Assessment of global megatrends — an update

Global megatrend 9: Increasingly severe consequences of climate change

European Environment Agency

Cover design: EEA
Layout: EEA/Pia Schmidt

The present chapter was authored by Tobias Lung and Hans-Martin Füssel with contributions from André Jol and Teresa Ribeiro.

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark
Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99
Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

Assessment of global megatrends — an update

Global megatrend 9: Increasingly severe consequences of climate change

European Environment Agency

Assessment of global megatrends — an update

Europe is bound to the rest of the world through an enormous number of systems — environmental, economic, social, political and others. Such networks enable complex flows of materials and ideas across the globe, producing uncertain feedbacks and knock-on effects over time. Greenhouse gas emissions in Europe today can affect the climate in distant locations and far into the future. Land management choices on the other side of the world can influence food and energy prices in Europe. Global communication and trade networks fuel innovation — sometimes boosting efficiency, sometimes creating new environmental pressures.

Most of these interactions are intimately linked and set to unfold over decades. All are likely to have important implications for living standards and well-being.

The European environment's status, trends and prospects have always depended in part on events outside its borders. Yet the growing importance of global networks and flows has augmented this interdependence, creating complex challenges for traditional governance systems framed within national or regional territories. To design effective ways to manage the environmental changes ahead, societies and governments need to understand the global drivers at work and their potential implications.

With this challenge in mind, the European Environment Agency in 2010 produced its first assessment of emerging global trends as part of its five-yearly flagship report on the European environment's state and outlook (SOER 2010). The exploratory analysis summarised 11 global megatrends grouped into five clusters — social, technological, economic, environmental and governance. Introducing the issues succinctly, it sought to trigger a discussion about how Europe should monitor and assess future changes in order to better inform environmental policymaking.

In preparation for its next report on the European environment's state and outlook (SOER 2015), the EEA has initiated an update of the assessment of global megatrends, analysing each of these drivers in a little more detail than previously in terms of their impacts on the European environment and well-being. During the second half of 2013 and early-2014, the EEA is reassessing the 11 megatrends and publishing the updates separately on its website. In 2014 the chapters will be consolidated into a single EEA technical report and will provide the basis for the analysis of megatrends included in SOER 2015. The present chapter addresses megatrend 9: 'Increasingly severe consequences of climate change'.

Again, it needs to be emphasised that the complexity of highly interconnected human and natural systems introduces considerable uncertainty into projections and forecasts. As much as anything, the assessment of megatrends aims to encourage readers to acknowledge this interdependence and uncertainty. In so doing, it may help point the way towards systems of planning and governance better adapted to meeting the challenges ahead.

GMT 9: Increasingly severe consequences of climate change

In the past 150 years, the atmosphere and the oceans have warmed, snow and ice cover has decreased, sea levels have risen and many extreme weather and climate events have become more frequent. This warming of the global climate is unprecedented over millennia.

The global mean temperature has increased by 0.85 °C since reliable measurements began in 1880 and is projected to increase further by the end of the 21st century – by between 1.0 °C, assuming strong emissions abatement, and 3.7 °C, assuming high emissions. This warming is expected to be accompanied by a global mean sea-level rise of up to 1 m, an increase of up to 2 °C in global upper-ocean temperature, a reduction of glaciers, ice sheets and sea ice, and an increased frequency of extreme weather events, such as droughts and floods, in many regions of the world.

Increasingly severe impacts of climate change are anticipated for the Earth's natural ecosystems, including substantial losses of biodiversity and increased rates of extinction. Of particular concern are such ecosystems as coral reefs, the Amazon forest and the boreal-tundra Arctic. Furthermore, climate change is likely to slow economic growth, erode global food security, increase global inequalities and adversely affect human health. These societal impacts are anticipated to be most severe in low-income countries and low-lying coastal areas.

Projected impacts directly affecting Europe include increased frequency of drought and water restrictions, increased damage due to flooding and increased impacts on human health from extreme temperatures.

9.1 Key drivers of a changing climate

Human influence vs. natural climate variability

Both natural and anthropogenic substances and processes can alter the Earth's energy balance and thus act as drivers of changes in the climate system. There is more scientific evidence than ever before, however, that the climatic changes observed since the industrial revolution, and in particular in the past 50 years, are largely caused by human activity. This relates primarily to greenhouse gas (GHG) emissions from fossil fuel burning, but also to other activities including agriculture, deforestation and waste management. Through these activities, atmospheric concentrations of GHGs, namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and various fluorinated gases, have increased, causing the Earth to heat up. The emission of aerosols and other human activities that change Earth's albedo ([1]) can either have a warming or cooling effect, but the magnitude of these effects is considerably less than the warming effect from GHG emissions.

Recent progress in climate science — more detailed and longer term observations in combination with improved climate models — allows for a clear attribution of the human contribution to the observed changes in many components of the climate system. Firstly, there have not been any significant long-term changes in the sun's energy output that could have contributed to the observed climatic changes (NAS and RS, 2014). Secondly, climate model simulations that purely use natural factors in their calculations cannot reproduce the increases in temperature observed in all world regions. Only when models include the substantial human influence on the atmosphere through emissions are the resulting simulations consistent with the observed changes. Therefore, it is extremely likely that most of the observed increase in global mean surface temperature since the mid-20th century has been caused by anthropogenic increases in GHGs. Furthermore, it is very likely that anthropogenic influence has substantially contributed to increases in upper ocean temperatures, Arctic sea-ice loss, global mean sea-level rise and changes in the frequency and intensity of temperature extremes, such as heat waves, since the mid-20th century (IPCC, 2013a).

([1]) Reflectivity or reflecting power

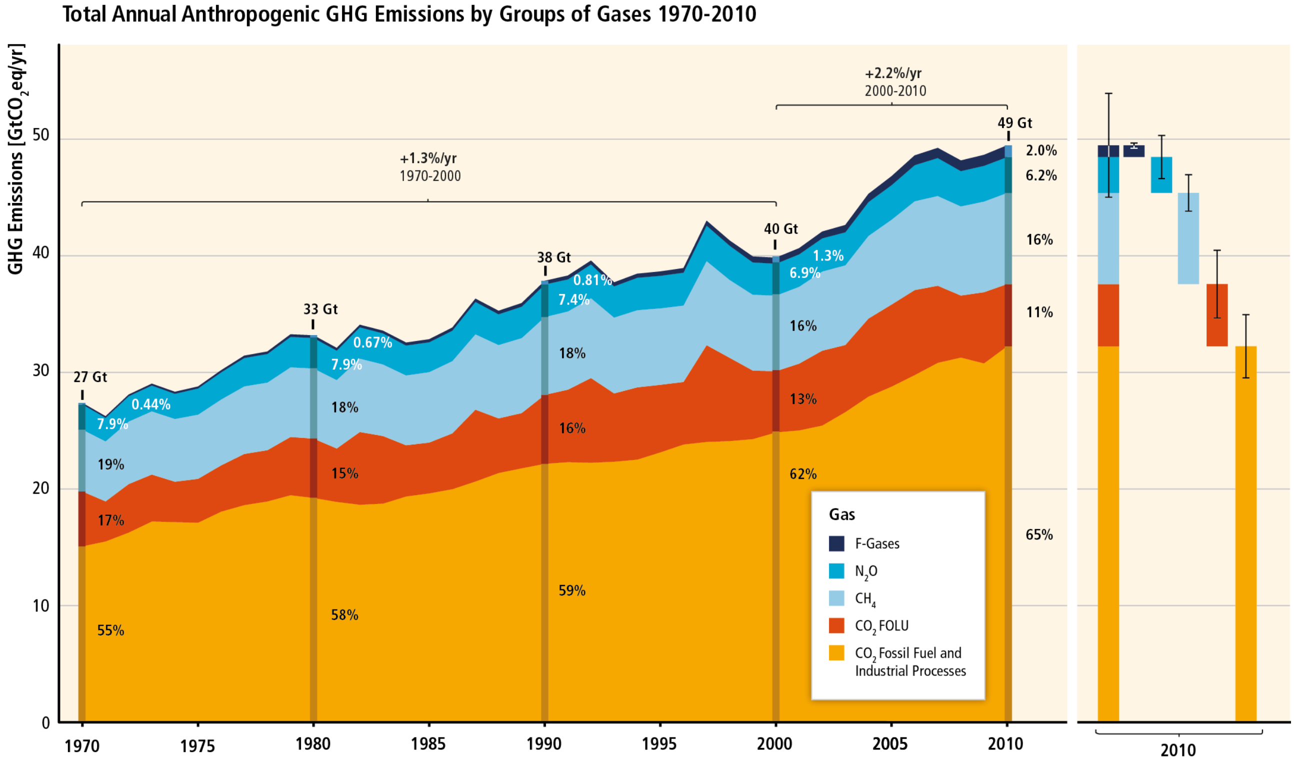
Greenhouse gas emissions and atmospheric concentrations

