Sixth meeting of the Executive Committee of the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts
Bonn, Germany, 11–13 October 2017

Reference document for item 4:

A draft compendium and discussion points for assessing and developing recommendations to improve knowledge to understand, and capacity to address, slow onset events and their impacts, including the capacity of regional agencies

I. Background

1. Excom 5 (21–24 March 2017) adopted a set of guidance[1] for undertaking activity (d) of Action Area 3 of the initial two-year workplan of the Excom,[2] and requested the secretariat to undertake technical work in accordance with the guidance. The guidance document is contained in annex I.
2. Excom 5 established an intersessional working group of champions to provide further guidance, as needed, to the secretariat in undertaking the technical work.

II. Process to date

3. The Secretariat compiled and synthesized existing scientific information, informed by work carried out under the initial two-year workplan of the Excom and other sources as specified in the guidance document, and reported back to the co-coordinators of the intersessional working group on 27 June 2017 on the outcome of the technical work. This technical output (draft compendium) is contained in annex II.
4. The intersessional working group developed a set of discussion points with a view to guiding the work at Excom 6 in addressing the remaining work on this activity, 'Assess and develop recommendations to improve the state of knowledge to understand, and capacity to address, slow onset events and their impacts, including the capacity of regional agencies' (Action Area 3, activity (d)). The discussion points are contained in annex III.

III. Next steps

5. The Excom will be invited to consider the draft compendium and the discussion points. It may wish to include the recommendations on this matter into its annual report to the 23rd session of the Conference of the Parties (COP) or follow-up activity(ies) thereon in the context of its five-year rolling workplan. Alternatively, or in addition, it may also wish to agree on next steps regarding the draft compendium.

[1] As contained in Annex I of reference document Excom/2017/5/2, available at http://unfccc.int/10400.
[2] Action Area 3, activity (d): Assess and develop recommendations to improve the state of knowledge to understand, and capacity to address, slow onset events and their impacts, including the capacity of regional agencies.

Annex I: Guidance to undertake technical work

AA3d – background document on the process and considerations thus far

> *Action area 3: Enhance data on and knowledge of the risks of slow onset events and their impacts, and identify ways forward on approaches to address slow onset events associated with the adverse effects of climate change with specific focus on potential impacts, within countries and regions*
>
> *(d) Assess and develop recommendations to improve the state of knowledge to understand, and capacity to address, slow onset events and their impacts, including the capacity of regional agencies*

1. Work shared so far

In addressing AA3d, the co-coordinators drafted a **guidance document** that was shared with the Excom in Annex I of **this** guidance background document.

The document says that AA3d needs to be split up in **(1) assessment of knowledge** and, based on this, **(2) development of recommendations**. The document provides **guiding questions** for (1) and suggested areas for (2).

2. Proposed way forward

The **following phased approach on (1), assessment of knowledge**, is a result of exchanges between the co-coordinators and including questions and concerns raised by Miwa in response to the guidance document.

Plenary agreement would be needed on the steps proposed, as well as on the timing for completion of the work.

Step 1: Do we have comprehensive knowledge of the relevant SOEs in all regions?

Comment: Prepare an initial inventory of SOEs*, e.g. beginning from the decision 1/CP.16 footnote list, to determine which SOEs relate to which region (i.e. Caribbean, Pacific, Indian Ocean, Africa, Asia, Latin America), which would have to be broad, but would still go a step further than AR5, by pulling out the SOEs from the larger "jumble" of climate change impacts.*

There would need to be some agreement in advance as to which of the AR5 chapters information would be drawn from and perhaps even a loose agreement as to the format of the summary e.g. a table matching SOE to region along with a timeframe accompanied by a map. Perhaps, a table might be slightly preferable, as a map can only contain a limited amount of information. Perhaps the table can include a column on the societal effects of each SOE, accompanied by an illustrative map though.

Step 2: What are the sources of information on SOEs?

Comment: Put together a literature review organised by region to trigger more in-depth research *at a later date, for which information provided during the Research Dialogue on SOEs could be a starting point. RD8 outcomes can be complemented by AR5 literature for global coverage.*

Step 2 / 3: What information / technology / capacity is lacking at this point, identified by type of impact and region?

Step 3: Are there monitoring networks in place?

Comment: Bolster our understanding of data collection and risk management processes *in place via the results of the AA5 questionnaires, analyzing to extract gaps where the answers to the questionnaires are incomplete or lack global coverage.*

Step 4: What instruments / tools exist to address impacts from slow onset events?

Comment: Identify financial instruments and tools for addressing SOEs *by way of the SCF Forum and outcomes, including a gap analysis/assessment in global coverage.*

Annex II: Technical work in response to the guiding questions of the Excom

Information material in the context of Action Area 3, activity (d) of the initial two-year workplan of the Executive Committee for Loss and Damage

Introduction

Slow onset events and their impacts worldwide are of concern to international climate policy. Under the Warsaw International Mechanisms for Loss and Damage in the UNFCCC process, Parties have expressed a desire to better understand the current and potential future implications of slow onset events related to climate change.

Mandate and guidance from the Excom

The Executive Committee of the Warsaw International Mechanisms for Loss and Damage (Excom), at its fifth meeting (21–24 March 2017), requested the secretariat to compile and synthesize existing scientific information, as well as knowledge arising from the relevant previous activities carried out under the workplan of the Excom or from that facilitated by the Excom, in order to *'assess and develop recommendations to improve the state of knowledge to understand, and capacity to address, slow onset events and their impacts, including the capacity of regional agencies'* (Action Area 3, activity (d), initial two-year workplan).

Structure of this document

This document is divided into the following three parts:

> Part 1: A one-page overview of the four requests by the Excom in details[3] and hyperlinks to the corresponding products developed by the secretariat. It serves as an index to Part II of this document.
>
> Part 2: Four technical products delivered. The products are colour-coded consistently throughout this document for ease of reference.
>
> Part 3: A short description of the methodology and sources used for developing each technical product.

In compiling and synthesizing the voluminous information researched from the set of sources, every effort has been made to ensure the accuracy of the information contained in this document. For contextual or more comprehensive information, the Excom should refer to the original sources. Electronic links to these sources are included throughout this document for ease of reference for full details.

[3] As contained in Annex I of reference document Excom/2017/5/2, available at <http://unfccc.int/10400>.

Table of contents

Part 1: Overview of requests by the Excom and technical products by the secretariat

The table below provides excerpts of the request by the Excom[1] to the secretariat, with a view to assisting the Excom to assess the state of knowledge regarding slow onset events (SOEs) in the context of Action Area 3, activity (d) of the initial two-year workplan.

Requested steps and guidance	Outputs	Page
Step 1: Do we have comprehensive knowledge of the relevant SOEs in all regions? **Prepare an initial inventory of SOEs**, e.g. beginning from the decision 1/CP.16 footnote list, to determine which SOEs relate to which region (i.e. Caribbean, Pacific, Indian Ocean, Africa, Asia, Latin America), which would have to be broad, but would still go a step further than AR5, by pulling out the SOEs from the larger 'jumble' of climate change impacts. There would need to be some agreement in advance as to which of the AR5 chapters information would be drawn from and perhaps even a loose agreement as to the format of the summary e.g. a table matching SOEs to region along with a timeframe accompanied by a map. Perhaps, a table might be slightly preferable, as a map can only contain a limited amount of information. The table can include a column on the societal effects of each SOEs, accompanied by an illustrative map.	Initial inventory of slow onset impacts by region, drawn from IPCC's 5th Assessment Report: • One-page pictograph summary • Eight tables with further information on the regional impacts associated with slow onset events	4 >>
Step 2: What are the sources of information on SOEs? **Put together a literature review** organised by region to trigger more in-depth research at a later date, for which information provided during the Research Dialogue on SOEs could be a starting point. RD8 outcomes can be complemented by AR5 literature for global coverage.	Literature review, organized by region, drawn from the 8th Research Dialogue	26 >>
Step 2/3: What information/technology/capacity is lacking at this point, identified by type of impact and region? **Step 3**: Are there monitoring networks in place? Bolster understanding of data collection and risk management processes in place via the results of the Action Area 5 questionnaires, **analysing to extract gaps** where the answers to the questionnaires are incomplete or lack global coverage.	A summary of the state of risk management and data collection processes by region, drawn from responses to questionnaires under Action Area 5	41 >>
Step 4: What instruments/tools exist to address impacts from slow onset events? **Identify financial instruments and tools for addressing SOEs** by way of the SCF Forum and outcomes, including a gap analysis/assessment in global coverage.	A table of financial instruments and tools for addressing impacts of SOEs, drawn from 2016 Forum of the Standing Committee on Finance	56 >>

[1] As contained in Reference document Excom/2017/5/2, Annex I.

Part 2: Technical products

Part 2 contains technical outputs developed in response to the request by the Excom. Section A relates to Step 1, Section B responds to Step 2, Section C addresses Step 2/3 and Step 3, finally Section D focuses on Step 4.

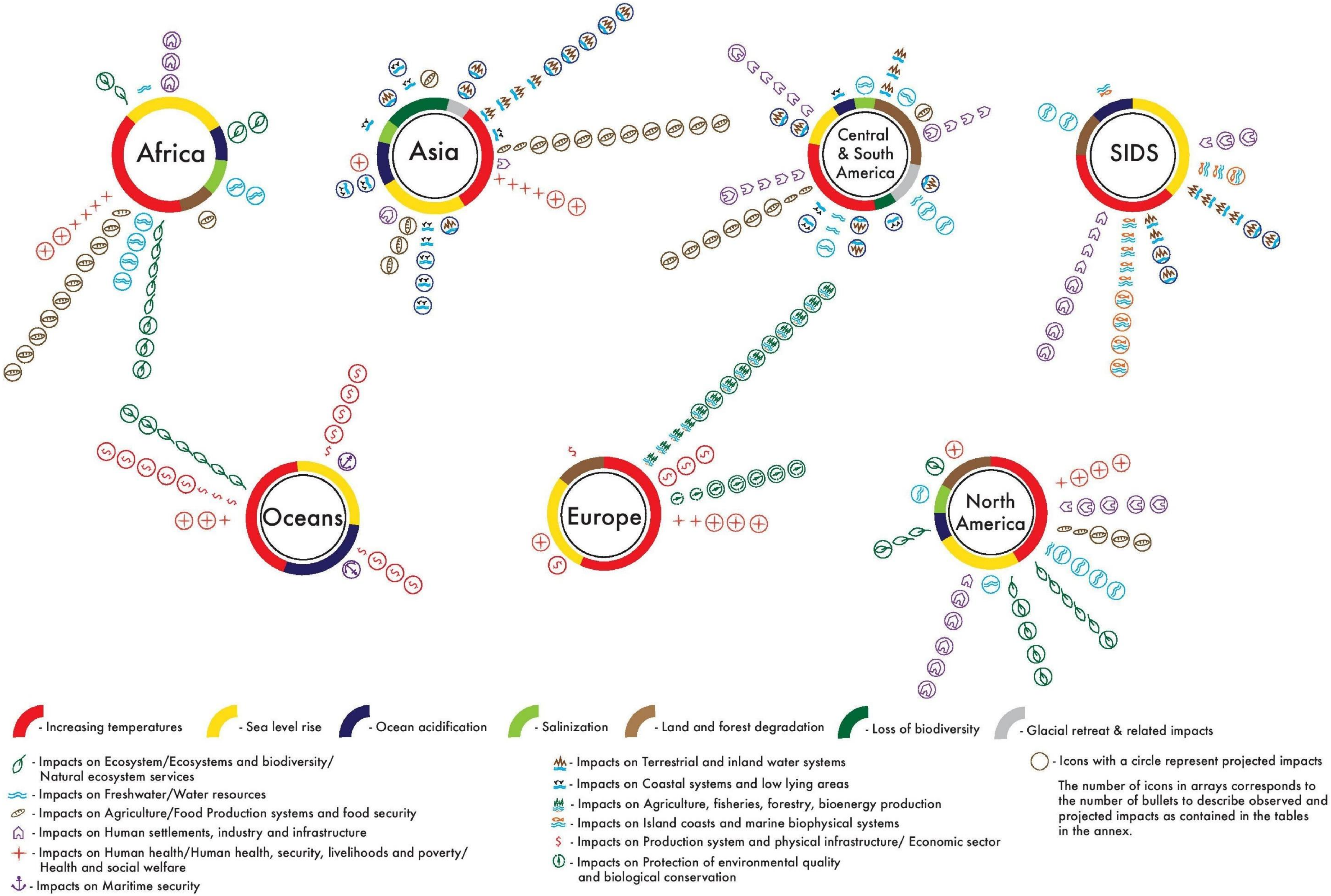
A. An initial inventory of slow onset impacts by region, drawn from IPCC's 5th Assessment Report *(Step 1)*

This initial inventory of slow onset events has been put together in the context of *Step 1 of the guidance by the Excom.*

This initial inventory provides:

1. One-page pictograph summary of slow onset events by region (for visualization purposes)
2. Eight tables with detailed information on the regional impacts associated with slow onset events by:
    - Region;
    - Slow onset event;
    - Environmental and social impacts (observed and projected).

Overview of slow onset events and their impacts by region



Increasing temperatures | Salinization | Land and forest degradation | Glacial retreat | Text boxes with outline only represent projected impacts; colour boxes represent observed impacts

Sea level rise | Ocean acidification | Loss of biodiversity

AFRICA

Ecosystems

• During the last quarter of the 20th century, total **forest cover** has decreased by 16% and total **non-forest** cover by 5% in sub-Saharan Africa. These changes have been attributed to increasing temperatures, changing rainfall patterns, and increasing CO2 (*low confidence*).

• On Mt. Kilimanjaro, increased vulnerability to **anthropogenic fires** has driven decreases in forests.

• Increased surface temperature and reduced **nutrient fluxes** and **primary productivity** in lakes have been attributed to increasing

• With increasing temperature, **reptiles and amphibians** in mountainous regions (e.g., Madagascar) are moving upslope.

• Canary current has warmed since the early 1980s. The changing temperatures have resulted in changes to important **fisheries species**.

• Warming is projected to continue in the Canary current, and the synergies between this increase in water temperature and ocean acidification could influence a number of **biological processes**.

• In Africa, **fisheries** mainly depend on either coral reefs or coastal upwelling. These two ecosystems will be affected by climate change through ocean acidification, a rise in sea surface temperatures, and changes in upwelling

• The combined effects of global warming and ocean acidification have been demonstrated to lower both coral **reef productivity** and resilience.

Water resources

• Reduced **snowpack** in the Atlas Mountains from a combination of warming and reduced precipitation, combined with more rapid springtime melting is expected to reduce supplies of seasonal meltwater for lowland areas of Morocco.

• The Blue Nile is expected to experience **increased flows** followed by a reduction by late century due to a combination of climate change (higher temperatures and declining precipitation) and upstream water development for irrigation and hydropower.

• **Seasonal runoff** volumes in the Lake Tana Basin are estimated to decrease by the 2080s (*A2 and B2 scenarios*). The Mara, Nyando, and Tana Rivers in eastern Africa are projected to have increased flow in the second half of this century.

• Higher temperatures coupled with declining rainfall would reduce **water resources** in Tunisia. (*A2 and B1 scenarios*)

• **Coastal aquifers** are vulnerable to climate change because of high rates of groundwater extraction, which leads to saltwater intrusion in aquifers, coupled with increased saltwater ingression resulting from SLR. Some studies have shown additional impacts of SLR on aquifer salinization with salinity potentially reaching very high levels. Although these effects are expected to be localized, in some cases they will occur in densely populated areas.

• The profitability of **irrigated agriculture** is expected to decline (*B1 and A1B scenarios*) owing to increased pumping of groundwater and increased salinization risk for aquifers (especially in Morocco).

Food production systems and food security

• The 1999 – 2002 drought was the most severe since the 15th century (based on a study in Tunisia and Algeria).

• Increasing temperatures are likely to result in diminished **yield potential** of major crops in Africa by midcentury (*A1B scenario*).

• Increasing temperatures and changes in precipitation are very likely to **reduce cereal crop productivity,** e.g. some regions are estimated to see a yield loss in maize farming exceeding 30% by mid-century.

• In eastern Africa **maize production** could benefit from warming at high elevation locations (*A1FI scenario*), thereby implying a potential change in the distribution of maize cropping.

• Several recent studies indicate that climate change will have variable impacts on **non-cereal crops**, with both production losses and possible gains (*low confidence*). E.g.:

o Bean yields in eastern Africa are estimated to experience yield reductions under various scenarios, while Peanuts are estimated to benefit from moderate climate change

o Banana and plantain production could decline in West Africa and lowland areas of East Africa, whereas in highland areas of East Africa it could increase with temperature rise.

• Warming in highland regions of eastern Africa could lead to range expansion of **crop pests** (*low confidence*). For example, the coffee berry borer, which is becoming a serious threat to coffee brewing regions, or the destructive burrowing nematode in banana-producing areas.

Human settlements, industry, and infrastructure

• SLR along coastal zones including coastal settlements could disrupt economic activities such as **tourism and fisheries** (More than a quarter of Africa's population lives within 100 km of the coast and more than half of Africa's total population living in low-elevation coastal zones is urban, accounting for 11.5% of the total urban population of the continent.)

• An assessment of the impact of **coastal flooding** due to SLR in Kenya found that, by 2030, 10,000 to 86,000 people would be affected, with associated economic costs ranging between US$7 million and US$58 million.

• An assessment suggests that in the Nile about 23% - 49% of the total area of **coastal regions** would be susceptible to inundation (flooding) under SLR (*A1f1 scenario*). Another study, assessing the economic impacts of SLR on the Nile Delta, suggested that losses in terms of housing and road would range between 1 and 2 billion EGP in 2030 and between 2 and 16 billion EGP in 2060 under current SLR trends (*the A1FI and B1 emissions scenarios*).

Human health, security, livelihoods, and poverty

• The frequency and duration of **cholera outbreaks** are associated with heavy rainfall in coastal West African countries (incl. Senegal, Ghana), and South Africa (possible association with the El Nino-Southern Oscillation (ENSO)). Also, in Zanzibar, Tanzania, and Zambia, an increase in temperature or rainfall has resulted in increase in the number of cholera cases.

• Zoonotic **cutaneous leishmaniasis** which emerged during the 20th century, as an epidemic disease in Algeria, Morocco, and Tunisia, has become more frequent and is now endemic. Additionally, increased minimum temperatures have expanded the transmission of zoonotic cutaneous leishmaniasis to adjacent areas in West Africa and East Africa.

• **Epidemics** in 2006–2007 in the Horn of Africa and southern Africa were associated with heavy rainfall, strengthening earlier analyses by showing that River Valley Fever (RVF) epizootics and epidemics are closely linked to the occurrence of the warm phase of ENSO and La Nina events and elevated Indian Ocean temperatures.

• High ambient temperatures are associated with increased **mortality** in Ghana, Burkina Faso, and Nairobi.

• Highland areas will experience increased **malaria epidemics**. The geographic areas suitable for transmission of schistosomiasis will increase with climate change (*2070–2099, A2 and B2 scenarios*).

• Climate change is likely to exacerbate the prevalence of **severe stunting**. An increase of 31 – 55% in the relative percent of children

AFRICA				
Ecosystems	*Water resources*	*Food production systems and food security*	*Human settlements, industry, and infrastructure*	*Human health, security, livelihoods, and poverty*
• During the time frame of 1975-2010, dieback of seaward edge of **mangroves** in Cameroon has been observed. • SLR in combination with storm swells will impact the **coastal systems** through coastal erosion. • **Upwellings** may be vulnerable to ocean acidification and its impacts. • Projections indicate that severe reductions of **reef accretion** by organisms such as corals are substantial potential impacts of ocean acidification. These effects will have consequences for reef biodiversity, ecology, and ecosystem services.	• Drought conditions in Africa may become more prevalent due to increased saline intrusion and stress on groundwater delivery infrastructure.	• Studies point that keeping **heat-tolerant livestock** will become more prevalent in response to warming trends. For example, higher temperatures in lowland areas of Africa could result in reduced stocking of dairy cows in favor of cattle, a shift from cattle to sheep and goats, a• Studies point that keeping **heat-tolerant livestock** will become more prevalent in response to warming trends. For example, higher temperatures in lowland areas of Africa could result in reduced stocking of dairy cows in favor of cattle, a shift from cattle to sheep and goats, and decreasing reliance on poultry. While livestock-keeping in highland areas, would potentially benefit from increased temperatures. • Additionally, the distribution of some **diseases in cattle** could shift. • Coastal countries of West Africa will experience a significant negative impact from climate change. Resulting in decline in **fisheries-related employment** of nearly 50% and a total annual loss of US$311 million to the region's economy (*by 2050 - A1B scenario*). • High temperatures are likely to increase spoilage further worsening weaknesses in the food system • Under an *A2 scenario*, by midcentury crop **suitable agro-climatic zones** will decrease; the constriction of crop suitability could be severe in some cases and could result in loss of productivity of high-value crops such as tea, coffee, and cocoa which would in turn have detrimental impacts on export earnings.		

Increasing temperatures	Sea level rise
Salinization	Ocean acidification
Land and forest degradation	Loss of biodiversity
Glacial retreat	

Text boxes with outline only represent projected impacts; colour boxes represent observed impacts

ASIA

Terrestrial and inland water systems

• Changes in **species distributions** consistent with a response to warming have been widely reported: upwards in elevation or polewards (*high confidence in detection, medium confidence in attribution to climate change*). Changes in the **distributions of major vegetation types** (biomes) have also been reported from the north and high altitudes, where trees are invading treeless vegetation, and forest understories are being invaded from adjacent biomes. In central Siberia, dark needle conifers (DNCs) and birch have invaded larch-dominated forest over the last 3 decades. Meanwhile, warming has driven larch stand crown closure and larch invasion into tundra at a rate of 3 to 10 m yr–1 in the northern forest-tundra ecotone. Shrub expansion in arctic tundra has also been observed.

• In Mongolia, mean annual **permafrost** temperature at 10 to 15 m depth increased over the past 10 to 40 years in the Hovsgol, Hangai, and Hentei Mountain regions. Permafrost warming during the past 15 to 20 years was greater than during the previous 15 to 20 years. In the Kazakh part of the Tien Shan Mountains, permafrost temperature and active layer thickness have increased since the early 1970s. Significant permafrost warming also occurred in the eastern Tien Shan Mountains, in the headwaters of the Urumqi River. Monitoring across the Qinghai-Tibet Plateau over recent decades has also revealed permafrost degradation caused by warming and other impacts. Areas of permafrost are shrinking, the active layer depth is increasing, the lower altitudinal limit is rising, and the seasonal frost depth is thinning. In the alpine headwater regions of the Yangtze and Yellow Rivers, rising temperatures and permafrost degradation have resulted in lower lake levels, drying swamps, etc.

Coastal system and low lying areas

Warming **coastal waters** have been implicated in the northward expansion of tropical and subtropical macro-algae and toxic phytoplankton, fish, and tropical corals, including key reef-forming species, over recent decades. The decline of large temperate seaweeds and expansion of tropical species in southwest Japan has been linked to rising sea surface temperatures, and these changes have impacted fish communities.

• Most **large deltas** in Asia are sinking (as a result of groundwater withdrawal, floodplain engineering, and trapping of sediments by dams) much faster than global sea level is rising.

• In Arctic Asia, changes in **permafrost** and the effects of SLR and sea ice retreat on storm-wave energy have increased erosion. Average erosion rates range from 0.27 m yr–1 (Chukchi Sea) to 0.87 m yr–1 (East Siberian Sea), with a number of segments in the Laptev and East Siberian Sea experiencing rates greater than 3 m yr–1.

• Future rates of SLR are expected to exceed those of recent decades, increasing **coastal flooding ,erosion, and saltwater intrusion** into surface and groundwaters. In the absence of other impacts, coral reefs may grow fast enough to keep up with rising sea levels, but beaches may erode and mangroves, salt marshes, and seagrass beds will decline, unless they receive sufficient fresh sediment to keep pace or they can move inland. A study in 2010, predict a 96% decline in tiger habitat in Bangladesh's Sunderbans mangroves with a 28 cm SLR if sedimentation does not increase surface elevations.

Food production systems and food security

• In some regions of Asia, **yields** were positively correlated with temperature when they were also positively related with solar radiation. However, in other places, lower yield with higher temperature was accompanied by a positive correlation between yield and rainfall (*high confidence in detection, high confidence in at*• In some regions of Asia, **yields** were positively correlated with temperature when they were also positively related with solar radiation. However, in other places, lower yield with higher temperature was accompanied by a positive correlation between yield and rainfall (*high confidence in detection, high confidence in attribution*).

• In Japan, where mean air temperature rose by about 1°C over the 20th century, effects of recent warming include **phenological changes in many crops**, increases in fruit coloring disorders and incidences of chalky rice kernels, reductions in yields of wheat, barley, vegetables, flowers, milk, and eggs, and alterations in the type of disease and pest (*high confidence in detection, high confidence in attribution*).

