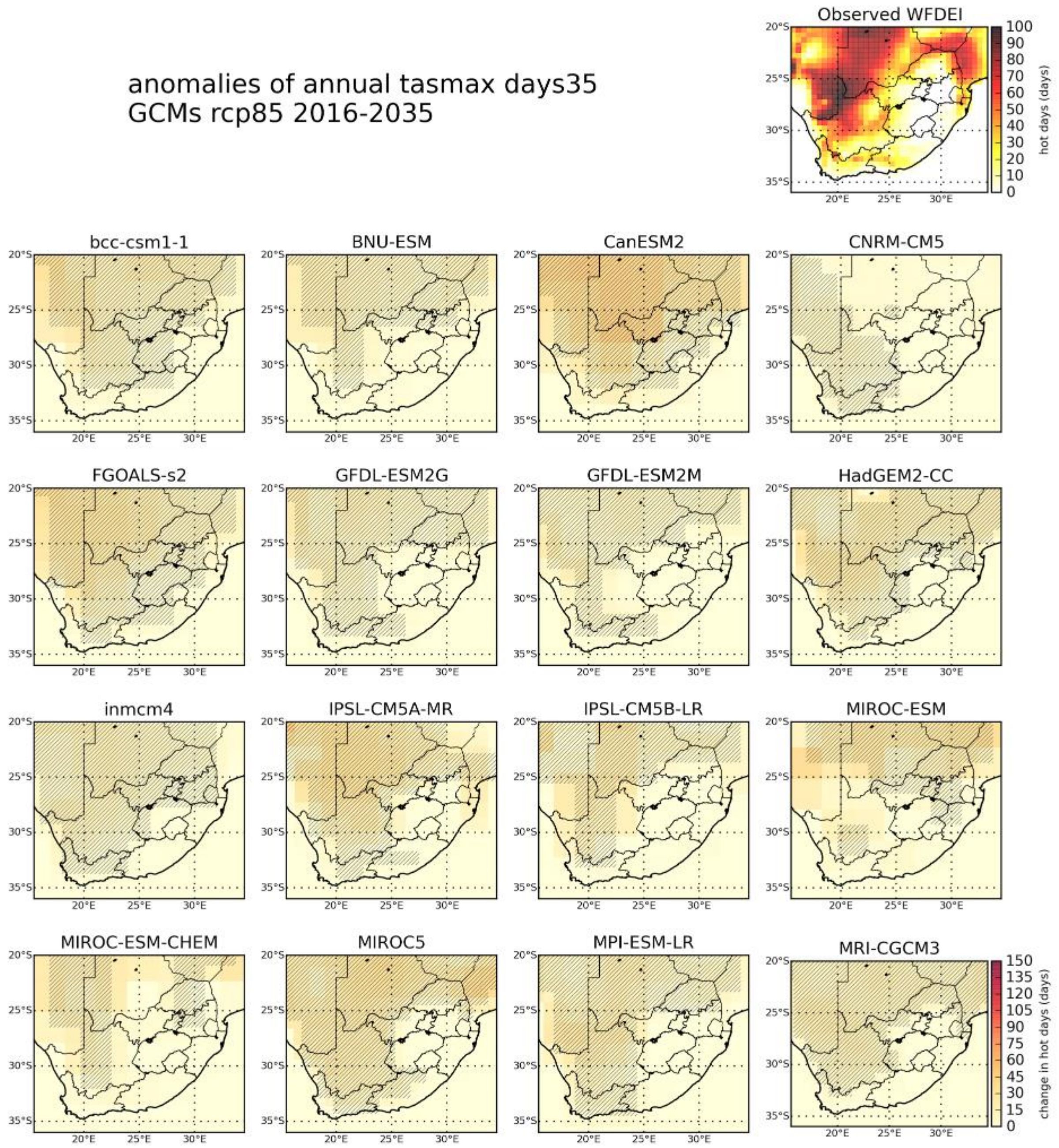


Figure B.19a: GCM-projected changes in the number of very hot days under RCP8.5 for the 2016-2035 period.

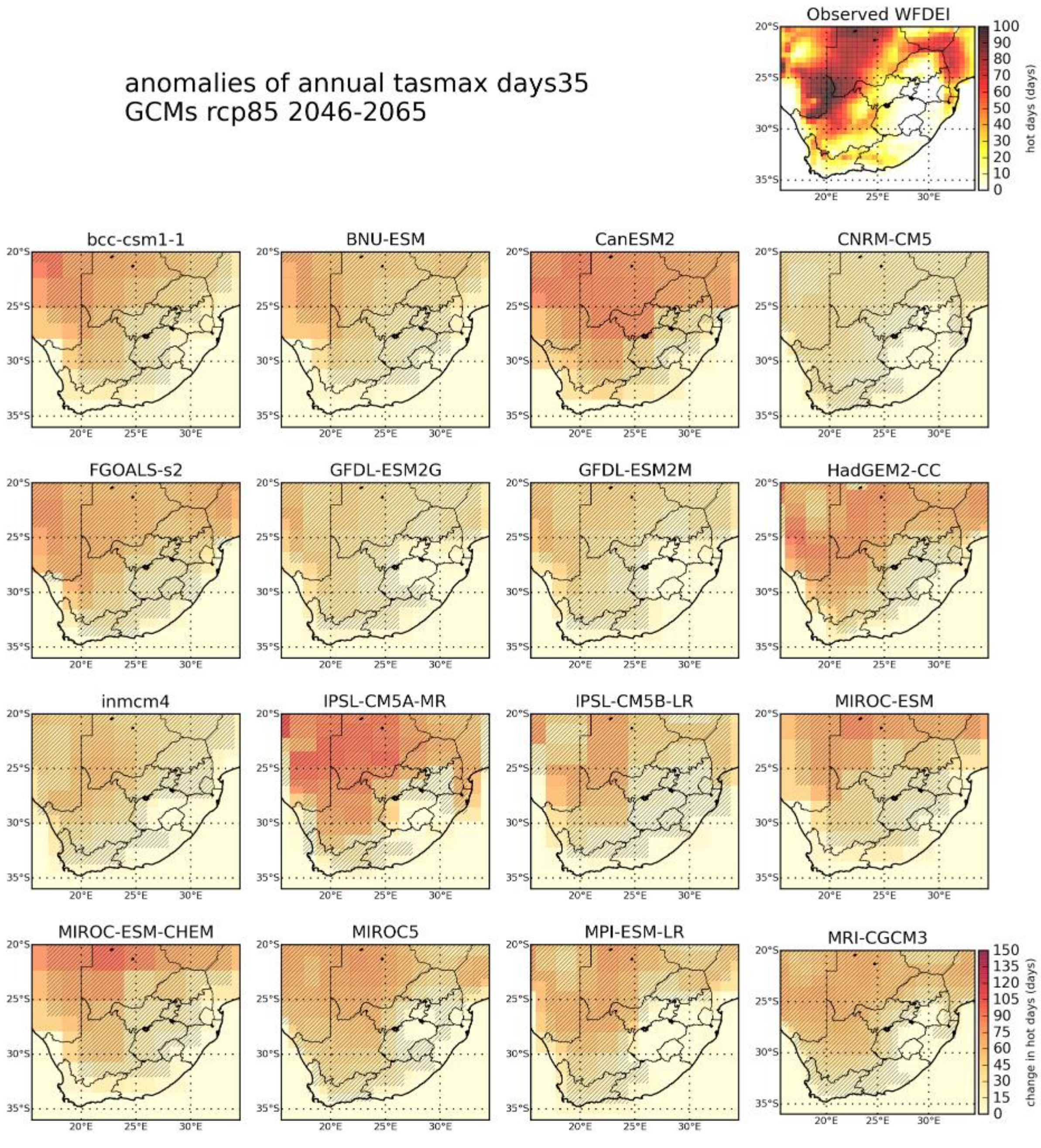


Figure B.19b: GCM-projected changes in the number of very hot days under RCP8.5 for the 2046-2065 period.

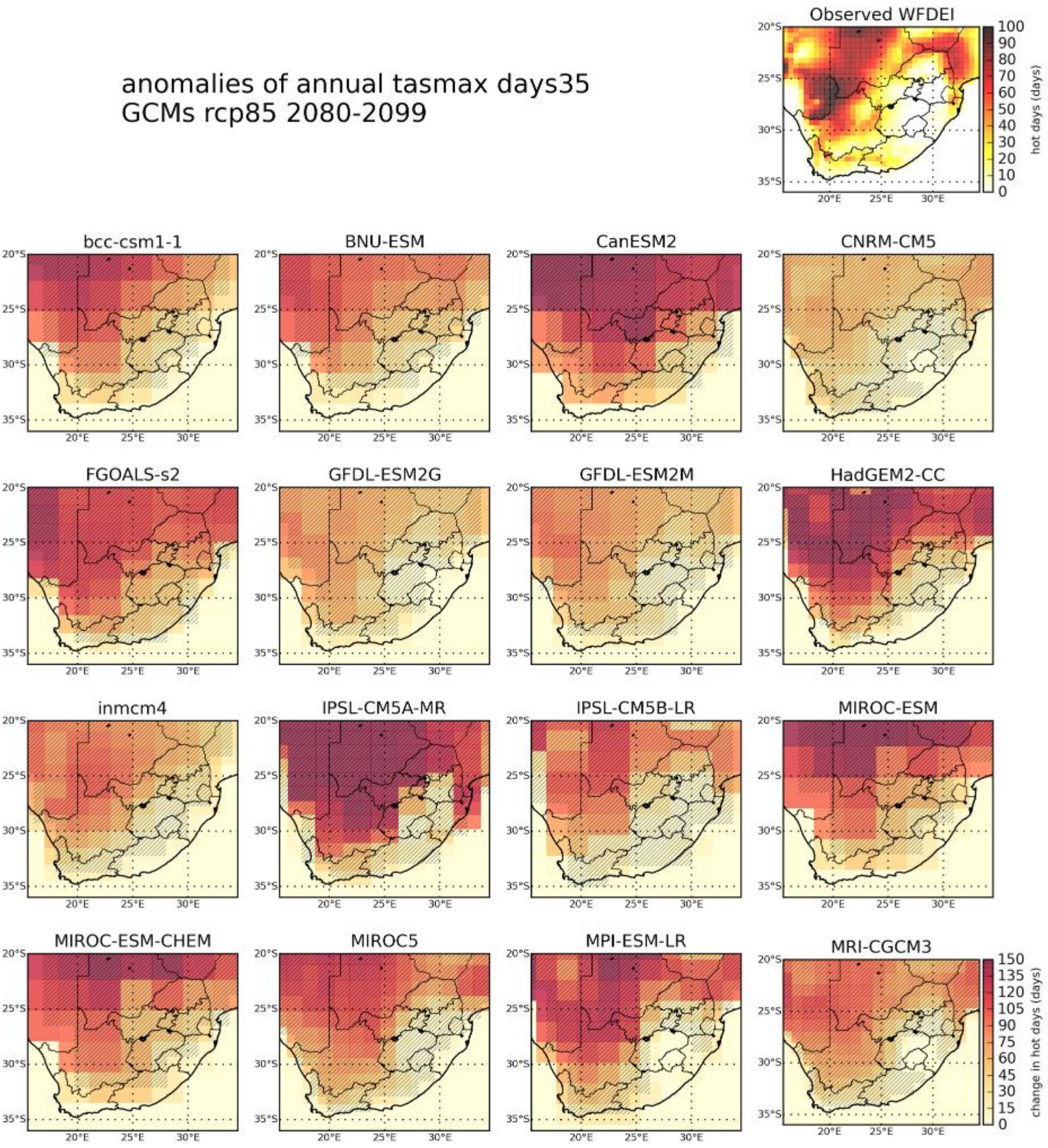


Figure B.19c: GCM-projected changes in the number of very hot days under RCP8.5 for the 2080-2099 period.

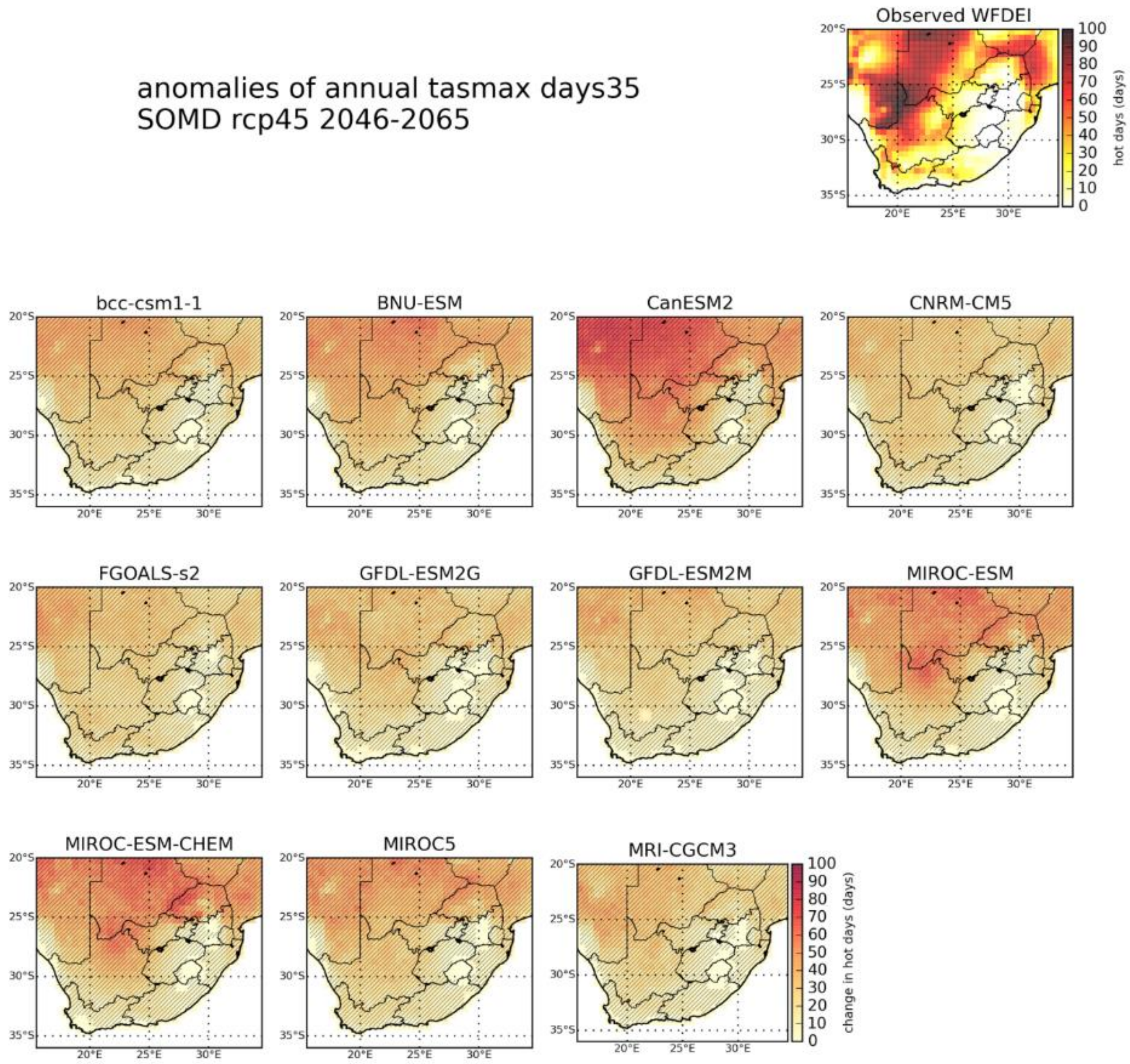


Figure B.20a: Statistically downscaled changes in the number of very hot days under RCP8.5 for the 2016-2035 period.

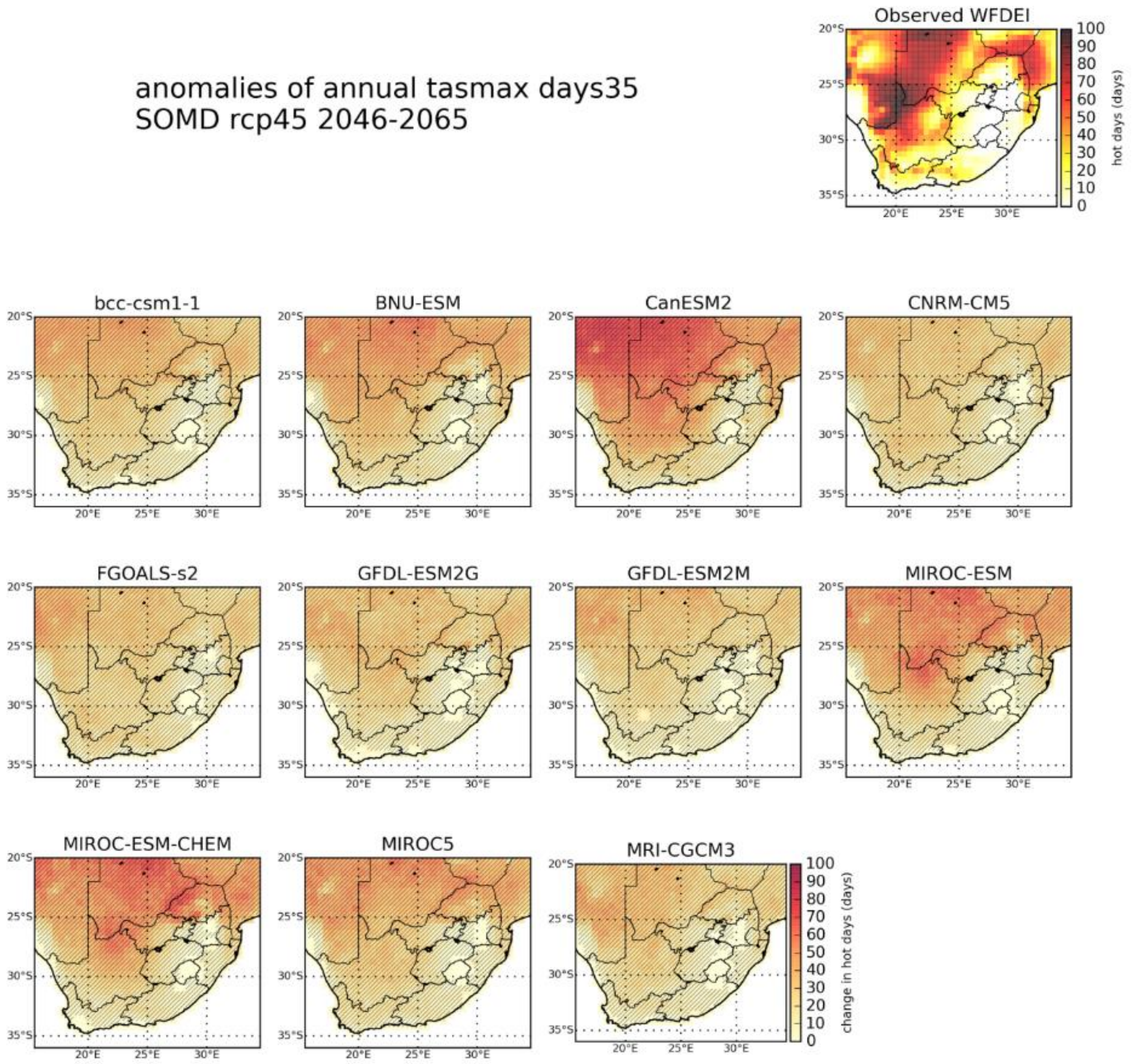


Figure B.20b: Statistically downscaled changes in the number of very hot days under RCP8.5 for the 2046-2065 period.

