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# Turn Down the Heat

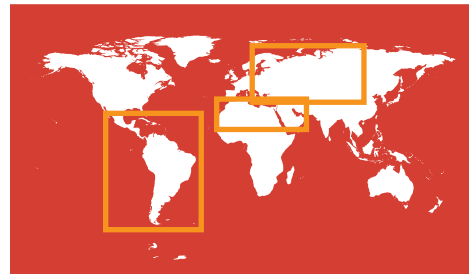
## Confronting the New Climate Normal



4°

Turn Down  
the Heat

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the New Climate Normal



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# Acknowledgments

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## Foreword

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Dramatic climate changes and weather extremes are already affecting millions of people around the world, damaging crops and coastlines and putting water security at risk.

Across the three regions studied in this report, record-breaking temperatures are occurring more frequently, rainfall has increased in intensity in some places, while drought-prone regions like the Mediterranean are getting dryer. A significant increase in tropical North Atlantic cyclone activity is affecting the Caribbean and Central America.

There is growing evidence that warming close to 1.5°C above pre-industrial levels is locked-in to the Earth's atmospheric system due to past and predicted emissions of greenhouse gases, and climate change impacts such as extreme heat events may now be unavoidable.

As the planet warms, climatic conditions, heat and other weather extremes which occur once in hundreds of years, if ever, and considered highly unusual or unprecedented today would become the “new climate normal” as we approach 4°C—a frightening world of increased risks and global instability.

The consequences for development would be severe as crop yields decline, water resources change, diseases move into new ranges, and sea levels rise. Ending poverty, increasing global prosperity and reducing global inequality, already difficult, will be much harder with 2°C warming, but at 4°C there is serious doubt whether these goals can be achieved at all.

For this report, the third in the *Turn Down the Heat* series, we turned again to the scientists at the Potsdam Institute for Climate Impact Research and Climate Analytics. We asked them to look at the likely impacts of present day (0.8°C), 2°C and 4°C warming on agricultural production, water resources, cities and ecosystems across Latin America and the Caribbean, Middle East and North Africa, and parts of Europe and Central Asia.

Their findings are alarming.

In Latin America and the Caribbean, heat extremes and changing precipitation patterns will have adverse effects on agricultural productivity, hydrological regimes and biodiversity. In Brazil, at 2°C warming, crop yields could decrease by up to 70 percent for soybean and up to 50 percent for wheat. Ocean acidification, sea level rise, tropical cyclones and temperature changes will negatively impact coastal livelihoods, tourism, health and food and water security, particularly in the Caribbean. Melting glaciers would be a hazard for Andean cities.

In the Middle East and North Africa, a large increase in heat-waves combined with warmer average temperatures will put intense pressure on already scarce water resources with major consequences for regional food security. Crop yields could decrease by up to 30 percent at 1.5–2°C and by almost 60 percent at 3–4°C. At the same time, migration and climate-related pressure on resources might increase the risk of conflict.

In the Western Balkans and Central Asia, reduced water availability in some places becomes a threat as temperatures rise toward 4°C. Melting glaciers in Central Asia and shifts in the timing of water flows



will lead to less water resources in summer months and high risks of torrential floods. In the Balkans, a higher risk of drought results in potential declines for crop yields, urban health, and energy generation. In Macedonia, yield losses are projected of up to 50 percent for maize, wheat, vegetables and grapes at 2°C warming. In northern Russia, forest dieback and thawing of permafrost threaten to amplify global warming as stored carbon and methane are released into the atmosphere, giving rise to a self-amplifying feedback loop.

*Turn Down the Heat: Confronting the New Climate Normal* builds on our 2012 report, which concluded the world would warm by 4°C by the end of this century with devastating consequences if we did not take concerted action now. It complements our 2013 report that looked at the potential risks to development under different warming scenarios in Sub-Saharan Africa, South East Asia and South Asia, and which warned that we could experience a 2°C world in our lifetime.

Many of the worst projected climate impacts outlined in this latest report could still be avoided by holding warming below 2°C. But, this will require substantial technological, economic, institutional and behavioral change. It will require leadership at every level of society.

Today the scientific evidence is overwhelming, and it's clear that we cannot continue down the current path of unchecked, growing emissions. The good news is that there is a growing consensus on what it will take to make changes to the unsustainable path we are currently on.

More and more voices are arguing that is possible to grow greener without necessarily growing slower. Today, we know that action is urgently needed on climate change, but it does not have to come at the expense of economic growth. We need smart policy choices that stimulate a shift to clean public transport and energy efficiency in factories, buildings and appliances can achieve both growth and climate benefits.

This last report in the *Turn Down the Heat* series comes at a critical moment. Earlier this year, the UN Secretary General's Climate Summit unleashed a new wave of optimism. But our reports make clear that time is of the essence.

Governments will gather first in Lima and then Paris for critical negotiations on a new climate treaty. Inside and outside of the conference halls, global leaders will need to take difficult decisions that will require, in some instances, short term sacrifice but ultimately lead to long term gains for all.

At the World Bank Group we will use our financial capacity to help tackle climate change. We will innovate and bring forward new financial instruments. We will use our knowledge and our convening power. We will use our evidence and data to advocate and persuade. In short, we will do everything we can to help countries and communities build resilience and adapt to the climate impacts already being felt today and ensure that finance flows to where it is most needed.

Our response to the challenge of climate change will define the legacy of our generation. The stakes have never been higher.

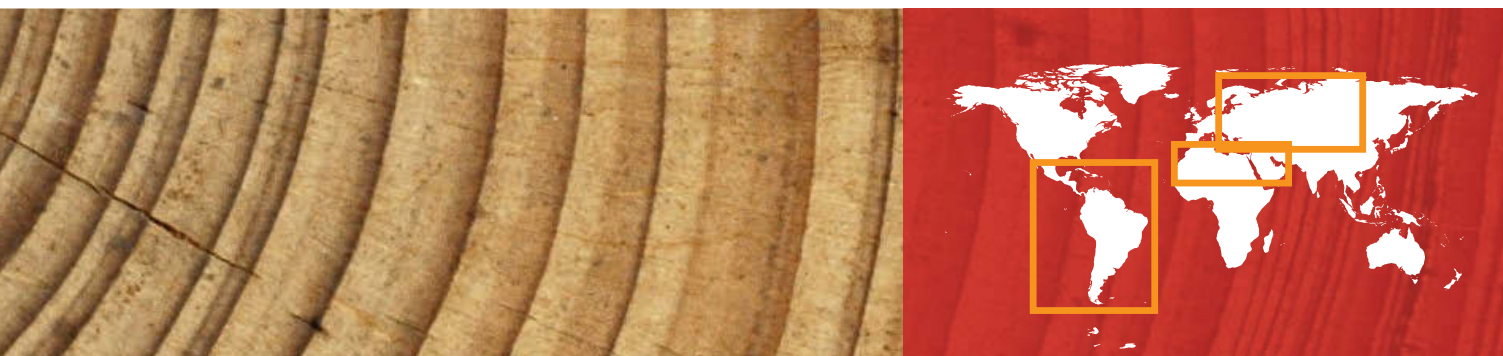


Dr. Jim Yong Kim  
President, World Bank Group



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# Executive Summary



## Executive Summary

The data show that dramatic climate changes, heat and weather extremes are already impacting people, damaging crops and coastlines and putting food, water, and energy security at risk. Across the three regions studied in this report, record-breaking temperatures are occurring more frequently, rainfall has increased in intensity in some places, while drought-prone regions are getting dryer. In an overview of social vulnerability, the poor and underprivileged, as well as the elderly and children, are found to be often hit the hardest. There is growing evidence, that even with very ambitious mitigation action, warming close to 1.5°C above pre-industrial levels by mid-century is already locked-in to the Earth's atmospheric system and climate change impacts such as extreme heat events may now be unavoidable.<sup>1</sup> If the planet continues warming to 4°C, climatic conditions, heat and other weather extremes considered highly unusual or unprecedented today would become the new climate normal—a world of increased risks and instability. The consequences for development would be severe as crop yields decline, water resources change, diseases move into new ranges, and sea levels rise. The task of promoting human development, of ending poverty, increasing global prosperity, and reducing global inequality will be very challenging in a 2°C world, but in a 4°C world there is serious doubt whether this can be achieved at all. Immediate steps are needed to help countries adapt to the climate impacts being felt today and the unavoidable consequences of a rapidly warming world. The benefits of strong, early action on climate change, action that follows clean, low carbon pathways and avoids locking in unsustainable growth strategies, far outweigh the costs. Many of the worst projected climate impacts could still be avoided by holding warming to below 2°C. But, the time to act is now.

This report focuses on the risks of climate change to development in Latin America and the Caribbean, the Middle East and North Africa, and parts of Europe and Central Asia. Building on earlier *Turn Down the Heat* reports this new scientific analysis examines the likely impacts of present day (0.8°C), 2°C and 4°C warming above pre-industrial temperatures on agricultural production, water resources, ecosystem services and coastal vulnerability for affected populations.

### Scope of the Report

This third report in the *Turn Down the Heat* series<sup>2</sup> covers three World Bank regions: Latin America and the Caribbean (LAC); the Middle East and North Africa (MENA); and parts of Europe and

Central Asia (ECA).<sup>3</sup> The focus is on the risks of climate change to development. While covering a range of sectors, special attention is paid to projected impacts on food and energy systems, water resources, and ecosystem services. The report also considers the social vulnerability that could magnify or moderate the climate

<sup>1</sup> Holding warming to below 2°C and bringing warming back to 1.5°C by 2100 is technically and economically feasible but implies stringent mitigation over the short term. While IPCC AR5 WGIII identified many mitigation options to hold warming below 2°C with a *likely* chance, and with central estimates of 1.5–1.7°C by 2100, only “a limited number of studies have explored scenarios that are *more likely than not* to bring temperature change back to below 1.5°C by 2100”. The scenarios in these studies are “characterized by (1) immediate mitigation action; (2) the rapid upscaling of the full portfolio of mitigation technologies; and (3) development along a low-energy demand trajectory”.

<sup>2</sup> *Turn Down the Heat: Why a 4°C Warmer World Must Be Avoided*, launched by the World Bank in November 2012; and *Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience*, launched by the World Bank in June 2013 constitute the first two reports.

<sup>3</sup> The World Bank Europe and Central Asia region in this report includes only the following countries: Albania, Bosnia and Herzegovina, Kazakhstan, Kosovo, the Kyrgyz Republic, the former Yugoslav Republic of Macedonia, Montenegro, the Russian Federation, Serbia, Tajikistan, Turkmenistan, and Uzbekistan.

change repercussions for human well-being. The report complements the first *Turn Down the Heat* report (2012) that offered a global overview of climate change and its impacts in a 4°C world<sup>4</sup> and concluded that impacts are expected to be felt disproportionately in developing countries around the equatorial regions. Also, it extends the analysis in the second report (2013) that focused on the consequences of climate change for present day, 2°C, and 4°C warming above pre-industrial levels in Sub-Saharan Africa, South Asia, and South East Asia and demonstrated the potential of early onset of impacts at lower levels of warming.

This analysis draws on the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) Working Group reports released in 2013 and 2014, as well as peer-reviewed literature published after the cutoff dates for AR5. The few cases where there are significant differences in interpretation of projected impacts from the IPCC assessments (such as for sea-level rise and El Niño) are highlighted and explained.

## The Global Picture

This report reaffirms earlier assessments, including the IPCC AR5 and previous *Turn Down the Heat* reports, that in the absence of near-term mitigation actions and further commitments to reduce emissions the likelihood of 4°C warming being reached or exceeded this century has increased. Under current policies there is about a 40 percent chance of exceeding 4°C by 2100 and a 10 percent chance of exceeding 5°C.<sup>5</sup> However, many of the worst projected climate impacts in this report could still be avoided by holding warming below 2°C.

## Selected Key Findings from Across the Regions

At the current level of 0.8°C warming above pre-industrial levels, adverse impacts of climate change have already been observed. Examples include:

- Extreme heat events are occurring more frequently. The occurrence of record-breaking monthly mean temperatures has been attributed to climate change with 80 percent probability.

<sup>4</sup> In this report, as in the previous two reports, “a 4°C world” and “a 2°C world” is used as shorthand for warming reaching 4°C or 2°C above pre-industrial levels by the end of the century. It is important to note that, in the case of 4°C warming, this does not imply a stabilization of temperatures nor that the magnitude of impacts is expected to peak at this level. Because of the slow response of the climate system, the greenhouse gas emissions and concentrations that would lead to warming of 4°C by 2100 and associated higher risk of thresholds in the climate system being crossed, would actually commit the world to much higher warming, exceeding 6°C or more in the long term with several meters of sea-level rise ultimately associated with this warming. A 2°C world implies stabilization at this level beyond 2100.

<sup>5</sup> IEA (2012) World Energy Outlook 2012. This was reported in the second *Turn Down the Heat* report.

## Box 1: The Case for Immediate Action

**CO<sub>2</sub> emissions continue unabated.** Current warming is at 0.8°C above pre-industrial levels. CO<sub>2</sub> emissions are now 60 percent higher than in 1990, growing at about 2.5 percent per year. If emissions continue at this rate, atmospheric CO<sub>2</sub> concentrations in line with a likely chance of limiting warming to 2°C would be exceeded within just three decades.

**Observed impacts and damages.** Widespread, recently observed impacts on natural and human systems confirm the high sensitivity of many of these systems to warming and the potential for substantial damage to occur at even low levels of warming. Examples include negative impacts on crop yields, the accelerating loss of ice from Antarctica and Greenland, and widespread bleaching of coral reefs. The physical effects of warming to 1.5°C, such as extreme heat events, may be unavoidable.

**21st-century projected impacts.** The projected impacts for the 21st century confirm the scale of the risk to development at 2°C—and the severe consequences of exceeding this level of warming. Even at warming of 1.5°C–2°C, significant, adverse risks are projected for a number of regions and systems, such as the potential for the complete loss of existing long-lived coral reefs, associated marine biodiversity and the livelihoods from tourism and fishing.