• With rising temperatures, the process of **rice development** accelerates and reduces the duration for growth. A study concluded that, in terms of risks of increasing heat stress, there are parts of Asia where current temperatures are already approaching critical levels during the susceptible stages of the rice plant. These include Pakistan/North India, South India, East India, Bangladesh, Myanmar, Thailand, Laos, Cambodia, Vietnam, Philippines, Indonesia, and China.

• Projected temperature increases of 1.5°C and 3°C would lead to wheat **yield declines** (by 7% and 24%, respectively) in Swat district but to increases (by 14% and 23%) in Chitral district of Pakistan.

Human settlements, industry, and infrastructure

• East Asia region is experiencing increasing **water shortages**, negatively affecting its socioeconomic, agricultural, and environmental conditions, which is attributed to lack of rains and high evapotranspiration, as well as over-exploitation of water resources.

• The drop in groundwater levels often results in **land subsidence**, which can enhance hazard exposure due to coastal inundation and SLR, especially in settlements near the coast, and deterioration of groundwater quality. Cities susceptible to human induced subsidence (developing country cities in deltaic regions with rapidly growing populations) could see significant increases in exposure.

Human health, security, livelihoods, and poverty

• **Dengue outbreaks** in South and Southeast Asia are correlated with temperature and rainfall with varying time lags. Temperature was linked to distribution and seasonality of malaria mosquitoes in Saudi Arabia. The reemergence of malaria in central China has been attributed to rainfall and increases in temperature close to water bodies. In China, temperature, precipitation, and the virus-carrying index among rodents have been found to correlate with the prevalence of hemorrhagic fever with renal syndrome.

• The effects of heat on **mortality** and morbidity have been studied in many countries, with a focus on the elderly and people with cardiovascular and respiratory disorders. Associations between high temperatures and mortality have been shown for populations in India and Thailand and in several cities in East Asia. Intense heat waves have been shown to affect outdoor workers in South Asia.

• Many pathogens and parasites multiply faster at higher temperatures. Temperature increases have been correlated with increased incidence of **diarrheal diseases** in East Asia. Other studies from South and East Asia have shown an association between increased incidence of diarrhea and higher temperatures and heavy rainfall. Increasing coastal water temperatures correlated with outbreaks of systemic Vibrio vulnificus infection in Israel and South Korea. Cholera outbreaks in coastal populations in South Asia have been associated with increased water temperatures and algal blooms. The El Nino Southern Oscillation (ENSO) cycle and Indian Ocean Dipole have been associated with cholera epidemics in Bangladesh.

• Urban heat island effects have increased. **Heat stress disorders** among workers and consequent productivity losses have also been reported.

• Biological changes consistent with climate trends have been reported in the north and at high altitudes, where rising temperatures have relaxed constraints on **plant growth and the distributions of organisms**. Growth rates have increased with warming in recent decades. Tree-ring data for temperate East Asia suggests recent summer temperatures have exceeded those during past warm periods of similar length, although this difference was not statistically significant.

• In North Asia, rising temperatures are expected to lead to large changes in the **distribution of potential natural ecosystems** (*high confidence*). It is likely that the boreal forest will expand northward and eastward, and that tundra will decrease. Boreal forest expansion and the continued invasion of the existing larch-dominated forest by DNCs could lead to larch reaching the Arctic shore, while the traditional area of larch dominance turns into mixed forest. Both the replacement of summer-green larch with evergreen conifers and expansion of trees and shrubs into tundra decrease albedo, causing regional warming and potentially accelerating vegetation change. In East Asia, subtropical evergreen forests are projected to expand north into the deciduous forest and tropical forests to expand along China's southern coast, but vegetation change may lag climate change by decades or centuries. On the Tibetan Plateau, projections suggest that alpine vegetation will be largely replaced by forest and shrubland, with tundra and steppe retreating to the north.

• Projected temperature increases and precipitation decreases in the western part of Kazakhstan, Uzbekistan, and Turkmenistan could exacerbate the problems of **water shortage and distribution**.

• Increases in water temperature will impact species- and temperature-dependent processes. Coldwater fish will be threatened as rising water temperatures make much of their current habitat unsuitable.

• Rising winter temperatures are expected to result in poleward expansion of mangrove ecosystems.

• In the Asian Arctic, rates of **coastal erosion** are expected to increase because of interactions between rising sea levels and changes in permafrost and the length of the ice-free season (*medium evidence; high agreement*). If SLRs by 0.5 m over this century, modeling studies predict that the rate of recession will increase 1.5- to 2.6-fold for the coasts of the Laptev Sea, East Siberian Sea, and West Yamal in the Kara Sea, compared to the rate observed in the first years of the 21st century.

• **Coastal freshwater wetlands** may be vulnerable to saltwater intrusion with rising sea levels, but in most river deltas local subsidence for non-climatic reasons will be more important. Current trends in cyclone frequency and intensity are unclear but a combination of cyclone intensification and SLR could increase coastal flooding and losses of coral reefs and mangrove forests would exacerbate wave damage.

• **Coastal freshwater wetlands** may be vulnerable to saltwater intrusion with rising sea levels, but in most river deltas local subsidence for non-climatic reasons will be more important.

• Warming would permit the expansion of **coral habitats** to the north but acidification is expected to limit this.

• Acidification is also expected to have negative impacts on other **calcified marine organisms** (algae, molluscs, larval echinoderms), while impacts on non-calcified species are unclear. On rocky shores, warming and acidification are expected to lead to range shifts and changes in biodiversity.

• The decline of large temperate **seaweeds** and expansion of tropical species in southwest Japan has been linked to rising sea surface temperatures, and these changes have impacted fish communities.

• In the Huang-Hai Plain, China's most productive wheat growing region, modelling indicated that winter **wheat yields** would increase on average by 0.2 Mg ha–1 in 2015–2045 and by 0.8 Mg ha–1 in 2070–2099, due to warmer night-time temperatures and higher precipitation, under *A2 and B2 scenarios* using the HadCM3 model. In the North China Plain, an ensemble-based probabilistic projection projected that maize yield will change by –9.7 to –9.1%, –19.0 to –15.7%, and –25.5 to –24.7%, during 2020s, 2050s, and 2080s as a percentage of 1961–1990 yields (Tao et al., 2009). In contrast, winter wheat yields could increase with high probability in future due to climate change. Extreme temperatures could lower yields of rice.

• In India, the Indo-Gangetic Plains are under threat of a significant reduction in **wheat yields**. This area produces 90 million tons of wheat grain annually (about 14 to 15% of global wheat production). Climate projections based on a doubling of CO_2 using a CCM3 model downscaled to a 30 arc-second resolution as part of the WorldClim data set showed that there will be a 51% decrease in the most favourable and high yielding area due to heat stress. About 200 million people (using the current population) in this area whose food intake relies on crop harvests would experience adverse impacts.

• Central Asia is expected to become warmer in the coming decades and increasingly arid, especially in the western parts of Turkmenistan, Uzbekistan, and Kazakhstan. Cereal production in northern and eastern Kazakhstan could benefit from the longer growing season, warmer winters, and a slight increase in winter precipitation, while others could be losers - particularly western Turkmenistan and Uzbekistan, where frequent droughts could negatively affect **cotton production**, increase already extremely high water demands for irrigation, and exacerbate the already existing water crisis and human-induced desertification.

• Recent studies validate the likely northward shifts of **crop production** with current croplands under threat from the impacts of climate change (*medium evidence, medium agreement*). Cooler regions are likely to benefit as warmer temperatures increase arable areas (*medium evidence, high agreement*).

• In North Asia, climate-driven changes in tundra and forest-tundra biomes may influence **indigenous peoples** who depend on nomadic tundra pastoralism, fishing, and hunting.

• **Rural poverty** in parts of Asia could be exacerbated as a result of impacts on the rice crop and increases in food prices and the cost of living. The poverty impacts of climate change will be heterogeneous among countries and social groups. In a low crop productivity scenario, producers in food exporting countries, such as Indonesia, the Philippines, and Thailand, would benefit from global food price rises and reduce poverty, while countries such as Bangladesh would experience a net increase in poverty of approximately 15% by 2030.

• Projected climate change is expected to intensify the existing pressures in many areas, most clearly for **coral reefs**, where increases in sea surface temperature and ocean acidification are a threat to all reefs in the region and the millions of people who depend on them.

• Marine biodiversity at temperate latitudes is expected to increase as temperature constraints on warmwater taxa are relaxed (*high confidence*), but biodiversity in tropical regions may fall if, as evidence suggests, tropical species are already near their thermal maxima (*medium confidence*). Individual fish species are projected to shift their ranges northward in response to rising sea surface temperatures. The combined effects of changes in distribution, abundance, and physiology may reduce the body size of marine fishes, particularly in the tropics and intermediate latitudes.

• Reduced **dry season flows** are expected to combine with SLR to increase saltwater intrusion in deltas although non-climatic impacts will continue to dominate in most estuaries.

• In North Asia, the replacement of **summer-green larch** with evergreen conifers and expansion of trees and shrubs into tundra is likely to decrease albedo, causing regional warming and potentially accelerating vegetation change.

• Melting of glaciers implies more meltwater, possibly explaining limited observations of increased **runoff** but also an eventual decrease of **meltwater yield**. More immediately, it entails a hazard due to the formation of moraine-dammed glacial lakes.

• It is suggested that **freshwater resources** will be influenced by changes in rainfall variability, snowmelt, glacier retreat.

• Climate change may lead to a massive redistribution of **fisheries catch** potential, with large increases in high-latitude regions, including Asian Russia, and large declines in the tropics, particularly Indonesia. Other studies have made generally similar predictions, with climate change impacts on marine productivity expected to be large and negative in the tropics, in part because of the vulnerability of coral reefs to both warming and ocean acidification, and large and positive in Arctic and sub-Arctic regions, because of sea ice retreat and poleward species shifts (*high confidence*). Predictions of a reduction in the average maximum body weight of marine fishes by 14 to 24% by 2050 under a high-emission scenario are an additional threat to fisheries.

• In Russia, climate change may also lead to "**food production shortfall**," which is defined as an event in which the annual potential (i.e., climate-related) production of the most important crops in an administrative region in a specific year falls below 50% of its climate-normal (1961–1990) average. The study shows that the frequency of shortfalls in five or more of the main crop growing regions in the same year is around 2 years per decade under normal climate but could climb to 5 to 6 years per decade in the 2070s, depending on the scenario and climate model.

• An Asia-wide study revealed that climate change scenarios (*using 18 GCMs for A1B, 14 GCMs for A2, and 17 GCMs for B1*) would reduce **rice yield** over a large portion of the continent. The most vulnerable regions were western Japan, eastern China, the southern part of the Indochina peninsula, and the northern part of South Asia.

• Climate change may lead to a massive redistribution of **fisheries catch potential**, with large increases in high-latitude regions, including Asian Russia, and large declines in the tropics, particularly Indonesia. Other studies have made generally similar predictions, with climate change impacts on marine productivity expected to be large and negative in the tropics, in part because of the vulnerability of coral reefs to both warming and ocean acidification, and large and positive in Arctic and sub-Arctic regions, because of sea ice retreat and poleward species shifts (*high confidence*).

• SLR is expected to impact both **capture fisheries and aquaculture production** in river deltas.

• SLR threatens coastal and deltaic **rice production areas** in Asia, such as those in Bangladesh and the Mekong River Delta. For example, about 7% of Vietnam's agriculture land may be submerged due to 1-m SLR. In Myanmar, saltwater intrusion due to SLR could also decrease rice yield.

• SLR will be a key issue for many coastal areas as rich **agricultural lands** may be submerged and taken out of production.

		• Asia dominates both capture **fisheries** and **aquaculture**. More than half of the global marine fish catch in 2008 was in the West Pacific and Indian Ocean, and the lower Mekong River basin supports the largest freshwater capture fishery in the world. Fish production is also a vital component of regional livelihoods, with 85.5% of the world's fishers (28 m) and fish farmers (10 m) in Asia in 2008. Many more people fish part time. Fish catches in the Asian Arctic are relatively small, but important for local cultures and regional food security.		

Increasing temperatures | Salinization | Land and forest degradation | Glacial retreat | Text boxes with outline only represent projected impacts; colour boxes represent observed impacts
Sea level rise | Ocean acidification | Loss of biodiversity

CENTRAL AND SOUTH AMERICA

Terrestrial and inland water systems

• Various models are projecting a risk of reduced rainfall and higher temperatures and water stress, which may lead to an abrupt and irreversible replacement of **Amazon forests** by savannah-like vegetation. The possible "savannization" or "die-back" of the Amazon region would potentially have large-scale impacts on climate, biodiversity, and people in the region.

• In North and South America **species losses** are projected. Species with small geographic ranges restricted to high mountains, might be particularly vulnerable to global warming because of their high energetic and area requirements - particularly birds and mammals.

• SLR due to climate change and human activities on coastal and marine ecosystems pose threats to **fish stocks, corals, mangroves, recreation and tourism, and diseases** control in CA and SA.

• **Beach erosion** is expected to increase in southern Brazil and in scattered areas at the Pacific coast.

• Land use change has led to the existence of six biodiversity **hotspots**, that is, places with a great species diversity that show high habitat loss and high levels of species endemism: Mesoamerica, Chocó-Darien-Western Ecuador, Tropical Andes, Central Chile, Brazilian Atlantic forest, and Brazilian Cerrado.

• Rates of **deforestation** have been continuously increasing, mainly due to agricultural expansion, and land degradation has been intensified for the entire region. Plant species, as well as amphibian species are rapidly declining in CA and SA. Brazil is among the countries with most threatened bird and mammal species.

Water resources

• Fluctuations in Mendoza River **streamflow**, possibly linked to rising temperature and snowpack glacier effect, observed.

• Retreating of **tropical glaciers** has accelerated in the second half of the 20th century due to increasing temperatures. An area loss between 20 – 50% has been estimated.

• Risk of **water supply** shortages will increase owing to precipitation reductions and evapotranspiration increases, affecting water supply for cities, hydropower generation, and agriculture. Examples:

o The Lempa River basin, one of the largest basins in Central America (CA), covering portions of Guatemala, Honduras, and El Salvador is anticipated to experience a reduction of 20% in inflows to major reservoirs.
o Studies on northeast Brazil (NEB) have shown that future climate change scenarios would decrease water availability for agriculture irrigation. Further a study linked projected impacts on water availability for agriculture with economic impacts that could potentially drive full-scale migrations in the NEB region.

• Salinization is likely to deteriorate the water quality, exacerbating the existing **water stress**. This in addition to increases in future water demands, may push up irrigation costs and force many producers out of farming by 2030.

• Soybean-planted area in Amazonian states have been witnessing an expansion in recent years. This **landscape-scale conversion** from forest to soy and other large-scale agriculture can substantially alter the water balance for large areas of the region, resulting in important feedbacks to the local climate.

Coastal system and low lying areas

• Extreme high sea surface temperatures have been increasingly documented in the western Caribbean near the coast of CA and have resulted in frequent bleaching events (1993, 1998, 2005, and again in 2010) of the Mesoamerican coral reef, located along the coasts of Belize. Honduras. and Guatemala.

• **Coral bleaching and mortality** are often associated with ocean warming and acidification. If extreme sea surface temperatures were to continue, some projections indicate the possibility of the Mesoamerican coral reef collapsing by mid-century, causing major economic losses.

• Frequent **coral bleaching** events associated with ocean warming and acidification have occurred in the Mesoamerican Coral Reef.

• **Reef and mangrove ecosystems** are estimated to contribute greatly to goods and services in economic terms. In Belize, for example, this amount is approximately US$395 to US$559 million annually, primarily through marine-based tourism, fisheries, and coastal protection. Projected losses in the biodiversity could potentially results in, ecosystem collapse, fisheries reduction, loss of livelihoods and other important ecosystem goods and services. Specifications:

o It is estimated that climate change may lead to a maximum global loss of 10 to 15% of mangrove forest by 2100

o It is possible that the Mesoamerican coral reef will collapse by mid-century (*between 2050 and 2070*)

o Eastern Brazilian reefs might suffer a massive coral cover decline in the next 50 years.

Food production systems and food security

• In central Argentina, simulated potential **wheat yield**—without considering technological improvements—has been decreasing at increasing rates in response to increasing minimum temperature during October–November.

• Changes in the growing season temperature and precipitation have slowed the positive **yield** trends due to improved genetics in Brazilian **wheat, maize, and soy**, as well as Paraguayan soy (1980 - 2008). In contrast, **rice** in Brazil and soybean in Argentina have benefited from precipitation and temperature trends.

• Apart from the reduction in **crop yield**, increases in temperature could reduce the areas currently favourable for some crops. Examples:

o Productions of crops like Brazilian potato could be restricted to a few months in currently warm areas, which today allow potato production year-round.
o In south Brazil, irrigated rice yield, maize and bean productivity are expected to increase. Sugarcane production could benefit, as warming could allow the expansion of planted areas toward the south.
o In central Chile, temperature increases, reduction in chilling hours, and water shortages may reduce productivity of winter crops, fruits, vines, and radiata pine. Conversely, rising temperatures, more moderate frosts, and more abundant water will very likely benefit all species toward the south.

• Climate could strongly affect **milk production** and feed intake in dairy cattle where substantial modifications in areas suitable for livestock are expected (Brazil). Warming and drying conditions could reduce milk production, mainly among farmers who are already seriously affected under average dry season conditions (Nicaragua).

Human settlements, industry, and infrastructure

• Increase in **malaria** cases. Examples:
o The number of cases of malaria have increased in Colombia during the last 5 decades with rising temperatures and environmental changes.
o Malaria transmission has reached 2300 m in the Bolivian Andes, and vectors are found at higher altitudes from Venezuela to Bolivia.

• **Malaria, dengue fever** and its hemorrhagic variant are mostly urban diseases whose vector is affected by climate conditions. Their incidences have risen in tropical America in the last 25 years, causing annual economic losses of US$2.1+ (1 to 4) billion.
o In Rio de Janeiro a 1°C increase in monthly minimum temperature led to a 45% increase of dengue fever in the next month, and 10 mm increase in rainfall to a 6% increase.

• **Hantaviruses** have been recently reported throughout the region, and El Niño and climate change augment their prevalence.

• Seawater temperature affects the abundance of **cholera** bacteria, which explains the outbreaks during El Niño in Peru, Ecuador, Colombia, and Venezuela.

• The worsening of air quality and higher temperatures in urban settings are increasing **chronic respiratory and cardiovascular diseases**, and morbidity from asthma and rhinitis, but also atherosclerosis, pregnancy-related outcomes, cancer, cognitive deficit, otitis, and diabetes.

• **Schistosomiasis** is endemic in rural areas of Suriname, Venezuela, the Andean highlands, and rural and peripheral urbanized regions of Brazil. It is highly likely that schistosomiasis will increase in a warmer climate.

CENTRAL AND SOUTH AMERICA

Terrestrial and inland water systems	*Water resources*	*Coastal system and low lying areas*	*Food production systems and food security*	*Human settlements, industry, and infrastructure*
• Deforestation and land degradation - attributed mainly to increased extensive and intensive agriculture (soy production, beef production and biomass production) - has affected fragile ecosystems, such as the **Amazon forest and the tropical Andes**. This has led to the reduction of environmental services provided by these ecosystems. • In tropical Andes, glacier retreat could also impact activities in high mountainous ecosystems such as alpine **tourism**, mountaineering, and adventure tourism.	• Glacier retreats and melting of ice fields, have been reducing flows in dry seasons and increasing them in wet seasons. Initially, **streamflow** tends to increase due to an acceleration of glacier melt, but after a peak in streamflow as the glacierized water reservoir gradually empties, runoff tends to decrease. • Projected changes in the cryosphere conditions of the Andes could affect the occurrence of extreme events, such as extreme low and high flows, Glacial Lake Outburst Floods (GLOF) in the ice fields of Patagonia, volcanic collapse and debris flow, as well as scenarios of water quality pollution by exposure to contaminants as a result of glaciers' retreat. • A reduction in **runoff** (especially during the summertime) could endanger high Andean wetlands and intensify conflicts between different water users among the highly vulnerable populations in high-elevation Andean tropical basins. Supply of water for various purposes may become more expensive and less reliable.		• Increases in temperature and decreases in rainfall could decrease the productivity in the short term (by 2030), threatening the local economies and **food security** of the poorest population. The current rate of chronic malnutrition is likely to increase. Examples: o Soybean yields would be reduced by 44% in the worst scenario by 2050 (in Amazon region). o 80% of crops might be impacted in > 60% of current areas of cultivation in Colombia (*by 2050, A2 scenario*). • Climate change may also alter the current scenario of **plant diseases** and their management, having effects on productivity. Examples: o In Argentina, years with severe infection of late cycle diseases in soybean could increase; severe outbreaks of the Mal de Rio Cuarto virus in maize could be more frequent; o Wheat head fusariosis will increase slightly in the south of the Pampas region by the end of the century. o In Brazil, favourable areas for soybean and coffee rusts will move toward the south (*2080, A2 scenario*). o Potato late blight severity is expected to increase in Peru. • **Rice** in southeast Brazil, maize in CA and SA (South America), and soybean in central Brazil will be the crops and zones most affected by increases in temperature (*by 2071– 2100, A1B scenario*). • The choice of **livestock** species could change. By 2060, under a hot and dry scenario beef/dairy cattle, pig, and chicken production choice could decrease by 0.9 to 3.2%, while sheep election could increase by 7% mainly in the Andean countries. • By 2100, SA could lose between 1 and 21% (*A1B and B1 scenarios*) of its **arable land** due to climate change and population growth. Current land use changes disrupt water and biogeochemical cycles and may result in soil salinization, altered carbon and nitrogen storage, surface runoff, and stream acidification.	• SLR varied from 2 to 7 mm per year between 1950 and 2008 in CA and SA, which is a reason for concern because a large proportion of the **population** of the region lives by the coast. • **Coastal structures** have been reported to be affected by SLR induced increase in wave heights. • Since **flooding probability** increases with increasing sea level, one may expect a higher probability of flooding in locations showing >40% of change over the last 60 years in the 100-years total sea level (excluding hurricanes). Taking the future SLR projections in consideration, there is a reduction in the reliability of the coastal structures owing to the increase in wave height estimates. • A scenario of 1 m SLR would affect some **coastal populations** in Brazil and the Caribbean islands. • During the 1930s and 1940s, dry and windy conditions together with deforestation, overgrazing, over-cropping, and non-suitable tillage produced severe dust storms, **cattle mortality, crop failure, and rural migration**. • Degradation of natural resources (land, forest, water, soil, etc.) has reportedly encouraged farmers toward off-farm activities; however, no improvement of their well-being has been observed. • Deforestation and land degradation has increased the **vulnerability of communities** exposed to floods, landslides, and droughts. • The expansion of sugarcane, soy, and oil palm may have some effect on land use, leading to **deforestation** in parts of the Amazon and CA, among other regions, and loss of employment in some countries.

(orange)	Increasing temperatures	(light green)	Salinization	(brown)	Land and forest degradation	(grey)	Glacial retreat
(yellow)	Sea level rise	(blue)	Ocean acidification	(green)	Loss of biodiversity		

Text boxes with outline only represent projected impacts; colour boxes represent observed impacts

SMALL ISLAND DEVELOPING STATES (SIDS)

Terrestrial systems (island biodiversity and water resources)

- Altitudinal **species** range - shifts and declines mainly due to temperature increase on high islands:
  - o for example: In parallel with rising temperatures the upper altitudinal limits of plant distributions had risen by about 3.6 m yr–1 during the last century in Taiwan. (Pacific)
- Exotic and **pest species** range and invasions increase mainly due to temperature rise in high-latitude islands.
  - o Altitudinal temperature change has also been reported to influence the distribution of disease vectors such as mosquitoes, potentially threatening biota unaccustomed to such vectors.
- Increasing global temperatures may lead to altitudinal **species** range shifts and contractions within high islands, with an upward creep of the tree line and associated fauna.
- Increasing temperatures and decreasing rainfall alongside economic and management failures in the water sector are likely to results in reduced **freshwater** availability. *(Caribbean, Indian Ocean, Pacific)*
- Storm surge wash-over has caused the **freshwater** lens to become brackish and has rendered the water unfit for human use in the Cook Islands. *(Pacific)*
- Rates of relative SLR at Funafuti (Tuvalu) between 1950 and 2009 have been approximately three times higher than the global average, and saline flooding of internal low-lying areas has occurred regularly. *(Pacific)*
- SLR has been observed to threaten the long-term persistence of **freshwater-dependent ecosystems** within low-lying islands. *(Caribbean)*
- **Pine forest** area has declined to 34% (1935 – 1991) due to salinization and rising groundwater which triggered vegetation transition in Florida Keys. *(Caribbean)*
- Area loss for more than 12,900 islands and more than 3000 terrestrial **vertebrates** in the tropical Pacific region has been estimated for three SLR scenarios. A study estimated that for SLR of 1 m, 37 island endemic species in this region risk complete inundation. *(Pacific)*

Island coasts and marine biophysical systems

- Studies implicate thermal stress in reduced **coral calcification rates**, and regional declines in calcification of corals that form reef frameworks.
- Higher temperatures may negatively affect the spawning of adult **reef species**.
- **Seagrass** shoot mortality and recruitment rates have been negatively influenced by higher temperatures. *(Mediterranean)*
- Temperature-induced **coral bleaching** has been recorded during ENSO events. *(Pacific)*
- Climate-sensitive **diseases** such as yellow, white, and black band; white plague; and white pox travel across national boundaries and infect coral reefs directly. This is variously supported by examples from the Pacific, the Mediterranean, and the Caribbean and Atlantic reefs. (*Pacific, Mediterranean, Caribbean, Atlantic*)
- Rise in Sea Surface Temperature and acidification of oceans, will result in accelerated **coral bleaching and reef degradation**. These are likely to threaten the function of island coral reef ecosystems.
- Warming in the future from the current accumulation of GHGs in the atmosphere could cause more than half of the world's **coral reefs** to experience harmfully frequent thermal stress by 2080. This timeline could be brought forward to as early as 2030 under medium emissions scenarios.
- The most expected impact of climate change on **seagrass** is increasing temperature stress. It is likely to negatively influence seagrass shoot mortality and recruitment rates.
- A possible 2°C temperature increase by the year 2100 has potentially far-reaching consequences for sentinel ecosystems such as **coral reefs** that are important to tropical islands. *(Pacific, Caribbean, Indian Ocean)*
- Since 2004, 17 out of 18 islands (of Wotje Atoll, Marshall Islands) became net erosive, potentially corresponding to the high sea levels in the region over the last 10 years. *(Pacific)*

Freshwater resources

- Reduction in the number and size of **endemic populations** - caused by habitat constriction and changes in species composition - is more likely in the mountain systems.
- Socio-ecological stresses, such as **habitat loss and degradation**, invasive species, overexploitation, pollution, human encroachment, and disease can harm biodiversity and reduce the ability of socio-ecological systems to bounce back after shocks.