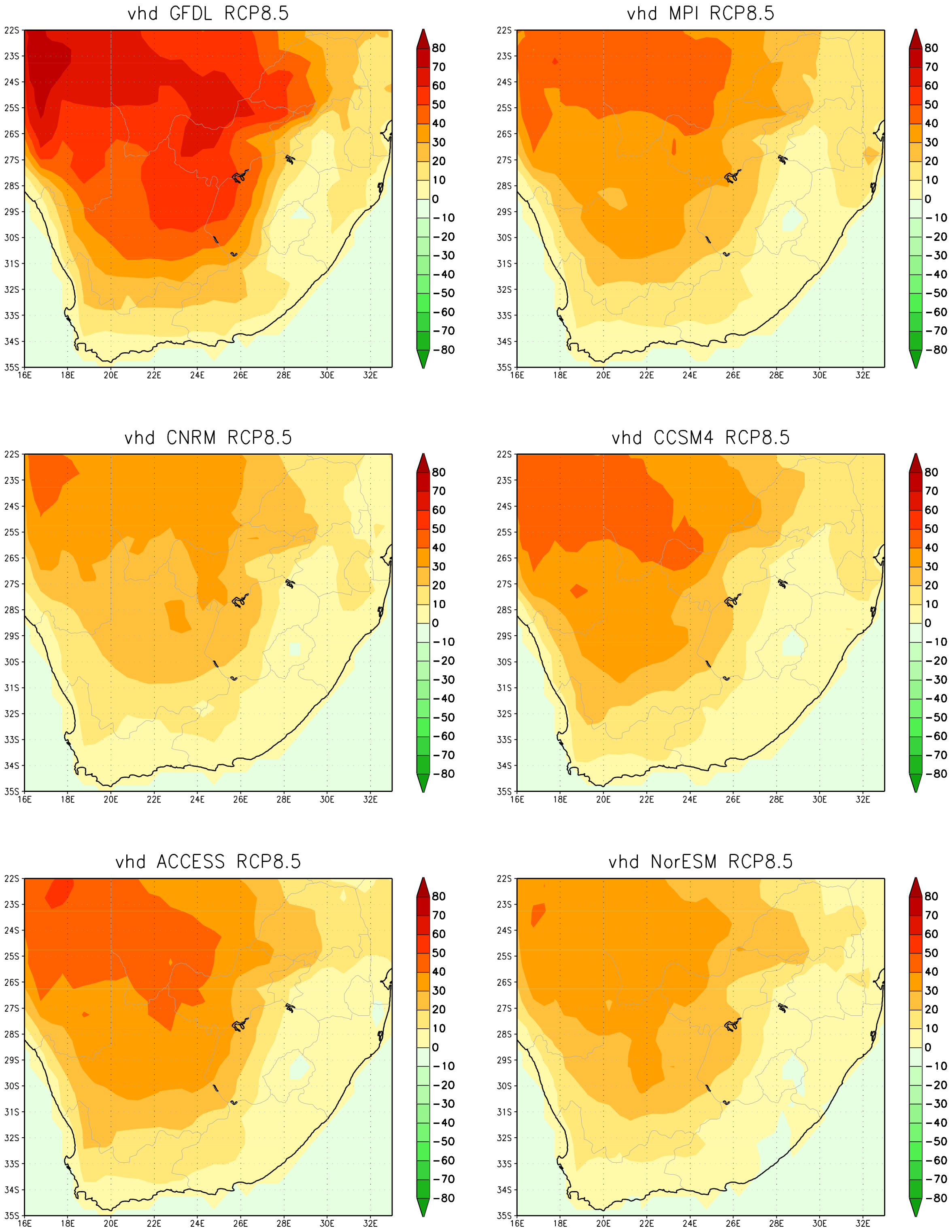


Figure B.21a: Dynamically downscaled changes in the number of very hot days under RCP8.5 for the 2016-2035 period.

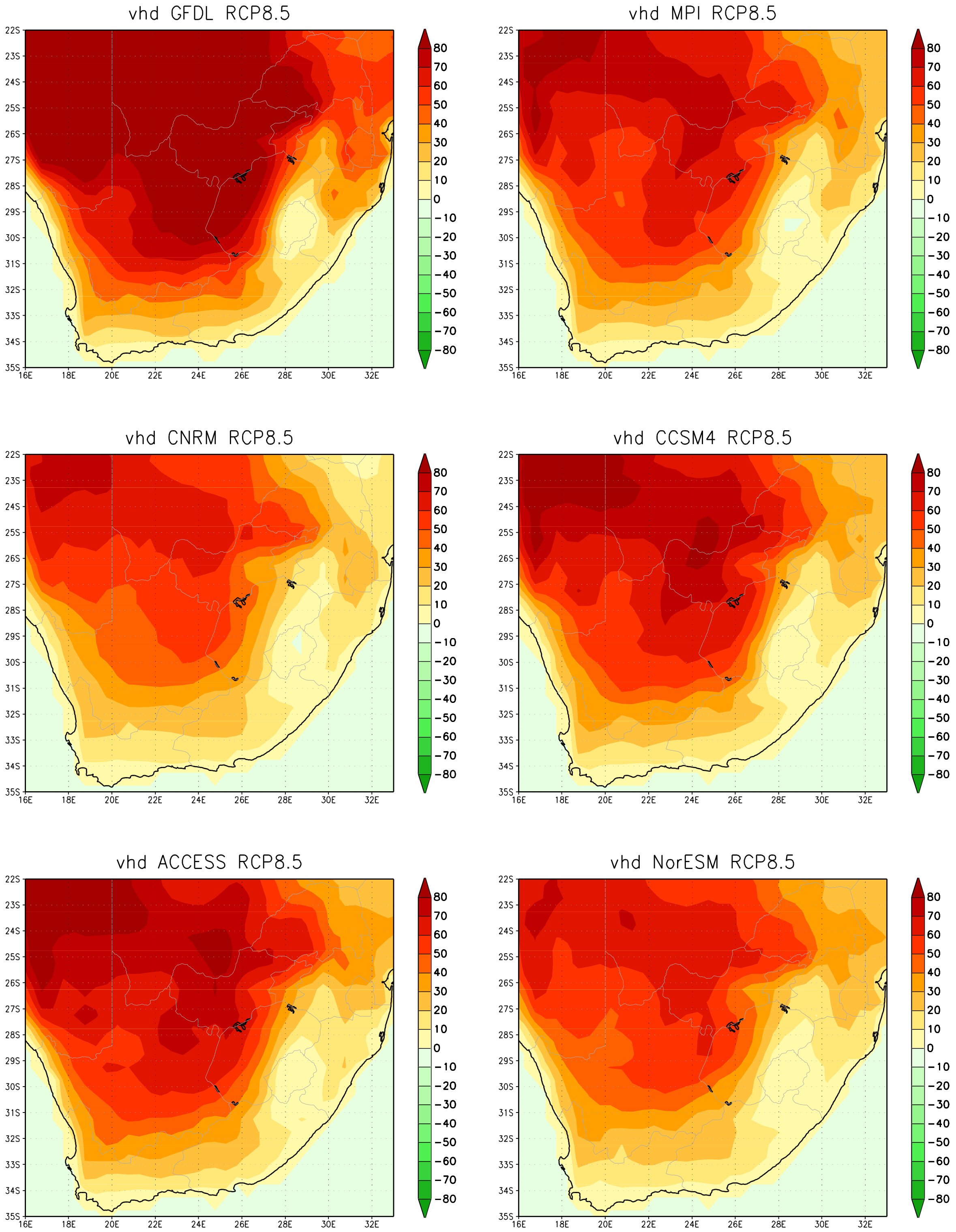


Figure B.21b: Dynamically downscaled changes in the number of very hot days under RCP8.5 for the 2046-2065 period.

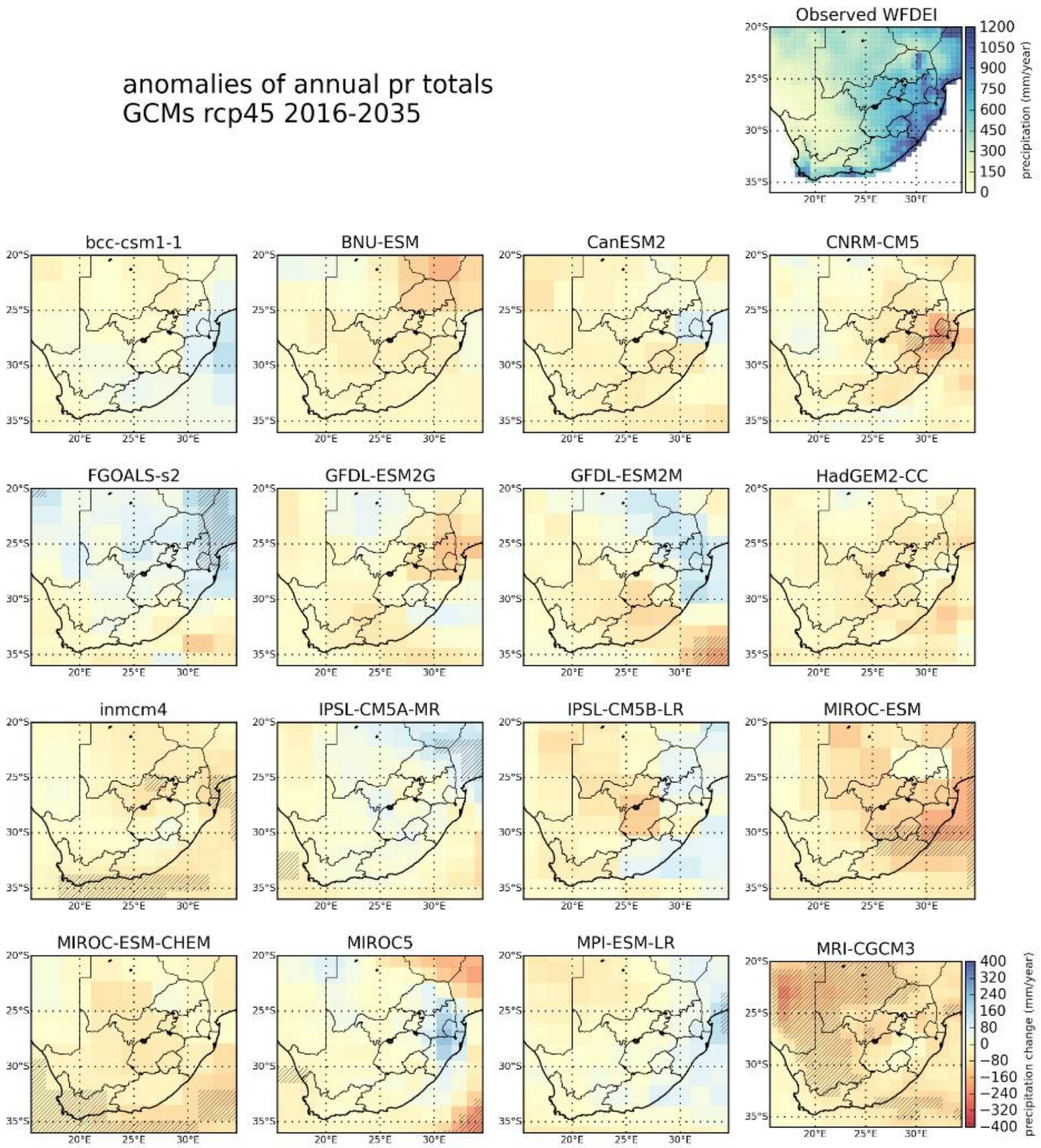


Figure B.22a: GCM-projected changes in annual total rainfall (mm) under the RCP 4.5 pathway for the 2016-2035 period.

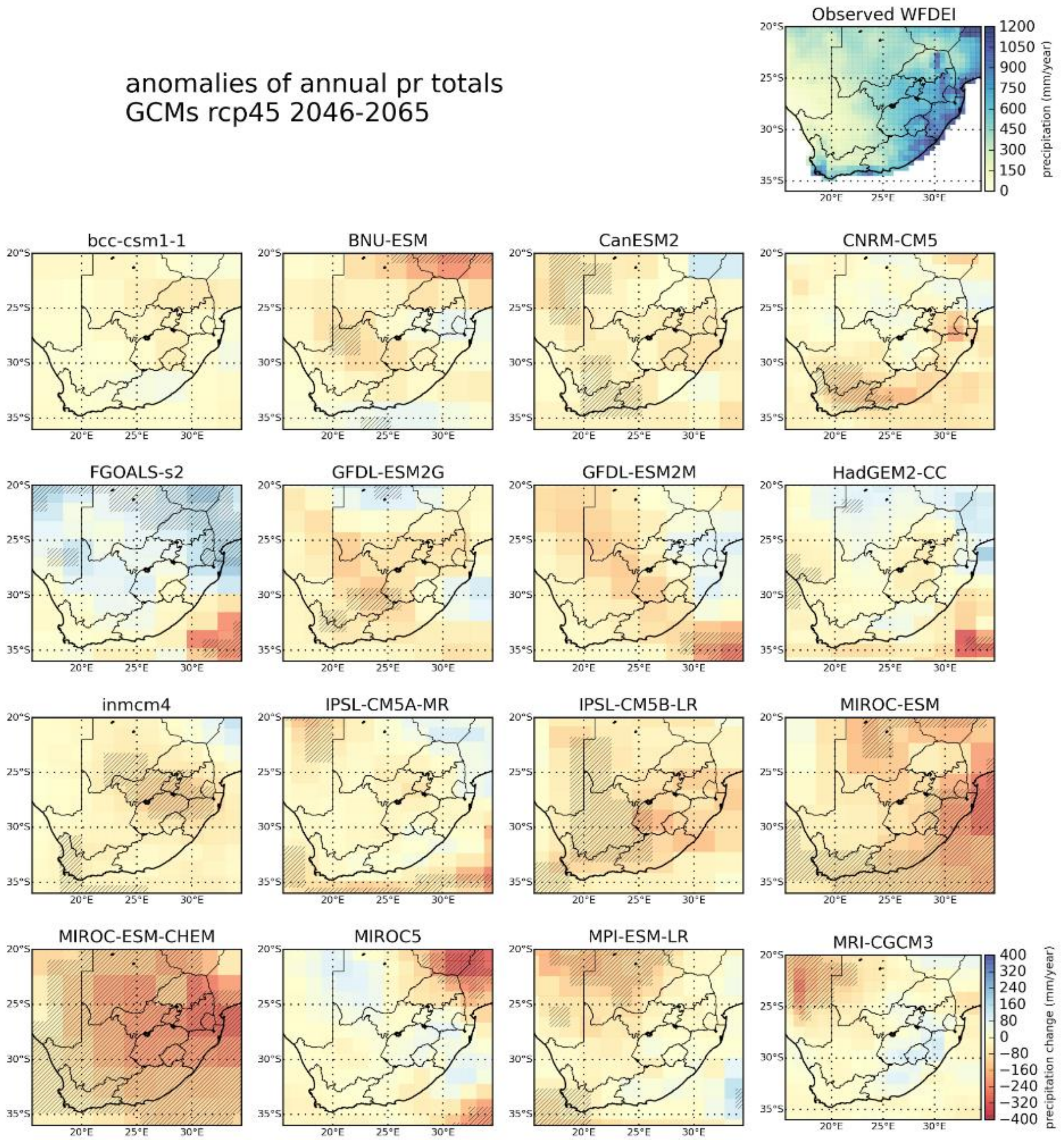


Figure B.22b: GCM-projected changes in annual total rainfall (mm) under the RCP 4.5 pathway for the 2046-2065 period.

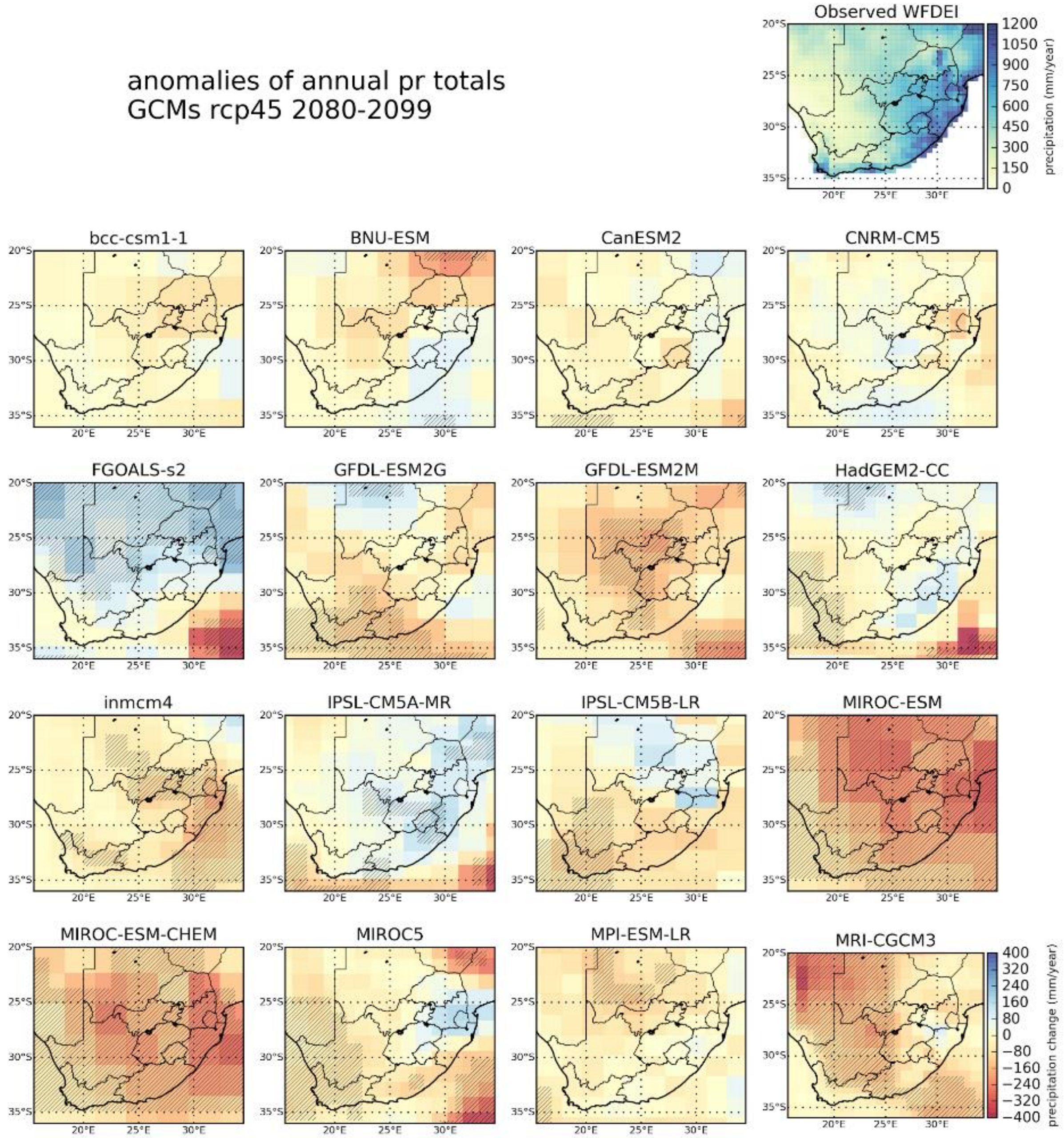


Figure B.22c: GCM-projected changes in annual total rainfall (mm) under the RCP 4.5 pathway for the 2080-2099 period.

