CGE Training Materials
for Vulnerability and Adaptation Assessment

Chapter 4
Climate Change Scenarios

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4.1. Introduction

This chapter provides guidance on the key steps required in climate change scenario development and gives an overview of the key approaches, models, tools and data sources available. Much has been written on the use of climate models in developing climate change scenarios, and this is not replicated here. Instead, this chapter aims to provide a roadmap to the commonly used approaches, models, tools and data sources available for climate change scenario development and provides links to key resources for further information. As with many aspects of climate change vulnerability assessment and adaptation analysis, the field has become much more crowded and complex. As an example, the number of global climate models (GCMs) used by the Intergovernmental Panel on Climate Change (IPCC) went from 23 models in the Third and Fourth Assessment reports (Randall et al., 2007) to 42 in the Fifth Assessment Report (AR5) (IPCC, 2013). There are also a growing number of sources of information on downscaling and tools for applying climate models to help assess vulnerability to climate change and adaptation options.

This chapter provides context on the current understanding of climate change on both a global and regional levels, drawing upon the findings from IPCC AR5 Working Groups I and II, as well as upon recent literature and developments in climate datasets and tools.

As noted in chapter 2, risk management has emerged as a paradigm for climate change assessment (Jones et al., 2014). Risk management is based on the fact that uncertainty is fundamental to all long-term projections, including climate. Because risk is a product of both the probability of an outcome and the severity of its consequences, some decision makers will focus on high-probability events, while others will focus on lower-probability outcomes, depending in part on the potential consequences should climate outcomes (such as a flood of a certain level) occur.

Risk management framing leads naturally to the use of climate change scenarios (box 4-1). Climate change scenarios can consider a range of different futures tailored to the needs of individual decision makers and risk profiles, and they reinforce the idea that, although the future cannot be predicted with certainty, sufficient scientific information about the future is available to support decisions that minimize risks associated with climate change.

Box 4-1
What are climate change scenarios?

Climate change scenarios: are plausible combinations of conditions that can represent possible future situations. They are used to understand what the consequences of climate change may be, including how sensitive systems are to climate change. Scenarios can also be used to provide inputs for change impacts and vulnerability assessments, to identify and evaluate adaptation strategies, and to communicate the relative importance of greenhouse gas (GHG) mitigation.

This chapter addresses the following topics:

- Why use climate change scenarios?

- What are some reasonable approaches to developing climate change scenarios, including:
    - What global datasets on current (observed) climate are accessible?
    - What datasets, tools and methods are available for developing climate change scenarios?

- Section 4.4 provides some thoughts on how data and climate change scenarios may change in the future.

- Section 4.5 provides final summary thoughts on creating climate change scenarios.

- The appendix briefly summarizes the latest projections of climate change at the global and regional scales.

4.1.1. Why use climate change scenarios?

Climate change scenarios have been developed and applied widely because we cannot provide reliable forecasts of change in future climate. This is true for average global climate, but particularly true at the regional and local scales. The regional scale can mean scales ranging from the subcontinental scale to the country-level scale to the provincial-level scale. Although it is highly likely that temperatures will continue to rise in most regions of the world,1 changes at the regional scale in many other key variables, such as precipitation, are uncertain for many regions. Even if we can project with some confidence the direction of change, there remains uncertainty about the magnitude and path of change.

Table 4-1 briefly describes key sources of uncertainty about global and regional climate change. A critical point is that **we do not expect a significant reduction in any of these sources of uncertainty within a few years** – or perhaps longer.

If regional climate change scenarios are to be used in a vulnerability and adaptation (V&A) assessment, they must provide information on the climate variables needed by V&A assessors at the spatial and temporal scale needed for analysis. This may require daily or even sub-daily spatial data to help detect changes at a finer scale.

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1   Other anthropogenic activities, such as land-use change and emissions of air pollutants, can have significant effects on local and regional climate change relative to the influence of increased greenhouse gas concentrations.

Table 4-1
Key sources of uncertainty for climate change scenarios

Source of uncertainty	Comments
Greenhouse gas (GHG) emissions	There are a number of wide-ranging scenarios of future emissions of GHGs and other radiative important agents such as aerosols (e.g. Nakićenovic et al., 2000; Moss et al., 2010). The uncertainty is not only about anthropogenic emissions but also about balances between natural emissions and sequestration, which could change with climate change.
Climate sensitivity to changes in GHG concentrations	The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) concluded that it is very likely that a doubling of carbon dioxide (CO_2) will result in a 1°C to 6°C warming (IPCC, 2013). But science suggests that any reduction in this range does not appear feasible soon (Roe and Baker, 2007).
Regional patterns of change	Climate models continue to show significant differences on projections of regional change in climate. Furthermore, some local features such as sea breezes, which could change with climate change, are difficult to predict due to their local scale.
Climate variability	Modes of climate variability such as the El Niño Southern Oscillation (ENSO), the Arctic Oscillation and the Pacific Decadal Oscillation will continue to be important (and largely unpredictable) influences on inter-annual and inter-decadal timescales. Additionally, climate change could modify these modes of variability.

Climate change scenarios should meet the following five criteria (IPCC Data Distribution Centre, 2013):

- ***Criterion 1: Consistency with global projections.*** Scenarios should be consistent with a broad range of global warming projections based on increased concentrations of GHGs. This global range is variously cited as 1.4°C to 5.8°C by 2100, or 1.5°C to 4.5°C for a doubling of atmospheric carbon dioxide (CO2) concentration (otherwise known as the 'equilibrium climate sensitivity'). Note that greater warming is generally expected in the mid and high latitudes, while relatively less warming is expected in the tropics;

- ***Criterion 2: Physical plausibility.*** Scenarios should be physically plausible (i.e. they should not violate the basic laws of physics). Hence, changes in one region should be physically consistent with those in another region and globally. In addition, the combination of changes in different variables (which are often correlated with each other) should be physically consistent;

- ***Criterion 3: Applicability in impact assessments.*** Scenarios should describe changes in a sufficient number of variables on spatial and temporal scales that allow for an impact assessment. For example, impact models may require input data on variables such as precipitation, solar radiation, temperature, humidity and windspeed at spatial scales ranging from global to site-specific, and at temporal scales ranging from annual means to daily or hourly values;

- ***Criterion 4: Representative.*** Scenarios should be representative of the potential range of future regional climate change. Only in this way can a realistic range of possible impacts be estimated;

- ***Criterion 5: Accessibility.*** Scenarios should be straightforward to obtain, interpret and apply for impact assessment. Many impact assessment projects include a separate scenario development component that specifically aims to

address this last point. The IPCC Data Distribution Centre (DDC) and this guidance document are also designed to help meet this need.

The best ways to ensure these conditions are met is to work with experts on climate change modelling to verify that scenarios are consistent with estimated changes in global climate. Working with regional climate specialists to verify whether regional changes are consistent with what is known about regional climatology is also advised.

It is critical to keep in mind that regional climate change scenarios are not a prediction of future climate change, but rather they are a means to represent what could happen as a result of human-induced climate change (through GHG emissions), and to facilitate the understanding of how different systems could be affected by climate change.

The IPCC DDC has published several guidelines on scenario development, including:

- General guidelines on scenario development;
- Guidelines for regional climate downscaling;
- Guidelines for statistical downscaling;
- Guidelines for sea level rise scenarios.

These guidance documents can be downloaded from the IPCC DDC website[2].