Human settlements, industry, and infrastructure

- The Caribbean has been identified as a "highly endemic zone for **leptospirosis**," with Trinidad and Tobago, Barbados, and Jamaica representing the highest annual incidence in the world, with only the Seychelles being higher. *(Caribbean, Indian Ocean)*
- In Pacific islands the incidence of **malaria** and **dengue** fever has been increasing and a direct link between climate variability and occurrence of Dengue and Malaria has been established. *(Pacific)*
- **Ciguatera Fish Poisoning** (CFP) occurs in tropical regions and is the most common non-bacterial food-borne illness associated with consumption of fish. Distribution and abundance of the organisms that produce these toxins, are reported to correlate positively with water temperature. *(Caribbean, Pacific)*
- Studies in the Caribbean demonstrated the link of **leptospirosis** incidences with rates increasing in El Niño years. *(Caribbean)*
- Health risks including **cholera** alongside **dengue** and **malaria** are projected to increase as a consequence of climate change.
- Changes in the epidemiology of **leptospirosis** have been detected, which may be enhanced with increases in ambient temperature and changes in precipitation, vegetation, and water availability as a consequence of climate change.
- Decrease in **crop yield** is projected in Puerto Rico for various scenarios during September although increased crop yield is suggested during February. *(Caribbean)*
- There is growing concern that increasing temperatures associated with climate change could increase the incidence of **CFP** in the island regions of the Caribbean, Pacific the Mediterranean, and the Canary Islands in the Atlantic. *(Caribbean, Pacific, Mediterranean, Atlantic)*

SMALL ISLAND DEVELOPING STATES (SIDS)

Terrestrial systems (island biodiversity and water resources)	*Island coasts and marine biophysical systems*	*Freshwater resources*	*Human settlements, industry, and infrastructure*
• Wave overtopping and wash-over can be expected to become more frequent with SLR, and this has been shown to impact freshwater lenses dramatically. Saline flooding of internal low-lying areas is expected to become more frequent and extensive over time which will result in degradation of fresh groundwater resources.	• SLR is reported as the most significant climate change threat to the survival of **mangroves**. E.g.: Loss of the seaward edge of mangroves due to SLR at Hungry Bay, Bermuda, has been reported. *(Caribbean)* • It is virtually certain that global mean SLR rates are accelerating. Projected increases to the year 2100 superimposed on extreme sea level events (e.g., swell waves, storm surges, El Niño-Southern Oscillation) present severe sea flood and erosion risks for low-lying coastal areas and atoll islands. The rate and extent of erosion is likely to increase. • Unprecedented **bleaching** events leading to coral mortality have been recorded. *(Pacific)* Examples: o Nearly 100% coral mortality in the lagoon (Phoenix Islands, Kiribati) o 62% mortality on the outer leeward slopes of the reefs of Kanton Atoll (Kiribati).		• **Relocation** and **displacement** are frequently cited as outcomes of SLR, salinization, and land loss on islands. Examples: o On the Torres Islands, Vanuatu communities have been displaced as a result of increasing inundation of low-lying settlement areas owing to a combination of tectonic subsidence and SLR. (Pacific) o An inundation event in Papua New Guinea and Solomon Islands alone displaced some 63,000 people. Remotely generated swell waves, and the severity of flooding induced by anomalously high regional sea levels linked with ENSO and ongoing SLR, have been associated with this displacement. (Pacific) • A 4°C warming scenario - producing a 0.5 to 2.0 m SLR, has been estimated to produce **displacement** of between 1.2 and 2.2 million people from the Caribbean and Indian and Pacific Oceans. *(Caribbean, Pacific, Indian Ocean)* o The intrinsic exposure of rapidly expanding settlements and agriculture in the low-lying flood prone Rewa Delta, Fiji, is shown to place populations in increasingly severe conditions of vulnerability to flooding and marine inundation. (Pacific) o In Majuro atoll (Marshall Islands), socio-ecological stress is exacerbating shoreline change associated with SLR, especially on the lagoon side of islands. Islands faced with multiple stressors can therefore be assumed to be more at risk from climate impacts. *(Pacific)* • Small island economies can also be objectively shown to be at greater risk from SLR in comparison to other geographic areas because most of their **population** and **infrastructure** are in the coastal zone. o Of those most impacted by the cost of SLR expressed as percent of GDP most of the top ten and four of the are small islands from the Pacific (Federated States of Micronesia, Palau, Marshall Islands, Nauru) and Caribbean (Bahamas). The damage costs for these small island states are enormous in relation to the size of their economies and, together with deltaic areas, they will find it most difficult to locally raise the finances necessary to implement adequate coastal protection. (Pacific, Caribbean) o Impact example: In the Caribbean, SLR of 1m has been estimated to put 49 – 60 % of tourist resort properties at risk of beach erosion and inundation. This could potentially transform the competitive position and sustainability of coastal tourism destinations. (Caribbean)

Increasing temperatures | Salinization | Land and forest degradation | Glacial retreat | Text boxes with outline only represent projected impacts; colour boxes represent observed impacts

Sea level rise | Ocean acidification | Loss of biodiversity

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Natural ecosystem services

• Warming oceans and increasing acidification has led to rapid changes in the physical and chemical conditions within ocean sub-regions, which have already affected the distribution and abundance of **marine organisms and ecosystems**. Responses of species and ecosystems to climate change have been observed from every ocean sub-region. Examples:
- o Marine organisms are moving to higher latitudes, with fish and zooplankton migrating at the fastest rates, particularly in High-Latitude Spring Bloom Systems regions.
- o Changes to sea temperature have also altered the timing of key life-history events such as plankton blooms, over recent decades.
- o Climate Change in conjunction with local stressors (pollution, etc.) have led to the rapid decline of coral reefs through events like mass coral bleaching and mortality.
- o Changes to ocean temperature along with other factors, are resulting in loss of coastal and oceanic habitat, the spread and increase of disease and invading species, and changes in primary production.

• **Coral reef ecosystems** in the Indian Ocean have been heavily affected.

• Elevated sea temperatures within the Pacific Ocean have increased the frequency of widespread mass **coral bleaching and mortality**.

• Rising sea temperature has resulted in low primary production and a major shift in **tuna stocks**. Many countries have lost revenue related to tuna and other large pelagic fishes. As a result, fishing fleets are shifting towards the eastern basin.

• Changes in sea temperature also lead to changes in the distribution of key **pelagic fisheries** such as different sorts of tuna, which make up the majority of key fisheries in the Pacific Ocean.

• Overall, warming temperatures are projected to shift optimal environments for individual species polewards and redistribute production; however, changes will be region specific.

Economic sector

• Changes to ocean temperature and upwelling patterns along with other factors are generating new challenges for **fisheries**, as well as benefits.

o There has been a boost in fish stocks of high-latitude fisheries in the High-Latitude Spring Bloom Systems (HLSBS) of the North Pacific and North Atlantic, partly as a result of 30 years of increase in temperature. This is very likely to continue, although some fish stocks will eventually decline.

• Industries for **non-food products**, which can be important for regional livelihoods such as Black Pearl in Polynesia, are also affected by rising sea surface temperatures. As higher temperatures affect the quality of pearl nacre, and can increase levels of disease in adult oysters.

• Studies have noted reduced **tourist satisfaction** and identified "dead coral" as one of the reasons for disappointment.

• **Fisheries** for certain species, provide substantial economic and social benefits to the people of Small Island Developing States (SIDS). For example, tuna fishing license fees contribute substantially (up to 40%) to the government revenue of several Pacific Island. Tuna fishing and processing operations also contribute up to 25% of gross domestic product in some of these nations and employ more than 12,000 people. Climate Change is a risk to the sustainability of capture fisheries and aquaculture development. In Equatorial Upwelling System (EUS) and Subtropical Gyres, shifts in large pelagic fish stocks have the potential to create "winners" and "losers" among island nations and economies as catches change among and within their exclusive economic zones.

• Increasing sea temperatures can change attractiveness of locations and the opportunities for **tourism** through their influence on the movement of organisms and the state of ecosystems such as coral reefs. Tourists respond to changes in factors such as weather by expressing different preferences. For example, tourism is projected to shift toward higher latitudes with climate change, or from summer to cooler seasons.

• The impacts of climate change on **marine fish stocks** are expected to affect the economics of fisheries and livelihoods in fishing nations.

Maritime security

• UNCLOS defined limits of maritime jurisdiction will contract as national baselines shift inland. Potential uncertainty increases in some areas with respect to the international boundaries to maritime jurisdiction.

• National maritime **security capacity** and **infrastructure** might be posed with new challenges as a result of climate change and ocean acidification.

Human health

• The frequency of **cholera** outbreaks is correlated with sea surface temperatures, multi-decadal fluctuations of ENSO, and plankton blooms, which may provide insight into how this disease may change with projected rates of ocean warming.

• The incidence of diseases such as **ciguatera** also shows links to ENSO, with ciguatera becoming more prominent after periods of elevated sea temperature.

• **Ciguatera** may become more frequent in a warmer climate, particularly given the higher prevalence of ciguatera in areas with degraded coral reefs (*low confidence*)

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Natural ecosystem services	*Economic sector*	*Maritime security*	*Human health*
• Most of the Ocean will continue to warm and acidify, although the rates will vary regionally. The projected changes in ocean temperature pose serious risks to the productivity of **fisheries and aquaculture**, and the security of regional livelihoods and food production. Global warming will result in more frequent extreme events. o Frequent occurrence events like mass coral bleaching and mortality will eliminate ecosystems, and increase risks and vulnerabilities to coastal livelihoods and food security. o Elevated sea temperatures are projected to cause the loss of coral reefs from most sites globally by 2050 under mid to high rates of ocean warming. o Expansion of low productivity areas is likely as a consequence of thermal stratification and changes in wind stress.	• Most **marine aquaculture** species are sensitive to changing ocean temperature. Environmental changes can therefore impact farm profitability, depending on target species and farm location. • Potential habitats are predicted to contract for example for the **blue whale**, while potential habitats for others are predicted to expand for example for the sooty shearwater. • Increasing sea levels have also caused changes in **seagrass** and **mangrove systems**. • SLR, through its influence on coastal erosion and submergence, salinization of water supplies, and changes to storm surge, increases the vulnerability of coastal **tourism** infrastructure, tourist safety, and iconic ecosystems. For example, approximately 29% of resorts in the Caribbean are within 1 m of the high tide mark. • **Coastal inundation and habitat loss** due to SLR, as well as intensified precipitation events are likely to exacerbate the emerging risks associates with collapsed fisheries • **Coastal inundation and habitat loss** due to SLR, as well as intensified precipitation events are likely to exacerbate the emerging risks associates with collapse fisheries. • Inundation of **coastal aquifers** is likely to reduces water supplies and decreases coastal agricultural productivity. • In the Coastal Boundary Systems (CBS), SLR is likely to modify **coastlines** and increase flooding, challenging aquaculture such as shrimp farms. • Seasonal upwelling of acidified waters in the California Current region has recently affected **oyster hatcheries** along the coast of Washington and Oregon. • In ecosystems that are heavily dependent on the accumulation of calcium carbonate over time (e.g., **coral reefs**), increasing ocean acidification puts at risk ecosystems services that are critical for hundreds of thousands of marine species, plus people and industries. • **Fisheries**, in particular shellfish, are also vulnerable to declining pH and carbonate ion concentrations. As a result, the global production of shellfish fisheries is likely to decrease with further ocean acidification. • Acidification of seasonally upwelling waters will impact **shellfish aquaculture** in Eastern Boundary Upwelling Systems.		

Examples of projected impacts and vulnerabilities associated with climate change in Ocean regions

(1) Expansion of low-productivity areas as a consequence of thermal stratification and changes in wind stress. (*Low*)

(2) Northward expansion of plankton, invertebrate, and fish communities with warming. Increase in fish biomass at high latitude fringes. (*High*)

(6) Decline in dissolved oxygen through changes in oxygen solubility (temperature), and ocean ventilation and circulation. (*Medium*)

(7) Expansion of seasonally hypoxic waters due to thermal stratification and eutrophication. Mass coral bleaching events leading to degradation of coral reefs and loss of associated biodiversity. (*High*)

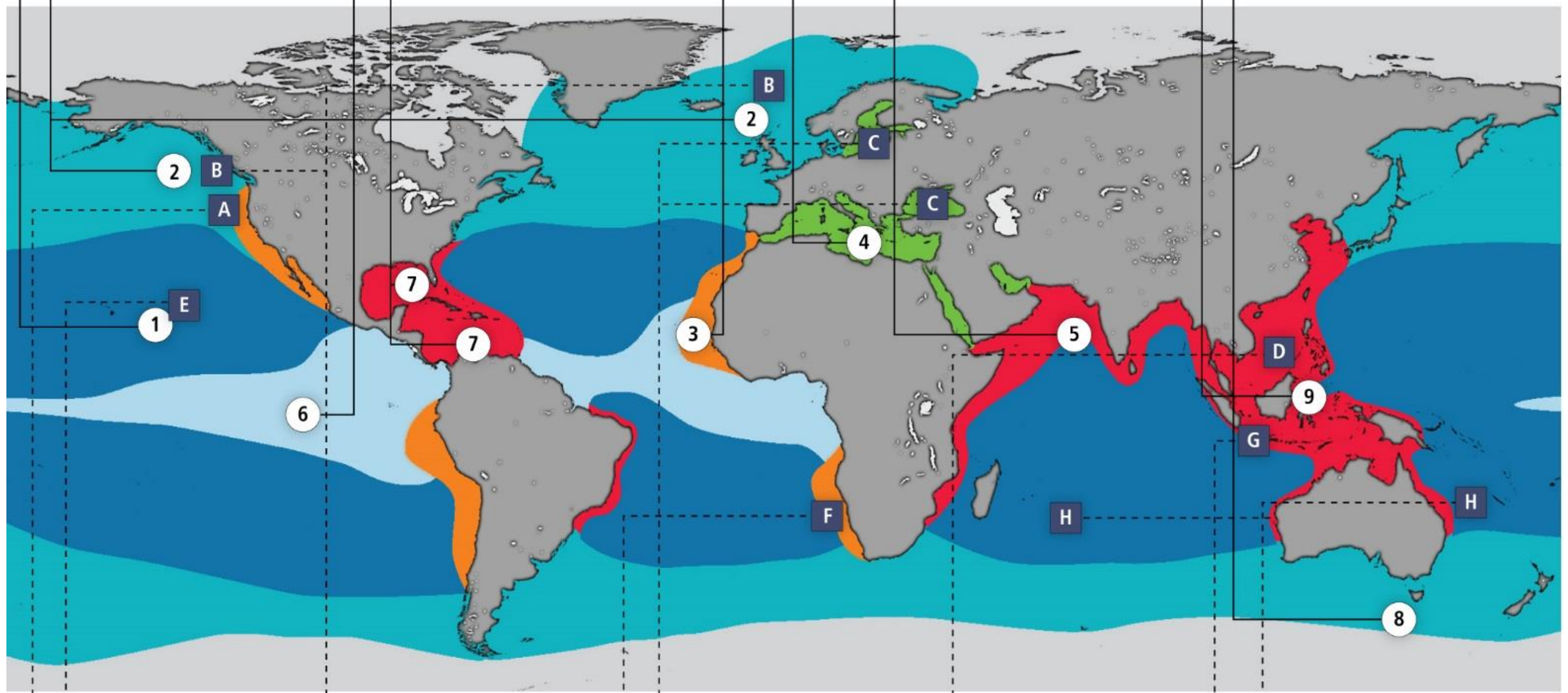
(3) Upwelling, hence productivity, changes as a result of climate variability, particularly wind stress variability. *(Low)*

(4) Spread of tropical species originating from Indian and Atlantic Oceans. Increased frequency of mass mortality events of benthic plants and animals linked to extreme temperature events. (*High*)

(5) Declining dissolved oxygen concentrations and expansion of Oxygen Minimum Zones (OMZ). (*High*)

(9) Mass coral bleaching and mortality in response to warming as well as temperature-driven decline in growth rates of some corals leading to degradation of coral reefs and loss of associated biodiversity. (*Very high*)

(8) Shoaling of aragonite saturation horizon reduces biological calcification and alters plankton communities. (*High*)



(E) Warming leads to decline in primary production and reductions in fish catch. (*Low*)

(A) Acidification of seasonally upwelling waters impacts shellfish aquaculture. (*Medium*)

(B) Increased fish catches at high-latitude fringes with economic disruptions and jurisdictional tensions as some fish stocks shift distributions. (*Medium*)

(C) Thermal stratification and eutrophication reduces dissolved oxygen with impacts on fish stocks. (*Medium*)

(F) Increase in variability of upwelling in some EBUEs adds uncertainty to fisheries management. (*Medium*)

(D) Sea level rise modifies coastlines and increases flooding, challenging aquaculture such as shrimp farms. (*Medium*)

(H) Temperature-driven shifts in stocks of large pelagic fish create winners and losers among country and island economies. (*High*)

(G) Degradation of coral reefs and associated fish stocks as the extent and intensity of mass coral bleaching and mortality increases, increasing risks to regional food security. (*High*)

Examples of risks to fisheries from observed and projected impacts

- High-Latitude Spring Bloom Systems
- Semi-Enclosed Seas
- Coastal Boundary Systems
- Eastern Boundary Upwelling Systems
- Equatorial Upwelling Systems
- Subtropical Gyres

Increasing temperatures	Salinization	Land and forest degradation	Glacial retreat	Text boxes with outline only represent projected impacts; colour boxes represent observed impacts
Sea level rise	Ocean acidification	Loss of biodiversity		

EUROPE

Agriculture, fisheries, forestry, bioenergy production

- Wide ranging effects have been observed throughout the European region including the distribution, phenology, and abundance of animal, fish, and plant species (*high confidence*); and forest decline in some sub-regions (*medium confidence*).

- Observed warming has shifted **marine fish species** ranges to higher latitudes (*high confidence*) and reduced body size in species (*medium confidence*). Observed higher water temperatures have adversely affected both wild and farmed freshwater salmon production in the southern part of their distribution (*high confidence*).

- Climate change has contributed to **vector-borne disease** in ruminants in Europe (*high confidence*) and northward expansion of tick disease vectors (*medium confidence*).

- Yields of some **arable crop species** like wheat have been negatively affected by observed warming in some European countries since the 1980s (*medium confidence, limited evidence*).

- Climate change is very likely to increase the frequency and intensity of **heat waves**, particularly in Southern Europe (*high confidence*), with mostly adverse implications for health, agriculture, forestry, energy production and use, transport, tourism, labor productivity, and the built environment.

- The geographic distribution of **wine grape varieties** will change (high confidence) and this will reduce the value of wine products and the livelihoods of local wine communities in Southern and Continental Europe (*medium confidence*) and increase production in Northern Europe (*low confidence*).

- By the 2050s, irrigation will not be sufficient to prevent damage **from heat waves** to crops in some sub-regions (*medium confidence*). System costs will increase under all climate scenarios (*high confidence*).

- **Cereal yields** is likely to increase in Northern Europe (*medium confidence, disagreement*) but decrease in Southern Europe (high confidence).

Production systems and physical infrastructure

- Climate change is projected to affect the impacts of hot and cold weather extremes on **transport** leading to economic damage and/or adaptation costs, as well as some benefits (e.g., reduction of maintenance costs) during winter (*medium confidence*).
  - o Severe accidents in road transport are projected to decrease (medium confidence) and adversely affect inland water transport in summer in some rivers (e.g., the Rhine) after 2050 (medium confidence).
  - o Damages to rail infrastructure from high temperatures may increase (medium confidence).

- Climate change is expected to impede **economic activity** in Southern Europe more than in other sub-regions (*medium confidence*) and may increase future intra-regional disparity (*low confidence*).

- Climate change is expected to affect future **energy production and transmission**:
  - o Hydropower production is likely to decrease in all sub-regions except Scandinavia (*high confidence*).
  - o CC will have a negative impact on wind energy production in summer and a varied impact in winter after 2050 (*medium confidence*).
  - o Thermal power production is likely to decrease during summer (high confidence).
  - o Problems associated with overheating in buildings will increase (*medium confidence*).
  - o Although climate change is very likely to decrease space heating demand (high confidence), cooling demand will increase (*very high confidence*) although income growth mostly drives projected cooling demand up to 2050 (*medium confidence*).

- SLR and increases in extreme rainfall are projected to further increase **coastal and river flood risk** in Europe and, without adaptive measures, will substantially increase flood damages (people affected and economic losses) (*high confidence*).

- The current cost of soil erosion, organic matter decline, salinization, landslides, and contamination is estimated to be €38 billion annually for the EU, in the form of damage to infrastructures, treatment of water contaminated through the soil, disposal of sediments, depreciation of land, and costs related to the ecosystem functions of soil.

Protection of environmental quality and biological conservation

- Observed climate change is affecting a wide range of **flora and fauna**, including plant **pests and diseases** (*high confidence*) and the disease vectors and hosts (*medium confidence*).

- Rapid glacier retreat has been observed in 30 Swiss **glaciers** since the 1980s.

- Changes in **habitats and species**, with local extinctions (*high confidence*) and continental-scale shifts in species distributions is very likely (*medium confidence*).
  - o The habitat of alpine plants is very likely to be significantly reduced (*high confidence*). Phenological mismatch will constrain both terrestrial and marine ecosystem functioning under climate change (high confidence), with a reduction in some ecosystem services (*low confidence*).
  - o The introduction and expansion of invasive species, especially those with high migration rates, from outside Europe is likely to increase (*medium confidence*).
  - o Climate change is likely to entail the loss or displacement of coastal wetlands (*high confidence).*

- Climate change may also increase **soil erosion** (from increased extreme events) and reduce **soil fertility** (*low confidence, limited evidence*).

- **Wildfire** risk in Southern Europe and damages from storms in Central Europe may also increase. Climate change is likely to cause ecological and socioeconomic damages from shifts in forest tree species range (from southwest to northeast). (*medium confidence*).

- Climate warming will increase **forest productivity** in Northern Europe (*medium confidence*), although damage from pests and diseases in all sub-regions will increase (*high confidence*).

- Surface water quality is likely to decrease due to higher temperatures and changes in precipitation patterns (*medium confidence*), and **soil salinity** in coastal regions is likely to increase (*low confidence*).

Health and social welfare

- Climate change has affected both human health (from increased heat waves) (*medium confidence*) and animal health (changes in infectious diseases) (*high confidence).*

- Extreme weather events currently have significant impacts in Europe in multiple economic sectors as well as adverse social and health effects (*high confidence*).

- Climate change is likely to affect **human health** in Europe.
  - o Heat-related deaths and injuries are likely to increase, particularly in Southern Europe (medium confidence).
  - o The distribution and seasonal pattern of some human infections, including those transmitted by arthropods may change (medium confidence), and the risk of introduction of new infectious diseases will increase (low confidence).

- After 2050, **tourism** activity is projected to decrease in Southern Europe (*low confidence*) and increase in Northern and Continental Europe (*medium confidence*).

