Scientific Evidence of Climate Change and Its Effects: Lessons from IPCC Special Report on Ocean and Cryosphere

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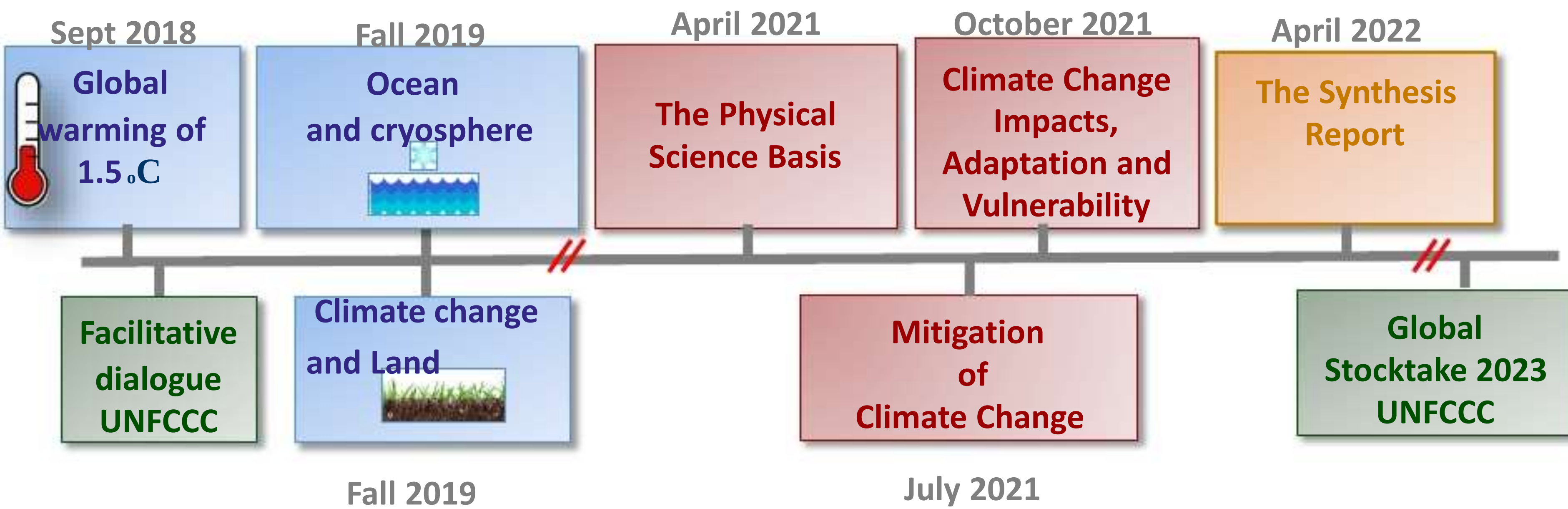
Outline

1. Background
2. Cryospheric Changes
3. Impacts and Risks
4. Implementing Responses

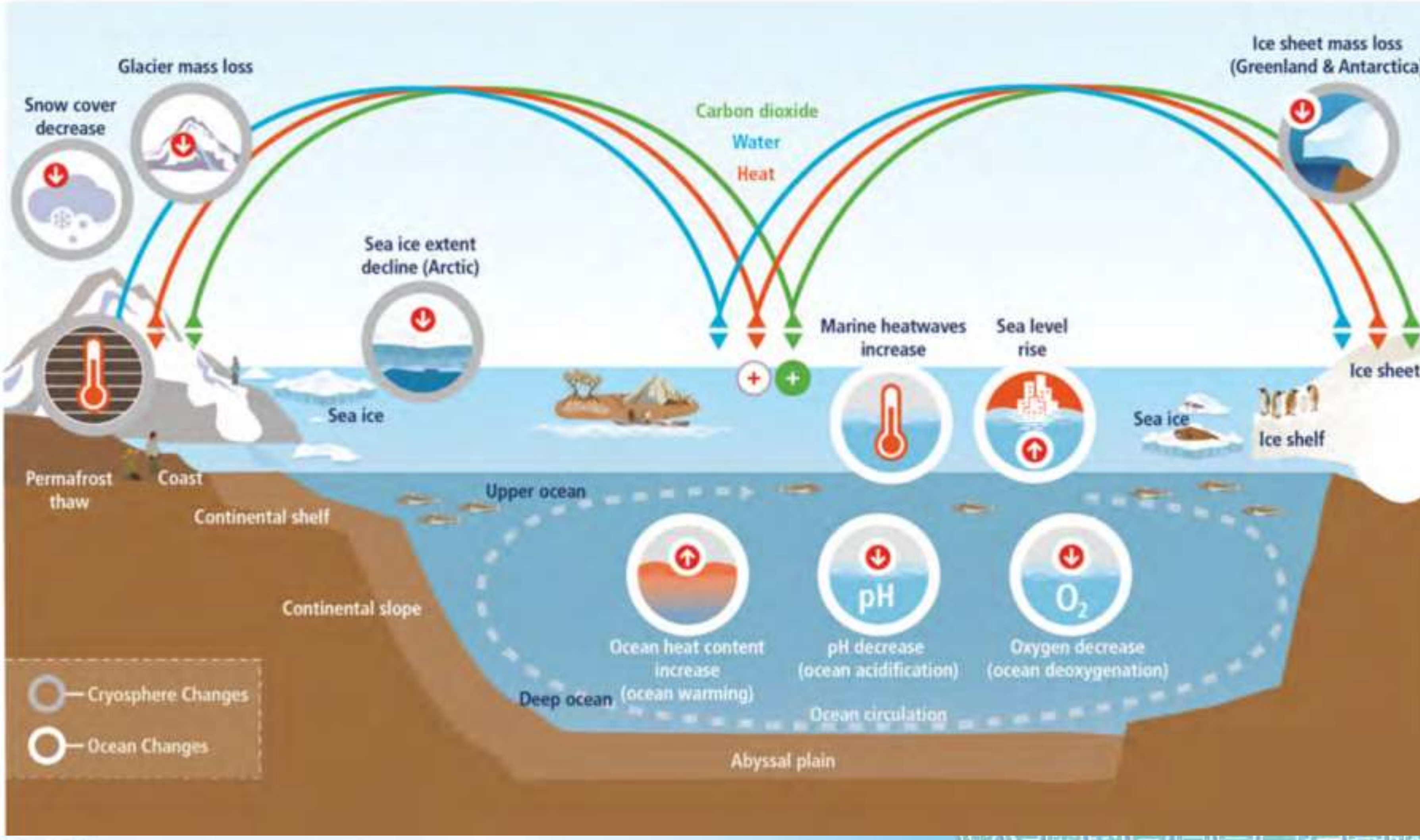
AR6 cycle, IPCC reports



SROCC: Special Report on Ocean and Cryosphere in a changing climate

SROCC Framing and context

Schematic illustration of key components and changes of the ocean and cryosphere, and their linkages.



Abram N. et al., 2019

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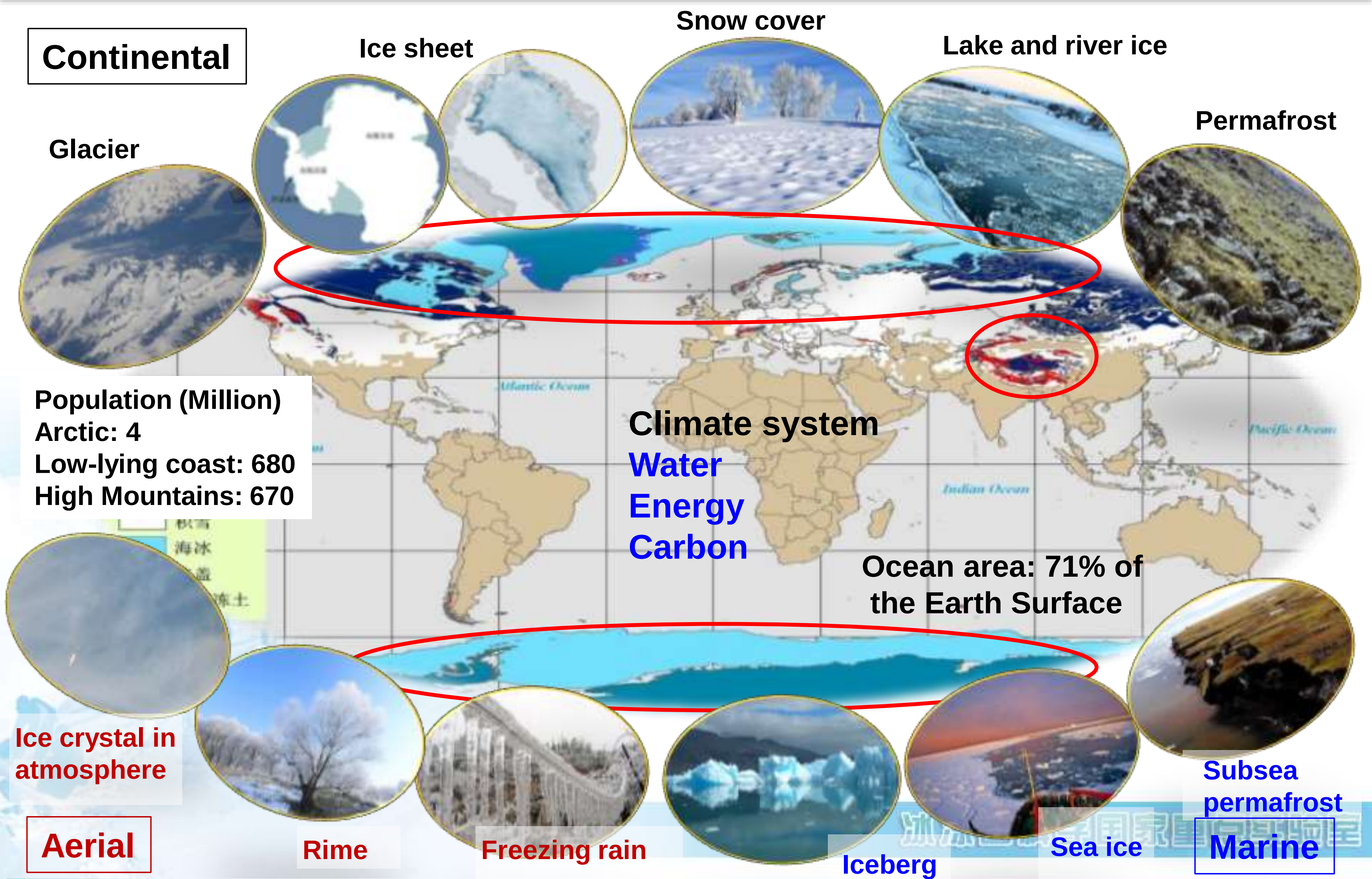
Cryosphere: the sphere with certain thickness and temperature below 0 ºC on the Earth.

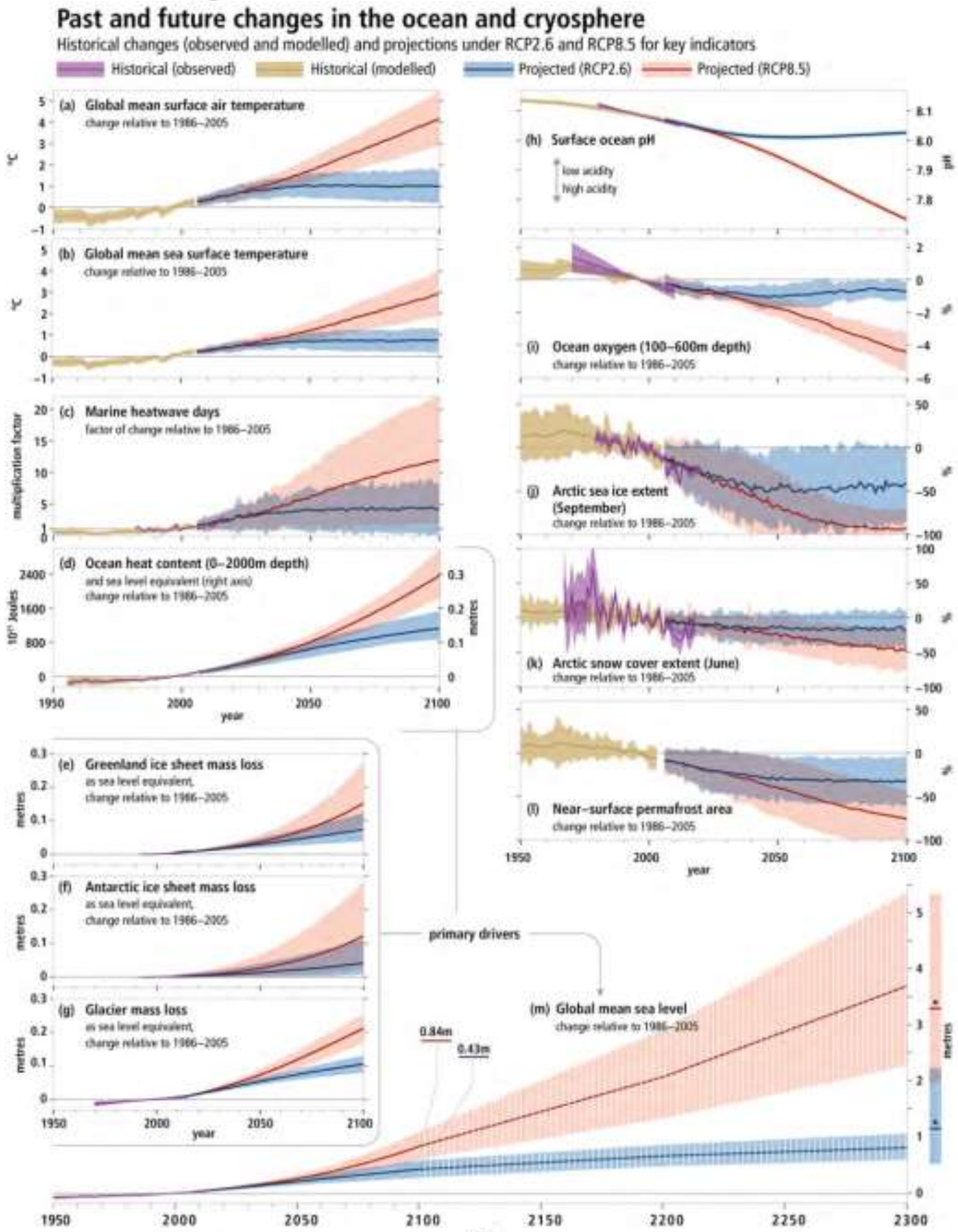


Representative statistics for cryospheric components indicating their general significance