Measurements of CO_2 in the atmosphere and from air trapped in ice show that atmospheric concentrations have increased by about 40 % since 1800, with most of the increase happening since the 1970s when global energy consumption started to rise strongly. Furthermore, measurements from ice cores suggest that current CO_2 concentrations are higher than at any time in the last 800 000 years (NAS and RS, 2014).

Despite a growing number of climate mitigation measures, total global anthropogenic GHG emissions have grown continuously over the period 1970–2010, reaching their highest level in human history in the most recent decade, 2000–2010 (Figure 9.1). Of the total anthropogenic GHG emissions in 2010, CO_2 accounted for 76 % (65 % related to fossil fuel combustion and industrial processes and 11 % related to such land use and land-use change as agriculture and deforestation), while 16 % came from CH_4, 6 % from N_2O oxide and 2 % from fluorinated gases (IPCC, 2014b).

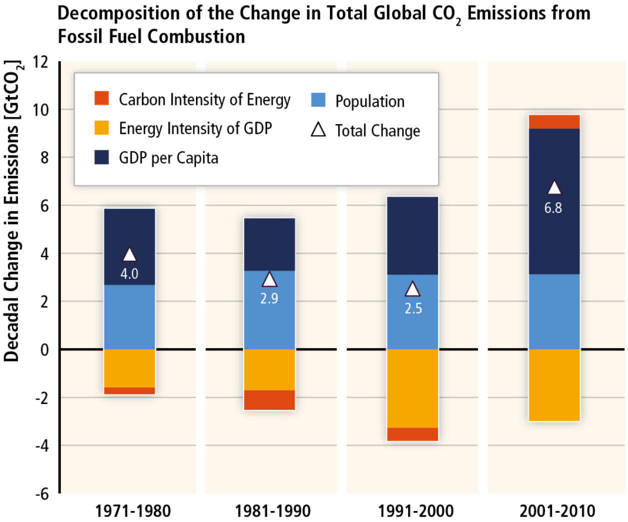
Population growth and current patterns of consumption and production are the most important drivers of increasing global CO_2 emissions, as seen from an analysis of the change in global CO_2 emissions from fossil fuel combustion for 1971–2010 (Figure 9.2). While the contribution of population growth remained at similar levels over the 40-year period, however, the contribution of current patterns of consumption and production (dark blue in Figure 9.2) rose sharply in 2001–2010. A breakdown by country income group reveals that CO_2 emissions from upper-mid-income countries, such as China and South Africa, doubled between 1990 and 2010, and have almost reached the level of high-income countries, US and most EU countries, although per person emissions are still much lower in the former group. Over the same period, lower-mid-income countries, such as India and Indonesia, also experienced substantial increases in national CO_2 emissions (Figure 9.3; IPCC, 2014b).

Figure 9.1 Total annual anthropogenic greenhouse gas emissions, 1970-2010



Source: IPCC, 2014b.

Figure 9.2 Change in total global CO_2 emissions from fossil fuel combustion



Source: IPCC, 2014b.

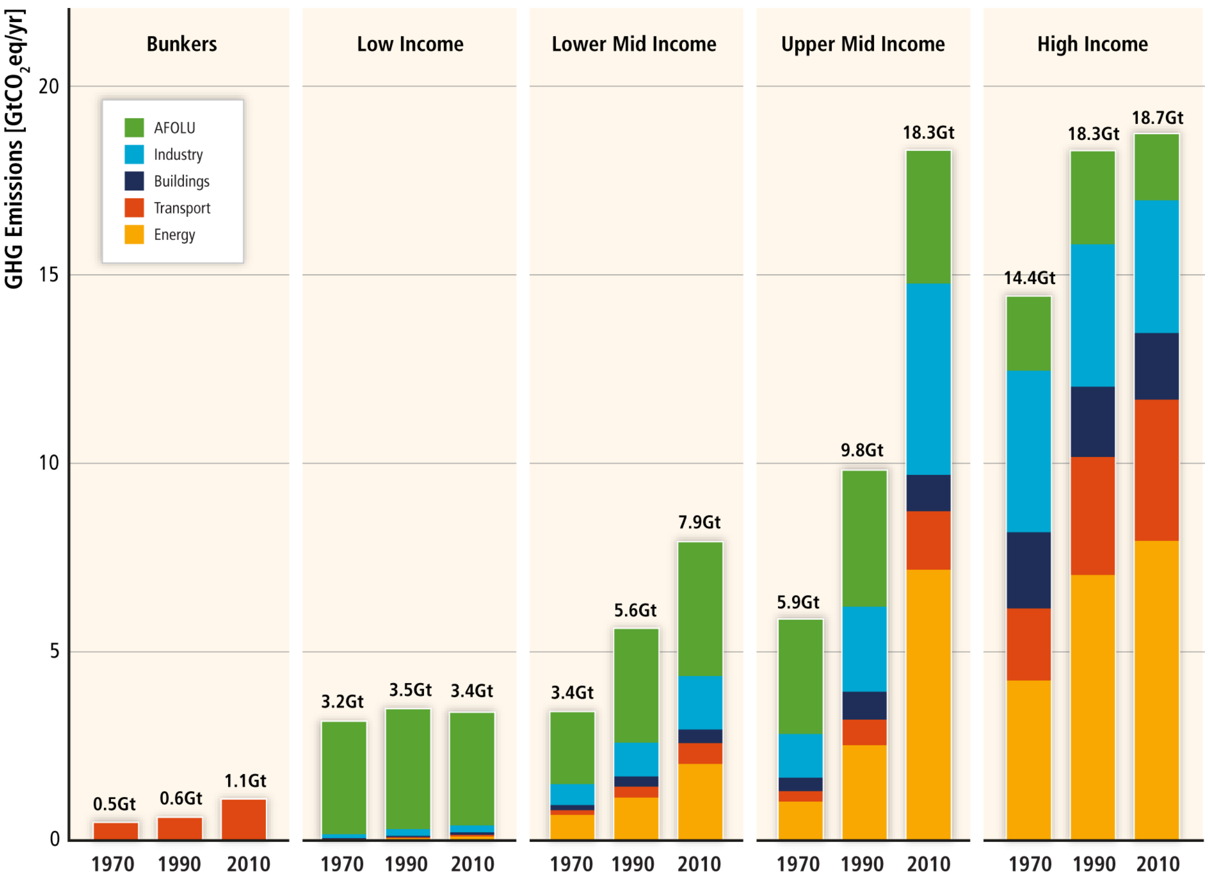
9.2 Trends of change in the global climate system

Observed changes

The Earth's combined land and ocean surface temperature has warmed by 0.85 °C [0.65–1.06 °C] (2) over the period 1880–2012, the period for which reliable measurements are available. In addition, changes in extreme temperatures have been observed since the 1950s. It is very likely that the number of hot days and nights has increased over most land areas, and in Europe, Asia and Australia it is likely that the frequency of heat waves has also increased.