- The provision of **cultural services** is projected to decline in the Continental, Northern, and Southern sub-regions (*low confidence*).

- Climate change and SLR may damage European **cultural heritage**, including buildings, local industries, landscapes, archaeological sites, and iconic places (medium confidence), and some cultural landscapes may be lost forever (*low confidence*).

EUROPE			
Agriculture, fisheries, forestry, bioenergy production	***Production systems and physical infrastructure***	***Protection of environmental quality and biological conservation***	***Health and social welfare***
• High temperatures may increase the frequency of harmful **algal blooms** and affect the marine and freshwater ecosystems (*low confidence*). • Climate change may adversely affect **dairy production** in Southern Europe because of heat stress in lactating cows (*medium confidence*). • The provision of **ecosystem services** is projected to decline across all service in Southern Europe (*high confidence*). Both gains and losses in the provision of ecosystem services are projected for the other European sub-regions (high confidence) • As a result of increased evaporative demand, water availability from river abstraction and from groundwater resources likely to significantly reduce (*medium confidence*). • **Bioenergy** cultivation patterns will be affected in Europe through northward shift in their potential area of production (*medium confidence*).			

Increasing temperatures | Salinization | Land and forest degradation | Glacial retreat | Text boxes with outline only represent projected impacts; colour boxes represent observed impacts

Sea level rise | Ocean acidification | Loss of biodiversity

NORTH AMERICA

Ecosystems and biodiversity	Water resources	Agriculture and food security	Human settlements, industry, and infrastructure	Human health
• North American ecosystems are under increasing stress from rising temperatures, carbon dioxide (CO_2) concentrations, and sea levels, and are particularly vulnerable to climate extremes (*very high confidence*). • Increases in sea surface temperature in estuaries alter metabolism, threatening **species**, especially cold-water fish. Historical warm periods have coincided with low salmon abundance and restriction of fisheries in Alaska. North Atlantic cetaceans and tropical coral reefs in the Gulf of California and the Caribbean have been affected by increases in the incidence of diseases associated with warm waters and low water quality. • Increased ecosystem vulnerability to multiple and interacting climate stresses in forest ecosystems, through wildfire activity, regional drought, high temperatures, and infestations (*medium confidence*); and in coastal zones due to increasing temperatures, ocean acidification, coral reef bleaching, increased sediment load in runoff, SLR (SLR), storms, and storm surges has been highlighted (*high confidence*). • Droughts of unusual severity, extent, and duration have affected large parts of western and southwestern North America and resulted in regional-scale forest dieback in Canada, the USA, and Mexico. Extensive tree mortality has been related to drought exacerbated by high summertime temperatures. • Projected impacts of increased water temperatures include contraction of cold-water **fish habitat** and expansion of warm-water fish habitat, which can increase the presence of invasive species that threaten resident populations. Chinook salmon in the Pacific Northwest may decline by 20 to 50% by 2040–2050. • Changes in phenology and **species' distributions**, particularly in the USA and Canada, have been attributed to rising temperatures.	• **Decreases in snowpacks are already influencing seasonal streamflows (*high confidence*). Peak flow of snowmelt runoff in snow-dominated streams and rivers has been formally detected and attributed to anthropogenic climate change (Western North America).** • **Existing stresses on water resources in North America are likely to exacerbated due to climate change (*high confidence*).** **oGlobal warming of approximately 4°C is very likely to cause larger changes in extreme heat events, daily-scale precipitation extremes and snow accumulation and runoff, as well as emergence of a locally novel temperature regime throughout North America.** **oTogether with climate hazards such as higher sea levels and associated storm surges, more intense droughts, and increased precipitation variability, these changes are projected to lead to increased stresses to water, agriculture, economic activities, and urban and rural settlements (high confidence).** • **A range of impacts such as increased phytoplankton, fish, and cyanobacteria biomass; lengthened stratification periods with risks of significant hypolimnetic oxygen deficits in late summer with solubilization of accumulated phosphorus and heavy metals with accelerated reaction rates; and decreased lake clarity have been predicted for fresh water bodies (Tahoe, Great Lakes, Lake Onondaga, and shallow polymictic lakes).** • **The 21st century is projected to witness decreases in water quality and increases in urban drainage flooding throughout most of North America under climate change as well as a decrease in in stream uses such as hydropower in some regions (high confidence). Increased wildfires linked to a warming climate are expected to affect water quality downstream of forested headwater**	• Effects of temperature and climate variability on **yields** of major crops have been observed (*high confidence*). • Increase is **crop** losses since 1999 have been attributed to climate related events such as droughts, extreme heat, and storms with significant negative impacts on the economy across North America (*high confidence*). • Heat-induced **livestock** stress, combined with reduced forage quality, would reduce milk production and weight gain in cattle. • Projected increases in temperature, reductions in precipitation in some regions, and increased frequency of extreme events would result in net **productivity** declines in major North American crops by the end of the 21st century without adaptation, although the rate of decline varies by model and scenario, and some regions, particularly in the north, may benefit (*very high confidence*). Given that North America is a significant source of global food supplies, projected productivity declines may affect global food security (*medium confidence*). • In many North American regions optimum temperatures have been reached for dominant **crops**; thus continued regional warming would diminish rather than enhance yields (*high confidence*). A study projects a reduction in US corn yield loss from 14 to 6% with 2°C warming.	• Observed impacts on lives, livelihoods, economic activities, infrastructure, and access to services in North American human settlements have been attributed to SLR, changes in temperature and precipitation, and occurrences of extreme events such as heat waves, droughts, and storms. • Higher temperatures and increased climate variability can have adverse impacts on **renewable energy production** such as wind and solar. Temperature change and water availability can affect biomass production. • Increases in high temperatures, intense precipitation, drought, sea level, and storm surge could affect **transportation** across the USA. o In southern Canada by the 2050s, cracking of roads from freeze and thaw would decrease (B2 and A2 scenarios). Higher extreme temperatures however could increase maintenance and rehabilitation costs. o Increase in global mean temperature (1°C to 1.5°C) would increase the costs of keeping paved and unpaved roads in the USA in service by, respectively, US$2 to US$3 billion per year by 2050. Moreover, new materials may be needed so pavement and rail lines can better withstand more extreme temperatures. • Demand for summer cooling is projected to increase and demand for winter heating is projected to decrease. Total **energy** demand in North America is projected to increase in coming decades • Higher temperatures and humidity would lead to decreased productivity and increased occupational **health** risks. • Water resources and transportation infrastructure are in many cases deteriorating, thus more vulnerable to extremes than strengthened ones (high confidence).	• A range of water, food, and **vector-borne infectious diseases**, air pollutants, and airborne pollens are influenced by climate variability and change (*medium confidence*). o There has been an increasing number of cases of Lyme disease in Canada, and Lyme disease vectors are spreading along climate-determined trajectories. • Exposure to **pollen** has been associated with a range of allergic outcomes, including exacerbations of allergic rhinitis. Increase in temperature and precipitation chances affects the release of pollens, as a result exposure and allergic disease morbidity could change in response to climate change. • Climate warming will lead to continuing **health stress** related to extreme high temperatures, particularly for the northern parts of North America. • **Forest fire** is a source of particle emissions in North America, and can lead to increased cardiac and respiratory disease incidence, as well as direct mortality.

NORTH AMERICA				
Ecosystems and biodiversity	***Water resources***	***Agriculture and food security***	***Human settlements, industry, and infrastructure***	***Human health***
• Climate stresses occur alongside other anthropogenic influences on ecosystems, including land use changes, non-native species, and pollution, and in many cases will exacerbate the existing pressures on North American Ecosystems (very high confidence). o Projected drought stress by the 2050 (under A2 scenario), exceeds the most severe droughts of the past 1000 years. Owing to this, ecosystems may be increasingly vulnerable, with impacts including vegetation mortality. More frequent droughts in tropical forests may change forest structure and regional distribution, favouring a higher prevalence of deciduous species in the forests of Mexico. o Shifts in climate are expected to lead to changes in forest infestation, including shifts of insect and pathogen distributions into higher latitudes and elevations (example, Bark Beetle). o Towards the end of this century, 20 to 40% decrease in soil water content has been projected due to elevated evapotranspiration rates in addition to a 5.0°C rise in the growing season temperatures (*A2 scenario, Southern Quebec*). • SLR across the coasts of North America is directly related to flooding and loss of coastal dunes and wetlands, oyster beds, seagrass, and mangroves. • Projected increases in sea levels, particularly along the coastlines will threaten many **plants** in coastal ecosystems through increased inundation, erosion, and salinity levels (Florida, Louisiana, North Carolina, and Texas). • Highly productive estuaries, coastal marshes, and mangrove ecosystems are present along the Gulf Coast and the East and West Coasts of North America. In addition to other stresses, climate change adds risks from SLR, warming, ocean acidification, extratropical cyclones, altered upwelling, and hurricanes and other storms. • In settings where landward shifts are not possible, a 1 m rise in sea level will result in loss of **wetlands** and **mangroves** along the Gulf of Mexico of 20% in Tamaulipas to 94% in Veracruz.	• In arid and semiarid western USA and Canada and in most of Mexico, except the southern tropical area, **water supplies** for urban areas and irrigation are projected to be further stressed by climate change, resulting in less water availability, increased drought conditions and increased surface and groundwater over-exploitation (high to medium confidence). • Throughout the eastern USA, water supply systems will be negatively impacted by lost snowpack storage, rising sea levels contributing to increased storm intensities and saltwater intrusion, possibly lower streamflows, land use and population changes, and other stresses. • Stresses on **water resources** are likely exacerbate due to climate change, resulting in less water availability and increased drought conditions. Compounding factors like saltwater intrusion, and increased groundwater and surface water pollution would worsen the situation.		• Changes in physical-chemical-biological parameters and micropollutants are predicted to negatively affect **drinking water** treatment and distribution systems. • SLR is also predicted to threaten **water and electricity infrastructure** with inundation and increasing salinity. • SLR can also exacerbate vulnerability of **coastal settlements** to extreme events such as Hurricanes. By 2070 with a 0.5 m rise in sea level and under scenarios of socioeconomic growth, storm surges, and subsidence, populations at risk in New York, Miami, and New Orleans might increase three-fold, while asset exposure will increase more than 10-fold. • A 1-m SLR combined with a 7-m storm surge could inundate over half of the **highways, arterials, and rail lines** in the US Gulf Coast. • **Wastewater treatment plants** would face reduced hydraulic capacities due to higher sea levels and increased river and coastal flooding with higher sea levels also threatening sewage collection systems.	

NORTH AMERICA				
Ecosystems and biodiversity	***Water resources***	***Agriculture and food security***	***Human settlements, industry, and infrastructure***	***Human health***
• Along the temperate coasts of North America, acidification directly affects calcareous organisms, including colonial mussel beds, with indirect influences on food webs of benthic species. • Increased acidity in conjunction with high temperatures has been identified as a serious threat to **coral reefs** and other marine ecosystems in the Bahamas and the Gulf of California. • Continuing ocean acidification will decrease **coral growth** and interactions with temperature increases will lead to increased risk of coral bleaching, leading to declines in coral ecosystem biodiversity • Widespread **forest-mortality** events triggered by extreme climate events can alter ecosystem structure and functions.				

Long-term climate change: Projections, Commitments and Irreversibility (Chapter 12.4 and 12.5)

Increasing temperatures	*Projected climate change over the 21st century:*
	• **Global mean temperatures will continue to rise over the 21st century if greenhouse gas (GHG) emissions continue unabated.**
	  ○ Under the assumptions of the concentration-driven RCPs, global mean surface temperatures for 2081–2100, relative to 1986–2005 will *likely* be in the 5 to 95% range of the CMIP5 models; 0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), 2.6°C to 4.8°C (RCP8.5).
	  ○ Global temperatures averaged over the period 2081– 2100 are projected to *likely* exceed 1.5°C above 1850-1900 for RCP4.5, RCP6.0 and RCP8.5 (*high confidence*)
	• **Temperature change will not be regionally uniform**
	  ○ Globally averaged changes over land will exceed changes over the ocean at the end of the 21st century by a factor that is likely in the range 1.4 to 1.7 (*very high confidence)*
	  ○ In the absence of a strong reduction in the Atlantic Meridional Overturning, the Arctic region is projected to warm most *(very high confidence).*
	• **It is virtually certain that, in most places, there will be more hot and fewer cold temperature extremes as global mean temperatures increase.**
	  ○ Increases in the frequency, duration and magnitude of hot extremes along with heat stress are expected; however, occasional cold winter extremes will continue to occur.
	  ○ Under RCP8.5 it is likely that, in most land regions, a current 20-year high temperature event will occur more frequently by the end of the 21st century (at least doubling its frequency, but in many regions becoming an annual or 2-year event) and a current 20-year low temperature event will become exceedingly rare.
	• **It is virtually certain that, in the long term, global precipitation will increase with increased global mean surface temperature.**
	  ○ There is high confidence that the contrast of annual mean precipitation between dry and wet regions and that the contrast between wet and dry seasons will increase over most of the globe as temperatures increase.
	  ○ High latitude land masses are likely to experience greater amounts of precipitation whereas many mid-latitude and subtropical arid and semi-arid regions will likely experience less precipitation and many moist mid-latitude regions will likely experience more precipitation by the end of this century under the RCP8.5 scenario.
	  ○ Globally, for short-duration precipitation events, a shift to more intense individual storms and fewer weak storms is likely as temperatures increase.
	
	Climate change beyond 2100, commitment, stabilization and irreversibility:
	• **Global temperature equilibrium would be reached only after centuries to millennia if Radiative Forcing (RF) were stabilized.**
	  ○ Continuing GHG emissions beyond 2100, as in the RCP8.5 extension, induces a total RF above 12 W m–2 by 2300.
	  ○ Sustained negative emissions beyond 2100, as in RCP2.6, induce a total RF below 2 W m–2 by 2300.
	  ○ The projected warming for 2281–2300, relative to 1986–2005, is 0.0°C to 1.2°C for RCP2.6 and 3.0°C to 12.6°C for RCP8.5 (*medium confidence*).
	  ○ In much the same way as the warming to a rapid increase of forcing is delayed, the cooling after a decrease of RF is also delayed.
	• **Some aspects of climate will continue to change even if temperatures are stabilized.**
	  ○ Processes related to vegetation change, changes in the ice sheets, deep ocean warming and associated sea level rise and potential feedbacks linking (for example ocean and the ice sheets) have their own intrinsic long time scales and may result in significant changes hundreds to thousands of years after global temperature is stabilized.

Sea level rise	*Projected climate change over the 21st century:*
	• **It is very likely that the rate of global mean sea level rise during the 21st century will exceed the rate observed during 1971– 2010 for all Representative Concentration Pathway (RCP) scenarios due to increases in ocean warming ad expansion and loss of mass from glaciers and ice sheets.**
	  ○ For the period 2081–2100, compared to 1986–2005, global mean sea level rise is likely (medium confidence) to be in the 5 to 95% range of projections from process-based models, which give 0.26 to 0.55 m for RCP2.6, 0.32 to 0.63 m for RCP4.5, 0.33 to 0.63 m for RCP6.0, and 0.45 to 0.82 m for RCP8.5.
	
	Climate change beyond 2100, commitment, stabilization and irreversibility:
	• **It is virtually certain that global mean sea level rise will continue beyond 2100, with sea level rise due to thermal expansion to continue for many centuries.**
	• **The amount of longer term sea level rise depends on future emissions.**
	  ○ Models indicate that global mean sea level rise above the pre-industrial level to be less than 1 m by 2300 for RCP2.6 (GHG concentration below 500 ppm CO2-eq). The projected rise for RCP8.5 scenario (GHG concentration 700 – 1500 ppm CO2-eq) is 1 m to more than 3 m *(medium confidence).*
	• However, it should be noted that the amount of ocean thermal expansion increases with global warming (0.2 to 0.6 m °C–1) but the rate of the glacier contribution decreases over time as their volume (currently 0.41 m sea level equivalent) decreases.

Salinization	*Projected climate change over the 21st century:* • Projections available suggest that high Sea Surface Salinity (SSS) subtropical regions that are dominated by net evaporation are typically getting more saline; lower SSS regions at high latitudes are typically getting fresher. They also suggest a continuation of this trend in the Atlantic where subtropical surface waters become more saline as the century progresses. At the same time, the North Pacific is projected to become less saline.

Glacier retreat	*Projected climate change over the 21st century:*
	• Even though current GCMs do not explicitly include glacier evolution, we can expect that glaciers will continue to recede, and the volume of water they provide to rivers in the summer may dwindle in some locations as they disappear.
	• Loss of glaciers will also contribute to a reduction in springtime river flow. However, if annual mean precipitation increases—*either as snow or rain*—then these results do not necessarily mean that annual mean river flow will decrease.
	• **It is very likely that the Arctic sea ice cover will continue shrinking and thinning year-round in the course of the 21st century as global mean surface temperature rises. At the same time, in the Antarctic, a decrease in sea ice extent and volume is expected, but with low confidence.**
	  ○ Projections of average reductions in Arctic sea ice extent for 2081– 2100 compared to 1986–2005 range from 8% for RCP2.6 to 34% for RCP8.5 in February and from 43% for RCP2.6 to 94% for RCP8.5 in September *(medium confidence).*
	  ○ In the Antarctic, projections indicate a decrease in sea ice extent that ranges from 16% for RCP2.6 to 67% for RCP8.5 in February and from 8% for RCP2.6 to 30% for RCP8.5 in September for 2081–2100 compared to 1986–2005 *(low confidence).*
	• By the end of the 21st century, diagnosed near-surface permafrost area is projected to decrease by between 37% (RCP2.6) and 81% (RCP8.5) (medium confidence).
	
	Climate change beyond 2100, commitment, stabilization and irreversibility:
	• All available modelling studies agree that the Greenland ice sheet will significantly decrease in area and volume in a warmer climate as a consequence of increased melt rates not compensated for by increased snowfall rates and amplified by positive feedbacks. Conversely, the surface mass balance of the Antarctic ice sheet is projected to increase in most projections because increased snowfall rates outweigh melt increase.
	• Rapid summer Arctic sea ice losses are likely to occur in the transition to seasonally ice-free conditions. These abrupt changes might have consequences throughout the climate system.
	• Furthermore, the inter annual-to-decadal variability in the summer Arctic sea ice extent is projected to increase in response to global warming.
	• Studies suggest that large anomalies in Arctic sea ice areal coverage might become increasingly frequent.
	• There is little evidence in global climate models of a tipping point (or critical threshold) in the transition from a perennially ice-covered to a seasonally ice-free Arctic Ocean beyond which further sea ice loss is unstoppable and irreversible.

Forest and land degradation	*Projected climate change over the 21st century:*
	• **Vegetation cover can also be affected by climate change, with forest cover potentially being decreasing (e.g., in the tropics) or increasing (e.g., in high latitudes).**
	  ○ In particular, the Amazon forest has been the subject of several studies, generally agreeing that future climate change would increase the risk tropical Amazon forest being replaced by seasonal forest or even savannah
	• **Simulations with interactive vegetation confirms biophysical feedback associated with large-scale changes in vegetation.**
	  ○ In the northern high latitudes, warming-induced vegetation expansion reduces surface albedo, enhancing the warming over these regions, with potentially larger amplification due to ocean and sea ice response. Over tropical forest, reduction of forest coverage would reduce evapotranspiration, also leading to a regional warming
	• **Future changes in land cover will have an impact on the climate system through biophysical and biogeochemical processes**.
	
	Climate change beyond 2100, commitment, stabilization and irreversibility:
	• Simulations with coupled regional climate/potential vegetation models are consistent in simulating an increase in dry season length, a 70% reduction in the areal extent of the Amazon rainforest by the end of the 21st century (A2 scenario).
	• The transition could be abrupt when the dry season becomes too long for the vegetation to survive. Deforestation may also increase dry season length and drier conditions increase the likelihood of wildfires that, combined with fire ignition associated with human activity, can undermine the forest's resiliency to climate change. If climate change brings drier conditions closer to those supportive of seasonal forests rather than rainforest, fire can act as a trigger to abruptly and irreversibly change the ecosystem.

Desertification	*Projected climate change over the 21st century:*
	• **Annual surface evaporation is projected to increase as global temperatures rise over most of the ocean and is projected to change over land following a similar pattern as precipitation.**
	  ○ Regional to global-scale projected decreases in soil moisture and increased risk of agricultural drought are likely in presently dry regions and are projected with medium confidence by the end of the 21st century under the RCP8.5 scenario.
	  ○ Prominent areas of projected decreases in evaporation include southern Africa and north western Africa along the Mediterranean. Soil moisture drying in the Mediterranean, southwest USA and southern African regions is consistent with projected changes in Hadley Circulation and increased surface temperatures, so surface drying in these regions as global temperatures increase is likely with high confidence by the end of this century under the RCP8.5 scenario.
	  ○ In regions where surface moistening is projected, changes are generally smaller than natural variability on the 20-year time scale.
	
	Climate change beyond 2100, commitment, stabilization and irreversibility:
	• Long-term droughts (often called megadroughts) are a recurring feature of Holocene paleoclimate records in North America, East and South Asia, Europe, Africa and India. The transitions into and out of the long-term droughts take many years. Because the long-term droughts all ended, they are not irreversible. Nonetheless transitions over years to a decade into a state of long-term drought would have impacts on human and natural systems.
	• Projections suggest widespread drying and drought across most of southwestern North America and many other subtropical regions by the mid to late 21st century, although without abrupt change. Some studies suggest that this subtropical drying may have already begun in southwestern North America.
	• Climate models project that southwest North America region will undergo progressive aridification as part of a general drying and poleward expansion of the subtropical dry zones driven by rising GHGs. Models project the aridification to intensify steadily as RF and global warming progress without abrupt changes.

B. A literature review, drawn from the 8th Research Dialogue and organized by region *(Step 2)*

This literature review has been put together in the context of Step 2 *of the guidance by the Excom*

This literature review provides:

1. A list of literature (journal papers, reports, projects, etc.) shared at the SBSTA 8th Research Dialogue which took place on 19 May 2016, organized by:
   - Region; and
   - Slow onset event (*Table 1*)
2. A set of relevant abstracts from each piece of literature listed above (*Table 2*)

For ease of reference, each piece of literature has been assigned a code (e.g. 1A, 1B, 2A, etc.) which is cross-referenced in the two tables below.

