Climate Change: from Mountains to Plain

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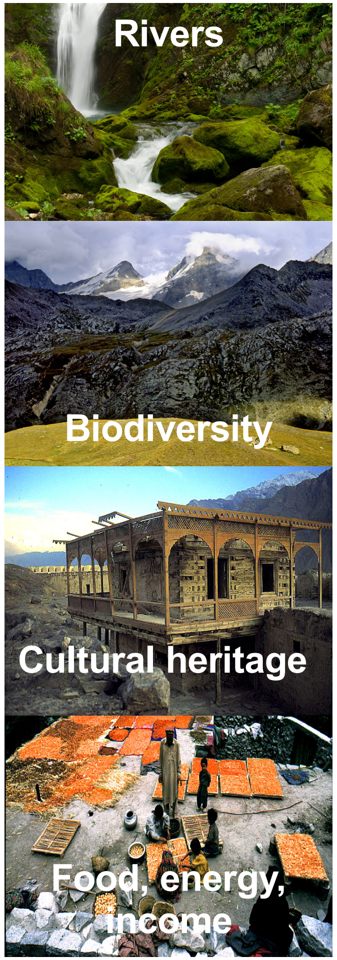
Why are mountains important?

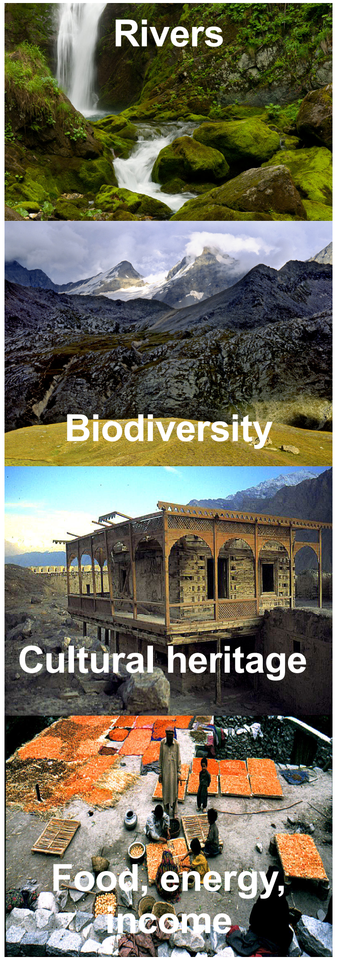


- They occupy about **one-quarter of the Earth's land surface and host ~20% of the world's population** → mountains are globally distributed and are transnational

- They **are storehouse of biological diversity and endangered species: they support about 25% of the terrestrial biodiversity** → mountains are biodiversity hot-spots

- **32% of protected areas worldwide are in mountains**

Why are mountains important?



- The influence of mountains extends far beyond their ranges: they **provide benefits** to over half the global population, making them crucial not only for people living in mountains, but also for those living downstream

  - **Provisioning services (water, food, energy, timber)**
  - **Regulating services (mountain water cycle and regional feedbacks, modulation of runoff regimes, mitigation of the risks from natural hazards, water storage,)**
  - **Cultural services (**cultural heritage and intrinsic spiritual values for humanity, aesthetic value, recreation, diversity of cultures)

The importance of mountains

1992 - **Rio de Janeiro Earth Summit, Chapter 13 of Agenda 21** confirmed the need for sustainable development in mountain regions, given mountains' crucial role as sources of water, energy, biodiversity, minerals, forest products and agricultural products.

2001- International programs of **FAO** (focus on mountains) and **IGBP (**Report 49)

2002- **Declaration of the International Year of Mountains by the United Nations**

2002 - **Johannesburg World Summit on Sustainable Development,** underlines that specific actions to be taken for the preservation and sustainable development of mountain regions

2008 - Mountain ecosystems were identified in 2008 report **of the General Assembly of the United Nations** (UN, A/Res/62/196, 2008) as key indicators of such effects of climate change, especially in terms of vulnerable resources like biodiversity and water.

2019 – Chapter 2 of the IPCC SROCC Report dedicated to «**high mountain areas**»: «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»

Mountain regions are highly sensitive to climate and environmental changes (including water and air pollution, changes in land use, alien species), with common and context-specific manifestations of these changes

Ecosystem functions and services

Water quality and quantity

Food production

Economic growth

It is essential to monitor the mountain environment, to better understand the drivers of the observed changes and to estimate the response of mountains to future climate conditions

- Cryosphere (glaciers, snow, glacial lakes, permafrost)
- Changes in biodiversity
- Changes in mountain ecosystems (mismatches)

Research needs

A better <u>understanding of the key processes and mechanisms</u> in mountain environments requires

Measurement data (in-situ and EO) and their integration

Improving and homogenizing observations, designing proper metadata on existing observations

Model simulations

Increase the spatial resolution, improve the parameterizations, implement modelling chains, to test and improve our understanding of the physical processes that drive the climate system, identify feedbacks, predict future changes

<u>Handle (and possibly reduce) uncertainties</u> in both observations and models

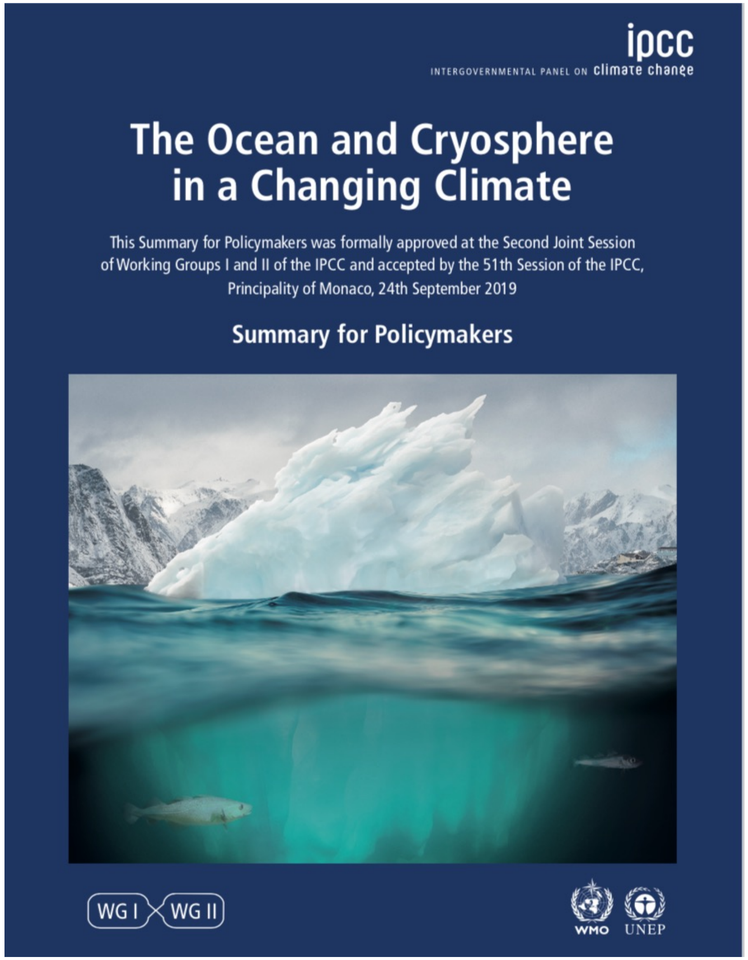
Mountains as an opportunity

to develop new research approaches

- The spatial heterogeneity of the mountains generates methodological challenges for Earth observation (cloudiness, shadows, etc.)