**Multi-century consequences of 21st-century emissions.** Scientific evidence is growing of the multi-century consequences of CO<sub>2</sub> and other greenhouse gas emissions. Examples include: ‘locking-in’ a long-term sea-level rise of about two meters per degree Celsius of sustained global mean warming and a multi-century ocean acidification with wide-ranging adverse consequences on coral reefs, marine ecology, and ultimately the planet.

**Risk of large-scale, irreversible changes in the Earth’s biomes and ecosystems.** Large scale, irreversible changes in the Earth’s systems have the potential to transform whole regions. Examples of risks that are increasing rapidly with warming include degradation of the Amazon rainforest with the potential for large emissions of CO<sub>2</sub> due to self-amplifying feedbacks, disintegration of the Greenland and Antarctic ice sheets with multi-meter sea-level rise over centuries to millennia, and large-scale releases of methane from melting permafrost substantially amplifying warming. Recent peer reviewed science shows that a substantial part of the West Antarctic ice sheet, containing about one meter of sea-level rise equivalent in ice, is now in irreversible, unstable retreat.

**Rapidly closing window for action.** The buildup of carbon intensive, fossil-fuel-based infrastructure is locking us into a future of CO<sub>2</sub> emissions. The International Energy Agency (IEA) has warned, and numerous energy system modelling exercises have confirmed, that unless urgent action is taken very soon, it will become extremely costly to reduce emissions fast enough to hold warming below 2°C.

- Extreme precipitation has increased in frequency and intensity in many places.
- A robust drying trend has been observed for already drought-prone regions such as the Mediterranean.
- A significant increase in tropical North Atlantic cyclone activity has been observed and is affecting the Caribbean and Central America.

Under future climate change scenarios *projected impacts* include:

1. **Highly unusual and unprecedented heat extremes:** State-of-the-art climate modeling shows that extreme heat events increase not only in frequency but also impact a larger area of land under unabated warming. The prevalence of *highly unusual* and *unprecedented* heat extremes increases rapidly under an emissions pathway associated with a 4°C world.<sup>6</sup> *Highly unusual* heat extremes are similar to those experienced in Russia and Central Asia in 2010 and the United States in 2012 and *unprecedented* heat extremes refer to events essentially absent under present day climate conditions. *Unprecedented* heat extremes would likely remain largely absent in a 2°C world but in a 4°C world, could affect 70–80 percent of the land area in the Middle East and North Africa and Latin America and the Caribbean and approximately 55 percent of the land area in the parts of Europe and Central Asia assessed in this report.
2. **Rainfall regime changes and water availability:** Precipitation changes are projected under continued warming with substantial, adverse consequences for water availability. Central America, the Caribbean, the Western Balkans, and the Middle East and North Africa stand out as hotspots where precipitation is projected to decline 20–50 percent in a 4°C world. Conversely, heavy precipitation events are projected to intensify in Central and Eastern Siberia and northwestern South America with precipitation intensity increasing by around 30 percent and flooding risks increasing substantially in a 4°C world.
  - In the Western Balkans and Central Asia, water availability becomes a threat as temperatures rise toward

<sup>6</sup> In this report, *highly unusual* heat extremes refer to 3-sigma events and *unprecedented* heat extremes to 5-sigma events. In general, the standard deviation (sigma) shows how far a variable tends to deviate from its mean value, which in this report refers to the possible year-to-year changes in local monthly temperature because of natural variability. For a normal distribution, 3 sigma events have a return time of 740 years. Monthly temperature data do not necessarily follow a normal distribution (for example, the distribution can have long tails, making warm events more likely) and the return times can be different but will be at least 100 years. Nevertheless, 3-sigma events are extremely unlikely and 4-sigma events almost certainly have not occurred over the lifetime of key infrastructure. A warming of 5 sigma means that the average change in the climate is 5 times larger than the normal year-to-year variation experienced today, and has a return period of several million years. These events, which have almost certainly never occurred to date, are projected for the coming decades.

4°C. With earlier glacier melt in Central Asia shifting the timing of water flows, and a higher risk of drought in the Balkans, this carries consequences for crop yields, urban health, and energy generation. In Macedonia, for example, there could be yield losses of up to 50 percent for maize, wheat, vegetables and grapes at 2°C warming. Flood risk is expected to increase slightly along the Danube, Sava and Tisza rivers.

3. **Agricultural yields and food security:** Significant crop yield impacts are already being felt at 0.8°C warming, and as temperatures rise from 2°C to 4°C, climate change will add further pressure on agricultural systems.
  - The risks of reduced crop yields and production losses increase rapidly above 1.5°–2°C warming. In the Middle East and North Africa and the Latin America and the Caribbean regions, without further adaptation actions, strong reductions in potential yield are projected for around 2°C warming. For example, a 30–70 percent decline in yield for soybeans and up to 50 percent decline for wheat in Brazil, a 50 percent decrease for wheat in Central America and the Caribbean, and 10–50 percent reduction for wheat in Tunisia. Projected changes in potential crop yields in Central Asia are uncertain at around 2°C warming. Increasing droughts and flooding events represent a major risk for agriculture in the Western Balkans.
  - While adaptation interventions and CO<sub>2</sub> fertilization may compensate for some of the adverse effects of climate change below 2°C warming, this report reaffirms the findings of the IPCC AR5 that under 3–4°C warming large negative impacts on agricultural productivity can be expected. There is some empirical evidence that, despite possible positive CO<sub>2</sub> fertilization effects leading to increased productivity, higher atmospheric levels of carbon dioxide could result in lowered protein and micronutrient (iron and zinc) levels of some major grain crops (e.g., wheat and rice).
  - The projected impacts on subsistence and export crops production systems (e.g., soybeans, maize, wheat, and rice) would be felt at the local, national, and global levels. While global trade can improve food security and protect against local shocks, there is a possibility for some regions to become over dependent on food imports and thus more vulnerable to weather events in other world regions and to the interruption of imports because of export bans in those regions.
4. **Terrestrial Ecosystems:** Ecosystem shifts are projected with increasing temperatures and changes in precipitation patterns significantly diminishing ecosystem services. This would

have major repercussions on, for example, the global carbon cycle. For example:

- Projected increases in heat and drought stress, together with continuing deforestation, substantially increase the risk of large-scale forest degradation (reduction in forest biomass and area) in the Amazon rainforest. This could turn this carbon sink of global importance into a source of carbon; this has already been observed as a consequence of the severe droughts in 2005 and 2010 when scientists estimated that the Amazon faced a decrease in carbon storage of approximately 1.6 Pg carbon (2005) and 2.2 Pg carbon (2010) compared to non-drought years.<sup>7</sup>
- Russia's permafrost regions and boreal forests are sensitive to changes in temperature that could lead to productivity increases. But there is a risk of increasing disturbances, such as fires and pests, leading to widespread tree mortality. Forest dieback and thawing of permafrost threaten to amplify global warming as stored carbon and methane are released into the atmosphere, giving rise to a self-amplifying feedback loop. With a 2°C warming, methane emissions from permafrost thawing could increase by 20–30 percent across boreal Russia.

5. **Marine ecosystems:** Substantial, adverse effects on marine ecosystems and their productivity are expected with rising temperatures, increases in ocean acidity, and likely reductions in available oxygen due to their combined effects. Observed rates of ocean acidification are already the highest in 300 million years and rates of sea level rise are the highest for 6,000 years.

Projections of coral bleaching indicate that preserving more than 10 percent of these unique ecosystems calls for limiting global warming to 1.5°C. Reef-building corals are critical for beach formation, coastal protection, fisheries, and tourism.

Physiological changes to fish and fish larvae have been observed and are expected with future ocean acidification. Below 2°C warming and without taking into account changes in ocean acidity, fishery catches in a number of locations are projected to markedly decrease by 2050 as fish populations migrate towards cooler waters.

6. **Sea-level rise:** In a 1.5°C world sea level rise is projected to increase by 0.36 m (range of 0.20 m to 0.60 m) and by 0.58 m (range of 0.40 m to 1.01 m) in a 4°C world for the period

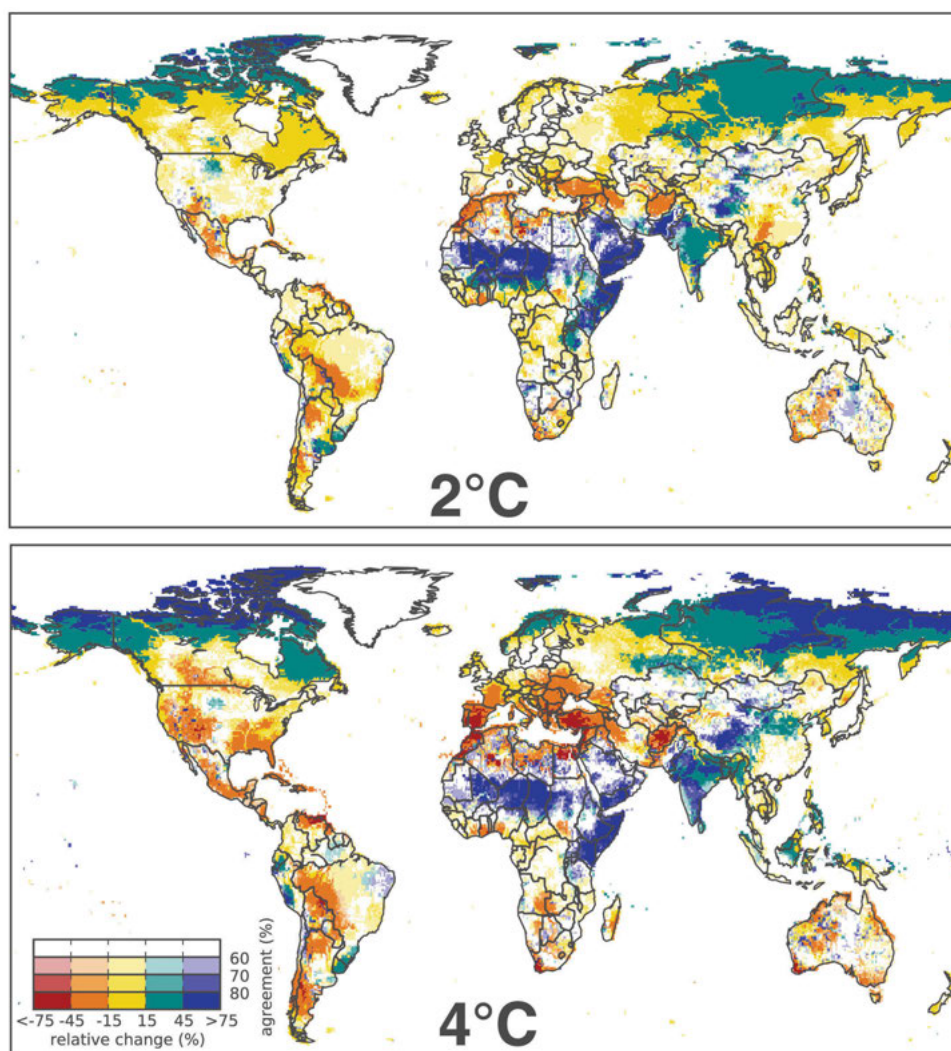
2081–2100 compared to the reference period 1986–2005.<sup>8</sup> Due to the time lag in the oceans' response and the long response time of the Greenland and Antarctic ice sheets to atmospheric temperatures (thermal inertia) sea levels will continue to rise for many centuries beyond 2100.

- Sea-level rise poses a particular threat to urban communities in the Middle East and North Africa and Latin America and the Caribbean, where large urban settlements and important infrastructure are situated along coastlines. The impact of rising sea levels will be particularly severe for the Caribbean island communities as possibilities for retreat are extremely limited. Rising sea levels will substantially increase the risk posed by storm surges and tropical cyclones, in particular for highly exposed small island states and low-lying coastal zones. In addition, rising sea levels could contribute to increased salt-water intrusion in freshwater aquifers (particularly in the Middle East and North Africa), a process made worse by other climate impacts (e.g., reduction in water availability) and other human-induced drivers (e.g., resource overuse).
7. **Glaciers:** A substantial loss of glacier volume and extent has been observed under current levels of warming in the Andes and Central Asia. Increasing glacial melt poses a high risk of flooding and severely reduces freshwater resources during crop growing seasons. It can also have negative impacts on hydropower supply.
- Tropical glaciers in the Central Andes have lost large amounts of ice volume throughout the 20th century and complete deglaciation is projected in a 4°C world. In Peru it is estimated that a 50 percent reduction in glacier runoff would result in a decrease in annual power output of approximately 10 percent, from 1540 gigawatt hours (GWh) to 1250 GWh.
  - Since the 1960s Central Asian glaciers have reduced in area by 3–14 percent depending on their location. Further substantial losses of around 50 percent and up to 80 percent are projected for a 2°C and a 4°C world respectively. As a result, river flows are expected to shrink

<sup>7</sup> The change in carbon sequestration is caused by the combined effects of reduced uptake of carbon resulting from suppressed tree growth due to the drought, and loss of carbon due to drought induced tree mortality and decomposition over several years.

<sup>8</sup> The sea-level projections presented here follow the methodology adopted in the IPCC AR5 WGI with the important update that more realistic scenario-dependent contributions from Antarctica based on post-IPCC literature are included. Recent publications suggest that IPCC estimates are conservative given the observed destabilization of parts of the West Antarctic Ice Sheet. Note that the regional projections given in this report are also based on this adjustment to the AR5 WGI methodology and do not include land subsidence. Sea-level rise projections presented in this report are based on a larger model ensemble with an ensemble mean warming of less than 1.75°C; as a result, end-of-century sea-level rise in RCP2.6 is classified as 1.5° warming. See Box 2.1 and Section 6.2, Sea-Level Rise Projections for further explanation.

**Figure 1:** Water resources: Relative change in annual discharge for a 2°C and a 4°C world in the 2080s relative to the 1986–2005 period based on an ISI-MIP model inter-comparison.



