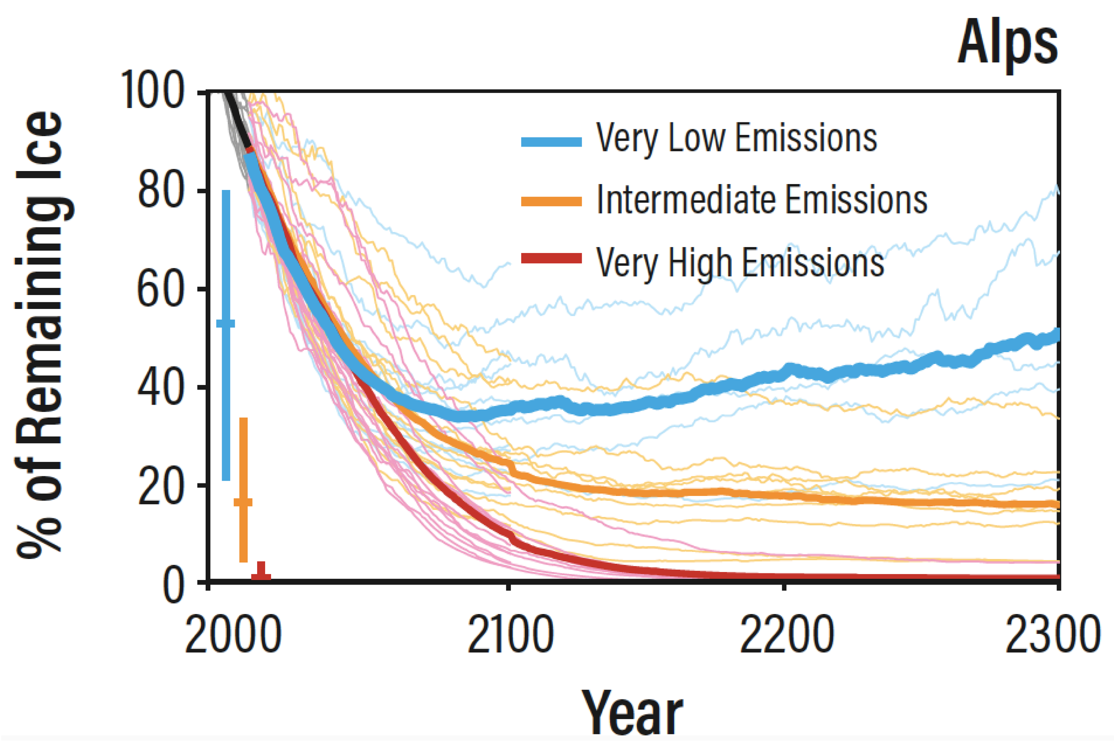
MELTING OF MOUNTAIN GLACIERS

Large regional impacts and limits of adaptation



From Marzeion et al. (2012)

Glaciers and snowpack provide important seasonal supplies of water for drinking, agriculture, and industry for at least 3 billion people on the planet. However, all glaciers on the globe have been losing ice over at least the past few decades; and many have been declining since the 1800s.

"Mid-latitude" glaciers have experienced particularly severe losses in the past century. These include the Alps, southern Andes and Patagonia, Iceland, Scandinavia, the North American Rockies and New Zealand. These losses will continue at a steep rate over the next several decades just due to current warming, with smaller glaciers disappearing completely and others decreasing to only 10–20% of their previous size. With very low emissions, these losses will slow and eventually, stabilize; with at least remnants of most glacier systems remaining. Once even 2 degrees is passed however, nearly all these mid-latitude glacier systems will disappear and take centuries to thousands of years to restore, even should we return to pre-industrial temperatures; making this an essentially permanent change for these important sources of water.