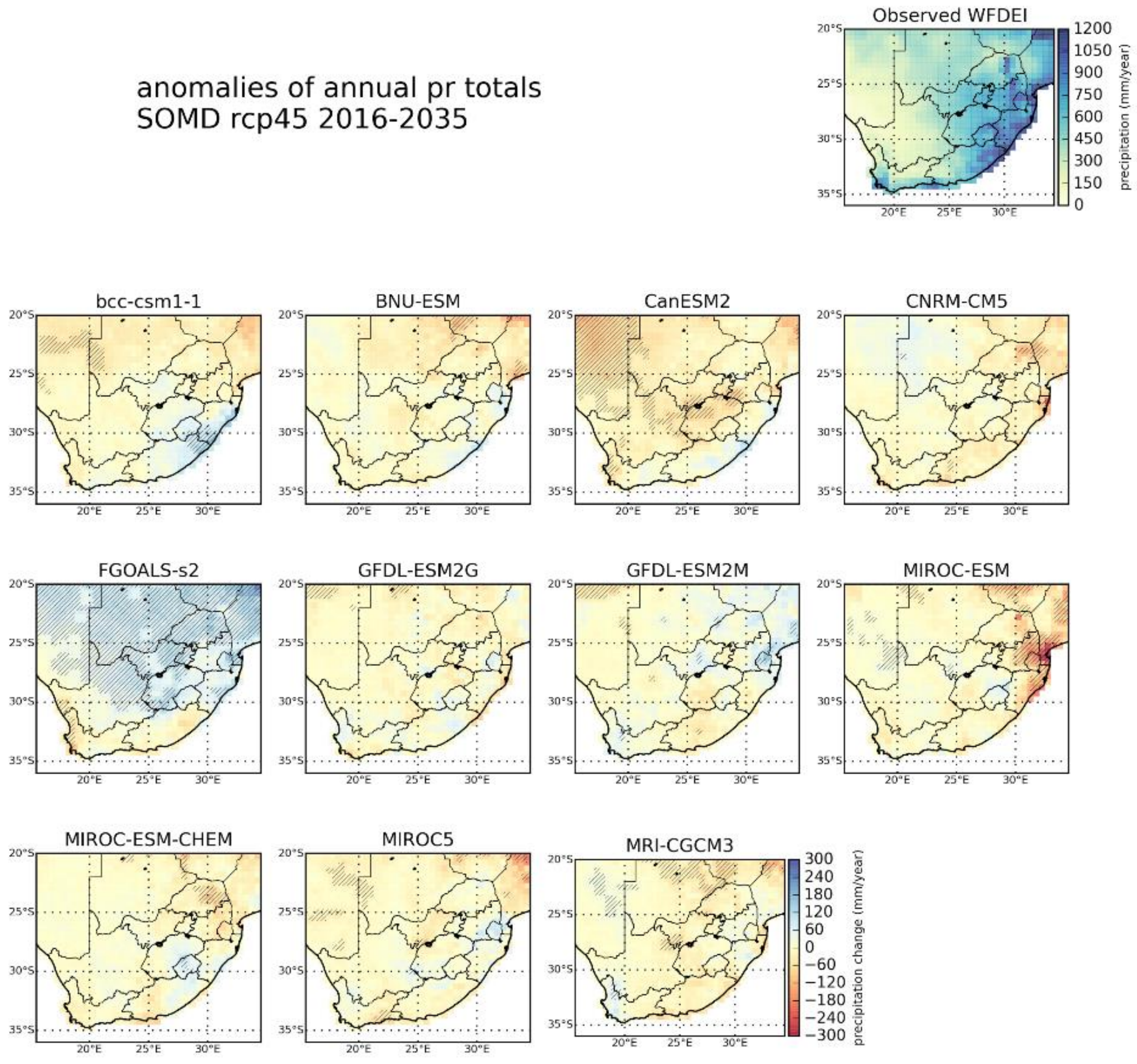


Figure B.23a: Statistically-downscaled projected changes in annual total rainfall (mm) under the RCP 4.5 pathway for the 2016-2035 period.

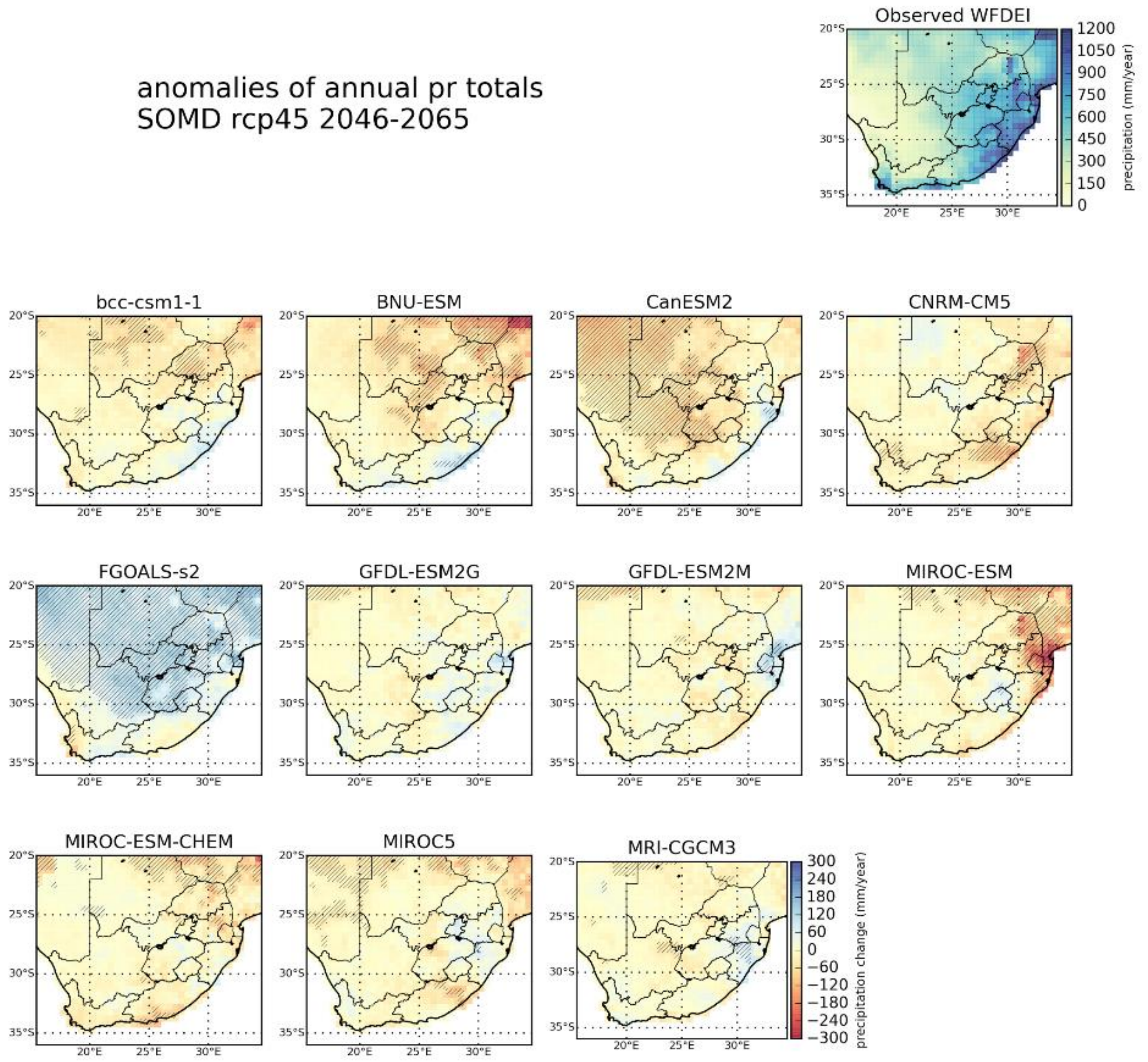


Figure B.23b: Statistically-downscaled projected changes in annual total rainfall (mm) under the RCP 4.5 pathway for the 2046-2065 period.

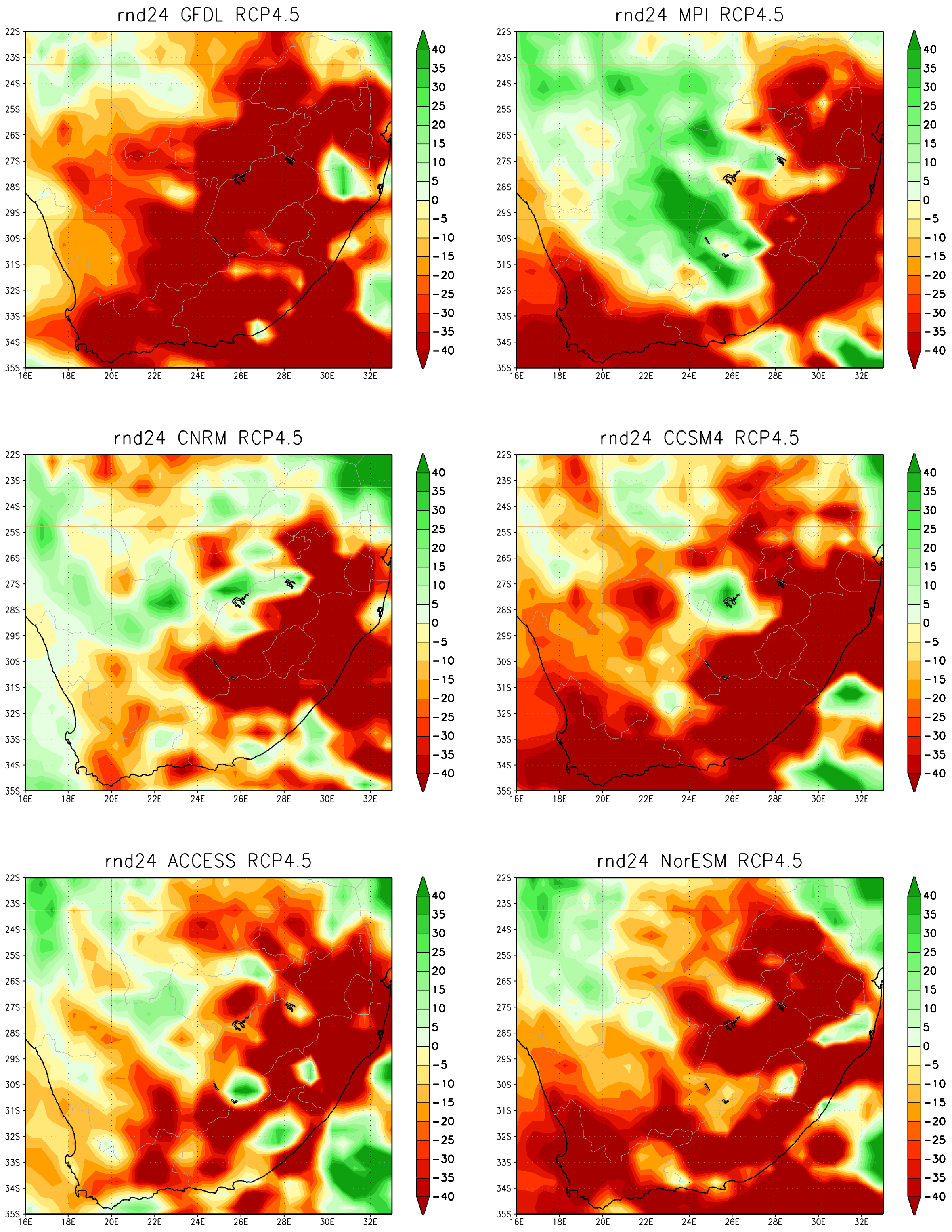


Figure B.24a: CCAM dynamically downscaled projected changes in annual total rainfall (mm) under the RCP 4.5 pathway for the 2016-2035 period.

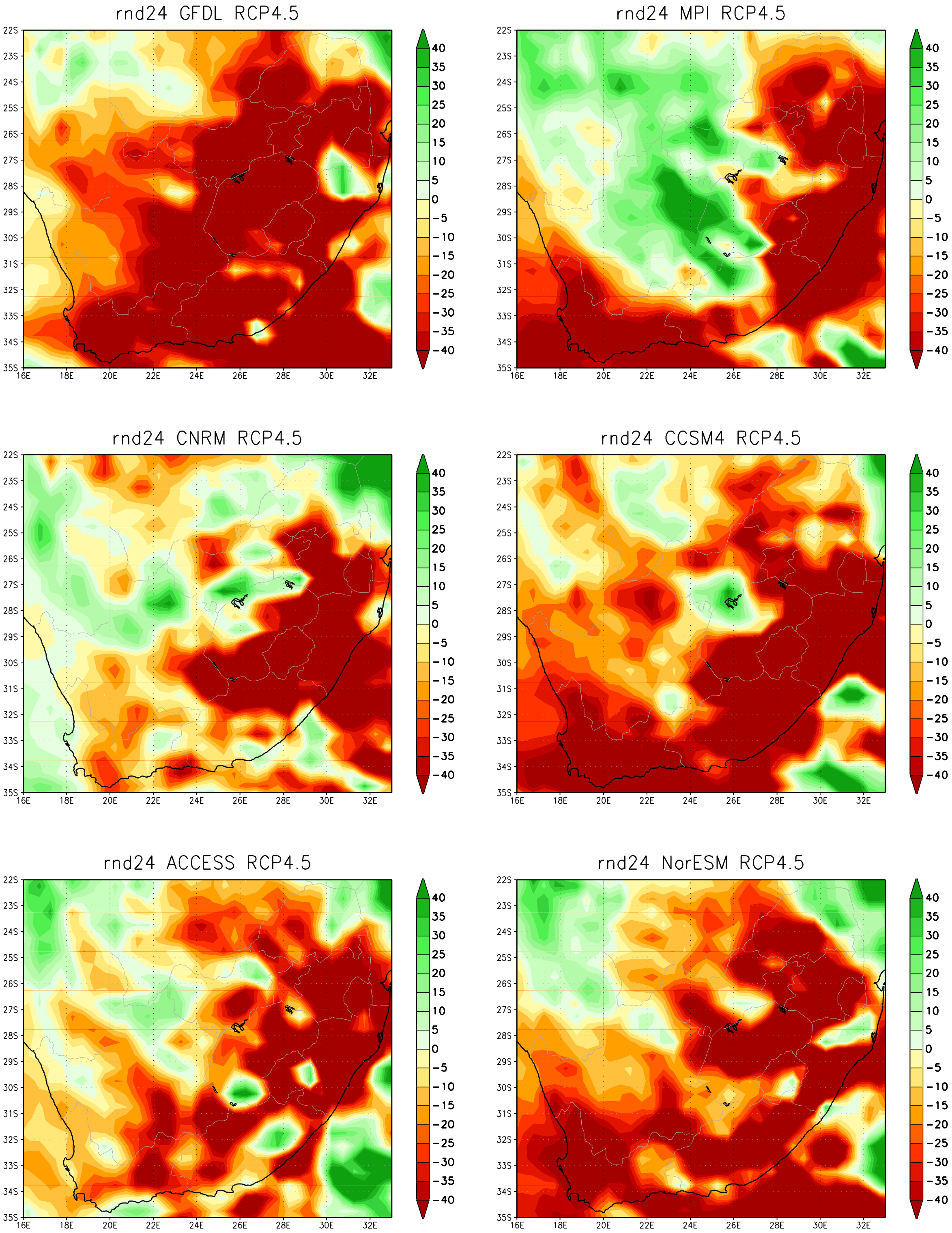


Figure B.24b: CCAM dynamically downscaled projected changes in annual total rainfall (mm) under the RCP 4.5 pathway for the 2046-2065 period.

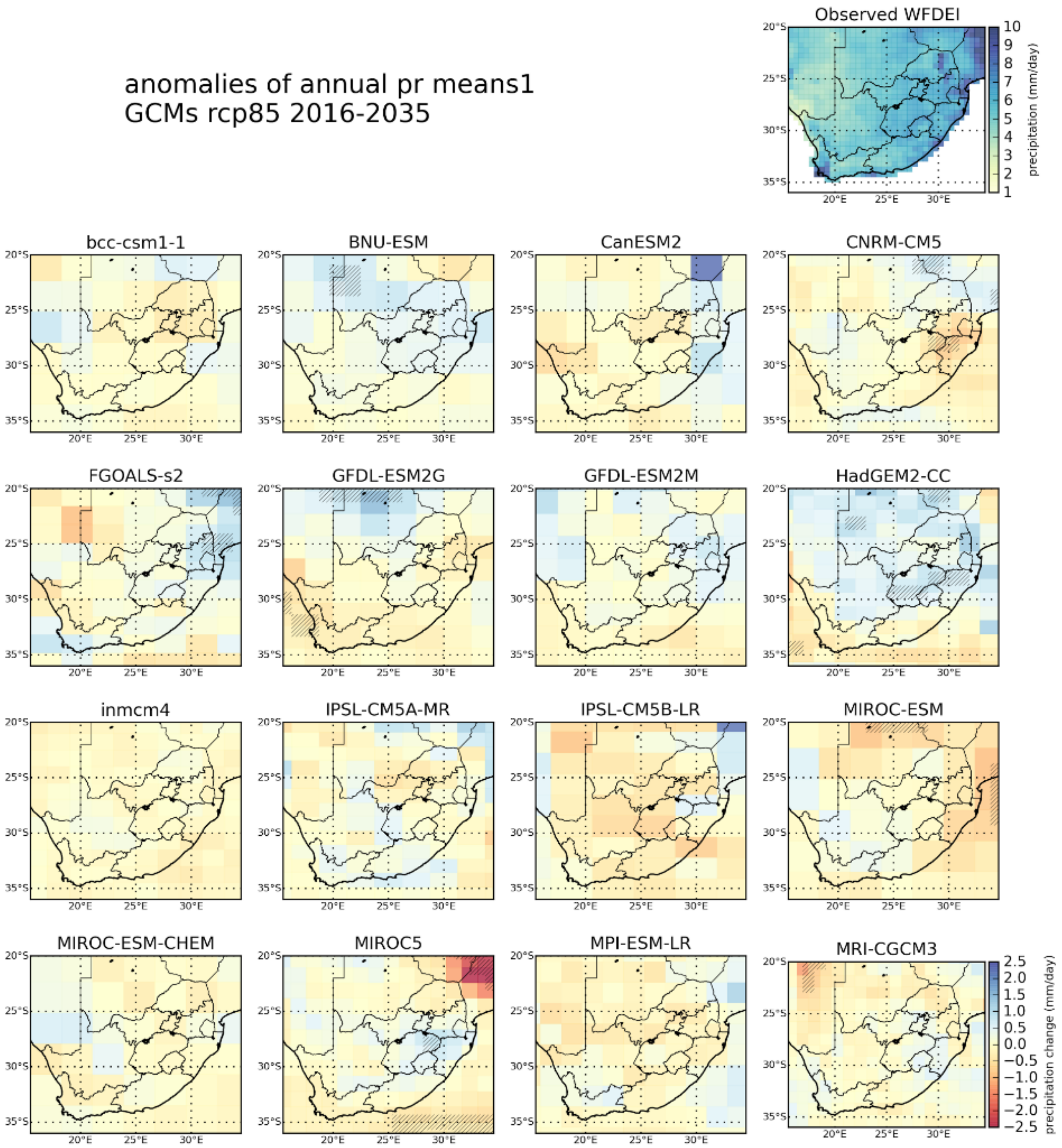


Figure B.25a: GCM-projected changes in annual total rainfall (mm) under the RCP 8.5 pathway for the 2016-2035 period.