- Mountain areas represent an important opportunity to
  - **Develop more robust approaches of study and to integrate different kinds of observations**
  - **Improve model simultions**

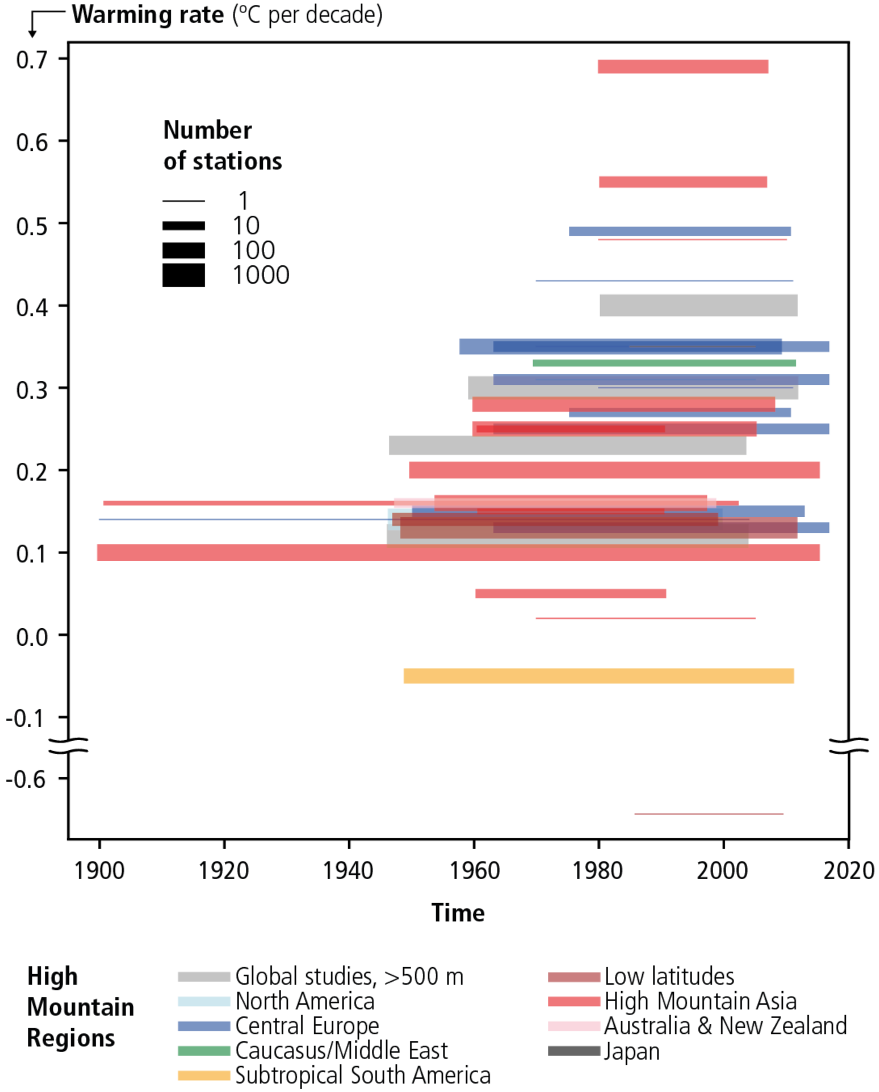
IPCC Special Report, 2019



The Ocean and Cryosphere in a Changing Climate

SROCC, IPCC 2019

Mountain warming rates



Synthesis of trends in **mean annual surface air temperature in mountain regions**, reported in <u>40 studies based on 8703 observation stations</u> in total (partly overlapping).

- Each line refers to a warming rate from one study, averaged over the time period indicated by the extent of the line.

- Colors indicate mountain region, and line thickness the number of observation stations used.

Average warming rate in mountains: 0.3°C/decade (to be compared to the globally averaged warming rate of 0.2°C/decade)

IPCC SROCC, 2019

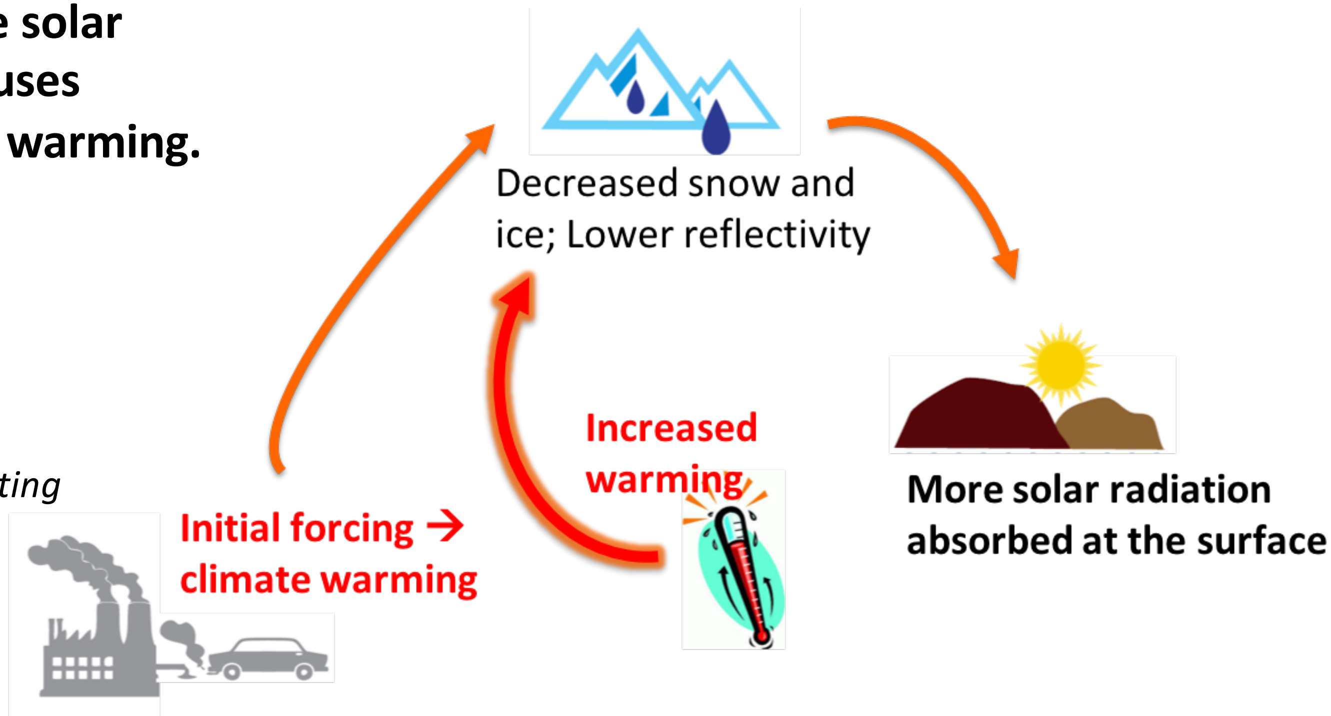
Snow-ice albedo feedback

A positive feedback amplifies changes in the direction they start. With climate, that means a positive feedback amplifies a change.