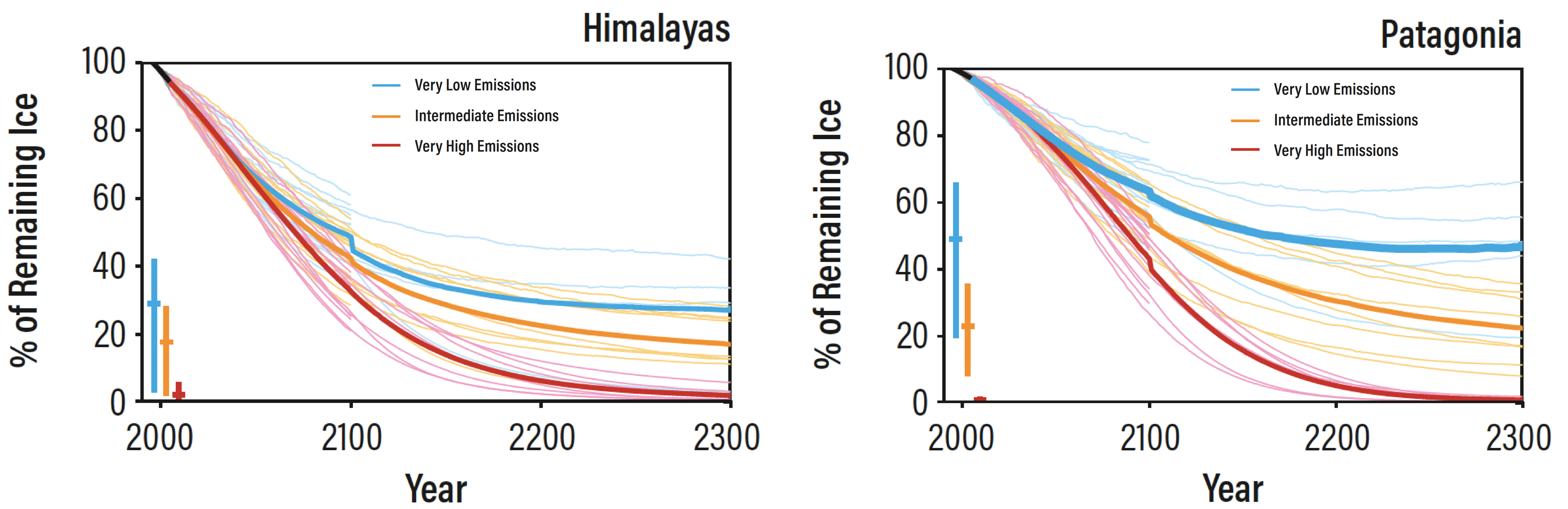
High-latitude (or polar) glaciers, and extremely high altitude glaciers (mostly in High Mountain Asia, including the Himalayas) have been the most difficult to study; and until the past couple of decades, did not seem to be as affected by current global warming. Even these, however, are receding today.

In addition to glaciers, mountains actually hold far more seasonal water in the form of snow. Snowfall has however become more unreliable in many mountain watersheds, with extremes of snow drought alternating with high amounts that increase risk of avalanche and flood. In many mountain snow systems, it now appears that snow generally is following the same downward trajectory as the glaciers: smaller amounts, with snow today instead falling as rain. This carries economic harm for farming and tourism; as well as decreased reliability of water supply for some large urban populations, such as in the southwestern United States where rising temperatures have paired with snowpack loss, leading to ever more severe drought conditions.

Nearly all of this research on the future of glaciers and snow under different emissions scenarios is quite new. Many of the citations below date from after the IPCC SROCC (2019) and the research is being updated even today.

With very low emissions, much of our glaciers and snowpack can be saved, especially in the mid-latitude glacier regions. Losses would begin to slow slightly around 2040, though many glaciers are not expected to stabilize until the next century, between 2100–2200.

Some glacier regions in the mid-latitudes, such as the Alps, may even begin to show very slow re-growth (a few percent per decade) by 2100.



From Marzeion et al. (2012)

Scenario	Temperature peak	Impacts
Low emissions	1.6-1.8°C ...and declining	With very low emissions, much of our glaciers and snowpack can be saved, especially in the mid-latitude glacier regions. Losses would begin to slow slightly around 2040, though many glaciers are not expected to stabilize until the next century, between 2100–2200. Some glacier regions in the mid-latitudes, such as the Alps, may even begin to show very slow re-growth (a few percent per decade) by 2100. Others may require temperatures closer to pre-industrial for greater recovery. Tragically, due to human emissions to-date, nearly all equatorial glaciers (Andes, East Africa, Indonesia) will essentially disappear entirely by 2100, even with very low emissions. They will not recover until the next Ice Age. This, along with loss of Arctic summer sea ice, is one of two major cryosphere thresholds passed due to human activity.
Optimistic fulfillment of all current pledges	1.9-3.1°C	Once two degrees is passed, by 2300 the only glaciers of any substantial size will be limited to the polar regions and highest mountains, such as the Himalayas. Even in these regions, glaciers will shrink to under one-third of their current size. Snowfall also will become more rare outside these regions, falling instead as rain that may at times be extreme in this warmer climate, leading to increased erosion, flooding and landslides. In the Himalayas, this loss of glaciers and snowpack will radically decrease seasonal water supplies in some river systems, for example the Tarim in northwestern China. In polar and "high altitude" (mostly High Mountain Asia, including the Himalayas) regions, around 30–50% of glacier volume will remain by the end of this century under all emissions scenarios; but losses even there will continue. At peak global mean temperatures of 3°C over pre-industrial, very little ice will remain elsewhere on the globe by 2300. Snowfall will become more rare outside the polar regions and high altitudes.
Current emissions growth	4-5°C ...and rising	Virtually no glaciers will remain anywhere on the globe by 2200, with mid-latitude glaciers 90% gone by 2100. Snowfall by 2100 will be extremely limited outside polar regions and high altitudes. However, snowfall and seasonal snowpack would begin to return as soon as temperatures decline. With such very high ice and glacier loss exposing bare ground, any meaningful glacier re-growth, especially at today's mid-latitude glacier regions, will take hundreds to thousands of years, even with temperatures returning to those of today. Recovery of equatorial glaciers cannot occur unless temperatures in the distant future return to below pre-industrial, e.g. a new Ice Age.

