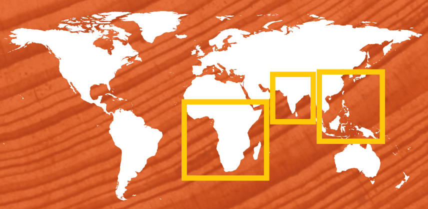
Executive Summary

4° Turn Down the Heat

Climate Extremes, Regional Impacts, and the Case for Resilience



THE WORLD BANK

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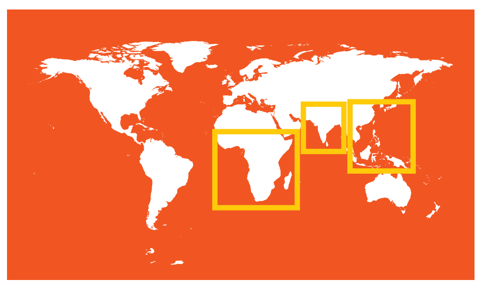

June 2013

A Report for the World Bank
by the Potsdam Institute for
Climate Impact Research and
Climate Analytics

THE WORLD BANK

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Contents

Acknowledgments

The report ***Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience*** is a result of contributions from a wide range of experts from across the globe. The report follows *Turn Down the Heat: Why a 4°C Warmer World Must be Avoided*, released in November 2012. We thank everyone who contributed to its richness and multidisciplinary outlook.

The report has been written by a team from the Potsdam Institute for Climate Impact Research and Climate Analytics, including Hans Joachim Schellnhuber, Bill Hare, Olivia Serdeczny, Michiel Schaeffer, Sophie Adams, Florent Baarsch, Susanne Schwan, Dim Coumou, Alexander Robinson, Marion Vieweg, Franziska Piontek, Reik Donner, Jakob Runge, Kira Rehfeld, Joeri Rogelj, Mahé Perette, Arathy Menon, Carl-Friedrich Schleussner, Alberte Bondeau, Anastasia Svirejeva-Hopkins, Jacob Schewe, Katja Frieler, Lila Warszawski and Marcia Rocha.

The ISI-MIP projections were undertaken by modeling groups at the following institutions: ORCHIDEE[1] (Institut Pierre Simon Laplace, France); JULES (Centre for Ecology and Hydrology, UK; Met Office Hadley Centre, UK; University of Exeter, UK); VIC (Norwegian Water Resources and Energy Directorate, Norway; Wageningen University, Netherlands); H08 (Institute for Environmental Studies, Japan); WaterGAP (Kassel University, Germany; Universität Frankfurt, Germany); MacPDM (University of Reading, UK; University of Nottingham, UK); WBM (City University of New York, USA); MPI-HM (Max Planck Institute for Meteorology, Germany); PCR-GLOBWB (Utrecht University, Netherlands); DBH (Chinese Academy of Sciences, China); MATSIRO (University of Tokyo, Japan); Hybrid (University of Cambridge, UK); Sheffield DGVM (University of Sheffield, UK; University of Bristol, UK); JeDi (Max Planck Institut für Biogeochemie, Germany); ANTHRO-BGC (Humboldt University of Berlin, Germany; Leibniz Centre for Agricultural Landscape Research, Germany); VISIT (National Institute for Environmental Studies, Japan); GEPIC (Eawag, Switzerland); EPIC (University of Natural Resources and Life Sciences, Vienna, Austria); pDSSAT (University of Chicago, USA); DAYCENT (Colorado State University, USA); IMAGE (PBL Netherlands Environmental Assessment Agency, Netherlands); PEGASUS (Tyndall Centre, University of East Anglia, UK); LPJ-GUESS (Lunds Universitet, Sweden); MAgPIE (Potsdam Institute, Germany); GLOBIOM (International Institute for Applied Systems Analysis, Austria); IMPACT (International Food Policy Research Institute, USA; International Livestock Research Institute, Kenya); DIVA (Global Climate Forum, Germany); MARA (London School of Hygiene and Tropical Medicine, UK); WHO CCRA Malaria (Umea University, Sweden); LMM 205 (The University of Liverpool, UK); MIASMA (Maastricht University, Netherlands); and VECTRI (Abdus Salam International Centre for Theoretical Physics, Italy).

[1] A full list of ISI-MIP modeling groups is given in Appendix 2 of the Main Report

The report was commissioned by the World Bank's Global Expert Team for Climate Change Adaptation and the Climate Policy and Finance Department. The Bank team, led by Kanta Kumari Rigaud and Erick Fernandes under the supervision of Jane Ebinger, worked closely with the Potsdam Institute for Climate Impact Research and Climate Analytics. The team comprised Raffaello Cervigni, Nancy Chaarani Meza, Charles Joseph Cormier, Christophe Crepin, Richard Damania, Ian Lloyd, Muthukumara Mani, and Alan Miller. Robert Bisset, Jayna Desai, and Venkat Gopalakrishnan led outreach efforts to partners, the scientific community, and the media. Patricia Braxton and Perpetual Boateng provided valuable support to the team.

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Foreword

The work of the World Bank Group is to end extreme poverty and build shared prosperity. Today, we have every reason to believe that it is within our grasp to end extreme poverty by 2030. But we will not meet this goal without tackling the problem of climate change.

Our first *Turn Down the Heat* report, released late last year, concluded the world would warm by 4°C by the end of this century if we did not take concerted action now.

This new report outlines an alarming scenario for the days and years ahead—what we could face in our lifetime. The scientists tell us that if the world warms by 2°C—warming which may be reached in 20 to 30 years—that will cause widespread food shortages, unprecedented heat-waves, and more intense cyclones. In the near-term, climate change, which is already unfolding, could batter the slums even more and greatly harm the lives and the hopes of individuals and families who have had little hand in raising the Earth's temperature.

Today, our world is 0.8°C above pre-industrial levels of the 18th century. We could see a 2°C world in the space of one generation.

The first *Turn Down the Heat* report was a wake-up call. This second scientific analysis gives us a more detailed look at how the negative impacts of climate change already in motion could create devastating conditions especially for those least able to adapt. The poorest could increasingly be hit the hardest.

For this report, we turned again to the scientists at the Potsdam Institute for Climate Impact Research and Climate Analytics. This time, we asked them to take a closer look at the tropics and prepare a climate forecast based on the best available evidence and supplemented with advanced computer simulations.

With a focus on Sub-Saharan Africa, South East Asia and South Asia, the report examines in greater detail the likely impacts for affected populations of present day, 2°C and 4°C warming on critical areas like agricultural production, water resources, coastal ecosystems and cities.

The result is a dramatic picture of a world of climate and weather extremes causing devastation and human suffering. In many cases, multiple threats of increasing extreme heat waves, sea-level rise, more severe storms, droughts and floods will have severe negative implications for the poorest and most vulnerable.

In Sub-Saharan Africa, significant crop yield reductions with 2°C warming are expected to have strong repercussions on food security, while rising temperatures could cause major loss of savanna grasslands threatening pastoral livelihoods. In South Asia, projected changes to the monsoon system and rising peak temperatures put water and food resources at severe risk. Energy security is threatened, too. While, across South East Asia, rural livelihoods are faced with mounting pressures as sea-level rises, tropical cyclones increase in intensity and important marine ecosystem services are lost as warming approaches 4°C.

Across all regions, the likely movement of impacted communities into urban areas could lead to ever higher numbers of people in informal settlements being exposed to heat waves, flooding, and diseases.

The case for resilience has never been stronger.

This report demands action. It reinforces the fact that climate change is a fundamental threat to economic development and the fight against poverty.

At the World Bank Group, we are concerned that unless the world takes bold action now, a disastrously warming planet threatens to put prosperity out of reach of millions and roll back decades of development.

In response we are stepping up our mitigation, adaptation, and disaster risk management work, and will increasingly look at all our business through a "climate lens."

But we know that our work alone is not enough. We need to support action by others to deliver bold ideas that will make the biggest difference.

I do not believe the poor are condemned to the future scientists envision in this report. In fact, I am convinced we can reduce poverty even in a world severely challenged by climate change.

We can help cities grow clean and climate resilient, develop climate smart agriculture practices, and find innovative ways to improve both energy efficiency and the performance of renewable energies. We can work with countries to roll back harmful fossil fuel subsidies and help put the policies in place that will eventually lead to a stable price on carbon.

We are determined to work with countries to find solutions. But the science is clear. There can be no substitute for aggressive national emissions reduction targets.

Today, the burden of emissions reductions lies with a few large economies. Not all are clients of the World Bank Group, but all share a commitment to ending poverty.

I hope this report will help convince everyone that the benefits of strong, early action on climate change far outweigh the costs.

We face a future that is precarious because of our warming planet. We must meet these challenges with political will, intelligence, and innovation. If we do, I see a future that eases the hardships of others, allows the poor to climb out of poverty, and provides young and old alike with the possibilities of a better life.

Join us in our fight to make that future a reality. Our successes and failures in this fight will define our generation.