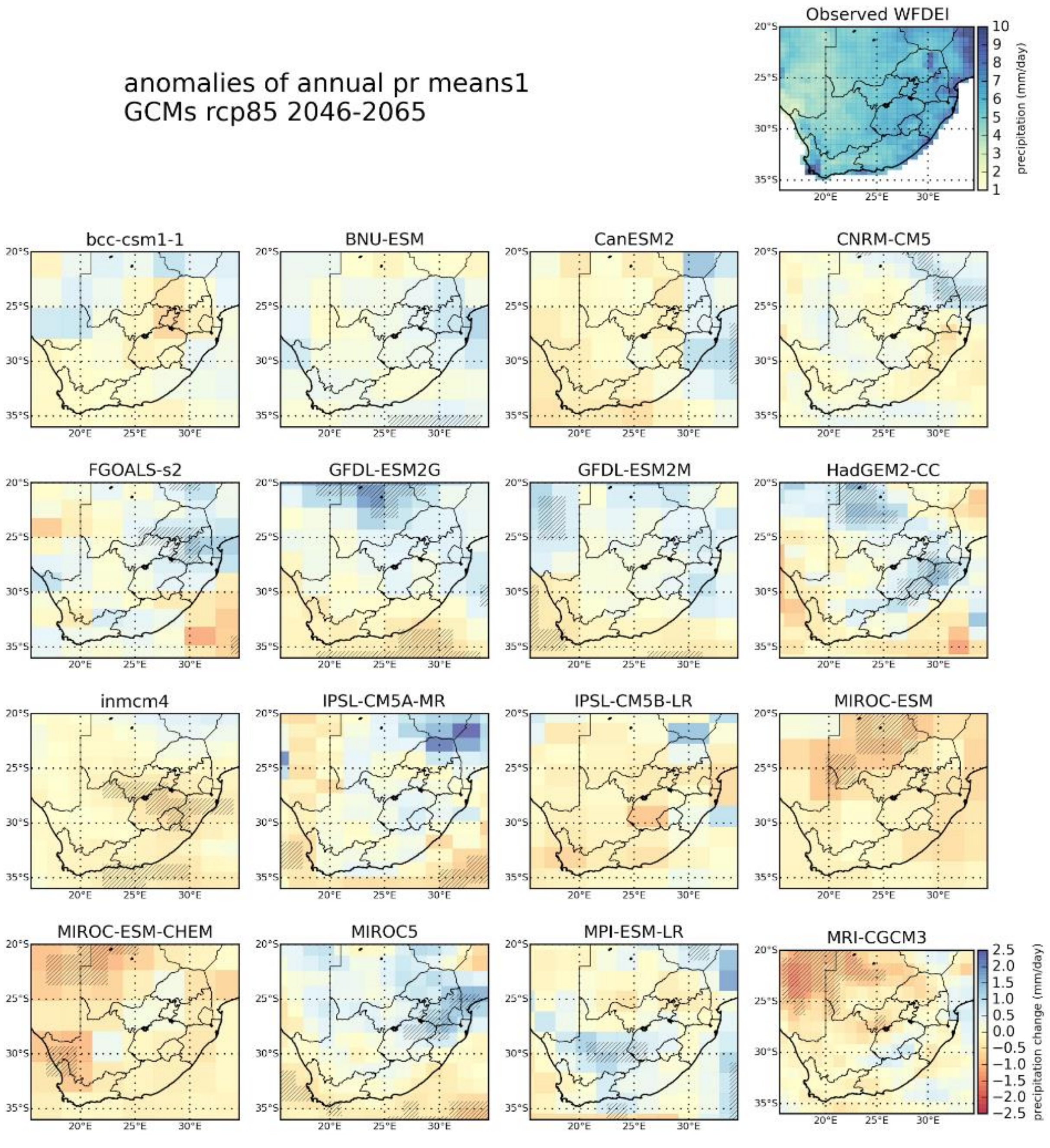


Figure B.25b: GCM-projected changes in annual total rainfall (mm) under the RCP 8.5 pathway for the 2046-2065 period.

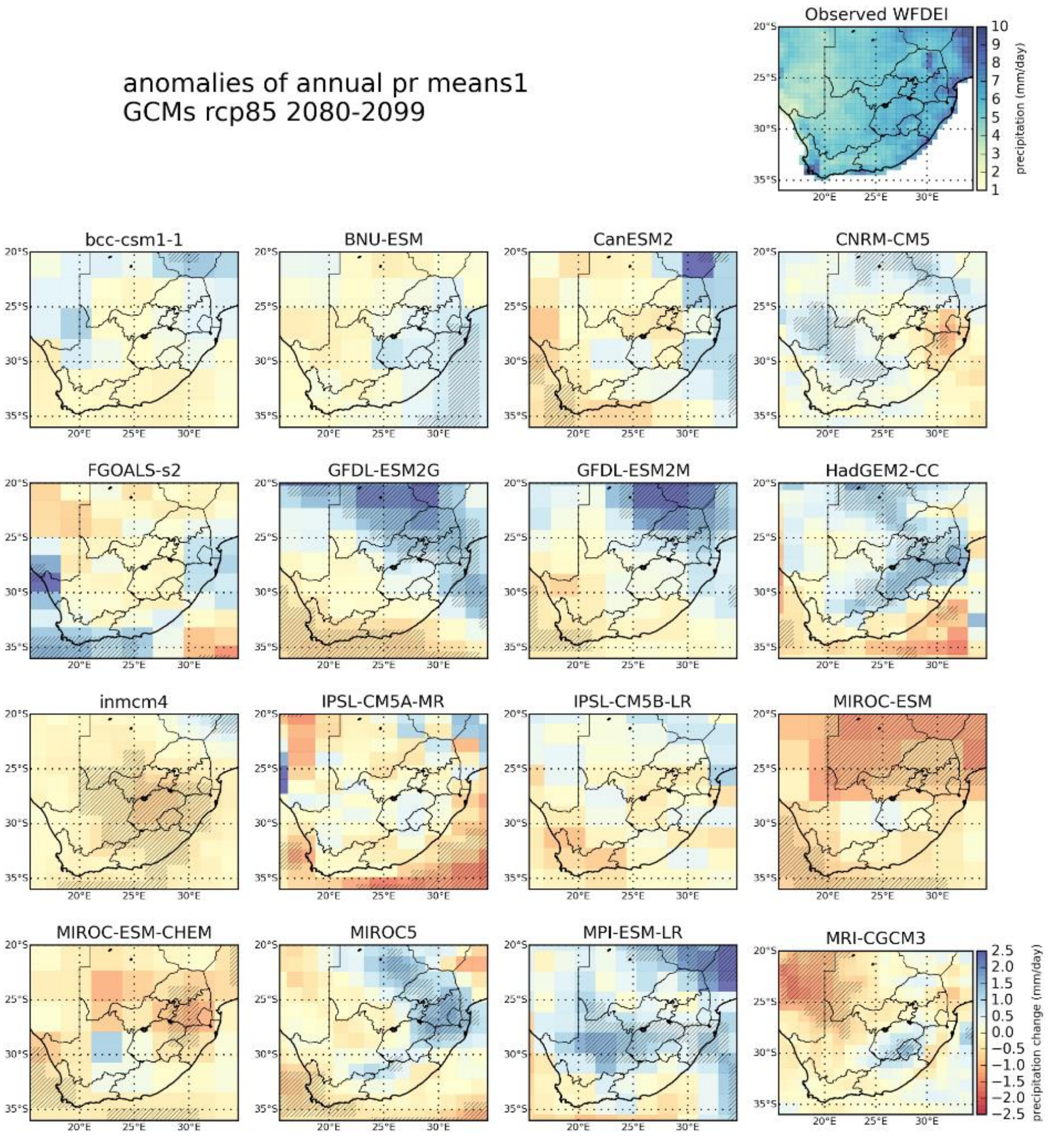


Figure B.25c: GCM-projected changes in annual total rainfall (mm) under the RCP 8.5 pathway for the 2080-2099 period.

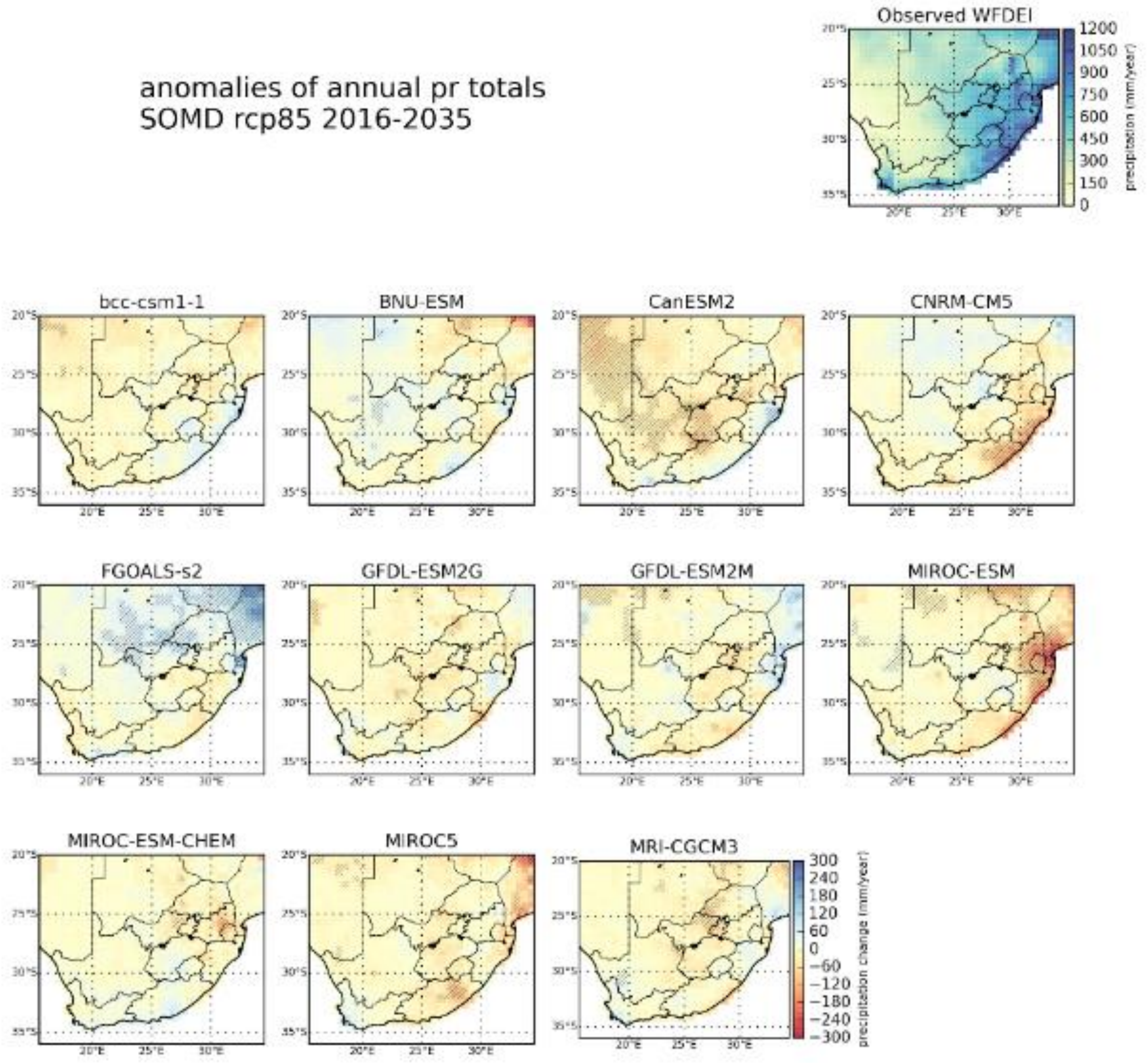


Figure B.26a: Statistically-downscaled projected changes in annual total rainfall (mm) under the RCP 8.5 pathway for the 2016-2035 period.

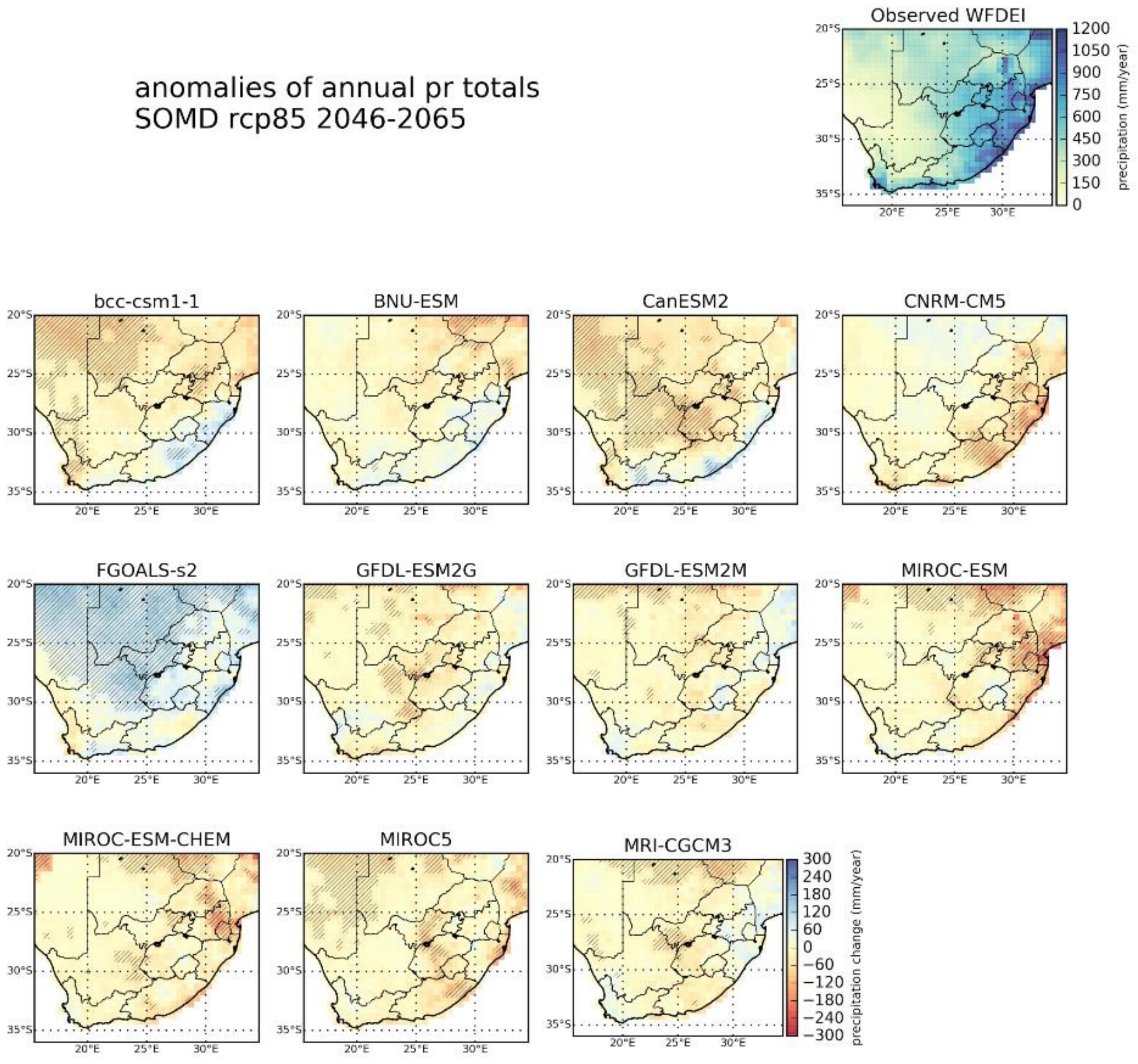
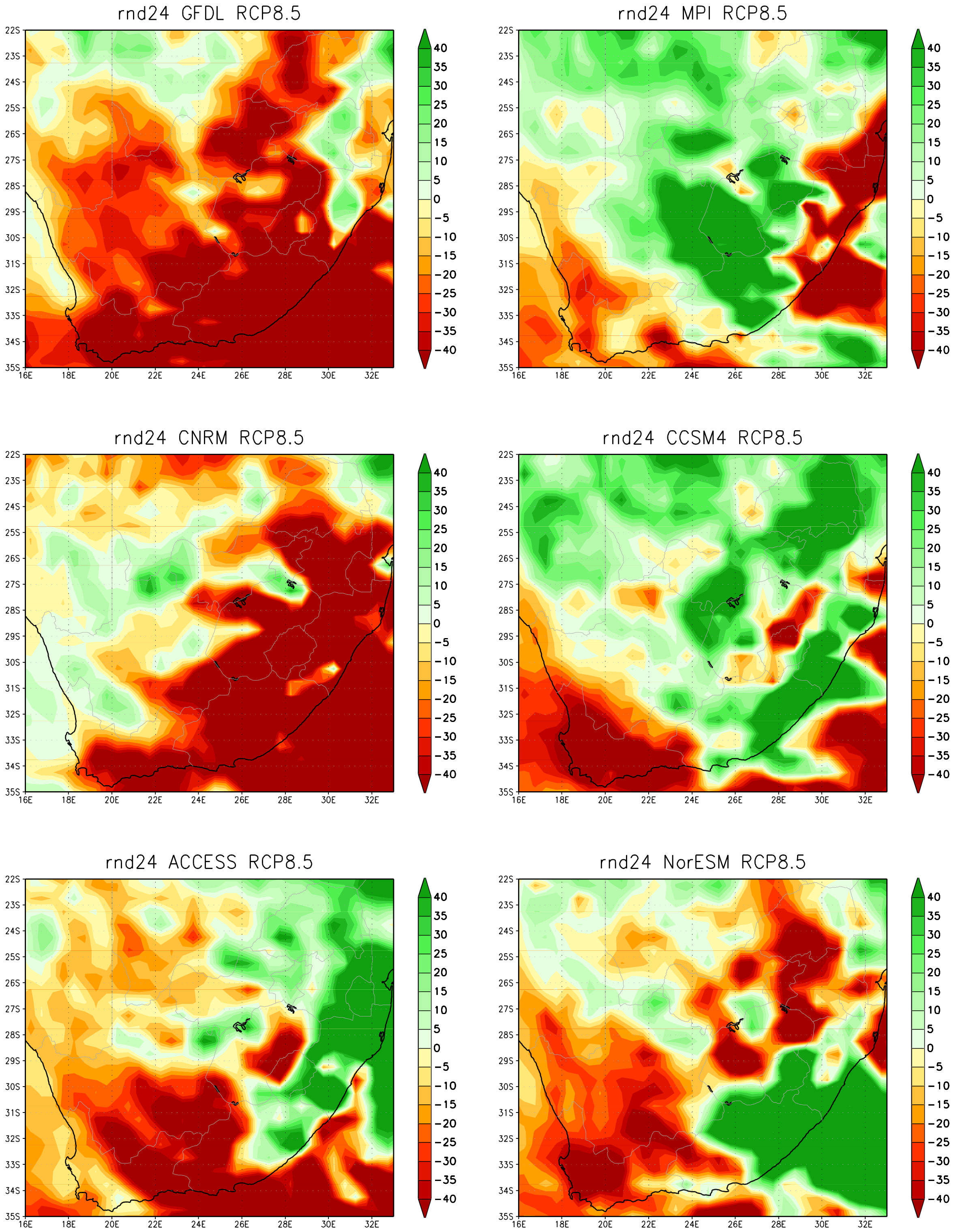


Figure B.26b: Statistically-downscaled projected changes in annual total rainfall (mm) under the RCP 8.5 pathway for the 2046-2065 period.



rnd24 GFDL RCP8.5

rnd24 MPI RCP8.5

rnd24 CNRM RCP8.5

rnd24 CCSM4 RCP8.5

rnd24 ACCESS RCP8.5

rnd24 NorESM RCP8.5

Figure B.27a: CCAM dynamically downscaled projected changes in annual total rainfall (mm) under the RCP 8.5 pathway for the 2016-2035 period.