Ice on Land	Percent of Global Land Surface [j]	Sea Level Equivalent[k] (metres)
Antarctic ice sheet[a]	8.3	58.3
Greenland ice sheet[b]	1.2	7.36
Glaciers [c]	0.5	0.41
Terrestrial permafrost[d]	9–12	0.02–0.10[q]
Seasonally frozen ground[e]	33	Not applicable
Seasonal snow cover (seasonally variable)[f]	1.3–30.6	0.001–0.01
Northern Hemisphere freshwater (lake and river) ice[p]	1.1	Not applicable
Total[m]	52.0–55.0%	~66.1

Ice in the Ocean	Percent of Global Ocean Area[j]	Volume[l] (10^3 km^3)
Antarctic ice shelves	0.45[g]	~380
Antarctic sea ice, austral summer (spring)[n]	0.8 (5.2)	3.4 (11.1)
Arctic sea ice, boreal autumn (winter/spring)[n]	1.7 (3.9)	13.0 (16.5)
Sub-sea permafrost[h]	~0.8	Not available
Total[o]	5.3–7.3	

（IPCC，2013）



Observed and modelled historical changes in the ocean and cryosphere since 1950, and projected future changes

(a) Global mean surface air temperature change with likely range. **Ocean-related changes** with very likely ranges for (b) Global mean sea surface temperature change; (c) Change factor in surface ocean marine heatwave days; (d) Global ocean heat content change (0–2000 m depth). An approximate steric sea level equivalent is shown with the right axis by multiplying the ocean heat content by the global-mean thermal expansion coefficient (ε ≈ 0.125 m per 1024 Joules)12 for observed warming since 1970; (h) Global mean surface pH (on the total scale). Assessed observational trends are compiled from open ocean time series sites longer than 15 years; and (i) Global mean ocean oxygen change (100–600 m depth). Assessed observational trends span 1970–2010 centered on 1996. **Sea-level changes** with likely ranges for (m) Global mean sea level change. Hashed shading reflects low confidence in sea level projections beyond 2100 and bars at 2300 reflect expert elicitation on the range of possible sea level change; and components from (e,f) Greenland and Antarctic ice sheet mass loss; and (g) Glacier mass loss. Further **cryosphere related changes** with very likely ranges for (j) Arctic sea ice extent change for September; (k) Arctic snow cover change for June (land areas north of 60° N); and (l) Change in near-surface (within 3–4 m) permafrost area in the Northern Hemisphere.

IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem,J. Petzold, B. Rama, N. Weyer (eds.)]. In press.

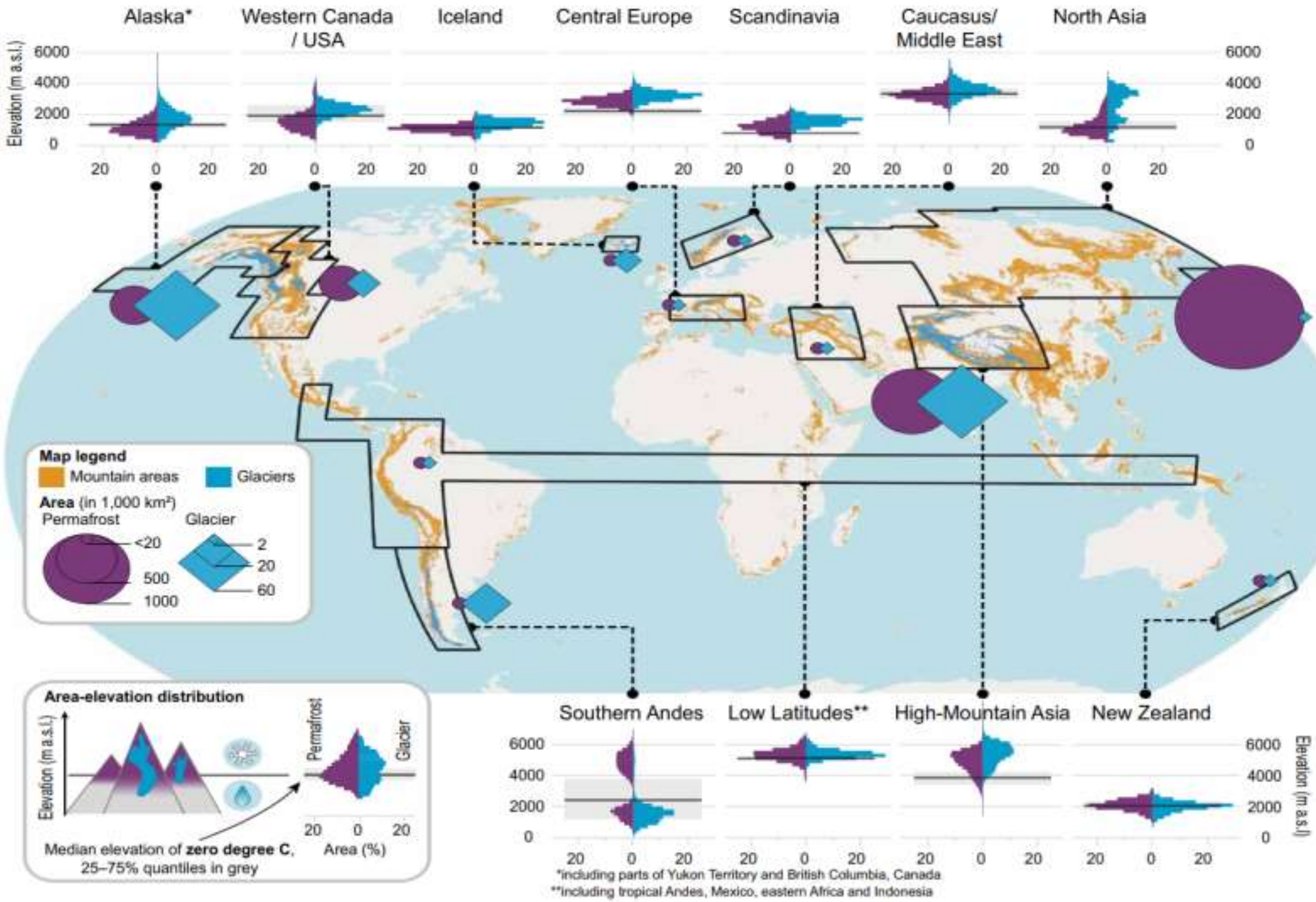


Figure 2.1 | Distribution of mountain areas (orange shading) and glaciers (blue) as well as regional summary statistics for glaciers and permafrost in mountains. Mountains are distinguished based on a ruggedness index (>3.5), a logarithmically scaled measure of relative relief (Gruber, 2012). Eleven distinct regions with glaciers, generally corresponding to the primary regions in the Randolph Glacier Inventory, RGI v6.0 (RGI Consortium, 2017) are outlined, although some cryosphere related impacts presented in this chapter may go beyond these regions. Region names correspond to those in the RGI. Diamonds represent regional glacier area (RGI 6.0) and circles the permafrost area in all mountains within each region boundary (Obu et al., 2019). Histograms for each region show glacier and permafrost area in 200 m elevation bins as a percentage of total regional glacier/permafrost area, respectively. Also shown is the median elevation of the annual mean 0°C free-atmosphere isotherm calculated from the ERA-5 re-analysis of the European Centre for Medium Range Weather Forecasts over each region's mountain area for the period 2006–2015, with 25–75% quantiles in grey. The annual 0°C isotherm elevation roughly separates the areas where precipitation predominantly falls as snow and rain. Areas above and below this elevation are loosely referred to as high and low elevations, respectively, in this chapter.

Hock et al., 2019

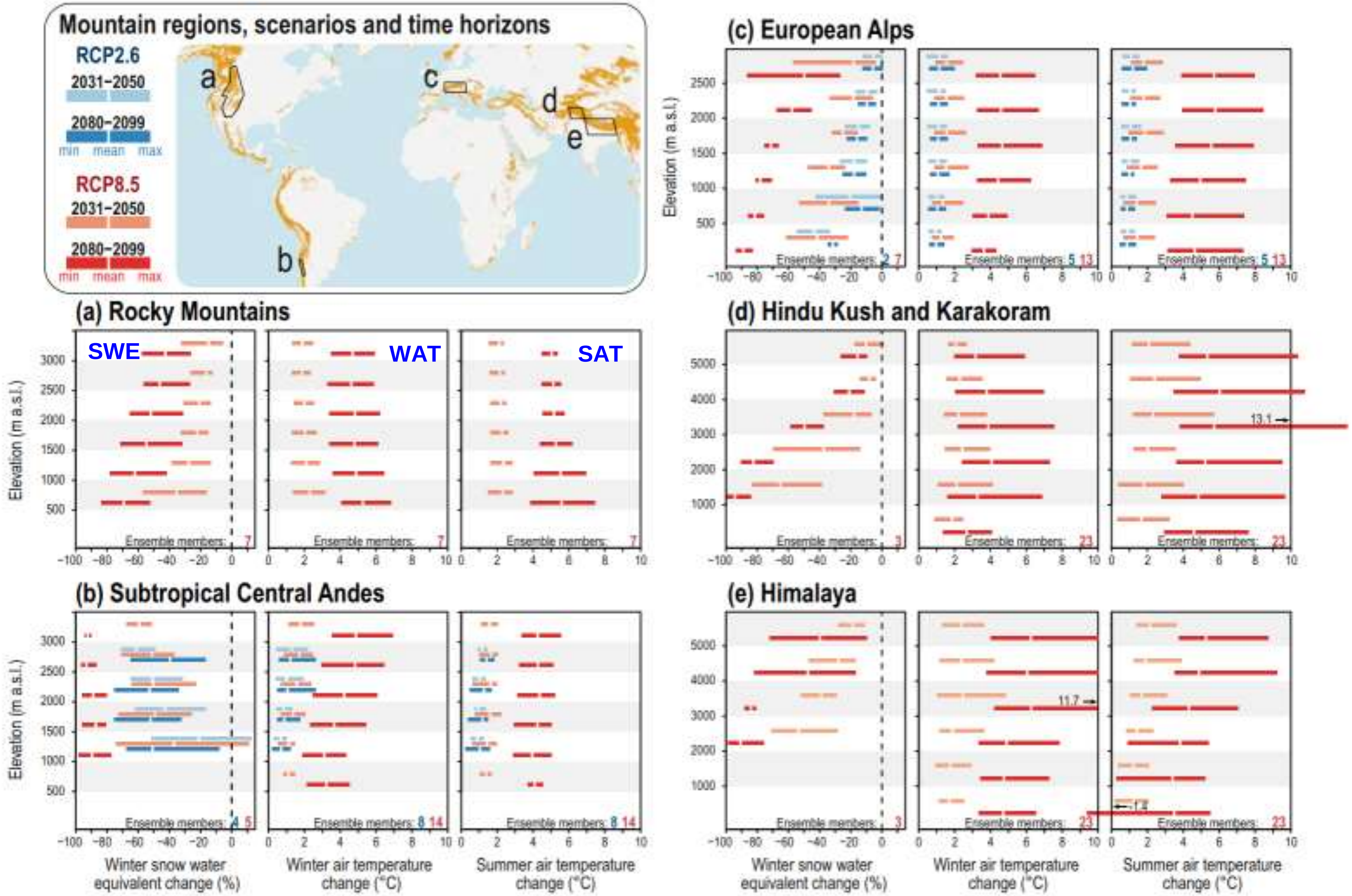


Figure 2.3 | Projected change (1986–2005 to 2031–2050 and 2080–2099) of mean winter (December to May; June to August in Subtropical Central Andes) snow water equivalent, winter air temperature and summer air temperature (June to August; December to February in Subtropical Central Andes) in five high 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 1,000 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 Coupled Model Intercomparison Project Phase 5 (CMIP5) General Circulation Models (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.

