Climate Change and Mountains

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The world's mountains are home to about 800 million people. They serve as water towers for billions and provide ecosystem services for the entire globe. Climate change will affect the world's mountain regions and may jeopardize the important services provided by mountains. This could include impacts on drinking water supplies, hydropower generation, agricultural suitability and risks of natural hazards. Climate change may produce intensified extreme weather events such as heat waves, drought, and heavy precipitation leading to flooding and landslides in mountains and to extensive flooding in surrounding lowlands.

Niesen, Switzerland (A. Stickler)

Mountain regions display large climate gradients within small spatial scales, and host a diversity of microclimates and macroclimates. This is due to their altitudinal extent, topography, and their effects on atmospheric flow. For instance, differences in solar insolation between mountains and forelands produce characteristic wind systems. The overflow over topography can trigger convection and precipitation.

Mountain climates

Large mountain ranges often act as climatic barriers, with humid climates on their windward side and semi-deserts on their lee side. Due to their altitudinal extent, many mountain regions intersect important environmental boundaries such as timber lines, snow lines or the occurrence of glaciers or permafrost. Climatically induced changes in these boundaries could possibly trigger feedback processes (see Box on page 11) affecting the local climate. For instance, a rising snow line and thawing permafrost could increase the risk of natural hazards as well as accelerate warming trends due to lower reflectance. Changes in these boundaries can have sharp consequences for ecosystems (e.g. species habitats) and can influence natural hazards, economic potential and land use.

At an even larger scale, mountain regions such as the Himalayas and the Tibetan Plateau (see case studies) play a pivotal role in monsoonal circulations. The effects of climate change on mountain regions could alter monsoon flow and intensify monsoon precipitation, affecting agricultural conditions for a huge portion of the global population.

Observed changes

Over the past 100 years, the globe has warmed by about 1 °C [1]. However, this warming has not been spatially uniform. The continents have warmed faster than the oceans and higher latitudes have warmed faster than lower ones. The Arctic has warmed especially fast (Figure 1.1). Rates of temperature increase have also changed over time. The last 50 years have seen a higher rate of warming than the last 100 years.

Mountain areas worldwide – i.e. areas over 1 000 m – have not warmed any more or less than lower-lying land areas over the last 35 years. However, the vertical structure of the atmospheric warming depends on the latitude (shown in Figure 1.2 for the period since 1979). In the Arctic, recent warming has been strongest near the ground. On the one hand, this is because of surface-level feedback processes such as "sea ice–albedo feedback" (see Box on page 11) – a positive feedback process commonly associated with the Arctic that also applies to snow-covered mountain regions. On the other, it is because convection is rare in the Arctic, so the greenhouse gas-induced warming of the Earth's surface has little effect on the higher reaches of the atmosphere here. In the tropics, by contrast, recent warming has been greatest at higher altitudes. This is due to the additional evaporation near the ground. Tropical convection transports the additional moisture to the upper troposphere, where heat is released during condensation. Such high-altitude amplification of warming trends could increasingly affect mountain regions and impact water resources in the future. Whether or not tropical mountain peaks such as those in the South American Andes might experience particularly magnified warming in a hotter, wetter world demands further analysis. Mountain climates often exhibit spatially complex trend patterns within a given region.

Policy messages

- Mountain regions have warmed considerably over the last 100 years, at a rate comparable to that of lowland regions.
- Mountain regions intersect important environmental boundaries such as tree lines or snow lines – boundaries whose altitudes have increased in the past century and will advance further in the future.