Chapter 2, Vulnerability and Adaptation Frameworks, discusses the selection of scenarios for different types of assessment. In general, climate change scenarios for use in V&A assessments should facilitate an understanding of the potential vulnerability of systems to climate change and the effectiveness and costs of adaptations. Two key issues are:

- How many scenarios should be used?
- How wide a range of potential conditions should the scenarios cover?

A key rule of thumb is **never to use just one climate change scenario**. One scenario will not communicate the uncertainty about how climate may change and clearly cannot cover a range of uncertainties. Thus multiple scenarios should be used.

However, the trade-off in running scenarios is that the greater the number of scenarios used, the more expensive, time-consuming and complicated the analysis can be to conduct, and the more challenging it can be to interpret and present results. Nonetheless, some studies have used hundreds of climate change scenarios (e.g. Asseng et al., 2013).

At a minimum **it is prudent to use at least two or three scenarios**. A key goal is to capture a range of uncertainty in key variables. For example, sea level rise scenarios should encompass a reasonable range of plausible increases in sea level, as should temperature scenarios. Scenarios for precipitation, however, are more complicated because climate projections for many regions will include some model projections with

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[2] See <http://www.ipcc-data.org/guidelines/>.

increased precipitation and some model projections with decreased precipitation. If the objective is to study a system that is sensitive to precipitation changes, such as water supply or agriculture, it will be important to include scenarios of increased and decreased precipitation. In this way, the people using the results of a V&A assessment will understand the different potential impacts of climate change as well as the differences in effectiveness of adaptations under varying climate change conditions.

4.1 Approaches to climate change scenario development

The development of climate change scenarios for impact assessment has been well-documented through guidelines published by various agencies and programmes that are outlined in table 4-2. This section provides a broad overview of the key steps in climate change scenario development. It is suggested that, where more detail is required, further guidance should be sought from the documents in table 4-2, in particular Puma and Gold (2011).

Table 4-2
Guidance documents on climate change scenario development

Title	Author
United Nations Development Programme/United Nations Environment Programme/ Global Environment Facility (UNDP/UNEP/GEF) National Communications Support Programme	
Formulating Climate Change Scenarios to Inform Climate-Resilient Development Strategies: A Guidebook for Practitioners <http://www.undp.org/content/undp/en/home/librarypage/environment-energy/low_emission_climateresilientdevelopment/formulating-climate-change-scenarios.html>	Puma and Gold, 2011
Applying Climate Information for Adaptation Decision-Making: A Guidance and Resource Document <http://www.undp.org/content/undp/en/home/librarypage/environment-energy/low_emission_climateresilientdevelopment/applying-climate-information-for-adaptation-decision-making.html>	Lu, 2007
Guidance on the Development of Regional Climate Scenarios for Application in Climate Change Vulnerability and Adaptation Assessments <http://ncsp.undp.org/sites/default/files/NCSP_climate_scenarios_guidance_0.pdf>	Lu, 2006
IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis	
Good Practice Guidance Paper on Assessing and Combining Multi Model Climate Projections: IPCC Expert Meeting on Assessing and Combining Multi Model Climate Projections <http://www.ipcc-wg2.gov/meetings/EMs/IPCC_EM_MME_GoodPracticeGuidancePaper.pdf>	Knutti et al., 2010
General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment, Version 2 <http://www.ipcc-data.org/guidelines/TGICA_guidance_sdciaa_v2_final.pdf>	Carter, 2007

Title	Author
Guidelines for Use of Climate Scenarios Developed from Regional Climate Model Experiments <http://www.ipcc-data.org/guidelines/dgm_no1_v1_10-2003.pdf>	Mearns et al., 2003
Other	
Downscaling of Climate Information	Mearns, Pryor and Magaña, 2014
Regional Climate Downscaling	Wilby and Fowler, 2011
A Framework for Assessing Uncertainties in Climate Change Impacts: Low-Flow Scenarios for the River Thames, United Kingdom (UK)	Wilby and Harris, 2006

The first – and key – step in the development of climate change scenarios is to thoroughly define and evaluate user needs. The second step is the specification of baseline climate for a defined period. Changes in mean climate conditions and climate variability under enhanced GHG effects can be derived in a third step using good-quality climate data (e.g. ground or satellite observations) for a given geographic area.[3] Experts should be cautious in the choice of models, tools and data when assessing actual climate change information.

4.2.1. Evaluation and determination of needs for climate change scenario development

The United Nations Development Programme (UNDP) publication *Formulating Climate Change Scenarios to Inform Climate-Resilient Development Strategies:* A Guidebook for Practitioners (Puma and Gold, 2011) found that choosing the right method for climate scenario development can only be done after carefully evaluating the available approaches against the needs (application) and constraints (e.g. financial, computing, workforce, scientific) that project managers and their teams face.

Figure 4-1 provides a useful set of focus questions to guide the needs analysis, with further discussion points useful for addressing each question (and capturing the data provided through the analysis) provided in Puma and Gold (2011).

An additional consideration may be whether scenarios should examine change in variability such as more frequent dry or wet years.

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[3]   Note, however, that with the exception of projections of change in seasonal climate and daily variability (e.g. more intense precipitation events and more days without precipitation), there are few reliable projections of change in inter-annual or decadal variability (e.g. Meehl et al., 2009).

Figure 4-1
Key questions to determine the purpose and needs for climate scenario development
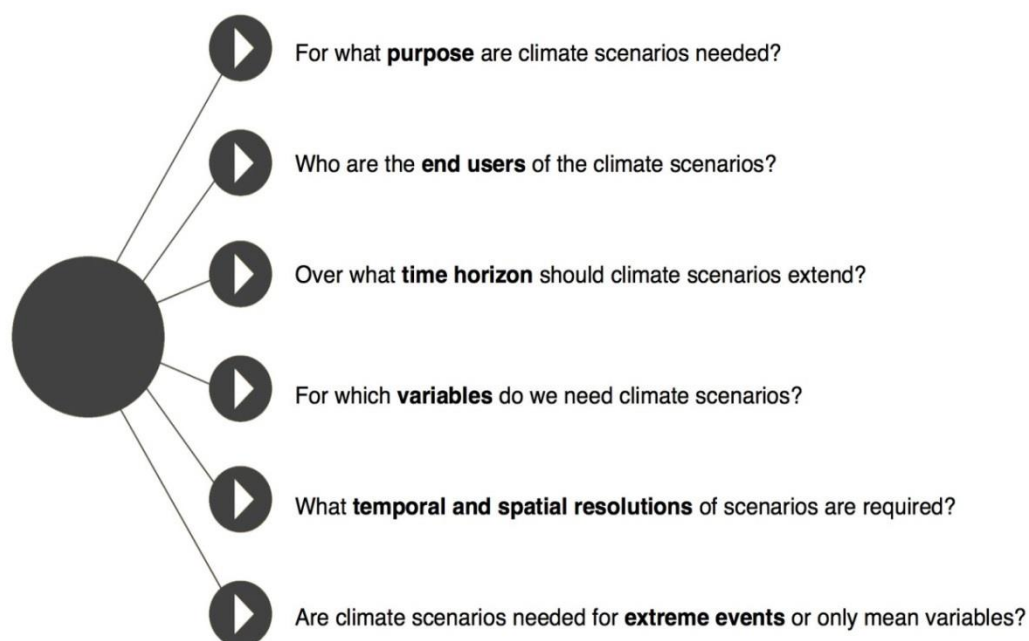
Source: Puma and Gold, 2011.