Colors indicate the multi-model mean change; the saturation of colors indicates the agreement across the model ensemble. More saturated colors indicate higher model agreement. Source: Adjusted from Schewe et al. (2013).

- by 25 percent at around 3°C warming during the summer months when water demand for agriculture is highest.
  - In Central Asia hydropower generation has the potential to play a major role in the future energy mix however the predicted changes in runoff distribution will mean that there will be less water available for energy generation in summer months when it will compete with demands from agriculture.
8. **Social Vulnerability to Climate Change.** The social impacts of climate change are hard to predict with certainty as they depend on climatic factors and their interaction with wider development trends. However, there is clear evidence that climate change is already affecting livelihoods and wellbeing in parts of the three regions and is likely to do so to a significantly greater extent if more extensive climate change occurs (Box 2). Where governance is weak, or infrastructure



## Box 2: Social Vulnerability Impacts of Climate Change

**Shocks and stresses related to climate change can undermine poverty reduction and push new groups into poverty.** Informal settlements on flood plains and steep hillsides in many Latin American cities and the Western Balkans, for example, have been severely affected by floods and landslides in recent years. While many poor people will be living in isolated, rural areas, continued urban expansion into hazard-prone areas means that a growing proportion of urban populations will be at risk of climate-related extreme events and rising food prices, and thus of increasing poverty levels among urban groups.

**The impacts of climate change will often be most severely felt by poor and socially excluded groups, whose capacity to adapt to both rapid- and slow-onset climate change is more limited.** These include indigenous people and ethnic minorities, migrant workers, women, girls, older people, and children. Although these groups—like their more advantaged counterparts—are already adapting to climatic and other changes, these efforts are often undermined by their limited assets, lack of voice, and discriminatory social norms. For example, increasing water stress, projected for parts of Latin America and low-income Middle East and North Africa countries, can dramatically increase the labor burden associated with fetching water in rural and poor urban environments; and child malnutrition linked to climate change reducing protein and micronutrient contents of staple foods (wheat, rice) could have irreversible, negative life-time consequences for affected children.

**Climate change may lead to displacement and also affect patterns and rates of migrations.** Most displacement related to extreme weather events has, to date, been temporary. However, if climate change renders certain areas uninhabitable (for example, if they become too hot, too dry, or too frequently affected by extreme events—or sea-level rise) such migration may increase in scale and more often lead to permanent resettlement (as already being seen in some water-scarce parts of MENA). Large-scale migration may pose significant challenges for family relations, health, and human security. There is a risk of disadvantaged groups being trapped in adversely affected rural areas as they lack the funds and/or social connections to move.

outdated or insufficient (as in parts of all three regions), this is likely to amplify the social challenges associated with adapting to further climate change.

## Latin America and the Caribbean

The Latin American and the Caribbean (LAC) region is highly heterogeneous in terms of economic development and social and indigenous history with a population of 588 million (2013), of which almost 80 percent is urban. The current GDP is estimated at \$5.655 trillion (2013) with a per capita GNI of \$9,314 in 2013. In 2012, approximately 25 percent of the population was living in poverty and 12 percent in extreme poverty, representing a clear decrease compared to earlier years. Undernourishment in the region, for example, declined from 14.6 percent in 1990 to 8.3 percent in 2012. Despite considerable economic and social development progress in past decades, income inequality in the region remains high.

At the current 0.8°C warming significant impacts of climate change are being felt throughout the LAC region's terrestrial (e.g. Andean mountains and rainforests) and marine (especially the coral reefs) biomes. As global mean temperatures rise to 2°C and beyond the projected intensity and severity of impacts will increase across the entire region (three significant impacts are described below).

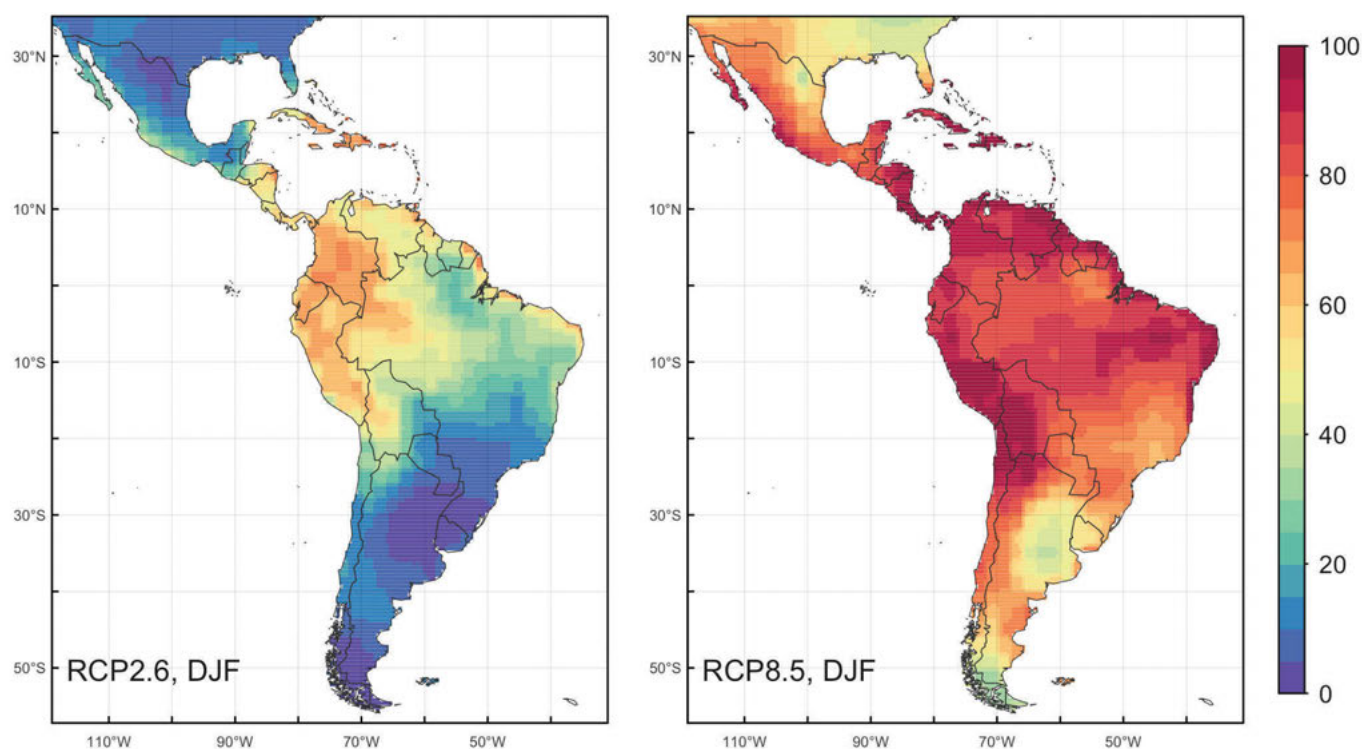
Figure 2 shows the occurrence of highly unusual summer temperatures in a 2°C and 4°C world. Box 3 gives an overview of the climate risks in the region.

### ***Changes to the hydrological cycle could endanger the stability of freshwater supplies and ecosystem services.***

Altered precipitation cycles characterized by more intense downpours followed by longer droughts, loss of glaciers, degradation of key ecosystems, and the loss of critical ecosystem services (e.g., water supplies, water buffering, retention, regulation, and soil protection) will impact freshwater supplies regionally and potentially generate upstream-downstream tradeoffs and synergies. A range of impacts are expected to increase in intensity and severity as global mean temperatures rise from 2°C to 4°C.

- **Projections indicate that most dry regions get drier and wet regions get wetter.** Reductions in precipitation are as high as 20–40 percent for the Caribbean, Central America, central Brazil, and Patagonia in a 4°C world. Drought conditions are projected to increase by more than 20 percent. Limiting warming to 2°C is projected to reduce the risk of drought significantly: to a one percent increase of days with drought conditions in the Caribbean and a nine percent increase for South America. At the same time, an increase in frequency and intensity of extreme precipitation events is projected particularly for the tropical and subtropical Pacific coastline and southern Brazil.
- **Massive loss of glaciers is projected in the Andes in a 2°C world (up to 90 percent) and almost complete glacier loss beyond 4°C.** Changes to glacial melt, in response to land surface warming, alter the timing and magnitude of river flows and result in a higher risk of flooding and freshwater shortages and damage to infrastructure assets.

**Figure 2:** Multi-model mean of the percentage of austral summer months (DJF), with highly unusual temperatures (normally unlikely to occur more than once in several hundred years) in a 2°C world (left) and a 4°C world (right) in 2071–2099 and relative to the 1951–1980 base line period.



- **Increased droughts and higher mean temperatures are projected to decrease water supplies and affect most ecosystems and agroecosystems.** The increasing risk of drought will raise the risk of forest fires, large-scale climate-induced forest degradation and the loss of associated ecosystem services.
- **Glaciers will melt at an even faster rate than observed, with a peak in river runoff expected in 20–50 years, and possibly earlier in some watersheds.** Glacial lake outbursts and connected flooding present a hazard for Andean cities. The loss of glaciers will likely impact the *páramos* (Andean, high carbon stock moorlands) which are the source of water for many Andean cities. Moreover, degraded highland ecosystems have less capacity to retain water and intensified downpours will increase erosion with a subsequent increase in siltation and damage to hydropower dams, irrigation works, and hydraulic and river defense infrastructure.
- **The projected trend of more intense rainfall can significantly increase the risk of landslides especially in sloping terrain often occupied by the poorer rural and urban communities.** The major landslides in 2011 in the State of Rio de Janeiro following intense rainfall are a harbinger of the likely severity of projected impacts from more intense rainfall events. Intense

rainfall events can quickly overwhelm natural drainage channels in the landscape as well as urban drainage systems that are unlikely to have been designed for the projected more intense future rainfall events and flows.

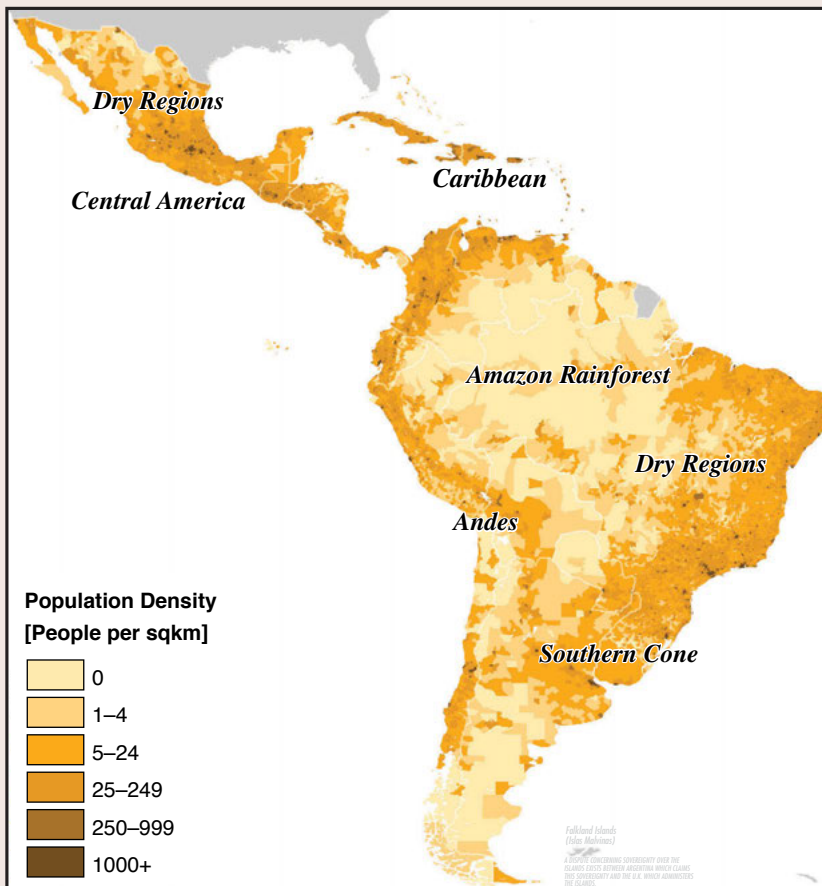
***Climate change will place at risk small-scale subsistence agriculture and large-scale agricultural production for export***

Agriculture in the Latin America and the Caribbean region is heavily dependent on rain-fed systems for both subsistence and export crops; it is therefore vulnerable to climatic variations such as droughts, changing precipitation patterns, and rising temperatures.

- **Increasing risks for agriculture as warming rises beyond 2°C.** There is a clear negative signal for a large variety of crops with 2°C warming, including soybeans (up to a 70 percent yield decline in some areas of Brazil) and maize (up to a 60 percent yield decline in Brazil and Ecuador) by 2050 relative to a 1989–2009 baseline. Simulated adaptation interventions (e.g. improved crop varieties, improved soil and crop management, and supplementary irrigation) alleviated but did not overcome the projected yield declines from climate change. Other studies

### Box 3: Selected Climate Risks in the Latin America and the Caribbean Region

In a 4°C world, heat extremes, changes in hydrological cycles, tropical cyclones and changes in the El Niño Southern Oscillation (ENSO) are expected to pose severe problems with risks cascading to the agricultural sector, human health, large urban centers and the functioning of critical ecosystem services. At lower levels of warming, glacial melt in the Andes will reduce freshwater and hydropower for communities and large Andean cities during the dry season, while increasing the risks of flooding in the short term and impacting agriculture and environmental services downstream. Severe threats are expected from sea-level rise, damages to low-lying areas and coastal infrastructures. Degrading coral reefs will endanger tourism revenues and undermine biodiversity, fisheries, and the protection of coastal zones thereby negatively impacting livelihoods. For the global community, the potential impact of climate change on the Amazon rainforest is of high relevance. With increasing warming, degradation—if not dieback—of the Amazon rainforest is increasingly possible potentially turning the forest into a large carbon source during dry years and triggering further climate change.