Ice-albedo feedback: Warming melts snow, the darker surface beneath absorbs more solar radiation and warms more, which causes melting more snow and causes more warming.

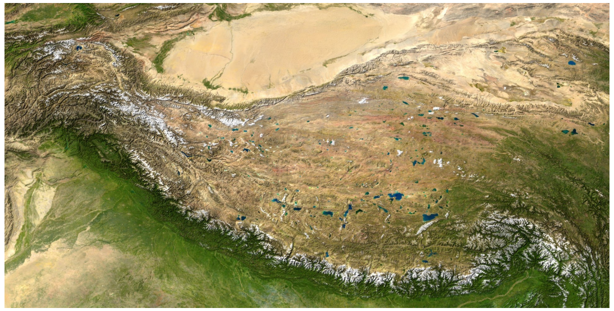
Other feedbacks

- *Cloud cover*
- *Water vapour modulation of longwave heating*
- *Absorbing Aerosols*
- *A mix of the mechanisms above*

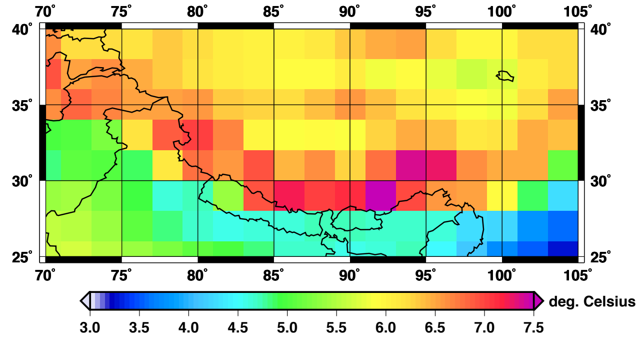


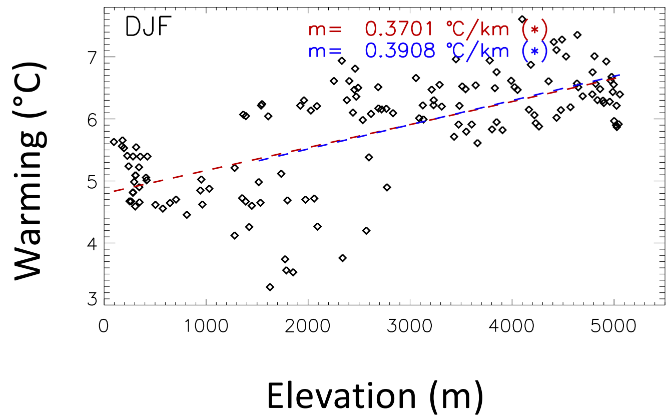
Elevation-dependent warming

Tibetan Plateau- Himalayas

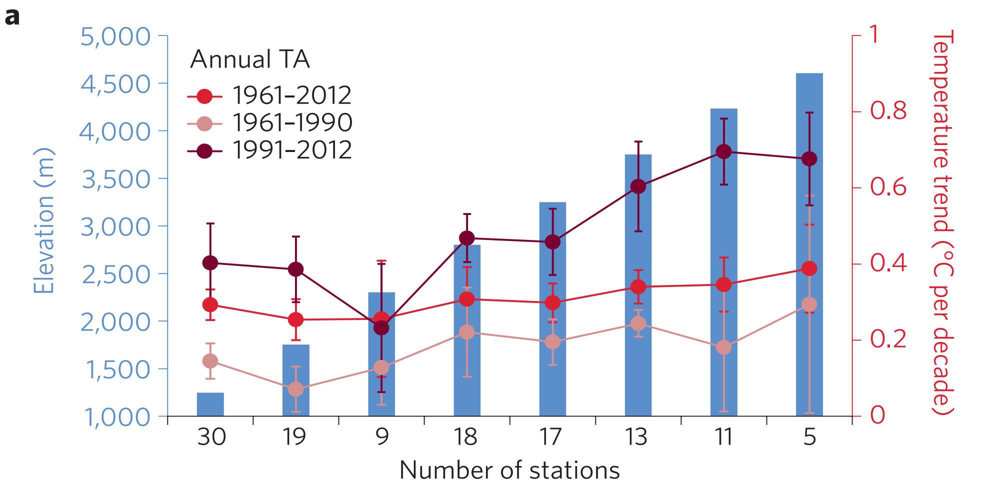


Palazzi, E., Filippi, L. & von Hardenberg, J. Clim Dyn (2017) 48: 3991. doi:10.1007/s00382-016-3316-z