Hock et al., 2019

Observed glacier mass balance changes

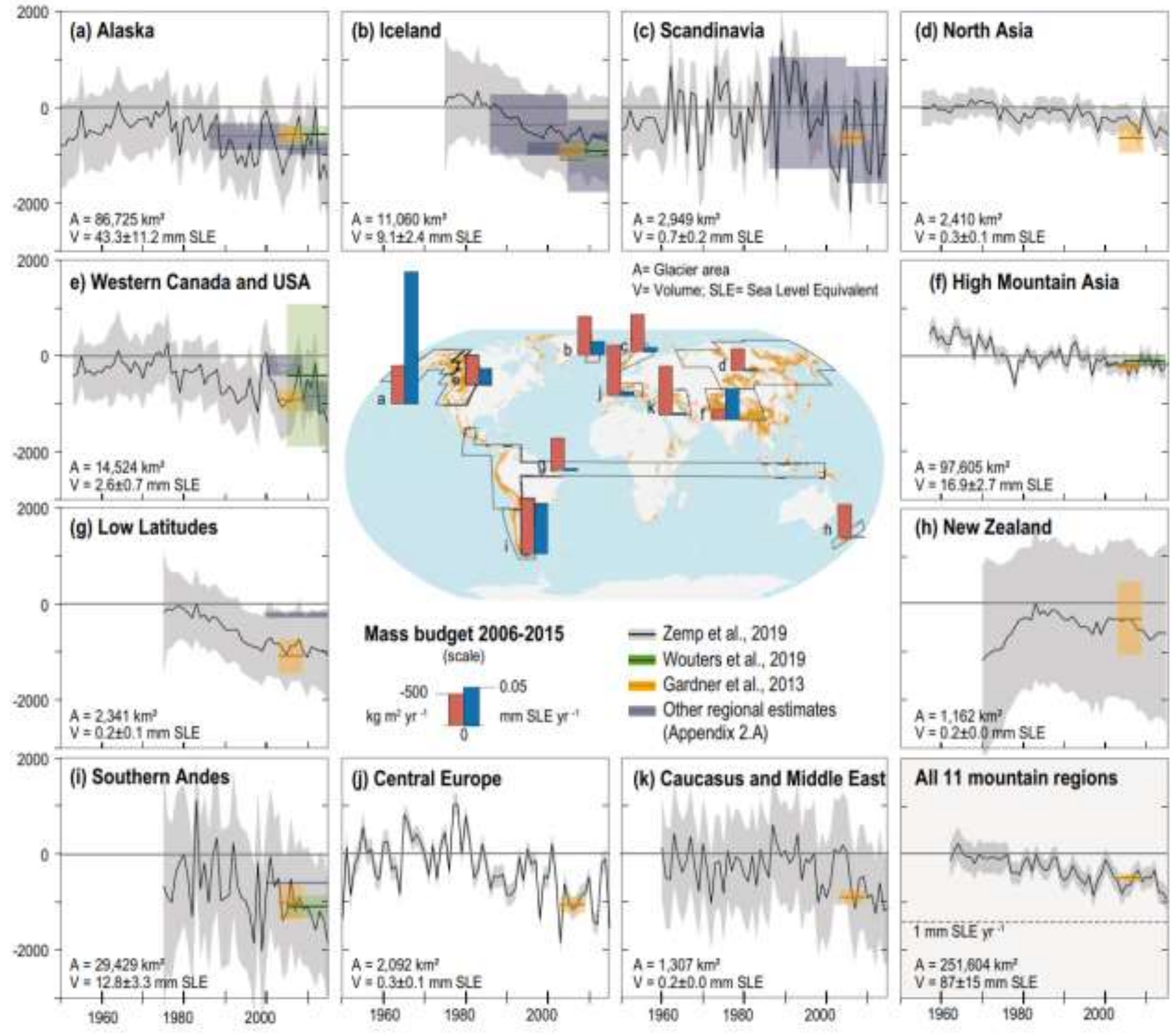
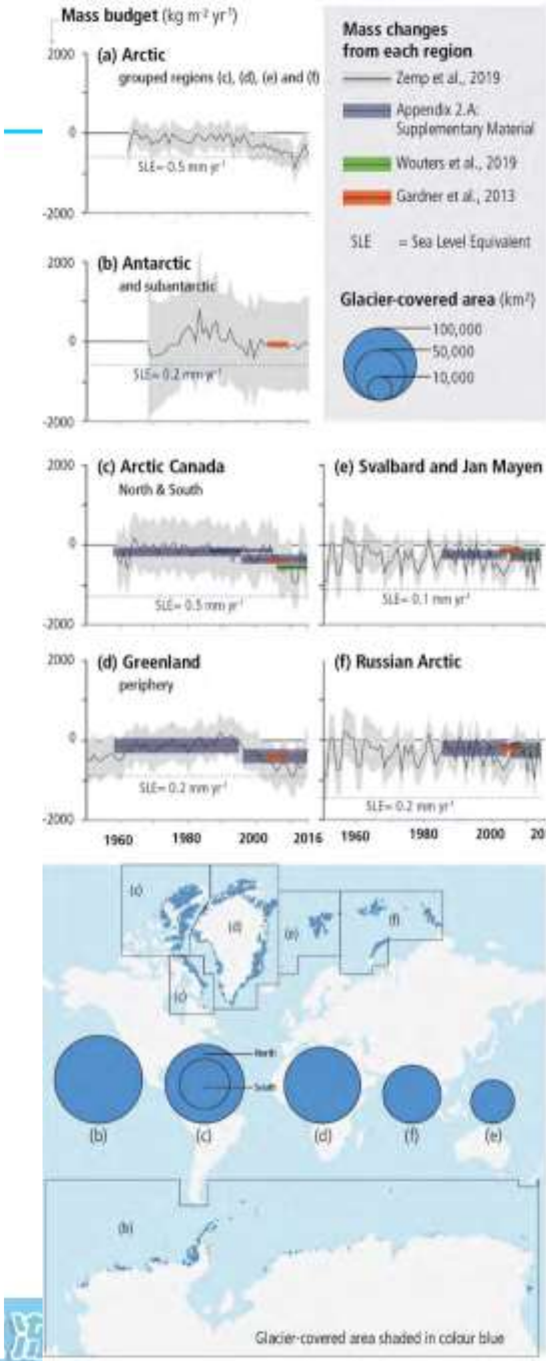


Figure 2.4 | Glacier mass budgets for the eleven mountain regions assessed in this Chapter (Figure 2.1) and these regions combined. Mass budgets for the remaining polar regions are shown in Chapter 3, Figure 3.8. Regional time series of annual mass change are based on glaciological and geodetic balances (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 km². Estimates by Gardner et al. (2013) were used in the IPCC 5th Assessment Report (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) yr-1, respectively, and are derived from each region's available mass-balance estimates (Appendix 2.A, Table 1).

Hock et al., 2019



Meredith et al., 2019

Observed ice sheet mass balance changes

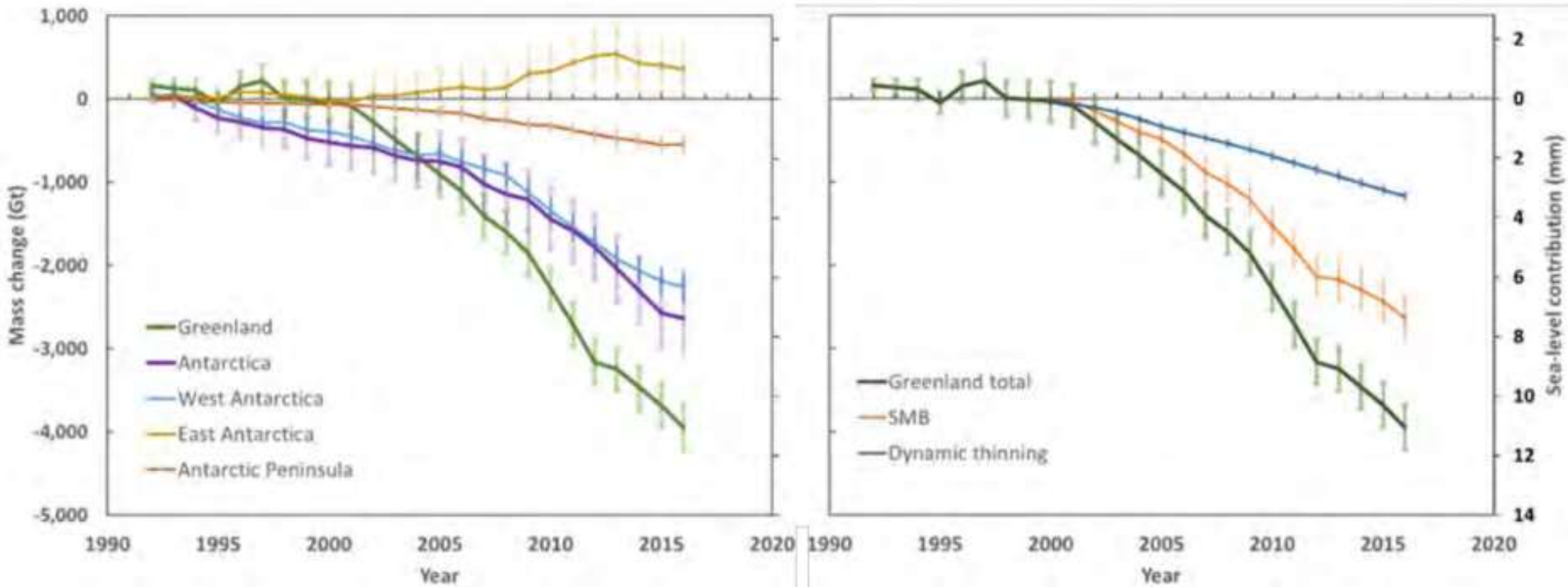


Figure 3.7: (a) Cumulative Ice Sheet mass change, 1992 to 2016, (after Bamber et al., 2018; The IMBIE Team, 2018). (b) Greenland Ice Sheet mass change components from surface mass balance (orange) and dynamic thinning (blue) from 2000-2016, (after Van den Broeke et al., 2016; King et al., 2018). Uncertainties are 1 standard deviation.

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Meredith et al., 2019

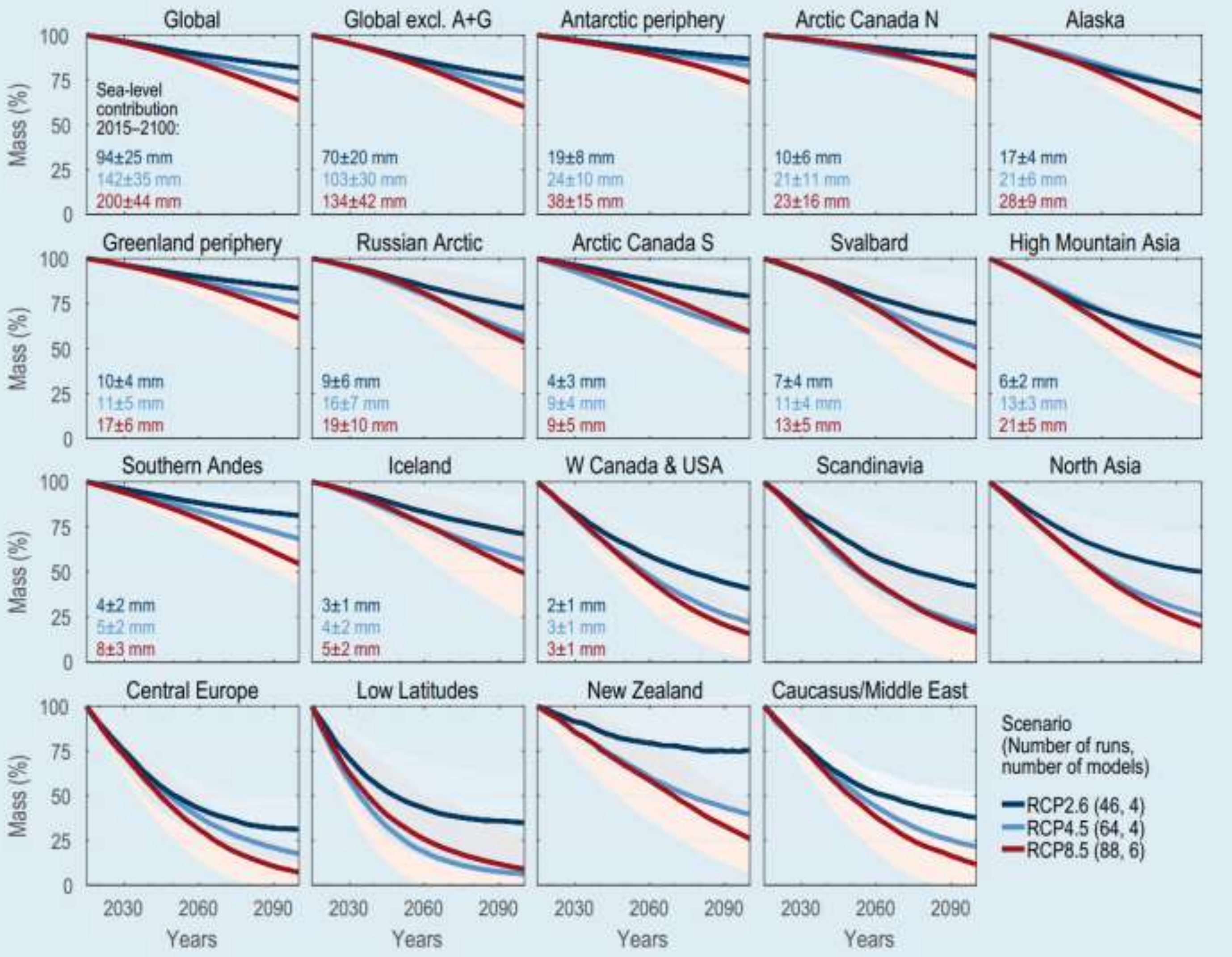


Figure CB6.1 | Projected glacier mass evolution between 2015 and 2100 relative to each region's glacier mass in 2015 (100%) based on three Representative Concentration Pathways (RCP) emission scenarios (Cross-Chapter Box 1 in Chapter 1). Thick lines show the averages of 46 to 88 model projections based on four to six glacier models for the same RCP, and the shading marks ± 1 standard deviation (not shown for RCP4.5 for better readability). Global projections are shown excluding and including the Antarctic (A) and Greenland (G) periphery. Regional sea level contributions are given for three RCPs for all regions with >0.5 mm seal level equivalent (SLE) between 2015–2100. The Low Latitudes region includes the glaciers in the tropical Andes, Mexico, eastern Africa and Indonesia. Region Alaska includes adjacent glaciers in the Yukon and British Columbia, Canada. Regions are sorted by glacier volume according to Farinotti et al. (2019). Data based on Marzeion et al. (2012); Giesen and Oerlemans (2013); Hirabayashi et al. (2013); Bliss et al. (2014); Huss and Hock (2015); Slangen et al. (2017). Modified from Hock et al. (2019).