Data sources: Center for International Earth Science Information Network, Columbia University; United Nations Food and Agriculture Programme; and Centro Internacional de Agricultura Tropical—(2005). Gridded Population of the World, Version 3 (GPWv3): Population Count Grid. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). This map was reproduced by the Map Design Unit of The World Bank. The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.

#### Central America & the Caribbean

Higher ENSO and tropical cyclone frequency, precipitation extremes, drought, and heat waves. Risks of reduced water availability, crop yields, food security, and coastal safety.

*Poor exposed to landslides, coastal erosion with risk of higher mortality rates and migration, negative impacts on GDP where share of coastal tourism is high.*

#### Amazon Rainforest

Increase in extreme heat and aridity, risk of forest fires, degradation, and biodiversity loss.

*Risk of rainforest turning into carbon source. Shifting agricultural zones may lead to conflict over land. Risks of species extinction threatening traditional livelihoods and cultural losses.*

#### Andes

Glacial melt, snow pack changes, risks of flooding, and freshwater shortages.

*In high altitudes women, children, and indigenous people particularly vulnerable; and agriculture at risk. In urban areas the poor living on steeper slopes more exposed to flooding.*

#### Dry Regions

Increasing drought and extreme heat events leading to cattle death, crop yield declines, and challenges for freshwater resources.

*Risks of localized famines among remote indigenous communities, water-related health problems. Stress on resources may lead to conflict and urban migration.*

#### Southern Cone

Decreasing agricultural yields and pasture productivity, northward migration of agro-ecozones.

*Risks for nutritious status of the local poor. Risks for food price increases and cascading impacts beyond the region due to high export share of agriculture.*

suggest that in a 3°C world, the projected negative impacts on individual crops become stronger. For example up to almost 70 percent decline in wheat in Central America and the Caribbean. This implies that climate change threatens not only smallholder farmers, and rural and indigenous communities but also large-scale commodity (soybeans, maize) producers, ranchers, and agribusinesses—with potential negative repercussions on food security and prices in the region and beyond.

- **Local food security is seriously threatened by the projected decrease in fishery catch potential.** The Caribbean coasts, the Amazon estuaries, and the Rio de la Plata are expected to be particularly affected by declines in catch potential of more than 50 percent as fish stocks migrate in response to warming waters. The Caribbean waters could see declines in the range of 5–50 percent. These estimates are for warming of 2°C by 2050, by which time many of the coral reefs—an important fish nursery and habitat—would be subject to annual bleaching events, further undermining the marine resource base. Ocean acidification could affect fish populations directly, including through physiological damages at early life stages. The effects on the food chain, however, are not yet clear.
- **The Southern Cone (Chile, Argentina, Uruguay, Paraguay, and southern Brazil) as a major grain and livestock producing region is susceptible to climate shocks,** mainly related to changing rainfall patterns and rising heat extremes. This is expected to severely impact maize and soy yields, important export commodities. For example, maize productivity is projected to decline by 15–30 percent in comparison to 1971–2000 levels under warming of 2°C by 2050, and by 30–45 percent under 3°C warming. Strong and/or extreme El Niño events resulting in floods or droughts in the cropping season pose further substantial risks to agriculture in the region.

***A stronger prevalence of extreme events is projected that would affect both rural and urban communities, particularly on sloping lands and in coastal regions.***

The region is heavily exposed to the effects of more frequent and intense extreme events, such as those that occur during strong El Niño events and tropical cyclones.

- **An increase of approximately 40 percent in the frequency of the strongest north Atlantic tropical cyclones is projected for a 2°C world, and of 80 percent for a 4°C world, compared to present.** In LAC, close to 8.5 million people live in the path of hurricanes, and roughly 29 million live in low-elevation coastal zones. The Caribbean is particularly vulnerable as more than 50 percent of its population lives along the coast, and around 70 percent live in coastal cities. More intense tropical cyclones would interact adversely with rising sea levels, exacerbating coastal flooding and storm surge risks, putting entire economies and livelihoods at risk (particularly for island states).

### **Box 4: El Niño Southern Oscillation (ENSO)**

**The Latin America and the Caribbean region is particularly exposed to the effects of strong\* El Niño and La Niña events,** which are related to the El Niño Southern Oscillation (ENSO). In Central America, El Niño usually results in excessive rainfall along the Caribbean coasts, while the Pacific coasts remain dry. Rainfall increases and floods tend to occur on the coast of Ecuador, the northern part of Peru, and in the southern part of Brazil, Argentina, Paraguay, and Uruguay while drought appears in the Andean zones of Ecuador, Peru and Bolivia and in north eastern Brazil. All these changes can substantially impair livelihoods through impacts on agricultural productivity, critical ecosystems, energy production, water supply, infrastructure, and public health in affected countries. For example, the extreme 1997–98 El Niño event resulted in many billions of dollars in economic damages, and tens of thousands of fatalities worldwide, including severe losses in Latin America. Substantial uncertainties remain regarding climate change impact projections on the intensity and frequency of extreme El Niño events. However, evidence of changes to ENSO-driven precipitation variability in response to global warming has emerged recently and represents an update to the assessment of ENSO projections in the IPCC AR5 report. Recent climate model inter-comparison studies suggest the likelihood of global warming leading to the occurrence of more frequent **extreme** El Niño events over the 21st century.

\* “The Oceanic Niño Index (ONI) is the standard that NOAA uses for identifying El Niño (warm) and La Niña (cool) events in the tropical Pacific. It is the running 3-month mean sea-surface temperature (SST) anomaly for the Niño 3.4 region (i.e., 5°N–5°S, 120°–170°W). Events are defined as 5 consecutive overlapping 3-month periods at or above the +0.5° anomaly for warm (El Niño) events and at or below the –0.5 anomaly for cold (La Niña) events. The threshold is further broken down into Weak (with a 0.5 to 0.9 SST anomaly), Moderate (1.0 to 1.4) and Strong ( $\geq 1.5$ ) events” [Source: <http://ggweather.com/enso/oni.htm>]

- **Risks associated with El Niño events and tropical cyclones would occur contemporaneously with a sea-level rise of 38–114 cm thus greatly increasing the risks storm surges.** Sea-level rise is projected to be higher at the Atlantic coast than at the Pacific coast. Sea-level rise off Valparaiso, for example, is projected at 0.35 m for a 2°C world and 0.55 m for a 4°C world (medium estimate). Recife sees projections of approximately 0.39 m and 0.63 m respectively, with the upper estimates as high as 1.14 m in a 4°C world—the highest in the region.
- **Extreme events will strongly affect the rural and urban poor who often reside in informal settlements in high-risk areas (e.g., flood plains and steep slopes).** In 2005, the percentage of people living in informal settlements in Latin America was highest in Bolivia (50 percent) and in the Caribbean highest in Haiti (70 percent). The negative effects of extreme events

also affect rural communities as they strongly depend on their environment and its natural resource base.

- **In the Caribbean, substantial adverse impacts on local critical ecosystems, agriculture, infrastructure, and the tourism industry can be expected in a 2°C world.** This is due to loss and/or degradation of important assets from the combined effects of increasing sea levels and associated impacts of saline intrusion and storm surges, ocean acidification, bleaching of coral reefs, and loss of the physical protection afforded to coastlines from dead and degrading reefs. Impacts from these and other climatic changes can be expected to grow substantially with increasing warming, especially given the increasing likelihood of more frequent intense tropical cyclones.

## The Middle East and North Africa

The Middle East and North Africa (MENA) is one of the most diverse regions in the world in economic terms, with per-capita annual GDP ranging from \$1,000 in Yemen to more than \$20,000 in the Arab Gulf States. Qatar, Kuwait, the United Arab Emirates, Morocco, the Arab Republic of Egypt, and Yemen rank 4, 12, 27, 130, 132, and 151 in GDP per capita on a list of 189 countries. In consequence, adaptive capacity and vulnerability to climate risks varies enormously within the region.

The region’s population is projected to double by 2050, which together with projected climate impacts, puts the region under enormous pressure for water and other resources. The region is already highly dependent on food imports. Approximately 50 percent of regional wheat and barley consumption, 40 percent of rice consumption, and nearly 70 percent of maize consumption is met through imports. The region has coped with its water scarcity through a variety of means: abstraction of groundwater, desalination, and local community coping strategies. Despite its extreme water scarcity, the Gulf countries use more water per capita than the global average, with Arab residential water and

energy markets among the most heavily subsidized in the world. The region is very diverse in terms of socio-economic and political conditions. Thus, adaptive capacity and vulnerability to climate risks varies enormously within the region, especially between the Arab Gulf States and the other Middle East and North Africa countries.

The Middle East and North Africa region emerges as one of the hotspots for worsening extreme heat, drought, and aridity conditions. Agriculture, where 70 percent is rain-fed, is highly exposed to changing climatic conditions. Warming of 0.2°C per decade has been observed in the region from the 1961–1990, and since then the region is warming at an even faster rate. Projections indicate that more than 90 percent of summers will have highly unusual heat extremes in a 4°C world compared to between 20–40 percent of summers in a 2°C world (Figure 3).

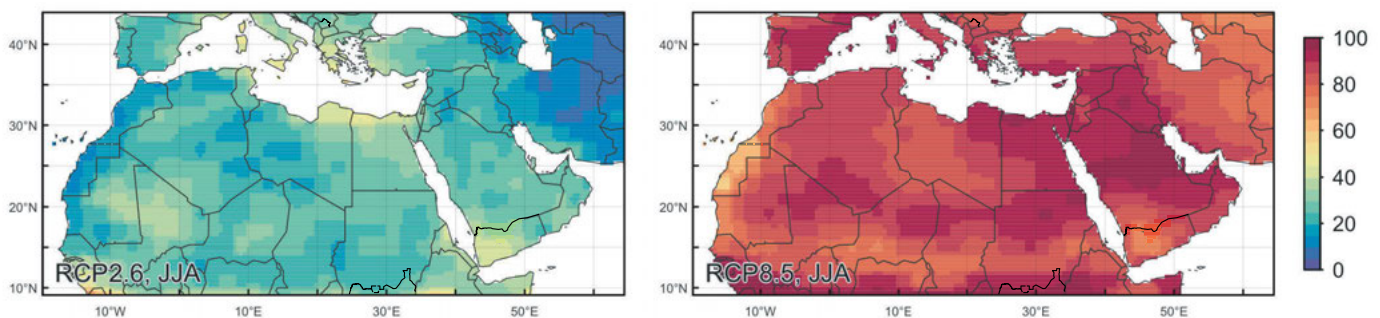
Given its high import dependency, the region is vulnerable to effects beyond its borders. While societal responses to such changes remain hard to predict, it is clear that extreme impacts, such as a more than 45 percent decrease in annual water discharge projected for a 4°C world in parts of the region, would present unprecedented challenges to the social systems affected. Climate change might act as a threat multiplier to the security situation in the region by imposing additional pressures on already scarce resources and by reinforcing pre-existing threats connected to migration following forced displacement. Box 5 gives an overview of the key climate risks in the region.

### **Changing precipitation patterns and an increase in extreme heat pose high risks to agricultural production and regional food security.**

Most agriculture in the region takes place in the semi-arid climate zone, either close to the coast or in the highlands, and is highly vulnerable to the effects of climate change.

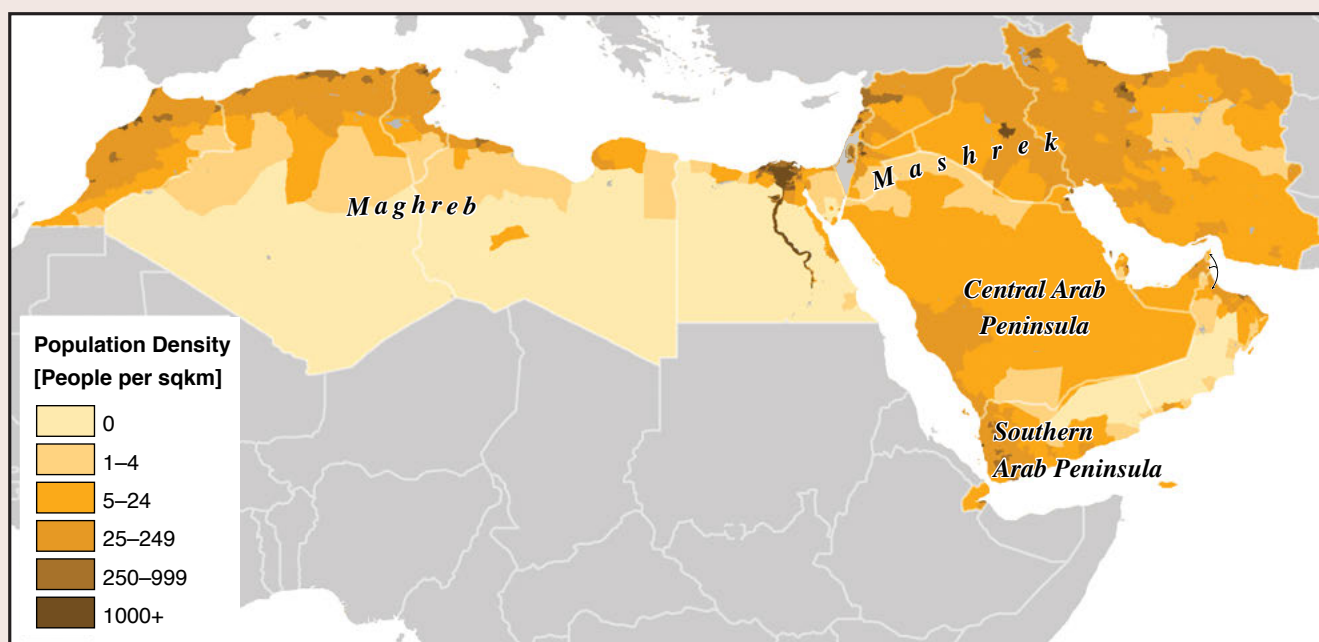
- **Rainfall is predicted to decline by 20–40 percent in a 2°C world and by up to 60 percent in a 4°C world in parts of the region.** Agricultural productivity is expected to drop in parts of the Middle East and North Africa region with increasing

**Figure 3:** Multi-model mean of the percentage of boreal summer months (JJA), with highly unusual temperatures (normally unlikely to occur more than once in several hundred years) in a 2°C world (left) and a 4°C world (right) in 2071–2099 and relative to the 1951–1980 base line period.