Contacts/reviewers

Matthias Huss, ETH-Zurich
huss@vaw.baug.ethz.ch

Carolina Adler, Mountain Research Initiative
carolina.adler@unibe.ch

Regine Hock, University of Oslo, Norway & University of Alaska Fairbanks, USA, SROCC coordinating lead author and AR6 Contributing Author
regine.hock@geo.uio.no

Ben Marzeion, University of Bremen, SROCC Lead Author and AR5 and AR6 WG1 Contributing Author
ben.marzeion@uni-bremen.de

Heidi Sevestre, Arctic Monitoring and Assessment Programme
heidi.sevestre@amap.no

Emma Needham, International Cryosphere Climate Initiative
emma@iccinet.org

ETH zürich — Mountain Research Initiative — University of Oslo — UAF University of Alaska Fairbanks — Universität Bremen

For more information, see the 2021 State of the Cryosphere Report: iccinet.org/statecryo21

International Cryosphere Climate Initiative

Literature

Adler, C., P. Wester, I. Bhatt, C. Huggel, G.E. Insarov, M.D. Morecroft, V. Muccione, and A. Prakash, 2022: Cross-Chapter Paper 5: Mountains. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press. https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/

Bliss, A., R. Hock, and V. Radić (2014) Global response of glacier runoff to twenty-first century climate change, Journal of Geophysical Research: Earth Surface, 119:717–730.

Huss, M., 2011, Present and future contribution of glacier storage change to runoff from macroscale drainage basins in Europe, Water Resources Research, 47, W07511. doi:10.1029/2010WR010299.

Hock, R. et al (2019). Glacier MIP: A model intercomparison of global scale glacier mass-balance models and projections. Journal of Glaciology. doi: 10.1017/jog.2019.22

Hock, R., G. Rasul, C. Adler, B. Cáceres, S. Gruber, Y. Hirabayashi, M. Jackson, A. Kääb, S. Kang, S. Kutuzov, Al. Milner, U. Molau, S. Morin, B. Orlove, and H. Steltzer, 2019: High Mountain Areas. 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, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 131–202. https://doi.org/10.1017/9781009157964.004

Huss M., and R. Hock R (2015) A new model for global glacier change and sea-level rise. Frontiers in Earth Science, 3:54. doi: 10.3389/ feart.2015.00054

Huss, M., and R. Hock (2014). Peak water from glaciers: advances and challenges in a global perspective. 2014 AGUEM.H42B..07H.

IPCC, 2018: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty[V. Masson- Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R.Shukla,A. Pirani, W. Moufouma-Okia, C.Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield(eds.)].

IPCC, 2019: 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, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

Kaser, G.; Großhauser, M.; Marzeion, B. , 2010 , Contribution potential of glaciers to water availability in different climate regimes , Proceedings of the National Academy of Sciences , 107 , 20223 - 20227 , DOI: 10.1073/pnas.1008162107

Kraaijenbrink et al, 2017. Impact of a global temperature rise of 1.5 degrees Celsius on Asia's glaciers. Nature 549(7671):257–260. doi: 10.1038/nature23878.

Mankin et al, 2015. The potential for snow to supply human water demand in the present and future. Environ. Res. Lett.10: 114016

Marzeion, B.; Cogley, J.G.; Richter, K.; Parkes, D. , 2014 , Attribution of global glacier mass loss to anthropogenic and natural causes, Science , DOI: 10.1126/science.1254702

Marzeion et al., 2020, Partitioning the Uncertainty of Ensemble Projections of Global Glacier Mass Change, Earth's Future, DOI: 10.1029/2019EF001470

Marzeion, B.; Jarosch, A.H.; Hofer, M. , 2012, Past and future sea-level change from the surface mass balance of glaciers , The Cryosphere , 6 , 1295 - 1322 , DOI: 10.5194/tc-6-1295-2012

Wester, P. et al (2019). The Hindu Kush Himalaya Assessment. International Centre for Integrated MountainDevelopment (ICIMOD), Kathmandu, Nepal. doi.org/10.1007/978-3-319-92288-1

Yao, J, Y Zhao and X Yu, 2018. Spatial-temporal variation and impacts of drought in Xinjiang (Northwest China) during 1961–2015. PeerJ. 6:4926. doi: 10.7717/peerj.4926