Hock et al., 2019

Observed Increasing in ground temperature of permafrost

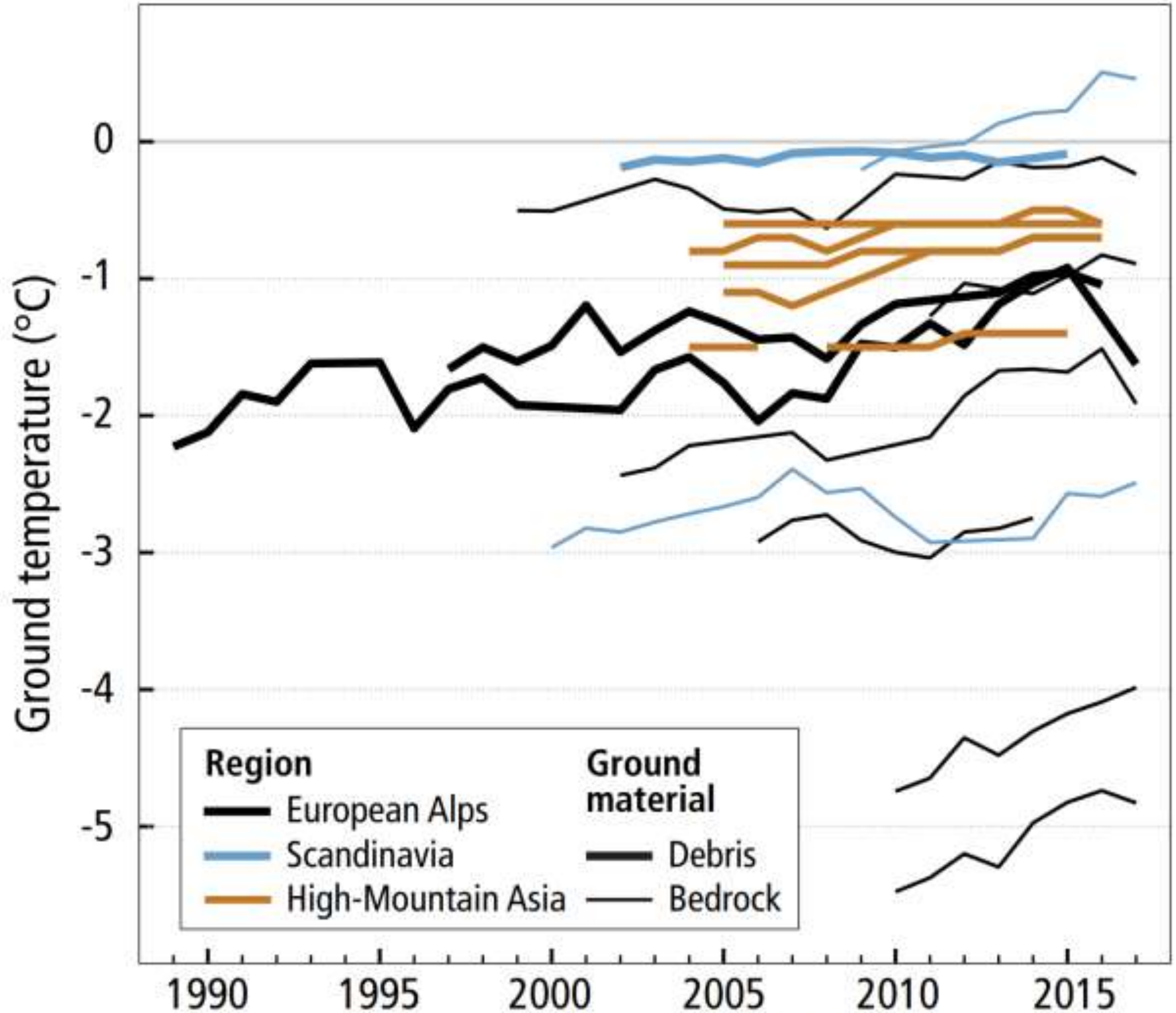


Figure 2.5: Mean annual ground temperature from boreholes in debris and bedrock in the European Alps, Scandinavia and High-Mountain Asia. Temperatures differ between locations and warming trends can be interspersed by short periods of cooling. One location shows degrading of permafrost. Overall, the number of observed boreholes is small and most records are short. The depth of measurements is approximately 10 m, and years without sufficient data are omitted (Noetzli et al., 2018).

Hock et al., 2019

Sea ice concentration changes in the polar regions

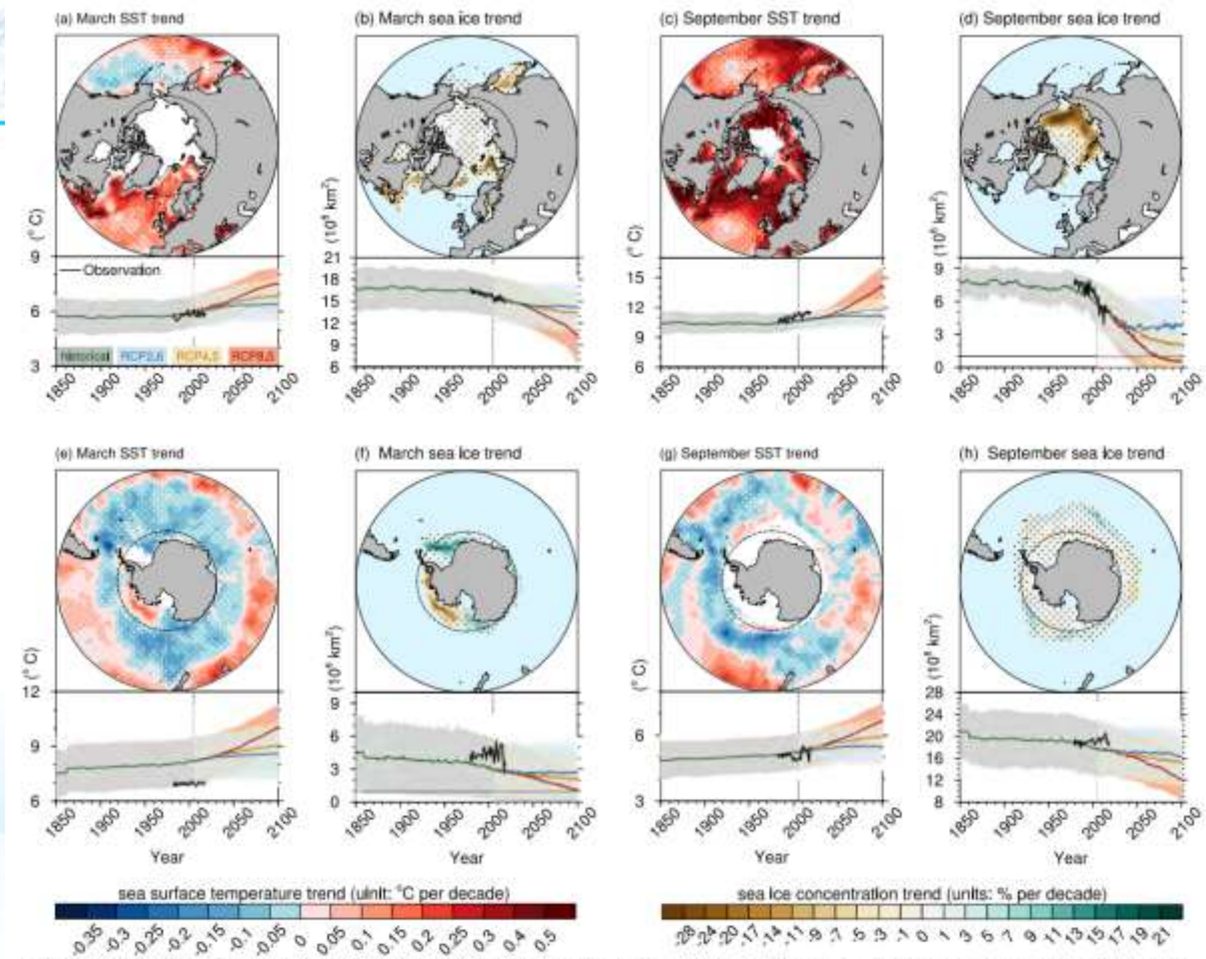
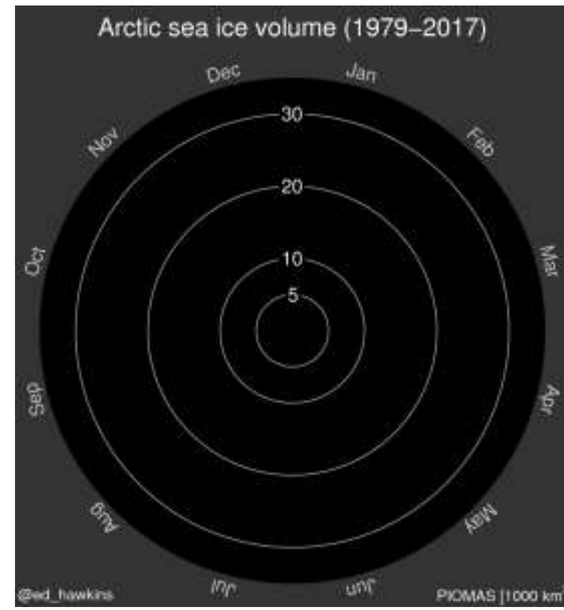


Figure 3.3: Maps of linear trends (in °C per decade) of Arctic (a, c) and Antarctic (e, g) sea surface temperature (SST) for 1982−2017 in March (a, e) and September (c, g). (b, d, f, h) same as (a, c, e, g), but for the linear trends of sea ice concentration (in % per decade). Stippled regions indicate the trends that are statistically insignificant. Dashed circles indicate the Arctic/Antarctic Circle. Beneath each map of linear trend shows the time series of SST (area-averaged north of 40°N/south of 40°S) or sea ice extent in the northern/southern hemisphere. Black, green, blue, orange, and red curves indicate observations, CMIP5 historical simulation, RCP2.6, RCP4.5, and RCP8.5 projections respectively; shading indicates +/- standard deviation of multi-models. SST trend was calculated from Hadley Centre Sea Ice and Sea Surface Temperature data set (Version 1, HadISST1; Rayner, 2003). Sea ice concentration trend was calculated from the NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration, Version 3 (https://nsidc.org/data/g02202). The time series of observed SST are averages of HadISST1 and NOAA Optimum Interpolation Sea Surface Temperature dataset (version 2; Reynolds et al., 2002). The time series of observed sea ice extent are the averages of HadISST, the NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration, and the Global sea ice concentration reprocessing dataset from EUMETSAT (http://osisaf.met.no/p/ice/ice_conc_reprocessed.html).

Meredith et al., 2019



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Changes in Snow cover, permafrost, runoff in Arctic

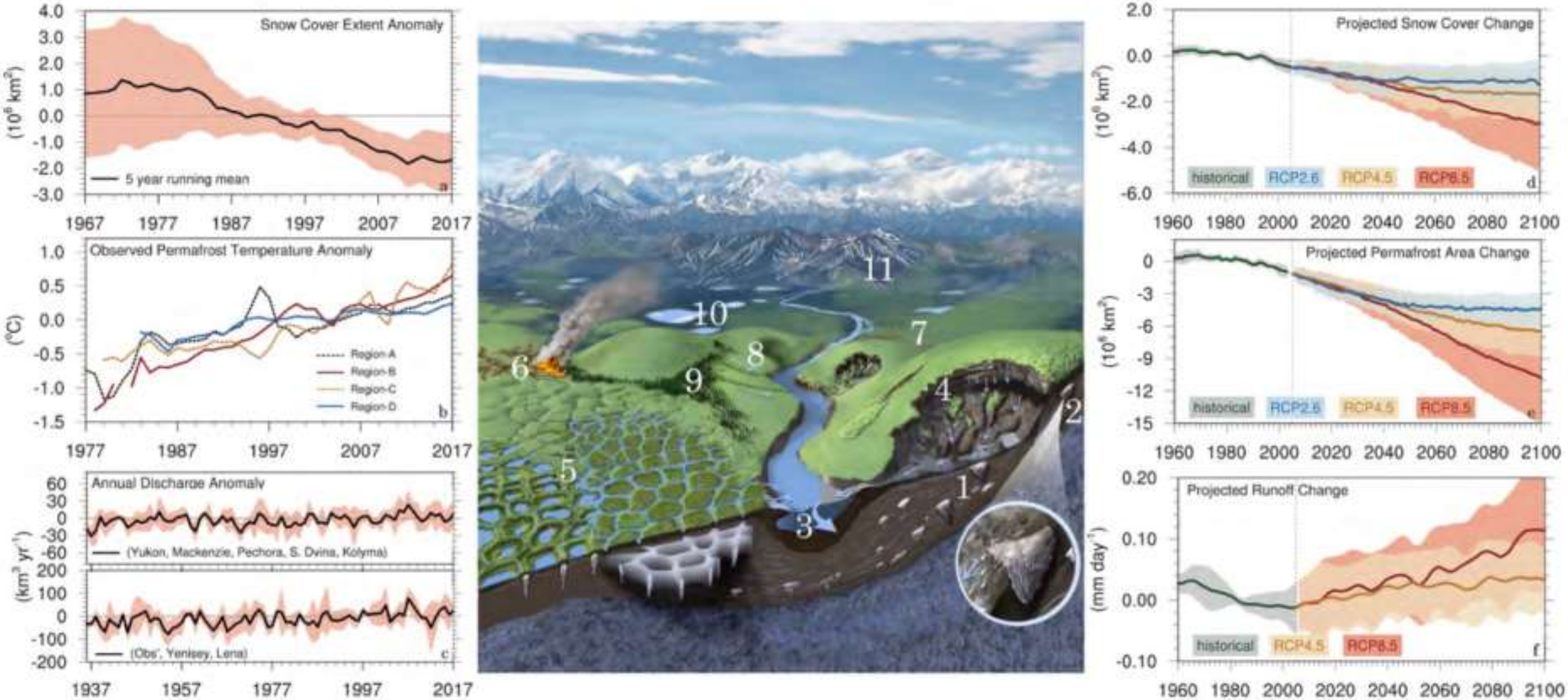


Figure 3.10: Schematic of important land surface components influenced by the Arctic terrestrial cryosphere (centre): permafrost (1); ground ice (2); river discharge (3); abrupt thaw (4); surface water (5); fire (6); tundra (7); shrubs (8); boreal forest (9); lake ice (10); seasonal snow (11). Left column: time series of snow cover extent anomalies in June (relative 1981–2010 climatology) from 5 products based on the approach of Mudryk et al. (2017); permafrost temperature change normalized to a baseline period (Romanovsky et al., 2017) and runoff from northern flowing watersheds normalized to a baseline period (1981–2010) (Holmes et al., 2018). Right column: CMIP5 multi-model average for different Representative Concentration Pathway scenarios for June snow cover extent (based on Thackeray et al., 2016), area of near-surface permafrost, and runoff to the Arctic Ocean (based on McGuire et al., 2018).