Harmony Lake, Canada (P. Noti)

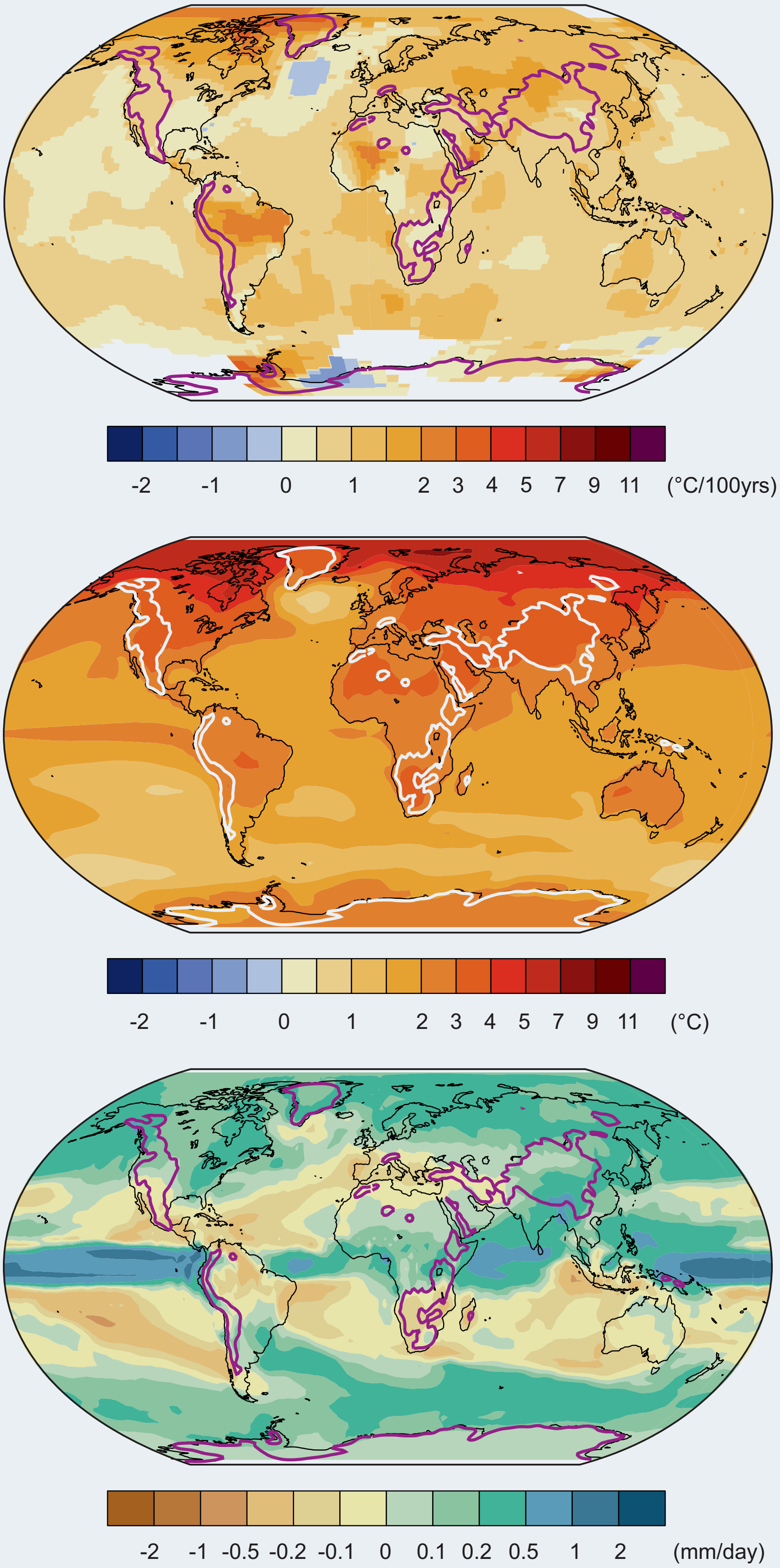

Figure 1.1. Linear trend in annual mean surface air temperature (top) from 1900 to 2013. Data source: NASA/GISS [2]. Modelled changes in temperature (middle) and precipitation (bottom) from 1985–2005 to 2081–2100 according to a moderate-to-high emissions scenario (RCP6.0, CMIP5 Atlas subset from KNMI Climate explorer; see [3]). Purple and white lines indicate topography over 1 000 m