Dr. Jim Yong Kim
President, World Bank Group

Executive Summary

Executive Summary

This report focuses on the risks of climate change to development in Sub-Saharan Africa, South East Asia and South Asia. Building on the 2012 report, *Turn Down the Heat: Why a 4°C Warmer World Must be Avoided*[1], this new scientific analysis examines the likely impacts of present day, 2°C and 4°C warming on agricultural production, water resources, and coastal vulnerability for affected populations. It finds many significant climate and development impacts are already being felt in some regions, and in some cases multiple threats of increasing extreme heat waves, sea-level rise, more severe storms, droughts and floods are expected to have further severe negative implications for the poorest. Climate-related extreme events could push households below the poverty trap threshold. High temperature extremes appear likely to affect yields of rice, wheat, maize and other important crops, adversely affecting food security. Promoting economic growth and the eradication of poverty and inequality will thus be an increasingly challenging task under future climate change. Immediate steps are needed to help countries adapt to the risks already locked in at current levels of 0.8°C warming, but with ambitious global action to drastically reduce greenhouse gas emissions, many of the worst projected climate impacts could still be avoided by holding warming below 2°C.

Scope of the Report

The first *Turn Down the Heat* report found that projections of global warming, sea-level rise, tropical cyclone intensity, aridity and drought are expected to be felt disproportionately in the developing countries around the equatorial regions relative to the countries at higher latitudes. This report extends this previous analysis by focusing on the risks of climate change to development in three critical regions of the world: Sub-Saharan Africa, South East Asia and South Asia.

While covering a range of sectors, this report focuses on how climate change impacts on agricultural production, water resources, coastal zone fisheries, and coastal safety are likely to increase, often significantly, as global warming climbs from present levels of 0.8°C up to 1.5°C, 2°C and 4°C above pre-industrial levels. This report illustrates the range of impacts that much of the developing world is already experiencing, and would be further exposed to, and it indicates how these risks and disruptions could be felt differently in other parts of the world. Figure 1 shows projections of temperature and sea-level rise impacts at 2°C and 4°C global warming.

The Global Picture

Scientific reviews published since the first *Turn Down the Heat* report indicate that recent greenhouse gas emissions and future emissions trends imply higher 21st century emission levels than previously projected. As a consequence, the likelihood of 4°C warming being reached or exceeded this century has increased, in the absence of near-term actions and further commitments to reduce emissions. This report reaffirms the International Energy Agency's 2012 assessment that in the absence of further mitigation action there is a 40 percent chance of warming exceeding 4°C by 2100 and a 10 percent chance of it exceeding 5°C in the same period.

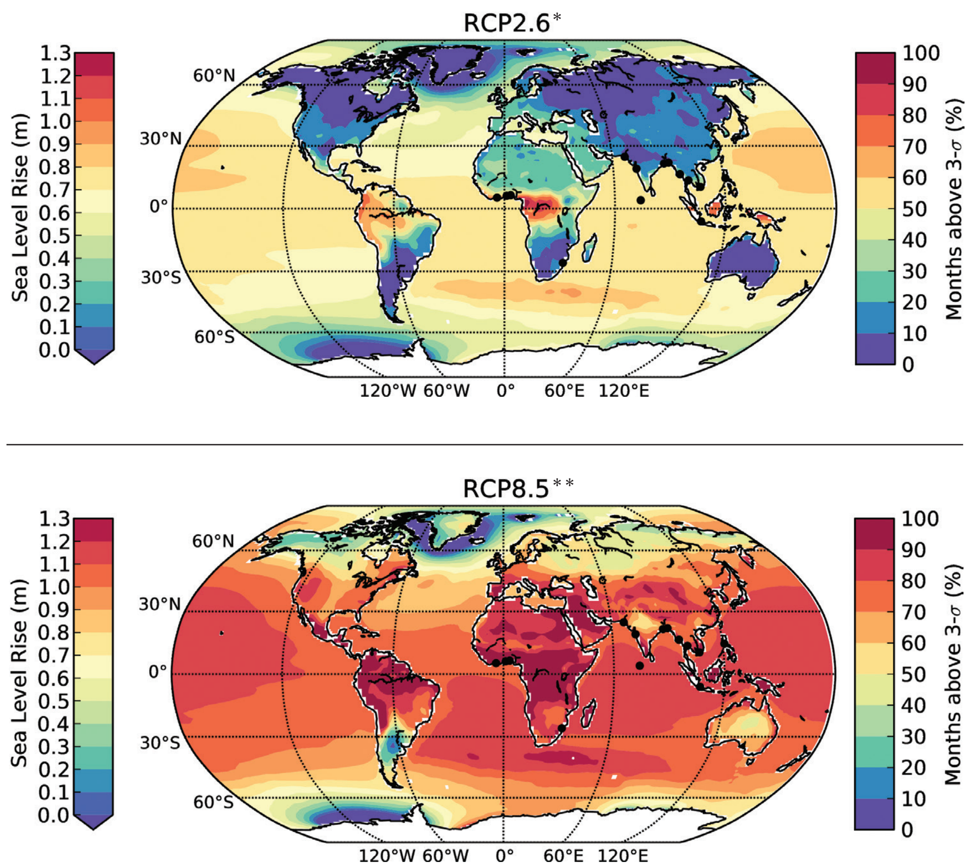
The 4°C scenario does not suggest that global mean temperatures would stabilize at this level; rather, emissions scenarios leading to such warming would very likely lead to further increases in both temperature and sea-level during the 22nd century. Furthermore,

1 *Turn Down the Heat: Why a 4°C Warmer World Must be Avoided*, launched by the World Bank in November 2012.

even at present warming of 0.8°C above pre-industrial levels, the observed climate change impacts are serious and indicate how dramatically human activity can alter the natural environment upon which human life depends.

The projected climate changes and impacts are derived from a combined approach involving a range of climate models of varying complexity, including the state of the art Coupled Model Intercomparison Project Phase 5 (CMIP5), semi-empirical modeling, the "Simple Climate Model" (SCM), the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC; see Appendix 1 of the Main Report) and a synthesis of peer reviewed literature.

Figure 1 Projected sea-level rise and northern-hemisphere summer heat events over land in a 2°C World (upper panel) and a 4°C World (lower panel)



Upper panel: In a 2°C world, sea-level rise is projected to be less than 70 cm (yellow over oceans) and the likelihood that a summer month's heat is unprecedented is less than 30 percent (blue/purple colors over land)

Lower panel: In a 4°C world, sea-level rise is projected to be more than 100 cm (orange over oceans) and the likelihood that a summer month's heat is unprecedented is greater than 60 percent (orange/red colors over land)

*RCP2.6, IPCC AR5 scenario aiming to limit the increase of global mean temperature to 2°C above the pre-industrial period.

**RCP8.5, IPCC AR5 scenario with no-climate-policy baseline and comparatively high greenhouse gas emissions. In this report, this scenario is referred to as a 4°C World above the pre-industrial period.

Key Findings Across the Regions

Among the key issues highlighted in this report are the early onset of climate impacts, uneven regional distribution of climate impacts, and interaction among impacts which accentuates cascade effects. For example:

1. **Unusual and unprecedented heat extremes[2]:** Expected to occur far more frequently and cover much greater land areas, both globally and in the three regions examined. For example, heat extremes in South East Asia are projected to increase substantially in the near term, and would have significant and adverse effects on humans and ecosystems under 2°C and 4°C warming.

2. **Rainfall regime changes and water availability:** Even without any climate change, population growth alone is expected to put pressure on water resources in many regions in the future. With projected climate change, however, pressure on water resources is expected to increase significantly.
    - Declines of 20 percent in water availability are projected for many regions under a 2°C warming and of 50 percent for some regions under 4°C warming. Limiting warming to 2°C would reduce the global population exposed to declining water availability to 20 percent.
    - South Asian populations are likely to be increasingly vulnerable to the greater variability of precipitation changes, in addition to the disturbances in the monsoon system and rising peak temperatures that could put water and food resources at severe risk.

3. **Agricultural yields and nutritional quality:** Crop production systems will be under increasing pressure to meet growing global demand in the future. Significant crop yield impacts are already being felt at 0.8°C warming.
    - While projections vary and are uncertain, clear risks emerge as yield reducing temperature thresholds for important crops have been observed, and crop yield improvements appear to have been offset or limited by observed warming (0.8°C) in many regions. There is also some empirical evidence that higher atmospheric levels of carbon dioxide (CO_2) could result in lower protein levels of some grain crops.
    - For the regions studied in this report, global warming above 1.5°C to 2°C increases the risk of reduced crop yields and production losses in Sub-Saharan Africa, South East Asia and South Asia. These impacts would have strong repercussions on food security and are likely to negatively influence economic growth and poverty reduction in the impacted regions.