Meredith et al., 2019

Summary: Observed and Projected Changes

- **Over the last decades, global warming has led to widespread shrinking of the cryosphere, with mass loss from ice sheets and glaciers (*very high confidence*), reductions in snow cover (*high confidence*) and Arctic sea ice extent and thickness (*very high confidence*), and increased permafrost temperature (*very high confidence*).**

- **Glacier mass loss, permafrost thaw, and decline in snow cover and Arctic sea ice extent are projected to continue in the near-term (2031–2050) due to surface air temperature increases (*high confidence*), with unavoidable consequences for river runoff and local hazards (*high confidence*). The Greenland and Antarctic Ice Sheets are projected to lose mass at an increasing rate throughout the 21st century and beyond (*high confidence*). The rates and magnitudes of these cryospheric changes are projected to increase further in the second half of the 21st century in a high greenhouse gas emissions scenario (*high confidence*). Strong reductions in greenhouse gas emissions in the coming decades are projected to reduce further changes after 2050 (*high confidence*).**

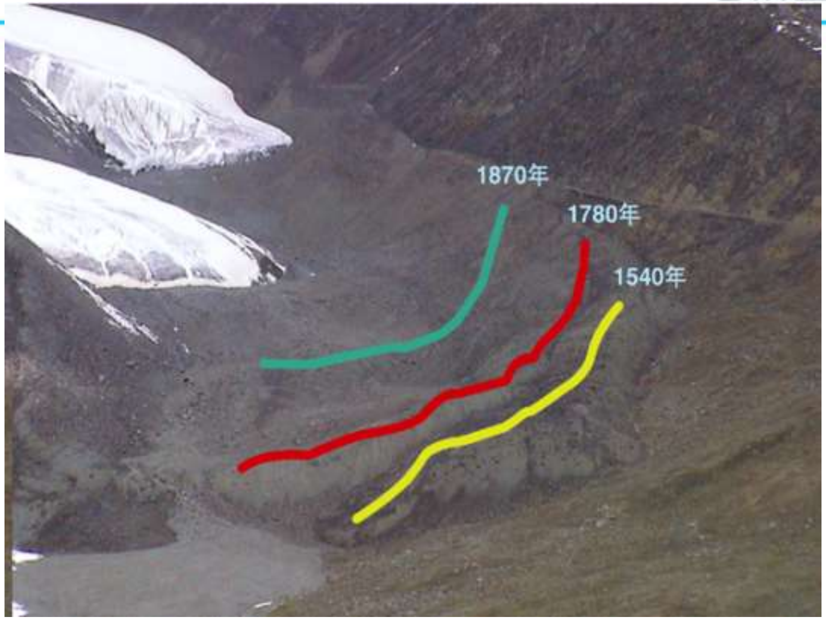
IPCC, 2019: Summary for Policymakers

1921

2007

Rongbuk glacier

(http://www.weather.com.cn/climate/qhbhyw/12/1570550.shtml?p=3)



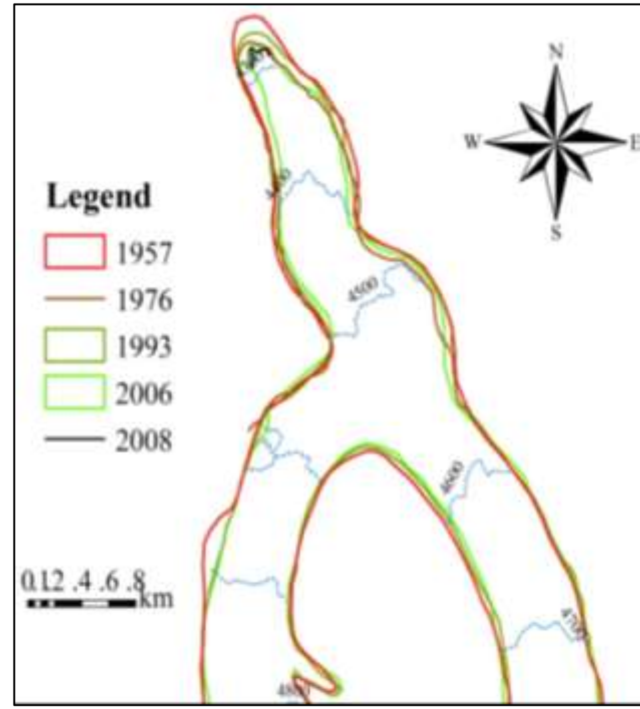
Glacier No. 1 at the headwater of Urumuqi river in Tienshan