The framework developed by UNDP for developing climate change scenarios has a critical part that is intended to help decision makers identify the constraints they face, including capacity, financial, technical and others. The framework also assists in fostering an understanding of the interplay among these decision makers to better approach climate change scenario development, in particular with respect to resource allocation. The framework advises project managers to work together with a team of scientific and technical experts to manage uncertainties, select appropriate scenario methods and build a prospective range of scenarios. Furthermore, scientific experts in charge of scenario development are often not fully aware of the needs of decision maker and the context that extends beyond purely physical sciences. Therefore, the framework provides a platform that should foster clear and frequent dialogue between team members.

4.2.2. Specification of baseline climate

In climate change scenario development, after establishing the needs, the next step is to specify a baseline climate against which future changes in climate variables can be measured and impacts assessed. Baseline climate data help to identify key characteristics of the current climate regime (such as seasonality, trends and variability, extreme events and local weather phenomena). Depending on the purpose of the climate change scenario, the data sources and techniques required to define the baseline can vary widely (Lu, 2006).

Several questions need to be answered to define the baseline climate:

1. Which variables/metrics are needed, and at what resolutions and scale?

   - The selection should match the scenarios sought under a changing climate, in terms of everything from the number of variables sought, to the spatial and temporal scales (sub-daily, daily, seasonal, decadal to multi-decadal or even century time scales);

2. Which baseline period should be selected?

   - A climatological baseline period is a non-overlapping, 30-year, 'normal' period (e.g. 1900–1930, 1931–1960, 1961–1990), as defined by the World Meteorological Organization (WMO). The current WMO normal period is 1981–2010.

3. What data sources are available?

   - A range of data sources is available to define the climate baseline. These sources can be categorized following Lu (2006), as described below.

National meteorological agencies and archives

National meteorological agencies maintain the day-to-day operations of station-based weather observations and publish weather statistics. Therefore, these agencies and their archives are often the primary sources of observed climate data, particularly at daily or sub-daily intervals. However, many of the Parties not included in Annex I to the Convention (non-Annex I Parties) reported in their initial national communications that they had difficulty in accessing quality-controlled, observed weather data. Therefore, at the outset of the national communication project implementation, it is very important for the National Communication Steering Committee (or other institutions managing the national communication project) to ensure institutional arrangements are in place to grant free access to this observational climate data for the national communication team.

Supranational and global datasets

Observations from different countries have been combined into various supranational and global datasets, typically using funding from the governments of Parties included in Annex I to the Convention (Annex I Parties) and/or international organizations. These datasets often include mean values for surface variables for various periods, interpolated to a regular grid. But with improved processing and storage capacity, there are now also a number of historical datasets providing annual, monthly and even daily time series of gridded or site observations (see section 4.3.2). For example, figures 4-2 and 4-3, respectively, display the 24-hour return period for extreme precipitation over the baseline period 1948–2008 using the Princeton reanalysis precipitation data dataset and current precipitation from the Princeton dataset for a single day (July 1, 1980) over all of Africa.

Figure 4-2
Gridded observed precipitation data from Princeton dataset based on 1948–2008 data
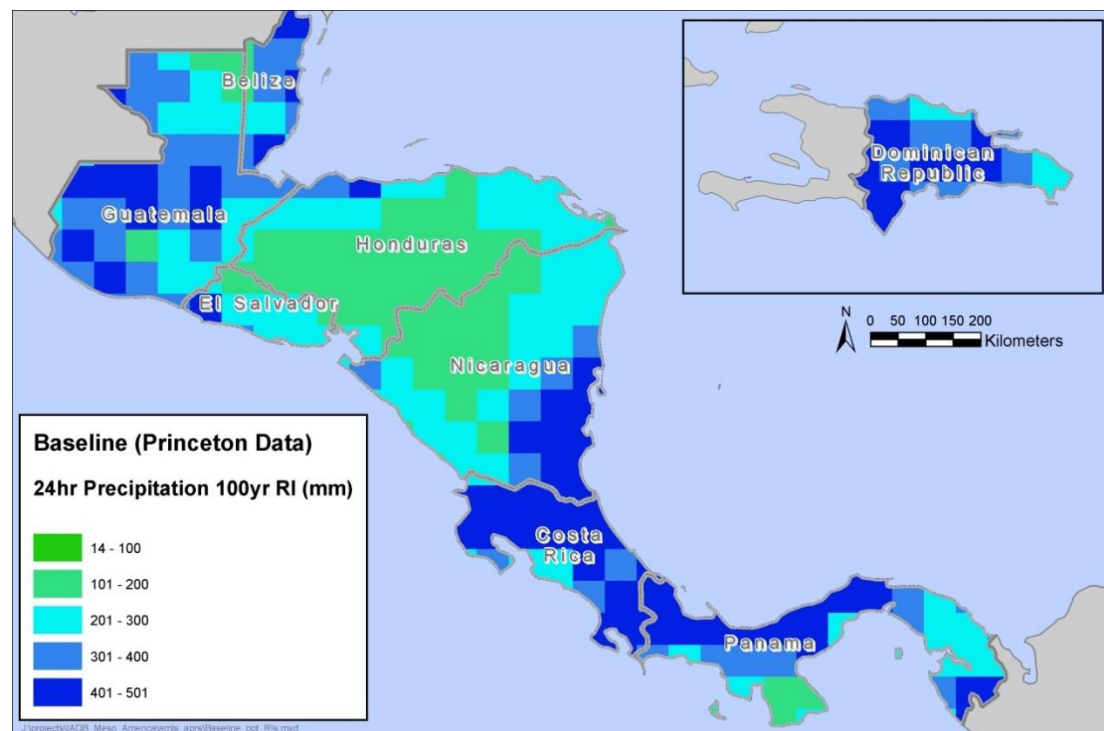
Source: Figure is based on reanalysis data from the Terrestrial Hydrology Research Group at Princeton University (Sheffield, Goteti and Wood, 2006). RI = return interval.

Weather generators

Weather generators are statistical models that describe the properties of an observed climate variable in a region using a few parameters. The ability to generate a climatological time series of unlimited length can be particularly helpful in regions with sparse observed data. In some cases, a weather series can be generated from statistical parameters obtained from observed data at a neighbouring site or at sites with sparse or broken records. An example of a widely used weather generator is the 'LARS-WG' tool[4] (Semenov and Barrow, 1997).

Reanalysis data

To overcome the problem of sparse and irregular meteorological observations often found in non-Annex I countries, reanalysis data can be used to define baseline climatologies. Reanalysis data are gridded and combine observations (usually sparse and irregular in distribution) with simulated data from climate models, through a process called data assimilation. In addition to filling gaps in conventional observations of surface variables, the assimilation process can provide estimates of unobserved quantities such as vertical motion, radiative fluxes and precipitation. Therefore, reanalysis data have been very helpful for establishing statistical relationships between locally observed surface variables and large-scale, upper-air- circulation indices. Such

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[4] Available at: <http://www.rothamsted.ac.uk/mas-models/larswg.php>.

relationships are needed to statistically downscale coarse-resolution GCM outputs to create local-scale climate scenarios.