Substantial inter-annual to decadal variability in the rate of warming exists, due to the influence of such natural factors as the *El Niño* effect (Figure 9.4). For instance, since about 2000, global climate datasets suggest a slowdown in the rise of global mean

Figure 9.3 Total anthropogenic greenhouse gas emissions in 1970, 1990 and 2010 by economic sector and country income groups



Source: IPCC, 2014d.

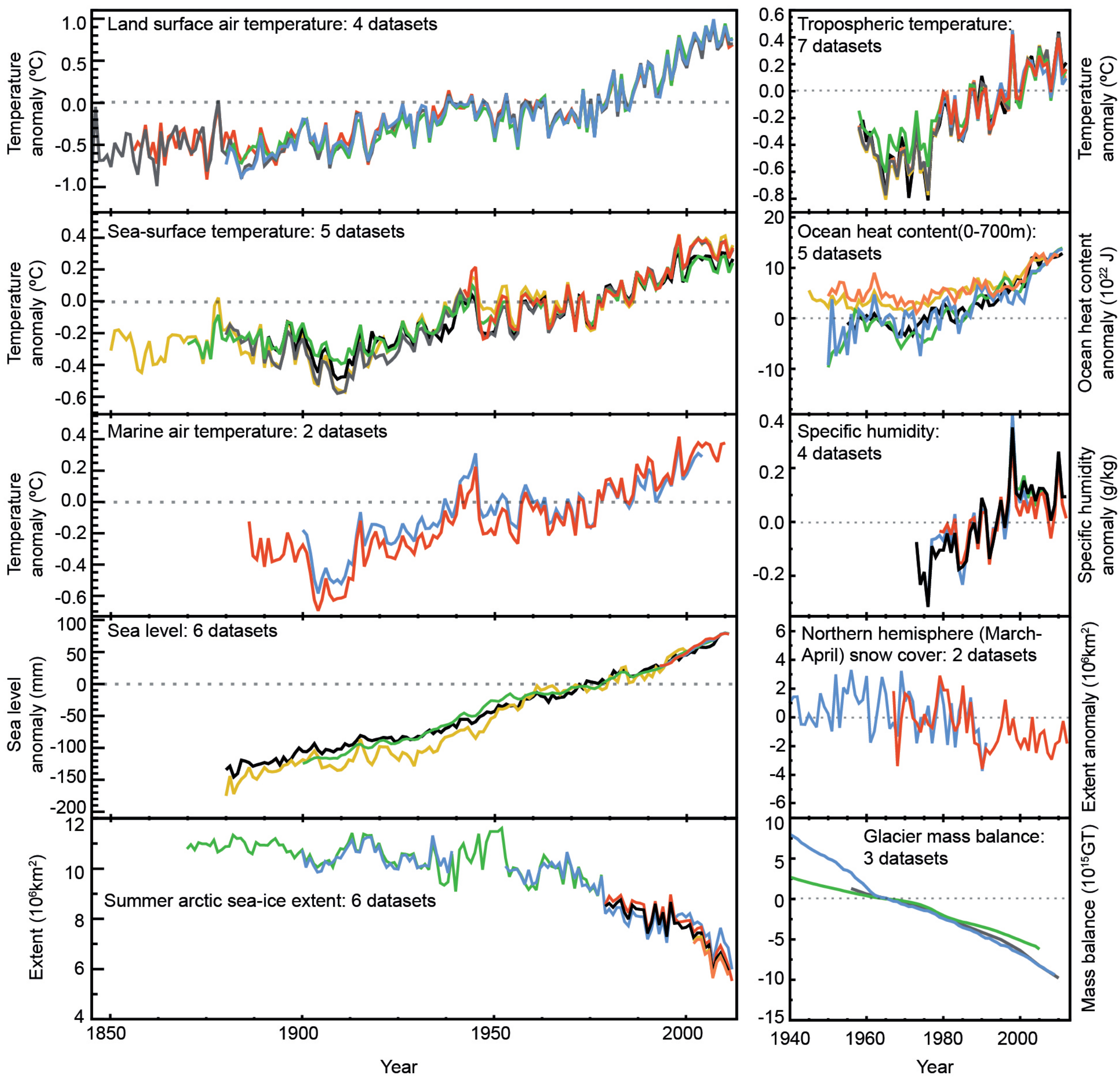
(2) Ranges reported in square brackets express uncertainty about the real value by means of the 90 % confidence interval. This means that the estimated value is between the lower and upper value, with 90 % likelihood.

surface temperature, and this has been linked to an intensification of wind-driven heat uptake in the Pacific Ocean (England et al., 2014) Recent research, however, suggests that the slowdown is at least partly an artefact of the exclusion of data-poor regions, in particular in Africa and around the poles, in the calculation of the global mean temperature. Indeed, a re-processed data set, which was interpolated across these data-poor regions, did not show any statistically significant slowdown in global mean surface temperature increase in the last 15 years (Cowtan and Way, 2014). In any case, short-term climate variations lasting a decade or so would not contradict the long-term warming trend (IPCC, 2013a).

The world oceans have also warmed considerably in recent decades. Ocean warming has been observed between 0–2000 m from 1957 to 2013 (Figure 9.4; Levitus et al., 2012; IPCC, 2013a).

Climate change is affecting ice and snow cover across the world. The Arctic sea ice extent at its late-summer minimum has decreased by about 40 % since 1979, while northern hemisphere snow-cover extent in June has decreased by 11.7 % per decade

Figure 9.4 Indicators of a changing global climate



Source: IPCC, 2013b.

over the period 1967–2012, with substantial decreases also occurring in other months. Most of the world's glaciers are losing mass, and, indeed, the Greenland ice sheet's loss increased substantially between 2002 and 2011; both processes contributing to global sea-level rise. Furthermore, permafrost temperatures have increased in most regions since the early 1980s, leading to risks of infrastructure damage and CH_4 release (IPCC, 2013a).

Sea levels are rising faster than at any time over the past 2 000 years – they have risen by about 20 cm since 1901 due to thermal expansion of warming ocean water and the melting of glaciers and ice sheets. The rate of increase has almost doubled from 1.7 mm per year between 1901 and 2010 to 3.2 mm per year between 1993 and 2010 (Figure 9.4; IPCC, 2013a).

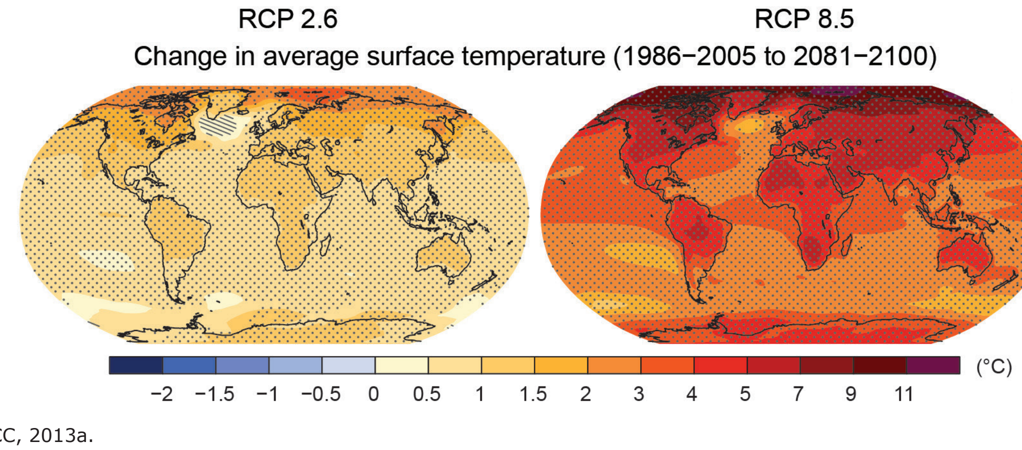
Observed changes in precipitation show strong regional variations. In many regions, including Europe and North America, increases in either the frequency or intensity of heavy precipitation events have been observed. In contrast, climate records show an increased frequency and intensity of drought events in the Mediterranean and parts of Africa (IPCC, 2013a).