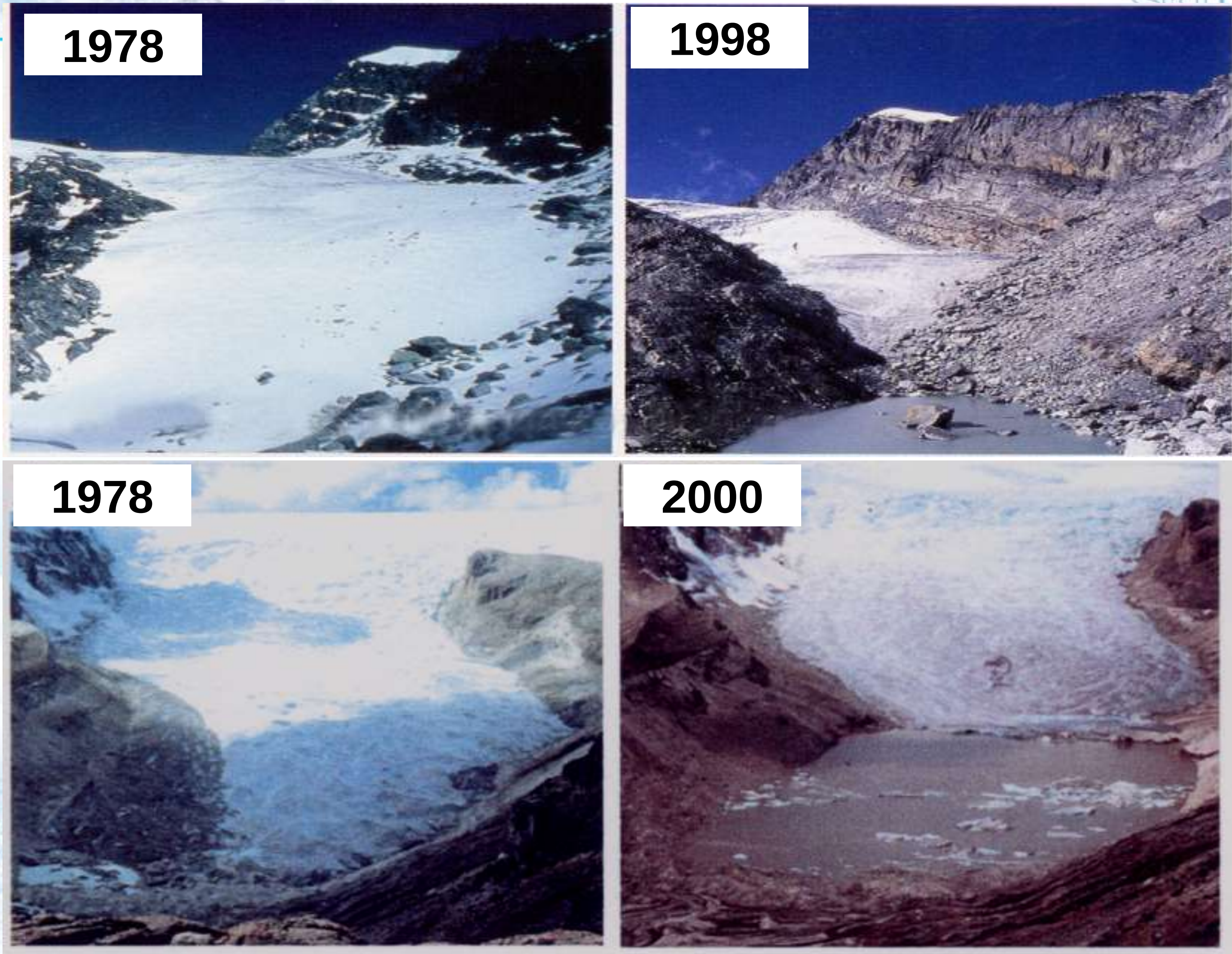
1959

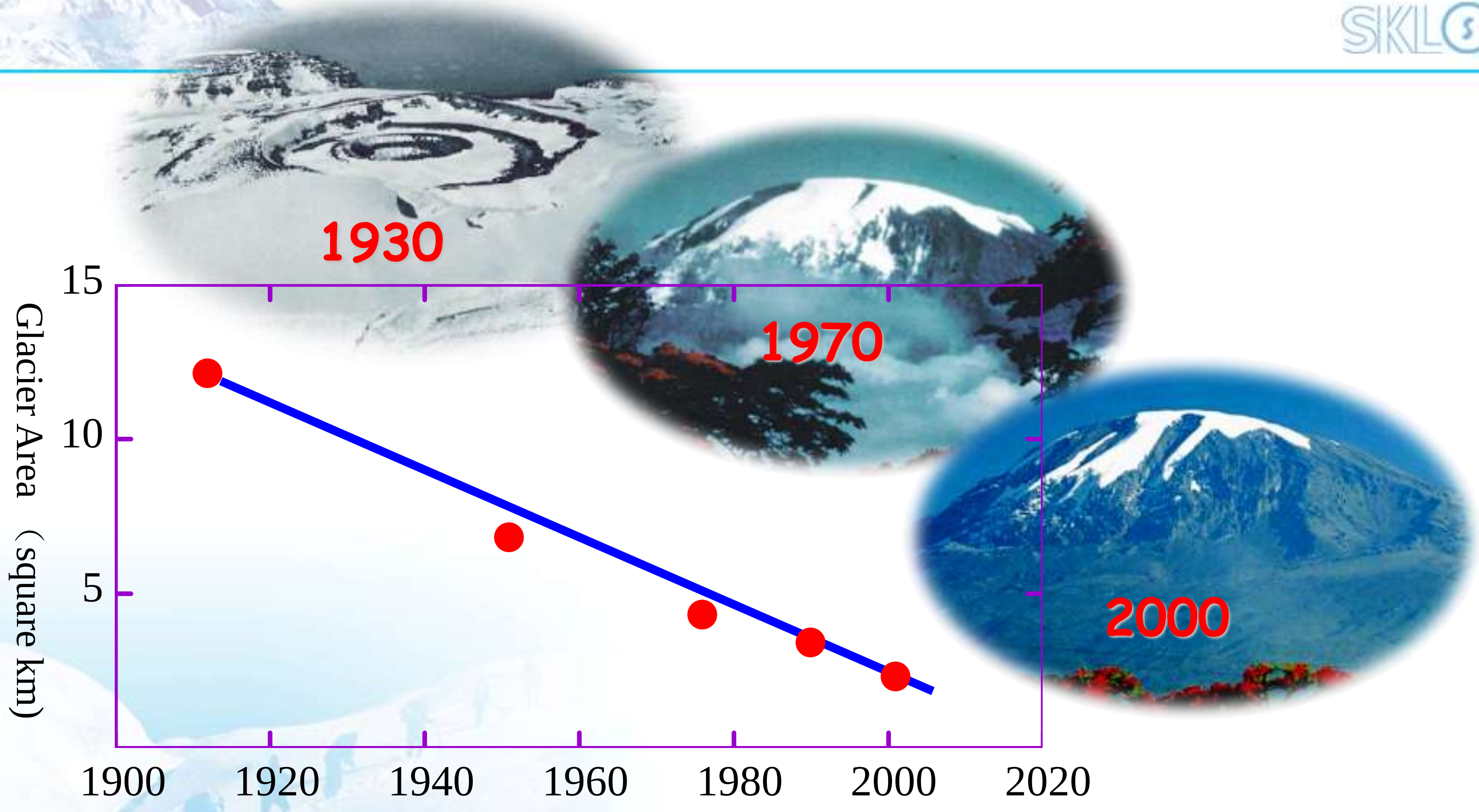
1976

2006

2008



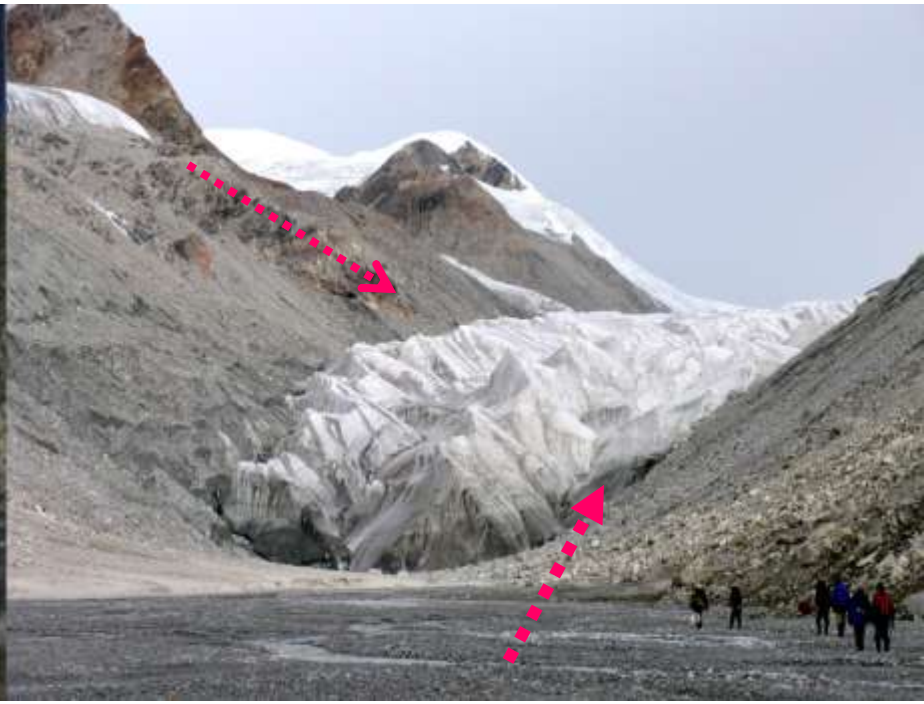

1978
1998
1978
2000



Kilimanjaro Mts., Africa

Panu glacier, Nyainquentanglha Mts., Tibetan Plateau

1999



2007

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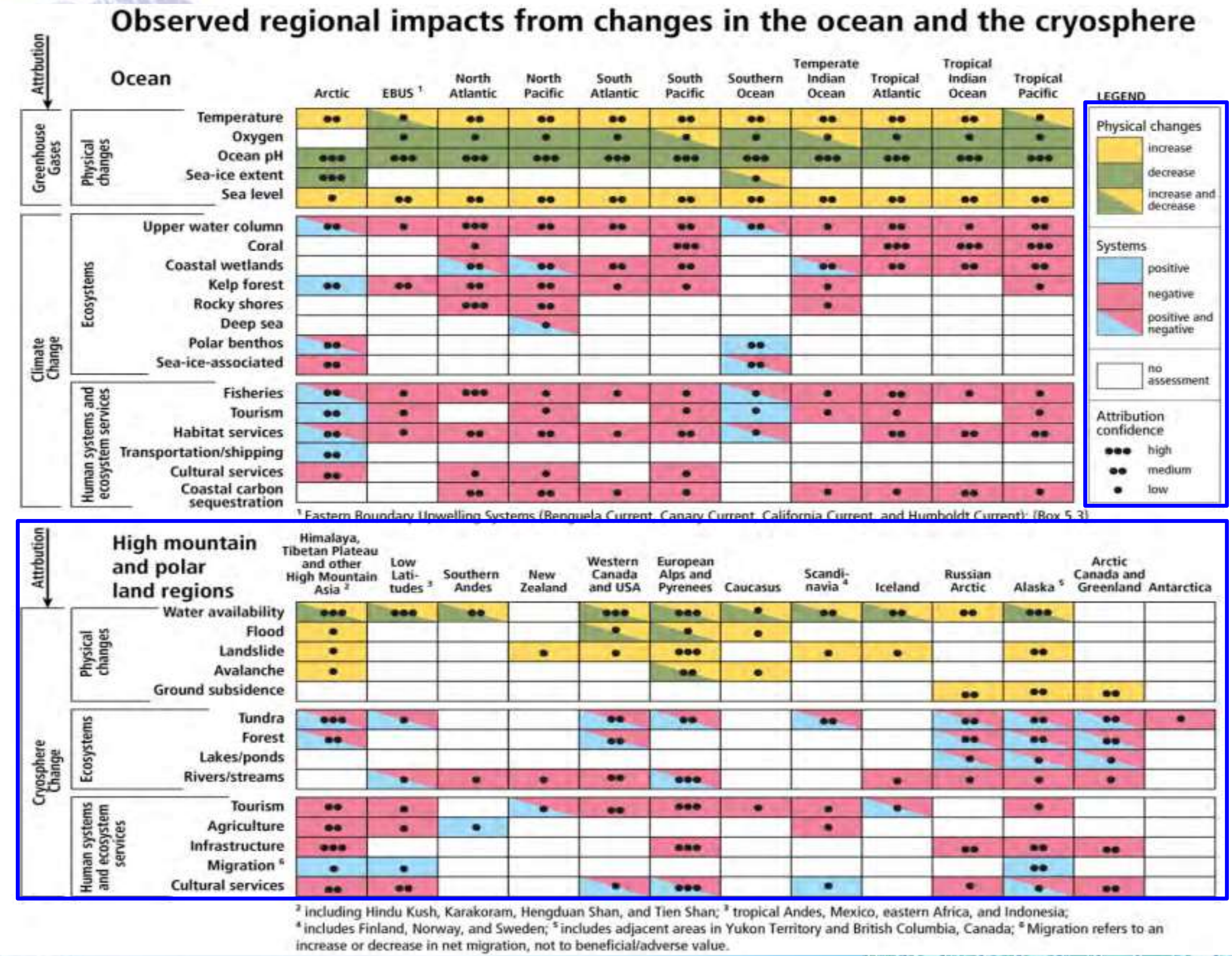
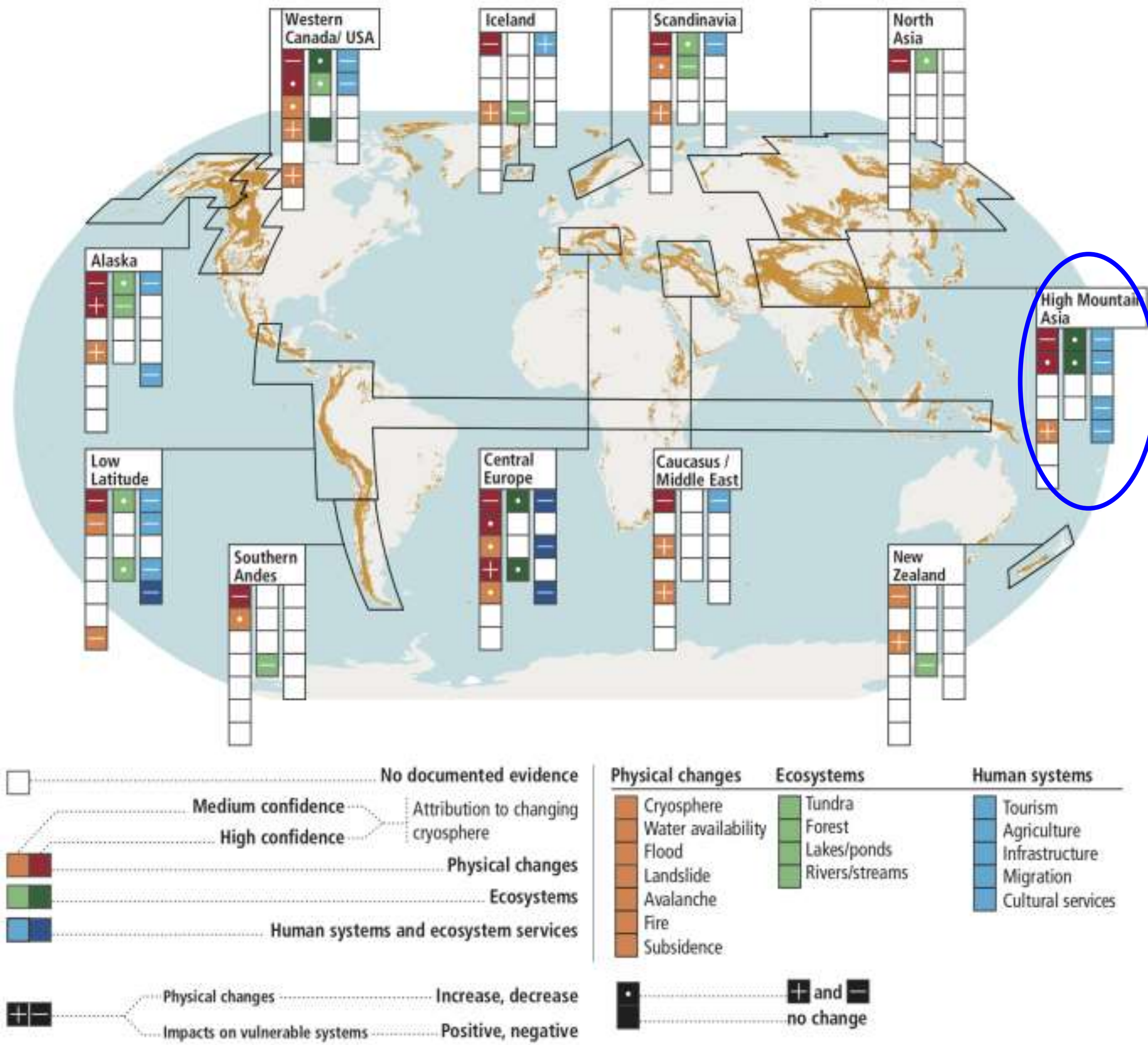
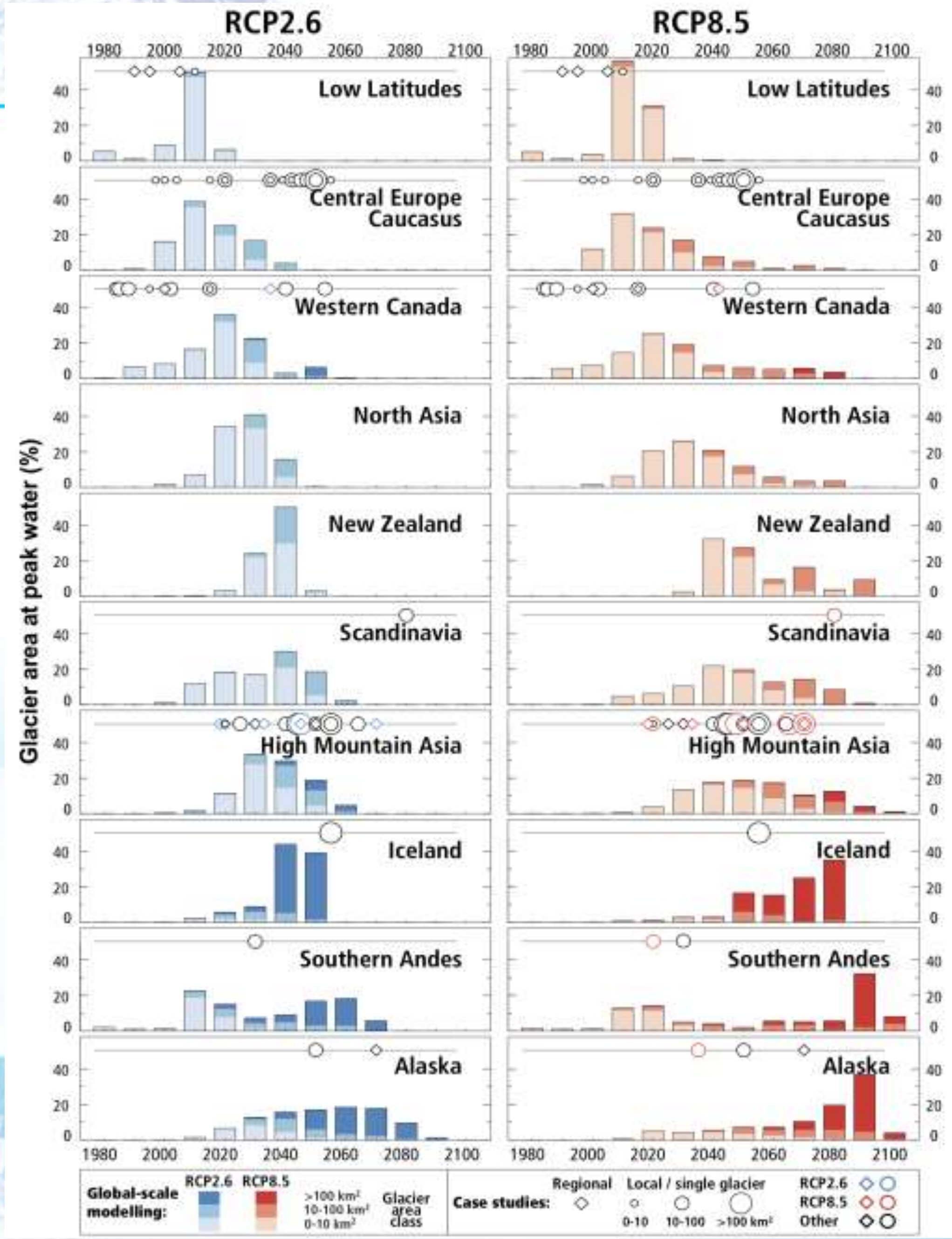


IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. Weyer (eds.)]. In press.