Figure 4-3
Gridded observed precipitation data from Princeton dataset
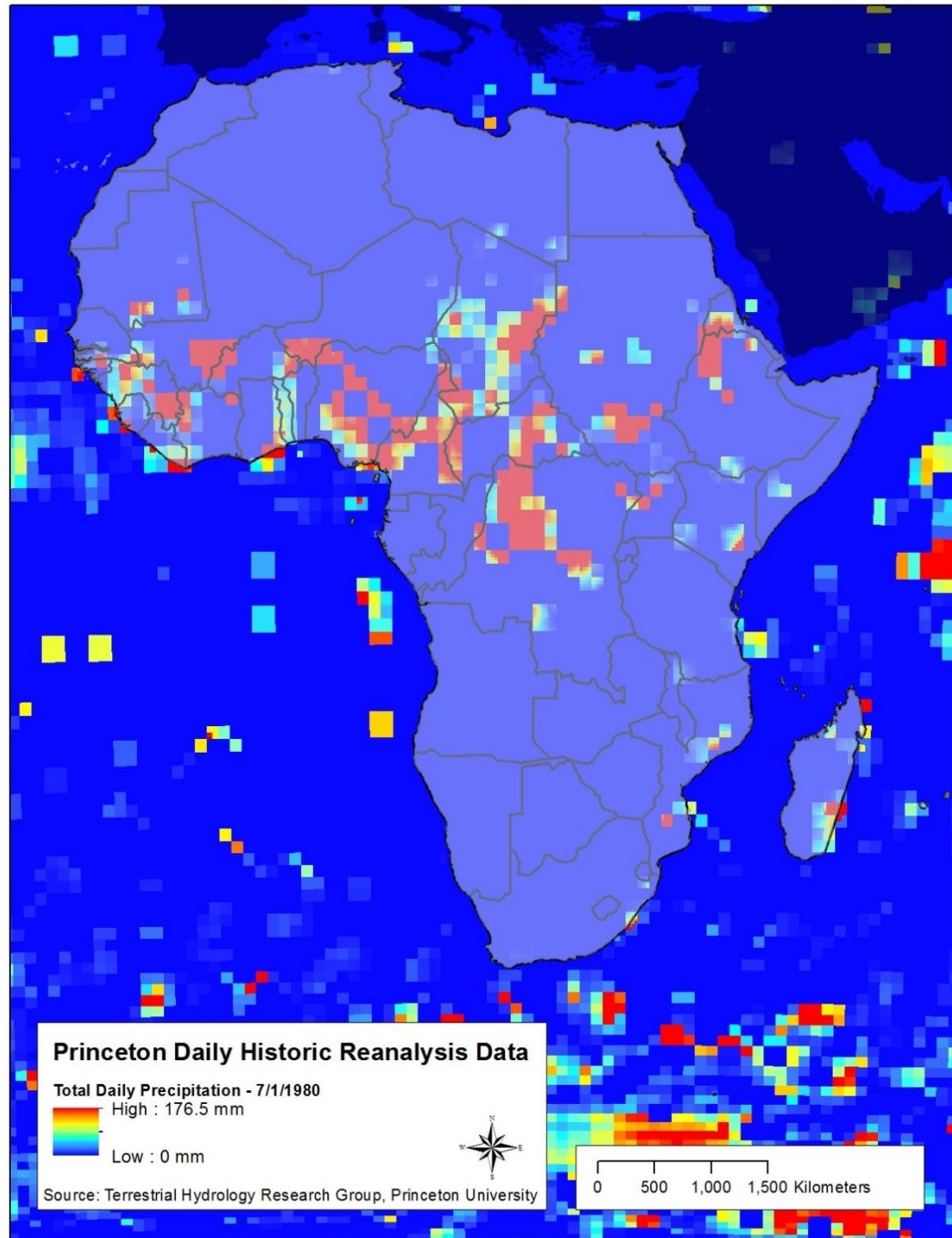
Source: Figure is based on reanalysis data from the Terrestrial Hydrology Research Group at Princeton University (Sheffield, Goteti and Wood, 2006).

Outputs from global climate model control simulations

GCM control simulations attempt to represent the dynamics of the global climate system unforced by anthropogenic changes in atmospheric composition. Most Atmosphere–Ocean General Circulation Model (AOGCM) control simulations are run over multiple centuries, and hence can provide data to analyse the natural variability of regional climate. Since actual observations barely extend beyond one century in duration, model control simulations offer an alternative source of data-enabling impact analysis for investigating the impact of multi-decadal variations in climate. Control simulation data from a range of AOGCMs are currently available from the IPCC DDC.[5]

Bias corrected spatially disaggregated datasets

Bias corrected spatially disaggregated (BCSD) datasets use a quantile approach to align GCM output to observations at a much higher resolution than GCMs (Maurer et al., 2007; Wilby and Fowler, 2011). BCSD have been applied globally up to a resolution of 25 km.

How can climate baselines be applied for vulnerability and adaptation assessments?

Climate baselines can be used in V&A assessments to characterize the sensitivity of an exposure unit – such as crop yields – to present-day climate. Extreme events as well as trends could be also addressed. Comparing the outputs of biophysical 'impact' models driven by baseline climate data to historical data is critical to validating and ultimately improving the impact models. Such improvements ultimately increase confidence in the assessment of future changes, the subject of the next section.

Once the baseline climate has been established, there are several possible methodologies that can be employed to develop scenarios of future change.

4.2.3. Development of climate change scenarios

Once the baseline climate has been established, there are several possible approaches that can be employed to develop scenarios of future change. These are detailed in the *Guidance on the Development of Regional Climate Scenarios for Application in Climate Change Vulnerability and Adaptation Assessments* (Lu, 2006).

There are several possible approaches that can be employed to develop scenarios of future climate changes:

1. Assume arbitrary changes in climate variables (synthetic scenarios):

   - Arbitrary adjustments (often using integers) can be used as inputs to sectoral studies. For example:

     i. Temperature changes of +1°C, +1.5°C, –1°C, –2°C, etc., could be applied to a crop model to test the sensitivity of crop growth to temperature change;

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[5] Available from: <www.ipcc-data.org/>.

ii. Similarly, precipitation could be adjusted by +5%, +10%, +15%, –5%, –10%, –15%, etc., to estimate the impacts of such changes on the same crop;

- Note that the use of arbitrary scenarios has become less common in recent years, but they can be helpful to identify sensitivities and thresholds. The major limitations of arbitrary scenarios are: that they typically do not consider variability (e.g. different precipitation changes in different seasons); and that the relationship between variables may not be physically plausible.

2. Use temporal and spatial analogues:

- Analogues are built by identifying recorded climate regimes that may resemble future climatic conditions for a given region;

- The recorded regime could be from the past (temporal analogues) or from a different region in the present (spatial analogues):

  i. Temporal analogues can come from the instrumental record (e.g. 'the observed drought of record') or from earlier, pre-observational paleoclimate reconstructions. Note that the latter tend to have limited detailed temporal resolution (e.g. change on a monthly basis);

  ii. Spatial analogues are applied by selecting a region that has a climate resembling a potential future climate. It is highly unlikely that a future climate would be similar in all respects to the current climate in another region. However, spatial analogues can be a powerful tool for communicating about the magnitude of potential future climate changes;

- These analogues are physically consistent since they are built with observed data, although climate change may not match the temporal or spatial analogues.