***Projected changes: temperature and precipitation* (3)**

The warming of the Earth during the 21st century is projected to be significantly greater than during the 20th century, with the magnitude depending on the emissions scenario. Global mean temperature is projected to increase further – between 1.0 °C [0.4–1.6 °C] assuming strong emissions abatement and 2.0 °C [1.4–2.6 °C] assuming high emissions (RCP8.5) – by mid-century (2046–2065), compared to the reference period of 1986–2005. Warming by the late 21st century (2081–2100) is projected to be between 1.0 °C [0.3–1.7 °C] (RCP2.6; Figure 9.5, left) and 3.7 °C [2.6–4.8 °C] (RCP 8.5; Figure 9.5, right). In order to have a two thirds chance of keeping the global mean surface temperature rise below 2 °C compared to the pre-industrial period, the agreed target of the United Nations Framework Convention on Climate Change (UNFCCC), cumulative carbon emissions since 1870 need to be kept below 1 000 gigatonnes (GtC). More than half of this amount, 515 GtC, has already been emitted between 1870 and 2011 (IPCC, 2013a).

As temperature increases, it is very likely that the number and intensity of hot temperature extremes and heat waves will increase globally. Under the

Figure 9.5 Projected changes in average temperature, 2081–2100 relative to 1986–2005 for low-emission (RCP2.6, left) and high-emission (RCP8.5; right) scenarios



Source: IPCC, 2013a.

(3) Projections of changes in the climate systems as given here are based on four so-called Representative Concentration Pathways (RCPs; van Vuuren *et al.*, 2011). The RCPs represent radiative forcing up to 2100 from different levels of emissions and atmospheric concentrations of GHGs. Technically the RCPs are forcing scenarios rather than emissions scenarios. However, this difference is significant for policy-making, as a low RCP can only be achieved by a low emissions scenario and a high RCP is always caused by a high emissions scenario. The RCPs cover a mitigation scenario leading to a very low level of radiative forcing (RCP2.6), two so-called 'stabilisation scenarios' with greater levels of GHG concentrations (RCP 4.5 and RCP 6); and a scenario with very high GHG emissions (RCP 8.5 — the scenario towards which GHG emissions are currently heading if no further abatement measures are taken). The RCPs were developed to aid climate modelling and underpin the IPCC's Fifth Assessment Report. A full description of the comprehensive set of multi-model estimates, as well as further details on the projected trajectories for the various climate components, can be found in the IPCC Fifth Assessment Report (IPCC, 2013b).

RCP8.5 scenario, heat events that currently occur every 20 years are likely to become annual or 2-yearly events in many regions by the end of the 21st century (IPCC, 2013b).

The tropical regions of Africa, South and Central America and Asia are projected to be particularly affected by increases in temperature extremes, because natural temperature variability is lower there than in other world regions. Even under a low emissions scenario, in these tropical regions an average summer at the end of this century is projected to be hotter than any summer experienced there during the 20th century (Figure 9.6, left). Under a high emissions scenario, in most world regions an average summer at the end of this century is projected to be warmer than any summer experienced during the 20th century; in most tropical regions, almost every summer at the end of this century is projected to be hotter than the warmest summer experienced during the 20th century Figure 9.6, right; Coumou and Robinson, 2013)climate models predict more substantial warming. Here we show that the multi-model mean of the CMIP5 (Coupled Model Intercomparison Project.

This warming will be accompanied by changes in precipitation, but will vary significantly between regions. Mean precipitation is likely to decrease further in such regions as the Mediterranean and northern Africa, in particular under a high-emission scenario. In contrast, more intense and frequent extreme precipitation events are very likely in most mid-latitude regions, Europe and North America, for example, and wet tropical regions (IPCC, 2013a).

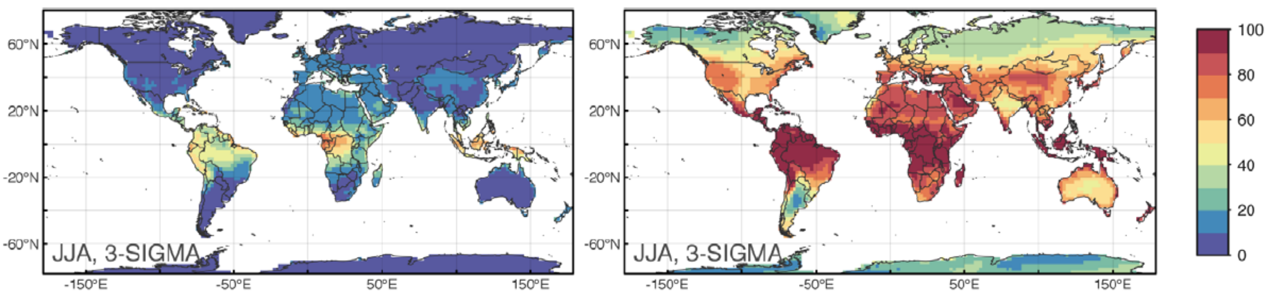
*Projected changes: ocean, cryosphere and sea level*2

Global ocean temperature in the upper 100 m of the oceans is projected to increase by 0.6–2.0 °C by 2100, depending on the emissions scenario. Moreover, heat will penetrate from the surface to the deep ocean and affect circulation. It is very likely that the Atlantic Meridional Overturning Circulation, which includes the Gulf Stream, will weaken, with reductions of 11–34 % projected by 2100 depending on the emissions scenario. However, a collapse, that would significantly alter climatic conditions in north-western Europe, is very unlikely in the 21st century (IPCC, 2013a).

Global warming will lead to further declines in ice, snow and permafrost globally. A nearly ice-free Arctic Ocean in September is likely to be a reality before mid-century under a high-emissions scenario (RCP8.5) while, under all scenarios, there will still be Arctic sea ice in winter throughout the 21st century. Moreover, by 2100 northern hemisphere snow cover is projected to be reduced by 7 % (RCP2.6) to 25 % (RCP8.5), while the area of near-surface permafrost (upper 3.5 m) is projected to diminish by 37 % (RCP2.6) to 81 % (RCP8.5; IPCC, 2013a).

Confidence in estimates of global sea-level rise has increased considerably in recent years. Global mean sea-level rise in the 21st century is projected to be greater than in the 20th century, with an additional rise by 2081–2100 of 0.26–0.55 m under a strong emissions-abatement scenario (RCP2.6) and of 0.52–0.98 m under a high emissions scenario (RCP8.5; Figure 9.7, left; IPCC, 2013b).