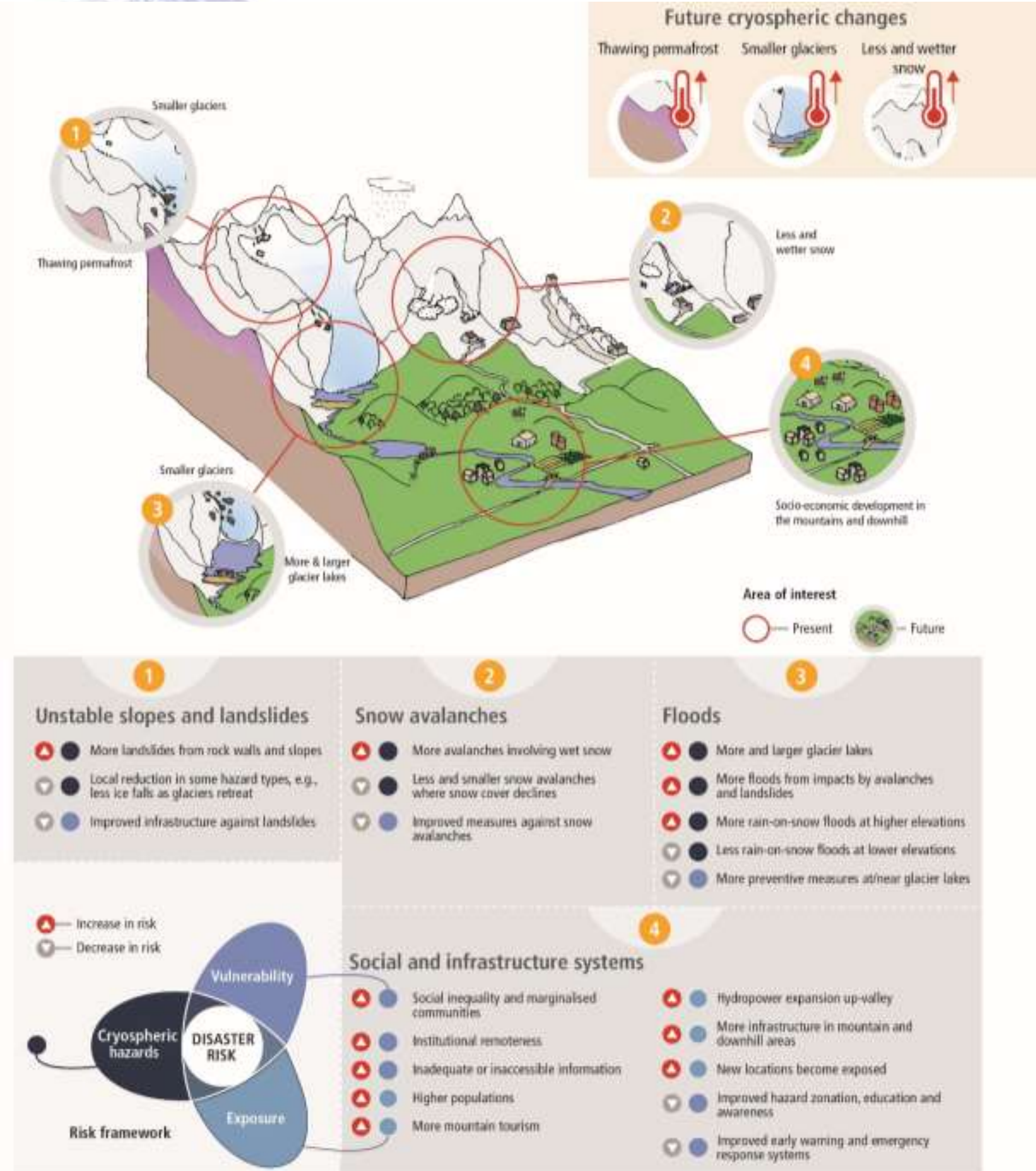


Observed changes in the cryosphere and impacts on ecosystems, other natural systems and human systems over past decades that can at least partly be attributed to changes in the cryosphere. Only observations documented in the scientific literature are shown, but impacts may also be experienced elsewhere.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



Timing of peak water from glaciers in different regions under two emission scenarios for Representative Concentration Pathways (RCPS) (RCP2.6 and RCP8.5).

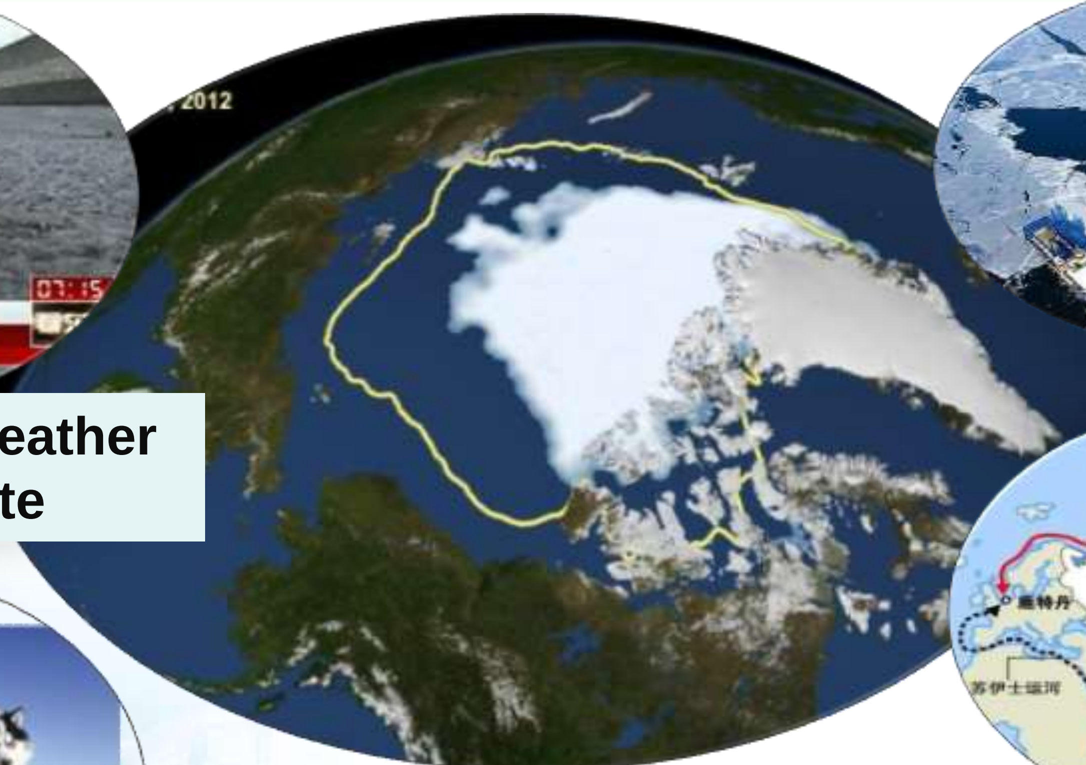
Peak water refers to the year when annual runoff from the initially glacierised area will start to decrease due to glacier shrinkage after a period of melt induced increase. The bars are based on Huss and Hock (2018) who used a global glacier model to compute the runoff of all individual glaciers in a region until year 2100 based on 14 General Circulation Models (GCMs). Depicted is the area of all glaciers that fall into the same 10-year peak water interval expressed as a percentage of each region's total glacier area, i.e., all bars for the same RCP sum up to 100% glacier area. Shadings of the bars distinguish different glacier sizes indicating a tendency for peak water to occur later for larger glaciers. Circles mark timing of peak water from individual case studies based on observations or modelling (Table SM2.10). Circles refer to results from individual glaciers regardless of size or a collection of glaciers covering <150 km^2 in total, while triangles refer to regional-scale results from a collection of glaciers with >150 km^2 glacier coverage. Case studies based on observations or scenarios other than RCP2.6 and RCP8.5 are shown in both the left and right set of panels.



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.

The impacts of Arctic Changes

Mid-latitude weather and climate



Energy

Navigation

Indigenous people

Fishery

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Modeled net soil carbon pool changes in Arctic permafrost

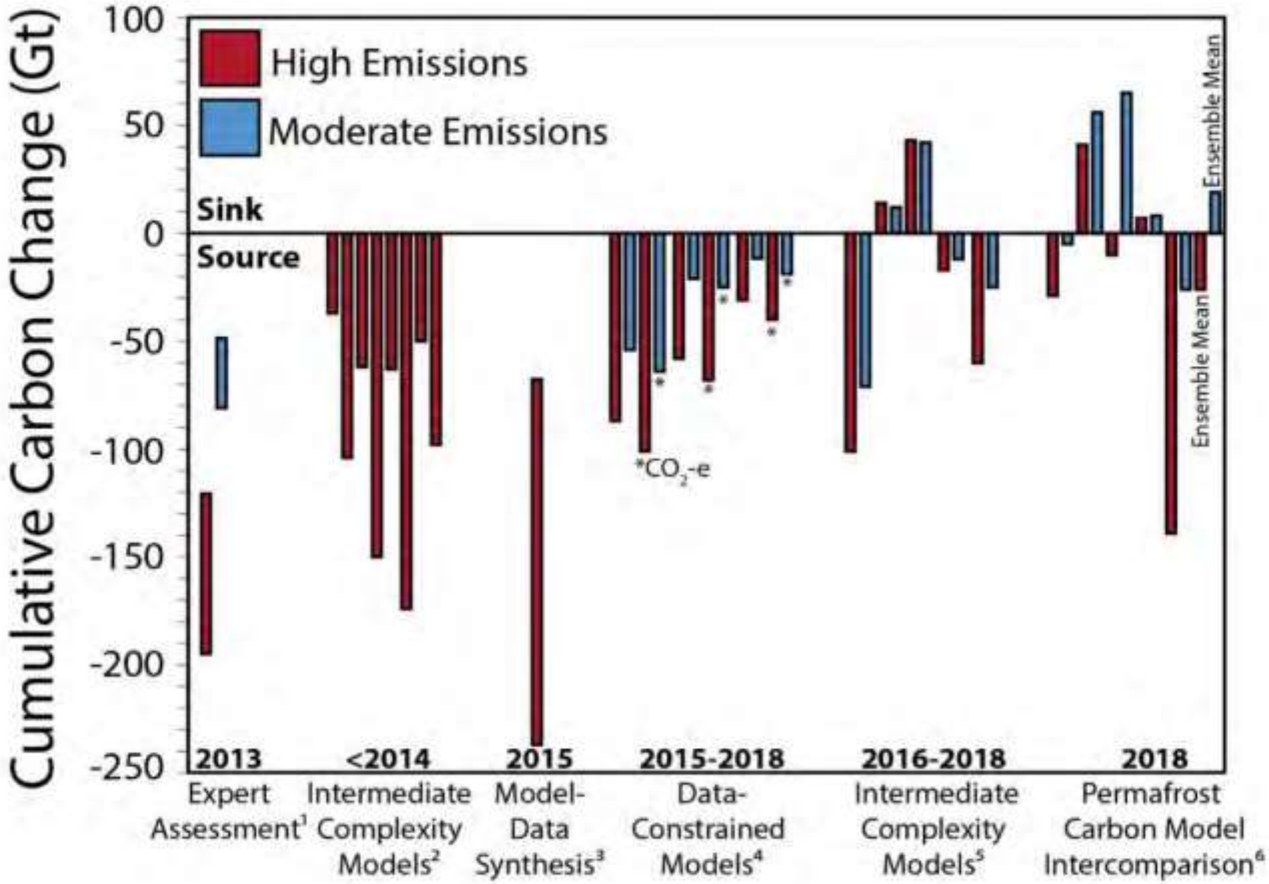

Figure 3.11: Estimates of cumulative net soil carbon pool change for the northern circumpolar permafrost region by 2100 following medium and high emission scenarios (e.g. RCP4.5 and RCP8.5 or equivalent). Cumulative carbon amounts are shown in Gigatons C (1 Gt C=1 billion metric tons), with source (negative values) indicating net carbon movement from soil to the atmosphere and sink (positive values) indicating the reverse. Some data-constrained models differentiated CO_2 and CH_4; bars show total carbon by weight, paired bar with * indicate CO_2-equivalent, which takes into account the global warming potential of CH_4. Ensemble mean bars refer to the model average for the Permafrost Carbon Model Intercomparison Project [5 models]. Bars that do not start at zero are in part informed by expert assessment and are shown as 95%CI ranges; all other bars represent model mean estimates. Data are from [1](Schuur et al., 2013); [2](Schaefer et al., 2014) [8 models]; [3](Schuur et al., 2015); [4](Koven et al., 2015; Schneider von Deimling et al., 2015; Walter Anthony et al., 2018); [5](MacDougall and Knutti, 2016; Burke et al., 2017a; Kleinen and Brovkin, 2018); [6](McGuire et al., 2018)

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Changes in public infrastructure damage costs by 2100 in Alaska