4. **Terrestrial ecosystems:** Increased warming could bring about ecosystem shifts, fundamentally altering species compositions and even leading to the extinction of some species.
    - By the 2030s (with 1.2–1.3°C warming), some ecosystems in Africa, for example, are projected to experience maximum extreme temperatures well beyond their present range, with all African eco-regions exceeding this range by 2070 (2.1–2.7°C warming).
    - The distribution of species within savanna ecosystems are projected to shift from grasses to woody plants, as CO_2 fertilization favors the latter, although high temperatures and precipitation deficits might counter this effect. This shift will reduce available forage for livestock and stress pastoral systems and livelihoods.

5. **Sea-level rise:** Has been occurring more rapidly than previously projected and a rise of as much as 50 cm by the 2050s may be unavoidable as a result of past emissions: limiting warming to 2°C may limit global sea-level rise to about 70 cm by 2100.
    - As much as 100 cm sea-level rise may occur if emission increases continue and raise the global average temperature to 4°C by 2100 and higher levels thereafter. While the unexpectedly rapid rise over recent decades can now be explained by the accelerated loss of ice from the Greenland and Antarctic ice sheets, significant uncertainty remains as to the rate and scale of future sea-level rise.
    - The sea-level nearer to the equator is projected to be higher than the global mean of 100 cm at the end of the century. In South East Asia for example, sea-level rise is projected to be 10–15 percent higher than the global mean. Coupled with storm surges and tropical cyclones, this increase is projected to have devastating impacts on coastal systems.

6. **Marine ecosystems:** The combined effects of warming and ocean acidification are projected to cause major damages to coral reef systems and lead to losses in fish production, at least regionally.
    - Substantial losses of coral reefs are projected by the time warming reaches 1.5–2°C from both heat and ocean

[2] In this report, "unusual" and "unprecedented" heat extremes are defined by using thresholds based on the historical variability of the current local climate. The absolute level of the threshold thus depends on the natural year-to-year variability in the base period (1951–1980), which is captured by the standard deviation (sigma). 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 US heat wave and the 2010 Russian heat wave classify as 3-sigma events. Unprecedented heat extremes are defined as 5-sigma events. They have a return time of several million years. These events which have almost certainly never occurred to date are projected for the coming decades. See also Chapter 2 (Box 2.2).

acidification effects, with a majority of coral systems no longer viable at current locations. Most coral reefs appear unlikely to survive by the time 4°C warming is reached.

- Since the beginning of the Industrial Revolution, the pH of surface ocean waters has fallen by 0.1 pH units. Since the pH scale, like the Richter scale, is logarithmic, this change represents approximately a 30 percent increase in acidity. Future predictions indicate that ocean acidity will further increase as oceans continue to absorb carbon dioxide. Estimates of future carbon dioxide levels, based on business as usual emission scenarios, indicate that by the end of this century the surface waters of the ocean could be nearly 150 percent more acidic, resulting in pH levels that the oceans have not experienced for more than 20 million years.

Sub-Saharan Africa: Food Production at Risk

Sub-Saharan Africa is a rapidly developing region of over 800 million people, with 49 countries, and great ecological, climatic and cultural diversity. Its population for 2050 is projected to approach 1.5 billion people.

The region is confronted with a range of climate risks that could have far-reaching repercussions for Sub-Saharan Africa´s societies and economies in future. Even if warming is limited below 2°C, there are very substantial risks and projected damages, and as warming increases these are only expected to grow further. Sub-Saharan Africa is particularly dependent on agriculture for food, income, and employment, almost all of it rain-fed. Under 2°C warming, large regional risks to food production emerge; these risks would become stronger if adaptation measures are inadequate and the CO_2 fertilization effect is weak. Unprecedented heat extremes are projected over an increasing percentage of land area as warming goes from 2 to 4°C, resulting in significant changes in vegetative cover and species at risk of extinction. Heat and drought would also result in severe losses of livestock and associated impacts on rural communities.

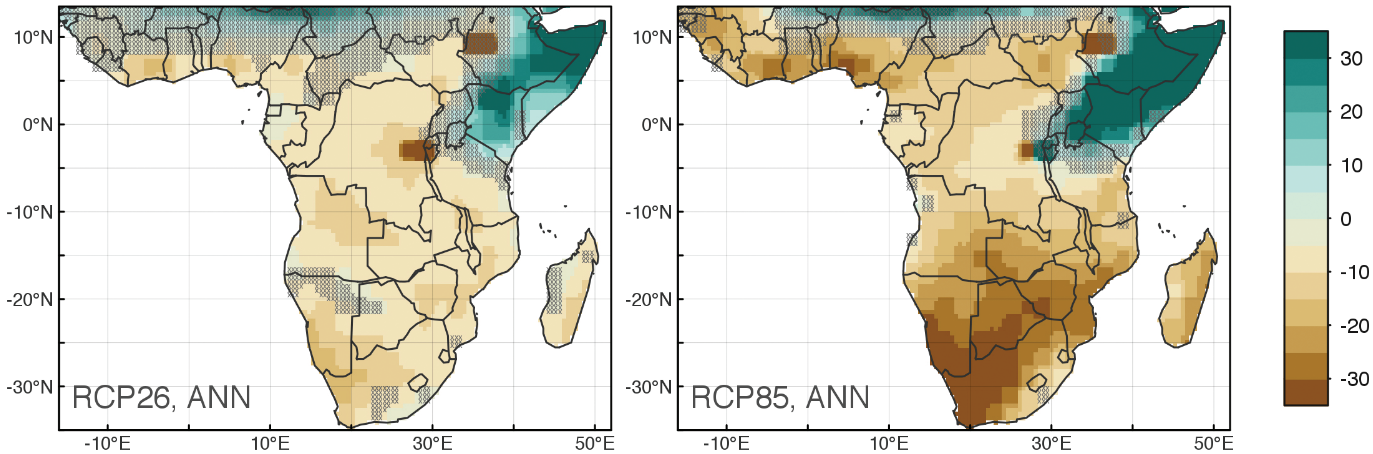
Likely Physical and Biophysical Impacts as a Function of Projected Climate Change

- **Water availability:** Under 2°C warming the existing differences in water availability across the region could become more pronounced.
  - In southern Africa, annual precipitation is projected to decrease by up to 30 percent under 4°C warming, and parts of southern and west Africa may see decreases in groundwater recharge rates of 50–70 percent. This is projected to lead to an overall increase in the risk of drought in southern Africa.
  - Strong warming and an ambiguous precipitation signal over central Africa is projected to increase drought risk there.
  - In the Horn of Africa and northern part of east Africa substantial disagreements exists between high-resolution regional and global climate models. Rainfall is projected by many global climate models to increase in the Horn of Africa and the northern part of east Africa, making these areas somewhat less dry. The increases are projected to occur during higher intensity rainfall periods, rather than evenly during the year, which increases the risk of floods. In contrast, high-resolution regional climate models project an increasing tendency towards drier conditions. Recent research showed that the 2011 Horn of Africa drought, particularly severe in Kenya and Somalia, is consistent with an increased probability of long-rains failure under the influence of anthropogenic climate change.
- **Projected aridity trends:** Aridity is projected to spread due to changes in temperature and precipitation, most notably in southern Africa (Figure 2). In a 4°C world, total hyper-arid and arid areas are projected to expand by 10 percent compared to the 1986–2005 period. Where aridity increases, crop yields are likely to decline as the growing season shortens.

Sector Based and Thematic Impacts

- **Agricultural production is expected to be affected in the near-term,** as warming shifts the climatic conditions that are conducive to current agricultural production. The annual average temperature is already above optimal values for wheat during the growing season over much of the Sub-Saharan Africa region and non-linear reductions in maize yield above certain temperature thresholds have been reported. Significant impacts are expected well before mid-century even for relatively low levels of warming. For example, a 1.5°C warming by the 2030s could lead to about 40 percent of present maize cropping areas being no longer suitable for current cultivars. In addition, under 1.5°C warming, significant negative impacts on sorghum suitability in the western Sahel and southern Africa are projected. Under warming of less than 2°C by the 2050s, total crop production could be reduced by 10 percent. For higher levels of warming there are indications that yields may decrease by around 15–20 percent across all crops and regions.
- **Crop diversification strategies will be increasingly important:** The study indicates that sequential cropping is the preferable option over single cropping systems under changing climatic conditions. Such crop diversification strategies have long been

Figure 2 Projected impact of climate change on the annual Aridity Index in Sub-Saharan Africa



Multi-model mean of the percentage change in the annual Aridity Index in a 2°C world (left) and a 4°C world (right) for Sub-Saharan Africa by 2071–2099 relative to 1951–1980. In non-hatched areas, at least 4/5 (80 percent) of models agree. In hatched areas, 2/5 (40 percent) of the models disagree. Note that a negative change corresponds to a shift to more arid conditions. Particular uncertainty remains for east Africa, where regional climate model projections tend to show an increase in precipitation, which would be associated with a decrease in the Aridity Index. A decrease in aridity does not necessarily imply more favorable conditions for agriculture or livestock, as it may be associated with increased flood risks.

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practiced in Africa, providing a robust knowledge base and opportunity for scaled up approaches in this area.