Table 1. List of literature by region

Region	*Slow onset event*	*Code*	*Title of literature and reference*
1. Africa	*Desertification*	1A	Catalogue of abrupt shifts in IPCC climate models: Abrupt Sahel vegetation changes *Drijfhout, S. et al. (2015) Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models. Proc. Natl. Acad. Sci. 201511451. <https://doi.org/10.1073/pnas.1511451112>.*
2. Asia	*Glacier retreat*	2A	Catalogue of abrupt shifts in IPCC climate models: abrupt Tibetan snow melt *Drijfhout, S. et al. (2015) Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models. Proc. Natl. Acad. Sci. 201511451. <https://doi.org/10.1073/pnas.1511451112>.*
	All SOEs	2B	*Project*: Enhancing capacity of policy makers and practitioners in India, Sri Lanka and Nepal on loss and damage related to slow onset events in the region by Asia-Pacific Network for Global Change Research (APN) *<http://www.apn-gcr.org/resources/items/show/1980>.*
3. Central and South America	*Land and forest degradation*	3A	Catalogue of abrupt shifts in IPCC climate models: Amazon forest dieback *Drijfhout, S. et al. (2015) Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models. Proc. Natl. Acad. Sci. 201511451. <https://doi.org/10.1073/pnas.1511451112>.*

4. SIDS	*Ocean acidification and sea level rise*	4A	*Project:* Four new monitoring stations and pilot sites, provided by the Secretariat of the Pacific Regional Environment Programme (SPREP). *<http://unfccc.int/files/science/workstreams/research/application/pdf/part2.4_sprep_ronneberg.pdf>.*
5. The Ocean	*Ocean acidification*	5A	*Project:* Workshop on ocean acidification at the SIDS conference in 2014 *<http://www.sids2014.org/index.php?menu=1566>.*
	Ocean circulation	5B	Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation *Rahmstorf, S., Box, J., Feulner, G., Mann, M., Robinson, A., Rutherford, S., Schaffernicht, E. (2015): Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. Nature Climate Change. <https://doi:10.1038/nclimate2554>.*
		5C	Catalogue of abrupt shifts in IPCC climate models: Collapse of the AMOC *Drijfhout, S. et al. (2015) Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models. Proc. Natl. Acad. Sci. 201511451. <https://doi.org/10.1073/pnas.1511451112>.*
		5D	Catalogue of abrupt shifts in IPCC climate models: Regional convection collapse in the North Atlantic *Drijfhout, S. et al. (2015) Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models. Proc. Natl. Acad. Sci. 201511451. <https://doi.org/10.1073/pnas.1511451112>.*
6. Australasia	*Increasing temperatures*	6A	Did climate change-induced rainfall trends contribute to the Australian millennium drought? *Cai et al. (2014). Did Climate Change–Induced Rainfall Trends Contribute to the Australian Millennium Drought? Journal of Climate. <https://doi.org/10.1175/JCLI-D-13-00322.1>.*
7. Europe	*Land and forest degradation*	7A	Spatiotemporal drought variability in the Mediterranean over the last 900 years *Cook et al. (2016). Spatiotemporal drought variability in the Mediterranean over the last 900 years. J. Geophys. Res. Atmos., 121, no. 5, 2060-2074. https://doi.org/10.1002/2015JD023929.*
8. North America	*Increasing temperatures*	8A	Contribution of anthropogenic warming to California drought during 2012-2014 *Williams et al. (2015). Contribution of anthropogenic warming to California drought during 2012–2014, Geophys. Res. Lett., 42, 6819–6828. <https://doi.org/10.1002/2015GL064924>.*
		8B	Anthropogenic warming has increased drought risk in California *Diffenbaugh et al. (2015). Anthropogenic warming has increased drought risk in California, PNAS 112 (13), 3931–3936. <https://doi.org/10.1073/pnas.1422385112>.*

	Sea level rise	8C	*Project*: National Oceanic and Atmospheric Administration (NOAA) created a tool for coastal managers and scientists to visualize sea level rise and coastal flooding impacts. *<https://coast.noaa.gov/slr/>.*
	Ocean acidification	8D	*Project*: NOAA and partners developed an ocean acidification data portal, which supports shellfish growers on the Pacific coast who use the information to understand when sea water acidity is high and young oysters in hatcheries are most vulnerable and thus modify the environment in their hatcheries. *<http://www.ipacoa.org/Explorer>.*
9. Polar regions	*Sea level rise*	9A	Potential sea-level rise from Antarctic ice-sheet instability constrained by observations *Ritz et al. (2015). Potential sea-level rise from Antarctic ice-sheet instability constrained by observations. Nature, 2015 528, 115–118. <https://doi.org/10.1038/nature16147>.*
		9B	Sea-level rise due to polar ice-sheet mass loss during past warm periods *Dutton et. al. (2015). Sea-level rise due to polar ice-sheet mass loss during past warm periods. Science 349 (6244). <https://doi.org/10.1126/science.aaa4019>.*
		9C	The multi-millennial Antarctic commitment to future sea-level rise *Golledge et. al. (2015). The multi-millennial Antarctic commitment to future sea-level rise. Nature 526, 421–425. <https://doi.org/10.1038/nature15706>.*
		9D	Contribution of Antarctica to past and future sea-level rise *DeConto and Pollard (2016). Contribution of Antarctica to past and future sea-level rise. Nature 531,591-597. <https://doi.org/10.1038/nature17145>.*
	Glacial retreat	9E	Catalogue of abrupt shifts in IPCC climate models: Arctic winter sea ice collapse *Drijfhout, S. et al. (2015) Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models. Proc. Natl. Acad. Sci. 201511451. <https://doi.org/10.1073/pnas.1511451112>.*
	Increasing temperatures	9F	Catalogue of abrupt shifts in IPCC climate models: Transition from Tundra to Boreal Forest *Drijfhout, S. et al. (2015) Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models. Proc. Natl. Acad. Sci. 201511451. <https://doi.org/10.1073/pnas.1511451112>.*
		9G	Evidence for a wavier jet stream in response to rapid Arctic warming *Francis and Vavrus (2015): Evidence for a wavier jet stream in response to rapid Arctic warming Environ. Res. Lett. 10 014005. <http://iopscience.iop.org/1748-9326/10/1/014005>.*
	Loss of biodiversity	9H	Catalogue of abrupt shifts in IPCC climate models: Arctic permafrost collapse *Drijfhout, S. et al. (2015) Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models. Proc. Natl. Acad. Sci. 201511451. <https://doi.org/10.1073/pnas.1511451112>.*
10. Global	*Sea level rise*	10A	Differential climate impacts for policy-relevant limits to global warming: the case of 1.5°C and 2°C *Schleussner et al. (2016): Differential climate impacts for policy-relevant limits to global warming: the case of 1.5 °C and 2 °C Earth Syst. Dynam., 7, 1–25, 2016 <https://doi.org/10.5194/esd-7-327-2016>.*

Desertification	10B	Assessment of future changes in water availability and aridity *Greve and Seneviratne, S. I. (2015). Assessment of future changes in water availability and aridity. Geophysical research letters, 42(13), 5493-5499. <https://doi.org/10.1002/2015GL064127>.*
	10C	On the assessment of aridity with changes in atmospheric CO_2 *Roderick et al. (2015). On the assessment of aridity with changes in atmospheric CO2, Water Resources Research, 51, 5450–5463. <https://doi.org/10.1002/2015WR017031>.*
	10D	Expansion of global drylands under a warming climate *Feng and Fu (2013). Expansion of global drylands under a warming climate, Atmos. Chem. Phys., 13, 10081-10094. <https://doi.org/10.5194/acp-13-10081-2013>.*
Increasing temperatures	10E	Revisiting trends in wetness and dryness in the presence of internal climate variability and water limitations over land *Kumar et al. (2015). Revisiting trends in wetness and dryness in the presence of internal climate variability and water limitations over land, GRL 42(24), 10,867–10,875. <https://doi.org/10.1002/2015GL066858>.*
	10F	A drier future? *Sherwood and Fu (2014). A drier future? Science 343 (737). <https://doi.org/10.1126/science.1247620>*
	10G	Global warming and 21st century drying *Cook et al. (2014). Global warming and 21st century drying. Climate Dynamics, 43, 2607-2627. <https://doi.org/10.1007/s00382-014-2075-y>.*
	10H	Science understanding and gaps on temperature change *<http://unfccc.int/files/science/workstreams/research/application/pdf/part1.2_ipcc_zhai.pdf>.*

Table 2. Relevant abstracts from the list of literature

Region	*Code*	*Title of literature and abstract*
1. Africa	1A	Catalogue of abrupt shifts in IPCC climate models: Abrupt Sahel vegetation changes
		Vegetation cover in the Sahel region is sensitive to any imposed climate change, or to increased water use efficiency due to the fertilization effect of elevated CO2 concentrations. We find an abrupt decline in bare soil around year 2050 in the RCP8.5 simulation of BNU-ESM. Abrupt vegetation cover change is in line with earlier conceptual models. However, here it only occurs locally. A transitional spike in the grass fraction follows this shift before a further rapid shift toward enhanced tree cover occurs after year 2060. These abrupt changes in vegetation composition in Africa imply Sahel greening and are likely driven by climate change and the ecophysiological effects of raised atmospheric CO2 concentrations. We note that the responsible drivers and spatial patterns of vegetation cover changes differ among models.
2. Asia	2A	Catalogue of abrupt shifts in IPCC climate models: abrupt Tibetan snow melt
		We observe two cases (models GISS-E2-H and GISS-E2-R) of sudden snow melt on the Tibetan Plateau in more than half of all realizations of RCP4.5 and RCP8.5 runs with those models. Also, this type of abrupt change has not been described before. The most abrupt volume change, from an annual mean of 400 kg·m−2 down to 50 kg·m−2 in only 20 y, occurs in a small area at the eastern boundary of the plateau. However, a still relatively rapid decrease of snow amount during the first half of the 21st century occurs over most of the Tibetan Plateau. The snow cover fraction shows a much less pronounced decline than the volume, and is only abrupt in one realization (in the GISS-E2-H model, RCP8.5 scenario). We therefore conclude that the surface albedo feedback via the atmosphere is not the reason for the sudden snowmelt. Instead, the rising temperature drives the system into a regime where the annual mass flux balance becomes negative and snow becomes a seasonal phenomenon. Although the abruptness and magnitude of the change could be an artefact of simplifications in the model and its low resolution, in particular the coarse representation of orography, the general mechanism is well understood, and the region where the largest change is observed is in line with regional climate model simulations.
	2B	Project by the Asia-Pacific Network for Global Change Research (APN): Enhancing capacity of policy makers and practitioners in India, Sri Lanka and Nepal on loss and damage related to slow onset events in the region: project summary
		South Asia is highly vulnerable to climate change impacts, including slow onset events: Sea level rise, increasing temperatures, ocean acidification, glacial retreat and related impacts, salinization, land and forest degradation, loss of biodiversity and desertification are described as slow onset events. The region, of which population and economy are highly dependent on natural resources and climate sensitive sectors, is already witnessing the loss of livelihood, reduction in agricultural productivity, negative health impacts and displacement. Though various stakeholders are engaged actively in adaptation work and its integration in the development policies, understanding on slow onset events causing loss and damage to various sectors is limited among the stakeholders. The proposed project is aimed at diagnosing the extent to which the problem persists and what approaches can be developed linking with the existing work in relation to DRR, CCA and development policies and practices. The project will: 1. Mobilize scientists, policymakers and practitioners to comprehensively assess the impact of slow onset events and prepare a comprehensive response. 2. Spread awareness about loss and damage caused by slow onset events to people and eco-systems. 3. Sensitize, engage and build capacity of stakeholders, particularly policymakers and practitioners to develop appropriate solutions.

3. Central and South America	3A	**Catalogue of abrupt shifts in IPCC climate models: Amazon forest dieback**
		Amazon forest dieback remains one of the iconic potential major changes to the Earth system. The most significant terrestrial ecosystem changes we find are indeed for the Amazon forest. The change in vegetation is slower than a decade but still constitutes a major shift to a new regime. In two models, we find the Amazon forest dieback (HadGEM2-ES and IPSL-CM5A-LR) as a consequence of warming or reduced rainfall, impacting photosynthesis. The complete dieback takes place over more than a few decades. Amazon dieback only occurs in RCP8.5 runs that are extended beyond year 2100. The dieback is particularly notable in one model with dynamic vegetation, HadGEM2-ES. Analysis of the scenario extension to year 2300 highlights how "committed" changes (for a given level of atmospheric greenhouse concentrations reached much earlier—here, year 2100) might not manifest until a longer period after such a particular radiative forcing is realized. Anthropogenic land cover changes are absent in the extension of RCP8.5; hence all dynamics from 2100 to 2300 is exclusively due to natural vegetation processes. The tree cover in HadGEM2-ES experiences large changes. Similar to the tree cover loss observed in earlier versions of the Hadley Centre family of climate models, it is mainly driven by a reduction in precipitation, generating a potential positive feedback between tree cover and precipitation due to reduced moisture recycling. The identified shifts only occur in extended RCP8.5 runs and for those two models reaching the highest temperature increase in year 2300.
4. SIDS	4A	**Project by the Secretariat of the Pacific Regional Environment Programme**
		In the Pacific region there is limited observations and monitoring of slow onset events. The Pacific region does have a good data set going back 25 years for sea level rise, but there is only one station per country in the region and there are gaps in the data sets. There is some monitoring of coral bleaching but at least 140 more sites are required. There is extremely limited monitoring of the ocean and several more hundred stations are needed. The region is suffering from four main impacts: ocean acidification, sea level rise, sea surface temperature and impacts on atoll islands – drying, saline intrusion and wave intrusion. These impacts are compounded by insufficient research. To address this problem, the Secretariat of the Pacific Regional Environment Programme (SPREP) has provided four new monitoring stations and pilot sites, supported by New Zealand and Monaco.
5. The Ocean	5A	**Project: workshop on ocean acidification at the SIDS conference in 2014**
		The workshop fostered the creation of Ocean Acidification networks for the Caribbean, Pacific Islands, and AIMS SIDS regions which will continue to develop next steps in their regions, including engaging participants from countries not present at the workshop, and through the near-term development of SIDS-driven, SIDS-connected and SIDS-focused "Joint SIDS Recommendations on Ocean Acidification". Participants recognized that resilience-building strategies and practical adaptation actions, where feasible, must be simultaneously explored and developed given the serious nature of ocean acidification impacts. Strategies and action should include, but not be limited to, efforts that enhance functioning of local marine ecosystems (for example, management of nutrient run-off, overfishing, land-use change, seagrass beds, and use of marine protected areas), and strengthen resilience of the local communities through open sharing of scientific findings and capacity building to develop local awareness, expertise and knowledge.

5B Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation

Possible changes in Atlantic meridional overturning circulation (AMOC) provide a key source of uncertainty regarding future climate change. Maps of temperature trends over the 20th century show a conspicuous region of cooling in the northern Atlantic. Here we present multiple lines of evidence suggesting that this cooling may be due to a reduction in the AMOC over the twentieth century and particularly after 1970. Since 1990 the AMOC seems to have partly recovered. This time evolution is consistently suggested by an AMOC index based on sea surface temperatures, by the hemispheric temperature difference, by coral-based proxies and by oceanic measurements. We discuss a possible contribution of the melting of the Greenland Ice Sheet to the slowdown. Using a multi-proxy temperature reconstruction for the AMOC index suggests that the AMOC weakness after 1975 is an unprecedented event in the past millennium ($p > 0.99$). Further melting of Greenland in the coming decades could contribute to further weakening of the AMOC.

5C Catalogue of abrupt shifts in IPCC climate models: Collapse of the AMOC

In one instance (FIO-ESM), a gradual weakening of the AMOC, which already set in during the 20th century in the historical simulation, then induces sudden changes in air temperature and sea ice cover. These start in the Greenland Sea but affect the whole North Atlantic later on. A collapse of the AMOC is mainly governed by an advective salt feedback. We find this event to be associated with indicators of decreasing stability for SST (Sea Surface Temperature) but not for the AMOC itself, whereas, in other instances of rapid change investigated, such generic early warning signals are absent. In FIO-ESM, abrupt cooling starts in the Nordic Seas around year 2040 in all four RCP scenarios. Recovery occurs around year 2050 in the RCP8.5 scenario, whereas, in the other three scenarios, the cooling stabilizes around year 2080. The RCP2.6 scenario features the largest cooling. Inspection of various physical fields and associated time series reveals the following mechanism. As the modelled 20th century progresses, the AMOC starts declining in response to global warming. Until approximately year 2020, reduced heat transport balances increased radiative forcing and ocean temperatures hardly change. SAT and SST show larger interannual variability between years 1970 and 2020. In this period, the decline of the AMOC accelerates and salinity in the area starts diminishing. After 2020, the increase in radiative forcing is no longer able to compensate for weakened advection of warm water into the area, and SST and SAT start to diminish and the related decrease in salinity accelerates. After year 2040, sea ice starts to form in the area, which was largely ice-free in the period before 2040. Ice albedo feedbacks amplify the cooling, and SST abruptly drops. Between 2040 and 2060, the amplitude of the cooling increases from 3 times the SD to 14 times the SD. SAT follows SST but, normalized with its SD, the signal is weaker, although still 8 SDs. The AMOC effectively collapses after year 2060. As a result of the AMOC collapse, cooling in the Nordic Seas spreads westward toward other deep water formation areas, like the Labrador Sea. Increase of sea ice in the whole Atlantic sector of the Arctic causes a temperature decrease of more than 4 °C in a 20°-wide latitude band (55°N−75°N), stretching from 60°W to 40°E. Between Iceland and Svalbard, a large region develops that features cooling above 10 °C. South of 40°N and outside the Atlantic, global warming dominates. In the other RCP scenarios, the same mechanism operates, but stronger warming through increased radiative forcing is better able to counteract the cooling associated with the AMOC collapse. Hence the cooling weakens with stronger forcing.

5D Catalogue of abrupt shifts in IPCC climate models: Regional convection collapse in the North Atlantic

In the GISS-E2-R, CESM-CAM5, GFDL-ESM2G, MIROC5, and CSIRO-Mk3-6.0 model projections, we observe abrupt changes in the Labrador Sea. Convection in the Labrador Sea suddenly collapses after an increase in stratification in response to warming and freshening of the convective areas and associated decrease in surface density. In case of a regional convection

surface salinity (SSS), and sea ice cover variations are observed in different RCP projections, inducing large regional cooling and a modification in large-scale precipitation patterns. These changes take place during a period of less than 10 years and appear in all of the analysed scenarios. As an example, we examine the GISS-E2-R model for the RCP2.6 scenario. The shift in

SST is more than 6 times the SD computed over the historical era, more than 12 times the historical SD for SSS, and more modest (3 times the historical SD) for the Atlantic Meridional Overturning Circulation.

The threshold for abrupt changes in SSS and SST is related to deep ocean convection, which normally occurs during winter in the Labrador Sea, but halts in the model after the threshold is passed. Large changes in vertical stratification occur before and after the abrupt shift, with a far stronger stratification after the decade 2040–2049 (the density difference between the upper 500 m and the deep ocean increases from 0.15 $kg \cdot m^{-3}$ to more than 0.45 $kg \cdot m^{-3}$). After that, the stratification has become too strong to be broken by winter cooling, which makes deep ocean convection no longer possible. The collapse of convective activity leads to a positive feedback via modifications in ocean circulation, causing less warm and salty Atlantic water entering the Labrador Sea.

When convection has ceased, a shallow halocline forms in the Labrador Sea, so that mixed layer depth decreases from a few hundred meters to around 10 m. The decrease in thickness of this upper layer then strongly reduces the heat capacity of the active layer in contact with the atmosphere. Thus, sea ice formation becomes more efficient in winter. We observe a strong increase in sea ice cover a few years after the decrease in SST sets in, and SSS changes lead SST changes by around a year. This change in sea ice cover, in turn, leads to strong cooling of the atmosphere around the Labrador Sea, affecting the global atmospheric circulation. We find, in all models, a cooling in North Atlantic surface air temperature (SAT) by about 2 °C and up to 3–4 °C in GFDL-ESM2G. Such substantial regional changes may influence the large-scale atmospheric circulation, affecting North Atlantic storm tracks or the Intertropical Convergence Zone. Indeed, analysis of tropical precipitation shows considerable changes in all five models in response to abrupt changes in ocean convection.

6. Australasia

6A Did climate change-induced rainfall trends contribute to the Australian millennium drought?

The Australian decade-long “Millennium Drought” broke in the summer of 2010/11 and was considered the most severe drought since instrumental records began in the 1900s. A crucial question is whether climate change played a role in inducing the rainfall deficit. The climate modes in question include the Indian Ocean dipole (IOD), affecting southern Australia in winter and spring; the southern annular mode (SAM) with an opposing influence on southern Australia in winter to that in spring; and El Niño–Southern Oscillation, affecting northern and eastern Australia in most seasons and southeastern Australia in spring through its coherence with the IOD. Furthermore, the poleward edge of the Southern Hemisphere Hadley cell, which indicates the position of the subtropical dry zone, has possible implications for recent rainfall declines in autumn. Using observations and simulations from phase 5 of the Coupled Model Intercomparison Project (CMIP5), it is shown that the drought over southwest Western Australia is partly attributable to a long-term upward SAM trend, which contributed to half of the winter rainfall reduction in this region. For southeast Australia, models simulate weak trends in the pertinent climate modes. In particular, they severely underestimate the observed poleward expansion of the subtropical dry zone and associated impacts. Thus, although climate models generally suggest that Australia’s Millennium Drought was mostly due to multidecadal variability, some late-twentieth-century changes in climate modes that influence regional rainfall are partially attributable to anthropogenic greenhouse warming.

7. Europe

7A Spatiotemporal drought variability in the Mediterranean over the last 900 years

Recent Mediterranean droughts have highlighted concerns that climate change may be contributing to observed drying trends, but natural climate variability in the region is still poorly understood. We analyze 900 years (1100–2012) of Mediterranean drought variability in the Old World Drought Atlas (OWDA), a spatiotemporal tree ring reconstruction of the June-July-August self-calibrating Palmer Drought Severity Index. In the Mediterranean, the OWDA is highly correlated with spring precipitation (April–June), the North Atlantic Oscillation (January–April), the Scandinavian Pattern (January–March), and the East Atlantic Pattern (April–June). Drought variability displays significant east-west coherence across the basin on multidecadal to centennial timescales and north-south antiphasing in the eastern Mediterranean, with a tendency for wet anomalies in the Black Sea region (e.g., Greece, Anatolia, and the Balkans) when coastal Libya, the southern Levant, and the Middle East are dry, possibly related to the North Atlantic Oscillation. Recent droughts are centered in the western Mediterranean, Greece, and the Levant. Events of similar magnitude in the western Mediterranean and Greece occur in the OWDA, but the recent 15-year drought in the Levant (1998–2012) is the driest in the record. Estimating uncertainties using a resampling approach, we conclude that there is an 89% likelihood that this drought is drier than any comparable period of the last 900 years and a 98% likelihood that it is drier than the last 500 years. These results confirm the exceptional nature of this drought relative to natural variability in recent centuries, consistent with studies that have found evidence for anthropogenically forced drying in the region.

8. North America

8A Contribution of anthropogenic warming to California drought during 2012-2014

A suite of climate data sets and multiple representations of atmospheric moisture demand are used to calculate many estimates of the self-calibrated Palmer Drought Severity Index, a proxy for near-surface soil moisture, across California from 1901 to 2014 at high spatial resolution. Based on the ensemble of calculations, California drought conditions were record breaking in 2014, but probably not record breaking in 2012–2014, contrary to prior findings. Regionally, the 2012–2014 drought was record breaking in the agriculturally important southern Central Valley and highly populated coastal areas. Contributions of individual climate variables to recent drought are also examined, including the temperature component associated with anthropogenic warming. Precipitation is the primary driver of drought variability but anthropogenic warming is estimated to have accounted for 8–27% of the observed drought anomaly in 2012–2014 and 5–18% in 2014. Although natural variability dominates, anthropogenic warming has substantially increased the overall likelihood of extreme California droughts.

8B Anthropogenic warming has increased drought risk in California

California is currently in the midst of a record-setting drought. The drought began in 2012 and now includes the lowest calendar-year and 12-mo precipitation, the highest annual temperature, and the most extreme drought indicators on record. The extremely warm and dry conditions have led to acute water shortages, groundwater overdraft, critically low streamflow, and enhanced wildfire risk. Analysing historical climate observations from California, we find that precipitation deficits in California were more than twice as likely to yield drought years if they occurred when conditions were warm. We find that although there has not been a substantial change in the probability of either negative or moderately negative precipitation anomalies in recent decades, the occurrence of drought years has been greater in the past two decades than in the preceding century. In addition, the probability that precipitation deficits co-occur with warm conditions and the probability that precipitation deficits produce drought have both increased. Climate model experiments with and without anthropogenic forcing reveal that human activities have increased the probability that dry precipitation years are also warm. Further, a large ensemble of climate model realizations reveals that additional global warming over the next few decades is very likely to create ∼100% probability that any annual-scale dry period is also extremely warm. We therefore conclude that anthropogenic warming is increasing the probability of co-occurring warm–dry conditions like those that have created the acute human and ecosystem impacts associated with the "exceptional" 2012–2014 drought in California.

9. Polar regions

9A Potential sea-level rise from Antarctic ice-sheet instability constrained by observations

Large parts of the Antarctic ice sheet lying on bedrock below sea level may be vulnerable to marine-ice-sheet instability (MISI), a self-sustaining retreat of the grounding line triggered by oceanic or atmospheric changes. There is growing evidence that MISI may be underway throughout the Amundsen Sea embayment (ASE), which contains ice equivalent to more than a meter of global sea-level rise. If triggered in other regions, the centennial to millennial contribution could be several meters. Physically plausible projections are challenging: numerical models with sufficient spatial resolution to simulate grounding-line processes have been too computationally expensive to generate large ensembles for uncertainty assessment, and lower-resolution model projections rely on parameterizations that are only loosely constrained by present day changes. Here we project that the Antarctic ice sheet will contribute up to 30 cm sea-level equivalent by 2100 and 72 cm by 2200 (95% quantiles) where the ASE dominates. Our process based, statistical approach gives skewed and complex probability distributions (single mode, 10 cm, at 2100; two modes, 49 cm and 6 cm, at 2200). The dependence of sliding on basal friction is a key unknown: nonlinear relationships favor higher contributions. Results are conditional on assessments of MISI risk on the basis of projected triggers under the climate scenario A1B, although sensitivity to these is limited by theoretical and topographical constraints on the rate and extent of ice loss. We find that contributions are restricted by a combination of these constraints, calibration with success in simulating observed ASE losses, and low assessed risk in some basins. Our assessment suggests that upper-bound estimates from low-resolution models and physical arguments9 (up to a meter by 2100 and around one and a half by 2200) are implausible under current understanding of physical mechanisms and potential triggers.

9B Sea-level rise due to polar ice-sheet mass loss during past warm periods

Interdisciplinary studies of geologic archives have ushered in a new era of deciphering magnitudes, rates, and sources of sea-level rise from polar ice-sheet loss during past warm periods. Accounting for glacial isostatic processes helps to reconcile spatial variability in peak sea level during marine isotope stages 5 and 11, when the global mean reached 6 to 9 meters and 6 to 13 meters higher than present, respectively. Dynamic topography introduces large uncertainties on longer time scales, precluding robust sea-level estimates for intervals such as the Pliocene. Present climate is warming to a level associated with significant polar ice-sheet loss in the past. Here, we outline advances and challenges involved in constraining ice-sheet sensitivity to climate change with use of paleo–sea level records.

