CRYOSPHERE

Earth’s frozen landscapes have been pushed beyond safe planetary limits



The cryosphere plays an irreplaceable role in regulating energy, water, carbon, and methane. Photo: Martin Jakobsson/Stockholm University

New global assessment of the cryosphere, published in *Science*, finds that land ice, sea ice, snow cover, and permafrost declines have already crossed safe levels and calls for urgent international action at COP31.

Story highlights

- Ice, snow, permafrost and other frozen parts of the planet – known as the cryosphere – are crucial for humanity to thrive.
- For more than 10,000 years of Holocene conditions, they have been relatively stable.
- Now, climate change has pushed those landscapes beyond their safe operating space.

New research published at COP31 issues a stark warning about the health of the frozen parts of the planet – ice sheets, mountain glaciers, sea ice, permafrost, and snow cover – known as the cryosphere. The study, published in *Science*, finds that human-driven climate change is degrading these landscapes beyond safe environmental limits, systematically threatening the Earth system conditions on which humanity fundamentally depends. The research highlights that cryosphere degradation now poses increasing long-term risks to the planet, its ecosystems, and human societies.

The cryosphere's frozen landscapes play an irreplaceable role in regulating the Earth's energy, water, carbon, methane cycles, and carbon storage capabilities. Their breakdown puts communities, ecosystems, and valuable freshwater resources at risk by accelerating global temperature, sea level rise, ecosystem degradation, and the likelihood of catastrophic flooding and drought events – posing a threat to communities across the planet especially in polar, high-mountain, coastal, and low-lying regions.

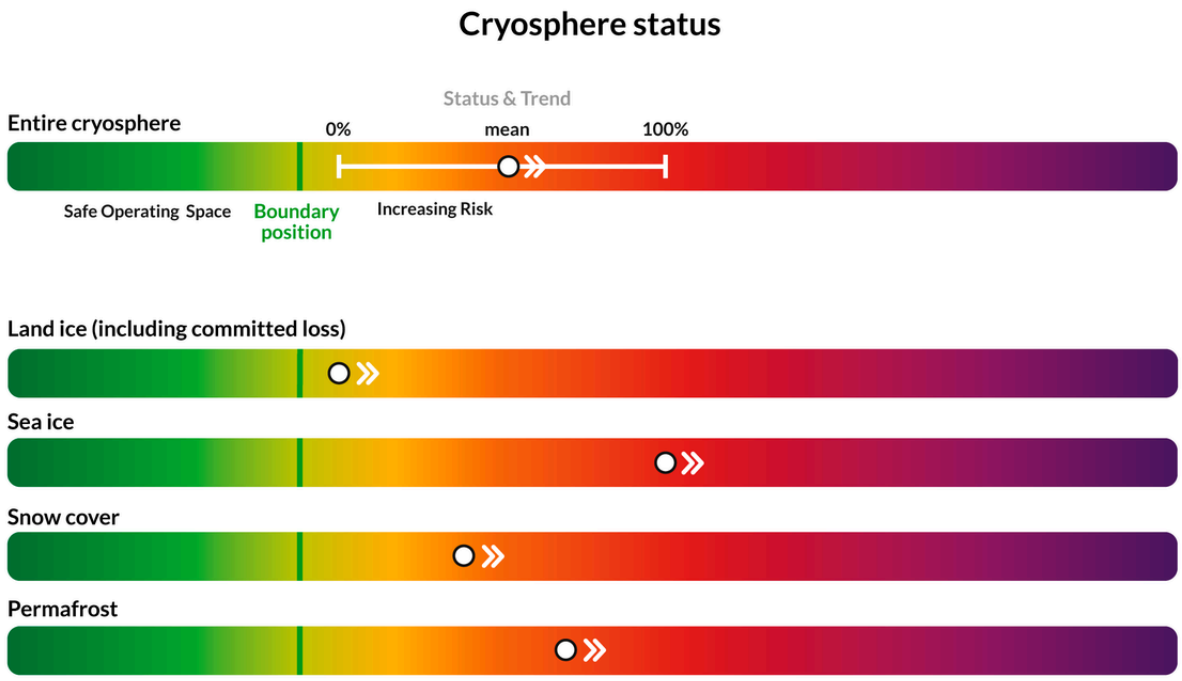
> ***"The cryosphere has already exceeded its planetary safe operating space, threatening the frozen foundations of our planet that have supported human civilisations for millennia."***
>
> Centre researcher Bo Su, lead author

The new study *The Cryosphere Beyond a Planetary Safe Operatin Space* was led by Centre researcher Bo Su and is compiled by an interdisciplinary and international research team of more than 30 scientists, including Centre researchers Lan Wang-Erlandsson, Ingo Fetzer, Albert Norström, Juan Rocha, Steven Lade, Jonathan Donges, Centre co-founder Johan Rockström, and colleagues from the Potsdam Institute for Climate Impact Research (PIK), Tsinghua University, Beijing Normal University, the Earth Commission, the International Association of Cryospheric Sciences (IACS), the Climate and Cryosphere (CliC) Project of the World Climate Research Programme (WCRP), the Third Pole Environment Programme, and the WWF Arctic Programme.