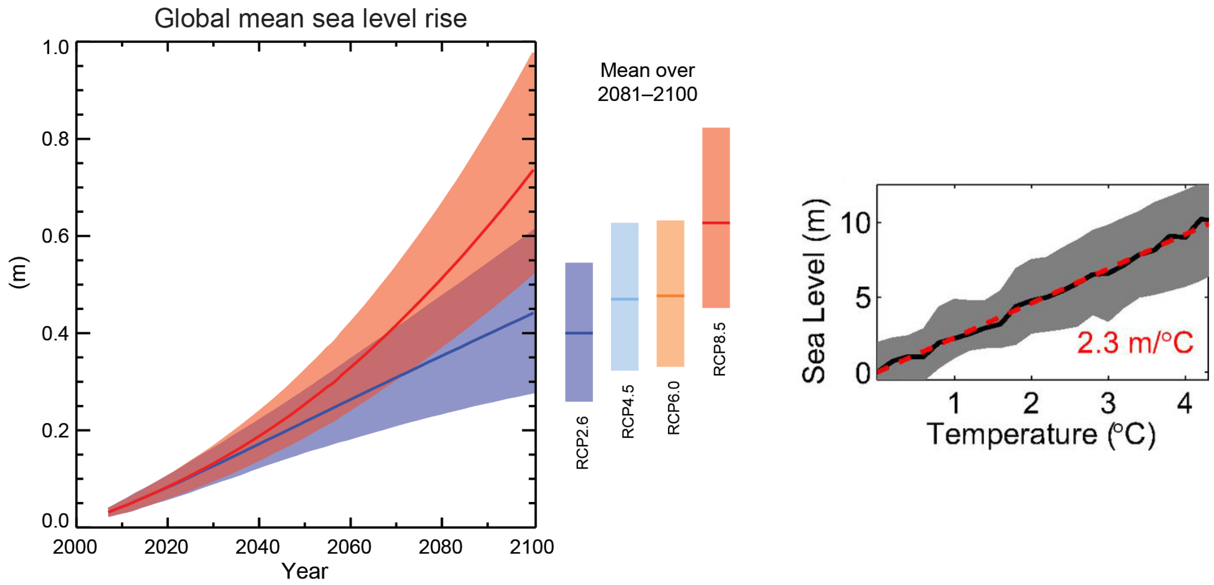
Figure 9.6 Projected changes in hot seasonal temperature extremes over the 21st century under a low emission (RCP2.6, left) and high emission scenario (RCP8.5, right)



Note: This assessment focusses on the occurrence of seasonal (June, July, August; corresponding to the boreal summer) hot temperate extremes. The maps show how frequent a '3-sigma summer' is projected to occur in the period 2071–2100. A 3-sigma event represents an extremely warm 'summer' that would occur only once in 370 years in the absence of climate change. In most world regions, a 3-sigma 'summer' is warmer than any summer experienced in the 20th century. For example, in regions shown in yellow, orange or red, at least every second summer by the end of the 21st century would be warmer than the warmest summer in the 20th century.

Source: Coumou and Robinson, 2013.

Figure 9.7 **Projected change of global mean sea level, 2000–2100 (left) and committed change in global sea level over 2 000 years per degree of warming (right)**



Sources: IPCC, 2013a; Levermann et al., 2013

Sea level will continue to rise for many centuries or even millennia after the climate has stabilized due to the thermal inertia of the deep ocean and a continued melting of glaciers and ice sheets. Even a modest sustained warming of 2 °C above pre-industrial levels is estimated to cause a sea-level rise of at least 4 m over a time horizon of 2 000 years (Figure 9.7, right; Foster and Rohling, 2013; Levermann et al., 2013)global sea level is determined largely by the volume of ice stored on land, which in turn largely reflects the thermal state of the Earth system. Here we use observations from five well-studied time slices covering the last 40 My to identify a well-defined and clearly sigmoidal relationship between atmospheric CO_2 and sea level on geological (near-equilibrium. Very recent research has suggested that a collapse of the West Antarctic ice sheet is inevitable and unstoppable, which alone could cause several metres of sea-level rise over a period of several centuries to a millennium (Joughin et al., 2014; Rignot et al., 2014).

9.3 Implications of climate change

Drawing on a larger scientific knowledge base than ever before, the Intergovernmental Panel on Climate Change (IPCC) concluded in its *Fifth Assessment Report* (IPCC, 2014a) that continued warming increases the likelihood for severe, pervasive and irreversible consequences in most world regions. Moreover, the IPCC provides five integrated reasons for concern, as a framework for evaluating dangerous anthropogenic interference with the climate system:

1. *Unique and threatened systems*. The number of such systems at risk of severe consequences is expected to increase already with additional warming of 1 °C. Some systems such as Arctic sea ice and coral reefs are expected to face very high risks already with an additional warming of 2 °C.

2. *Extreme weather events*. These include heat waves, extreme precipitation and coastal flooding, and are expected to become more frequent with increasing warming.

3. *Distribution of impacts*. Climate-related risks are unevenly distributed, with higher risks for disadvantaged people in countries at all income levels. The risk of further increases in global inequalities is high with additional warming of 2 °C.

4. *Global aggregate impacts*. The overall risks for the Earth's ecosystems and global economy are moderate with additional warming of 1–2 °C, but accelerate as temperatures rise further, leading to high risks at around 3 °C of additional warming.

5. *Large-scale singular events.* There are increased risks of abrupt and irreversible changes that

increase disproportionally as temperatures increase. These risks become high above 3 °C of additional warming (IPCC, 2014c).

The IPCC has published two assessments of these reasons for concern, its *Third* and *Fifth Assessment Reports* (IPCC, 2001, 2014c), concluding in the *Fifth Assessment* that larger risks occur at lower levels of climate change for all reasons for concern (Figure 9.8). In other words, the risks for a given level of climate change are now assessed to be more severe than previously.

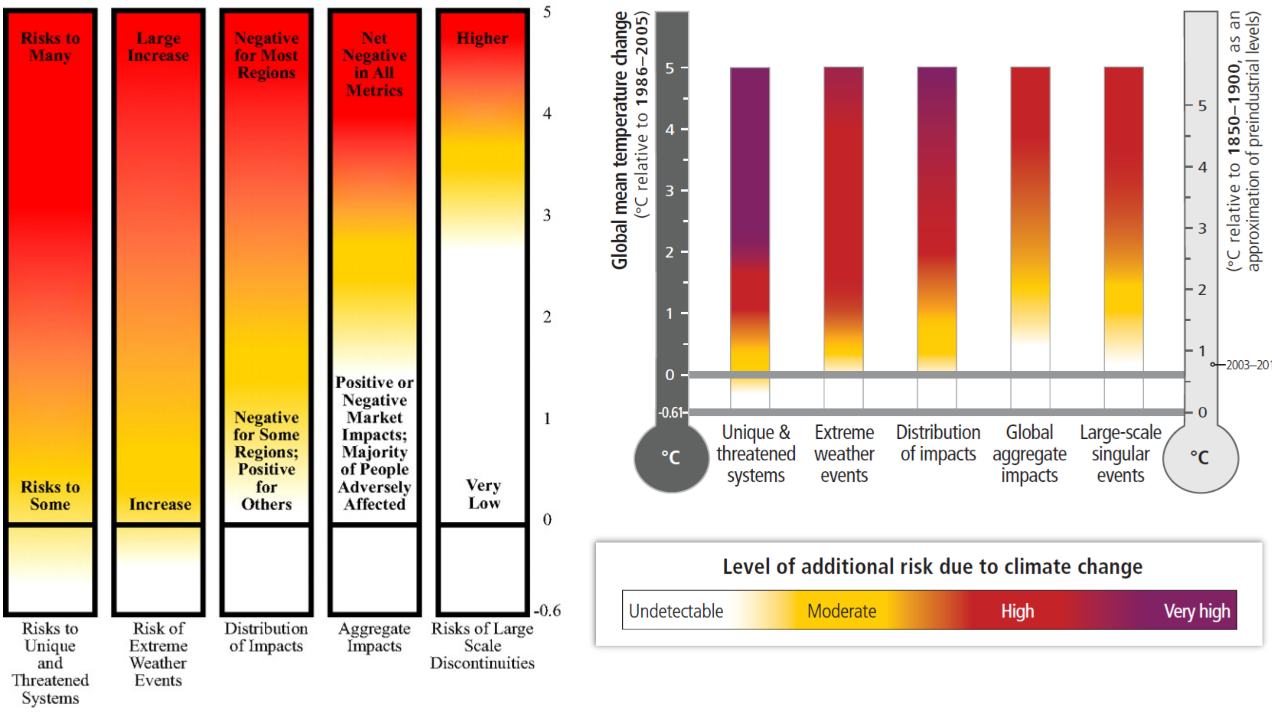
Risk reduction is possible through climate-change mitigation and adaptation. Mitigation is the only way to reduce the risk of large-scale climate change, with action taken now and in the next few decades determining the severity of consequences in the second half of the 21st century and beyond. Side benefits of mitigation, however, such as the reduction of air pollution, could be felt immediately. The benefits of most adaptation actions, such as increasing resilience to reduce the severity of the consequences of climate change, are realized soon after they are taken (EEA, 2013).