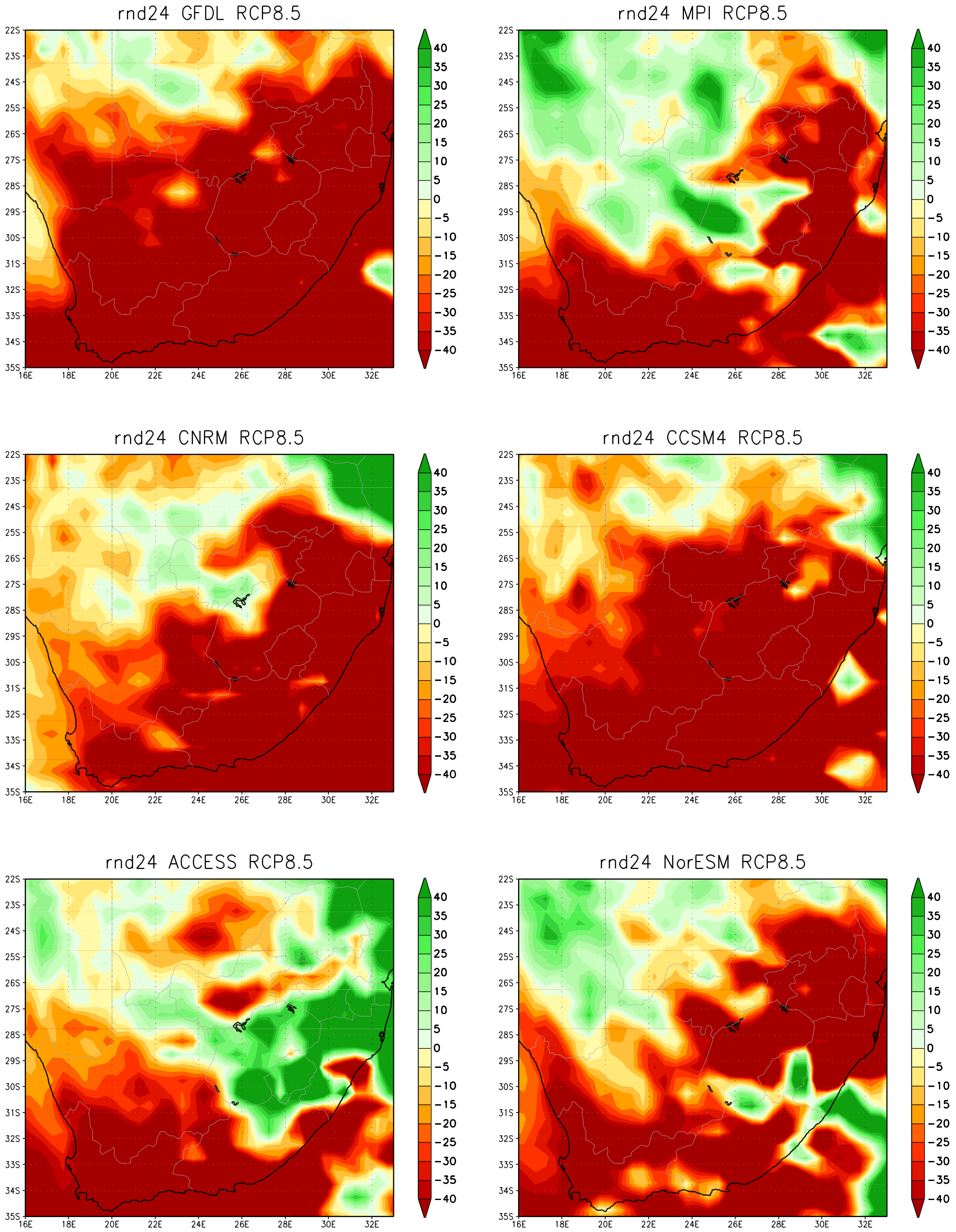


Figure B.27b: CCAM dynamically downscaled projected changes in annual total rainfall (mm) under the RCP 8.5 pathway for the 2046-2065 period.

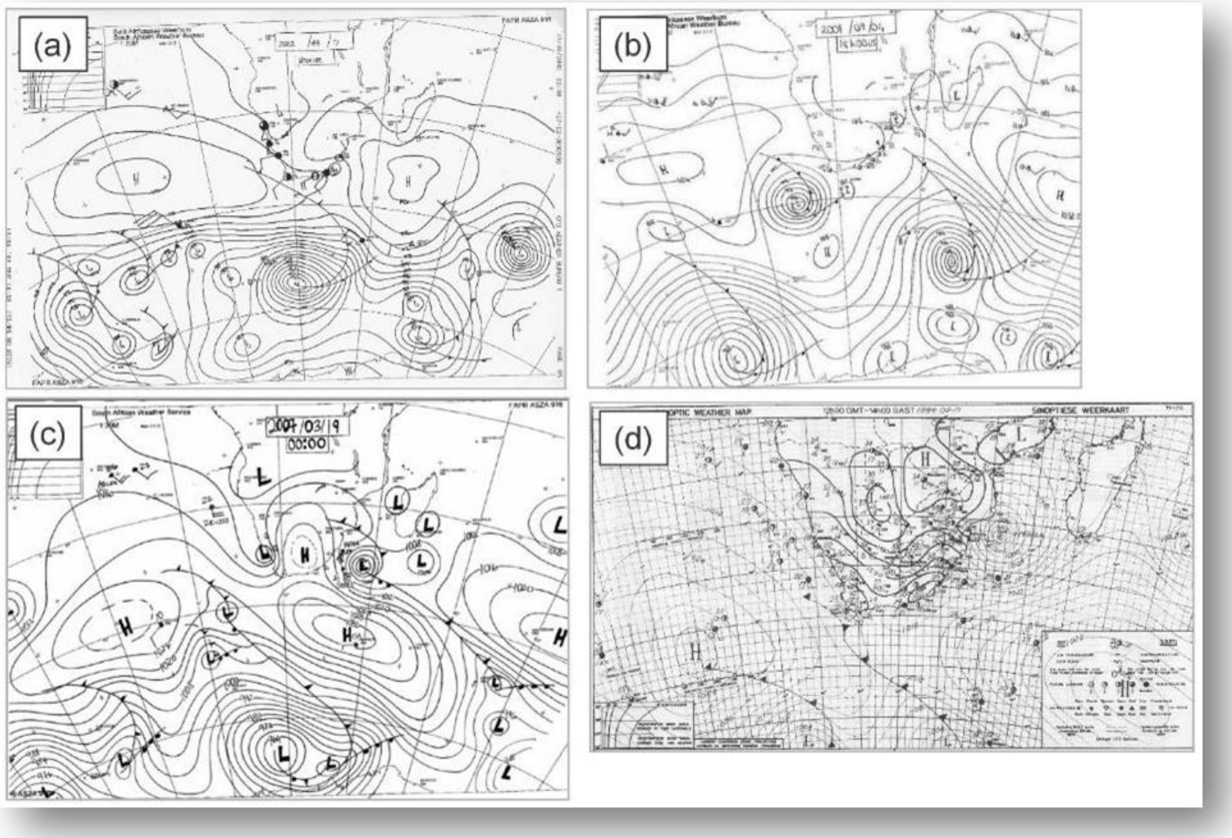


Figure B.28a-d: Synoptic charts illustrating four types of weather system (Produced by the South African Weather Service, 1984, 2001, 2002 and 2007).

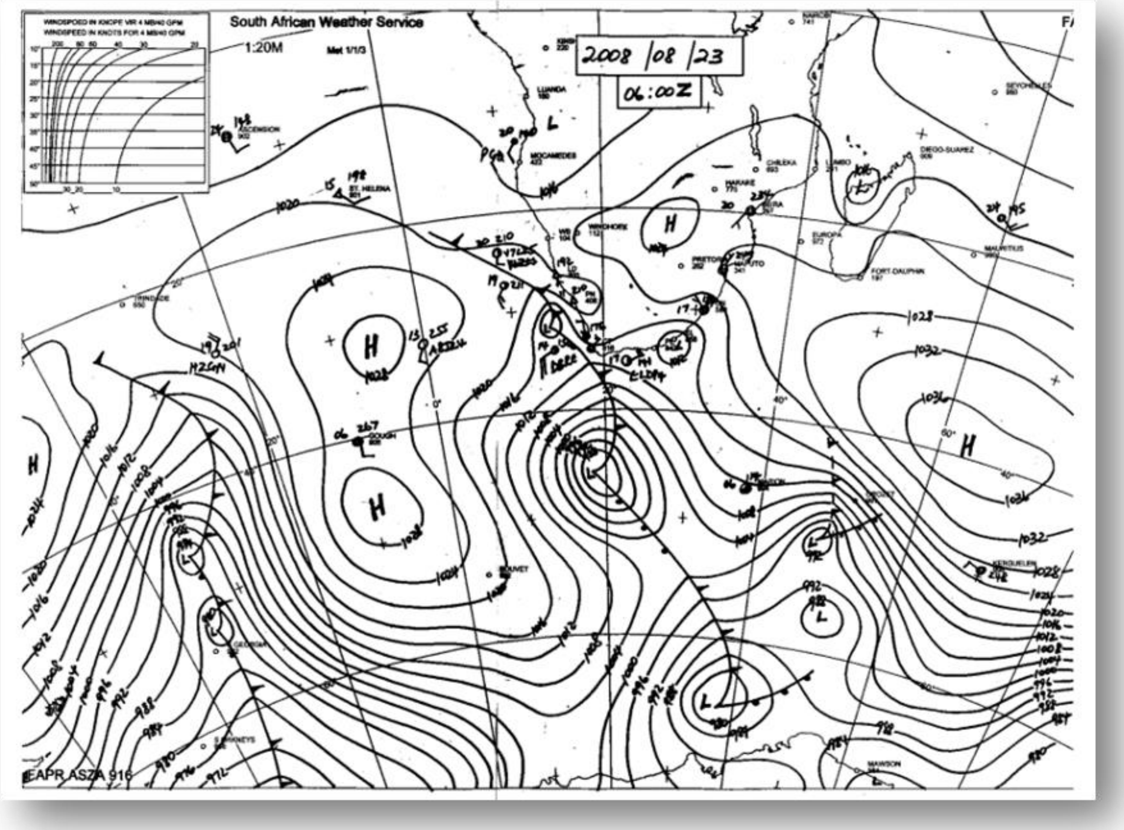
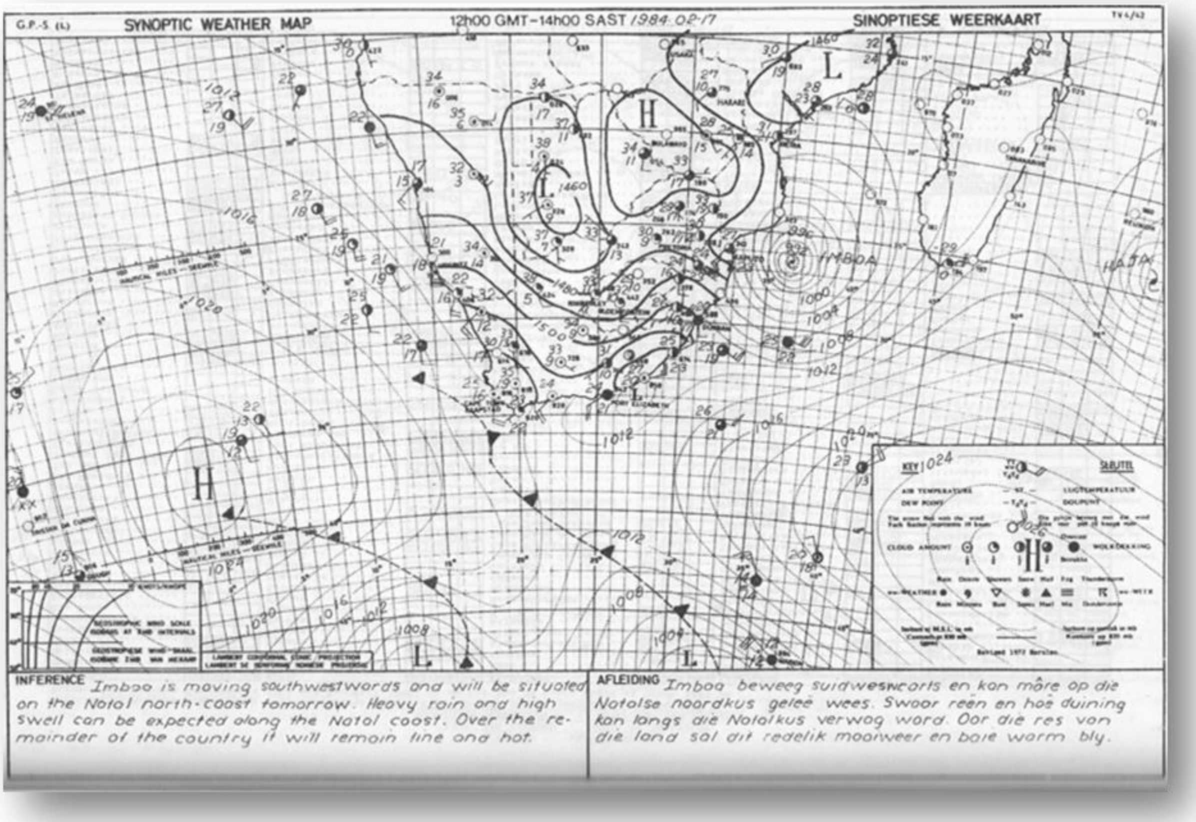


Figure B.29: Synoptic chart illustrating the frontal system approaching the Cape coast (**Produced by the South African Weather Service**).



INFERENCE Imboa is moving southwestwards and will be situated on the Natal north-coast tomorrow. Heavy rain and high swell can be expected along the Natal coast. Over the remainder of the country it will remain fine and hot.

AFLEIDING Imboa beweeg suidweswaarts en kan môre op die Natalse noordkus geleë wees. Swaar reën en hoë deining kan langs die Natalkus verwag word. Oor die res van die land sal dit redelik mooiweer en baie warm bly.

Figure B.30: Synoptic chart illustrating the cut-off low system off the east coast (**Produced by the South African Weather Service**)

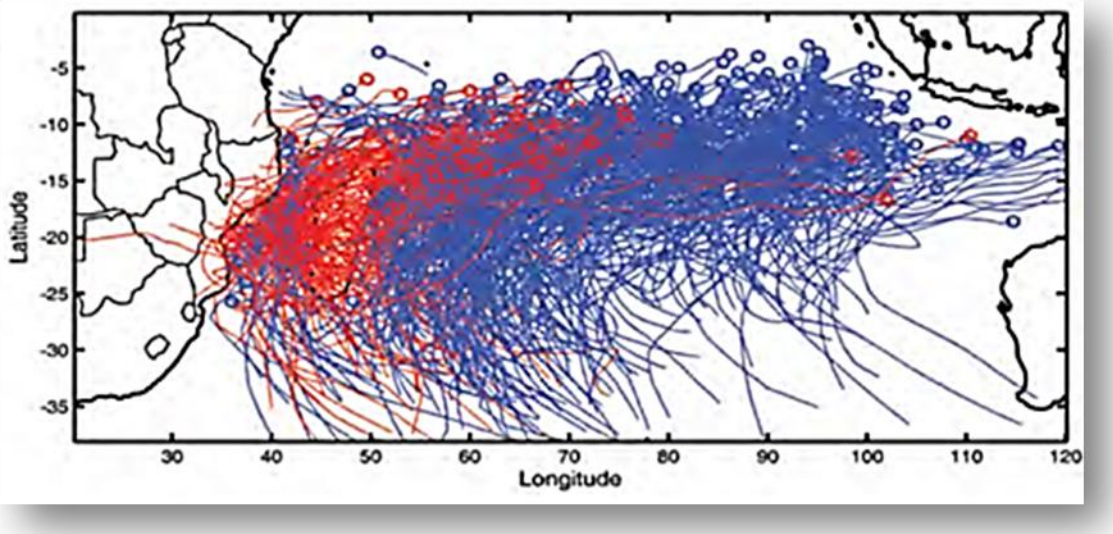
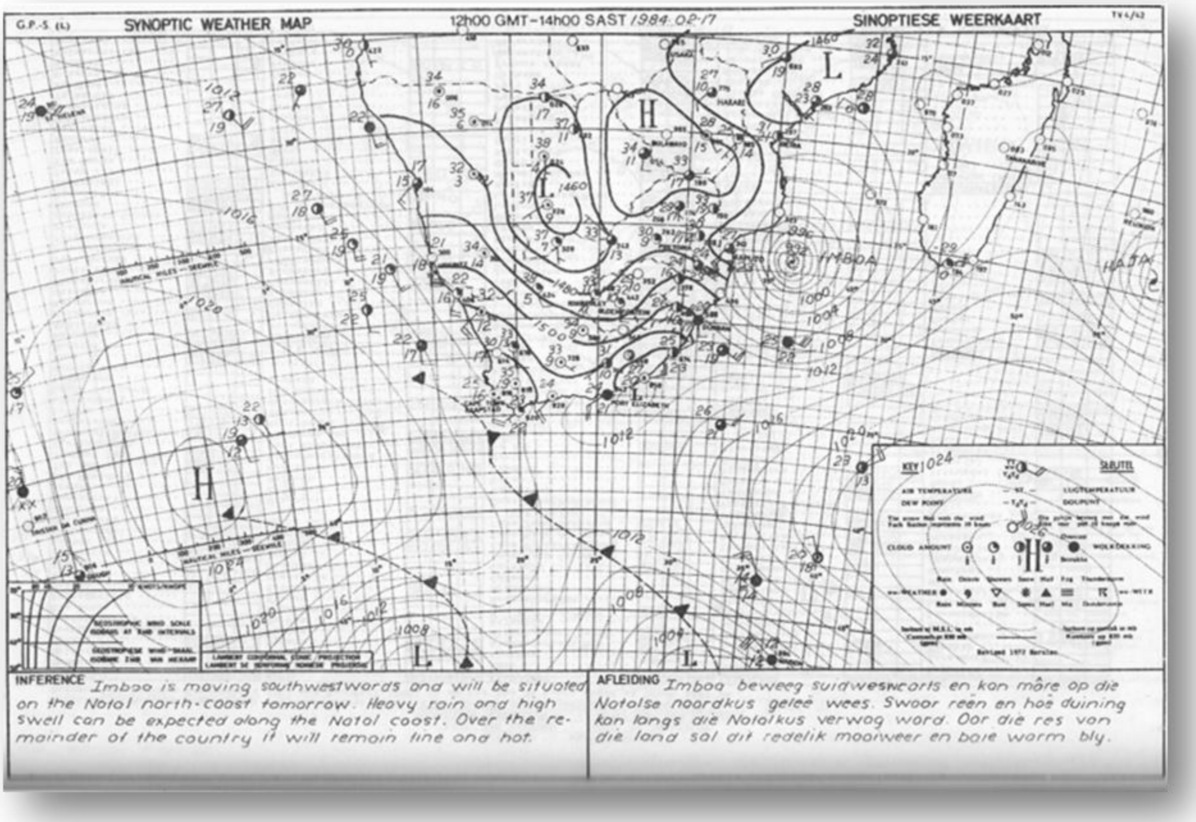


Figure B.31: Cyclone tracks during November to April in the south-western Indian Ocean from 1952 to 2007 (**Mavume** ***et al.,*** **2009**)



INFERENCE Imboa is moving southwestwards and will be situated on the Natal north-coast tomorrow. Heavy rain and high swell can be expected along the Natal coast. Over the remainder of the country it will remain fine and hot.