Pepin et al. Nature Climate Change 5, 424–430 (2015) doi:10.1038/nclimate2563

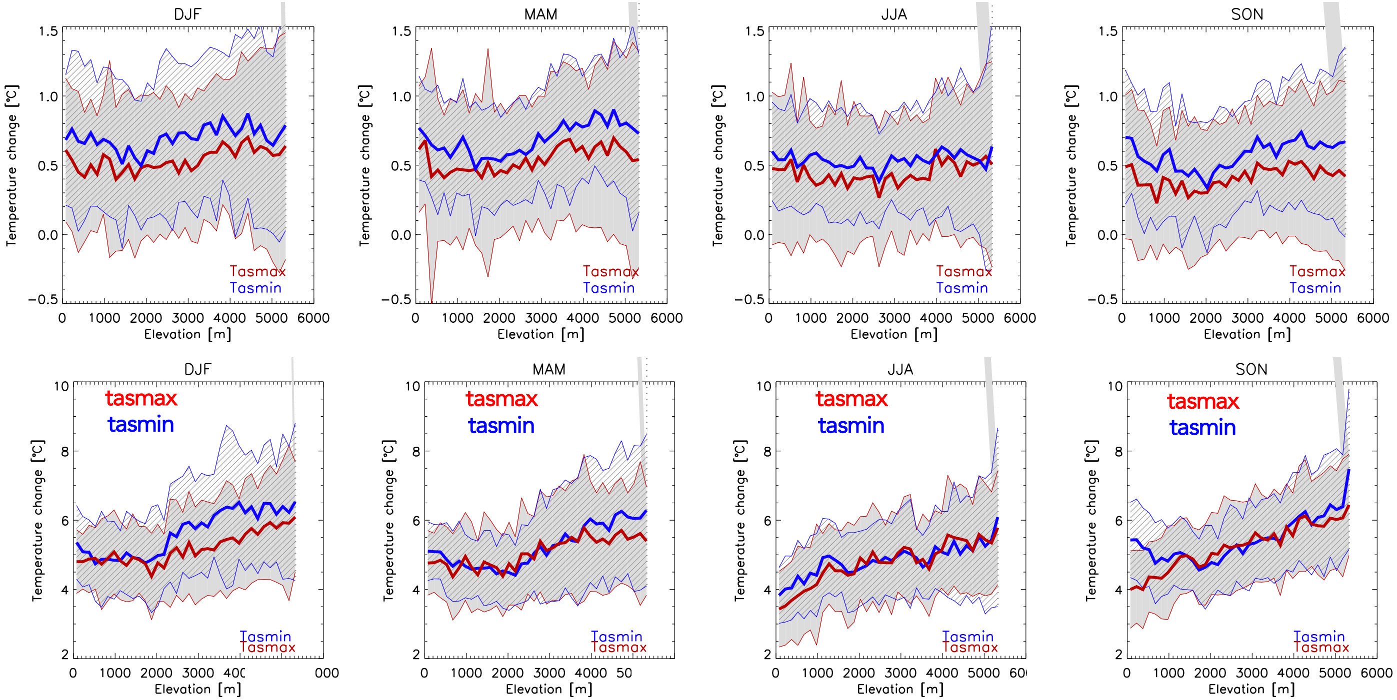


Between 1991 and 2012 temperature has increased at a rate of 0.7 °C/decade above 4.000 m compared to 0.3-0.4°C/decade below 2500 m

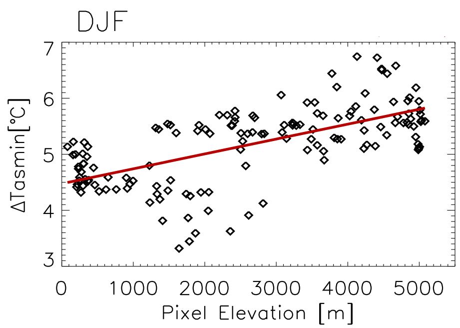
Elevation-dependent warming

historical

Scenario RCP 8.5

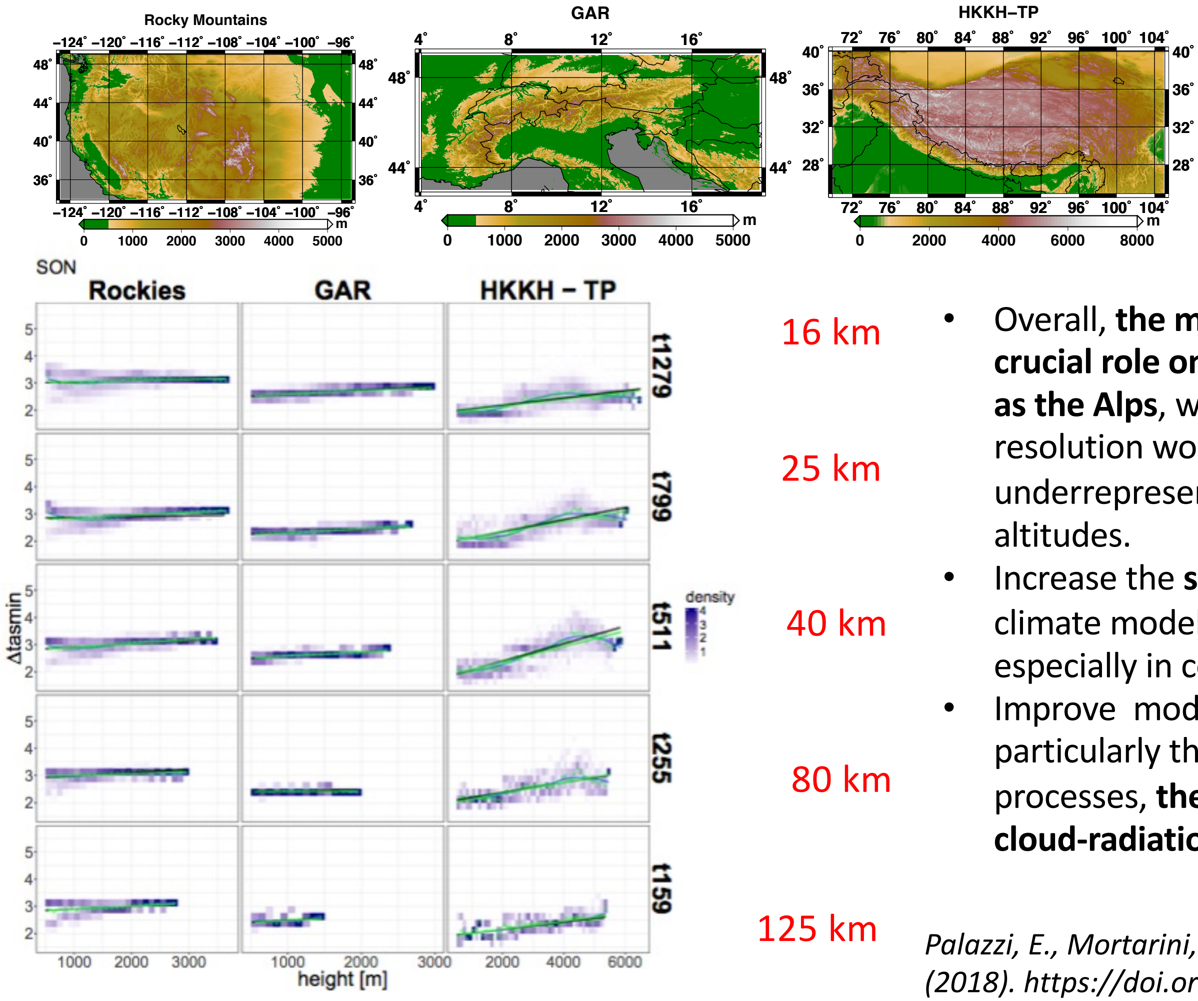


	1871-2000	DJF	MAM	JJA	SON
Hist	tasmin	0.0135	0.0348	0.0106	0.0173
	tasmax	0.0262	0.165	0.0154	0.0164
	1971-2100	DJF	MAM	JJA	SON
Scenario RCP 8.5	tasmin	0.3701	0.2803	0.2807	0.2789
	tasmax	0.2635	0.2231	0.3816	0.4584