- **Diversification options for agro-pastoral systems are likely to decline** (e.g. switching to silvopastoral systems, irrigated forage production, and mixed crop-livestock systems) as climate change reduces the carrying capacity of the land and livestock productivity. For example, pastoralists in southern Ethiopia lost nearly 50 percent of their cattle and about 40 percent of their sheep and goats to droughts between 1995 and 1997.
- **Regime shifts in African ecosystems are projected** and could result in the extent of savanna grasslands being reduced. By the time 3°C global warming is reached, savannas are projected to decrease to approximately one-seventh of total current land area, reducing the availability of forage for grazing animals. Projections indicate that species composition of local ecosystems might shift, and negatively impact the livelihood strategies of communities dependent on them.
- **Health is expected to be significantly affected by climate change.** Rates of undernourishment are already high, ranging between 15–65 percent, depending on sub-region. With warming of 1.2–1.9°C by 2050, the proportion of the population undernourished is projected to increase by 25–90 percent compared to the present. Other impacts expected to accompany climate change include mortality and morbidity due to extreme events such as extreme heat and flooding.
- **Climate change could exacerbate the existing development challenge of ensuring that the educational needs of all children are met.** Several factors that are expected to worsen with climate change, including undernourishment, childhood stunting, malaria and other diseases, can undermine childhood educational performance. The projected increase in extreme monthly temperatures within the next few decades may also have an adverse effect on learning conditions.

South East Asia: Coastal Zones and Productivity at Risk

South East Asia has seen strong economic growth and urbanization trends, but poverty and inequality remain significant challenges in the region. Its population for 2050 is projected to approach 759 million people with 65 percent of the population living in urban areas. In 2010, the population was 593 million people with 44 percent of the population living in urban areas.

South East Asia has a high and increasing exposure to slow onset impacts associated with rising sea-level, ocean warming and increasing acidification combined with sudden-onset impacts associated with tropical cyclones and rapidly increasingly heat extremes. When these impacts combine they are likely to have adverse effects on several sectors simultaneously, ultimately undermining coastal livelihoods in the region. The deltaic areas of South East Asia that have relatively high coastal population densities are particularly vulnerable to sea-level rise and the projected increase in tropical cyclones intensity.

Likely Physical and Biophysical Impacts as a Function of Projected Climate Change

- **Heat extremes:** The South East Asian region is projected to see a strong increase in the near term in monthly heat extremes. Under 2°C global warming, heat extremes that are virtually absent at present will cover nearly 60–70 percent of total land area in summer, and unprecedented heat extremes up to 30–40 percent of land area in northern-hemisphere summer. With 4°C global warming, summer months that in today´s climate would be termed unprecedented, would be the new normal, affecting nearly 90 percent of the land area during the northern-hemisphere summer months.
- **Sea-level rise:** For the South East Asian coastlines, projections of sea-level rise by the end of the 21st century relative to 1986–2005 are generally 10–15 percent higher than the global mean. The analysis for Manila, Jakarta, Ho Chi Minh City, and Bangkok indicates that regional sea-level rise is likely to exceed 50 cm above current levels by about 2060, and 100 cm by 2090.
- **Tropical cyclones:** The intensity and maximum wind speed of tropical cyclones making landfall is projected to increase significantly for South East Asia; however, the total number of land-falling cyclones may reduce significantly. Damages may still rise as the greatest impacts are caused by the most intense storms. Extreme rainfall associated with tropical cyclones is expected to increase by up to a third reaching 50–80 mm per hour, indicating a higher level of flood risk in susceptible regions.
- **Saltwater intrusion:** A considerable increase of salinity intrusion is projected in coastal areas. For example, in the case of the Mahaka River region in Indonesia for a 100 cm sea-level rise by 2100, the land area affected by saltwater intrusion is expected to increase by 7–12 percent under 4°C warming.

Sector Based and Thematic Impacts

- **River deltas are expected to be impacted by projected sea-level rise and increases in tropical cyclone intensity,** along with land subsidence caused by human activities. These factors will increase the vulnerability of both rural and urban populations to risks including flooding, saltwater intrusion and coastal erosion. The three river deltas of the Mekong, Irrawaddy and Chao Phraya, all with significant land areas less than 2 m above sea-level, are particularly at risk. Aquaculture, agriculture, marine capture fisheries and tourism are the most exposed sectors to climate change impacts in these deltas.
- **Fisheries would be affected** as primary productivity in the world´s oceans is projected to decrease by up to 20 percent by 2100 relative to pre-industrial conditions. Fish in the Java Sea and the Gulf of Thailand are projected to be severely affected by increased water temperature and decreased oxygen levels, with very large reductions in average maximum body size by 2050. It is also projected that maximum catch potential in the southern Philippines could decrease by about 50 percent.
- **Aquaculture farms may be affected by several climate change stressors.** Increasing tropical cyclone intensity, salinity intrusion and rising temperatures may exceed the tolerance thresholds of regionally important farmed species. Aquaculture is a rapidly growing sector in South East Asia, which accounts for about 5 percent of Vietnam's GDP. As nearly 40 percent of dietary animal protein intake in South East Asia comes from fish, this sector also significantly contributes to food security in the region.
- **Coral reef loss and degradation would have severe impacts for marine fisheries and tourism.** Increasing sea surface temperatures have already led to major, damaging coral bleaching events in the last few decades.[3] Under 1.5°C warming and increasing ocean acidification, there is a high risk (50 percent probability) of annual bleaching events occurring as early as 2030 in the region (Figure 3). Projections indicate that all coral reefs in the South East Asia region are very likely to experience severe thermal stress by the year 2050, as well as chemical stress due to ocean acidification.

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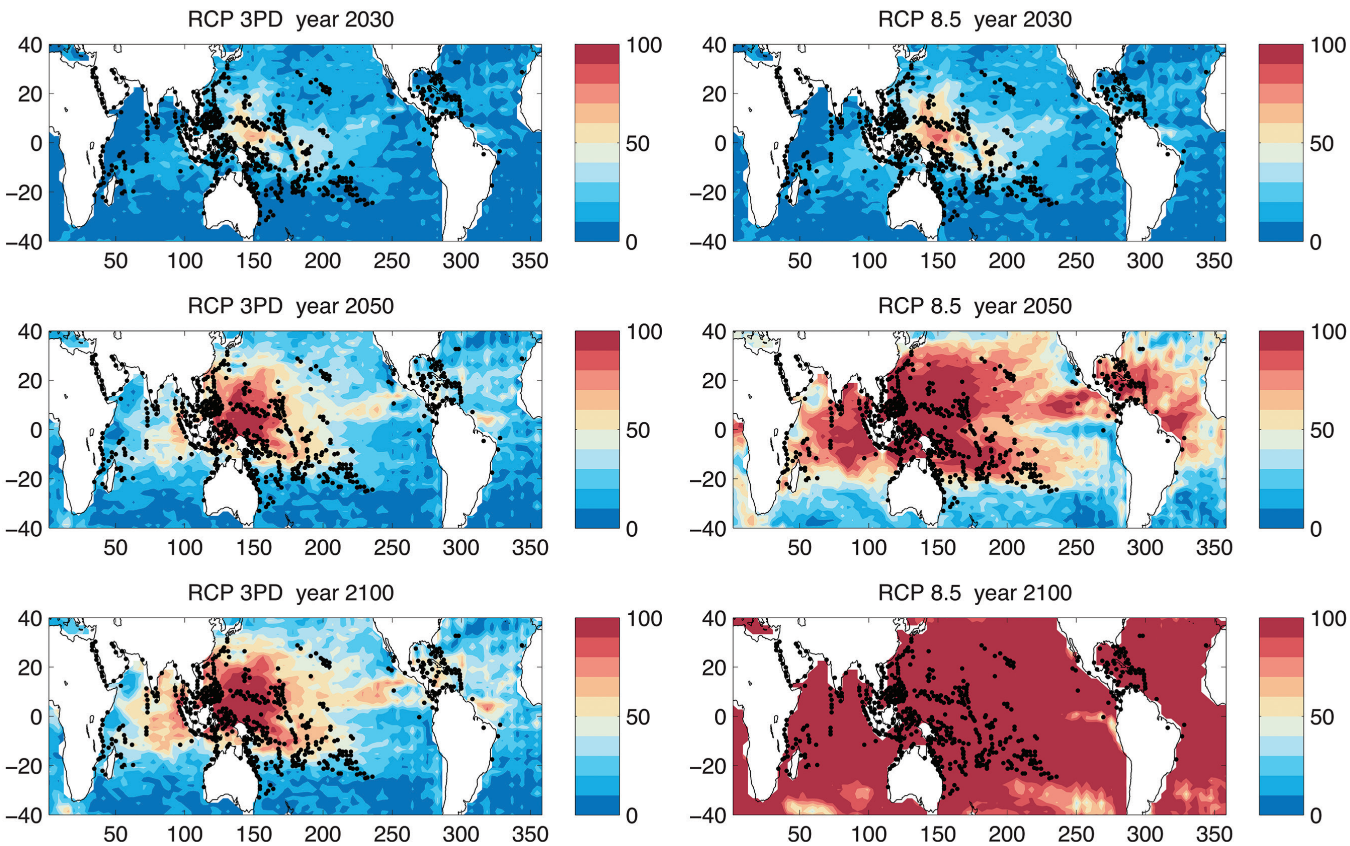
3 Coral bleaching can be expected when a regional warm season maximum temperature is exceeded by 1°C for more than four weeks and bleaching becomes progressively worse at higher temperatures and/or longer periods over which the regional threshold temperature is exceeded. Whilst corals can survive a bleaching event they are subject to high mortality and take several years to recover. When bleaching events become too frequent or extreme coral reefs can fail to recover.