9C The multi-millennial Antarctic commitment to future sea level rise

Atmospheric warming is projected to increase global mean surface temperatures by 0.3 to 4.8 degrees Celsius above pre-industrial values by the end of this century. If anthropogenic emissions continue unchecked, the warming increase may reach 8–10 degrees Celsius by 2300.

The contribution that large ice sheets will make to sea-level rise under such warming scenarios is difficult to quantify because the equilibrium-response timescale of ice sheets is longer than those of the atmosphere or ocean. Here we use a coupled ice-sheet/ice-shelf model to show that if atmospheric warming exceeds 1.5 to 2 degrees Celsius above present, collapse of the major Antarctic ice shelves triggers a centennial- to millennial-scale response of the Antarctic ice sheet in which enhanced viscous flow produces a long-term commitment (an unstoppable contribution) to sea-level rise. Our simulations represent the response of the present-day Antarctic ice-sheet system to the oceanic and climatic changes of four representative concentration pathways (RCPs) from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. We find that substantial Antarctic ice loss can be prevented only by limiting greenhouse gas emissions to RCP 2.6 levels. Higher-emissions scenarios lead to ice loss from Antarctic that will raise sea level by 0.6–3 meters by the year 2300. Our results imply that greenhouse gas emissions in the next few decades will strongly influence the long-term contribution of the Antarctic ice sheet to global sea level.

9D Contribution of Antarctica to past and future sea level rise

Polar temperatures over the last several million years have, at times, been slightly warmer than today, yet global mean sea level has been 6–9 meters higher as recently as the Last Interglacial (130,000 to 115,000 years ago) and possibly higher during the Pliocene epoch (about three million years ago). In both cases the Antarctic ice sheet has been implicated as the primary contributor, hinting at its future vulnerability. Here we use a model coupling ice sheet and climate dynamics—including previously underappreciated processes linking atmospheric warming with hydrofracturing of buttressing ice shelves and structural collapse of marine-terminating ice cliffs—that is calibrated against Pliocene and Last Interglacial sea-level estimates and applied to future greenhouse gas emission scenarios. Antarctica has the potential to contribute more than a meter of sea-level rise by 2100 and more than 15 meters by 2500, if emissions continue unabated. In this case atmospheric warming will soon become the dominant driver of ice loss, but prolonged ocean warming will delay its recovery for thousands of years.

9E Catalogue of abrupt shifts in IPCC climate models: Arctic winter sea ice collapse

Among the forced changes in sea ice, the one of largest geographical extent is the disappearance of all Arctic winter sea ice in the RCP8.5 simulations. We find five cases of such large-scale Arctic winter sea ice collapse. Abrupt winter sea ice loss was previously attributed to a different feedback mechanism. The mechanism we propose is a different one (threshold-driven). Once sea ice becomes very thin, the fast warming and the lack of areas with enhanced sea ice thickness can quickly collapse all remaining sea ice in the Arctic. This geometric mechanism does not require radiative feedbacks. Arctic winter sea ice collapse only occurs in RCP8.5 runs that are extended beyond 2100, which represents a small subset of the models. Here, we only retain those cases that meet the abrupt criteria for annual mean values. Further analysis of those cases, however, reveals that the abrupt change in Arctic sea ice cover is usually limited to winter and spring averages. The summer averaged sea ice cover decreases gradually, but a much more accelerated decline appears for winter and spring averages. This implies that for time series of year-to-year changes of a particular season or month, the changes appear faster and more abrupt than when considering annual means. When one considers yearly changes in the March−May average sea ice cover, for instance, the transition appears most abrupt in the MPI-ESM and CSIRO models. In the MIROC, HadGEM2-ES, and GFDL models, a collapse also occurs in the winter months. These sea ice collapses occur when the large area of thin ice, which re-forms each winter, suddenly fails to return when temperatures have become sufficiently warm that the freezing point is no longer realized.

Several potential mechanisms to explain abrupt sea ice cover changes have been proposed: the ice albedo feedback, the convective cloud feedback, and the increased open-water formation efficiency of thin ice. In addition, ocean heat transport feedbacks may also play a role. The ice albedo feedback and cloud feedback operate with specific timing during the day. Our analysis reveals that the timing of abrupt changes differs among the models. Additional simulations with MPI-ESM confirm that the collapse is not due to albedo or cloud feedbacks in that model. Instead, the simple fact that, at a certain stage, Arctic sea ice thickness becomes thin enough everywhere, combined with the fast forcing and surface melt, is sufficient to explain the rapid area loss: Although it takes decades to melt the present-day thick multiyear sea ice (grown over multiple years), the area extent of sea ice can respond much faster to changes in temperature when sea ice becomes very thin.

9F Catalogue of abrupt shifts in IPCC climate models: Transition from Tundra to Boreal Forest

In the extended RCP8.5 simulation (i.e., beyond year 2100) of HadGEM2-ES, vegetation cover in the Arctic above 70°N changes quickly from a mixture of bare soil and shrubs into tree cover after year 2150. Although the timescale of forest growth is multidecadal, it is still sufficiently fast to satisfy our formal criteria for abrupt changes. This type of abrupt change is governed by feedbacks similar to those for type 11. The mechanism behind the forest northward expansion is based on increased ability of boreal trees to become more productive and to grow faster under strong warming as simulated by the model. This mechanism is also present in the other models with dynamic vegetation representation in the land surface component, such as MPI-ESM-LR. This is reflected in the IPCC AR5, although the boreal forest expansion in MPI-ESM-LR has stronger interannual variability and therefore is not as abrupt as in HadGEM2-ES. The expansion of boreal forest to the Arctic coast in Eastern Siberia during warmer summer climate in the mid-Holocene is supported by analysis of pollen data. There is also a positive feedback between boreal tree cover and temperature due to the snow-masking effect of forest, which, however, should ultimately decline in a warmer climate due to shorter snow period.

9G Evidence for a wavier jet stream in response to rapid Arctic warming

New metrics and evidence are presented that support a linkage between rapid Arctic warming, relative to Northern hemisphere mid-latitudes, and more frequent high-amplitude (wavy) jet-stream configurations that favor persistent weather patterns. We find robust relationships among seasonal and regional patterns of weaker poleward thickness gradients, weaker zonal upper-level winds, and a more meridional flow direction. These results suggest that as the Arctic continues to warm faster than elsewhere in response to rising greenhouse-gas concentrations, the frequency of extreme weather events caused by persistent jet-stream patterns will increase.

9H Catalogue of abrupt shifts in IPCC climate models: Arctic permafrost collapse

For Arctic tundra, HadGEM2-ES projects a rapid thawing of permafrost; total soil moisture content decreases quickly as the ice in the soil melts and moisture drains away. This type of abrupt change has not been described before. Shortly after 2100, soil water content declines abruptly, caused by a rapid decrease of ice fraction in the soil. This leaves the soil moisture, now in liquid phase, more susceptible to drought conditions in a changing climate, as it can be evaporated much more easily than frozen water. Due to the substantial latent heat flux involved in the water to ice phase transition, the presence of ice fraction has a stabilizing (dampening) effect on soil temperature and moisture storage. With less ice, however, the rest of the soil potentially warms more quickly, triggering a positive feedback in the soil water storage. To our knowledge, HADGEM2-ES is the only model that accounts explicitly for an ice fraction in the soil. Therefore, other models could not simulate this mechanism.

10A Differential climate impacts for policy-relevant limits to global warming: the case of 1.5°C and 2°C

Robust appraisals of climate impacts at different levels of global-mean temperature increase are vital to guide assessments of dangerous anthropogenic interference with the climate system. The 2015 Paris Agreement includes a two-headed temperature goal: "holding the increase in the global average temperature to well below 2C° above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5C°". Despite the prominence of these two temperature limits, a comprehensive overview of the differences in climate impacts at these levels is still missing. Here we provide an assessment of key impacts of climate change at warming levels of 1.5C° and 2C°, including extreme weather events, water availability, agricultural yields, sea level rise and risk of coral reef loss. Our results reveal substantial differences in impacts between a 1.5C° and 2C° warming that are highly relevant for the assessment of dangerous anthropogenic interference with the climate system. For heat-related extremes, the additional 0.5C° increase in global-mean temperature marks the difference between events at the upper limit of present-day natural variability and a new climate regime, particularly in tropical regions. Similarly, this warming difference is likely to be decisive for the future of tropical coral reefs. In a scenario with an end-of-century warming of 2C°, virtually all tropical coral reefs are projected to be at risk of severe degradation due to temperature-induced bleaching from 2050 onwards. This fraction is reduced to about 90% in 2050 and projected to decline to 70% by 2100 for a 1.5C° scenario. Analyses of precipitation-related impacts reveal distinct regional differences and hot-spots of change emerge. Regional reduction in median water availability for the Mediterranean is found to nearly double from 9% to 17% between 1.5C° and 2C°, and the projected lengthening of regional dry spells increases from 7 to 11 %. Projections for agricultural yields differ between crop types as well as world regions. While some (in particular high-latitude) regions may benefit, tropical regions like West Africa, South-East Asia, as well as Central and northern South America are projected to face substantial local yield reductions, particularly for wheat and maize. Best estimate sea level rise projections based on two illustrative scenarios indicate a 50 cm rise by 2100 relative to year 2000-levels for a 2C° scenario, and about 10 cm lower levels for a 1.5C° scenario. In a 1.5C° scenario, the rate of sea-level rise in 2100 would be reduced by about 30% compared to a 2C° scenario. Our findings highlight the importance of regional differentiation to assess both future climate risks and different vulnerabilities to incremental increases in global mean temperature. The article provides a consistent and comprehensive assessment of existing projections and a good basis for future work on refining our understanding of the difference between impacts at 1.5C° and 2C° warming.

10B Assessment of future changes in water availability and aridity

Substantial changes in the hydrological cycle are projected for the 21st century, but these projections are subject to major uncertainties. In this context, the "dry gets drier, wet gets wetter" (DDWW) paradigm is often used as a simplifying summary. However, recent studies cast doubt on the validity of the paradigm and also on applying the widely used P − E (precipitation−evapotranspiration) metric over global land surfaces. Here we show in a comprehensive CMIP5-based assessment that projected changes in mean annual P − E are generally not significant, except for high-latitude regions showing wetting conditions until the end of the 21st century. Significant increases in aridity do occur in many subtropical and also adjacent humid regions. However, combining both metrics still shows that approximately 70% of all land area will not experience significant changes. Based on these findings, we conclude that the DDWW paradigm is generally not confirmed for projected changes in most land areas.

10C On the assessment of aridity with changes in atmospheric CO2

A recent interpretation of climate model projections concluded that “warmer is more arid.” In contrast, dust records and other evidence have led the geoscience community to conclude that “warmer is less arid” leading to an aridity paradox. The “warmer is more arid” interpretation is based on a projected increase in the vapor pressure deficit (∼ 7–9% K−1) that results in a projected increase in potential evaporation that greatly exceeds the projected increase in precipitation. However, the increase in potential evaporation does not result in an increase in (actual) evaporation which remains more or less constant in the model output. Projected changes in the long-term aridity can be assessed by directly interrogating the climate model output. To that end, we equate lack of precipitation with meteorological aridity and lack of runoff with hydrologic aridity. A third perspective, agro-ecological aridity, is not directly related to the water lost but rather to the carbon gain and is equated with the reduction in photosynthetic uptake of CO2. We reexamine the same climate model output and conclude that “warmer is less arid” from all perspectives and in agreement with the geological records. Future research will need to add the critical regional and seasonal perspectives to the aridity assessments described here.

10D Expansion of global drylands under a warming climate

Global drylands encompassing hyper-arid, arid, semiarid, and dry sub humid areas cover about 41 percent of the earth's terrestrial surface and are home to more than a third of the world's population. By analyzing observations for 1948–2008 and climate model simulations for 1948–2100, we show that global drylands have expanded in the last sixty years and will continue to expand in the 21st century. By the end of this century, the world's drylands (under a high greenhouse gas emission scenario) are projected to be 5.8 × 106 km2 (or 10%) larger than in the 1961–1990 climatology. The major expansion of arid regions will occur over southwest North America, the northern fringe of Africa, southern Africa, and Australia, while major expansions of semiarid regions will occur over the north side of the Mediterranean, southern Africa, and North and South America. The global dryland expansions will increase the population affected by water scarcity and land degradations.

10E Revisiting trends in wetness and dryness in the presence of internal climate variability and water limitations over land

A theoretically expected consequence of the intensification of the hydrological cycle under global warming is that on average, wet regions get wetter and dry regions get drier (WWDD). Recent studies, however, have found significant discrepancies between the expected pattern of change and observed changes over land. We assess the WWDD theory in four climate models. We find that the reported discrepancy can be traced to two main issues: (1) unforced internal climate variability strongly affects local wetness and dryness trends and can obscure underlying agreement with WWDD, and (2) dry land regions are not constrained to become drier by enhanced moisture divergence since evaporation cannot exceed precipitation over multiannual time scales. Over land, where the available water does not limit evaporation, a “wet gets wetter” signal predominates. On seasonal time scales, where evaporation can exceed precipitation, trends in wet season becoming wetter and dry season becoming drier are also found.

10F A drier future?

Global temperature increases affect the water cycle over land, but the nature of these changes remains difficult to predict. A key conceptual problem is to distinguish between droughts, which are transient regional extreme phenomena typically defined as departures from a local climatological norm that is presumed known, and the normal or background dryness itself. This background dryness depends on precipitation, but also on how fast water would evaporate. As the planet warms, global average rainfall increases, but so does evaporation. What is the likely net impact on average aridity?

10G Global warming and 21st century drying

Global warming is expected to increase the frequency and intensity of droughts in the twenty-first century, but the relative contributions from changes in moisture supply (precipitation) versus evaporative demand (potential evapotranspiration; PET) have not been comprehensively assessed. Using output from a suite of general circulation model (GCM) simulations from phase 5 of the Coupled Model Intercomparison Project, projected twenty-first century drying and wetting trends are investigated using two offline indices of surface moisture balance: the Palmer Drought Severity Index (PDSI) and the Standardized Precipitation Evapotranspiration Index (SPEI). PDSI and SPEI projections using precipitation and Penman-Monteith based PET changes from the GCMs generally agree, showing robust cross-model drying in western North America, Central America, the Mediterranean, southern Africa, and the Amazon and robust wetting occurring in the Northern Hemisphere high latitudes and east Africa (PDSI only). The SPEI is more sensitive to PET changes than the PDSI, especially in arid regions such as the Sahara and Middle East. Regional drying and wetting patterns largely mirror the spatially heterogeneous response of precipitation in the models, although drying in the PDSI and SPEI calculations extends beyond the regions of reduced precipitation. This expansion of drying areas is attributed to globally widespread increases in PET, caused by increases in surface net radiation and the vapor pressure deficit. Increased PET not only intensifies drying in areas where precipitation is already reduced, it also drives areas into drought that would otherwise experience little drying or even wetting from precipitation trends alone. This PET amplification effect is largest in the Northern Hemisphere mid-latitudes, and is especially pronounced in western North America, Europe, and southeast China. Compared to PDSI projections using precipitation changes only, the projections incorporating both precipitation and PET changes increase the percentage of global land area projected to experience at least moderate drying (PDSI standard deviation of ≤−1) by the end of the twenty-first century from 12 to 30 %. PET induced moderate drying is even more severe in the SPEI projections (SPEI standard deviation of ≤−1; 11 to 44 %), although this is likely less meaningful because much of the PET induced drying in the SPEI occurs in the aforementioned arid regions. Integrated accounting of both the supply and demand sides of the surface moisture balance is therefore critical for characterizing the full range of projected drought risks tied to increasing greenhouse gases and associated warming of the climate system.

10H Science understanding and gaps on temperature change

Key challenges for the science community:

- There is a need for further work to understand changes in diurnal temperature ranges as these are related to agriculture, ecosystems and growing seasons.
- For effective impact assessments, there is a need to look more closely at regional differences in temperature and precipitation changes. Furthermore, future projections must be combined with precipitation at the regional level as uncertainties still exist in regards to impacts. Higher temperatures plus decreased precipitation may lead to drought but higher temperatures plus increased precipitation may be a good sign for ecosystems and agriculture. Obtaining this regional information will rely on CMIP5, CMIP6 and CORDEX.
- There is continuing emerging research on global temperature and regional aspects, however questions exist in regards to rates of change under different scenarios.
- There are new findings on climate sensitivity, suggesting that the climate has higher sensitivity to aerosol and cloud processes than previously thought. Better understanding of these processes is important for multi-model spread, understanding climate response to forcing and making emission scenarios compatible with targets.

C. An analysis of the current state of risk management and data collection processes, based on the responses to questionnaires under Action Area 5 and organized by region *(Steps 2/3 and 3)*

Section C has been put together in the context of *Steps 2/3 and 3 of the guidance by the Excom.*

Based on the responses from 43 non-Annex I Parties and eight international organizations to a questionnaire under Action Area 5 of the initial two-year workplan of the Executive Committee, this section provides:

1. An overview of existing risk management processes at the global level and by region, including:
    - Climate risk analysis/assessment and associated challenges and gaps
    - Integration of climate risk analyses into national comprehensive disaster risk management plans and their implementation and associated challenges and gaps
2. An overview on existing data collection processes at the global level and by region
3. General remarks related to gaps identified from the responses to questionnaires.

The information is summarized by region.

The map below shows the countries and institutions which responded to the questionnaires.

Institutions which responded to the questionnaire

- African Risk Capacity
- CARE International
- Food and Agriculture Organization of the United Nations
- International Institute for Applied Systems Analysis
- International Organization for Migration
- United Nations Economic and Social Commission for Asia and the Pacific
- United Nations Office for Disaster Risk Reduction
- World Health Organization

1. Overview of existing risk management processes, including challenges and gaps, in different regions

1.1. Africa

Information in this subsection is drawn from responses of the following countries and organizations: Benin, Burundi, Comoros, Egypt, Ethiopia, Guinea-Bissau, Malawi, Mauritius, Mali, Niger, Nigeria, Senegal, ARC Ltd.

- *Climate risk analysis/assessment*

Countries in the region recognize various slow onset events as highly relevant (in the order of importance): (1) land and forest degradation, (2) desertification, (3) loss of biodiversity, (4) increasing temperatures, sea level rise, (5) salinization and (6) ocean acidification.

Nine of the twelve countries conduct climate risk analyses. In Egypt and Ethiopia the risk analysis is updated regularly every 6-10 years. Ethiopia's risk analysis takes into consideration the initial and second national communications to the UNFCCC. In Benin the analysis is updated in the context of the elaboration of new national communications. ARC Ltd conducts risk analyses, including climate risk analysis or assessments, in supporting national governments. It has conducted such analyses in the eight countries to which it has sold climate insurance (Burkina Faso, Senegal, The Gambia, Mali, Mauritania, Niger, Kenya, Malawi) and initiated some technical work in several other countries of the African Union including Nigeria, Ghana, Madagascar, Zimbabwe, Lesotho. It thereby uses the same climate risk analysis methodology to assess a country's drought risk. Using its Africa RiskView model it uses two kinds of input data: (1) RFE2/ARC2 satellite rainfall data and (2) household survey data to generate drought vulnerability profiles. The household data incorporates, among others, current farming practices which is critical in order for the model to accurately reflect the reality as such practices change after disasters or when households adapt to changing climate conditions. ARC Ltd updates the climate risk assessment for each country on an annual basis. ARC Ltd also supports national governments in undertaking sectoral climate risk analyses (for agriculture, infrastructure, food security and budgetary dislocation).

Four countries also carry out a climate risk analysis at the subnational level of which two include the assessment of loss and damage. In Ethiopia, this analysis has been based on data collected at the household and community level through disaster risk profiling conducted by the National Disaster Risk Management Commission. Such climate risk information is available for 360 districts and will be available for all other districts by 2020.

Six countries include the analysis of potential and/or already occurring losses and damages associated with the adverse effects of slow onset events in their national climate risk analysis. ARC Ltd incorporates loss and damage from increasing temperatures in the risk analyses it assists countries with.

- *Challenges and gaps related to climate risk analysis/assessment*

Four of the nine countries in the region that conduct national climate risk analyses state that the analysis of slow onset events is confronted with challenges in terms of lack of knowledge, information and understanding. These relate to lack of adequate data and information as well as skilled man power for the assessments. The absence of modern equipment such as satellites, to complement information collected from communities is a problem. These challenges lead to absence of spatially distributed information of the risks of slow onset events and their likely impact chains.

All nine countries in the region underline that there are challenges in integrating long-term changes from extreme weather events and slow onset events in their climate risk analyses, which include (in the order of importance): (1) lack of funding, (2) lack of capacity at the national level, (3) lack of available data and information, (4) difficulty in finding a way forward due to uncertainty of data, (5) insufficient public understanding or involvement, (6) the prioritization of other national issues and the issue being new on the national agenda.

ARC Ltd sees a lack of information on climate change and impacts, a lack of capacity to collect, enter, store or process required data, a lack of capacity to analyse or interpret data and inadequate finance for continuous data collection, processing and analysis as the main reasons for countries not conducting climate risk analyses. When supporting countries in undertaking climate risk analysis it also faces the challenge of frequent turnover of government officials leading to frequent replacements of staff trained on using the climate model (e.g. due to political instability and changes in senior government decision makers). Changes in government priorities or outdated or sparse data may also lead to challenges in generating climate risk assessments. In addition, the assessments are discontinued when financial constraints hinder a government to purchase the insurance or when premium payment fatigue occurs due to the absence of disasters and related pay-outs.

- *Integration of climate risk analyses into national comprehensive disaster risk management plans and their implementation*

Seven of the twelve respondents from the African region state to have a comprehensive national disaster risk management process, plan or strategy in place. Of these, six integrate the national climate risk analysis into the DRR process. The following slow onset events are fully or partially integrated into DRR work in the region: land and forest degradation (eleven countries), loss of biodiversity and desertification (nine countries each), rising temperature (seven countries), salinization (six countries), sea level rise (five countries), ocean acidification (two countries), and glacial retreat (one country).

ARC Ltd states that the climate risk analyses it helps to conduct are usually used for or integrated in national adaptation, risk management or development plans. It also supports national governments in using the climate risk analysis, including the analysis of loss and damage, in preparing national comprehensive disaster risk management plans or schemes and implementing them. Such plans are a precondition for countries to purchase insurance and receive pay-outs from ARC's insurance schemes. ARC Ltd monitors the implementation of the DRR management plan or contingency plan through an audit process and supports the incorporation of lessons learned into future contingency plans.

All seven countries that have DRR plans or processes in place indicate that these processes focus on prevention, preparedness and emergency response, five countries additionally include rehabilitation and four include recovery aspects.

ARC Ltd supports national governments in implementing anticipatory actions to reduce the risk of loss and damage, including from slow onset events, by providing its Africa RiskView model to countries which also plays an early warning function, e.g. by estimating how many people of a country might be affected by drought by the end of a particular season (based on the collected rainfall data). Countries may take early action if the model shows a bad season start.

- *Challenges and gaps related to the integration of climate risk analyses into disaster risk management processes*

In general, all twelve countries rate the importance of the adverse effects of climate change and their analysis and understanding as very high for their country. In this context, several areas exist that countries feel they have not adequately addressed or implemented yet. These include (in the order of importance): (1) data and projections of climate impacts on natural hazards at the sub-national level, data and knowledge of non-economic losses associated with the adverse effects of climate change, (2) data and knowledge of economic losses associated with the adverse effects of climate change, data/knowledge of vulnerability at sub-national level, (3) data/knowledge of vulnerability at national level, well-functioning national coordination mechanisms to assess the adverse effects of climate change, (4) data and projections of climate impacts on natural hazards at sectoral level, data and projections of climate impacts on natural hazards at national level and (5) promoting the relevance of the adverse effects of climate change for the national disaster risk management.

ARC Ltd reports that from its experience in supporting national governments in integrating the risk of loss and damage into national disaster risk management planning, the most relevant challenges governments face include unavailability of national climate risk analysis, lack of knowledge of slow onset events, lack of research on or information of climate change impacts, including associated losses and damages, and lack of finance. Additional challenges include lack of sufficient time for countries to review existing best practices in contingency/disaster planning and climate risk analysis in order to better inform their own plan development. In cases where experts from different government entities and from external organizations work together to develop such plans, they often face the same problem of not having sufficient time to coordinate and exchange on their different perspectives.

ARC Ltd further reports that the most relevant challenges regarding the implementation of disaster risk management plans are the lack of appropriate institutional coordination at the territorial or local level, a lack of institutional technical capacities or skills and inadequate finance. It has also noted that there is a lack of adequate systems to monitor implementation and to report thereon. Another problem is the long-time funds take to flow from national treasury to the implementing agencies when a disaster has occurred.

1.2. Asia, incl. Pacific

Information in this subsection is drawn from responses of the following countries and organizations: Cook Islands, Indonesia, Kazakhstan, Kuwait, Mongolia, Myanmar, Singapore, State of Palestine, Thailand, Vietnam, UNESCAP.