3. Develop scenarios from climate models outputs:

- This is the most common approach to deriving climate change scenarios because climate models are generally the best source of information on how climate may change;

- Several types of climate model have been developed to provide projections of future climate changes, each with progressively higher resolution:

  i. *Simple climate models.* Models such as the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) project change in global mean temperature and sea level rise;

  ii. *GCMs.* These complex models project climate change around the world by dividing the surface into grid boxes. The model resolution in the latest suite of model runs (Coupled Model Intercomparison Project Phase 5 (CMIP5)) typically ranges from 100 to 200 km. Most GCMs model the atmosphere, land surface, oceans and cryosphere;

  iii. *Regional climate models (RCMs).* RCMs are higher-resolution climate models run over a portion of the Earth's surface such as a continent. They are typically run using GCM output as boundary

conditions, but at a much higher spatial resolution than GCMs (e.g. 25 to 50 km). Since they have higher resolution, they can better simulate the effects of topography such as mountains, coastlines and large lakes;

iv. *Statistical downscaling models (SDSMs).* These models use statistics to correlate outputs from GCMs to specific locations or small areas. They are computationally easier to apply than RCMs but do not account for potential changes in the relationship between variables simulated by GCMs and point estimates of climate;

v. *BCSD datasets.* BCSD datasets use quantile methods to align GCM simulation of current climate and observations. Projections are available globally at 0.5°C.

Users of climate model outputs often prefer downscaled (higher spatial resolution) data rather than direct GCM outputs. Downscaling can be statistical or dynamical. However, guidance (see Wilby and Fowler, 2011; Mearns, Pryor and Magaña, 2014) is needed on how to select, treat and combine the vast amount of climate model outputs into useful climate scenarios. It is important to note that downscaling does not necessarily reduce uncertainty or improve reliability of projections.

The key advantages and disadvantages of each approach is summarized in table 4-3 to provide support for choosing an approach appropriate for a particular context.

Table 4-3
Key advantages and disadvantages of climate change scenario options

Options	Sub-options	Advantages	Disadvantages
Arbitrary changes in climate variables	Typically assume uniform annual changes such as +1°C or +2°C or ±10°C, 20% changes in precipitation	Easy to create and apply Can represent a broad range of potential changes in climate Tend to emphasize the limited precision possible with any predictions	Combinations may be physically inconsistent Could represent very unlikely changes in regional climate Arbitrary changes often assume uniform annual changes in climate
Analogue scenarios	Instrumental record	High spatial and temporal resolution Capture climate variability	Recent record captures only a limited increase in greenhouse gas (GHG) concentrations
	Paleoclimate reconstructions	Can reflect a wider range of climate conditions than the instrumental record	Forcing conditions are not the same as anthropogenic increases in GHG concentrations Paleoclimate proxies tend to have larger error terms and uncertainties than the instrumental record

Options	Sub-options	Advantages	Disadvantages
Climate models	Global climate models (GCMs)	Simulate global response to increased GHG concentrations Internally consistent	Low spatial resolution Models have different starting conditions and parameterizations, which makes comparison of results challenging
	Regional climate models (RCMs)	Similar to GCMs, but with substantially higher spatial resolution (see figure 4-4)	Will not correct for GCM mistakes Limited applications (i.e. run with few GCMs) Often run for limited time periods Resolution may be too low to simulate some processes such as cloud formation Interactions – and lack thereof – at the boundary between the GCM and RCM can introduce errors
Climate models	Statistical downscaling	Uses statistical relationship between large-scale variables and local climate conditions Relative to RCMs, this is a computationally simpler method to obtain high spatial and temporal resolution output based on GCMs The output can be optimized to a specific application or location	Will not capture change in the relationship between GCM variables and climate at the local scale
	Bias corrected spatially disaggregated (BCSD) data	Use quantile methods to align GCM simulation of current climate and observations Available globally at 0.5°C With high resolution, easy-to-use dataset Output can be used directly in impacts analysis	BCSD data does not disaggregate change in climate at the sub-GCM scale

Source: Modified from Lu, 2006.

Figure 4-4
The issue of spatial resolution: Global versus regional analysis
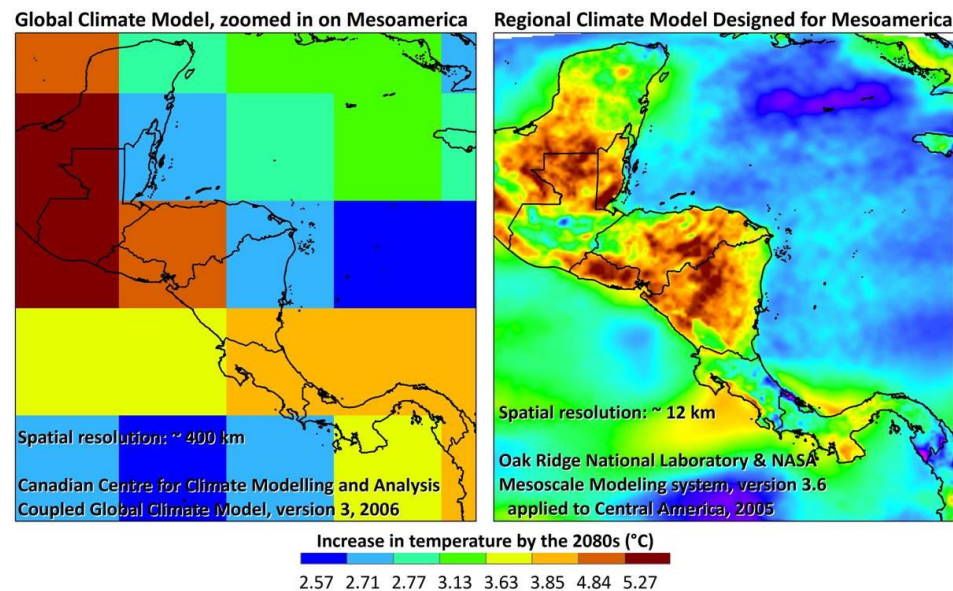
Source: SERVIR, 2009.

Selection of emissions scenarios

A key decision when selecting climate change scenarios is the choice of GHG emissions scenarios to capture what may happen if GHG emissions continue unabated (sometimes referred to as **business-as-usual scenarios**), and what may happen if measures are taken to reduce and stabilize GHG emissions and atmospheric concentrations (referred to as **policy** or **stabilization scenarios**).

There is no right or wrong choice of emissions scenarios. If the objective is to examine consequences from unabated climate change, then the use of higher r**epresentative concentration pathways**[6] (RCPs) (e.g. the 6.0 or 8.5 scenarios) may be justified, although the RCP6.0 scenario is also considered a stabilization scenario. If the objective is to assess the consequences should substantial (and rapid) mitigation happen, then lower RCPs (e.g. the 4.5 or 2.6 scenarios) may be justified. A risk-averse analysis of adaptation might consider the consequences of climate change should future GHG emissions not be reduced and might use the higher RCPs.

For near-term projections (i.e. before roughly 2040), projections are not sensitive to the choice of RCP. In contrast, for end-of-century projections, GHG scenarios can be the dominant source of uncertainty for some locations and variables (e.g. temperature; Hawkins and Sutton, 2012) but not for others (e.g. sea level change; Little et al., 2014).

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[6] RCP discussed in chapter 3.

4.2. Methods, tools and data sources

4.3.1. Models and tools

This section provides an overview of the models, tools and data sources for non-Annex I Parties to develop climate change scenarios for use in national communications. Further details on the majority of these resources can be found in the United Nations Framework Convention on Climate Change (UNFCCC) *Compendium on Methods and Tools to Evaluate Impacts of, and Vulnerability and Adaptation to, Climate Change*.[7]

Table 4-4 summarizes the different models and tools that have been widely used to generate climate scenarios in national communications. Each of these models and tools are explored in greater detail in *Guidance on the Development of Regional Climate Scenarios for Application in Climate Change Vulnerability and Adaptation Assessments* (Lu, 2006) developed for United Nations Development Programme/United Nations Environment Programme/Global Environment Facility (UNDP/UNEP/GEF). Further documentation for each specific model and tool can be found through the web links in table 4-4.