Figure 3 Projected impact of climate change on coral systems in South East Asia



Probability of a severe bleaching event (DHW>8) occurring during a given year under scenario RCP2.6 (approximately 2°C, left) and RCP8.5 (approximately 4°C, right). Source: Meissner et al. (2012).

- **Agricultural production, particularly for rice in the Mekong Delta, is vulnerable to sea-level rise.** The Mekong Delta produces around 50 percent of Vietnam's total agricultural production and contributes significantly to the country's rice exports. It has been estimated that a sea-level rise of 30 cm, which could occur as early as 2040, could result in the loss of about 12 percent of crop production due to inundation and salinity intrusion relative to current levels.
- **Coastal cities concentrate increasingly large populations and assets exposed to climate change risks** including increased tropical storm intensity, long-term sea-level rise and sudden-onset coastal flooding. Without adaptation, the area of Bangkok projected to be inundated due to flooding linked to extreme rainfall events and sea-level rise increases from around 40 percent under 15 cm sea-level rise above present (which could occur by the 2030s), to about 70 percent under an 88cm sea-level rise scenario (which could occur by the 2080s under 4°C warming). Further, the effects of heat extremes are particularly pronounced in urban areas due to the urban heat island effect and could result in high human mortality and morbidity rates in cities. High levels of growth of both urban populations and GDP further increase financial exposure to climate change impacts in these areas. The urban poor are particularly vulnerable to excessive heat and humidity stresses. In 2005, 41 percent of the urban population of Vietnam and 44 percent of that of the Philippines lived in informal settlements. Floods associated with sea-level rise and storm surges carry significant risks in informal settlements, where lack of drainage and damages to sanitation and water facilities are accompanied by health threats.

South Asia: Extremes of Water Scarcity and Excess

South Asia is home to a growing population of about 1.6 billion people, which is projected to rise to over 2.2 billion people by 2050. It has seen robust economic growth in recent years, yet poverty remains widespread, with the world's largest concentration of poor people residing in the region. The timely arrival of the summer monsoon, and its regularity, are critical for the rural economy and agriculture in South Asia.

In South Asia, climate change shocks to food production and seasonal water availability appear likely to confront populations with ongoing and multiple challenges to secure access to safe drinking water, sufficient water for irrigation and hydropower production, and adequate cooling capacity for thermal power production. Potential impact hotspots such as Bangladesh are projected to be confronted by increasing challenges from extreme river floods, more intense tropical cyclones, rising sea-level and very high temperatures. While the vulnerability of South Asia's large and poor populations can be expected to be reduced in the future by economic development and growth, climate projections indicate that high levels of local vulnerability are likely to remain and persist.

Many of the climate change impacts in the region, which appear quite severe with relatively modest warming of 1.5–2°C, pose a significant challenge to development. Major investments in infrastructure, flood defense, development of high temperature and drought resistant crop cultivars, and major improvements in sustainability practices, for example in relation to groundwater extraction would be needed to cope with the projected impacts under this level of warming.

Likely Physical and Biophysical Impacts as a Function of Projected Climate Change

- **Heat extremes:** Irrespective of future emission paths, in the next twenty years a several-fold increase in the frequency of unusually hot and extreme summer months is projected. A substantial increase in mortality is expected to be associated with such heat extremes and has been observed in the past.
- **Precipitation:** Climate change will impact precipitation with variations across spatial and temporal scales. Annual precipitation is projected to increase by up to 30 percent in a 4°C world, however projections also indicate that dry areas such as in the north west, a major food producing region, would get drier and presently wet areas, get wetter. The seasonal distribution of precipitation is expected to become amplified, with a decrease of up to 30 percent during the dry season and a 30 percent increase during the wet season under a 4°C world (Figure 4). The projections show large sub-regional variations, with precipitation increasing during the monsoon season for currently wet areas (south, northeast) and precipitation decreasing for currently dry months and areas (north, northwest), with larger uncertainties for those regions in other seasons.
- **Monsoon:** Significant increases in inter-annual and intra-seasonal variability of monsoon rainfall are to be expected. With global mean warming approaching 4°C, an increase in intra-seasonal variability in the Indian summer monsoon precipitation of approximately 10 percent is projected. Large uncertainty, however, remains about the fundamental behavior of the Indian summer monsoon under global warming.
- **Drought:** The projected increase in the seasonality of precipitation is associated with an increase in the number of dry days, leading to droughts that are amplified by continued warming, with adverse consequences for human lives. Droughts are expected to pose an increasing risk in parts of the region. Although drought projections are made difficult by uncertain precipitation projections and differing drought indicators, some regions emerge to be at particularly high risk. These include north-western India, Pakistan and Afghanistan. Over southern India, increasing wetness is projected with broad agreement between climate models.
- **Glacial loss, snow cover reductions and river flow:** Over the past century, most of the Himalayan glaciers have been retreating. Melting glaciers and loss of snow cover pose a significant risk to stable and reliable water resources. Major rivers, such as the Ganges, Indus and Brahmaputra, depend significantly on snow and glacial melt water, which makes them highly susceptible to climate change-induced glacier melt and reductions in snowfall. Well before 2°C warming, a rapid increase in the frequency of low snow years is projected with a consequent shift towards high winter and spring runoff with increased flooding risks, and substantial reductions in dry season flow, threatening agriculture. These risks are projected to become extreme by the time 4°C warming is reached.
- **Sea-level rise:** With South Asian coastlines located close to the equator, projections of local sea-level rise show a stronger increase compared to higher latitudes. Sea-level rise is projected to be approximately 100–115 cm in a 4°C world and 60–80 cm in a 2°C world by the end of the 21st century relative to 1986–2005, with the highest values expected for the Maldives.

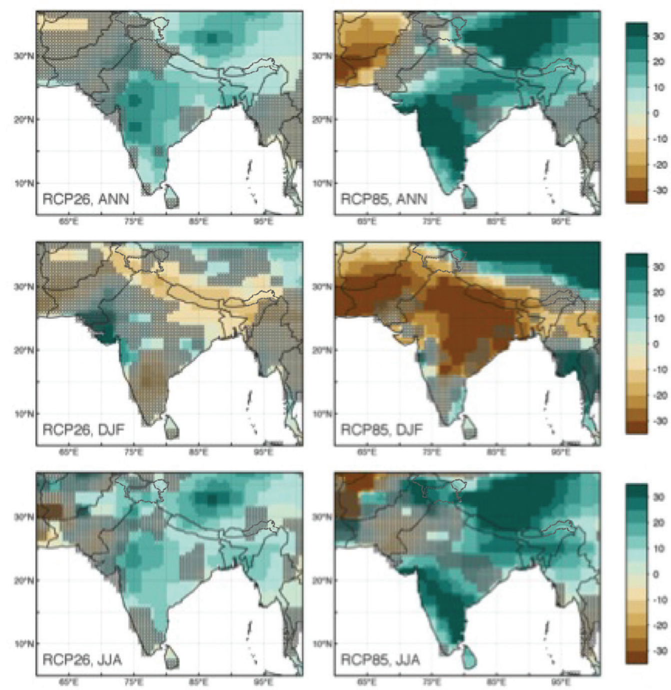
Sector Based and Thematic Impacts

- **Crop yields are vulnerable to a host of climate-related factors in the region,** including seasonal water scarcity, rising temperatures and salinity intrusion due to sea-level rise. Projections indicate an increasingly large and likely negative impact on crop yields with rising temperatures. The projected

CO_2 fertilization effect could help to offset some of the yield reduction due to temperature effects, but recent data shows that the protein content of grains may be reduced. For warming greater than 2°C, yield levels are projected to drop even with CO_2 fertilization.