Elevation dependent warming

Impact of the model resolution



16 km

25 km

40 km

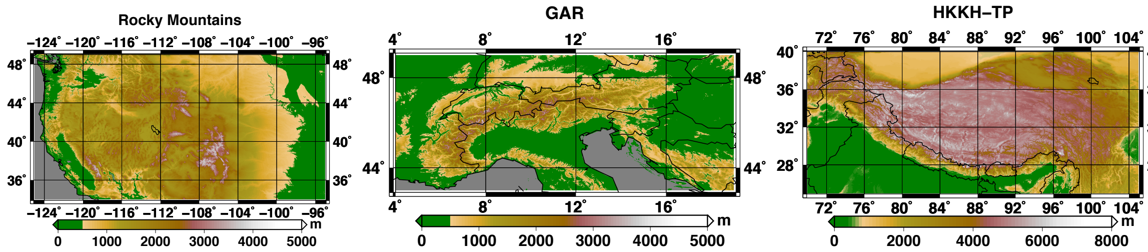
80 km

125 km

- Overall, **the model resolution plays a crucial role only in small areas such as the Alps**, where a too coarse resolution would lead to an underrepresentation of the highest altitudes.
- Increase the **spatial resolution** in climate models may be crucial especially in complex topography
- Improve model parameterizations, particularly those involving surface processes, **the snow-albedo and cloud-radiation feedbacks**

Palazzi, E., Mortarini, L., Terzago, S. et al. Clim Dyn (2018). https://doi.org/10.1007/s00382-018-4287-z

Elevation dependent warming

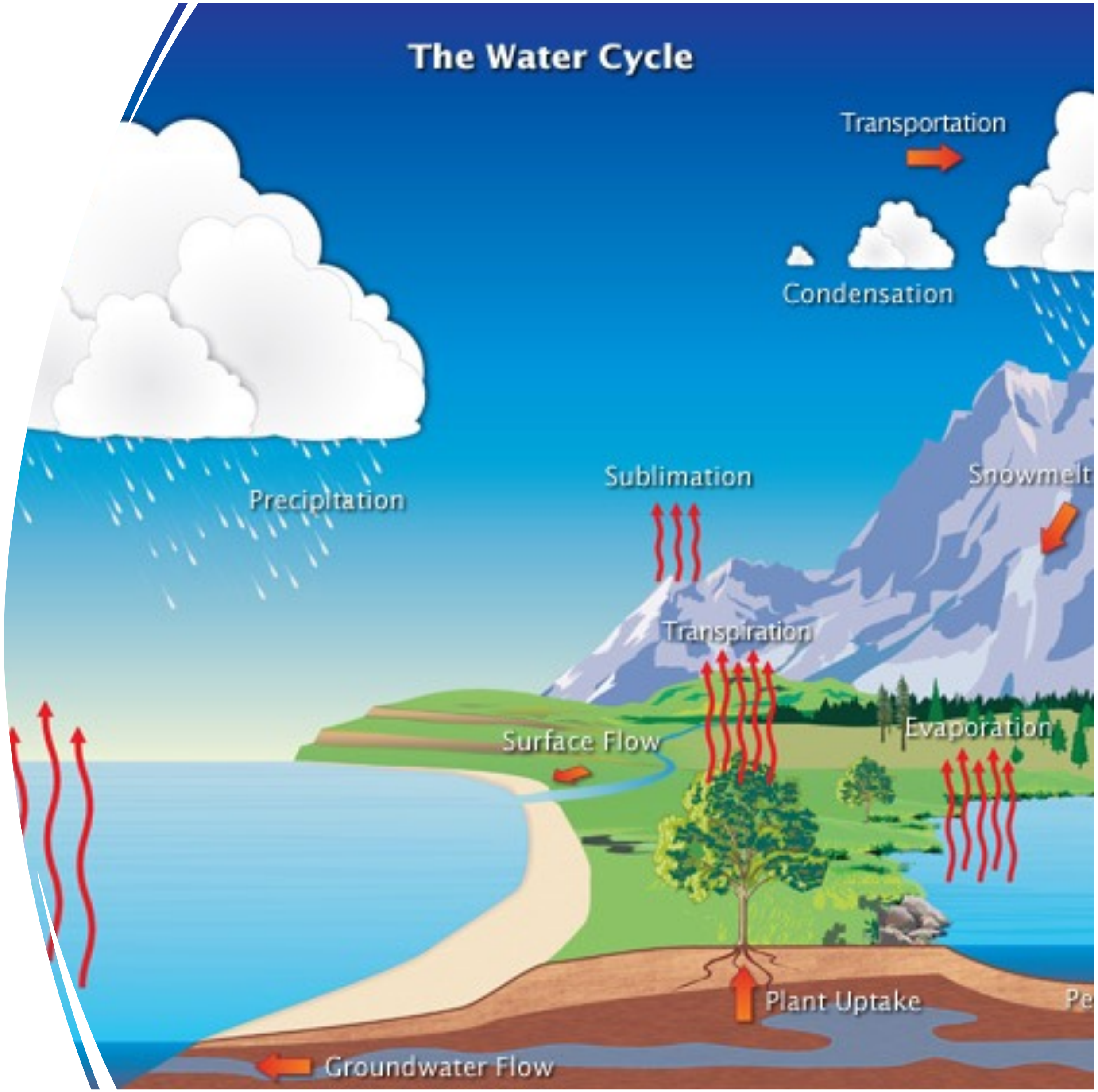


- The region which is found to be more prone to EDW is the HKKH-TP
- The season showing the most striking evidence of EDW in all regions is Autumn

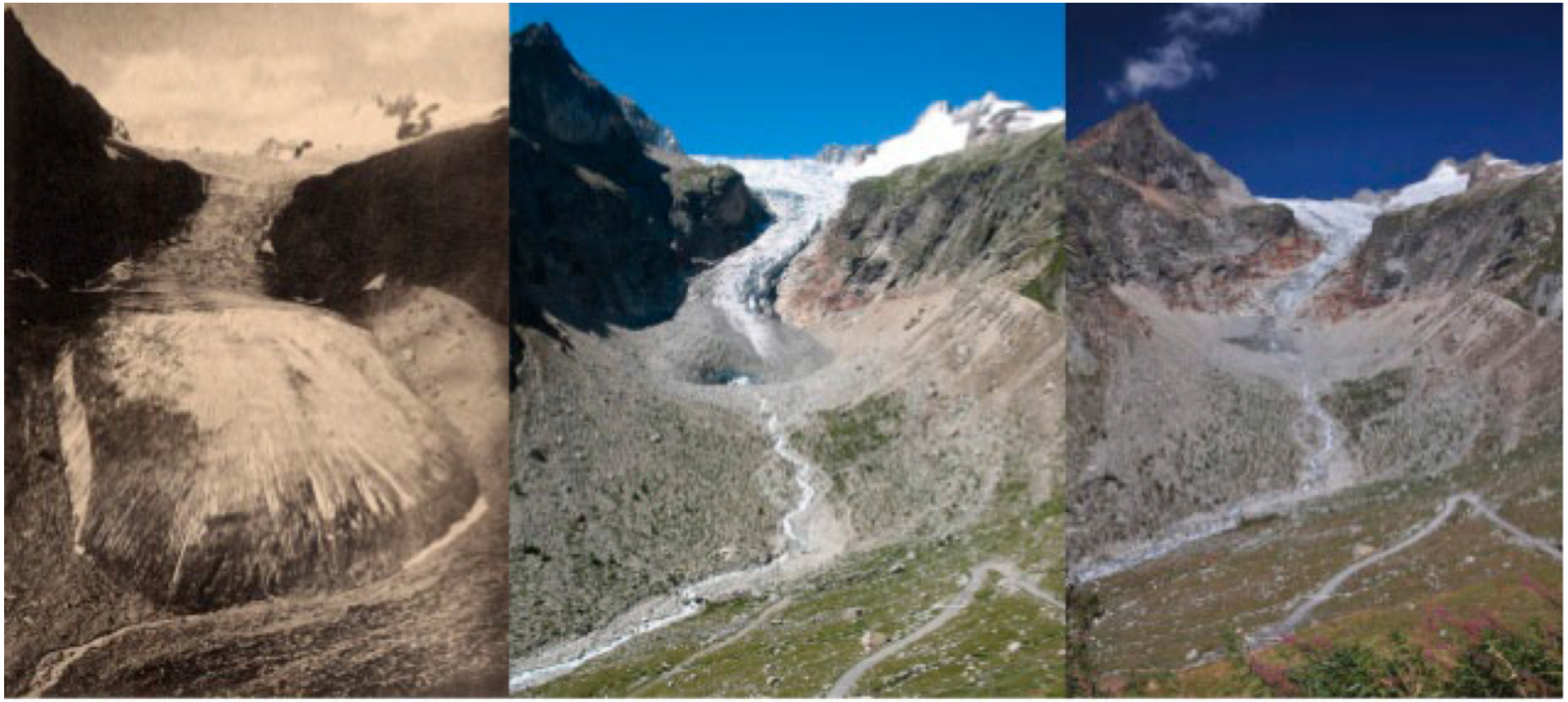
Autumn is a "transition season" between snow-free and snow-covered areas. **Climate warming is delaying the onset of snow cover at low and mid altitudes and this trend is expected to continue in the future, involving higher elevations.** Therefore, larger snow free areas are expected in autumn. (**Albedo change is the most important EDW driver in this study**)