Importantly, there are trade-offs between the level of complexity required from the climate modelling and the computational requirements (and associated costs and technical capacities) to produce results. The choice of models and tools has to be carefully considered as a result.

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[7] http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5457.php.

Table 4-4
Selected models and tools for climate change scenario development

Name	Source	Resolution	Computational requirements and training	Description	Link
PRECIS (Providing Regional Climates for Impacts Studies)	UK Met Office Hadley Centre	Regional (25-km grid)	High: (Linux OS, 1 GB RAM, > 2.0 GHz, > 500 GB available space) Training workshops available	PRECIS modelling provides high-resolution, regional climate projections. As a typical PRECIS experiment can take several months, the system is not designed to provide instant climate scenarios. Workshops and training are regularly conducted through institutions around the globe in developing nations. Note that PRECIS can only be run in conjunction with the UK Met Office GCMs (Jones et al., 2003).	<http://www.metoffice.gov.uk/precis/>
MAGICC/ SCENGEN (Scenario Generator)	US National Center for Atmospheric Research (NCAR)	Regional (2.5° by 2.5° grid)	Low (Windows OS) Training workshops available	MAGICC/SCENGEN is a coupled software package that allows users to investigate future climate change and its uncertainties, and the global mean and regional levels. MAGICC calculates energy balances whereas SCENGEN effectively presents the results of MAGICC to produce spatially detailed information on future changes in key climate variables. Note that SCENGEN has CMIP3 GCM data, not CMIP5.	<http://www.cgd.ucar.edu/cas/wigley/magicc/>
SDSM (Statistical DownScaling Model)	Dr Robert Wilby and Dr Chris Dawson (UK)	Regional	Low (Windows 98, XP) Training seminars available	SDSM is a software tool designed to implement statistical downscaling methods to produce high-resolution, monthly climate information from a GCM simulation.	<http://co-public.lboro.ac.uk/cocwd/SDSM/>
SimCLIM	CLIMsystems	Regional and global	Low/medium (Windows OS: XP, Vista, 7) Training available	SimCLIM is a commercial software package that links data and models in order to simulate the impacts of climatic variations and change.	<http://www.climsystems.com/simclim/>
ClimateWizard	The Nature Conservancy	Regional and global (50-km grid)	Very low (Internet connection only) No training required	ClimateWizard is an online tool that provides instant national-level projections for temperature and precipitation for a range of *Special Report on Emissions Scenarios* (SRES) scenarios.	<http://www.climatewizard.org/>

Name	Source	Resolution	Computational requirements and training	Description	Link
KNMI Climate Explorer	Red Cross	Global climate model (GCM) scale	Very low (Internet connection only) No training required	Climate Explorer is an online tool that provides mapping of GCM outputs from CMIP5 and CMIP3 data for a number of climate variables at global, regional, country and user-specified locations.	<http://climexp.knmi.nl/plot_atlas_form.py>

Key factors that should be considered in the choice of model and tools include:

- Ensuring a close alignment with evaluated user needs;

- Consideration of in-country technical, financial, data and time constraints;

- Opportunities to partner with neighbouring countries or regional groups to share costs and promote strengthening regional capacity;

- Thinking about the potential to develop a scenario-development pathway that uses less time and resource-intensive options initially (if these approaches can serve the purpose), and then using more complex models and tools in the future.

For example, a hypothetical country may decide that following a thorough evaluation of user needs, and drawing on the models and tools shown in table 4-4 (and following discussions with development partners, neighbouring countries and climate experts), opportunities exist to create an approach to develop and use climate scenarios that:

- Use visualization or simple tools such as ClimateWizard for the initial, high-level screening of climate model outputs and to facilitate early stakeholder engagement on key issues. It is important to remember that a distribution of model projections for a region should not be regarded as a probability distribution nor should it be interpreted as capturing the entire potential range of changes in climate;

- Investigate using BCSD datasets or desktop-computer tools, such as MAGICC/SCENGEN or SimCLIM (see table 4-4) to obtain GCM output data. Here it is important to note that none of these methods 'downscale' GCM output, (i.e. they do not estimate how changes in climate within GCM grid boxes can vary);

- For more complex situations, such as coastal or mountain areas or small islands, particularly where downscaling is needed, consider the following:

    - Investigate using SDSMs for statistical downscaling, depending on requirements;

    - Explore with neighbouring countries and regional expert groups the use of PRECIS or the development of specific regional modelling (dynamic downscaling) initiatives;

    - Coordinate with organizations such as CORDEX (Coordinated Regional Climate Downscaling Experiment) to consult with climate change researchers in Africa.

The approach outlined above also reflects, in broad terms, a pathway followed by Parties that have already undertaken a number of national communications. Considerable expertise has been developed within non-Annex I Parties in this regard, which is of great value to others approaching the process of choosing climate change scenario tools and models.

4.3.2. Data sources

A range of publicly available data sources is available for use in climate change scenario development. These data sources include meteorological datasets (table 4-5) and data from global and RCM outputs (table 4-6). These tables summarize and

provide a direct link to the key sources of data. Lu (2006) provides a comprehensive overview of each of the data sources listed in table 4-6.

Table 4-5
Sources of meteorological global data sets

Name	Description	Link
Intergovernmental Panel on Climate Change Data Distribution Centre (IPCC DDC)	The IPCC DDC provides gridded observed data, including mean climatology in a number of formats.	<http://www.ipcc-data.org/>
International Research Institute for Climate and Society	The International Research Institute for Climate and Society hosts a range datasets of gridded observed data and climate change projections for a range of spatial and temporal resolutions.	<http://iridl.ldeo.columbia.edu/docfind/databrief/?sem=iridl%3ADCAtmosphere>
US National Oceanic and Atmospheric Administration (NOAA)	Reanalysis data including six-hourly observations of daily and monthly averages for numerous climate variables. The reanalysis extends from 1948 to the present and covers the entire globe.	<http://www.esrl.noaa.gov/psd/data/gridded/>
National Climate Data Center (NCDC) Global Daily Climatology Network	The NOAA NCDC Global Daily Climatology Network has daily precipitation and minimum and maximum temperature data.	<http://www.ncdc.noaa.gov/oa/climate/research/gdcn/gdcn.html>
Princeton Terrestrial Hydrology Research Group	Fifty-year record of bias-corrected daily precipitation and maximum/minimum temperatures across the globe at a 1-degree spatial resolution. It is constructed by combining a suite of global, observation-based datasets with the National Centers for Environmental Prediction/NCAR reanalysis.	<http://hydrology.princeton.edu/data.pgf.php>
Tyndall Centre for Climate Change Research	Dataset of country-level, monthly time series for 1901–2013 for all land areas excluding Antarctica; providing climate variables at 0.5°-resolution, including cloud cover, diurnal temperature range, frost-day frequency, daily minimum temperature, daily mean temperature, daily maximum temperature, precipitation, potential evapotranspiration (PET), wet-day frequency and vapour pressure.	<http://www.cru.uea.ac.uk/cru/data/hrg/> (This website also contains other observed climate datasets.)
WorldClim	Global 50-year (1948–2000) dataset of meteorological data derived by combining reanalysis with observations. Available at 2.0-degree and 1.0-degree spatial resolution and daily and three-hourly temporal resolution.	<http://www.worldclim.org>