## Box 5: Selected Climate Risks in the Middle East and North Africa Region

The region will be severely affected at 2°C and 4°C warming, particularly because of the large increase in projected heat extremes, the substantial reduction in water availability, and expected consequences for regional food security. High exposure to sea-level rise in the coming decades is linked to large populations and assets in coastal areas. In a 2°C world already low annual river discharge levels are projected to drop by more than 15 percent and highly unusual heat extremes are projected to affect about a third of the land. Crop yield declines coupled with impacts in other grain-producing regions could contribute to increasing food prices in the region. The growing food import dependency further exacerbates such risks. Deteriorating rural livelihoods may contribute to internal and international migration, adding further stress on particularly urban infrastructure, with associated risks for poor migrants. Migration and climate related pressure on resources (e.g. water) might increase the risk of conflict.



### Maghreb

Strong warming reduction in annual precipitation, increased water stress and reduced agricultural productivity. Large coastal cities exposed to sea level rise.

*Climate change risks will have severe implications on farmers' livelihoods, country economy, and food security. Exposure of critical coastal assets would have impact on the economy, including tourism. There is risk for accelerated migration flows to urban areas and social conflict.*

### Mashrek and Eastern Parts

Highly unusual heat and decrease in annual precipitation will increase aridity, decrease in snow water storage and river runoff for example in Jordan, Euphrates and Tigris. Adverse consequences for mostly rain-fed agricultural and food production.

*Climate change risks will have severe implications on farmers' livelihoods, country economy, and food security. There is a risk for accelerated migration flows to urban areas and social conflict.*

### Arabian Peninsula

Highly unusual heat extremes in central Arabian Peninsula. In southern parts relative increase in annual precipitation, but uncertain trend of annual precipitation in central part. Sea level rise in the Arabian Sea likely higher than in Mediterranean and Atlantic coasts with risk of storm surges and adverse consequences for infrastructure.

*More heat extremes expected to increase thermal discomfort, posing risk to labor productivity and health.*

Data sources: Center for International Earth Science Information Network, Columbia University; United Nations Food and Agriculture Programme; and Centro Internacional de Agricultura Tropical—(2005). Gridded Population of the World, Version 3 (GPWv3): Population Count Grid. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). This map was reproduced by the Map Design Unit of The World Bank. The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.

water scarcity and higher temperatures which are expected to deviate more and more from the temperature optima of several crops (and possibly even exceed their heat tolerance levels).

- **Crop yields in the region may decrease** by up to 30 percent at 1.5–2°C warming in Jordan, Egypt, and Libya and by almost 60 percent (for wheat) at 3–4°C warming in the Syrian Arab Republic. The strongest crop reductions are expected for legumes and maize as they are grown during the summer period.
- **With 70 percent of agricultural production being rain-fed, the sector is highly vulnerable to temperature and precipitation changes and the associated potential consequences for food, social security, and rural livelihoods.** Forty-three percent of the population lives in rural areas and poor rural farmers are particularly vulnerable to hunger and malnutrition as a direct consequence of yield loss and high food prices. In combination with non-climatic pressures the decline in rural livelihood options could trigger further urban migration, potentially exacerbating urban vulnerability and intensifying the potential for conflict.
- **The increase in demand for irrigation water will be difficult to meet due to the simultaneous decrease in water availability** in the Middle East and North Africa countries which have traditionally invested in agriculture to improve the performance in the agriculture sector—about 30 percent of the agricultural land is irrigated whereas agriculture consumes 60 to 90 percent of all water used in the region.
- **Rising food prices that often follow production shocks and long-term declines make the growing number of urban poor increasingly vulnerable to malnutrition,** particularly against the background of increasing local food insecurity. Evidence suggests that child malnutrition could rise in the event of significant food price increases or sharp declines in yields. Child malnutrition is already high in parts of the Middle East and North Africa, with an average of 18 percent of children under age five developmentally stunted. Childhood stunting has been linked to lifelong adverse consequences, including lower economic productivity in adulthood.
- **With its high and growing import dependency the region is particularly vulnerable to worldwide and domestic agricultural impacts and related spikes in food prices.** For example, climatic and hydrological events (droughts and floods), together with global market forces, were contributing factors to high wheat prices in Egypt and affected the price of bread in 2008.

### **Heat extremes will pose a significant challenge for human health**

People in the region face a variety of health risks, many of which are exacerbated by the hot and arid conditions and relative water scarcity that characterize the region.

- **A substantial rise in highly unusual heat extremes is expected in the coming decades.** In a 2°C world, *highly unusual* heat

extremes would occur on average in one of the summer months in each year from the 2040s onward. In a 4°C world, this frequency would be experienced as early as the 2030s, and would increase to two summer months by the 2060s and virtually all months by the end of the century. Unprecedented heat extremes are absent in a 2°C world and affect about half the summer months by the end of the century in a 4°C world.

- **The period of consecutive hot days is expected to increase, particularly in cities due to the urban heat island effect.** For example, in a 2°C warmer world the number of consecutive hot days is projected to increase annually from four days to about two months in Amman, from eight days to about three months in Baghdad, and from one day to two months in Damascus. The number of hot days in Riyadh is expected to increase even more—from about three days to over four months. The number of hot days in a 4°C warmer world is projected to exceed the equivalent of four months in most capital cities.
- **Heat stress levels can approach the physiological limits of people working outdoors and severely undermine regional labor productivity, putting a burden on health infrastructure.** High temperatures can cause heat-related illnesses (e.g., heat stress, heat exhaustion, and heat stroke) especially for the elderly, people with chronic diseases or obesity, and pregnant women, children, and people working outside. Climate change is expected to undermine human health in other ways as well. For instance, the relative risk of diarrheal disease as a consequence of climatic changes and deteriorating water quality is expected to increase 6–14 percent for the period 2010–39 and 16–38 percent for the period 2070–99 in North Africa; and 6–15 percent and 17–41 percent, respectively, in the Middle East.

### **Sea-level rise will pose serious challenges to the region's coastal population, infrastructure, and economic assets.**

The dense concentration of people and assets in coastal cities translate into high exposure to the effects of sea-level rise.

- **Projections show that all coastlines are at risk from sea-level rise.** Depending on the city, sea levels are projected to rise by 0.34–0.39 m in a 1.5°C world and 0.56–0.64 m in a 4°C world (medium estimate), with the highest estimate reaching 1.04 m in Muscat.
- **The Maghreb countries of Egypt, Tunisia, Morocco, and Libya have been identified as among the most exposed African countries in terms of total population affected by sea-level rise.** In Morocco, for example, more than 60 percent of the population and over 90 percent of industry is located in key coastal cities. For example, Alexandria, Benghazi, and Algiers have been identified as particularly vulnerable to a sea-level rise of only 0.2 m by 2050. The United Arab Emirates also

ranks among the ten most vulnerable countries to sea-level rise worldwide.

- **Key impacts of climate change in coastal zones include inundation resulting from slow onset sea-level rise, flooding, and damages caused by extreme events (including storms, storm surges, and increased coastal erosion).** The exposure of critical assets may cause other impacts to have repercussions for the economy (e.g., where tourism infrastructure is exposed). In Egypt, for example, the ocean acidification and ocean warming threatens coral reefs and is expected to place the tourism industry—an important source of income revenue—under severe pressure.
- **Impacts on groundwater levels are significant, with potential negative repercussions on human health for local and migrant populations.** The Nile Delta, home to more than 35 million people and providing 63 percent of Egypt’s agricultural production, is especially vulnerable to salinization under changing climate conditions. These impacts will be exacerbated by land subsidence, especially in the eastern part of the delta, and by extensive landscape modification resulting from both coastal modification and changes in the Nile’s hydrogeology.

## Europe and Central Asia

Europe and Central Asia (ECA) in this report covers 12 countries<sup>9</sup> within Central Asia, the Western Balkans, and the Russian Federation. The analysis focuses on specific climate challenges related

<sup>9</sup> The World Bank Europe and Central Asia region in this report includes only the following countries: Albania, Bosnia and Herzegovina, Kazakhstan, Kosovo, the Kyrgyz Republic, the former Yugoslav Republic of Macedonia, Montenegro, the Russian Federation, Serbia, Tajikistan, Turkmenistan, and Uzbekistan.

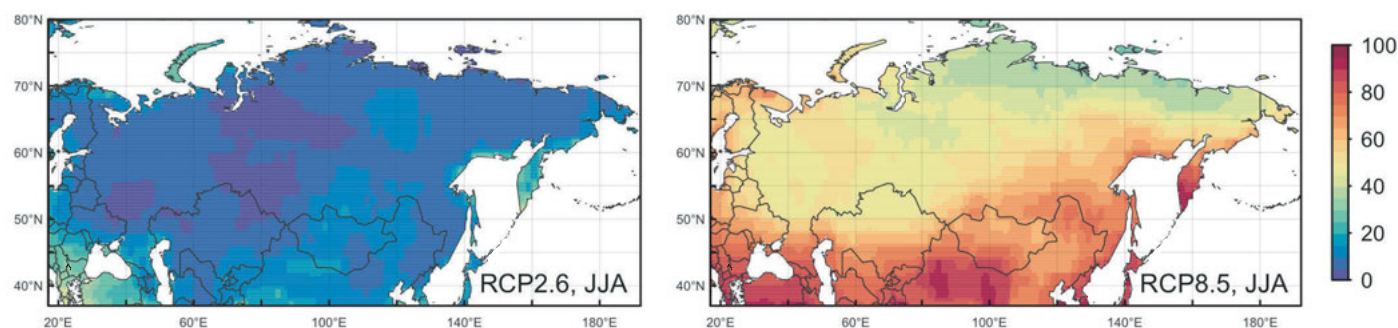
to the agriculture-water-energy nexus in Central Asia; climate extreme in the Western Balkans, and the forests in Russia. While the economic and political profiles of the countries differ greatly, a common denominator is their transition from various types of closed, planned economies to open, market-based systems. The region is characterized by relatively low levels of per-capita annual GDP, ranging from \$800 in Tajikistan to \$14,000 in Russia. Agricultural production plays an important role in the national economies of the region, particularly those of Tajikistan, the Kyrgyz Republic, Uzbekistan, and Albania. Large portions of the population in Central Asia (60 percent) and the Western Balkans (45 percent) live in rural areas, making them dependent on natural resources for their livelihoods and thus particularly vulnerable to climate change.

The parts of the Europe and Central Asia region covered by this report are projected to experience greater warming than the global average. The region displays a clear pattern where areas in the southwest are becoming drier and areas further northeast, including most of Central Asia, are becoming wetter as the world warms toward 4°C. The projected temperature and precipitation changes translate into increased risks for freshwater supplies that not only jeopardizes the sustainability of hydropower and agricultural productivity but also negatively impacts ecosystem services such as carbon sequestration for most of the region. A selection of sub-regional impacts is provided in Box 6.

***Water resources in Central Asia increase during the first half of the century and decline thereafter, amplifying the challenge of accommodating competing water demands for agricultural production and hydropower generation.***

Water resource systems in Central Asia (notably glaciers and snow pack) are sensitive to projected warming; with consequent impacts on water availability in the agriculture and energy sectors.

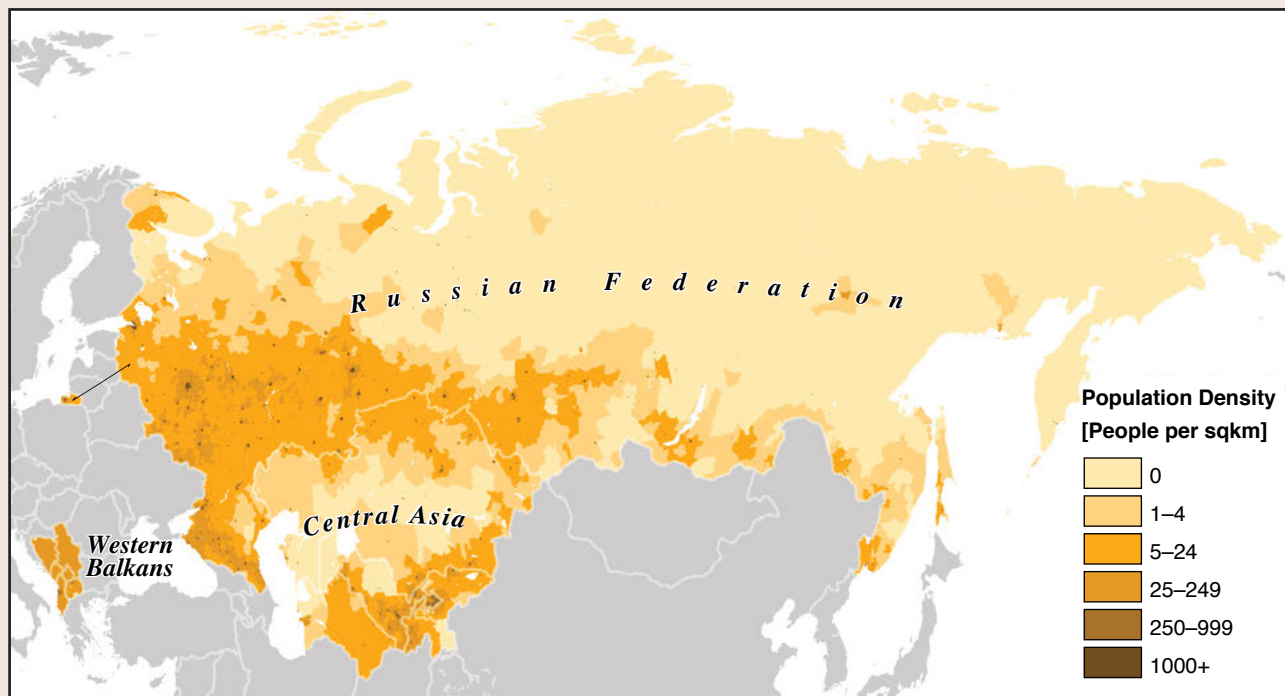
**Figure 4:** Multi-model mean of the percentage of boreal summer months (JJA) with highly unusual temperatures (normally unlikely to occur more than once in several hundred years) in a 2°C world (left) and a 4°C world (right) in 2071–2099 and relative to the 1951–1980 base line period.