- **Total crop production and per-capita calorie availability is projected to decrease significantly** with climate change. Without climate change, total crop production is projected to increase significantly by 60 percent in the region. Under a 2°C warming, by the 2050s, more than twice the imports might be required to meet per capita calorie demand when compared to a case without climate change. Decreasing food availability is related to significant health problems for affected populations, including childhood stunting, which is projected to increase by 35 percent compared to a scenario without climate change by 2050, with likely long-term consequences for populations in the region.
- **Water resources are already at risk in the densely populated countries of South Asia,** according to most methods for assessing this risk. For global mean warming approaching 4°C, a 10 percent increase in annual-mean monsoon intensity and a 15 percent increase in year-to-year variability of Indian summer monsoon precipitation is projected compared to normal levels during the first half of the 20th century. Taken together, these changes imply that an extreme wet monsoon that currently has a chance of occurring only once in 100 years is projected to occur every 10 years by the end of the century.
- **Deltaic regions and coastal cities are particularly exposed to compounding climate risks** resulting from the interacting effects of increased temperature, growing risks of river flooding, rising sea-level and increasingly intense tropical cyclones, posing a high risk to areas with the largest shares of poor populations. Under 2°C warming, Bangladesh emerges as an impact hotspot with sea-level rise causing threats to food production, livelihoods, urban areas and infrastructure. Increased river flooding combined with tropical cyclone surges also present significant risks. Human activity (building of irrigation dams, barrages, river embankments and diversions in the inland basins of rivers) can seriously exacerbate the risk of flooding downstream from extreme rainfall events higher up in river catchments.
- **Energy security is expected to come under increasing pressure from climate-related impacts to water resources.** The two dominant forms of power generation in the region are hydropower and thermal power generation (e.g., fossil fuel, nuclear and concentrated solar power), both of which can be undermined by inadequate water supply. Thermal power generation may also be affected through pressure placed on cooling systems due to increases in air and water temperatures.

Figure 4 Projected impact of climate change on annual, wet and dry season rainfall in South Asia



Multi-model mean of the percentage change in annual (top), dry-season (DJF, middle) and wet-season (JJA, bottom) precipitation for RCP2.6 (left) and RCP8.5 (right) for South Asia by 2071–2099 relative to 1951–1980. Hatched areas indicate uncertainty regions, with 2 out of 5 models disagreeing on the direction of change compared to the remaining 3 models.

Tipping Points, Cascading Impacts and Consequences for Human Development

This report shows that the three highly diverse regions of Sub-Saharan Africa, South East Asia, and South Asia that were analyzed are exposed to the adverse effects of climate change (Tables 1-3). Most of the impacts materialize at relatively low levels of warming, well before warming of 4°C above pre-industrial levels is reached.

Each of the regions is projected to experience a rising incidence of unprecedented heat extremes in the summer months by the mid-2020s, well before a warming of even 1.5°C. In fact, with temperatures at 0.8°C above pre-industrial levels, the last decade has seen extreme events taking high death tolls across all regions and causing wide-ranging damage to assets and agricultural production. As warming approaches 4°C, the severity of impacts is expected to grow with regions being affected differently (see Box 1).

Box 1: Regional Tipping Points, Cascading Impacts, and Development Implications

- **Sub-Saharan Africa's** food production systems are increasingly at risk from the impacts of climate change. Significant yield reductions already evident under 2°C warming are expected to have strong repercussions on food security and may negatively influence economic growth and poverty reduction in the region. Significant shifts in species composition and existing ecosystem boundaries could negatively impact pastoral livelihoods and the productivity of cropping systems and food security.
- **South East Asian** rural livelihoods are faced with mounting pressures as sea-level rises and important marine ecosystem services are expected to be lost as warming approaches 4°C. Coral systems are threatened with extinction and their loss would increase the vulnerability of coastlines to sea-level rise and storms. The displacement of impacted rural and coastal communities resulting from the loss of livelihood into urban areas could lead to ever higher numbers of people in informal settlements being exposed to multiple climate impacts, including heat waves, flooding, and disease.
- **South Asian** populations in large parts depend on the stability of the monsoon, which provides water resources for most of the agricultural production in the region. Disturbances to the monsoon system and rising peak temperatures put water and food resources at severe risk. Particularly in deltaic areas, populations are exposed to the multiple threats of increasing tropical cyclone intensity, sea-level rise, heat extremes and extreme precipitation. Such multiple impacts can have severe negative implications for poverty eradication in the region.

Tipping Points and Cascading Impacts

As temperatures continue to rise, there is an increased risk of critical thresholds being breached. At such "tipping points", elements of human or natural systems—such as crop yields, dry season irrigation systems, coral reefs, and savanna grasslands—are pushed beyond critical thresholds, leading to abrupt system changes and negative impacts on the goods and services they provide. Within the agricultural sector, observed high temperature sensitivity in some crops (e.g., maize), where substantial yield reductions occur when critical temperatures are exceeded, points to a plausible threshold risk in food production regionally. In a global context, warming induced pressure on food supplies could have far-reaching consequences.

Some major risks cannot yet be quantified adequately: For example, while large uncertainty remains, the monsoon has been identified as a potential tipping element of the Earth system. Physically plausible mechanisms for an abrupt change in the Indian monsoon towards a drier, lower rainfall state could precipitate a major crisis in the South Asian region.

Climate impacts can create a domino-effect and thereby ultimately affect human development. For example, decreased yields and lower nutritional value of crops could cascade throughout society by increasing the level of malnutrition and childhood stunting, causing adverse impacts on educational performance. These effects can persist into adulthood with long-term consequences for human capital that could substantially increase future development challenges. Most of the impacts presented in the regional analyses are not unique to these regions. For example, global warming impacts on coral reefs worldwide could have cascading impacts on local livelihoods, and tourism.

Multi-Sectoral Hotspots

Under 4°C warming, most of the world's population is likely to be affected by impacts occurring simultaneously in multiple sectors. Furthermore, these cascading impacts will likely not be confined to one region only; rather they are expected to have far-reaching repercussions across the globe. For example, impacts in the agricultural sector are expected to affect the global trade of food commodities, so that production shocks in one region can have wide-ranging consequences for populations in others. Thus, vulnerability could be greater than suggested by the sectoral analysis of the assessed regions due to the global interdependence, and impacts on populations are by no means limited to those that form the focus of this report. Many of the climatic risk factors are concentrated in the tropics. However, no region is immune to the impacts of climate change. In fact, under 4°C warming, most of the world´s population is likely to be affected by impacts occurring simultaneously in multiple sectors.

Results from the recent Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) were used to assess 'hotspots' where considerable impacts in one location occur concurrently in more than one sector (agriculture, water resources, ecosystems and health (malaria)). The proportion of the global population affected contemporaneously by multiple impacts increases significantly under higher levels of warming. Assuming fixed year-2000 population levels and distribution, the proportion of people exposed to multiple stressors across these sectors would increase by 20 percent under 2°C warming to more than 80 percent under 4°C warming above pre-industrial levels. This novel analysis[4] finds exposure hotspots to be the southern Amazon Basin, southern Europe, east Africa and the north of South Asia. The Amazon and

[4] Based on the first inter-sectoral climate model intercomparison, the first round of which was concluded in early 2013. Papers are in revision at the time of writing this report.

the East African highlands are particularly notable due to their exposure to three overlapping sectors. Small regions in Central America and West Africa are also affected.

Consequences for Development

Climate change is already undermining progress and prospects for development and threatens to deepen vulnerabilities and erode hard-won gains. Consequences are already being felt on every continent and in every sector. Species are being lost, lands are being inundated, and livelihoods are being threatened. More droughts, more floods, more strong storms, and more forest fires are taxing individuals, businesses and governments. Climate-related extreme events can push households below the poverty trap threshold, which could lead to greater rural-urban migration (see Box 2). Promoting economic growth and the eradication of poverty and inequality will thus be an increasingly challenging task under future climate change.

Actions must be taken to mitigate the pace of climate change and to adapt to the impacts already felt today. It will be impossible to lift the poorest on the planet out of poverty if climate change proceeds unchecked. Strong and decisive action must be taken to avoid a 4°C world—one that is unmanageable and laden with unprecedented heat waves and increased human suffering. It is not too late to hold warming near 2°C, and build resilience to temperatures and other climate impacts that are expected to still pose significant risks to agriculture, water resources, coastal infrastructure, and human health. A new momentum is needed. Dramatic technological change, steadfast and visionary political will, and international cooperation are required to change the trajectory of climate change and to protect people and ecosystems. The window for holding warming below 2°C and avoiding a 4°C world is closing rapidly, and the time to act is now.

Box 2: New Clusters of Vulnerability—Urban Areas

One of the common features that emerge from the regional analyses is of new clusters of vulnerability appearing in urban areas.

Urbanization rates are high in developing regions. For example, by 2050, it is projected that up to 56 percent of Sub-Saharan Africa's population will live in urban areas compared to 36 percent in 2010. Although the urbanization trend is driven by a host of factors, climate change is becoming an increasingly significant driver as it places rural and coastal livelihoods under mounting pressure.