Feedback and nonlinear behaviour of the climate system

The climate system – comprising the atmosphere, ocean, land, ice masses and the biosphere – is highly complex. It does not always react in a linear way to imposed disturbances. “Feedbacks” can either stabilize the system or amplify the response. The system may exhibit “tipping points”, and changes may be “irreversible” or exhibit path-dependent behaviour (“hysteresis”). Below are definitions of these terms, closely following IPCC (2013):

Feedback

An interaction in which a perturbation in one climate quantity causes a change in a second, leading to an additional change in the first quantity. If that change weakens the initial perturbation, the feedback is said to be negative; if it strengthens the initial perturbation, the feedback is positive. Sea ice–albedo feedback is an example of positive feedback: a decrease in sea ice reduces the reflectance of shortwave radiation, leading to an increase in the energy absorbed by the ocean, which in turn causes a further decrease in sea ice. The same type of feedback mechanism affects the snow line in mountain regions.

Tipping point

A tipping point is a critical threshold after which a global or regional climate shifts from one stable state to another stable state (reversibly or irreversibly). For instance, if ocean salinity in a certain area of the North Atlantic falls below a certain – presently unknown – threshold, Atlantic overturning circulation may cease. Several tipping points have been posited that could affect the large-scale climate system. They involve, for example, the melting of Arctic sea ice, ice shields, Tibetan glaciers, and deforestation in the Amazon. Nevertheless, our knowledge in this field is still very limited.

Irreversibility

A change in the climate system is considered irreversible if the recovery is significantly slower than the time scale of the change. In addition, irreversibility is often considered in terms of politically relevant time scales, or based on feasible planning horizons of several decades. Considered this way, the melting of Alpine glaciers is seen as irreversible.

Hysteresis

A system that displays a sort of memory, such as the climate system, may exhibit path dependence in its reaction to perturbations, termed hysteresis. For example, the strength of the Atlantic overturning circulation depends on freshwater input into the North Atlantic, but for the same input it may exhibit two quasi-stable states – active or absent – and which state the system is in then depends on the previous state of the system.

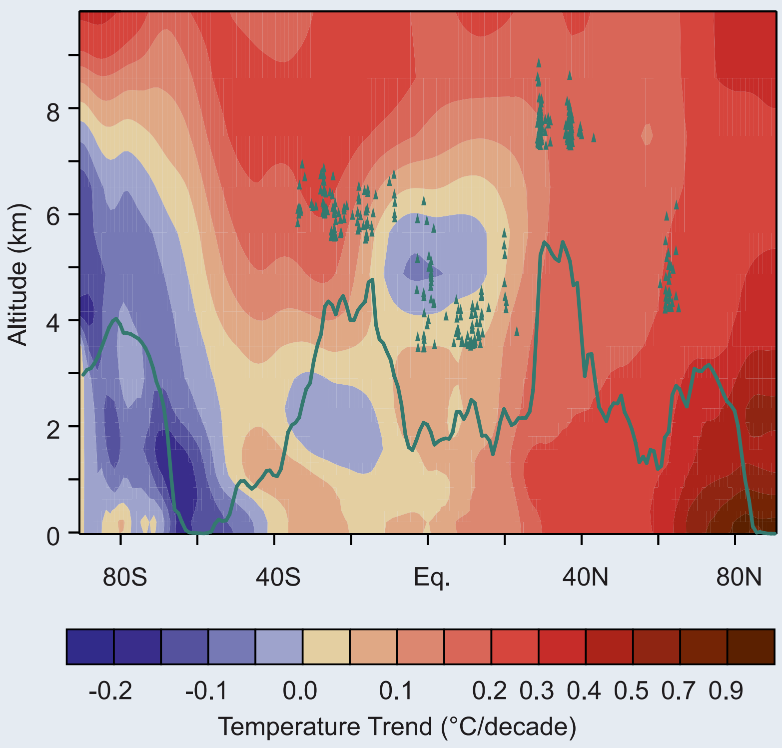

Figure 1.2. Linear trend in zonal annual mean temperature from 1979 to 2013. The green line denotes the heights of large mountain ranges (e.g. Andes ca. 4 000 m near 20° S, Tibetan Plateau ca. 5 000 m near 30° N); individual peaks are shown as green triangles. Data source: ERA-Interim reanalysis [4]