Name	Description	Link
APHRODITE	Daily precipitation (0.5°-resolution and 0.25°-resolution) for portions of Asia.	<http://www.chikyu.ac.jp/precip/cgi-bin/aphrodite/script/aphrodite_cgi.cgi/register>
Tropical Rainfall Measuring Mission (TRMM)	Data from satellites that provide information on the amount of precipitation within a column in the atmosphere, its areal distribution and its intensity (including convective cells).	<http://disc.sci.gsfc.nasa.gov/TRMM>

Table 4-6
Data archives of global and regional climate model outputs

Name	Description	Link
CORDEX (Coordinated regional Climate Downscaling Experiment)	Continental-scale databases of multi-dynamical and statistical downscaling models (SDSMs) considering multiple forcing global climate models (GCMs) from the CMIP5 archive. Initially a 50-km grid spacing was selected, favouring engagement of the wider community. Multiple common domains covering all (or most) land areas in the world have been selected (with an initial focus on Africa).	<http://www.meteo.unican.es/en/projects/CORDEX>
CMIP (Coupled Model Inter-comparison Project)	CMIP contains global model output data that will be the foundation of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) – CMIP5 – as well as model data used in IPCC Fourth and Third Assessment reports (CMIP3).	<http://cmip-pcmdi.llnl.gov>
US Bureau of Reclamation BCSD Global Dataset	The US Bureau of Reclamation developed BCSD data at 0.5°-resolution and 1° resolution for CMIP5 models. BCSD is applied to the models' simulation of current and future climates.	<ftp://gdo-dcp.ucllnl.org/pub/dcp/archive/cmip5/global_mon/BCSD/>
NASA Earth Exchange (NEX)	The NASA NEX Global Daily Downscaled Projections (GDDP) dataset includes downscaled projections for RCP4.5 and RCP8.5 from the 21 CMIP5 models at 0.25° resolution. Projections are given for daily maximum temperature, minimum temperature and precipitation for the periods from 1950 through 2100 (NASA, 2015).	<https://nex.nasa.gov/nex/projects/1356/>

4.3. Future directions in climate change scenario development

A number of developments in climate change scenarios, methods, models and data are evolving, which is why flexible, iterative approaches based on frequent communication between scientific experts and decision makers are needed. For example:

- We expect continued improvement in baseline climate datasets. On-the-ground and satellite data networks cover more territory and are providing continuous

datasets. Communication networks and software applications are advancing citizen science contributions to local weather data;

- With faster computers, the resolution and complexity of climate models is increasing. The CMIP5 GCMs had a resolution of 1° to 2° and future generations of global models will have higher resolutions, in some cases comparable to the resolution of current-generation RCMs (e.g. ~ 0.5° or finer);

- The resolution of RCMs has also increased dramatically in recent years. Some RCMs are being run at a high-enough resolution to better simulate vertical motion and cloud processes (Kendon et al., 2014), which may be an important breakthrough in simulating local weather events.

While these improvements in data and modelling should result in a better understanding of current climate and future climate change, they are unlikely in the near future to significantly narrow climate change projections. This is for two fundamental reasons, as Barsugli et al. (2012) describe:

1. There are still no credible published projections of the likelihood of future GHG emissions. Projections of changes in GHG emissions and natural carbon cycle feedbacks vary quite widely;

2. Even for a given change in radiative forcing, there are substantial differences in potential changes in global and regional climate patterns:

   a) There is inherent uncertainty about how much the global mean temperature will increase for a given level of radiative forcing and it is unlikely to be reduced soon (Roe and Baker, 2007). Thus, the 90 per cent confidence range of an increase of 1.5°C to 6°C in global mean temperature associated with CO2 doubling is unlikely to be significantly narrowed in the near future;

   b) This uncertainty in projections of change in regional climate is partially captured in the varied range of projections of regional climate under the same radiative forcing assumptions by different GCMs. Unless there are breakthroughs in understanding the changes in oceans and the atmosphere, these differences are also unlikely to be narrowed.

In this one sense, the future may continue to look like the past. We will continue to need a range of climate change scenarios to help capture a reasonable range of future climate conditions. V&A assessments will need to continue to use a range of projections to understand the sensitivity of impacts and adaptations to different climate outcomes.

4.4. Final thoughts

The selection of climate change scenarios has become much richer – and has therefore become more confusing – because there is so much more choice than there was more than a decade ago. Rather than just having the option of using GCM output, it is now possible to consider statistical or dynamic downscaling, spatial disaggregation techniques or tools such as SimCLIM. The choice can be difficult, even paralysing.

In selecting climate change scenarios, it is important to keep in mind a few key points:

1. We cannot precisely forecast future climate change. For some variables, we are not even confident about the direction of change, especially at smaller spatial scales. The magnitude of change in all climate variables remains uncertain;

2. The primary purpose of climate change scenarios includes education about what kinds of changes are possible and for use in V&A assessments to understand how systems or entities can be affected by climate change. Climate change scenarios can be used to see how significant impacts can be, whether there are thresholds and what variables or moments (e.g. average change, change in variance) systems or entities are sensitive to;

3. Whatever method is used, it is advisable to use a number of diverse scenarios to capture a reasonable range of uncertainty and help address the matters in the second point above;

4. Precision is not necessarily the same thing as accuracy. Higher-resolution techniques such as downscaling or spatial disaggregation can add much detail to GCM projections, but they may not make the projections more accurate. Higher resolution can, in principle, help improve our understanding of climate processes at smaller spatial scales.

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Appendix 4-1: Climate change overview

The Intergovernmental Panel on Climate Change (IPCC) has assessed the state of knowledge on climate change, its impacts and mitigation of greenhouse gas (GHG) emissions in its Fifth Assessment Report (AR5) published in 2013 (IPCC, 2013). The report can be found on the IPCC website.[8] It is important to note that climate change science is a rapidly evolving area. The IPCC in 2012 also published its *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (IPCC, 2012). The various scales of climate scenarios are discussed briefly in this section.

Key definitions

In order to maintain consistency and transparency in its climate change assessments, the IPCC uses a set of standard terms to treat likelihood. These terms are presented in table 4-7 and are referred to regularly through the different modules of the training materials.

Table 4-7
Standard terms used by the Intergovernmental Panel on Climate Change to define the likelihood of an outcome or result

Likelihood terminology	Likelihood of the occurrence/outcome
Virtually certain	> 99% probability
Very likely	> 90% probability
Likely	> 66% probability
About as likely as not	33% to 66% probability
Unlikely	< 33% probability
Very unlikely	< 10% probability
Exceptionally unlikely	< 1% probability

Source: IPCC, 2013.

Global climate change

Global-scale historical observations and projected trends in key climate variables are extensively discussed in the summary for policy makers in the contribution of Working Group I of the IPCC. Table 4-8 briefly summarizes what is known about changes in regional climate as a result of increased atmospheric GHG concentrations, drawing from the IPCC Working Group I observations.

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[8] Available at: <http://www.ipcc.ch/>.