- *Climate risk analysis/assessment*

Country respondents from the Asia-Pacific region report that the following slow onset events are of high relevance to them (in the order of importance): (1) increasing temperatures, (2) loss of biodiversity, salinization, (3) sea level rise, land and forest degradation, (4) desertification, (5) ocean acidification and (6) glacial retreat and related impacts.

In six of the ten countries, a national climate risk analysis is conducted. Singapore updates its assessments from time to time. Mongolia intends to update its assessments every four years with the original assessment undertaken in the context of Mongolia's third National Communication to the UNFCCC. UNESCAP's multi-donor trust fund on tsunami, disaster and climate preparedness supports regional inter-governmental institutions to enhance the capacity of UNESCAP's member countries to conduct comprehensive climate risk analysis as well as to organize the multi-sectoral risk communication platforms towards integrating them into the development process. UNESCAP reviews the climate risk analysis methodology which it supports twice a year. The methodology is applied by RIMES – an inter-governmental regional institution supported by UNESCAP which applies the WMO Climate Services framework to the regional and subregional levels, developing regional climate outlook forums and sectoral impact studies (agriculture and water resources/ availability).

Four of the six countries that conduct national climate risk analyses include an analysis of potential and/or already occurring losses and damages associated with the adverse effects of slow onset events in the climate risk analysis. The climate risk analyses that UNESCAP supports also incorporate the risk of loss and damage from slow onset events, e.g. from desertification, land and forest degradation and increasing temperatures. It supports the downscaling of climate scenarios for understanding the risk and developing the impact outlook, using a 25x25km resolution. The methodology it uses is one customized from UNECLAC for ex-post loss and damage assessments (DaLA) and econometric models from the APEC climate centre.

Five of the six countries also conduct subnational climate risk analysis which in four cases also include the assessment of potential and/or already occurring losses and damages associated with the adverse effects of climate change and climate variability.

- *Challenges and gaps related to climate risk analysis/assessment*

Seven countries state that there are gaps with regard to knowledge, information and understanding of slow onset events. These relate, for example, to lack of long-term and comprehensive data as well as gaps in the technology and know-how required to generate such data, leading to deficiencies in risk identification and prioritization. They also relate to general uncertainties around slow onset events and how to project them accurately and lack of common understanding and commitment amongst key stakeholders. UNESCAP states that, according to its experience, countries struggle with lack of data, information and scenarios, lack of funding, difficulties to understand and lack of awareness when analysing the risks of slow onset events.

All ten countries report that there are challenges related to the integration of long-term changes from extreme weather events or slow onset events into their national climate risk analysis. These include (in the order of importance): (1) lack of available data or information, challenges in choosing a path forward due to uncertainty in data (2) lack of capacity at the national level, lack of funding, insufficient public understanding or involvement, (3) other national priorities, (4) issue being new on the national agenda.

UNESCAP mentions the factoring in of uncertainties as an important challenge in including loss and damage in climate risk analyses. It further sees lack of information on climate change and related impacts and inadequate finance for continuous data collection, processing and analysis as the most important reasons for countries not conducting climate risk analyses. The organization itself is constrained by inadequate funding support when supporting countries in conducting climate risk analyses.

- *Integration of climate risk analyses into national comprehensive disaster risk management plans and their implementation*

Seven of the ten country respondents from the Asia-Pacific region have a comprehensive national disaster risk management process, plan or strategy in place of which four have integrated the national climate risk analysis. The following slow onset events are fully or partially integrated into DRR work in the region: loss of biodiversity, increasing temperatures, sea level rise, salinization, land and forest degradation (six countries each), ocean acidification, desertification (four countries each), and glacial retreat (two countries).

UNESCAP states that the climate risk analyses it helps to conduct are usually used for or integrated in national adaptation, risk management or development plans. It also supports national governments in using the climate risk analysis, including the analysis of loss and damage, in preparing national comprehensive disaster risk management plans or schemes and implementing them. It does this through the RIMES organization which supports integrated and seamless timescales of climate risk information from weather to seasonal climate and climate change timescales which are used to undertake climate risk analyses.

All countries with comprehensive DRR processes focus on preparedness, six each focus also on prevention, emergency response, and rehabilitation and five include recovery.

- *Challenges and gaps related to the integration of climate risk analyses into disaster risk management processes*

In general, all ten countries in the region rate the importance of the adverse effects of climate change and their analysis and understanding as very high for their country. In this context, several areas exist that countries feel they have not adequately addressed or implemented yet. These include (in the order of importance): (1) data and knowledge of economic losses associated with the adverse effects of climate change, (2) data and projections of climate impacts on natural hazards at the sub-national level, data and projections of climate impacts on natural hazards at sectoral level, data and knowledge of non-economic losses associated with the adverse effects of climate change, (3) well-functioning national coordination mechanisms to assess the adverse effects of climate change, data and knowledge of vulnerability at sub-national level, data and projections of climate impacts on natural hazards at national level, promoting the relevance of the adverse effects of climate change for the national disaster risk management, (4) data and knowledge of vulnerability at national level.

UNESCAP reports that from its experience in supporting national governments in integrating the risk of loss and damage into national disaster risk management planning, the most relevant challenges governments face include insufficient knowledge of slow onset events, lack of research on or information of climate change impacts, including associated losses and damages, lack of institutional technical capacities or skills and lack of finance. It further reports that the most relevant challenges regarding the implementation of disaster risk management plans are lack of institutional technical capacities or skills and inadequate finance. Another problem is that there are too many ad hoc interventions supported by different donors particularly in low-capacity countries.

1.3. Central and South America, incl. Caribbean

Information in this subsection is drawn from responses of the following countries by Antigua and Barbuda, Bolivia, Brazil, Colombia, Costa Rica, El-Salvador, Guyana, Jamaica, Mexico, Paraguay, Saint Lucia, Suriname, Uruguay.

- *Climate risk analysis/assessment*

Country respondents from the Central and South American, including the Caribbean, region report that the following slow onset events are highly relevant for their countries (in the order of importance): (1) increasing temperatures, land and forest degradation, loss of biodiversity, salinization, (2) sea level rise, (3) ocean acidification, (4) desertification, (5) glacial retreat.

Ten of the thirteen countries conduct national climate risk analyses. In one country (Jamaica), various studies have been undertaken that address or include climate risk, and such risk has been assessed for specific communities without, however, having conducted a holistic climate risk analysis for the entire country. In Costa Rica and Colombia, the climate risk analyses are updated every 6-10 years, in El Salvador and Jamaica every 1-5 years.

Three of the ten countries include the analysis of potential and/or already occurring losses and damages associated with the adverse effects of slow onset events.

Five countries also undertake subnational climate risk assessments of which three include assessments of loss and damage.

- *Challenges and gaps related to climate risk analysis/assessment*

Seven of the ten countries that conduct national climate risk analyses report lack of knowledge, information and understanding of slow onset events. These relate, among others, to lack of data and information and deficiencies in institutional frameworks and capacity. Another challenge is establishing a clear link between reports on losses from different sectors and systematic climate observations.

Twelve of the thirteen countries confirm that there are challenges in integrating long-term changes from extreme weather events and slow onset events in their climate risk analysis. These include (in the order of importance): (1) lack of funding, insufficient public understanding or involvement, (2) lack of capacity at the national level, lack of available data or information, (3) issue being new on the national agenda, other national priorities, (4) challenges in choosing a path forward due to uncertainty in data.

- *Integration of climate risk analyses into national comprehensive disaster risk management plans and their implementation*

Eleven of the thirteen countries have comprehensive national disaster risk management processes, plans or strategies in place. Of these, ten integrate the national climate risk analysis into DRR process. The following slow onset events are fully or partially integrated into DRR work in the region: land and forest degradation (ten countries), rising temperature (nine countries), sea level rise, salinization (seven countries each), loss of biodiversity (five countries), desertification (four countries), ocean acidification (three countries), and glacial retreat (two countries).

All eleven countries indicate that their comprehensive DRR processes focus on preparedness and emergency response. Nine of the eleven countries additionally include prevention, rehabilitation and recovery.

- *Challenges and gaps related to the integration of climate risk analyses into disaster risk management processes*

In general, all thirteen countries rate the importance of the adverse effects of climate change and their analysis and understanding as very high for their country. In this context, there are several areas that countries feel they have not adequately addressed or implemented yet. These include (in the order of importance): (1) data and projections of climate impacts on natural hazards at sectoral level, data and knowledge of non-economic losses associated with the adverse effects of climate change, (2) promoting the relevance of the adverse effects of climate change for the national disaster risk management, (3) data and projections of climate impacts on natural hazards at national level, data and projections of climate impacts on natural hazards at the sub-national level, (4) well-functioning national coordination mechanisms to assess the adverse effects of climate change, (5) data and knowledge of vulnerability at sub-national level, (6) data and knowledge of vulnerability at national level and data and knowledge of economic losses associated with the adverse effects of climate change.

1.4. Europe (Non-Annex I)

Information in this subsection is drawn from responses of the following countries and organizations: Armenia, Azerbaijan, Bosna and Herzegovina, Georgia, The former Yugoslav Republic of Macedonia, Montenegro, Serbia.

- *Climate risk analysis/assessment*

The following slow onset events have been reported to be of high relevance for the Eastern European region (in the order of importance): (1) land and forest degradation, (2) increasing temperatures, loss of biodiversity (3) sea level rise, desertification, (4) salinization and glacial retreat.

A climate risk analysis is conducted in five of the seven countries. In Armenia, Azerbaijan and Montenegro these are updated every 1-5 years. Three of the five countries include an analysis of potential and/or already occurring losses and damages associated with the adverse effects of climate change and climate variability. However, no country assesses the losses and damages associated with slow onset events.

Two countries conduct additionally subnational climate risk analyses that include the assessment of potential and/or already occurring losses and damages associated with the adverse effects of climate change and climate variability.

- *Challenges and gaps related to climate risk analysis/assessment*

Three countries report lack of knowledge, information and understanding of slow onset events. One underlines that analyses have been conducted by very few experts and that no common understanding exists so far of the importance of the issue.

Six of the seven countries confirm challenges in integrating long-term challenges from extreme weather events and slow onset events in their climate risk analysis. These include (in the order of importance): (1) lack of capacity at the national level, (2) lack of funding, insufficient public understanding or involvement, (3) other national priorities, lack of available data or information, (4) issue being new on the national agenda, (5) challenges in choosing a path forward due to uncertainty in data.

- *Integration of climate risk analyses into national comprehensive disaster risk management plans and their implementation*

All respondents from the Eastern European region have comprehensive national disaster risk management processes, plans or strategies in place. Four countries integrate the national climate risk analysis into the DRR process. The following slow onset events are fully or partially integrated into DRR work in the region: land and forest degradation and rising temperature (five countries each), desertification (three countries), sea level rise, loss of biodiversity, salinization (two countries each), ocean acidification and glacial retreat (one country each).

All countries have a focus on emergency response in their DRR process and five countries also focus on prevention, preparedness and rehabilitation, whereas four include issues related to recovery.

- *Challenges and gaps related to the integration of climate risk analyses into disaster risk management processes*

In general, all seven countries rate the importance of the adverse effects of climate change and their analysis and understanding as very high for their country. In this context, there are several areas that countries feel they have not adequately addressed or implemented yet. These include (in the order of importance): (1) well-functioning national coordination mechanisms to assess the adverse effects of climate change, data and knowledge of economic losses associated with the adverse effects of climate change, (2) data and knowledge of non-economic losses associated with the adverse effects of climate change, (3) data and projections of climate impacts on natural hazards at sectoral level, (4) data and projections of climate impacts on natural hazards at national level, data and projections of climate impacts on natural hazards at the sub-national level, data and knowledge of vulnerability at sub-national level, (5) data and knowledge of vulnerability at national level, (6) promoting the relevance of the adverse effects of climate change for the national disaster risk management.

1.5. Global

Information in this subsection is drawn from responses of the following organizations: IASSA, UNISDR, FAO, IOM, WHO, CARE.

- *Climate risk analysis/assessment*

At the global level, four of the six international organizations assist regional institutions and/or national/sub-national governments to conduct climate risk analyses that include the risk of loss and damage from slow onset events. These organizations are FAO, WHO, IOM and CARE. IASSA and UNISDR do not include the risk of loss and damage from slow onset events in their climate risk analysis work and hence have not been considered for this section.

The four organizations mentioned above support a number of countries to conduct climate risk analysis at different government levels. FAO, WHO and IOM support countries at the national level, CARE applies climate risk assessments within its programmes that support communities in applying disaster risk reduction tools. FAO also supports climate risk analysis processes at the sub-national level and both, FAO and IOM, support such processes at the regional level.

Regarding their sectoral work, WHO particularly conducts climate risk assessments of the health sector, whereas FAO supports such assessments in the agricultural, forest, water resources and food security sectors. IOM is active in the health, forest and ecosystems, infrastructure, water resources, human settlements, and food security sectors whereas CARE does not concentrate on particular sectors.

The following types of slow onset events are included in the organizations' assessments:

	Sea level rise	Ocean acidification	Loss of biodiversity	Desertification	Land and forest degradation	Increasing temperatures	Salinization	Glacial retreat and related impacts
WHO	X					X		
FAO			X	X	X	X	X	
IOM	X	X	X	X	X	X	X	X
CARE			X	X	X			X

All organizations apply specific methodology when conducting risk analyses of loss and damage associated with the adverse effects of climate change, including slow onset events. For example:

- CARE makes use of climate vulnerability and capacity assessments (CVCA), market assessment tools and gender assessments which it adapts to each specific location.
- FAO studies the impact of slow-onset events on agriculture and food security.
- IOM analyses the potential of migration for adaptation to environmental change, including to the adverse (slow onset) effects of climate change, from the perspective of three different population groups: the (environmental) migrants themselves, the community of origin and the community of destination. As a special case, IOM studies climate change hotspots. It considers these areas not only as migrant-sending areas but also as areas that migrants travel to, e.g. urban centres in low-lying or deltaic areas or growing megacities. As opposed to existing research on the effects of human activity in further degrading these ecologically fragile areas, IOM studies the influence current and future climate change and variability have on the inhabitants' perception of risk and according decision-making. It also looks at the influence of slow onset climate events on the communities' vulnerability and the role migration plays therein. As a third aspect it analyses the factors contributing to the line demarcating the tolerability of a place from inhabitability, hence the crossing of thresholds or tipping points, by looking both at those that decide to or are forced to migrate and those that stay.

- *Challenges and gaps related to climate risk analysis/assessment*

Three of the four organizations point out that the analysis of the risks of loss and damage associated with the adverse effects of climate change faces particular challenges, including the application of different climate scenarios and general difficulties in comprehending the concept of loss and damage, for example in relation to migration and displacement.

In addition, all organizations working at the global level underline that regional institutions and national/subnational governments face particular challenges in analysing the risks of slow onset events vis-à-vis the risks of extreme weather events. These challenges include (in the order of importance): (1) lack of data, information, and scenarios, difficulties to understand slow onset events, lack of funding, (2) lack of awareness, (3) slow onset processes not seen as pressing or urgent. Myopia and a lack of mature models that reflect the progression and evolution of hazard onset, community response and patterns of loss are other important factors.

Organizations have noted the following reasons for countries not conducting climate risk analysis at all (in the order of importance): (1) lack of capacity to collect, enter, store or process required data, inadequate finance for continuous data collection, data processing, and data analysis, lack of capacity to use or incorporate climate risk analysis in risk management plans and national/subnational planning tools and processes, (2) lack of capacity to analyse or interpret data, lack of information on climate change and related impacts, climate change information is available but too complicated or difficult to use. Additional reasons mentioned are: lack of collaboration between information providers and users at regional, national and subnational levels as well as challenges to ensure sustainability of efforts for climate risk analysis beyond a certain project period. As a special case, IOM mentions that the analysis of climate risk in relation to migration remains a relatively understudied field, with few concrete reference documents. In that context, despite a strong interest in the topic, few institutions possess the necessary expertise to conduct such complex analysis.

In general, organizations face the following challenges when supporting countries in conducting climate risk analyses: developing in-country technical capacity and retaining trained staff, obtaining relevant climate data and information, and finding appropriate finance (e.g. for the analysis of cross-cutting issues like climate and migration).

- *Integration of climate risk analyses into national comprehensive disaster risk management plans and their implementation*

At the global level, five of the six organizations state that the risk analyses they help to conduct are generally used or integrated in some of the national/subnational adaptation, risk management or development plans and all organizations confirm that they support, in some cases only upon request, regional institutions and national/subnational governments in using climate risk analyses in preparing national comprehensive disaster risk management plans/schemes.

Most organizations provide this support also for using climate risk analyses of loss and damage associated with the adverse effects of climate change, including slow onset events. IASSA, for example, supports communities with their Vulnerability Capacity Assessments and with integrating risk and other decision-relevant information into their disaster risk planning in order to support better decision-making on climate-related risks. IOM works with states on their climate and DRR policies to integrate human mobility related elements, in particular solutions to prevent forced forms of migration/displacement.

All organizations, except for IASSA, also have the capacity or experience to implement comprehensive disaster risk management plans or processes and they, except for WHO, support regional institutions and national/subnational governments in doing so. For example:

- UNISDR links historical and potential future losses with the financial information of a country to define the relevance of the losses in the current investment of the country and how, by knowing the historical and potential future losses, strategies of investment in disaster risk reduction and risk financing and transfer can be established to avoid fiscal vulnerability. It also coordinates and convenes partners to support the implementation of the Sendai Framework for Disaster Risk Reduction in the context of which it works on developing practical knowledge products and capacity development programmes to support the development of national and local disaster risk reduction strategies and plans in coherence with climate change adaptation plans and national development plans.

- FAO has helped to develop more than 15 national agricultural disaster risk reduction plans and has provided implementation support.
- IOM has implemented several hundreds of projects that link migration and disaster risk reduction.

Four of the six globally acting organizations state to have capacities to implement anticipatory actions to reduce the risk of loss and damage associated with the adverse effects of climate change, including slow onset events:

- UNISDR does this particularly through advocacy, coordination, normative guidance, partnership building, capacity development and monitoring.
- CARE implements disaster risk reduction and adaptation measures at the local level to prevent adverse effects of extreme events but also of slow onset events, e.g. drought.
- FAO provides early warning systems related to food security and nutrition.
- IOM seeks to anticipate potential migration and displacement movements linked to climate change through different types of programmatic actions. It works on solutions allowing people to remain in situ in areas exposed to adverse climate change impacts or on solutions that assist and protect people on the move, facilitating their mobility in an orderly and dignified way.

All six organizations support regional institutions and national/subnational governments in implementing anticipatory actions to reduce the risk of loss and damage. IASSA does this through the provision of information for implementing risk-based policies and actions. UNISDR develops and monitors regional action plans. IOM provides training in the development of anticipatory actions targeting regional and national policymakers from different policy areas, including migration, climate and disaster risk reduction.

- *Challenges and gaps related to the integration of climate risk analysis into disaster risk management processes*

When assisting regional institutions and national/sub-national governments in integrating the risk of loss and damage associated with the adverse effects of climate change, including slow onset events, into national disaster risk management planning, organizations have noted the following challenges and gaps (in the order of importance): (1) lack of research on or information of climate change impacts, including associated losses and damages, lack of institutional technical capacities or skills, (2) lack of finance, lack of adequate institutional coordination, (3) lack of knowledge of slow onset events, absence of climate risk analyses. The organizations themselves face the challenges of reaching a real understanding of risk assessments nationally or locally to use the results for more informed decision-making and finding the required data, resources, dedicated and technically skilled staff and knowledge in local and national governments that is maintained over longer time periods.

In terms of challenges and gaps that regional institutions and national/sub-national governments face when implementing disaster risk management plans, organizations report the following (in the order of importance): (1) lack of institutional technical capacities or skills, (2) inadequate finance, lack of appropriate institutional coordination at the territorial or local level, (3) lack of local, civil society, private sector engagement/ participation. Another challenge mentioned is the integration of risk and development planning.

When supporting the implementation process, the organizations themselves face the challenge of having to understand the different institutional cultures, to identify the right local players, which they strongly depend on, and to maintain local people participating in the projects.

2. Overview of existing data collection processes, including challenges and gaps, in different regions

The questionnaires did not include a specific question on whether there are data collection processes in place to monitor slow onset events. However, the questionnaires included questions regarding the scientific information, hydro-meteorological data, climate services, observed climate time series and climate change scenarios that organizations and countries use to conduct their climate risk analysis/assessments that give some indication of data available and used in the different regions. Nevertheless, information extracted from the responses can only be presented in general terms and it does not reveal whether such data and services are used to monitor and assess specific slow onset events.

2.1. Africa

Information in this subsection is drawn from responses of the following countries and organizations: Benin, Burundi, Comoros, Egypt, Ethiopia, Guinea-Bissau, Malawi, Mauritius, Mali, Niger, Nigeria, Senegal, ARC Ltd.

All countries in the African region that conduct climate risk analyses use scientific (e.g. generated through specific projects such as IMPETUS) and hydro-meteorological information as a basis. Eight of the nine countries also use climate scenarios (e.g. IPCC A1B and B1, RCP 8.5 and 4.5) and six use climate services (mainly data and information provided by national meteorological agencies). ARC Ltd uses RFE2/ARC2 satellite rainfall data as input to its Africa RiskView model that is used to assess a country's drought risk. The satellite data has been generated since 1983 and is produced every 10 days at a 10km x 10km resolution. ARC Ltd also uses observed climate time series and climate change scenarios when supporting national governments in conducting climate risk assessments and states that this information is in most cases easily available.

Countries in general have good coverage of science-based national climate impact projections, particularly for changes in temperature and changes in precipitation (eleven of the twelve countries). Four countries also have such projections for sea level rise, and three for drought and biodiversity loss each. One country has also projections for forest degradation, desertification and salinization each.

ARC Ltd has a policy or role to support or collaborate with national governments in building or enhancing capacities to access or generate the scientific information that is required to conduct climate risk assessments. It mostly does so through offering its Africa RiskView model which pulls free rainfall data online as an input and translates this information into an estimated drought impact on a country's population. ARC Ltd works with governments to set the parameters of the model to reflect current farming practices which requires the government officials having to draw on internal databases. ARC Ltd does not, however, have a mandate, nor resources, to help a government generate more scientific information. It is hoped that when governments see the benefit of having up to date and reliable data in controlling its disaster risk they, will be motivated to enhance their data maintenance and collect more and different types of data.

Eight of the twelve countries in the African region state that there are problems with the provision of climate services in their region. The main problems are related to a lack of high resolution weather and climate information. This is due in part to gaps in the coverage of weather stations and a lack of capacity at the national and regional levels, e.g. for downscaling data, modelling future climate, applying Geographical Information Systems to undertake geospatial monitoring and mapping, vulnerability assessments and the monitoring of impacts on climate sensitive sectors and for mainstreaming climate change considerations into such sectors. Another important problem is that data that has been generated is often stored at unknown places and not centralized in publicly accessible databanks.

2.2. Asia, incl. Pacific

Information in this subsection is drawn from responses of the following countries and organizations: Cook Islands, Indonesia, Kazakhstan, Kuwait, Mongolia, Myanmar, Singapore, State of Palestine, Thailand, Vietnam, UNESCAP.

In the Asia-Pacific region seven of the ten countries use scientific information, hydro-meteorological information and climate scenarios (e.g. IPCC AR5) for their climate risk assessments. Four also use climate services (e.g. numerical weather predictions). UNESCAP uses observed climate time series and climate change scenarios in conducting the climate risk analyses it helps regional organizations with. It states that this data and information is in most cases easily available.

Almost all countries in the region have a good coverage of science-based national climate impact projections for changes in temperature and precipitation (ten countries each). Seven countries have such projections for drought, six for sea level rise and three for biodiversity loss. One country has such projections for salinization and one for humidification conditions.

UNESCAP has a policy or role to support countries in building or enhancing capacities to access or generate the scientific information required for climate risk assessments by supporting the RIMES organization and its mechanism which has established a participatory climate data management system that ensures that a country focal point has the responsibility to feed national data into the system and accesses its products for national use.

Nine of the ten countries in the region state that there are problems with the provision of climate services in their region. These relate, among others, to gaps in methodologies, lack of coordination among national and subnational government agencies, research institutions and other stakeholders leading to gaps in the availability of data, gaps in localized and quantitative forecasts, insufficient number of studies, unavailability of databases, inappropriate institutional arrangements, remaining uncertainties and lack of expertise in some areas of climate projections, lack of national expertise and regional exchange of experience.

2.3. Central and South America, incl. Caribbean

Information in this subsection is drawn from responses of the following countries: Antigua and Barbuda, Bolivia, Brazil, Colombia, Costa Rica, El-Salvador, Guyana, Jamaica, Mexico, Paraguay, Saint Lucia, Suriname, Uruguay.

In the Central and South American, including the Caribbean, region, six of the ten countries that conduct national climate risk analyses use scientific and hydro-meteorological information for their assessments. Five also use climate services and seven use climate scenarios. In one country expert opinion was included in the analysis to compensate for deficiencies in data and information.