Amplified warming in mountain regions

- glaciers, snow at ground, permafrost, glacial lakes
- precipitation (snow/rain)
- extreme events
- biodiversity
- ecosystems mismatch



Retreating glaciers



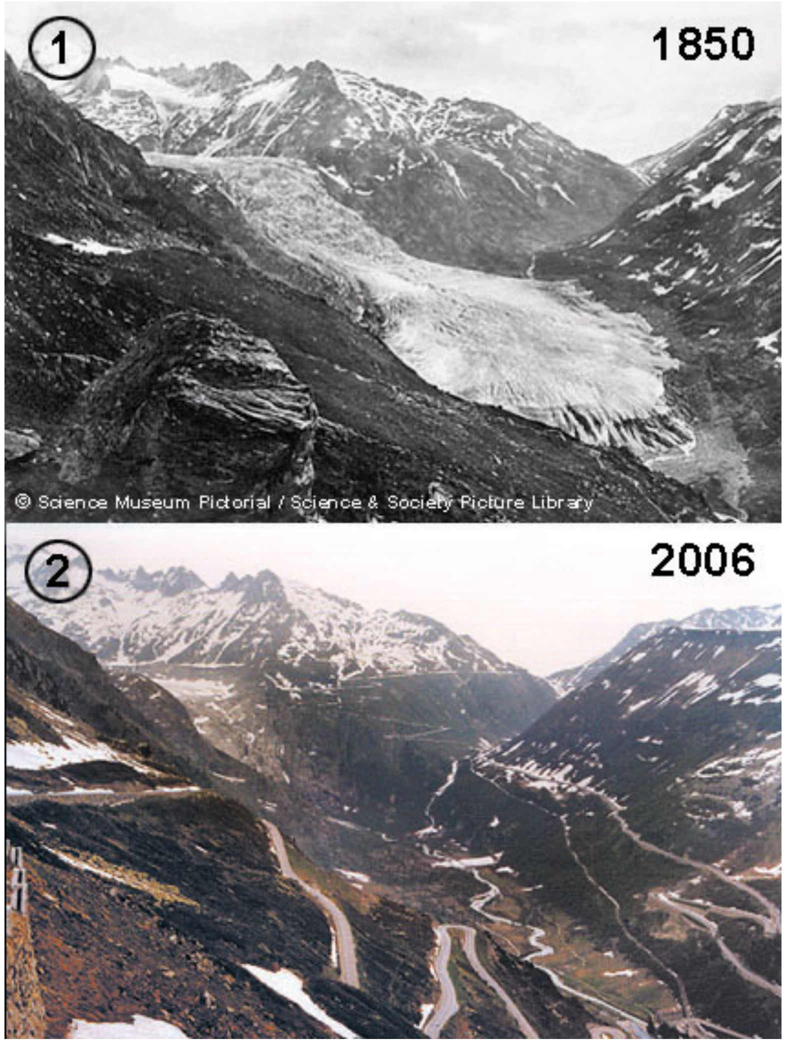
1897 (f. Druetti) | 2005 (f. L. Mercalli) | 2012 (f. L. Mercalli)

Are at the same time a consequence and a cause of increased warming in mountains

Retreating glaciers

Rhône Glacier, Switzerland

Painting by Caspar Wolf (1735-1783



Retreating glaciers

Fradusta, Pale di San Martino, Trentino

Marmolada, Credits Renato R. Colucci

Snow at ground melts earlier

Permafrost thawing

Un lago glaciale dell'Himalaya

Water-related climatic extremes

water: too little of it

water: too much of it

Biodiversity loss and migrations

From the rxhibition
"Un paese mille paesaggi - AltroVersante"