Table 4-8
State of knowledge on global climate change

Climate variable	Observed trends	Projected change to end of twenty-first century relative to 1986–2005	Degree of confidence
Global mean sea level rise[a]	Global mean sea level has been rising. From 1901 to 2010, the average rate of sea level rise was 1.7 ± 0.5 mm/year. The average rate from 1990 to 2010 has accelerated to 3.2 mm/year ± 0.4 mm/year. Significant spatial and temporal variability exists with sea level change.	Mean sea level rise will accelerate; Intergovernmental Panel on Climate Change (IPCC) projections across all scenarios range from 0.26 m to 0.82 m. Under the highest scenario, sea level could rise up to 0.98 m by 2100 (see Appendix 5-1 in chapter 5).	Likely
Mean surface air temperature	Global mean surface temperatures have risen by 0.85°C ± 0.18°C when estimated by a linear trend over the 1880–2012 period. There is substantial variability in the rate of warming.	All models project an increase in global mean temperature continuing into the 21st century. Modelling across all scenarios suggests an increase of 1.5°C to 4.0°C.[b]	Likely
Temperature extremes	It is very likely that, globally, the number of cold days and nights has decreased and the number of warm days and nights has increased.	It is very likely that heat waves will become more intense, more frequent and longer lasting in a future warmer climate. Occasional extreme cold winter temperatures will occur.	Very likely
Precipitation change	There is high confidence that total precipitation in mid-latitudes of the northern hemisphere has increased since 1951, while trends in other regions are less certain.	Models simulate that global mean precipitation increases with global warming; however, there are substantial spatial and seasonal variations. Increases are expected over the tropical and high-latitude regions, decreases are projected for many dry subtropical and mid-latitude regions, and increases are projected in many mid-latitude wet regions.	Likely for the end of century although confidence decreases at smaller geographic scales in the early century
Intensity of peak precipitation	More land areas have had an increase in heavy precipitation events than a decrease.	More frequent and intense events over mid-latitudes and wet tropical areas.	Very likely in many areas
Drought	There is a likely increase in droughts in many areas.	Decreases in soil moisture are projected for Mexico, north-east South America, south-west South America, southern Europe, north Africa, far-west Africa, southern Africa and central Asia (Field et al., 2012).	Likely

Climate variable	Observed trends	Projected change to end of twenty-first century relative to 1986–2005	Degree of confidence
Tropical cyclone intensity	There is low confidence in long-term changes globally, but an increase in the North Atlantic is virtually certain.	There will be a decrease or no change in the number of tropical cyclones but an increase in wind speed and precipitation. There is little confidence in projecting regional changes.	Likely

a. Further detail on sea level rise is provided in Chapter 5: Coastal Resources.
b. These projections are for RCPs 4.5, 6.0, and 8.5.

Source: Adapted from IPCC, 2013.

Regional climate change

A summary of projected climate change at a regional level relevant to Parties not included in Annex I of the Convention (non-Annex I Parties) is presented below and is based on Meehl et al. (2007), Field et al. (2012), and Hewitson et al. (2014). Although the analysis largely focuses on temperature and precipitation, changes in other variables such as sea level are likely to have large impacts on these regions as well.

Africa

Warming is very likely to be greater than the global annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moister tropics. An increase in the number of hot days and warm nights is likely, while a decrease in the number of days and nights considered cool is also likely. Heat waves are likely to be more frequent and longer. Annual rainfall is likely to decrease in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall closer to the Mediterranean coast. Rainfall in southern Africa is likely to decrease in much of the winter rainfall region and western margins. There is likely to be an increase in annual mean rainfall in East and Central Africa. It is unclear how rainfall in the Sahel, the Guinean Coast and the southern Sahara will evolve. Thus, northern and southern Africa are likely to face increased drought, while East Africa is projected to have decreased dryness. Only East Africa is likely to see an increase in heavy precipitation.

Mediterranean Region and Europe

Annual mean temperatures in Europe and the Mediterranean are likely to increase more than the global mean. Seasonally, the largest warming is likely to be in northern Europe in winter and in the Mediterranean area in summer. Minimum winter temperatures are likely to increase more than the average in northern Europe. Maximum summer temperatures are likely to increase more than the average in southern and central Europe. An increase in the number of hot days and a decrease in the number of cool nights is very likely, while an increase in intensity and frequency of heat waves, particularly in southern Europe and the Mediterranean, is likely. Annual precipitation is very likely to increase in most of northern Europe and decrease in most of the Mediterranean area. In central Europe, precipitation is likely to increase in winter but decrease in summer. Extremes of daily precipitation are very likely to increase in northern Europe with an unclear signal in southern Europe. The annual number of precipitation days is very likely to decrease in the Mediterranean area. The risk of drought is likely to increase in southern and central Europe and in the Mediterranean

area. The duration of the snow season is very likely to shorten, and snow depth is likely to decrease in most of Europe.

Asia

Warming is likely to be well above the global mean in central Asia, the Tibetan Plateau and northern Asia; above the global mean in eastern Asia and South Asia, and similar to the global mean in Southeast Asia. Precipitation in winter is very likely to increase in northern Asia and the Tibetan Plateau, and likely to increase in eastern Asia and the southern parts of Southeast Asia. The number of hot days and warm nights across Asia is likely to increase, with a decrease in cool days and cold nights. It is very likely that heat waves/hot spells in summer will be of longer duration, more intense and more frequent across Asia. Fewer very cold days are very likely in East Asia and South Asia. Precipitation in summer is likely to increase in northern Asia, East Asia, South Asia and most of Southeast Asia, but is likely to decrease in central Asia. There is very likely to be an increase in intense precipitation events in North Asia, parts of South Asia, Southeast Asia (although not all metrics point to an increase) and in East Asia. Extreme rainfall and winds associated with tropical cyclones are likely to increase in East Asia, Southeast Asia and South Asia. There is no consistent signal about change in drought across Asia.

Mexico, Central America and South America

The annual mean warming is likely to be similar to the global mean warming in southern South America but larger than the global mean warming in the rest of the area. The frequency of hot days and warm nights is likely to increase across the region, with the frequency of warm nights very likely to increase in the Amazon and in south-east South America. Heat waves are likely to be more frequent and intense, although the signal in south-east South America is weaker than across the rest of the region. Annual precipitation is likely to decrease in most of Mexico and Central America, except in the extreme south of the region, and in the southern Andes, although changes in atmospheric circulation may induce large local variability in precipitation response in mountainous areas. Winter precipitation in Tierra del Fuego and summer precipitation in south-eastern South America is likely to increase. It is uncertain how annual and seasonal mean rainfall will change over northern South America, including the Amazon rainforest. Drying is projected for south-west South America. Heavy precipitation is projected to increase in the Amazon and in northern parts of south-east South America and the tropics in the western part of the continent. Changes in heavy precipitation elsewhere are uncertain.

Small Islands

Sea levels on average are likely to rise during the century around the small islands of the Caribbean Sea, the Indian Ocean and the northern and southern Pacific oceans. The rise will likely not be geographically uniform but large deviations among models make regional estimates across the Caribbean, Indian and Pacific oceans uncertain. All Caribbean, Indian Ocean and North and South Pacific islands are very likely to warm during this century. The warming is likely to be somewhat smaller than the global annual mean. Summer rainfall in the Caribbean is likely to decrease in the vicinity of the Greater Antilles but changes elsewhere and in the winter are uncertain. Annual rainfall is likely to increase in the northern Indian Ocean with increases likely in the vicinity of the Seychelles in December, January and February; and in the vicinity of the Maldives in June, July and August; while decreases are likely in the vicinity of Mauritius

in June, July and August. Annual rainfall is likely to increase in the equatorial Pacific, while most models project decreases for areas just east of French Polynesia in December, January and February.