AFLEIDING Imboa beweeg suidweswaarts en kan môre op die Natalse noordkus geleë wees. Swaar reën en hoë deining kan langs die Natalkus verwag word. Oor die res van die land sal dit redelik mooiweer en baie warm bly.

Figure B.32: Synoptic chart showing tropical cyclone Imboa on the east coast (**Produced by the South African Weather Service**)

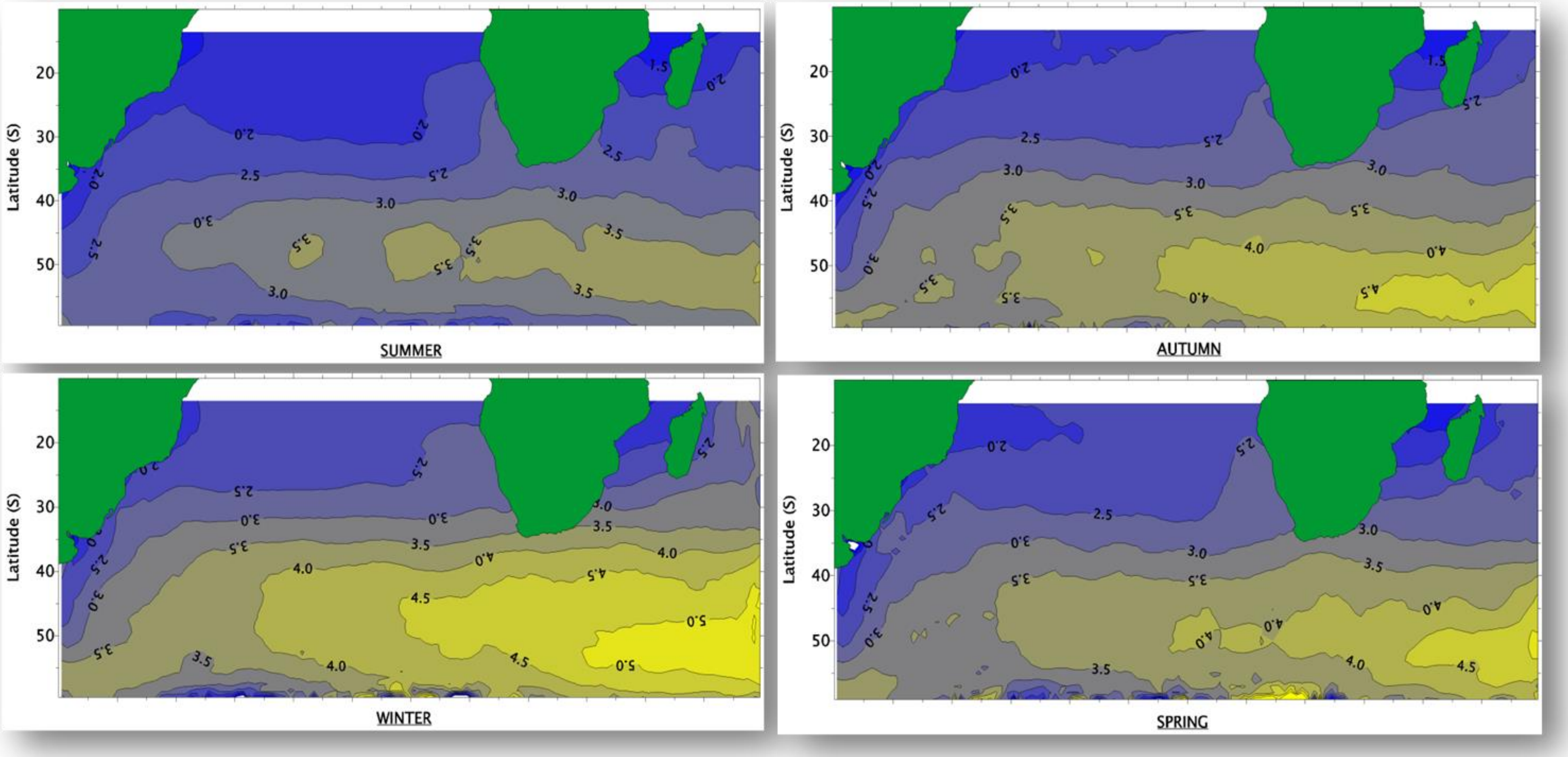


Figure B.33: Average wave height on a seasonal basis (**Based on Topex data**).

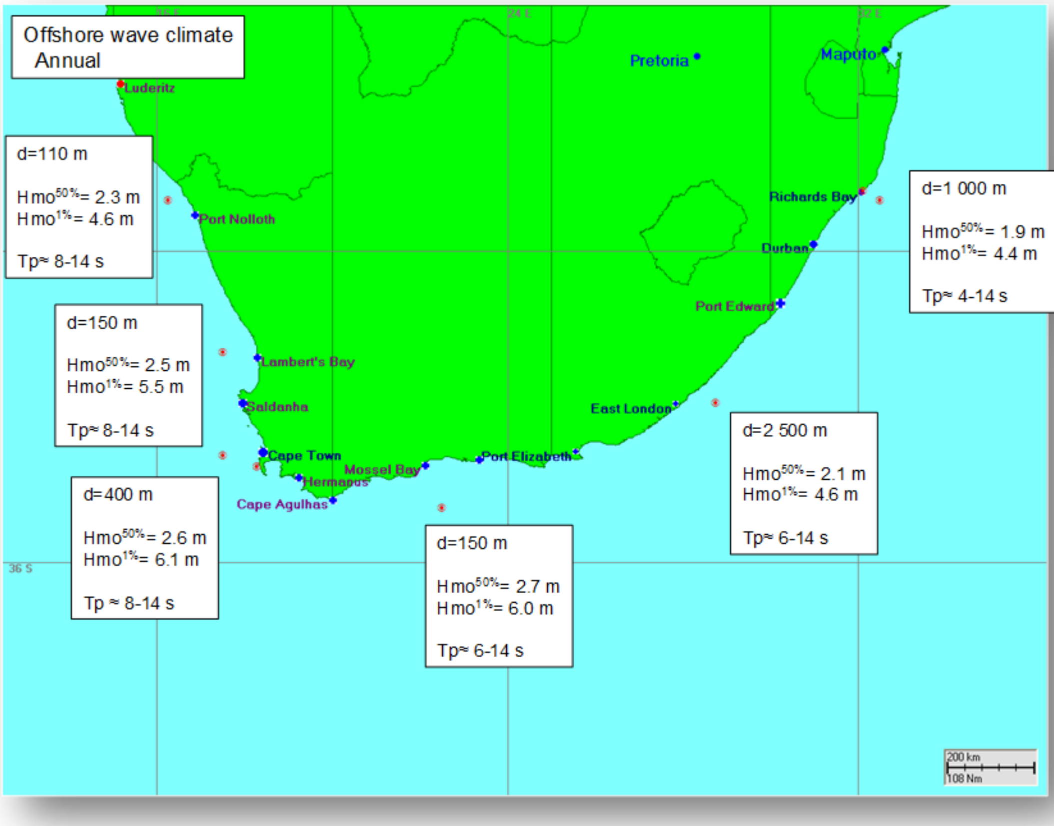


Figure B.34: Overview of wave height and period distribution around the South African coast.

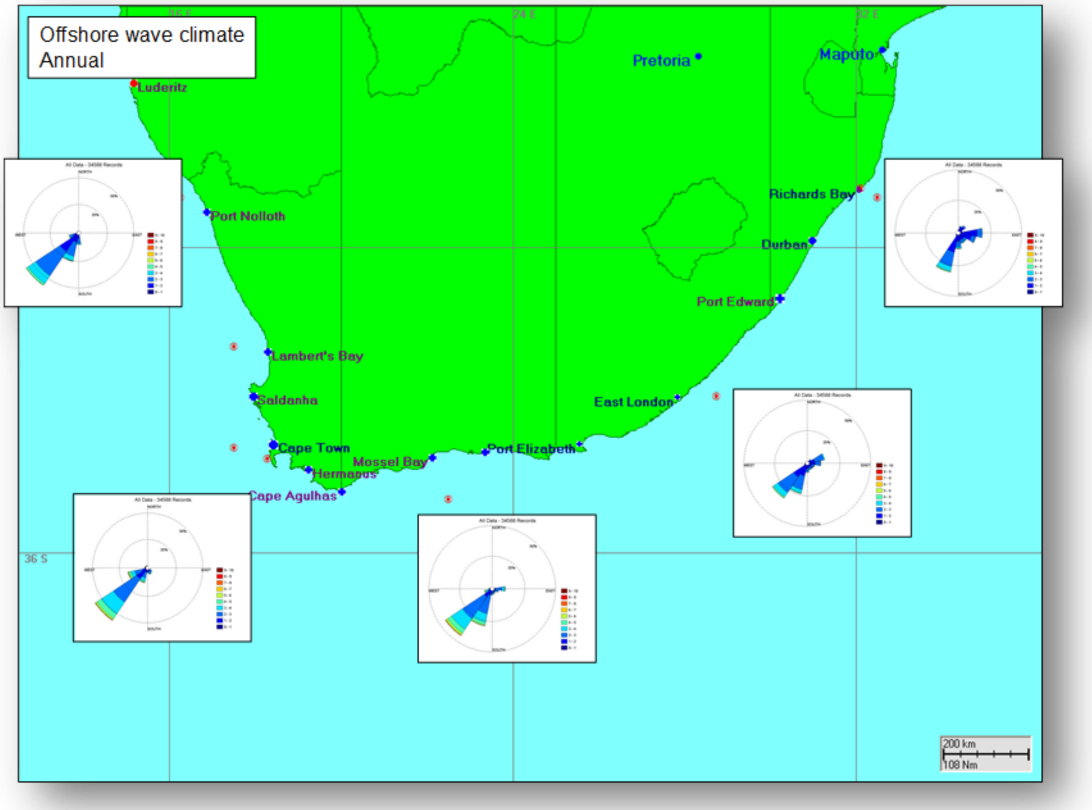


Figure B.35: Overview of wave directionality around the South African coast

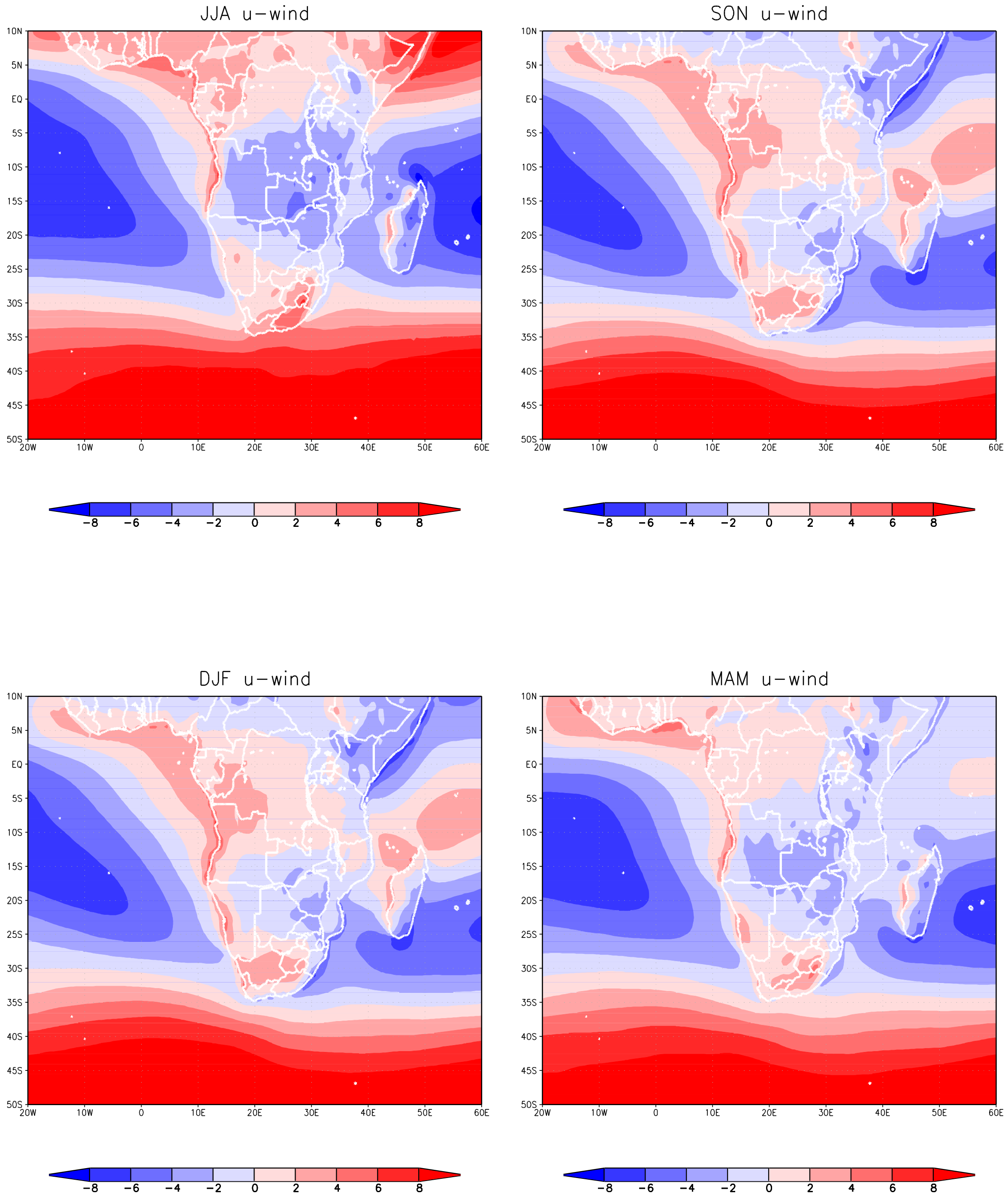


Figure B.36: CCAM simulated present-day (1961-1990) seasonal cycle in 1000 hPa zonal winds over southern Africa.

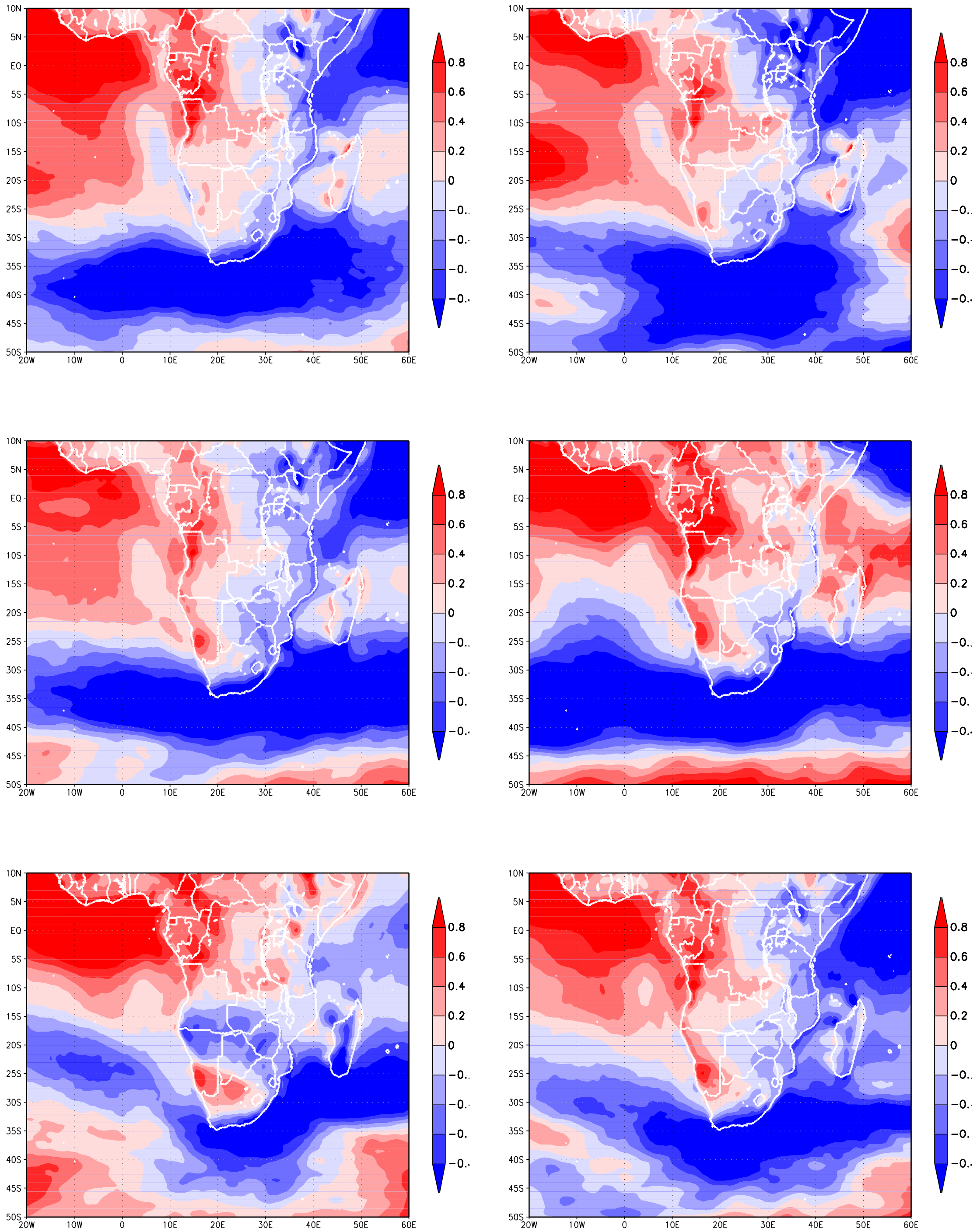


Figure B.37: CCAM projected changes in the average winter (June-August) zonal wind component over southern Africa, for 2071-2100 relative to 1961-1990.