## Box 6: Selected Climate Risks in the Europe and Central Asia Region

Increasing precipitation and glacial melt lead to increased water availability and flood risk in Central Asia in the coming decades. After mid-century and especially with warming leading to a 4°C world, unstable water availability poses a risk for agriculture and competing demands for hydropower generation. In the Western Balkans, extreme heat with a strong decrease in precipitation and water availability are projected to lead to large reductions in crop yields, adverse effects on human health, and increasing risks to energy generation for a 4°C world; but would already be present in a 2°C world. The Russian forests store enormous amounts of carbon in biomass and soils. While their productivity may generally increase with warmer temperatures, large-scale forest dieback and the release of carbon resulting from interacting heat stress, insect spread and fire, have the potential to further affect boreal forests in the second half of the century.



### Western Balkans

Increase in droughts, unusual heat extremes and flooding. High risks for agriculture, human health and stable hydropower generation.

*Risks for human health, food and energy security.*

### Central Asia

Increasing glacial melt alters river runoff. Risks of glacial lake outbursts, flooding and seasonal water shortages. Increasing competition for water resources due to rising agricultural water demand and demand for energy production.

*Risks for poor through rising food prices particularly affecting women, children and the urban poor. Risks for human health due to spreading disease, heat waves and flooding.*

### Boreal Forests of the Russian Federation

Unusual heat extremes and annual precipitation increase, rising risks of forest fires and spread of pests leading to tree mortality and decreasing forest productivity. Possible northward shift of treeline and changes in species composition. Risks of permafrost melt and methane release.

*Risk for timber production and ecosystem services, including carbon capture. Risks of substantial carbon and methane emissions.*

Data sources: Center for International Earth Science Information Network, Columbia University; United Nations Food and Agriculture Programme; and Centro Internacional de Agricultura Tropical—(2005). Gridded Population of the World, Version 3 (GPWv3): Population Count Grid. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). This map was reproduced by the Map Design Unit of The World Bank. The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.

Central Asia is increasingly likely to be a hotspot for heat stress for agriculture and human settlements as warming proceeds to 2°C and 4°C especially as temperatures are not moderated by oceanic winds. Since the beginning of the 20th century, Central Asian glaciers have already seen a one-third reduction in glacier volume. Glacier volume is projected to decline by about 50 percent in a 2°C world, concurrent with a 25 percent decrease in snow cover for the Northern Hemisphere, and by up to 80 percent in a 4°C world. Reductions in water availability are predicted to occur contemporaneously with an increase in demand for irrigation water.

- **River runoff will increase in the coming decades due to enhanced glacial melt rates but flows are expected to decrease for the second half of the century.** By the end of the 21st century a distinct decrease in the water volume of the Syr Darya, and an even more distinct decrease in the Amu Darya River, is expected because of declining glaciers that supply most of its flows. Critically, also the timing of high flow volumes changes. For example, available data for a headwater catchment (Panj) of the Amu Darya River reveal that the timing of peak flows is projected to shift toward spring, leading to a 25 percent reduction in discharge during the mid-summer (July-August) period in a 3°C world. As a result, less water will be available for agriculture during the crop-growing season while at the same time higher summer temperatures lead to higher water demand for plants.
- **Crop productivity is expected to be negatively impacted by increased heat extremes and variability of supply/demand for water that poses substantial risks to irrigated agricultural systems.** Rain-fed agriculture is likely to be affected by uncertain rainfall patterns and amounts, including where irrigation is important, and coupled with rising maximum temperatures can lead to the risk of heat stress and crop failure.
- **Rural populations that are especially dependent on agriculture for food are likely to be increasingly vulnerable** to any reductions in agricultural yields and nutritional quality of their staple food grains.
- **Unstable water availability is likely to increase the challenge of competing requirements for hydropower generation and agricultural production** at times of rising overall demand due to projected population and economic growth in Central Asia. The projected increase in highly unusual and unprecedented heat extremes during the summer months (see Figure 4) can be expected to simultaneously increase energy demand. As the efficiency of hydropower plants depends on inter- and intra-annually stable river runoff, the potential, for example, of installed hydropower plants for small catchments is projected to decrease by 13 percent in Turkmenistan and by 19 percent in the Kyrgyz Republic at around 2°C warming by the 2050s, while an increase of nearly seven percent is projected

for Kazakhstan. Overall, energy demand is projected to rise together with population and economic growth.

- Tajikistan and the Kyrgyz Republic, which are located upstream of the Syr Darya and Amu Darya, produce nearly 99 percent and 93 percent, respectively, of the total electricity consumed from hydropower. These upstream countries would have to manage the impact of climate change on their hydropower generation capacity, which is the backbone of their power systems; downstream countries (Kazakhstan, Uzbekistan, and Turkmenistan), meanwhile, would be hit particularly hard by competing demands for agricultural and energy production.

***Climate extremes in the Western Balkans pose major risks to agricultural systems, energy and human health.***

The Western Balkans are particularly exposed to the effects of extreme events, including heat, droughts, and flooding. Heat extremes will be the new norm for the Western Balkans in a 4°C world. In a 2°C world, highly unusual heat extremes are projected for nearly a third of all summer months compared to virtually all summer months in a 4°C world. Unprecedented heat extremes are projected to occur for 5–10 percent of summer months in a 2°C world compared to about two-thirds of summer months in a 4°C world.

- **The risk of drought is high. Projections indicate a 20 percent increase in the number of drought days and a decrease in precipitation of about 20–30 percent in a 4°C world.** Projections for a 2°C world are uncertain. At the same time, projections suggest an increase in riverine flood risk, mainly in spring and winter, caused by more intense snow melt in spring and increased rainfall in the winter months (precipitation projections are, however, particularly uncertain).
- **Most crops are rain-fed and very vulnerable to projected climate change.** While there are no projections that encompass the entire region, and projections for individual countries remain uncertain, clear risks emerge. For example, projections for FYR Macedonia indicate potential yield losses of up to 50 percent for maize, wheat, vegetables, and grapes for around 2°C global warming by 2050. Pasture yields and grassland ecosystems for livestock grazing may be affected by sustained drought and heat, and decline over large parts of the Western Balkans. The effects of extreme events on agricultural production are mostly not included in assessments, but observations indicate high vulnerability.
- **Energy systems are very vulnerable to extreme events and changes in river water temperatures; changing seasonality of river flows can further impact hydropower production.** Most countries in the Western Balkans depend on hydroelectric sources for at least one-fifth of their electricity production. Reductions in electricity production would be concurrent with

an increase in cooling demand which is projected to increase by 49 percent in a 4°C world.

- **Extreme climate events and the appearance of new disease vectors pose serious risks to human health.** The increased incidence and intensity of extreme heat events could cause the seasonality of temperature-related mortality to shift from winter to summer across continental Europe. Albania and the Former Yugoslav Republic of Macedonia are considered particularly vulnerable to heat waves. The net total number of temperature-related deaths is projected to increase for the period 2050–2100 above 2°C warming levels. Further health risks are likely due to climate change resulting in favorable conditions for the insect vectors transmitting diseases, such as dengue fever and Chikungunya fever.

### **Impacts of projected warming on Russian boreal forests and the permafrost can have severe consequences for forest productivity and global carbon stocks.**

The boreal ecosystems of the Russian Federation that account for about 20 percent of the world’s forest cover large permafrost regions (carbon and methane-rich frozen soil layers) are likely to be quite sensitive to projected warming and heat extremes. Perturbations to the forest or permafrost could result in severe consequences for local ecosystem services and the global carbon budget. Although slightly warmer average temperatures may increase forest productivity, there is a risk of increasing disturbances, such as fires and pests, leading to widespread tree mortality.

Above-average temperature rises and an overall increase in annual precipitation is projected. In a 2°C world, highly unusual heat extremes are projected to occur in 5–10 percent of summer months, increasing to 50 percent of all summer months in a 4°C world. Precipitation is expected to increase by 10–30 percent in a 2°C world and by 20–60 percent in a 4°C world. Permafrost in the region is highly vulnerable to warming, with projected permafrost thawing rate of 10–15 percent over Russia by 2050 in a 2°C world.

- **A northward shift of the tree line is projected in response to warming,** causing boreal forests to spread into the northern tundra zone, temperate forests into the present boreal zone, and steppes (grassland plains) into temperate forests. In a 4°C world the Eurasian boreal forest area would reduce around 19 percent and the temperate forest area increase by over 250 percent. With warming limited to around 1.5°C, boreal forests would decrease by around two percent and the temperate forest area would increase by 140 percent. This would lead to a net gain in total temperate and boreal forest area in Eurasia of seven percent in a 4°C world and 12 percent in a 1.5°C world. The potential carbon gains from the expansion of boreal forests in the north are likely to be offset, however, by losses in the south.

- **At lower latitudes the forest is likely to give way to steppe ecosystems.** If (partly uncertain) CO<sub>2</sub> fertilization effects do not enhance water-use efficiency sufficiently, the risk of fire, particularly in southern Siberia and Central Yakutia, will increase and could lead to increased carbon emissions. Projections for this area indicate an increase in the annual number of high fire danger days of an average of 10 days in a 3°C world, and 20–30 days in a 4°C world. The effects of heat waves promoting forest fires, and the increasing spread of pests and diseases, as well as the interaction of these factors, may lead to decreased productivity and even increased tree mortality.
- **In a 2°C world, the thawing of the permafrost is projected to increase methane emissions by 20–30 percent.** The projected perturbations to Russian forest ecosystems are of global importance. If pushed beyond critical thresholds and into positive feedback with regional and global warming, large carbon stocks in the boreal forests and methane in the permafrost zones may be released into the atmosphere—with major implications for the global carbon budget.

## **Consequences for Development**

### **Climate change risks undermining development and poverty reduction for present and future generations**

Climate change poses a substantial and escalating risk to development progress that could undermine global efforts to eliminate extreme poverty and promote shared prosperity. Without strong, early action, warming could exceed 1.5–2°C and the resulting impacts could significantly worsen intra- and inter-generational poverty in multiple regions across the globe.

Severe threats to development outlined in this report are beginning to occur across many sectors in all three regions. The analysis presented in this report reveals that amplified risks are emerging from multi-sectoral impacts in particular connected to food security due to projected large and severe crop yield losses for warming levels above 2°C.

As warming approaches 4°C very severe impacts can be expected to trigger impact cascades crossing critical thresholds of environmental and human support systems. Climatic conditions, heat and other weather extremes considered highly unusual or unprecedented today would become the new climate normal—a world of increased risks and instability.

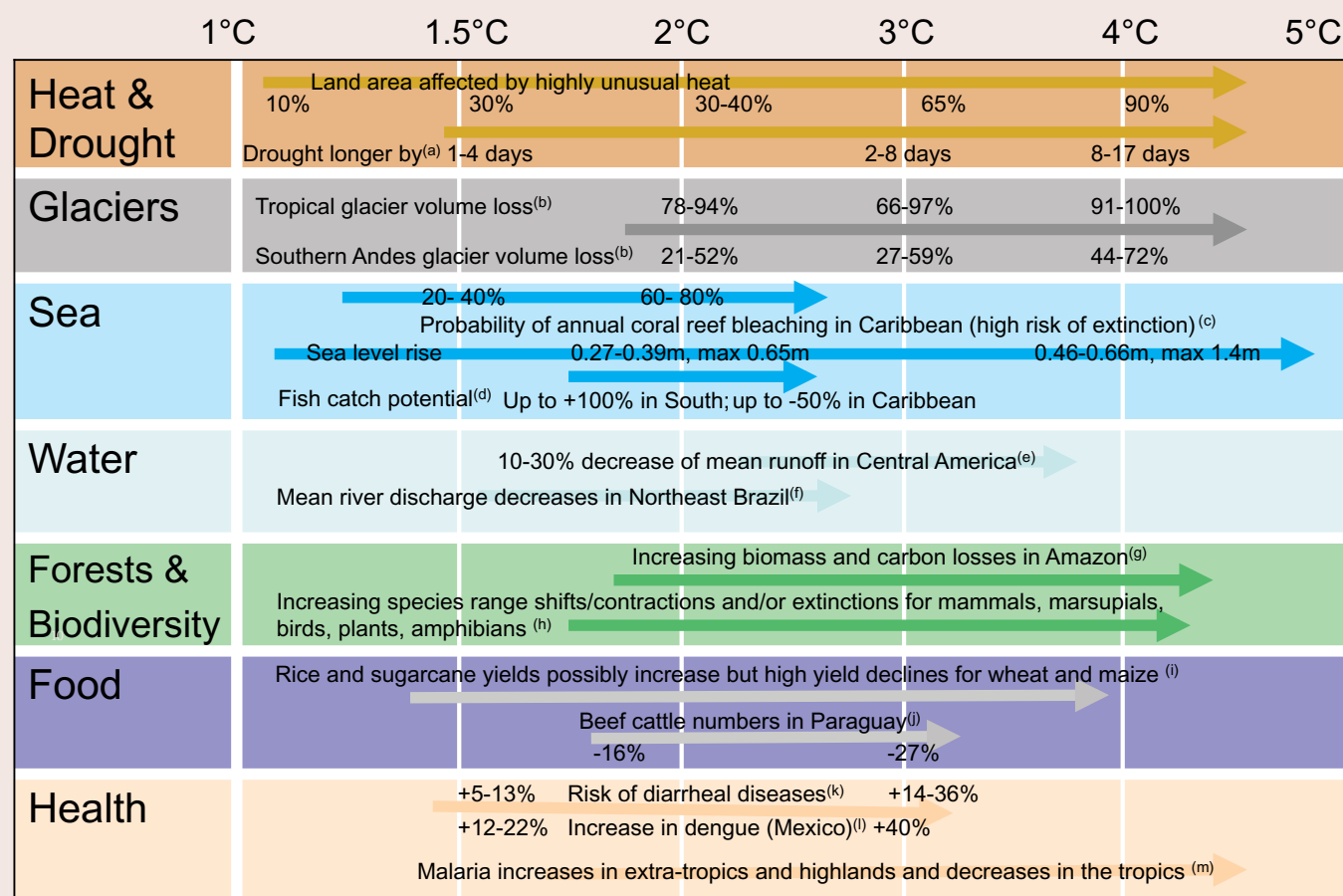
Every effort must be made to cut greenhouse gas emissions from our cities, land use, and energy systems now and transition to a clean, low carbon pathway. Action is urgently needed on climate change, but it does not have to come at the expense of economic growth. Immediate steps are also needed to help countries build resilience and adapt to the climate impacts being felt today and the unavoidable consequences of a rapidly warming world over the coming decades.

