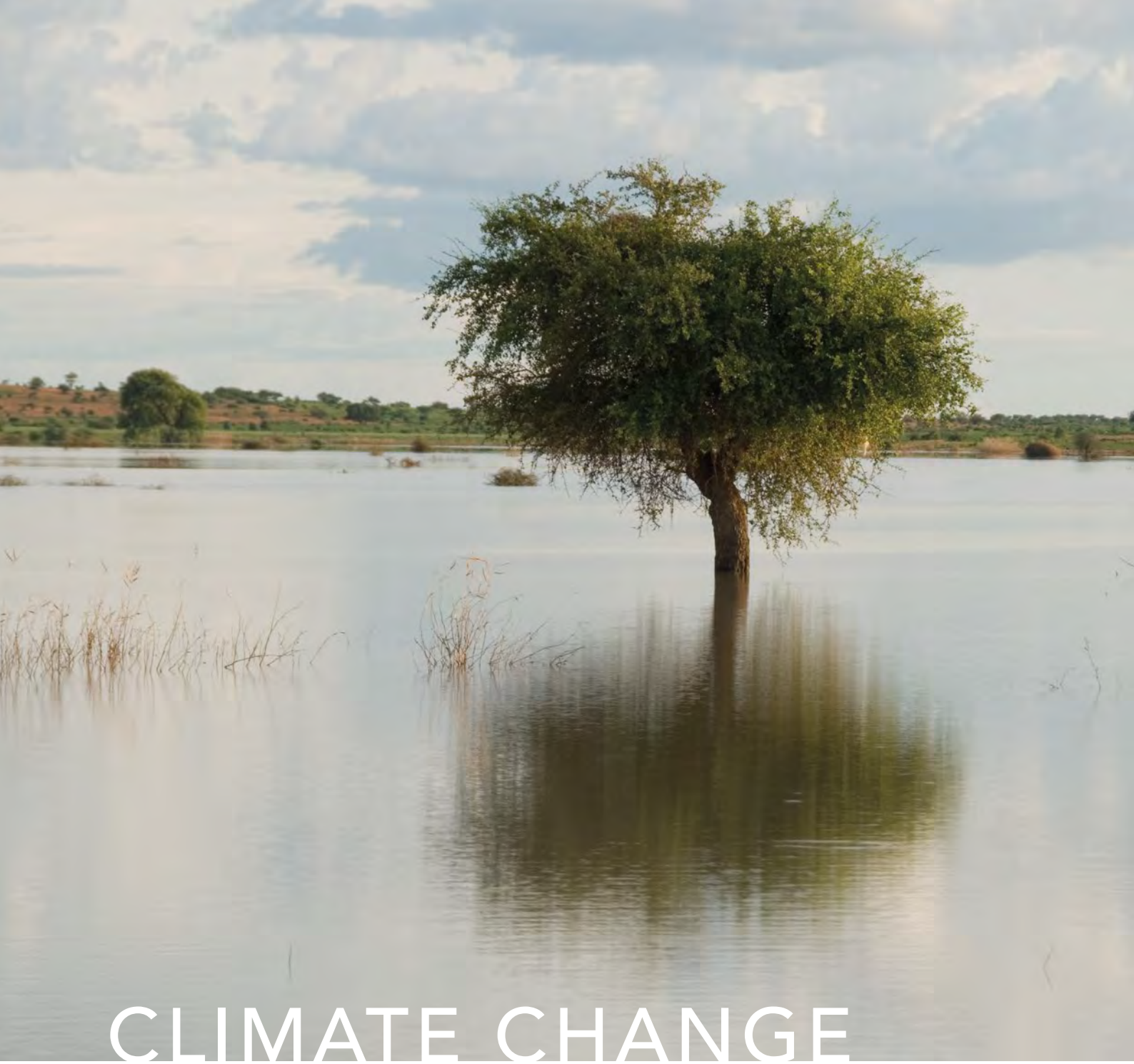

CLIMATE CHANGE

Thomas Stocker, PhD
Climate and Environmental Physics
Physics Institute
University of Bern
Bern, Switzerland

A THREAT TO THE PRIMARY RESOURCES OF LAND AND WATER

What the science tells us

"*Climate change is one of the greatest challenges of our time.*" This is the assertion of the parties to the United Nations Framework Convention on Climate Change made in the Copenhagen Accord in 2009. The scientific information concerning this problem has been delivered to the UNFCCC by a series of comprehensive assessment reports by the Intergovernmental Panel on Climate Change, IPCC, since 1990. The Fifth Assessment Report (1, 2) concludes:

- Human influence on the climate system is clear.
- Continued emission of greenhouse gases will

cause further warming […], increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems.

- Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks.

The power of these statements, which summarize the detailed scientific assessment, lies in the fact that the member countries of the IPCC have approved these formulations verbatim and in consensus.