Climate change mitigation and adaptation are intertwined with other aspects of sustainable development, in particular biodiversity protection and food and energy security (GMT 8). Examples include land-use conflicts and ecosystem impacts from the expansion of biofuel and hydropower production, water conflicts from expanding irrigation, and increasing energy demand from further application of sea-water desalination and air-conditioning. The development of climate mitigation and adaptation activities needs to consider these interactions in the context of a broader sustainable development policy. A recent study suggests, for example, that with rising populations (GMT 1) and consumption levels (GMTs 2, 5 & 6), there will not be enough land to simultaneously conserve all remaining natural areas, halt forest loss and switch totally to renewable energy (Kraxner et al., 2013).

Natural ecosystems and their services

Terrestrial and freshwater ecosystems are increasingly threatened under all RCP scenarios. A large share of species is very likely to face an increased risk of extinction, with associated losses of biodiversity and ecosystem services, particularly in areas where climate change acts in conjunction with other stressors such as over-exploitation,

Figure 9.8 Changes in the 'reasons for concern' from climate change between the IPCC Third (left) and Fifth (right) Assessments



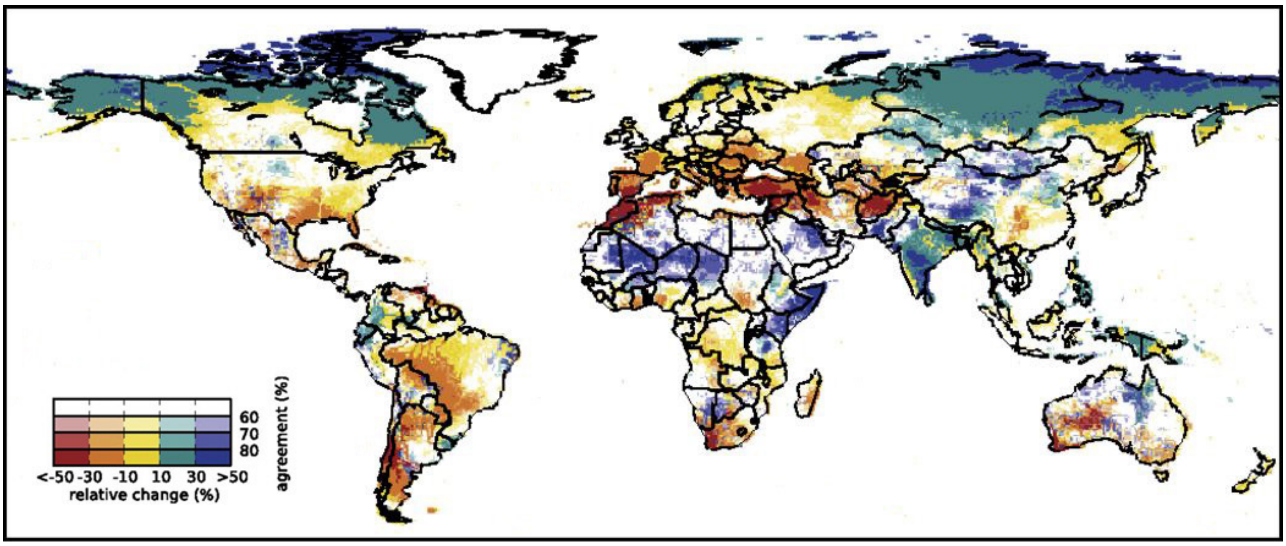
Sources: IPCC, 2001, 2014c.

habitat destruction (GMT 8) or pollution (GMT 10). Rates of climate change expected under medium- to high-emission scenarios (RCP4.5; RCP6.0; RCP8.5) pose high risks of abrupt and irreversible regional-scale changes in the composition, structure and function of ecosystems, including vital ecosystems such as the Amazon forest and Arctic ecosystems. Climate change will also lead to increased colonization by alien plant species in Europe and other world regions. The risk of forest fires, too, will increase in almost all world regions due to warming. In some regions, including in Europe, reduced precipitation is likely to contribute to increased tree mortality and forest dieback. Furthermore, carbon stored in the terrestrial biosphere, in, for example, peatland and permafrost, will be increasingly susceptible to being lost to the atmosphere. This loss occurs predominantly as CH_4, itself a powerful GHG, thereby further exacerbating global climate change (IPCC, 2014c).

Freshwater-related risks are expected to increase significantly, in particular changes in stream flow, water temperature, and water quality. These risks include droughts and subsequent water scarcity on the one hand, and major flood events on the other. While there is still considerable uncertainty for some regions including China, south Asia and large parts of South America, there is a high degree of agreement that average annual runoff will increase at high latitudes and in the wet tropics, but decrease in most dry tropical and subtropical regions (Figure 9.9). In the latter regions, renewable surface-water and groundwater resources are projected to be reduced significantly. Many currently dry regions, such as the Mediterranean, are likely to face an increased frequency of droughts, in particular under a high-emission scenario (RCP8.5). Consequently, increased competition for water among sectors, as well as risks to drinking water quality, are projected even when conventional water treatment is applied (IPCC, 2014c).