Almost all countries in the region have a good coverage of science-based national climate impact projections for changes in temperature (twelve countries) and changes in precipitation (thirteen countries). Less countries have such projections for other slow onset events such as loss of biodiversity (six countries), sea level rise (five countries), land and forest degradation (two countries), salinization (one country), and desertification (one country).

All but one country state that there are problems with the provision of climate services in their region. These relate, among others, to lack of tools for measuring climatic characteristics in the field, partly due to insufficient coverage of weather stations. One country reports that its database of historical climate events faced important gaps because of a civil war between 1980 and 1992 during which meteorological stations had been damaged or completely destroyed. Funding to re-establish the stations only became available in 2010. These kind of gaps are said to lead to irregularities in field data which do not adequately capture varying climatic characteristics.

Another challenge is linked to general lack of resources, capacities and economic models for downscaling climate and sectoral impact scenarios and the absence of respective baseline analyses. In this context, one country calls for sea level rise mapping at the subnational level. Some also see the need for interpretation of data in real time for relevant sectors such as agriculture and early warning systems for multiple risks.

In general, countries in the region demand more detailed data collection, analysis and reporting processes, including satellite- and radar-based monitoring systems, and more staff and equipment to meet this requirement.

2.4. Europe (Non-Annex I)

Information in this subsection is drawn from responses of the following countries: Armenia, Azerbaijan, Bosna and Herzegovina, Georgia, The former Yugoslav Republic of Macedonia, Montenegro, Serbia.

In the Eastern European region, four of the seven countries use hydro-meteorological data and information as well as climate scenarios (one specified this to be regional EBU-POM climate models) when conducting their national climate risk analysis. Three use scientific information (one specified this to be IPCC work and reports) and three use climate services.

All but one country have science-based national climate impact projections for changes in temperature and all but two countries have such projections for changes in precipitation. Two countries have such projections for sea level rise and two for biodiversity loss.

Four of the seven countries state that there are problems with the provision of climate services in their region. These relate to lack of systematic data collection and archiving processes, as well as a lack of appropriate data analyses, e.g. of economic losses. Linked to these problems are insufficient maintenance of instruments and understaffed national institutions with low budgets. Other problems include low awareness about climate change, lack of research activities on climate change impacts and low level of knowledge on available technologies to include climate change considerations into research and planning.

2.5. Global

Information in this subsection is drawn from responses of the following organizations: IASSA, UNISDR, FAO, IOM, WHO, CARE.

Four of the six globally acting organizations that support regional institutions and national/subnational governments in conducting climate risk analyses regularly use climate time series and climate change scenarios for their assessments. The availability of this scientific information is reported to range from a few cases in which it is available (one organization) to many cases (two organizations) and most cases (two organizations). All globally acting organizations, except for IOM, have a policy or role to support or collaborate with national/subnational governments in building/enhancing capacities to access or generate the scientific information that is required to conduct climate risk assessments. For example:

- UNISDR supports countries in developing national disaster loss databases and promotes the understanding of modelling future potential losses and the information required for this.

- CARE seconds technical capacities to government institutions, like ministries and meteorological services, to improve their capacity of service provision, including the setting up of weather stations.
- WHO supports countries in using services provided in accordance with e.g. the Global Framework for Climate Services.

3. General remarks related to gaps identified from the responses to questionnaires

The responses to the questionnaires reveal that slow onset events are seen as highly relevant by countries in all represented regions. However, only a limited number of countries include the assessment of the risks of loss and damage associated with the effects of slow onset events in their national climate risk analysis (about 50%[2] in Africa, about 30% in Central and South America, none in Eastern Europe and 40% in Asia-Pacific).

The main challenges and gaps related to the assessment of risks associated with slow onset events and its integration into disaster risk management processes, according to the information provided via the questionnaire, include lack of data, information, and scenarios, general lack of awareness of the urgency of the matter, difficulties to understand slow onset events, lack of funding and a lack of skilled or trained personnel that is available and committed over longer periods of time. These challenges and gaps have been identified in all regions with only slight differences in their respective regional relevance.

One reason for the absence of relevant data and information, as indicated by the respondents, is a general lack of adequate data collection and monitoring systems. Even though the questionnaires did not include a specific question on existing monitoring networks to monitor slow onset events, countries and organizations, their responses to other questions revealed the existence of gaps in the regional coverage of weather stations, absence of adequate access to modern equipment, such as satellites or radar systems, and lack of skilled staff to collect, analyze, interpret or downscale data.

A widely identified difficulties relate to cooperation among relevant institutions and stakeholders when it comes to the sharing of data and information, in cases where it exists.

Another reason indicated for the lack of information on the potential impacts, including sectoral impacts, of slow onset events, is absence of mature models that reflect the progression and evolution of hazard onset, community response and patterns of loss.

[2] Percentages in this parenthesis are in relation to the regional respondents to the questionnaires.

D. A summary of financial instruments and tools for addressing impacts of SOE's, drawn from 2016 Forum of the Standing Committee on Finance *(Step 4)*

This section has been put together in the context of *Step 4 of the guidance by the Excom.*

The table and accompanying information below provide:

1. A list of financial instruments and tools addressing impacts of slow onset events;
2. Remarks regarding key gaps, challenges and opportunities related to financial instruments for addressing slow onset events.

1. List of financial instruments and tools for addressing slow onset events

As opposed to rapid or sudden onset events which usually manifest themselves as single, discrete events that occur in a matter of days or even hours, slow onset events evolve gradually from incremental changes occurring over many years or from an increased frequency or intensity of recurring events.[3] As such, slow onset events trigger impacts which are not limited in time, but lead to a continuum of impacts along their unlimited lifespan. These impacts may manifest in 1) gradual or creeping impacts (e.g. creeping forms of coastal erosion in the case of sea level rise), 2) through sudden onset impacts with increased frequency or intensity due to the interaction of the gradual and rapid onset impacts (e.g. heavy floods due to the interaction of sea level rise and storm surges) or the surpassing of certain tipping points (e.g. sudden salinization of groundwater due to the surpassing of a certain sea level), or 3) large-scale transformations of geographical areas or societies (e.g. disappearance of low-lying islands).[4]

Thus, the continuum of the impacts of slow onset events needs to be addressed through a range of different approaches and respective financial instruments. Such approaches may stem from various schools of thought including adaptation, disaster risk reduction and resilience building as well as sustainable development in its broader sense.

Financial instruments for adaptation and resilience-building, such as grants, loans or lines of credit, may be utilized to manage the risks from gradual changes which occur at a rate that societies can adapt to (e.g. gradual sea level rise with creeping forms of coastal erosion). In this context, adaptation and resilience-building contribute to avert, minimize and address loss and damage. Similarly, financial instruments for risk reduction, risk transfer and risk retention, aiming at minimizing loss and damage, may be applicable in the case of extreme sudden onset events that are triggered through the interaction between gradual changes and sudden onset events (e.g. heavy floods due to the interaction of sea level rise and storm surges) or due to the surpassing of tipping points (e.g. sudden salinization of groundwater due to the surpassing of a certain sea level). This form of financing is effective as long as experienced losses and damages can be restored.

Impacts that societies can neither avert nor minimize, such as the disappearance of land due to sea level rise or the accumulation, prolongation or shortened return periods of extreme events, which make the continuation of previous lifestyles impossible or intolerable, require transformational approaches. These are

[3] Siegele L. 2012. Loss and Damage: The Theme of Slow Onset Impact. Germanwatch. Bonn, Germany.
[4] The information contained in this chapter is drawn from the sources described in Part 3, section D of this paper.

difficult to be addressed through traditional types of risk financing since they regularly surpass the financial capacity of a single society or nation, and are also costly to be covered by existing insurance schemes.

The table below summarizes existing and innovative financial instruments that may be applied to address the various effects of slow onset events.

Type of impact	Description	Approach	Examples of financial instrument/tool
a. Gradual	Creeping coastal erosion from sea level rise; gradual decrease of fresh water due to, e.g. glacial retreat; minor changes in biodiversity and composition of species	Adaptation/ risk reduction/ resilience building	Financial instruments suitable to support adaptation activities, such as grants, loans, lines of credit
b. Sudden onset as a result of the interaction between gradual changes and sudden onset or the surpassing of tipping points	Major floods due to the interaction of sea level rise and storm surges; glacial lake outburst flood (GLOF) due to surpassing of the water retentivity of glacial lakes; plagues due to extinction of important predators	Risk retention	Contingency funds/credits
			Disaster relief funds
			Public reserves
			Restoration fund for preferential interest rate financing
		Risk transfer	All forms of insurance including catastrophe risk insurance and index-based schemes, risk swaps, options, and loss warranties
c. Both gradual and sudden onset	*See descriptions of a. and b. above*	Adaptation/ risk retention	Micro grants
			Micro savings
			Micro credits
		Resilience building/ risk reduction/ risk retention/ risk transfer	Social protection schemes
		Resilience building/ risk transfer	(Climate) Resilience/ Catastrophe bonds
d. Large-scale	Disappearance of small islands or other coastal land; cut-off of freshwater sources due to complete disappearance of, e.g. glaciers; complete switch from one biome to another	Transformation/ migration	Refined types of insurance or credit to manage risks associated with transitioning from traditional to new livelihood practices (e.g. drought adaptation insurance or credit to help farmers shift from non-viable farming practices to more sustainable ones) or adapted life-insurance models*
			International insurance pool funded by developed countries to compensate small island and low-lying developing countries for the otherwise uninsured loss and damage from sea level rise (first proposed by AOSIS in 1991)*
			Compensation schemes*
			Migration facilities*
			Regional solidarity funds to pool risks, e.g. for SIDS*

**These instruments have not been applied in practice.*

This list of financial instruments and tools is not to be seen as exhaustive and the categorization not to be perceived as strict. Some of the instruments may well be suitable to address several effects of slow onset events.

Particularly those instruments listed in the second category, which can be used to address gradual changes and sudden onset events, have a large potential to create resilience beyond reducing the risk of discrete, extreme events. These include mainly social protection schemes and to a lesser degree (climate) resilience/catastrophe bonds and micro grants, savings and credits. Social protection schemes consist of policies and programmes designed to reduce poverty and vulnerability by promoting efficient labour markets, diminishing people's exposure to risks, and enhancing their capacity to manage economic and social risks, such as unemployment, exclusion, sickness, disability and old age. Micro grants, savings and credits are usually granted to low-income households or individuals and used to achieve a particular adaptation or risk reduction outcome and may be part of social protection schemes. Resilience and catastrophe bonds are risk-linked securities that are issued by public or private sponsors and help to transfer a specified set of their risks to investors. If during a specified period of time, risks (usually larger disasters) do not materialize, the sponsor repays the investor plus interest. If a catastrophe occurs, the principal and interest, or parts of them, are forgiven and the sponsor can use the money to address the impact of the catastrophe. Resilience bonds, as a new and special case, take into account any infrastructure improvements undertaken by the bond issuer during the lifetime of the bond that lead to reduced financial risks and will therefore reduce the amount of interest or principal needed to be repaid on the bond in case no disaster occurs. The principal of the catastrophe bond may be spent on adaptation or risk reduction activities but there is no obligation on the side of the issuer.

As opposed to micro grants, savings and credits and catastrophe and resilience bonds, social protection schemes have the advantage that they are usually not limited in time and not tied to a particular purpose. They are designed to respond predictably and effectively to protect vulnerable communities amidst evolving risks and are therefore particularly suitable to build resilience in the context of slow onset events.

The financial instruments and tools listed to address large-scale loss and damage are the category of instruments where least experience has been gathered. All of them are innovative instruments that have been proposed by different stakeholders but short of being applied in practice. This gap may benefit from further discussion and refinement at different arenas, levels, as well as from increased support.

2. Gaps, challenges and opportunities related to financial instruments for addressing slow onset events

The largest gap regarding effective financial instruments and tools to address slow onset events, as mentioned in the previous chapter, exists with regard to transformational approaches that would serve to address residual risks of large-scale loss and damage. Some participants at the 2016 SCF Forum identified that closing this gap should be the primary focus of the loss and damage policy domain. In their view, climate change conditions which can be mitigated, adapted to, or insured against, are already addressed by the climate change adaptation and disaster risk reduction communities or by public/private risk transfer schemes.[5] According to them, these communities and their respective instruments and tools mainly help to restore, rehabilitate, and reconstitute the status quo which often is the reason for being trapped in poverty and

[5] Wrathall, D.J., Oliver-Smith, A., Fekete, A., Gencer, E., Reyes, M.L. and Sakdapolrak, P. (2015) 'Problematising loss and damage', Int. J. Global Warming, Vol. 8, No. 2, pp.274–294.

remaining vulnerable, instead of enabling the society to attain transformational, structural changes required to address the risk of large-scale loss and damage.

Some of the obstacles in making available financial instruments for transformational approaches may include the following:

- The application of financial instruments and tools requires the quantification of the losses and damages likely to be experienced. However, migration and transformative approaches would entail many losses of indirect and non-economic nature which are difficult to attribute and valuate in quantitative terms and often too traumatizing to be compensated in monetary form;[6]
- Promoting risk management and respective financial instruments has so far been prioritized since transformational approaches bear many and large uncertainties;
- Funding one-time losses and damages is easier, may, in some cases, be considered cost-effective, hence more attractive than financing a country's sustained efforts to adapt through transformation.

While global discussions on innovative financial instruments to address large-scale loss and damage through migration or transformation require further deliberations, existing instruments that help to reduce, retain or transfer risk or to build resilience, as listed in table I, play an indispensable role in addressing the other effects of slow onset events.

However, these instruments also have challenges, some of which include:

- The design of financial instruments requires an in-depth understanding of risks in time and space, however the attribution of loss and damage to a particular slow onset event is often difficult, if not impossible, due to the large temporal and spatial scales involved and other potential stressors such as human-induced environmental change;
- Addressing the continuum of effects of slow onset events requires a smart combination of approaches and financial instruments. In this regard, it is challenging to assess the possible effects of slow onset events in a given geographical area and/or governance level, identify the appropriate combination and order of approaches and instruments to prevent and/ or mitigate their impacts while facilitating the continuous cooperation between relevant different schools of thought (adaptation, risk management, etc.).

General challenges regarding financial instruments, though not specific in the context of slow onset events, include a lack of enabling environments in developing countries (e.g. limited financial and regulatory infrastructure), deficits in climate and weather as well as vulnerability and exposure data that can be used as the basis for designing and deploying financial instruments, difficulties to forecast frequency, intensity or duration of climate events, design challenges so as to avoid providing disincentives, causing market failure and worsening equity situations.

There is broad agreement that addressing slow onset events through smart combinations of financial instruments and tools requires further research, refinement and innovation and that global cooperation and support is required in this regard.

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[6] Wrathall, D.J., Oliver-Smith, A., Fekete, A., Gencer, E., Reyes, M.L. and Sakdapolrak, P. (2015) 'Problematising loss and damage', Int. J. Global Warming, Vol. 8, No. 2, pp.274–294.

Part 3: Sources and methods used

The types of slow onset events referred to in this information material are those identified in decision 1/CP.16, paragraph 25, as follows: increasing temperatures, sea level rise, ocean acidification, salinization, land and forest degradation, desertification, glacial retreat and related impacts, loss of biodiversity.

To the extent possible, and where available, information has been organized by the following regions: Global, Africa, Asia, Central and South America, Small Island Developing States (SIDS), the Ocean, Australasia, Europe, North America, Polar regions.

Excom 5 provided guidance on a set of sources to be used for undertaking each of the Steps. These sources are indicated below under each of the four Steps.

A. Initial inventory of slow onset impacts by region drawn from IPCC's 5th Assessment Report *(Step 1)*

Sources

Relevant information has been extracted from the IPCC 5th Assessment Report:

- Working Group II 'Climate Change 2014: Impacts, Adaptation, and Vulnerability', regional chapters 22, 23, 24, 26, 27, 29, 30, including their executive summary;
- Working Group I 'The Physical Science Basis', chapters 12.4 and 12.5 'Long-term Climate Change: Projections, Commitments and Irreversibility'.[7]

Method

Keyword research method was used in order to extract relevant information. The table below contains key words searched for each of the eight types of slow onset events:

SOEs	*Key words searched*
Increasing temperatures	Increasing temperatures, rising temperature, warmth, warming, heat, evapotranspiration
Sea level rise	Sea, level, rise, SLR, rising sea, water level, inundation
Ocean acidification	Ocean, acidification, acid, acidity, pH, bleaching, carbon dioxide, CO_2
Salinization	Salt, saline, water, soil, brackish, total dissolved solids (TDS)
Land and forest degradation	Land, forest, degradation, deterioration, loss, vegetation, habitat, ecosystem
Desertification	Desertification, desert, soil, erosion, arable, arid, land, land use, moisture, evapotranspiration
Glacial retreat	Glacial, retreat, ice, snow, glacier, melting, permafrost
Loss of biodiversity	Biodiversity, loss, degradation, deterioration, habitat, ecosystem, coral, mangroves, deterioration

Extracted information for each region has been further organized in tabular format as follows (*see Part 2, Chapter A above*):

- By SOEs (of those that relevant information is found);
- By system as contained in the respective chapters (e.g. ecosystems, water resources, food production, etc.);

[7] Available at <https://www.ipcc.ch/report/ar5/>.

- By observed and projected impact as contained in the respective chapters.

Extracted information has been synthesised in a succinct bulleted format for ease of reading. Information that is highly complex, e.g. due to scientific language, or too specific/localized has not been included in these tables. Examples have been included, in sub-bullets, where appropriate, to provide contextual information.

To minimize repetition, the extracted information is associated with a most relevant SOE, although certain impacts may be associated with multiple SOEs.

In addition, a simple one-page visualization provides a further synthesis of the extracted information from the AR5 (*see Part 2, Chapter A above*).

Every attempt has been made to extract the most relevant information contained in the respective AR5 chapters, recognizing the challenge of reviewing a voluminous and very comprehensive report. Detailed information in full can be found in the respective chapters of AR5, available at http://www.ipcc.ch/report/ar5.

B. Literature review by region drawn from the 8th Research Dialogue *(Step 2)*

Sources

Relevant literature has been extracted from information shared at the SBSTA 8th Research Dialogue (RD8), held on 19 May 2016, including:

- Summary report of the RD8;[8]
- Presentations and posters presented at the RD8.[9]

Method

Relevant academic literature, reports and projects related to slow onset events have been compiled from these sources (*see Table 1 in Part 2, Chapter B above*). The table includes original sources of the extracted literature in the case they are not specified in the summary report of the RD8. Relevant contents of these literature have been extracted either from the abstracts or executive summaries of these literature (*see Table 2 in Part 2, Chapter B above*).

C. State of risk management and data collection processes by impact and region drawn from responses to questionnaires under Action Area 5 *(Steps 2/3 and 3)*

Sources

Responses to two sets of questionnaires on systems and/or processes currently in place for conducting and coordinating analyses of climate risk and loss and damage associated with the adverse effects of climate change, taking into account extreme and slow onset events, provided by:

- 43 non-Annex I Parties; and
- Eight institutions (six international, two regional).

The questionnaires were developed in the context of implementation of Action Area 5 of the Executive Committee's initial two-year workplan and responses were collected from August 2016 to June 2017.

Method

[8] Available at <http://unfccc.int/files/science/workstreams/research/application/pdf/researchdialogue_2016_2_summaryreport.pdf>.
[9] See <http://unfccc.int/9475>.

Relevant information from the two sets of questionnaires has been extracted and analysed, both qualitative and quantitative, and organized by region.

It is important to note that the questionnaires focus primarily on existing climate risk analysis/assessment processes, and only to a limited extent on other risk management components. Furthermore, the formulation of questions and the information provided by respondents, respectively, are not, in some cases, compatible with the context of the question included in Step 3 'Are there monitoring networks in place?' (i.e., the questionnaire under Action Area 5 did not include question on existing monitoring networks). Furthermore, in most cases, questions on certain risk management activities included in the questionnaire did not lead to clear distinction whether activities described by respondents include action on slow onset events or focus on extreme weather events.

D. Financial instruments and tools for addressing impacts of slow onset events drawn from 2016 Forum of the Standing Committee on Finance *(Step 4)*

Sources

Relevant information has been drawn from:

- Findings from the 2016 Forum of the Standing Committee on Finance dedicated on 'Financial instruments that address the risks of loss and damage associated with the adverse effects of climate change' (5-6 September 2016);[10]
- Information, submitted by Parties and relevant organizations, on best practices, challenges and lessons learned from existing financial instruments at all levels that address the risk of loss and damage associated with the adverse effects of climate change, as well as the Information Paper resulting from these submissions;[11]

In addition, the following sources of information have been reviewed:

- UNFCCC Technical paper on slow onset events;[12]
- Report on the UNFCCC expert meeting to consider future needs associated with slow onset events;[13]
- Literature review in the context of Thematic Area 2 of the work programme on loss and damage;[14]
- Report on the UNFCCC regional expert meetings conducted under Thematic Area 2;[15]
- Special Issue on Emerging Perspectives on Loss and Damage of the International Journal of Global Warming.[16]

Method

Relevant information from the first group of sources above, then the second, were synthesised and also presented in a succinct table-format, followed by initial analysis on gaps, challenges and opportunities related to financial instruments for addressing slow onset events.

It should be noted that the list of financial instruments and tools is not to be seen as exhaustive and the categorization not to be perceived as strict.

[10] The report on the Forum as well as presentations and other background material are available at <unfccc.int/9410>.
[11] Available at <http://unfccc.int/files/adaptation/groups_committees/loss_and_damage_executive_committee/application/pdf/aa7_d_information_paper.pdf>.
[12] FCCC/TP/2012/7.
[13] FCCC/SBI/2013/INF.14.
[14] FCCC/SBI/2012/INF.14.
[15] FCCC/SBI/2012/29.
[16] Wrathall, D.J., Oliver-Smith, A., Fekete, A., Gencer, E., Reyes, M.L. and Sakdapolrak, P. (2015) 'Problematising loss and damage', Int. J. Global Warming, Vol. 8, No. 2, pp.274–294.

Annex III: Discussion points on the knowledge compendium on slow onset events (SOEs) under AA3(d)

In response to steps agreed on taking forward action area (AA) 3(d), the Secretariat has compiled and synthesized existing scientific information, informed by ongoing work on SOEs being carried out under the initial two-year workplan of the ExCom, in order to *'assess and develop recommendations to improve the state of knowledge to understand, and capacity to address, slow onset events and their impacts, including the capacity of regional agencies'* (Action Area 3, activity (d), initial two-year workplan).
The compendium contains:

- Information on SOEs drawn from the IPCC´s Fifth Assessment Report
- Information on SOEs drawn from the 8th Research Dialogue
- Results from questionnaires on risk management under AA5
- A summary of financial instruments and tools for addressing impacts of SOEs

In reviewing the compendium, the Champions of this action area, Cornelia and Dawn, have identified a number of issues for discussion among the wider ExCom. These include:

1. Identifying areas of concern in the presentation of information in the compendium
2. Agreeing on the target audience for the compendium and how it should / could be used
3. Developing recommendations as agreed under AA3(d)

1. <u>Identifying areas of concern in the presentation of information in the compendium</u>
In reviewing the compendium, the Champions have identified some concerns, which they would like to bring to your attention. In addition, they welcome other members to provide their comments either before or during discussion at ExCom 6. Areas of concern raised were in the mapping section in relation to some of the terminology used, and in particular, the ring diagram representing SOEs by region, on page 6 of the draft compendium. There were also a number of concerns raised around Section D on financial instruments.
Possible discussion points:

- Does the ring diagram on page 6 of the compendium provide an accurate regional picture of potential impacts of SOEs and the vulnerabilities of developing countries in the face of these impacts?
- What sources of information should be included in section D on financial instruments?
- How can we ensure that information presented is as comprehensive as possible and captures the "state-of-the-art" in terms of knowledge and expertise?

2. <u>Agreeing on the target audience and how the compendium should / could be used</u>
A primary aim of the compendium was to bring together information on SOEs in a stepwise manner that would help inform the thinking of the ExCom in developing recommendations to improve the state of knowledge to understand, and capacity to address, SOEs and their impacts. Thus, for the time being, the compendium remains an internal document to inform the thinking and discussion of the members of the ExCom. Given the richness of information set out in the compendium and its potential benefits for other areas of work by the ExCom and others, the members may wish to consider broader dissemination of this document.

Possible discussion points:

- Should the compendium be used strictly as an internal document?
- What are other uses of the information synthesized in the compendium, e.g. in synergy with the online database on SOEs / clearing house for risk transfer / expert group on risk management?
- Should this compendium be disseminated more widely?

3. <u>Developing recommendations</u>
The mandate under AA3(d) is to develop *recommendations to improve the state of knowledge to understand, and capacity to address, slow onset events and their impacts, including the capacity of regional agencies*.
Possible discussion points:

- How do we use the compendium to develop recommendations?
- What further work is needed in order to develop recommendations?

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