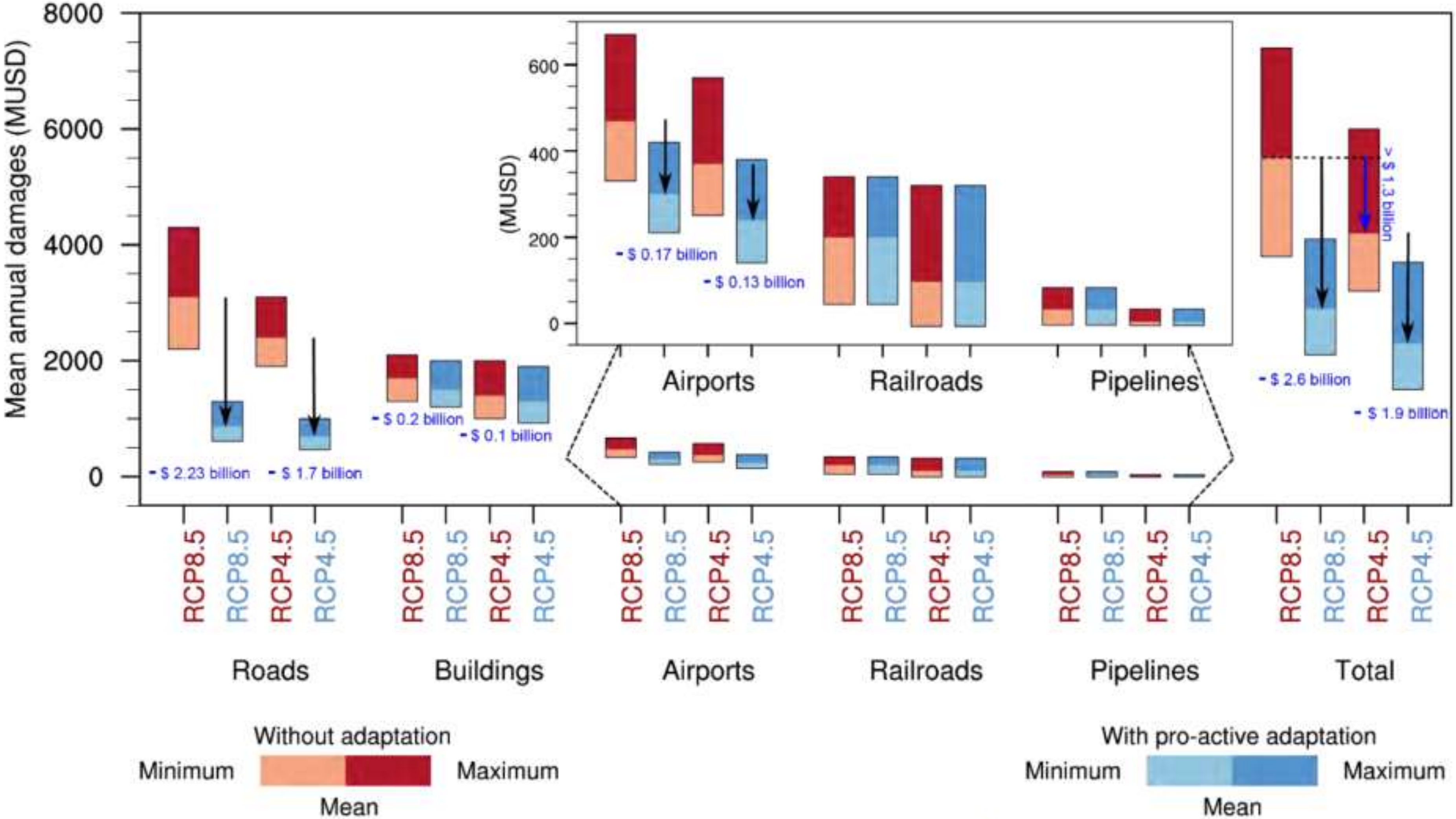

Figure 3.12: Changes in public infrastructure damage costs in cumulative $USD by 2100 in Alaska under different emission scenarios. The inset showing airports, railroads, and pipelines has a different in scale than roads, buildings, and the total. Dark shades represent climate-related costs of impact with no engineering adaptation measures, whereas light shades represent the cost savings after engineering adaptation (figure modified from Melvin et al., 2017).

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Observed Impacts

- Cryospheric changes have impacted terrestrial and freshwater species and ecosystems in high mountain and polar regions through the appearance of land previously covered by ice, changes in snow cover, and thawing permafrost. These changes have contributed to changing the seasonal activities, abundance and distribution of ecologically, culturally, and economically important plant and animal species, ecological disturbances, and ecosystem functioning (*high confidence*).

- Since the mid-20th century, the shrinking cryosphere in the Arctic and high-mountain areas has led to predominantly negative impacts on food security, water resources, water quality, livelihoods, health and well-being, infrastructure, transportation, tourism and recreation, as well as culture of human societies, particularly for Indigenous peoples (*high confidence*). Costs and benefits have been unequally distributed across populations and regions. Adaptation efforts have benefited from the inclusion of Indigenous knowledge and local knowledge (*high confidence*).

Project Risks

- Future land cryosphere changes will continue to alter terrestrial and freshwater ecosystems in high-mountain and polar regions with major shifts in species distributions resulting in changes in ecosystem structure and functioning, and eventual loss of globally unique biodiversity (*medium confidence*). Wildfire is projected to increase significantly for the rest of this century across most tundra and boreal regions, and also in some mountain regions.

- Future cryosphere changes on land are projected to affect water resources and their uses, such as hydropower (*high confidence*) and irrigated agriculture in and downstream of high-mountain areas (*medium confidence*), as well as livelihoods in the Arctic (*medium confidence*). Changes in floods, avalanches, landslides, and ground destabilization are projected to increase risk for infrastructure, cultural, tourism, and recreational assets (*medium confidence*).

Outline

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Key messages

- Impacts of climate-related changes in the ocean and cryosphere increasingly challenge current governance efforts to develop and implement adaptation responses from local to global scales, and in some cases pushing them to their limits. People with the highest exposure and vulnerability are often those with lowest capacity to respond (*high confidence*) .

- The far-reaching services and options provided by ocean and cryosphere-related ecosystems can be supported by protection, restoration, precautionary ecosystem-based management of renewable resource use, and the reduction of pollution and other stressors (*high confidence*). Integrated water management (*medium confidence*) and ecosystem-based adaptation (*high confidence*) approaches lower climate risks locally and provide multiple societal benefits. However, ecological, financial, institutional and governance constraints for such actions exist (*high confidence*), and in many contexts ecosystem-based adaptation will only be effective under the lowest levels of warming (*high confidence*).

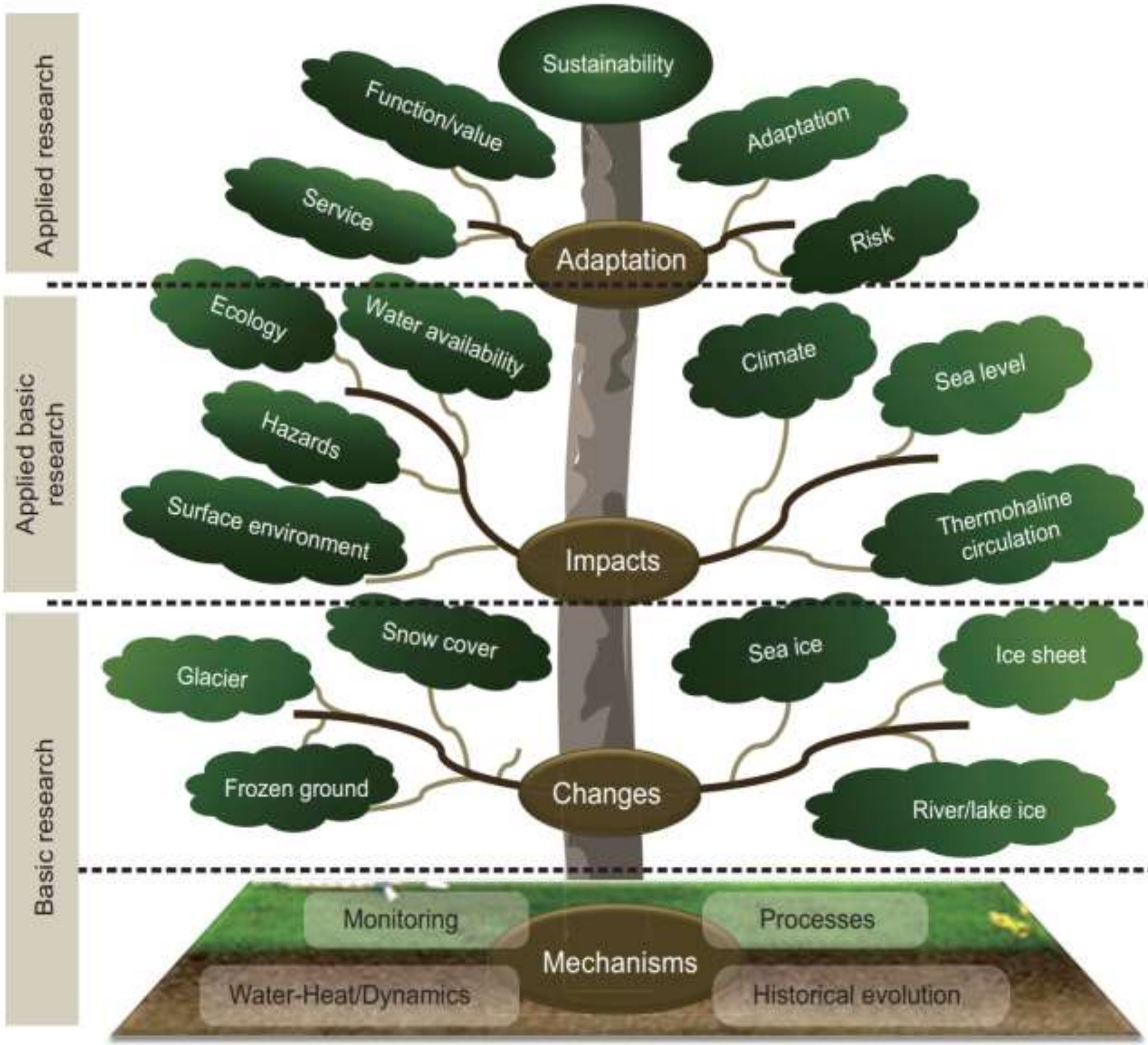
Key messages

SKLCS

Enabling climate resilience and sustainable development depends critically on urgent and ambitious emissions reductions coupled with coordinated sustained and increasingly ambitious adaptation actions (*very high confidence*). Key enablers for implementing effective responses to climate-related changes in the ocean and cryosphere include intensifying cooperation and coordination among governing authorities across spatial scales and planning horizons.

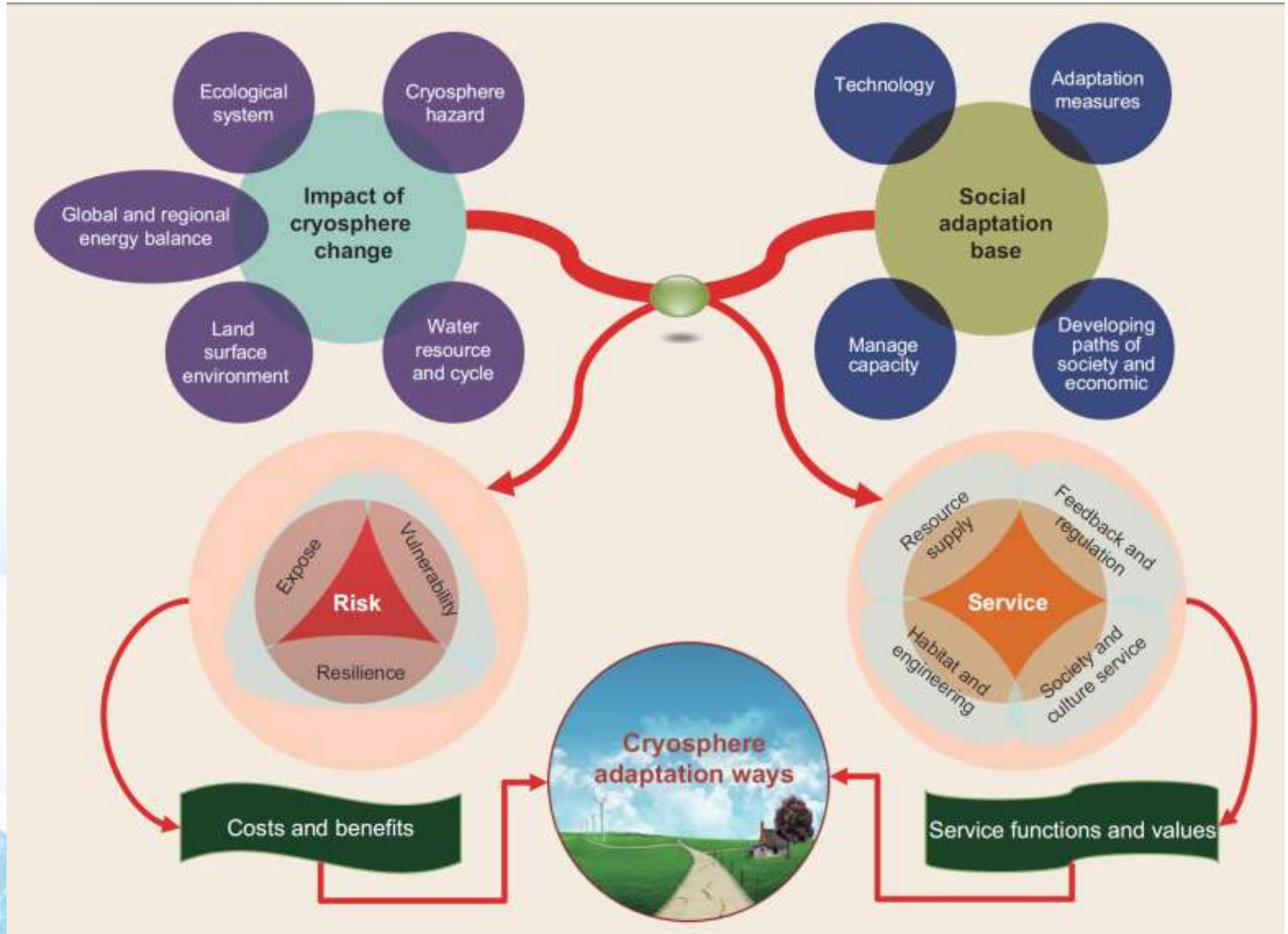
Education and climate literacy, monitoring and forecasting, use of all available knowledge sources, sharing of data, information and knowledge, finance, addressing social vulnerability and equity, and institutional support are also essential. Such investments enable capacity-building, social learning, and participation in context-specific adaptation, as well as the negotiation of trade-offs and realisation of co-benefits in reducing short-term risks and building long-term resilience and sustainability (*high confidence*).

Framework of Cryospheric Science



Qin et al. 2017, NSR

Cryospheric Change and Sustainable Development



Qin et al. 2017, NSR

Thank you!