Carbon dioxide concentrations in the atmosphere are now unprecedented in human history and 30% higher than during at least the last 800,000 years. They are rising more than 100 times faster than during the past 20,000 years due to the burning of fossil fuels and deforestation. Similar observations hold for methane and nitrous oxide, the two other important greenhouse gases. The chemical composition of the Earth's atmosphere is now fundamentally different from that which prevailed before the industrial revolution. Based on multiple lines of independent evidence from the atmosphere, the ocean and the cryosphere, IPCC has concluded that *warming in the climate system is unequivocal*. This warming increases sea level directly by the thermal expansion of the warming ocean water, and indirectly by the melting of the glaciers and the loss of mass from Greenland and Antarctica.

Numerous other changes have been detected over the past 50 years in all components of the Earth System. Among these observations are reductions in the Arctic sea ice cover in both extent and thickness, melting of the Greenland and Antarctic ice sheets, shrinking of glaciers worldwide, changes in the global water cycle and increases in the occurrence and strengths of extreme events such as the doubling in the frequency of heat waves. The warming and many of the consequent changes are caused by the increase in greenhouse gas concentrations and other substances in the atmosphere. This conclusion arises from the combination of global model simulations and observations which permit the attribution of the observed changes to various drivers and causes. This robust scientific evidence is encapsulated in IPCC's conclusion that *human influence on the climate system is clear*.

Anthropogenic climate change, however, has far greater dimensions that just those observed and projected. We need to recognize that climate change threatens our most important resources for life on Earth. These two resources are land and water.

Resource land shrinks in size

The resource land is irreversibly reduced by the rise of sea level globally, on average at a rate of 3.2 cm per decade over the past 20 years (Fig. 1). Further sea level rise, as is already committed by the past greenhouse gas emissions, will have severe and pervasive consequences for coastal communities, meaning many hundreds of millions of people. Land is a primary resource to live and grow food on. The impact of the global increase in greenhouse gas concentrations reduces this primary resource continually. Rising sea levels also increase the vulnerability of these settlements to extreme events such as cyclones and sea level surges caused by them. Therefore, adaptation has become a continuous necessity. So far, adaptation happened to a sea level rise of 19 cm since the beginning of the 20th century, noting that complete adaptation to this change was not necessary since many coastal infrastructures have only been built in the course of the 20th century. Comparing this with the committed adaptation under a business-as-usual scenario, another 70 cm, and considering mature infrastructure and established coastal settlements that must adapt, this indicates the dramatic challenges ahead. Many regions are likely to encounter their limits of adaptation already in the 21st century. As for sea level, adaptation limits also exist for ecosystems on land and in the ocean.

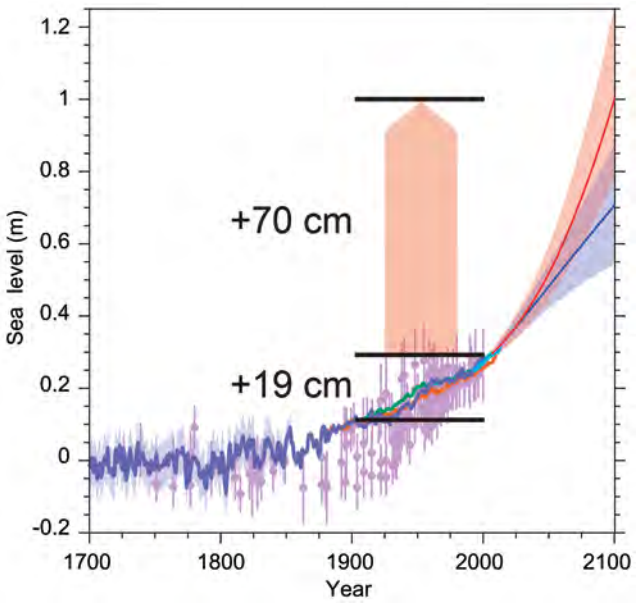

Figure 1:
Resource land: Past and estimated future changes in sea level depending on the greenhouse gas emission scenario. Figure modified from (4).

Water: *Too much or too little*?

Climate models are excellent tools to estimate future changes caused by increasing greenhouse gas concentrations in the atmosphere. These models are complex and consist of components describing the atmospheric and ocean circulations, their interactions, snow and sea ice cover and land surface

processes. Simulations covering the past 150 years are compared with observations demonstrating large-scale agreement and thus lending confidence to use such models for climate change projections. In addition to estimates of regional warming, they are also able to provide us with projections of changes in the global water cycle (Fig. 2). Depending on the greenhouse gas emission scenario these models provide information on the amount of annual and seasonal precipitation on the globe. Keeping the warming below 2°C, the target envisaged by the Paris Agreement (3), changes in precipitation are less than 10% in most regions of the world. Such a change is not much different from the year-to-year variability in the water cycle and thus adaptation is possible. In a "business-as-usual" scenario precipitation changes in response to the warming are much larger and reach increases of more than 50% in tropical and high latitudes, while decreases of more than 30% are projected to occur in other regions, primarily in sub-tropical latitudes. The warming that occurs worldwide therefore causes large regional differences in the changes in the water cycle. Those latitudes that are already today challenged by frequent flooding (mid to high latitudes) will receive even more precipitation, whereas dry latitudes will receive even less water. The risks of drought and water scarcity therefore will increase, which will become a serious issue in these regions.