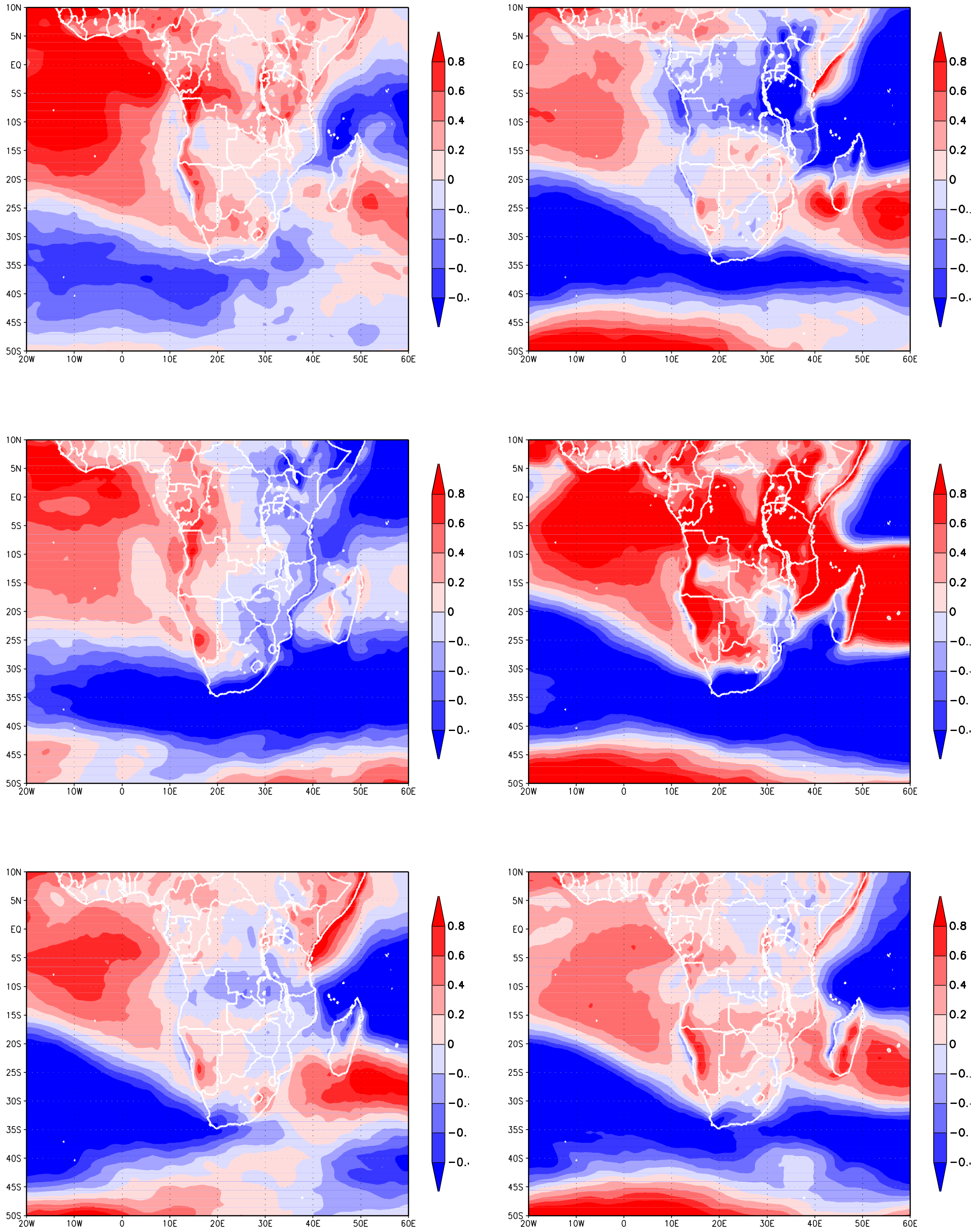


Figure B.38: CCAM projected changes in the average summer (January-February) zonal winds over southern Africa, for 2071-2100 relative to 1961-1990.

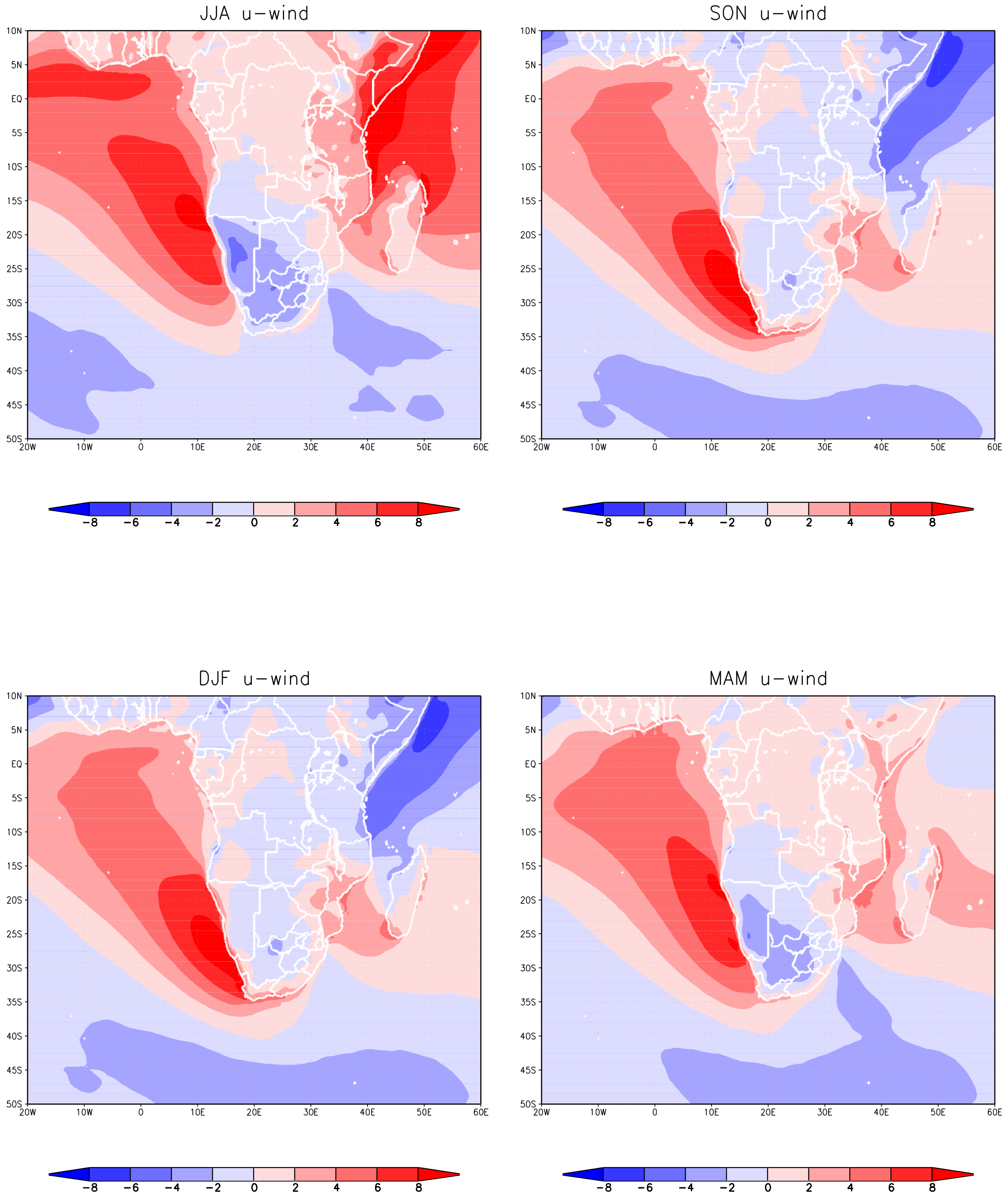


Figure B.39: CCAM simulated present-day (1961-1990) seasonal cycle in 1000 hPa meridional winds over southern Africa

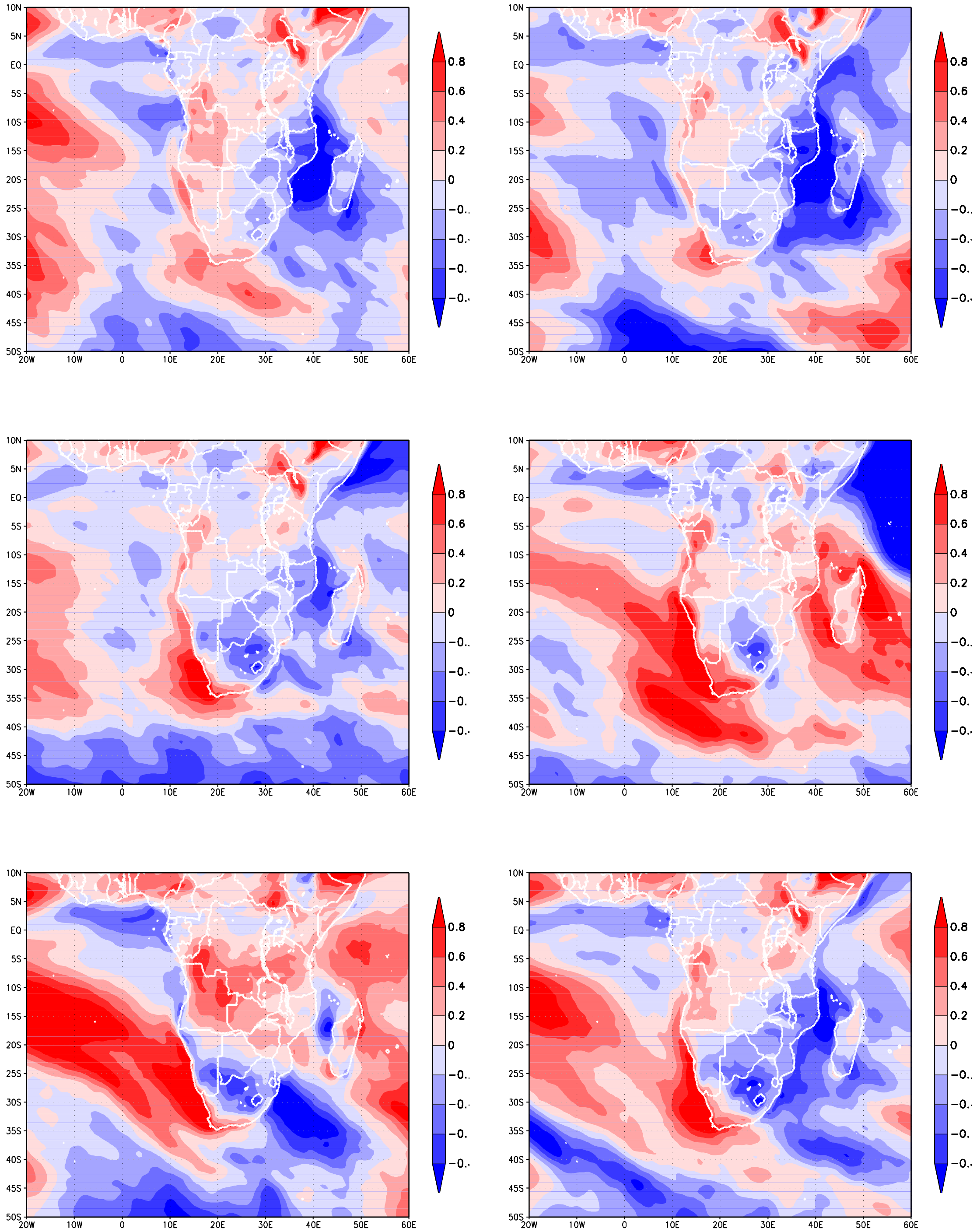


Figure B.40: CCAM projected changes in the average winter (June-August) meridional winds over southern Africa, for 2071-2100 relative to 1961-1990.

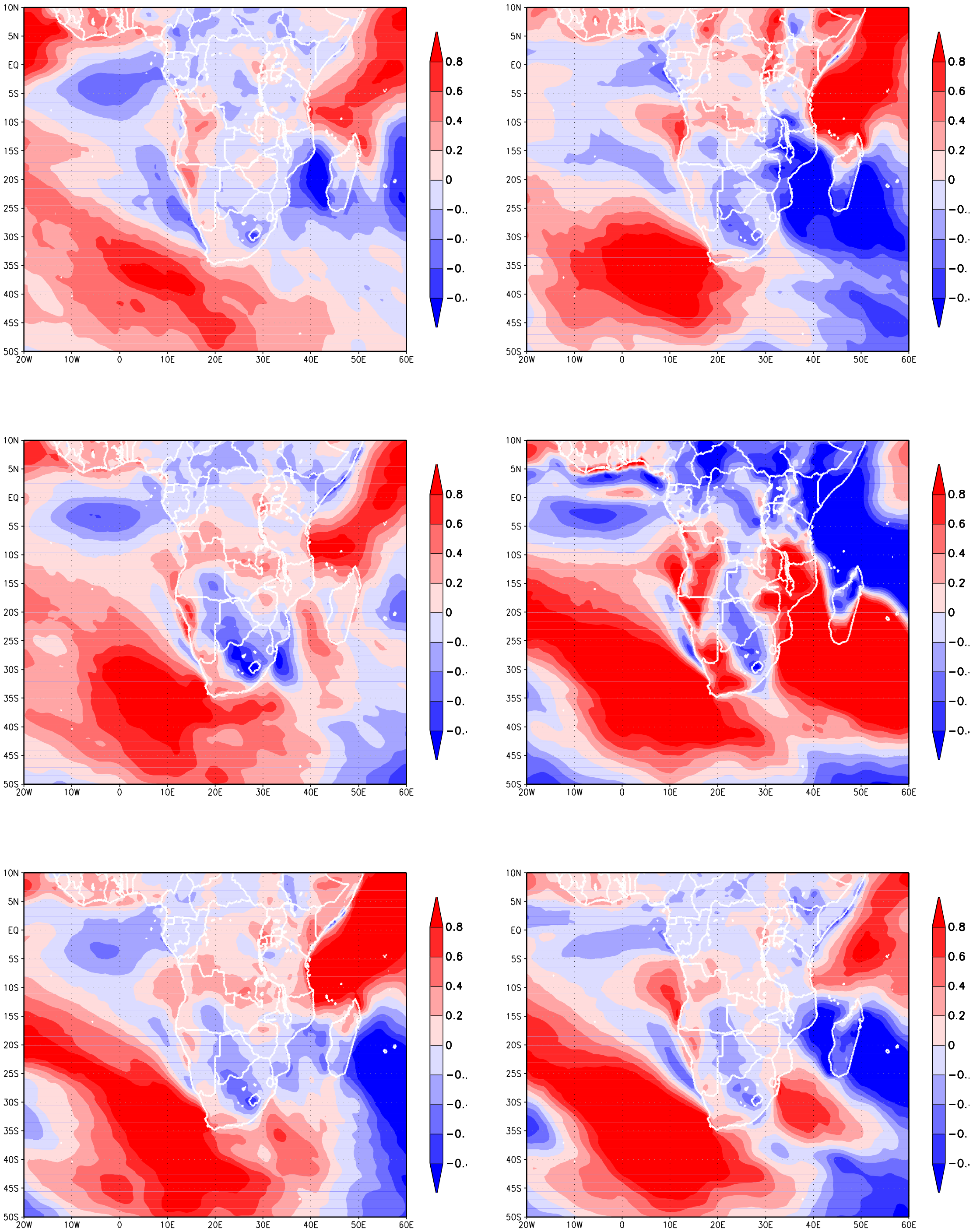


Figure B.40: CCAM projected changes in the average summer (December-February) meridional winds over southern Africa, for 2071-2100 relative to 1961-1990.

Appendix B3

B3.1 Sector vulnerability assessment framework

The following section outlines each component of the vulnerability assessment according to 5 key steps. In the sector assessments vulnerability to climate change is a function of three components; exposure, sensitivity and adaptive capacity, which are influenced by a range of biophysical and socio-economic factors. A highly vulnerable system would be one that is very sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and for which the ability to adapt is severely constrained. Through the sensitivity and adaptive components, this concept (Figure B.41) takes into account that socio-economic systems can reduce or intensify climate change impacts. These steps are described in more detail in Table B3.

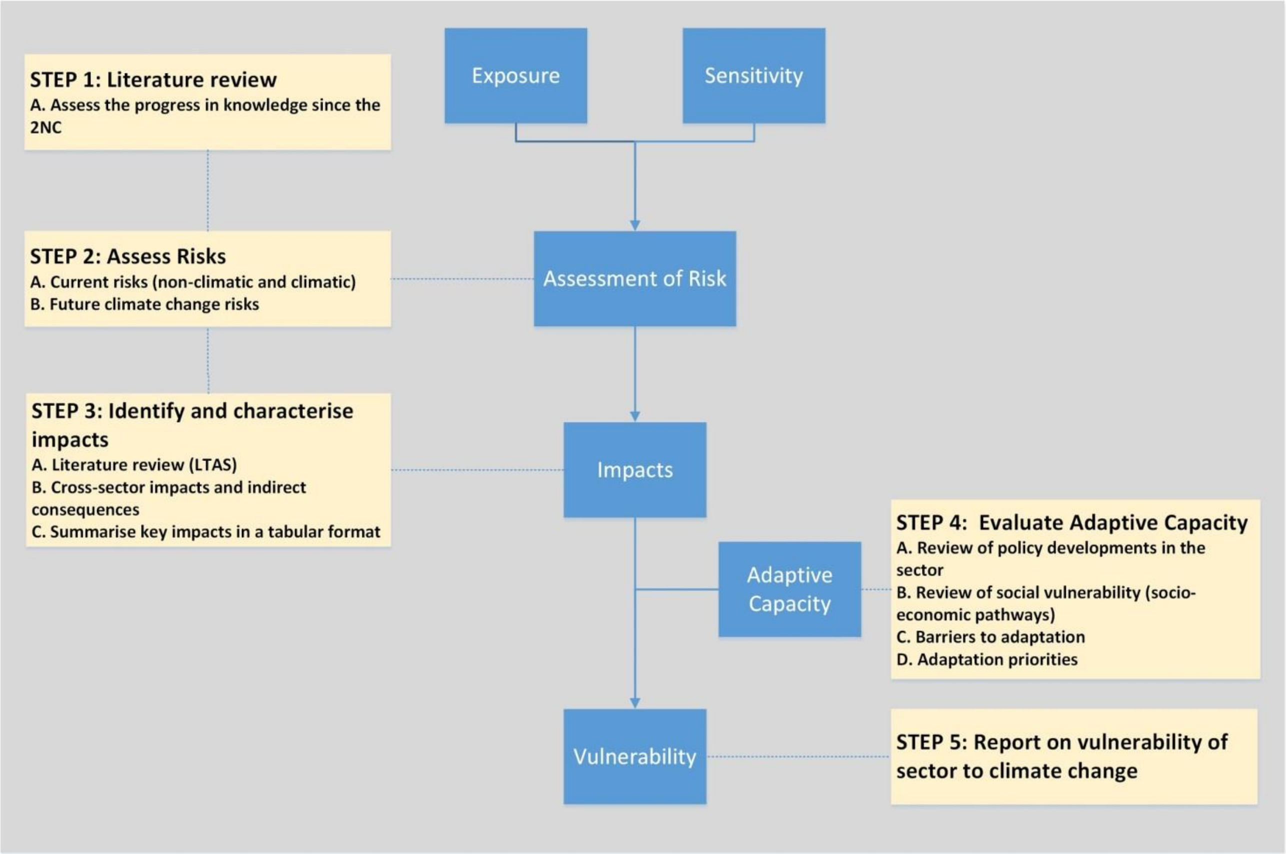


Figure B.41: Assessment framework: step-based approach to assess vulnerability in each of the sectors

Table B3: Description of each of the steps shown in the figure above

Conduct a literature review outlining specific progress in knowledge development since the 2nd National Communication. This needs to cover LTAS reports and any published or grey literature since 2011.