The task of promoting human development, of ending poverty, increasing global prosperity and reducing global inequality will be very challenging in a 2°C world, but in a 4°C world there is serious doubt whether it can be achieved at all. Many of the worst projected climate impacts outlined in this report could still

be avoided by holding warming below 2°C. This will require substantial technological, economic, institutional and behavioral change. And, most of all, it will require leadership at every level of society. The time to act is now.

### Box 7: Projected Impacts of Climate Change in Key Sectors in the Latin America and Caribbean Region

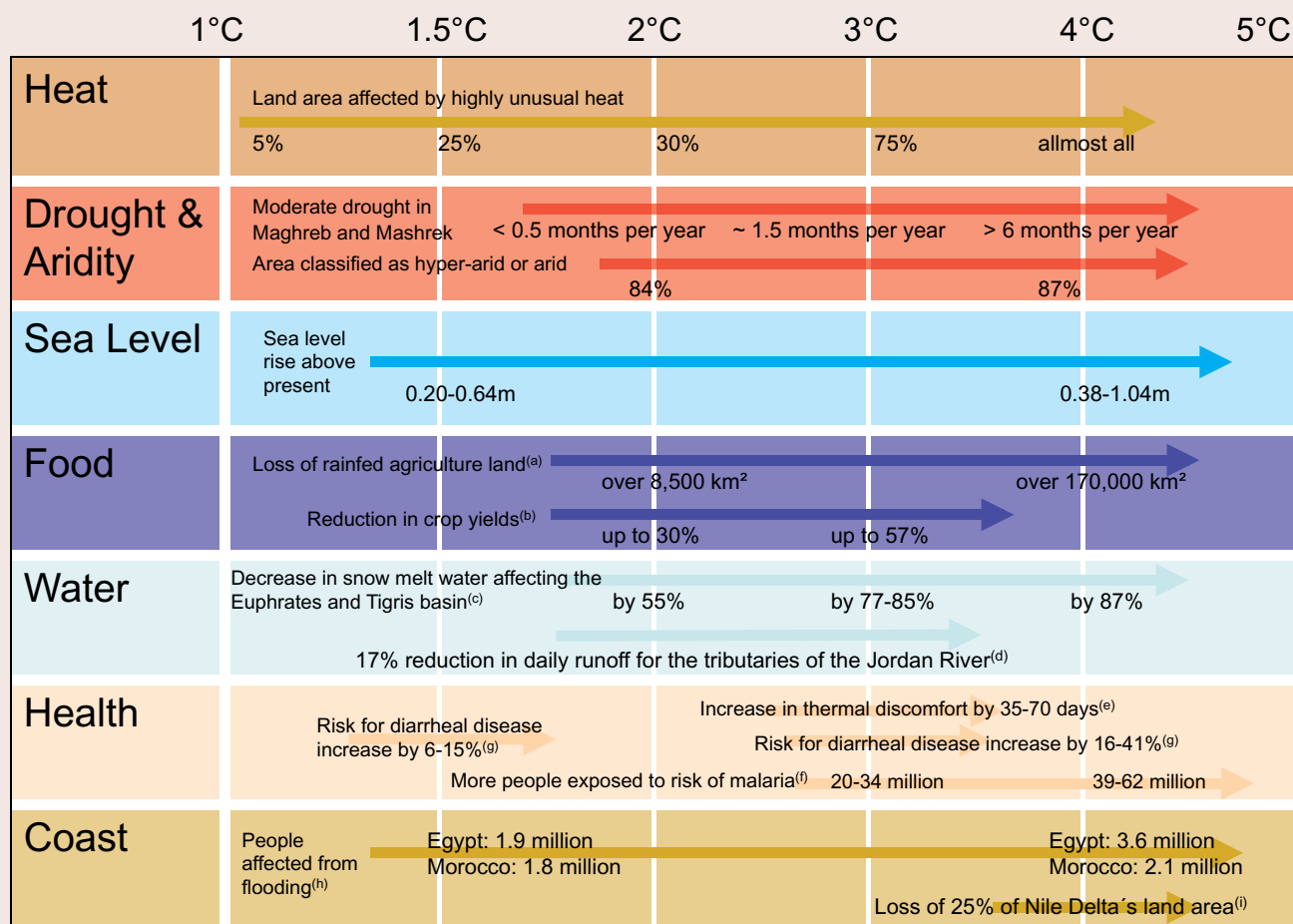
Warming levels are relative to pre-industrial temperatures. The impacts shown here are a subset of those summarized in Table 3.15 of the Main report. The arrows indicate solely the range of warming levels assessed in the underlying studies, but do not imply any graduation of risk unless noted explicitly. In addition, observed impacts or impacts occurring at lower or higher levels of warming that are not covered by the key studies highlighted here are not presented (e.g., coral bleaching already occurs earlier than 1.5°C warming but the studies presented here only start at 1.5°C). Adaptation measures are not assessed here although they can be crucial to alleviate impacts of climate change. The layout of the figure is adapted from Parry (2010). The lower-case superscript letters indicate the relevant references for each impact.<sup>10</sup> If there is no letter, the results are based on additional analyses for this report.



<sup>10</sup> a) Sillmann et al. (2013b); (b) Marzeion et al. (2012); Giesen and Oerlemans (2013); Radic et al. (2013); (c) Meissner et al. (2012); (d) Cheung et al. (2010); (e) Hidalgo et al. (2013); (f) Döll and Schmied (2012); (g) several studies without considering CO<sub>2</sub>-fertilization, see Table 3.1; (h) several studies, see Table 3.1; (i) several studies, see Table 3.1; (j) ECLAC (2010); (k) Kolstad and Johansson (2011); (l) Colon-Gonzalez et al. (2013); (m) Beguin et al. (2011); Caminade et al. (2014); Van Lieshout et al. (2004).

### Box 8: Projected Impacts of Climate Change in Key Sectors in the Middle East and North Africa Region

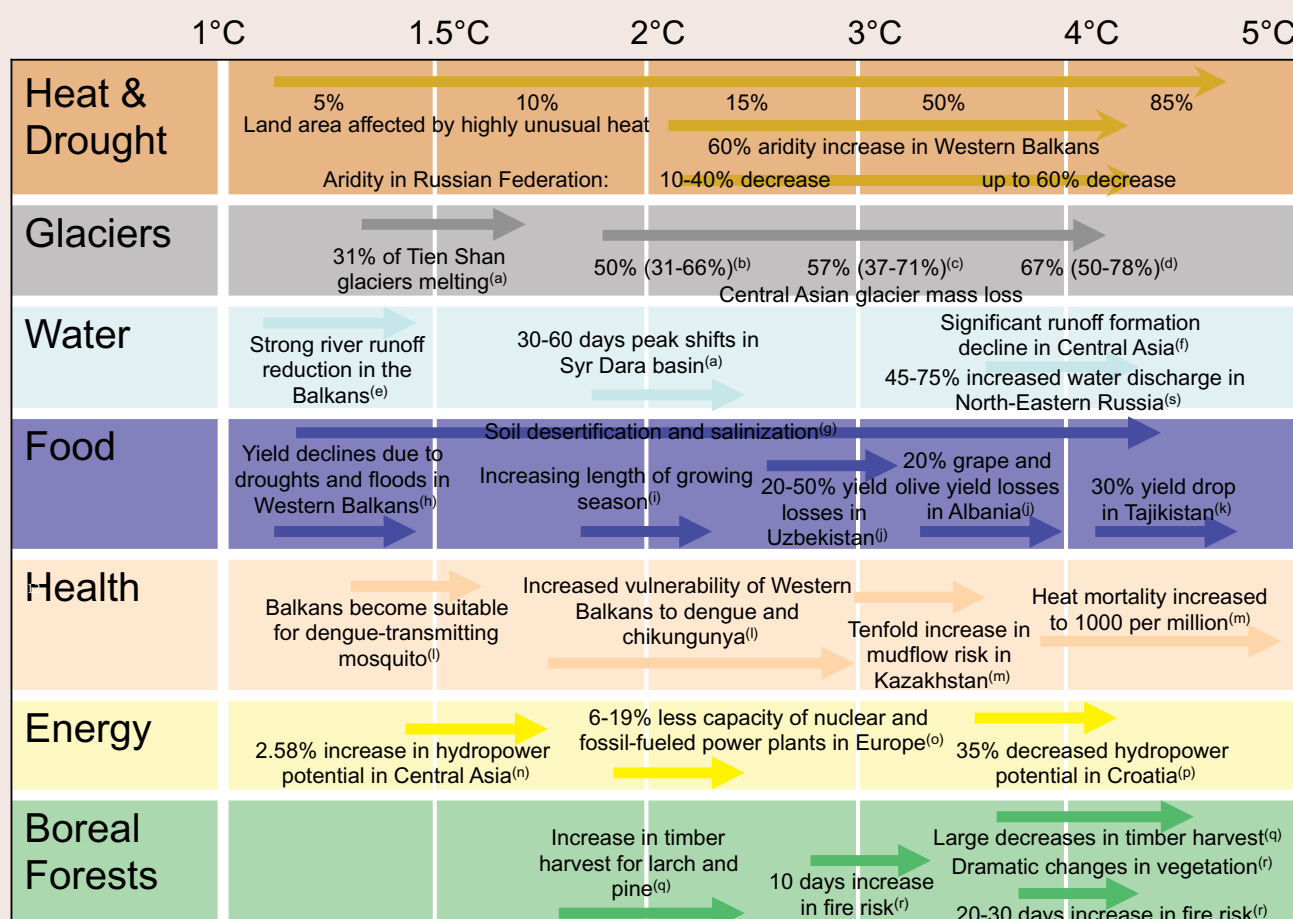
Warming levels are relative to pre-industrial temperatures. The impacts shown here are a subset of those summarized in Table 4.10 of the Main Report. The arrows solely indicate the range of warming levels assessed in the underlying studies; but do not imply any graduation of risk unless noted explicitly. In addition, observed impacts or impacts occurring at lower or higher levels of warming that are not covered by the key studies highlighted here are not presented (e.g., increase in drought and aridity is already observed, but the respective study does not assess impacts below 1.5°C). Adaptation measures are not assessed here although they can be crucial to alleviating the impacts of climate change. The layout of the figure is adapted from Parry (2010). The lower-case superscript letters indicate the relevant references for each impact.<sup>11</sup> If there is no letter, the results are based on additional analyses for this report.



<sup>11</sup> (a) Evans (2008); (b) several studies, see Table 4.1; (c) Bokurt and Sen (2013); (d) Samuels et al. (2010); (e) Giannakopoulos et al. (2013); (f) van Lieshout et al. (2004); (g) Kolstad and Johansson (2011); (h) Brown et al. (2011); (i) Dasgupta et al. (2009).

## Box 9: Projected Impacts of Climate Change in Key Sectors in the Europe and Central Asia Region

Warming levels are relative to pre-industrial temperatures. The impacts shown here are a subset of those summarized in Table 5.7 of the Main report. The arrows solely indicate the range of warming levels assessed in the underlying studies but do not imply any graduation of risk unless noted explicitly. In addition, observed impacts or impacts occurring at lower or higher levels of warming that are not covered by the key studies highlighted here are not presented (e.g., an increase in Tien Shan glacier melt is already observed, but the respective study does not assess the observed impacts). Adaptation measures are not assessed here, although they can be crucial to alleviating the impacts of climate change. The layout of the figure is adapted from Pary (2010). The lower-case superscript letters indicate the relevant references for each impact.<sup>12</sup> If there is no letter, the results are based on additional analyses conducted for this report.



<sup>12</sup> (a) Siegfried et al. (2012); (b) Marzeion et al. (2012); (c) Marzeion et al. (2012); Giesen and Oerlemans (2013); Radic et al. (2013); (d) Marzeion et al. (2012); Giesen and Oerlemans (2013); Radic et al. (2013); (e) Dimkic and Despotovic (2012); (f) Hagg et al. (2013); (g) Thurmman (2011); World Bank (2013f); World Bank (2013d); World Bank (2013a); (h) Maslac (2012); UNDP (2014); (i) Sutton et al. (2013a); Sommer et al. (2013); (j) Sutton et al. (2013a); (k) World Bank (2013m); (l) Caminade et al. (2012); (m) BMU and WHO-Europe (2009); (n) Hamududu and Killingtveit (2012); (o) van Vilet et al. (2012); (p) Pasicko et al. (2012); (q) Lutz et al. (2013b); (r) Tchebakova et al. (2009); (s) Schewe et al. (2013).