While rural residents are expected to be exposed to a variety of climatic risk factors in each region, a number of factors define the particular vulnerability of urban dwellers, especially the urban poor, to climate change impacts. For example:

- Extreme heat is felt more acutely in cities where the built-up environments amplify temperatures.
- As many cities are located in coastal areas, they are often exposed to flooding and storm surges.
- Informal settlements concentrate large populations and often lack basic services, such as electricity, sanitation, health, infrastructure and durable housing. In such areas, people are highly exposed to extreme weather events, such as storms and flooding. For example, this situation is the case in Metro Manila in the Philippines, or Kolkata in India, where poor households are located in low-lying areas or wetlands that are particularly vulnerable to tidal and storm surges.
- Informal settlements often provide conditions particularly conducive to the transmission of vector and water borne diseases, such as cholera and malaria that are projected to become more prevalent with climate change.
- The urban poor have been identified as the group most vulnerable to increases in food prices following production shocks and declines that are projected under future climate change.

Climate change poses a particular threat to urban residents and at the same time is expected to further drive urbanization, ultimately placing more people at risk to the clusters of impacts outlined above. Urban planning and enhanced social protection measures, however, provide the opportunity to build more resilient communities in the face of climate change.

Table 1: Climate Impacts in Sub-Saharan Africa

RISK/IMPACT		0.8°C WARMING (Observed)	2°C WARMING (2040s)[1]	4°C WARMING (2080s)
Heat extremes	Unusual heat extremes	Virtually absent	About 45 percent of land in austral summer months (DJF)	>85 percent of land in austral summer months (DJF)
	Unprecedented heat extremes	Absent	About 15 percent of land in austral summer months (DJF)	>55 percent of land in austral summer months (DJF)
Drought		Increasing drought trends observed since 1950	Likely risk of severe drought in southern and central Africa, increased risk in west Africa, possible decrease in east Africa but west and east African projections are uncertain[2]	Likely risk of extreme drought in southern Africa and severe drought in central Africa, increased risk in west Africa, possible decrease in east Africa, but west and east African projections are uncertain[3]
Aridity		Increased drying[4]	Area of hyper-arid and arid regions grows by 3 percent	Area of hyper-arid and arid regions grows by 10 percent
Sea-level rise			70cm (60–80cm) by 2080–2100	105 (85–125cm) by 2080–2100
Ecosystem shifts			10–15 percent Sub-Saharan species at risk of extinction (assuming warming too rapid to allow migration of species) [5]	
Water availability (Run-off / Groundwater recharge)			50–70 percent decrease in recharge rates in western southern Africa and southern west Africa; 30 percent increase in recharge rate in some parts of eastern southern Africa and east Africa[6]	Increase in blue water availability in east Africa and parts of west Africa[7]; decrease in green water availability in most of Africa, except parts of east Africa
Crop yields, areas and food production	Crop growing areas		Projected climate over less than 15 percent of maize, millet and sorghum areas overlaps with present-day climate of crop-growing areas	Reduced length of growing period by more than 20 percent
	Crop production	Baseline of approximately 81 million tonnes in 2000, about 121 kg/capita	Without climate change, a large projected increase of total production to 192 million tonnes that fails to keep up with population growth, hence decrease to 111 kg/capita. With climate change smaller increase to 176 million tonnes and further decrease to 101 kg/capita[8]	
Yields	All crops		Increased crop losses and damages (maize, sorghum, wheat, millet, groundnut, cassava)[9]	
Livestock		Severe drought impacts on livestock[10]		10 percent increase in yields of *B. decumbens* (pasture species) in east and southern Africa; 4 percent and 6 percent decrease in central and west Africa[11]
Marine fisheries			Significant reduction in available protein; economic and job losses projected[12]	
Coastal areas				Approximately 18 million people flooded per year without adaptation[13]
Health and poverty			Undernourishment is expected to increase significantly, and those affected by moderate and severe stunting is expected to increase[14]	

Table 2: Climate Impacts in South East Asia

RISK/IMPACT		0.8°C WARMING (Observed)	2°C WARMING (2040s)[1]	4°C WARMING (2080s)
Heat extremes	Unusual heat extremes	Virtually absent	About 60–70 percent of land in boreal summer months (JJA)	>90 percent of land in boreal summer months (JJA)
	Unprecedented heat extremes	Absent	30–40 percent of land area during boreal summer months (JJA)[15]	>80 percent of land area during boreal summer months (JJA)
Tropical cyclones			Overall decrease in tropical cyclone frequency [16,17]; global increase in tropical cyclone rainfall; increasing frequency of category 5 storms[18]	Decreased number of tropical cyclones making landfall, but maximum wind velocity at the coast is projected to increase by about 6 percent for mainland South East Asia and about 9 percent for the Philippines
Sea-level rise			75cm (65–85cm) by 2080–2100	110 cm (85–130 cm) by 2080–2100, lower around Bangkok by 5 cm
Sea-level rise impacts	Coastal erosion (loss of land)	For the south Hai Thinh commune in the Vietnamese Red River delta, about 34 percent (12 percent) of the increase of erosion rate between 1965 and 1995 (1995 and 2005) has been attributed to the direct effect of sea-level rise[19]		Mekong delta significant increase in coastal erosion[20]
	Population exposure	20 million people in South East Asian cities exposed to coastal flooding in 2005[21]		8.5 million people more than at present are projected to be exposed to coastal flooding by 2100 for global sea-level rise of 1 m[22]
	City exposure			Ho Chi Minh City—up to 60 percent of the built-up area projected to be exposed[23] to 1 m sea-level rise
Salinity intrusion		Mekong River delta (2005): Long An province's sugar cane production diminished by 5–10 percent; and significant rice in Duc Hoa district was destroyed[24]		Mahakam river region in Indonesia, increase in land area affected by 7–12 percent[25]
Ecosystem impacts (Coral reefs / coastal wetlands)			Nearly all coral reefs experience severe thermal stress under warming levels of 1.5–2°C	Coral reefs subject to severe bleaching events annually and coastal wetland area decrease[26]
Aquaculture			Estimations of the costs of adapting[27] aquaculture in South East Asia range from US$130–190 million per year from 2010–2050	
Marine fisheries			Decrease in maximum catch potential around the Philippines and Vietnam[28]	Markedly negative trend in bigeye tuna[29]
Health and poverty			The relative risk of diarrhoea is expected to increase[30]	
Tourism			Thailand, Indonesia, the Philippines, Myanmar and Cambodia among the most vulnerable tourism destinations[31]	

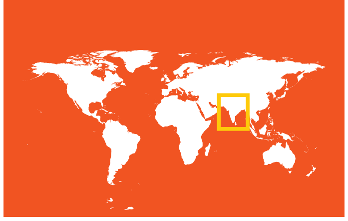


Table 3: Climate Impacts in South Asia

RISK/IMPACT		0.8°C WARMING (Observed)	2°C WARMING (2040s)[1]	4°C WARMING (2080s)
Heat extremes	Unusual heat extremes	Virtually absent	About 20 percent of land in boreal summer months (JJA)	>70 percent of land in boreal summer months (DJF)
	Unprecedented heat extremes	Absent	<5 percent of land in boreal summer months (JJA), except for the southernmost tip of India and Sri Lanka with 20-30 percent of summer months experiencing unprecedented heat	>40 percent of land in boreal summer months (DJF)
Drought				Increased drought over northwestern India, Pakistan, and Afghanistan[32]. Increased length of dry spells in eastern India and Bangladesh[33]
Sea-level rise			70cm (60–80cm) by 2080–2100[34]	105 cm (85–125cm) by 2080–2100, higher by 5–10 cm around Maldives, Kolkata
Tropical cyclones			Increasingly severe tropical cyclone impacts[35]	
Flooding			Increasingly severe flooding[36]	By 2070 approximately 1.5 million people are projected to be affected by coastal floods in the coastal cities of Bangladesh[37]
River run-off	Indus		Mean flow increase of about 65 percent[38]	
	Ganges		20 percent increase in run-off[39]	50 percent increase in run-off
	Brahmaputra		Very substantial reductions in late spring and summer flow[40]	
Water availability	Overall	In India, gross per capita water availability is projected to decline due to population growth[41]	Food water requirements in India projected to exceed green water availability[42, 43]. Around 3°C, it is very likely that per capita water availability in South Asia will decrease by more than 10 percent[44]	
	Groundwater recharge	Groundwater resources already under stress[45]	Climate change is projected to further aggravate groundwater stress	
Crop production			Overall crop production is projected to increase by only 12 percent above 2000 levels (instead of a 60 percent increase without climate change), leading to a one third decline in per capita crop production[46]	
Yields	All crops	Reduced rice yields, especially in rain-fed areas	Crop yield decreases regardless of potentially positive effects	
Health and poverty	Malnutrition and childhood stunting		With climate change percentages increase to 14.6 percent and about 5 percent respectively[47]	
	Malaria		Relative risk of malaria projected to increase by 5 percent in 2050[48]	
	Diarrheal disease		Relative risk of diarrheal disease increase by 1.4 percent compared to 2010 baseline by 2050	
	Heat waves vulnerability	New Delhi exhibits a 4 percent increase in heat-related mortality per 1°C above the local heat threshold of 20°C[49]	Most South Asian countries are likely to experience a very substantial increase in excess mortality due to heat stress by the 2090s[50]	

ENDNOTES

1 Years indicate the decade during which warming levels are exceeded in a business-as-usual scenario, not in mitigation scenarios limiting warming to these levels, or below, since in that case the year of exceeding would always be 2100, or not at all.