2. (A) Provide an assessment, based on literature, of the current risks as the starting point for the assessment in each sector. This process will identify either climatic and/or non-climatic drivers of change or stressors in each of the sectors. These would include, for example, the vulnerability of the sector to climate variability (droughts, flash floods) or to land-use change and urbanisation. Provide a list of current risks, each with a short narrative describing the sensitivity of the sector to the risk and highlighting the driver behind the risk.

2. (B) Using the climate change projections, and based on findings in literature, identify key climate change related risks that pose specific adverse consequences to the sector. Climate change projections will be provided and these will need to be used to guide assessment of this section. Provide a list of future climate related risks, each with a short narrative describing the sensitivity of the sector to the climate related risk and if possible spatial maps identifying risks.

3. (A) Building on Step 1A provide an assessment of the current state of knowledge of the key climate change impacts to the sector.

3. (B) Identify cross-sectoral impacts. This implies outlining impacts in your sector that will also play out in thematic areas such as economy and employment; infrastructure; food security; invasive species, land-use change; social protection/well-being; education and innovation.

4. (A) Review of policy developments in the sector since the 2nd National Communication. This provides an important context for understanding institutional capacity and the adaptive capacity of the sector to climate change. It also provides an understanding of the extent to which climate change risks are included in sector-specific policies.

4. (B) Assess if or how vulnerability to key climate risks has changed in the sector since the 2nd National Communication; increased or decreased and state the possible reasons for this. This section will capture the changing nature of vulnerability and the role of socio-economic changes in shaping the vulnerability to climate change. Ideally, this should also provide a measure against which the change of vulnerability to key climate risks can be compared at the time of the 4th National Communication.

4.(C) Provide an overview of institutional arrangements and the current allocations of responsibilities, and review the ability of the sector, including programmes, organisations and initiatives involved in working in the sector (e.g. Working For programmes), to respond to climate change.

4. (D) Identify barriers that are impacting or may come to impact the sector’s ability to improve the resilience to climate risks

4. (E) Provide a review of key adaptation priorities required in the sector in order to improve the resilience to climate risks.

Compile the final report

B3.2 Key terminology:

Adaptive capacity refers to the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC, 2014).

Exposure refers to the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC, 2014).

A natural **hazard** refers to a "process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage" (www.unisdr.org). A hazard can be incremental temperature or precipitation change, which unfolds gradually over a long time, or it can refer to weather-related hazards, such as droughts, floods and heat waves.

Impacts, in the context of this review, refer to the effects of climate change on natural and human systems (IPCC 2012).

Resilience is defined as the capacity for a socio-ecological system to (a) absorb stresses and maintain normal functioning in the face of external stress and (b) to adapt in order to be better prepared to future impacts (Folke 2006).

Risk is the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard (Field *et al.,* 2014).

Sensitivity is the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise) (Field *et al.,* 2014).

Vulnerability is the “propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt” (Field *et al.,* 2014).

Top-down vulnerability assessments is where vulnerability is seen through **“**global or regional climate change projections perspective, focused on direct cause-and-effect relationships within systems of interest;” approach is “amenable to quantitative analysis” (Jones & Preston, 2011: 299-300).

Bottom-up vulnerability assessments is where vulnerability **“**begins at the local scale perspective;” focuses on current and emerging risks, the social and environmental factors that underpin risk and the capacity for risk management” (Jones & Preston, 2011: 300; Science for Environment Policy, 2016).

B3.3 Vulnerability assessment expert workshop

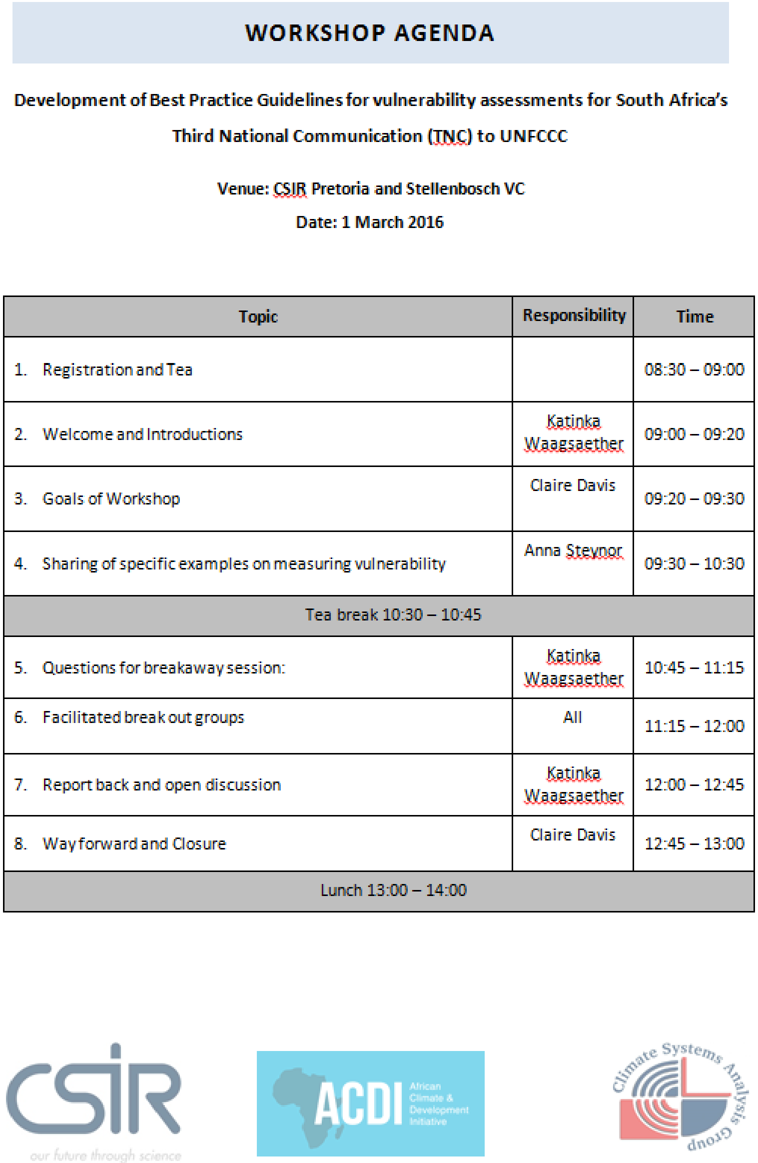
On 1 March 2016 CSIR, ACDI and CSAG hosted a workshop with vulnerability experts on climate vulnerability assessment methodologies. The purpose of the workshop was to exchange knowledge, research and experiences on climate vulnerability assessments (VAs), in order to inform the thinking and framing of the VA component of the Third National Communication (TNC). The workshop was designed around three key questions:

1. What should the purpose of a national vulnerability assessment be?
2. What are the principles and guidelines that should steer the development of a national framework for vulnerability assessments?
3. Given the status quo (time frames, sectoral approach, limited scope for new research), please provide a set of recommendations for how we can best frame the vulnerability component of the TNC?

The first question was intended to create a sense of *why*, ‘towards what end,’ a national VA should be developed. A diverse number of purposes arose, ranging from prioritisation of resources at a national scale, to consolidating role players and responsibilities, to enabling local and provincial implementation, to comparing sectors and monitoring progress. It was evident that it is not possible to consolidate the variety of purposes towards a single national VA framework. As was also illustrated in the literature review above, the variety of purposes identified at the workshop further made it evident that VAs are needed for a variety of contexts, scales and aims. Each of these will require a slightly different approach, and thus a different framing.

The second question was intended to reap expert experiences around *how* VAs can best be developed, in a way that is scientifically robust and ethically sound. A large number of suggestions were made, including for example “should integrate top down with bottom up approaches,” and “should have participatory – objective balance.” Again, it was not possible to consolidate the diversity of suggestions into one framework outlining how to conduct VAs. Instead, these were used as the foundation for the development of best practice guidelines for how to conduct VAs, presented in this section.

The third question was aimed at informing the sectoral vulnerability assessment chapter being developed as part of the TNC. Here, recommendations ranged the need to ensure that the chapters “reflect the changes/progress since the SNC” to “calculating the cost of adaptation” to applying “consistent projection methodologies.” The recommendations were used to guide development of the framework for the sectoral TNC chapters.



WORKSHOP AGENDA

Development of Best Practice Guidelines for vulnerability assessments for South Africa's Third National Communication (TNC) to UNFCCC

Venue: CSIR Pretoria and Stellenbosch VC

Date: 1 March 2016

Topic	Responsibility	Time
1. Registration and Tea		08:30 – 09:00
2. Welcome and Introductions	Katinka Waagsaether	09:00 – 09:20
3. Goals of Workshop	Claire Davis	09:20 – 09:30
4. Sharing of specific examples on measuring vulnerability	Anna Steynor	09:30 – 10:30
Tea break 10:30 – 10:45		
5. Questions for breakaway session:	Katinka Waagsaether	10:45 – 11:15
6. Facilitated break out groups	All	11:15 – 12:00
7. Report back and open discussion	Katinka Waagsaether	12:00 – 12:45
8. Way forward and Closure	Claire Davis	12:45 – 13:00
Lunch 13:00 – 14:00		

CSIR our future through science

ACDI African Climate & Development Initiative

Climate Systems Analysis Group

Figure 3B42: Vulnerability assessment workshop agenda

B3.4 National and International Tools

International guideline documents for assisting decision-makers in assessing vulnerability to climate change

Bottom-up

- CRiSTAL – Community-based Risk Screening Tool – Adaptation and Livelihoods (www.iisd.org/cristaltool)
- CARE Climate Vulnerability and Capacity Analysis Handbook (Daze *et al.,* 2009)
- Participatory Capacity and Vulnerability Analysis – Finding the Link Between Disasters and Development (de Dios 2002)
- CEDRA – Climate change and Environmental Degradation Risk and adaptation Assessment (Wiggins & Wiggins 2009)

Top-down

- Scanning the Conservation Horizon – A Guide to Climate Change Vulnerability Assessment (Glick *et al.,* 2011)
- Review of climate change adaptation methods and tools (Schipper *et al.,* 2010)
- Impacts, Vulnerabilities and Adaptation in Developing Countries (UNFCCC 2007)

Combination

- The Toolkit for Vulnerability and Adaptation Training by the Stockholm Environment Institute (Downing & Ziervogel 2004)
- The United Nations Framework Convention on
- Climate Change (UNFCCC) Compendium (UNFCCC 2008)
- Gender and Climate Change Research in Agriculture and Food Security for Rural Development by the Food and Agriculture Organization (Nelson & Chaudhury 2012)
- Vulnerability Assessment Methodology Review Synthesis (SADC-FANR RVAC), (Frankenberger *et al.,* 2005)

National Communication specific

- Handbook on Vulnerability and Adaptation Assessment (Benioff *et al.,* 2012)
- The UNFCCC Resource Guide for Preparing
- the National Communications of Non-Annex I Parties – Module 2: Vulnerability and Adaptation to Climate Change (Heaps & Kollmuss 2008)

Acronyms

ACCESS	Applied Centre for Climate and Earth Systems Sciences
ACC	Africa Adaptation Climate Change in Africa
ACDI	African Climate and Development Initiative
ACEP	African Coelacanth Ecosystem Programme
ACMP	Association of Cementitious Material Producers
AEON	African Earth Observation Network
AERONET	Aerosol Robotic Network
AFOLU	Agriculture, Forestry and Other Land Use
ANC	African National Congress
ARC	Agricultural Research Council
AREP	Atmospheric Research and Environment Programme
ARS AfricaE	Adaptive Resilience of Southern African Ecosystems
ARSAIO	Atmospheric Research in Southern Africa and Indian Ocean
ASCLME	Agulhas and Somali Current Large Marine Ecosystems
AU	African Union
BGIS	Biodiversity GIS
CACGP	International Commission on Atmospheric Chemistry and Global Pollution
CAIA	Chemical and Allied Industries Association
CAPS	Curriculum and Assessment Policy Statement
CAS	Commission for Atmospheric Science
CBO	Community Based Organisation
CC	Climate Change
CCE	Climate Change Education
CCESD	Climate Change Education for Sustainable Development
CCS	Carbon capture and storage

CDM	Clean Development Mechanism
CGS	Council for Geoscience
CIP	Climate Information Portal
CO2	Carbon dioxide
CO2eq	Carbon dioxide equivalent
COGTA	Cooperative Governance and Traditional Affairs
CoPs	Communities of Practice
CORDEX	Co-ordinated Regional Downscaling Experiment
CSAG	Climate System Analysis Group
CSIR	Council for Scientific and Industrial Research
DAAD	German Academic Exchange Service
DAEA	Department of Agriculture and Environmental Affairs
DAFF	Department of Agriculture, Forestry and Fisheries
DANIDA	Danish International Development Agency
DBE	Department of Basic Education
DEA	Department of Environmental Affairs
DEAD&P	Department of Environmental Affairs and Development Planning
DEBITS	Deposition of Biogeochemically Important Trace Species
DEDEA	Department of Economic Development and Environmental Affairs
DERO	Desired Emission Reduction Outcome
DHET	Department of Higher Education and Training
DMR	Department of Mineral Resources
DNA	Designated National Authority
DoA	Department of Agriculture
DoE	Department of Energy
DOH	Department of Health
DRR	Disaster Risk Reduction

DST	Department of Science and Technology
DTI	Department of Trade and Industry
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
ECDEDEA	Eastern Cape Department of Economic Development and Environmental Affairs
ELTOSA	Environmental Long Term Observatories of Southern Africa network
EM	Emission Factor
EO	Earth Observation
ESD	Education for Sustainable Development
FAO	Food and Agriculture Organization
FET	Further Education and Training
FMI	Finnish Meteorological Institute
FSA	Forestry South Africa
GAW	Global Atmospheric Watch
GBIF	Global Biodiversity Information Facility
GCA	Global Carbon Atlas
GCIS	Government Communication and Information System
GCOS	Global Climate Observing System
GCRP	Global Change Research Plan
GDARD	Gauteng Department of Agriculture and Rural Development
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GEOSS	Global Earth Observation System of Systems
GFCS	Global Framework for Climate Services
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GOODS	Global Ocean Observing System

GTI	GeoTerraImage
GWC	Growth without constraints
GWP	Global Warming Potential
HSRC	Human Sciences Research Council
HWP	Harvested wood products
ICSU	International Council for Science
ICT	Information and communication technology
IEP	Integrated Energy Plan
IGAC	International Global Atmosphere Chemistry
IOC	Intergovernmental Oceanographic Commission
IOCAFRICA	Intergovernmental Oceanographic Sub-Commission for Africa and Adjacent Island
IPAP	Industrial Policy Action Plan
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Process and Product Use
IRENA	International Renewable Energy Agency
ISCW	Institute of Soil Climate and Water
Kt	Kilotonne
LTMS	Long-Term Mitigation Scenario
LTSM	Learning and Teaching Support Material
MACC	Marginal abatement cost curve
MRC	Medical Research Council
Mt	Mega tonnes
NAAQMN	National Ambient Air Quality Monitoring Network
NAC	Net annual cost
NAMA	Nationally Appropriate Mitigation Action
NC	National Communications
NCCC	National Committee on Climate Change

NCCRD	National Climate Change Response Database
NCCRWP	National Climate Change Response White Paper
NDA	National Designated Authority
NDE	National Designated Entities
NERSA	National Energy Regulator of South Africa
NFCS	National Framework for Climate Services
NGO	Non-Governmental Organisation
NGO	Non-Governmental Organisation
NHGHIS	National GHG Inventory System
NIE	National Implementing Entity
NPC	National Planning Commission
NRF	National Research Foundation
NTCSA	National Terrestrial Carbon Sinks Assessment
NWIBR	National Waste Baseline Information Report
NWU	North-West University
ODINAFRICA	Ocean Data and Information Network for Africa
OFO	Organising Framework for Occupations
PDD	Peak, plateau and decline
PES	Payment for Ecosystem Services
QCTO	Quality Council for Trade and Occupations
REI4P	Renewable Energy Independent Power Producer Procurement Programme
RSSC	Regional Science Service Centre
RVAC	Risk and Vulnerability Assessment Centre
RVSC	Risk and Vulnerability Science Centre
SAAQIS	South African Air Quality Information System
SABIF	South African Biodiversity Information Facility
SACCCS	South African Centre for Carbon Capture and Storage

SADC	Southern African Development Community
SADCO	Southern African Data Centre for Oceanography
SAEON	South African Environmental Observation Network
SAEOSS	South African Earth Observation System of Systems
SAFFG	South African Flash Flood Guidance System
SAGE	Stratospheric Aerosol and Gas Experiment
SA-GEO	South African Group on Earth Observations
SAIAB	South African Institute of Aquatic Biodiversity
SA-ICON	South African Carbon Observatory Network
SAISI	South African Iron and Steel Institute
SALGA	South African Local Government Association
SAMI	South African Mineral Industry
SANAE	South African National Antarctic Expedition
SANAP	South African National Antarctic Programme
SANBI	South African National Biodiversity Institute
SANEDI	South African National Development Institute
SANParks	South African National Parks
SANSA	South African National Space Agency
SAP	Strategic Action Programme
SAPIA	South African Petroleum Industry Association
SARChI	South African Research Chairs Initiative
SARFFG	South African Regional Flood Guidance System
SARUA	Southern African Regional Universities Association
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land
SAURAN	Southern African Universities Radiometric Network
SAWEP	South African Wind Energy Project
SAWS	South African Weather Service

SHADOZ	Southern Hemisphere Additional Ozonesondes
SNC	Second National Communication
SOCAT	Surface Ocean CO2 Atlas
SOCCO	Southern Ocean Carbon and Climate Observatory
SOSCEx	Southern Ocean Seasonal Cycle Experiment
SWWS	Severe Weather Warning System
TDA	Transboundary Diagnostic Analysis
TECH4RED	Technology for Rural and Educational Development
TIA	Technology Innovation Agency
TVET	Technical, Vocational Education and Training
UCT	University of Cape Town
UH	University of Helsinki
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations International Children’s Emergency Fund
UP	University of Pretoria
UT-LS	Upper Troposphere-Lower Stratosphere
WAM	With additional measures
WASA	Wind Atlas for South Africa
WCRP	World Climate Research Programme
WEM	With existing measures
WESSA	Wildlife and Environment Society of South Africa
WIO	West Indian Ocean
WITS	University of the Witwatersrand

WMO	World Meteorological Organization
WOM	Without measures
WRC	Water Research Commission