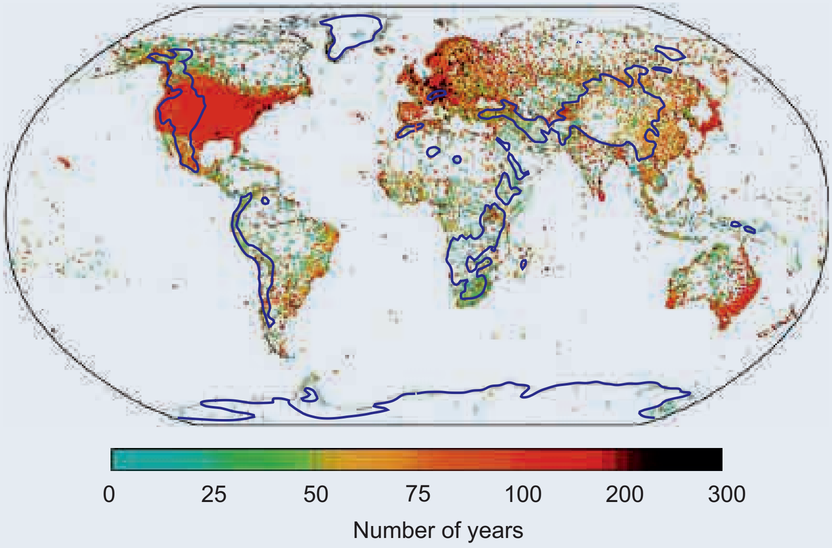

Figure 1.3. Location and length of record of 32 000 meteorological stations in the databank of the International Surface Temperature Initiative (ISTI, http://www.surfacetemperatures.org/). Blue lines indicate topography over 1 000 m

Ze dri Seewjene, Switzerland (P. Noti)

Changes in patterns of precipitation over the last century are even less well quantified. Clear trends have only emerged in certain specific regions. Mountain regions frequently appear to form a boundary between positive and negative precipitation trends [1].

Even though accounting for mountain regions' complex climatic processes is considered important for understanding broader climate trends, many mountain regions remain insufficiently monitored regarding climate parameters such as temperature and precipitation (Figure 1.3). Moreover, most of the meteorological stations in mountain regions are located in valleys, meaning that slopes and peaks are underrepresented in resulting data. At the same time, deriving climate data products for local users in mountain regions – by "downscaling" results from global climate models to the local scale – is difficult for providers of climate services. Yet there is a need for this type of local data because mountain regions host diverse economic activities such as agriculture, mining and tourism, as well as infrastructure that is susceptible to natural hazards (e.g. roads, hydropower stations).

Future changes

According to the IPCC Fifth Assessment Report [3], the globe will warm between 1.5 °C and 4.5 °C by the period of 2085–2100, depending on the prevailing emissions scenario (Figure 1.1). Similar to the previous century, future temperature increases are expected to be stronger over land than over the ocean, stronger at high latitudes than in the tropics and, in the tropics, stronger at high altitudes than near the ground [3]. The latter prediction of greater warming at high altitudes, supported by global models [5], demands further study in individual mountain regions. Nevertheless, it is clear that important environmental boundaries such as snow lines and freezing lines will move higher up in the future. For certain mountain regions, for instance the tropical Andes (see case study), this could accelerate the melting of glaciers and reduce water supplies in the long term. Precipitation is projected to increase in the inner tropics and at mid to high latitudes, but is expected to decrease in subtropical dry zones. However, seasonal differences are also predicted. Almost everywhere, heat waves will likely become more frequent and longer-lasting. Other extreme weather events such as heavy precipitation might increase in intensity, though not necessarily in frequency.