IPCC Special Report on

The Ocean and Cryosphere in a Changing Climate

Impacts of the Changing Cryosphere in a Warming World: A Mountain Perspective

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Abstract: The cryosphere (including, snow, glaciers, permafrost, lake and river ice) is an integral element of high mountain regions, which are home to roughly 10% of the global population. Widespread cryosphere changes affect physical, biological and human systems in the mountains and surrounding lowlands, with impacts evident even in the ocean. Building on the IPCC's 5th Assessment Report (AR5), this chapter assesses new evidence on observed recent and projected changes in the mountain cryosphere as well as associated impacts, risks and adaptation measures related to natural and human systems. Impacts in response to climate changes independently of changes in the cryosphere are not assessed in this chapter. Polar mountains are included in Chapter 3, except those in Alaska and adjacent Yukon, Iceland and Scandinavia, which are included in this chapter.

- The sum of ice sheet and glacier contribution are the dominant sources of sea level rise.
- Glacier, snow and permafrost decline has altered the frequency, magnitude and location of most related natural hazards
- Changes in snow and glaciers have changed the amount and seasonality of runoff in snow-dominated and glacier-fed river basins (very high confidence) with local impacts on water resources and agriculture.
- Species composition and abundance have markedly changed in high mountain ecosystems in recent decades (very high confidence), partly due to changes in the cryosphere.

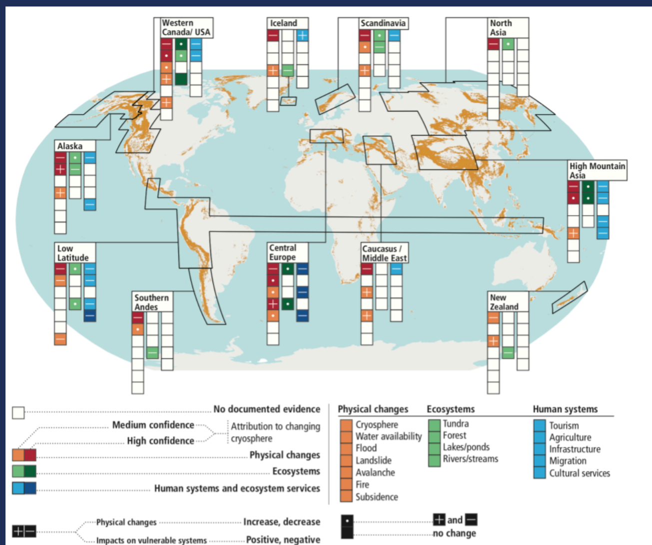

Figure 2.8: Observed changes in the cryosphere and impacts on ecosystems, other natural systems and human systems over past decades that can at least partly be attributed to changes in the cryosphere. Only observations documented in the scientific literature are shown, but impacts may also be experienced elsewhere. Shading denotes mountainous areas. Confidence levels (high shown by filled; medium shown by unfilled tetrix boxes) refer to confidence in attribution to cryospheric changes. Figure is based on observed impacts listed in Table SM2.11.

Figure 1. Ice Stupas in Ladakh, India (Photo: Radma Rigzi)

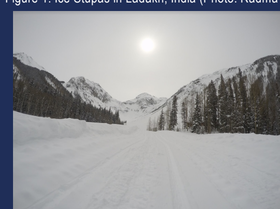

Figure 2. Colorado Mountains (Photo: Heidi Steltzer)

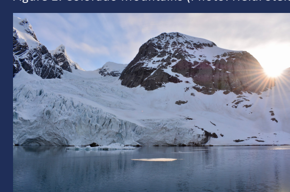

Figure 3. The Arctic (Photo: Heidi Steltzer)

The presence and persistence of snow and glaciers are decreasing around the world.

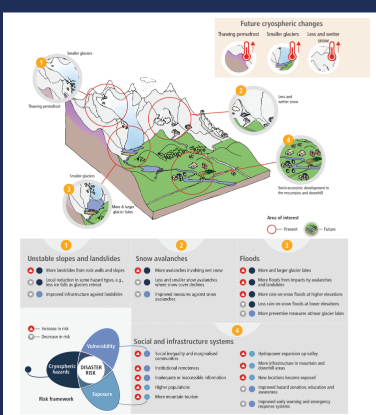

Figure 2.7: Anticipated changes in high mountain hazards under climate change, driven by changes in snow cover, glaciers and permafrost, overlay changes in the exposure and vulnerability of individuals, communities, and mountain infrastructure.

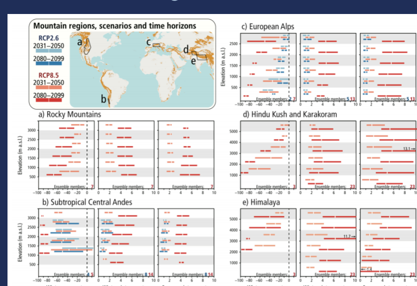

Figure 2.3: Projected change (1986-2005 to 2031-2050 and 2080-2099) of mean winter (December-May; June-August in Subtropical Central Andes) snow water equivalent, winter air temperature and summer air temperature (June-August; December-February in Subtropical Central Andes) in five high-mountain regions for RCP8.5 (all regions) and RCP2.6 (European Alps and Subtropical Central Andes). Changes are averaged over 500 m (a,b,c) and 1000 m (d,e) elevation bands. The numbers in the lower right of each panel reflect the number of simulations (note that not all models provide snow water equivalent). For the Rocky Mountains, data from NA-CORDEX RCMs (25 km grid spacing) driven by CMIP5 GCMs were used (Mearns et al., 2017). For the European Alps, data from EURO-CORDEX RCMs (12 km grid spacing) driven by CMIP5 GCMs were used (Jacob et al., 2014). For the other regions, CMIP5 GCMs were used: Zazulie (2016) and Zazulie et al. (2018) for the Subtropical Central Andes, and Terzago et al. (2014) and Palazzi et al. (2017) for the Hindu Kush and Karakoram and Himalaya. The list of models used is provided in Table SM2.8.

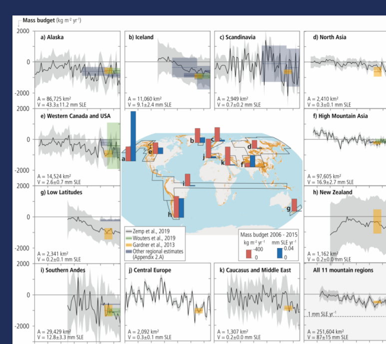

Figure 2.4: Glacier mass budgets for the eleven mountain regions assessed in this Chapter (Figure 2.1) and these regions combined. Mass budgets for the remaining polar regions are shown in Chapter 3, Figure 3.8. Regional time series of annual mass change are based on glaciological and geodetic balances (Zemp et al., 2019). Superimposed are multi-year averages by Wouters et al. (2019) based on the Gravity Recovery and Climate Experiment (GRACE), only shown for the regions with glacier area >3,000 km^2. Estimates by Gardner et al. (2013) were used in AR5. Additional regional estimates available in some regions and shown here are listed in Table 2.A.1. Annual and time-averaged mass-budget estimates include the errors reported in each study. Glacier areas (A) and volumes (V) are based on RGI Consortium (2017) and Farinotti et al. (2019), respectively. Red and blue bars on map refer to regional budgets averaged over the period 2006-2015 in units of kg m^{-2} yr^{-1} and mm sea-level equivalent (SLE) per year, respectively, and are derived from each region's available mass-balance estimates (Appendix 2.A, Table 1).

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