Alpine vegetation

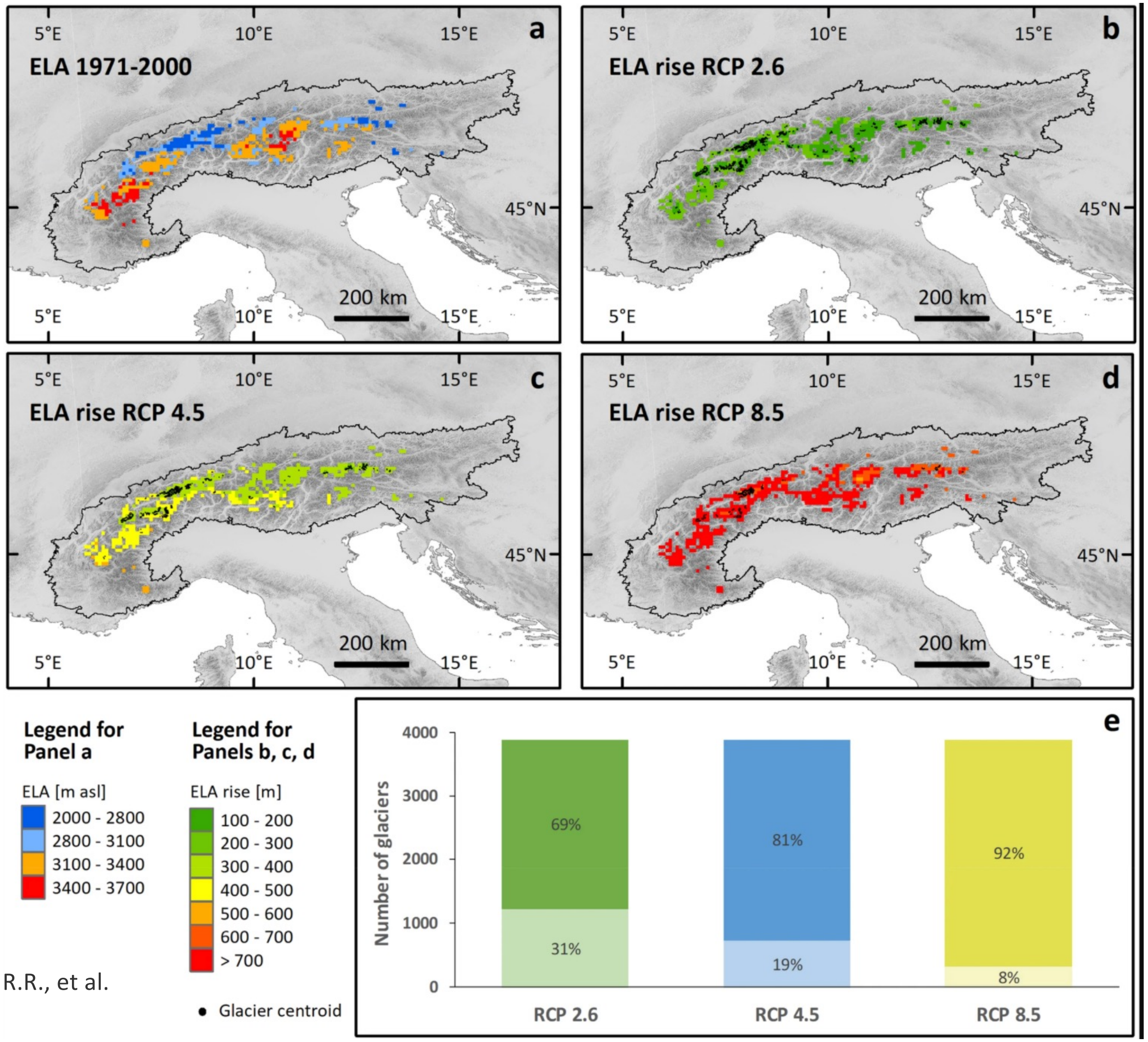
Shift to higher altitudes
1- 4 m/decade

Grabherr G. et al., 1994 *Nature*
EU project GLORIA-Europe

Several species of birds, butterflies, and alpine flora are seriously endangered by climate change.


The future of mountains

Equilibrium line altitude shifting in the Alps



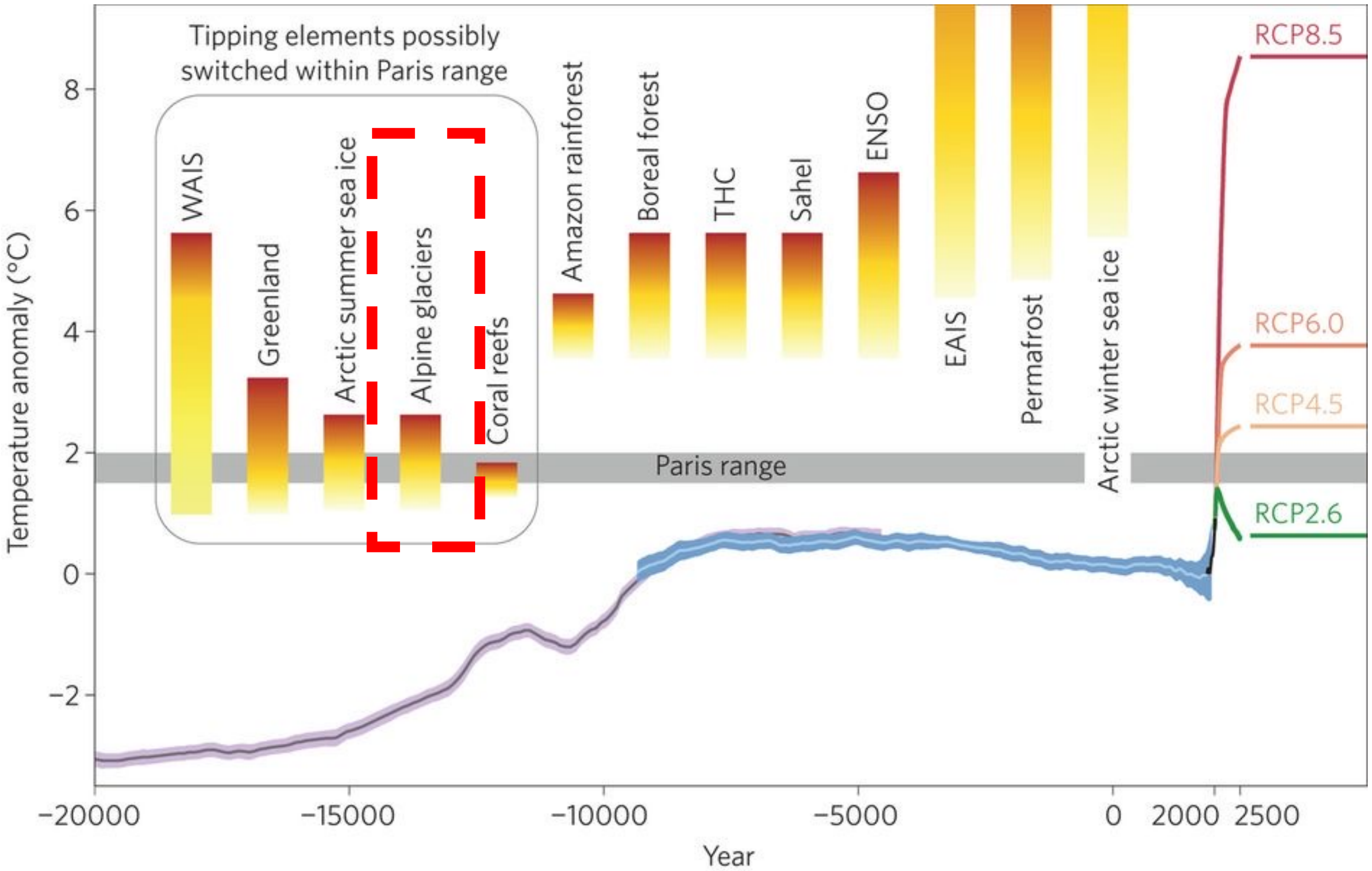
ELA rise between 2071–2100 for RCP 2.6, RCP 4.5 and RCP 8.5 relative to reference period (1971–2000).