## Abbreviations

<b>°C</b>	degrees Celsius	<b>JJA</b>	June, July, and August (the summer season of the northern hemisphere; also known as the boreal summer)
<b>\$</b>	United States Dollars	<b>LAC</b>	Latin America and the Caribbean
<b>AI</b>	Aridity Index	<b>LDC</b>	Least Developed Countries
<b>AOGCM</b>	Atmosphere-Ocean General Circulation Model	<b>MAGICC</b>	Model for the Assessment of Greenhouse Gas Induced Climate Change
<b>AR4</b>	Fourth Assessment Report of the Intergovernmental Panel on Climate Change	<b>MCMA</b>	The Mexico City Metropolitan Area
<b>AR5</b>	Fifth Assessment Report of the Intergovernmental Panel on Climate Change	<b>MENA</b>	Middle East and North Africa
<b>BAU</b>	Business as Usual	<b>MGIC</b>	Mountain Glaciers and Ice Caps
<b>CaCO<sub>3</sub></b>	Calcium Carbonate	<b>NAO</b>	North Atlantic Oscillation
<b>CAT</b>	Climate Action Tracker	<b>NDVI</b>	Normalized Differenced Vegetation Index (used as a proxy for terrestrial gross primary production)
<b>CMIP5</b>	Coupled Model Intercomparison Project Phase 5	<b>NH</b>	Northern Hemisphere
<b>CO<sub>2</sub></b>	Carbon Dioxide	<b>NPP</b>	Net Primary Production
<b>DGVM</b>	Dynamic Global Vegetation Model	<b>OECD</b>	Organization for Economic Cooperation and Development
<b>DIVA</b>	Dynamic Interactive Vulnerability Assessment	<b>PDSI</b>	Palmer Drought Severity Index
<b>DJF</b>	December, January, and February (the winter season of the northern hemisphere)	<b>PgC</b>	Petagrams of Carbon (1 PgC = 1 billion tons of carbon)
<b>ECA</b>	Europe and Central Asia	<b>ppm</b>	Parts Per Million
<b>ECS</b>	Equilibrium Climate Sensitivity	<b>PPP</b>	Purchasing Power Parity (a weighted currency based on the price of a basket of basic goods, typically given in US dollars)
<b>ENSO</b>	El-Niño/Southern Oscillation	<b>RCM</b>	Regional Climate Model
<b>FAO</b>	Food and Agricultural Organization	<b>RPC</b>	Representative Concentration Pathway
<b>FPU</b>	Food Productivity Units	<b>SCM</b>	Simple Climate Model
<b>GCM</b>	General Circulation Model	<b>SLR</b>	Sea-level Rise
<b>GDP</b>	Gross Domestic Product	<b>SRES IPCC</b>	Special Report on Emissions Scenarios
<b>GFDRR</b>	Global Facility for Disaster Reduction and Recovery	<b>SRES IPCC</b>	Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
<b>GLOF</b>	Glacial Lake Outburst Flood		
<b>HCS</b>	Humboldt Current System		
<b>IAM</b>	Integrated Assessment Model		
<b>IEA</b>	International Energy Agency		
<b>IPCC</b>	Intergovernmental Panel on Climate Change		
<b>ISI-MIP</b>	Inter-Sectoral Impact Model Intercomparison Project		
<b>ITCZ</b>	Intertropical Convergence Zone		



<b>TgC</b>	Teragrams of Carbon (1 TgC = 1 million tons of carbon)	<b>UNHCR</b>	United Nations High Commissioner for Refugees
<b>UNCCD</b>	United Nations Convention to Combat Desertification	<b>USAID</b>	United States Agency for International Development
<b>UNDP</b>	United Nations Development Programme	<b>WBG</b>	World Bank Group
<b>UNEP</b>	United Nations Environment Programme	<b>WGI</b>	Working Group I (also WGII, WGIII)
<b>UNFCCC</b>	United Nations Framework Convention on Climate Change	<b>WHO</b>	World Health Organization

## Glossary

**Aridity Index:** The Aridity Index (AI) is an indicator designed for identifying structurally arid regions; that is, regions with a long-term average precipitation deficit. AI is defined as total annual precipitation divided by potential evapotranspiration, with the latter a measure of the amount of water a representative crop type would need as a function of local conditions such as temperature, incoming radiation, and wind speed, over a year to grow, which is a standardized measure of water demand.

**Biome:** A biome is a large geographical area of distinct plant and animal groups, one of a limited set of major habitats classified by climatic and predominant vegetative types. Biomes include, for example, grasslands, deserts, evergreen or deciduous forests, and tundra. Many different ecosystems exist within each broadly defined biome, all of which share the limited range of climatic and environmental conditions within that biome.

**C3/C4 plants:** C3 and C4 refer to two types of photosynthetic biochemical pathways. C3 plants include more than 85 percent of plants (e.g., most trees, wheat, rice, yams, and potatoes) and respond well to moist conditions and to additional CO<sub>2</sub> in the atmosphere. C4 plants (e.g., savanna grasses, maize, sorghum, millet, and sugarcane) are more efficient in water and energy use and outperform C3 plants in hot and dry conditions.

**CAT:** The Climate Action Tracker is an independent, science-based assessment that tracks the emissions commitments of and actions by individual countries. The estimates of future emissions deducted from this assessment serve to analyze warming scenarios that could result from current policy: (i) *CAT Reference BAU*: a lower reference business-as-usual scenario that includes existing climate policies but not pledged emissions reductions; and (ii) *CAT Current Pledges*: a scenario additionally incorporating reductions currently pledged internationally by countries.

**CO<sub>2</sub> fertilization:** The CO<sub>2</sub> fertilization effect refers to the effect of increased levels of atmospheric CO<sub>2</sub> on plant growth. It may increase the rate of photosynthesis mainly in C3 plants and increase water use efficiency, thereby causing increases in agricultural productivity in grain mass and/or number. This effect may to some extent offset the negative impacts of climate change on crop yields, although grain protein content may decline. Long-term effects are uncertain as they heavily depend on a potential physiological long-term acclimation to elevated CO<sub>2</sub> and other limiting factors, including soil nutrients, water, and light. (See also Box 2.4 on the CO<sub>2</sub> fertilization effect on crop productivity.)

**CMIP5:** The Coupled Model Intercomparison Project Phase 5 (CMIP5) brought together 20 state-of-the-art GCM groups, which generated a large set of comparable climate-projection data. The project provided a framework for coordinated climate change experiments and includes simulations for assessment in the IPCC AR5.

**Development narratives:** Development narratives highlight the implications of climate change impacts on regional development. The *Turn Down the Heat* series, and in particular this report, discuss the potential climate change impacts on particularly vulnerable groups along distinct storylines—the so called development narratives. These development narratives were developed for each region in close cooperation with regional World Bank specialists. They provide an integrated, often cross-sectoral analysis of climate change impacts and development implications at the sub-regional or regional level. Furthermore, the development narratives add to the report by allowing the science-based evidence of physical and biophysical impacts to be drawn out into robust development storylines to characterize the plausible scenarios of risks and opportunities—showcasing how science and policy interface.

**GCM:** A General Circulation Model is the most advanced type of climate model used for projecting changes in climate due to increasing greenhouse gas concentrations, aerosols, and external forcing (like changes in solar activity and volcanic eruptions). These models contain numerical representations of physical processes in the atmosphere, ocean, cryosphere, and land surface on a global three-dimensional grid, with the current generation of GCMs having a typical horizontal resolution of 100–300 km.

**GDP:** Gross Domestic Product is the sum of the gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the product. It is calculated without deductions for depreciation of fabricated assets or for depletion and degradation of natural resources.

**GDP PPP:** This is GDP on a purchasing power parity basis divided by population. Whereas PPP estimates for OECD countries are quite reliable, PPP estimates for developing countries are often rough approximations.

**Highly unusual and Unprecedented:** In this report, *highly unusual* and *unprecedented* heat extremes are defined using thresholds based on the historical variability of the current local climate. The absolute level of the threshold depends on the natural year-to-year variability in the base period (1951–1980), which is captured by the standard deviation ( $\sigma$ ). Highly unusual heat extremes are defined as 3-sigma events. For a normal distribution, 3-sigma events have a return time of 740 years. The 2012 U.S. heat wave and the 2010 Russian heat wave classify as 3-sigma and thus highly unusual events. Unprecedented heat extremes are defined as 5-sigma events. They have a return time of several million years. Monthly temperature data do not necessarily follow a normal distribution (for example, the distribution can have long tails, making warm events more likely) and the return times can be different from the ones expected in a normal distribution. Nevertheless, 3-sigma events are extremely unlikely and 5-sigma events have almost certainly never occurred over the lifetime of key ecosystems and human infrastructure.

**Hyper-aridity:** This refers to land areas with very low Aridity Index (AI) scores, generally coinciding with the great deserts. There is no universally standardized value for hyper-aridity, and values between 0 and 0.05 are classified in this report as hyper-arid.

**IPCC AR4, AR5:** The Intergovernmental Panel on Climate Change (IPCC) is the leading body of global climate change assessments. It comprises hundreds of leading scientists worldwide and on a regular basis publishes assessment reports which provide a comprehensive overview of the most recent scientific, technical, and socioeconomic information on climate change and its implications.

The Fourth Assessment Report (AR4) was published in 2007. The Fifth Assessment Report (AR5) was published in 2013/2014.

**ISI-MIP:** The first Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) is a community-driven modeling effort which provides cross-sectoral global impact assessments based on the newly developed climate Representative Concentration Pathways and socioeconomic scenarios. More than 30 models across five sectors (agriculture, water resources, biomes, health, and infrastructure) were incorporated in this modeling exercise.

**Pre-industrial Level (what it means to have present 0.8°C warming):** Pre-industrial level refers to the level of warming before/at the onset of industrialization. The instrumental temperature records show that the 20-year average of global-mean, near-surface air temperature in 1986–2005 was about 0.6°C higher than the average over 1851–1879. There are, however, considerable year-to-year variations and uncertainties in the data. In addition, the 20-year average warming over 1986–2005 is not necessarily representative of present-day warming. Fitting a linear trend over the period 1901–2010 gives a warming of 0.8°C since “early industrialization.” Global mean, near-surface air temperatures in the instrumental records of surface-air temperature have been assembled dating back to about 1850. The number of measurement stations in the early years is small and increases rapidly with time. Industrialization was well on its way by 1850 and 1900, which implies using 1851–1879 as a base period, or 1901 as a start for linear trend analysis might lead to an underestimate of current and future warming. However, global greenhouse-gas emissions at the end of the 19th century were still small and uncertainties in temperature reconstructions before this time are considerably larger.

**RCP:** Representative Concentration Pathways are based on carefully selected scenarios for work on integrated assessment modeling, climate modeling, and modeling and analysis of impacts. Nearly a decade of new economic data, information about emerging technologies, and observations of such environmental factors as land use and land cover change are reflected in this work. Rather than starting with detailed socioeconomic storylines to generate emissions scenarios, the RCPs are consistent sets of projections of only the components of radiative forcing (the change in the balance between incoming and outgoing radiation to the atmosphere caused primarily by changes in atmospheric composition) that are meant to serve as inputs for climate modeling. These radiative forcing trajectories are not associated with unique socioeconomic or emissions scenarios; instead, they can result from different combinations of economic, technological, demographic, policy, and institutional futures. RCP2.6, RCP4.5, RCP6 and RCP8.5 refer,

respectively, to a radiative forcing of +2.6 W/m<sup>2</sup>, +4.5 W/m<sup>2</sup>, +6 W/m<sup>2</sup> and +8.5 W/m<sup>2</sup> in the year 2100 relative to pre-industrial conditions.

**RCP2.6:** RCP2.6 refers to a scenario which is representative of the literature on mitigation scenarios aiming to limit the increase of global mean temperature to 2°C above pre-industrial levels. This emissions path is used by many studies that have been assessed for the IPCC 5th Assessment Report and is the underlying low emissions scenario for impacts assessed in other parts of this report. In this report, the RCP2.6 is referred to as a 2°C world (with the exception of sea-level rise, where the subset of model used actually leads to 1.5°C world—see Box 2.1, Definition of Warming Levels and Base Period in this Report).

**RCP8.5:** RCP8.5 refers to a scenario with a no-climate-policy baseline with comparatively high greenhouse gas emissions which is used by many studies that have been assessed for the IPCC Fifth Assessment Report (AR5). This scenario is also the underlying high-emissions scenario for impacts assessed in other parts of this report. In this report, the RCP8.5 is referred to as a 4°C world above the pre-industrial baseline period.

**Severe and extreme:** These terms indicate uncommon (negative) consequences. These terms are often associated with an additional qualifier like “highly unusual” or “unprecedented” that has a specific quantified meaning.

**SRES:** The Special Report on Emissions Scenarios, published by the IPCC in 2000, has provided the climate projections for the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change. The scenarios do not include mitigation assumptions. The SRES study included consideration of 40 different scenarios, each

making different assumptions about the driving forces determining future greenhouse gas emissions. Scenarios were grouped into four families (A1FI, A2, B1 and B2), corresponding to a wide range of high- and low-emissions scenarios.

**SREX:** The IPCC published a special report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) in 2012. The report provides an assessment of the physical and social factors shaping vulnerability to climate-related disasters and gives an overview of the potential for effective disaster risk management.

**Tipping element:** Following Lenton et al. (2008), the term tipping element describes large scale components of the Earth system possibly passing a tipping point. A tipping point “commonly refers to a critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system” (Lenton et al. 2008). The consequences of such shifts for societies and ecosystems are likely to be severe.

**Virtual water:** A measure of the water resources used in the production of agricultural commodities. International trade in such commodities thereby implies a transfer of virtual water resources from one country to another embedded in the products.

**WGI, WGII, WG III:** IPCC Working Group I assesses the physical scientific aspects of the climate system and climate change. IPCC Working Group II assesses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and options for adapting to it. IPCC Working Group III assesses the options for mitigating climate change through limiting or preventing greenhouse gas emissions and enhancing activities that remove them from the atmosphere.