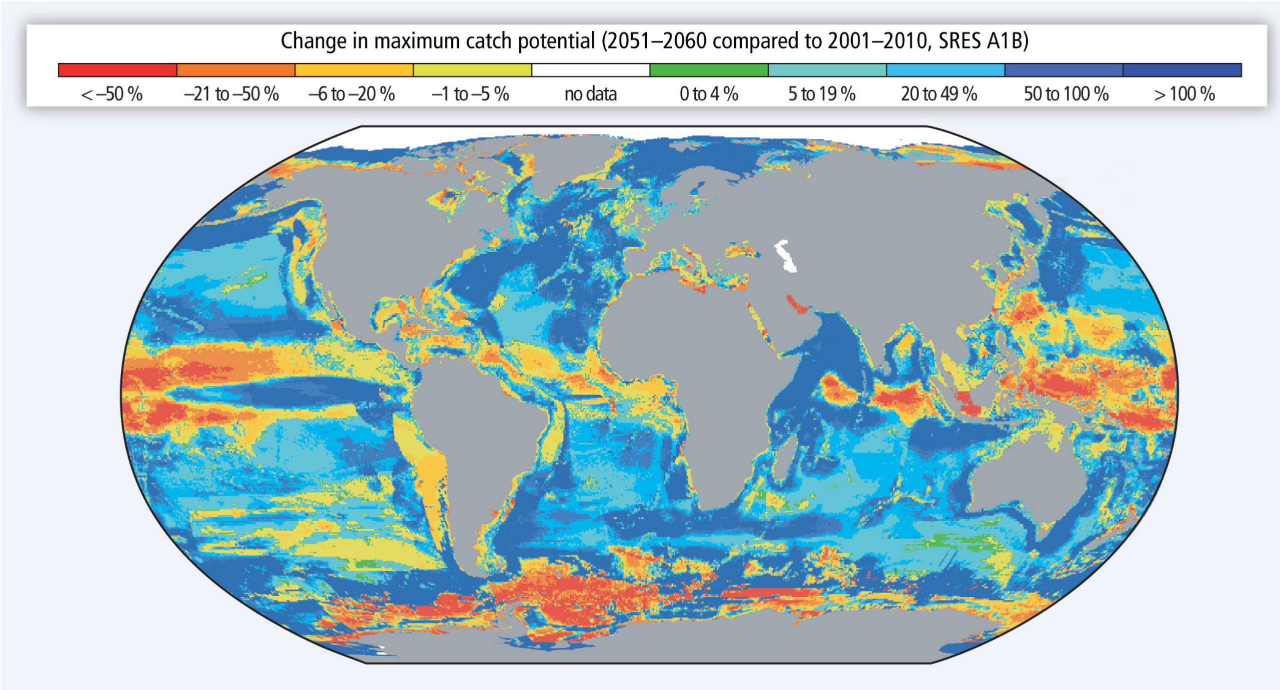
About 27 % [20–35 %] of CO_2 emissions are taken up by the Earth's oceans, thereby turning them sourer (IPCC, 2013a). Marine ecosystems are projected to face substantial risks due to the combined effects of this ocean acidification, ocean warming, changes in salinity and nutrient availability in some regions, and local stressors such as pollution, eutrophication and unsustainable fishing practices (GMT 10). These factors are expected to cause a decline in global marine biodiversity and a global redistribution of marine species that would reduce of the productivity of fisheries and other ecosystem services at tropical latitudes (Figure 9.10), bringing associated adverse implications for human livelihoods. Coral reefs are likely to be particularly affected, and, indeed, the number of coral bleaching events has increased significantly in recent decades. For a medium emissions scenario, almost all coral reefs are projected to experience severe bleaching every decade from 2060 onwards (Figure 9.11), leading to widespread reef mortality, with even stronger impacts expected for high emissions scenarios (IPCC, 2014c).

Figure 9.9 Change of mean annual stream flow for a global mean temperature rise of 2 °C above 1980–2010 (2.7 °C above pre-industrial)



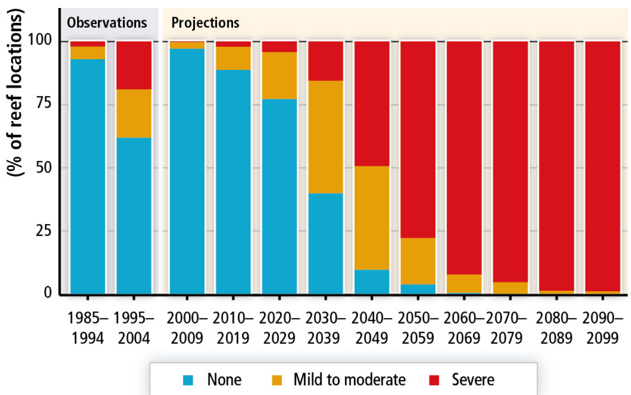
Source: Schewe et al., 2014.

Figure 9.10 Climate change risks for fisheries: projected global redistribution of maximum catch potential of ~ 1 000 exploited fish and invertebrate species, 2001–2010 to 2051–2060



Source: IPCC, 2014c.

Figure 9.11 Observed and projected change in extent of coral bleaching events



Source: IPCC, 2014a.

Coastal ecosystems are very likely to increasingly experience adverse consequences due to the combined effects of sea-level rise, coastal erosion, ocean acidification and human pressures, such as the expansion of settlements and some coastal protection measures (IPCC, 2014c).

Economic activities and human well-being

Many economic and leisure activities, food supply, human well-being and health are already affected and these impacts will intensify as climate change continues. Throughout the 21st century, climate change is projected to slow the rate of economic development, erode food security and increase both inequality and the displacement of people. Risks are unevenly distributed and are greater for disadvantaged people in countries regardless of their country's level of development, although the most severe impacts for economic development and livelihoods are expected in low-income developing countries, especially in Africa. In these and other regions, climate change impacts may also indirectly contribute to an increased risk of violence (IPCC, 2014c), and are expected to increasingly influence national security strategies.

Agricultural activities are significantly affected by changes in climate and CO_2 concentrations, which can lead to both adverse and beneficial impacts. Global agricultural production has experienced some regionally limited gains but mostly losses due to climate change since 1960. Yield projections suggest that local temperature increases of 2 °C or more will have negative impacts on yields of wheat, rice and maize in most temperate and tropical regions.

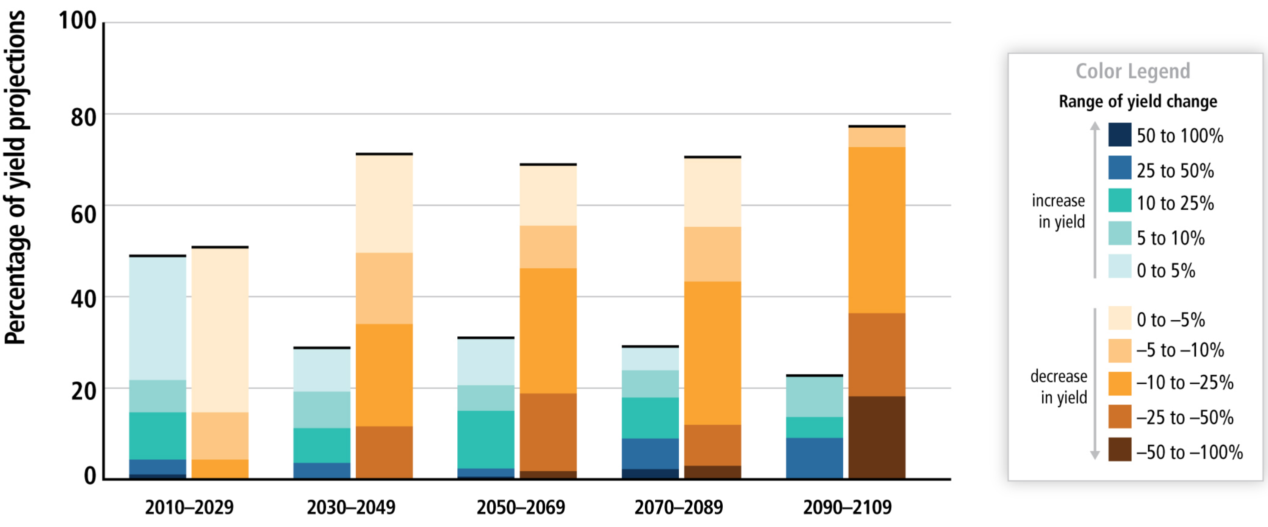
The overall impact on the global food system is expected to be adverse and continue to deteriorate throughout the 21st century (Figure 9.12). Strong global temperature increases of 4 °C or more towards the end of the 21st century, combined with increased food demand due to population growth, would pose significant risks for regional and global food security. Agricultural productivity is particularly threatened in low-latitude areas and in semi-arid regions where currently irrigated areas are projected to face an increased demand for water. Agriculture in the Mediterranean region faces a double stress – from increasing water demand and decreasing water availability (IPCC, 2014c). Increases in atmospheric CO_2 concentrations also directly impact plant growth – elevated levels can increase plant photosynthesis but decrease food quality by inhibiting nitrogen uptake (Bloom et al., 2014).