Number and percentage of glaciers that will remain (lower part)/disappear (upper part) by 2071–2100 according RCP 2.6, RCP 4.5 and RCP 8.5

Žebre, M., Colucci, R.R., et al.
Clim Dyn (2020)

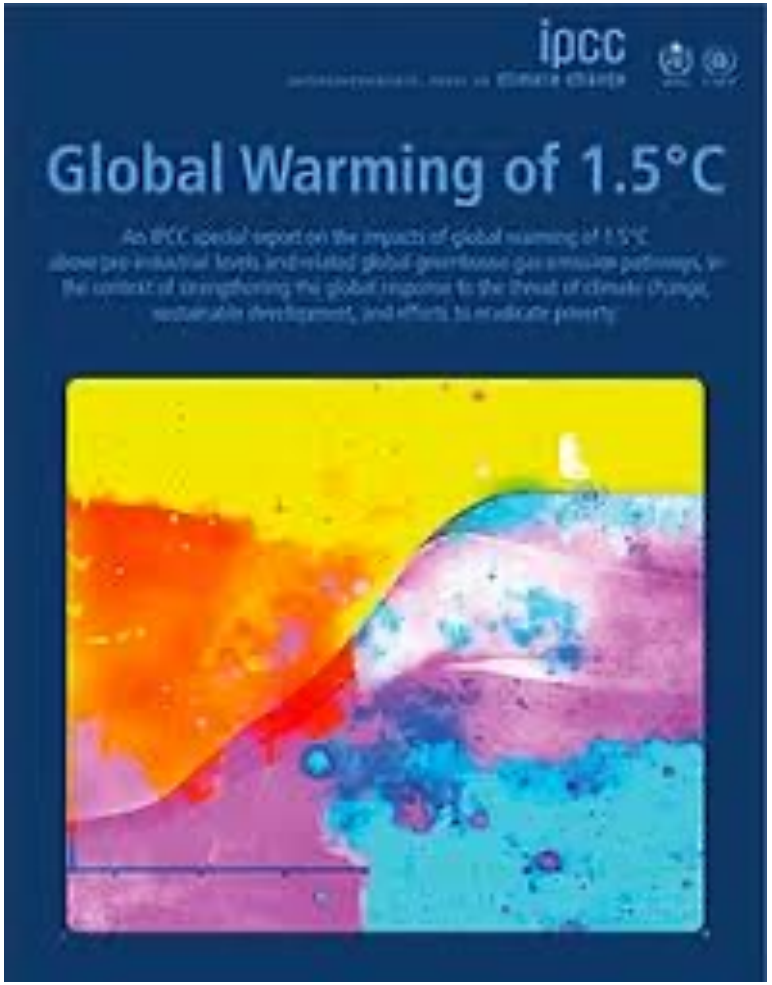
Tipping points

Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for ecosystems and for people.



Schellnhuber, H. J., et al. Nature Climate Change 6, 649-653 (2016). doi:10.1038/nclimate3013

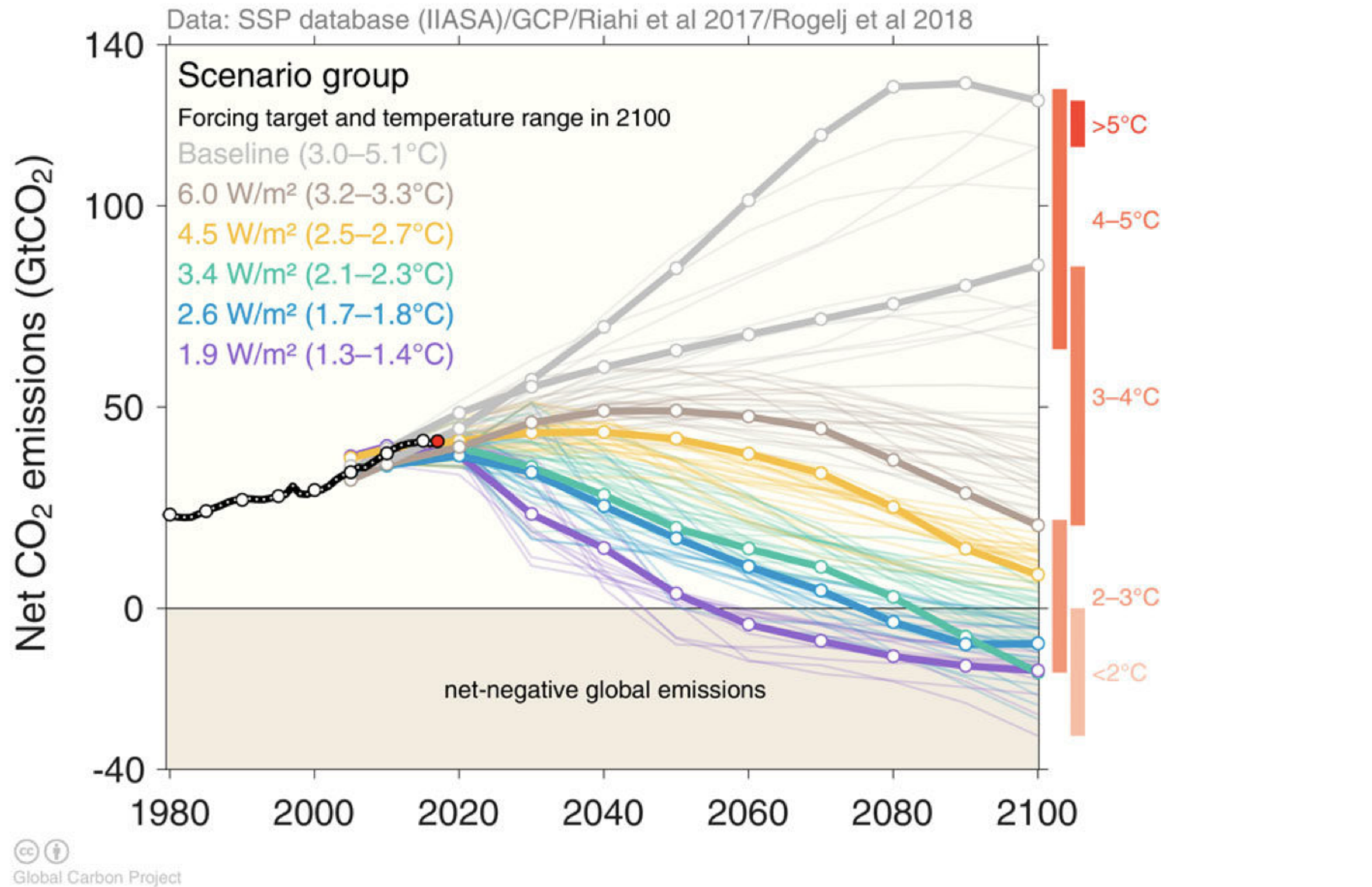
Global warming of 1.5°C in 2100



Special Report on Global Warming of 1.5 °C

SR15, IPCC 2018

CO2 emissions 2020 – 2100 (Gt) and global warming scenarios



«Today is only one day in all the days that will ever be.

But what will happen in all the other days that ever come can depend on what you do today.»

Ernest Hemingway