2 This is the general picture from CMIP5 global climate models; however, significant uncertainty appears to remain. Observed drought trends (Lyon and DeWitt 2012) and attribution of the 2011 drought in part to human influence (Lott et al. 2013) leaves significant uncertainty as to whether the projected increased precipitation and reduced drought are robust (Tierney, Smerdon, Anchukaitis, and Seager 2013).

3 Dai (2012). CMIP5 models under RCP4.5 for drought changes 2050–99, warming of about 2.6°C above pre-industrial levels.

4 see Endnote 2.

5 Parry et al. (2007).

6 Temperature increase of 2.3°C and 2.1°C for the period 2041–2079 under SRES A2 and B2 (Döll, 2009).

7 Gerten et al. (2011).

8 Nelson et al. (2010).

9 Schlenker and Lobell (2010).

10 FAO (2008).

11 Thornton et al. (2011).

12 Lam, Cheung, Swartz, & Sumaila (2012). Applying the same method and scenario as (Cheung et al., 2010).

13 Hinkel et al. (2011) high SLR scenario 126 cm by 2100. In the no sea-level rise scenario, only accounting for delta subsidence and increased population, up to 9 million people would be affected.

14 Lloyd, Kovats, and Chalabi (2011) estimate the impact of climate-change-induced changes to crop productivity on undernourished and stunted children under five years of age by 2050 and find that the proportion of undernourished children is projected to increase by 52 percent, 116 percent, 82 percent, and 142 percent in central, east, south, and west Sub-Saharan Africa, respectively. The proportion of stunting among children is projected to increase by 1 percent (for moderate stunting) or 30 percent (for severe stunting); 9 percent or 55 percent; 23 percent or 55 percent; and 9 percent or 36 percent for central, east, south, and west Sub-Saharan Africa.

15 Beyond 5-sigma under 2°C warming by 2071–2099.

16 Held and Zhao (2011).

17 Murakami, Wang, et al. (2012).

18 Murakami, Wang, et al. (2012). Future (2075–99) projections SRES A1B scenario.

19 Duc, Nhuan, & Ngoi (2012).

20 1m sea-level rise by 2100 (Mackay and Russell, 2011).

21 Hanson et al. (2011).

22 Brecht et al. (2012). In this study, urban population fraction is held constant over the 21st century.

23 Storch & Downes (2011). In the absence of adaptation, the planned urban development for the year 2025 contributes to increase Ho Chi Minh City exposure to sea-level rise by 17 percent.

24 MoNRE (2010) states "Sea-level rise, impacts of high tide and low discharge in dry season contribute to deeper salinity intrusion. In 2005, deep intrusion (and more early than normal), high salinity and long-lasting salinization occurred frequently in Mekong Delta provinces."

25 Under 4°C warming and 1 m sea-level rise by 2100 (Mcleod, Hinkel et al., 2010).

26 Meissner, Lippmann, & Sen Gupta (2012).

27 US$190.7 million per year for the period 2010–2020 (Kam, Badjeck, Teh, Teh, & Tran, 2012); US$130 million per year for the period 2010–2050 (World Bank, 2010).

28 Maximum catch potential (Cheung et al., 2010).

29 Lehodey et al. (2010). In a 4°C world, conditions for larval spawning in the western Pacific are projected to have deteriorated due to increasing temperatures. Overall adult mortality is projected to increase, leading to a markedly negative trend in biomass by 2100.

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Abbreviations

°C	degrees Celsius
3-sigma events	Events that are three standard deviations outside the historical mean
5-sigma events	Events that are five standard deviations outside the historical mean
AI	Aridity Index
ANN	Annual
AOGCM	Atmosphere-Ocean General Circulation Model
AR4	Fourth Assessment Report of the Intergovernmental Panel on Climate Change
AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change
BAU	Business as Usual
$CaCO_3$	Calcium Carbonate
CAT	Climate Action Tracker
CMIP5	Coupled Model Intercomparison Project Phase 5
CO_2	Carbon Dioxide
DIVA	Dynamic Interactive Vulnerability Assessment
DJF	December January February
ECS	Equilibrium Climate Sensitivity
GCM	General Circulation Model
GDP	Gross Domestic Product
FPU	Food Productivity Units
GFDRR	Global Facility for Disaster Reduction and Recovery
IAM	Integrated Assessment Model
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISI-MIP	Inter-Sectoral Impact Model Intercomparison Project
JJA	June July August
MAGICC	Model for the Assessment of Greenhouse-gas Induced Climate Change
MGIC	Mountain Glaciers and Ice Caps
NH	Northern Hemisphere
OECD	Organisation for Economic Cooperation and Development
PDSI	Palmer Drought Severity Index
ppm	parts per million
RCP	Representative Concentration Pathway
SCM	Simple Climate Model
SLR	Sea-level Rise
SRES	IPCC Special Report on Emissions Scenarios
SREX	IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
SSA	Sub-Saharan Africa
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNRCO	United Nations Resident Coordinator's Office
USAID	United States Agency for International Development
WBG	World Bank Group

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, which all share the limited range of climatic and environmental conditions within that biome.

C3/C4 plants refers to two types of photosynthetic biochemical "pathways". C3 plants include more than 85 percent of plants on Earth (e.g. most trees, wheat, rice, yams and potatoes) and respond well to moist conditions and to additional carbon dioxide in the atmosphere. C4 plants (for example savanna grasses, maize, sorghum, millet, sugarcane) are more efficient in water and energy use and outperform C3 plants in hot and dry conditions.

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

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-projections data. The project provided a framework for coordinated climate change experiments and includes simulations for assessment in the IPCC´s AR5.

CO_2 fertilization The CO_2 fertilization effect may increase the rate of photosynthesis mainly in C3 plants and increase water use efficiency, thereby producing increases in agricultural C3 crops in grain mass and/or number. This effect may to some extent offset the negative impacts of climate change, 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_2, as well as on other limiting factors including soil nutrients, water and light.

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 forcings 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 to 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 products. It is calculated without deductions for depreciation of fabricated assets or for depletion and degradation of natural resources.

GDP (PPP) per capita is GDP on a purchasing power parity basis divided by population. Please note: Whereas PPP estimates for OECD countries are quite reliable, PPP estimates for developing countries are often rough approximations.

Hyper-aridity Land areas with very low Aridity Index (AI), 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 give a comprehensive overview over the most recent scientific, technical and socio-economic information on climate change and its implications. The Fourth Assessment Report (AR4) was published in 2007. The upcoming Fifth Assessment Report (AR5) will be completed 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 (RCPs)] and socio-economic scenarios. More than 30 models across five sectors (agriculture, water resources, biomes, health and infrastructure) participated in this modeling exercise.

MAGICC Carbon-cycle/climate model of "reduced complexity," here applied in a probabilistic set-up to provide "best-guess" global-mean warming projections, with uncertainty ranges related to the uncertainties in carbon-cycle, climate system and climate sensitivity. The model is constrained by historical observations of hemispheric land/ocean temperatures and historical estimates for ocean heat-uptake, reliably determines the atmospheric burden of CO_2 concentrations compared to high-complexity carbon-cycle models and is also able to project global-mean near-surface warming in line with estimates made by GCMs.

Pre-industrial levels (what it means to have present 0.8°C warming) 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 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 to 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, but 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 (RCPs) 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 environmental factors, such 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 input for climate modeling. These radiative forcing trajectories are not associated with unique socioeconomic or emissions scenarios, and instead can result from different combinations of economic, technological, demographic, policy, and institutional futures.

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 the pre-industrial period. This emissions path is used by many studies that are being assessed for the IPCC´s Fifth Assessment Report and is the underlying low emissions scenario for impacts assessed in other parts of this report. In this report we refer to the RCP2.6 as a 2°C World.

RCP8.5 RCP8.5 refers to a scenario with no-climate-policy baseline with comparatively high greenhouse gas emissions which is used by many studies that are being assessed for the upcoming 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 we refer to the RCP8.5 as a 4°C World above the pre-industrial period.

Severe & extreme Indicating uncommon (negative) consequences. These terms are often associated with an additional qualifier like “unusual” or “unprecedented” that has a specific quantified meaning (see “Unusual & unprecedented”).

SRES The Special Report on Emissions Scenarios (SRES), published by the IPCC in 2000, has provided the climate projections for the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). They do not include mitigation assumptions. The SRES study includes consideration of 40 different scenarios, each making different assumptions about the driving forces determining future greenhouse gas emissions. Scenarios are grouped into four families, corresponding to a wide range of high and low emission scenarios.

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

Unusual & unprecedented In this report, 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 thus depends on the natural year-to-year variability in the base period (1951–1980), which is captured by the standard deviation (sigma). 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 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.

THE WORLD BANK