Human settlements, water supply, industrial facilities and other infrastructure in coastal regions across the world are threatened by sea-level rise. Large coastal cities, settlements in river deltas and on low-lying islands in developing countries are particularly vulnerable – flood losses in 136 major coastal cities around the globe could amount to US$1 trillion or more annually by 2050 unless protection is upgraded (Hallegatte et al., 2013)

Extreme precipitation events are projected to increase further in most regions, including Europe. As a result, more flood damage is considered a key climate-related risk for many cities, also for cities not located in coastal regions. Riverine and urban flooding is of particular concern in many parts of Europe, Australia, North and South America, and Asia. At the other extreme, increased drought stress, associated water restrictions and wildfires are expected in southern Europe, Australia, and parts of Africa, North America and Asia. Recent research suggests that many countries are highly vulnerable financially to extreme weather events and would be unable to cope with their costs without international assistance (Box 9.1).

Human health is expected to be increasingly affected by climate change. There is clear evidence of increased heat-related mortality in many regions over the past decades. Heat stress and related human mortality are of particular concern for urban populations; they have been identified as key climate risks for large parts of Europe as well as parts of Asia and North America. The combination of high temperatures and humidity is expected to compromise normal human activity during some months in many parts of the world by the end of the 21st century under a high emission scenario (RCP8.5). Climate change throughout the 21st century is also expected to increase ill health through greater risks of food- and water-borne diseases and the spread of such vector-borne diseases as tick-borne encephalitis and dengue fever. Developing countries are the most vulnerable but Europe is likely to be increasingly affected (EEA, 2012; IPCC, 2014c; Bouzid et al., 2014).

Figure 9.12 Change in global aggregate crop yields due to climate change considering both low-emission and high-emission scenarios



Source: IPCC, 2014c.

Box 9.1 Can vulnerable countries cope with extreme weather event damage?

The first comprehensive global assessment of public sector costs for dealing with climate-related disaster risk investigated the ability of countries to respond to extreme weather events (Hochrainer-Stigler et al., 2014). The study considered storms, flood and drought events with different likelihoods of occurrence and potential associated costs of recovery in 161 countries around the world. Extreme events that occur relatively often tend to be less destructive, and therefore less costly to recover from, compared with less frequent ones.

The study first calculated the direct risks and public-sector liability for losses. It also calculated the financial vulnerability of the 161 countries and identified the resource gap — between their available funding and the amount required for recovery from events with different recurrence intervals.

The study found that many countries appear fiscally vulnerable and require financial assistance from the donor community to bolster their resilience. According to the estimates, developed countries are generally able to cope with the costs of less destructive events but experience resource gaps for more destructive, less frequent ones. However, 70 out of the 161 countries have resource gaps already for events occurring every 50 years. Fifty-seven of these would be in need of financial assistance already for events occurring every 30 years. The countries with high financial vulnerability are mainly in Africa, the Middle East, and in South and Latin America.

These results are based on current extreme events and assume no further adaptation measures other than those currently in place. However, considering the projected increase in frequency and severity of extreme events throughout the 21st century, costs are expected to rise.

References

Bloom, A., Burger, M., Kimball, B.A. and Pinter, P.J. Jr., 2014. 'Nitrate assimilation is inhibited by elevated CO_2 in field-grown wheat', *Nature Climate Change* 4, 477–480.

Bouzid, M., Colón-González, F.J., Lung, T., Lake, I.R. and Hunter, P.R., 2014, 'Climate change and the emergence of vector-borne diseases in Europe: case study of dengue fever', *BMC Public Health* 14(1), pp. 781.

Coumou, D. and Robinson, A., 2013, 'Historic and future increase in the global land area affected by monthly heat extremes', *Environmental Research Letters* 8(3), pp. 034018.

Cowtan, K. and Way, R.G., 2014, 'Coverage bias in the HadCRUT4 temperature series and its impact on recent temperature trends', *Quarterly Journal of the Royal Meteorological Society* 140, 1 935–1 944.

EEA, 2012, *Climate change, impacts and vulnerability in Europe 2012*, EEA Report No 12/2012. European Environment Agency, Copenhagen, Denmark.

EEA, 2013, *Adaptation in Europe — Addressing risks and opportunities from climate change in the context of socio-economic developments*, EEA Report No 3/2013, European Environment Agency, Copenhagen, Denmark.

England, M.H., McGregor, S., Spence, P., Meehl, G.A., Timmermann, A., Cai, W., Gupta, A.S., McPhaden, M.J., Purich, A. and Santoso, A., 2014, 'Recent intensification of wind-driven circulation in the Pacific and the ongoing warming hiatus', *Nature Climate Change* 4(3), 222–227.

Foster, G. L. and Rohling, E.J., 2013, 'Relationship between sea level and climate forcing by CO_2 on geological timescales', *Proceedings of the National Academy of Sciences* 110(4), 1 209–1 214.

Hallegatte, S., Green, C., Nicholls, R.J. and Corfee-Morlot, J., 2013, 'Future flood losses in major coastal cities', *Nature Climate Change* 3(9), 802–806.

Hochrainer-Stigler, S., Mechler, R., Pflug, G. and Williges, K., 2014, 'Funding public adaptation to climate-related disasters', Estimates for a global fund. *Global Environmental Change* 25, 87–96.

IPCC, 2001, *Climate Change 2001: Synthesis Report. A contribution of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

IPCC, 2013a, *Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

IPCC, 2013b, *Technical Summary. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

IPCC, 2014a, *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

IPCC, 2014b, *Summary for Policymakers, In: Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

IPCC, 2014c, *Summary for Policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

IPCC, 2014d, *Technical Summary. In: Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Joughin, I., Smith, B.E. and Medley, B., 2014, 'Marine Ice Sheet Collapse Potentially Under Way for the Thwaites Glacier Basin, West Antarctica', *Science* 344(6185), 735–738.

Kraxner, F., Nordström, E-M., Havlík, P., Gusti, M., Mosnier, A., Frank, S., Valin, H., Fritz, S., Fuss, S., Kindermann, G., McCallum, I., Khabarov, N., Böttcher, H., See, L., Aoki, K., Schmid, E., Máthé, L. and Obersteiner, M., 2013, 'Global bioenergy scenarios — Future forest development, land-use implications, and trade-offs', *Biomass and Bioenergy* 57, 86–96.

Levermann, A., Clark, P.U., Marzeion, B., Milne, G. A., Pollard, D., Radic, V. and Robinson, A., 2013, 'The multimillennial sea-level commitment of global warming', *Proceedings of the National Academy of Sciences* 110(34), 13745–13750.

Levitus, S., Antonov, J.I., Boyer, T.P., Baranova, O.K., Garcia, H.E., Locarnini, R.A., Mishonov, A.V., Reagan, J.R., Seidov, D., Yarosh, E.S. and Zweng, M.M., 2012, 'World ocean heat content and thermosteric sea level change (0–2000 m), 1955–2010', *Geophysical Research Letters* 39(10).

NAS and RS, 2014, *Climate Change, Evidence and Causes*. National Academy of Science of the United States of America, Washington, DC, US and the Royal Society, London, UK.

Rignot, E., Mouginot, J., Morlighem, M., Seroussi, H. and Scheuchl, B., 2014, 'Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith, and Kohler glaciers, West Antarctica, from 1992 to 2011', *Geophysical Research Letters* 41(10), 3 502–3 509.

Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N.W., Clark, D.B., Dankers, R., Eisner, S., Fekete, B.M., Colón-González, F.J., Gosling, S.N., Kim, H., Liu, X., Masaki, Y., Portmann, F.T., Satoh, Y., Stacke, T., Tang, Q., Wada, Y. et al., 2014, 'Multimodel assessment of water scarcity under climate change', *Proceedings of the National Academy of Sciences* 111(9), 3 245–3 250.

Van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S.J. and Rose, S.K., 2011, 'The representative concentration pathways: an overview', *Climatic Change* 109(1-2), 5–31.

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99

Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

Publications Office

European Environment Agency