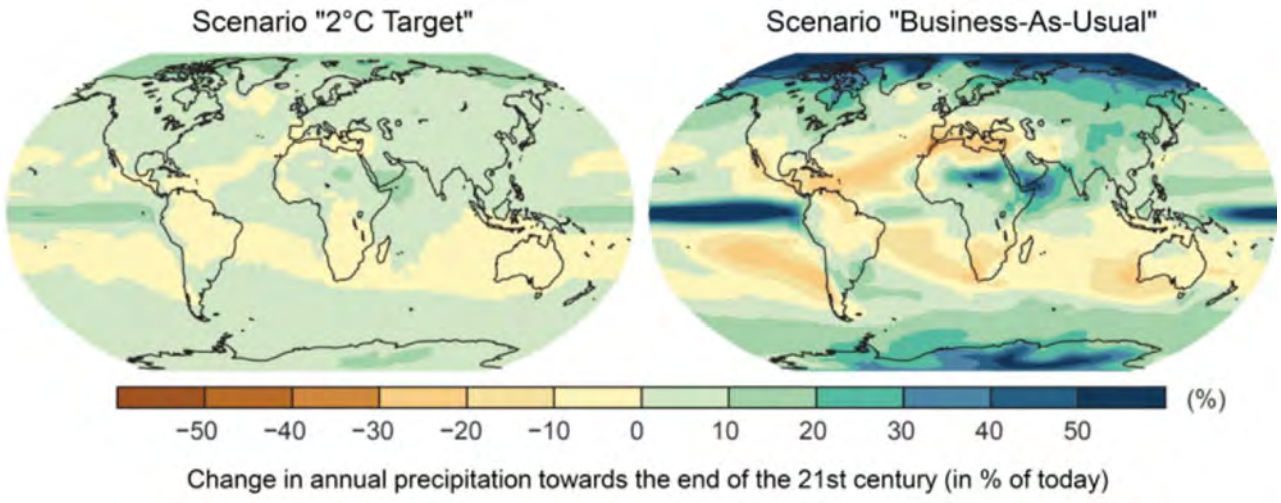

Figure 2:
Resource water: Estimated changes in annual precipitation depending on the greenhouse gas emission scenario. Figure modified from (4).

Taking a resource view of the climate change problem therefore brings the challenges into a clear focus. Limiting climate change to 2°C will require adaptation already now. This applies both to humans and ecosystems. As illustrated with the water cycle, many regions will be able to successfully adapt to these changes with ecosystem services, such

as food production, continuing on a global scale. However, a business-as-usual scenario will lead to a world that is fundamentally different from the one we now know. The warming will exceed 4°C relative to the end of the 20th century. On top of the slow warming, extreme events such as heat waves may reach magnitudes that are beyond the physiological tolerance. The primary resources of land and water will undergo unprecedented changes. Regions will emerge in which survival is possible only with a massive investment in technological infrastructure, such as cooling, freshwater production and irrigation. Such adaptation will be extremely costly, costs that will add to the those incurred by climate-related damages and disasters. Many regions will have difficulties confronting such challenges.

In some regions the changes will grow beyond the capacity for adaptation, for both human systems and ecosystems. Food production will be seriously damaged in areas which will experience more drought or where flooding will modify growing conditions on farmland. Continued growth of atmospheric carbon dioxide will further acidify the surface ocean. This, compounded with the warming, will impact many marine ecosystems and habitats with consequences that are still to be fully explored. It is clear, however, that acidification will make the shell formation of many marine organisms much more difficult. A burning question concerns the limits of the adaptation capacity of marine organisms and ecosystems (5).

The consequence of climate change resulting from business-as-usual is evident: as the primary resources become more difficult to access and or may disappear altogether, migration will be the only option left for people. The potential for conflict caused by such a development is unfortunately evident, already today.

Taking a broader perspective, we should recognize that addressing climate change is a sheer necessity if we want to achieve the Sustainable Development Goals that were agreed to by the United Nations in 2015. Effective climate change mitigation is an indispensable start on the pathway towards the Sustainable Development Goals and will accelerate reaching many of them. Business-as-usual, on the other hand, undoubtedly makes these goals unachievable. Addressing climate change, therefore, must be an integral part of any strategy to reach the Sustainable Development Goals.