The frozen foundations of our planet

"The cryosphere has already exceeded its planetary safe operating space, threatening the frozen foundations of our planet that have supported human civilisations for millennia," said Dr. Bo Su, lead author of the paper and researcher at Stockholm Resilience Centre and Beijing Normal University, and co-chair of the Cryosphere Stewardship Working Group under the IACS. "Compared to other spheres of the Earth system, our systematic understanding of the cryosphere arrived late – only in recent decades have we

come to recognise its critical role in maintaining planetary stability, resilience, and habitability, and to grasp the severity of its ongoing degradation. Drawing on the latest advances in cryosphere and Earth system sciences, this work presents a holistic framework for assessing the cryosphere's role in Earth-system resilience."



The status of the cryosphere in relation to its safe operating space. An aggregated score on the top; below the four variables analysed in the study: land ice (including committed loss), sea ice, snow cover, and permafrost. Illustration: Azote for Stockholm Resilience Centre

The cryosphere's "safe operating space" ("SOS"), a framework outlined in the paper, defines precautionary boundaries for the planet's frozen areas, the absence of which has limited policymakers' ability to understand and govern cryosphere stability to date. The boundaries are defined using conditions over the past 11,700 years, an epoch known as the Holocene, as their reference point. This period was characterised by relatively stable global environmental and climate conditions that allowed human civilisations to develop and thrive. Moving beyond these conditions takes humanity into uncharted territory.

The study concludes that the cryosphere has moved beyond its Safe Operating Space, as current and committed changes are taking it increasingly far from the relatively stable conditions of the past 11,700

years. These changes also risk triggering reinforcing feedback loops that accelerate further cryosphere degradation and make return to those conditions increasingly difficult.

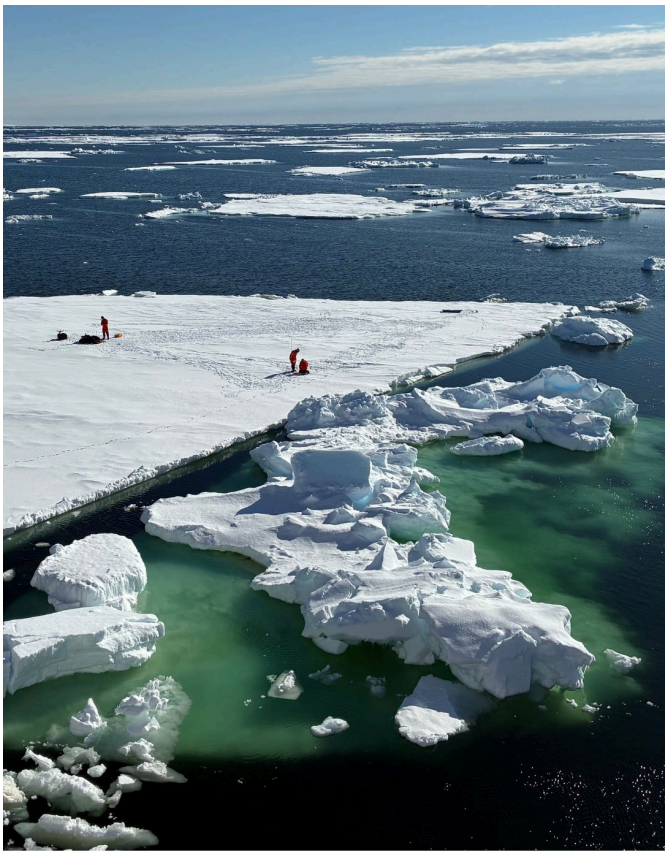
> ***“As cryosphere risks unfold before our eyes – most recently with the floods in Nepal – the report’s arrival at COP31 issues an important reminder for global leaders of the significance of cryosphere governance,”***
>
> Centre co-founder Johan Rockström

A clear warning for COP31

The degradation of frozen landscapes is driven predominantly by human-induced climate change, in addition to regional human disturbances including black carbon emissions and industrial and infrastructure expansion. The authors therefore urge policymakers to use the proposed SOS as a scientific basis for developing precautionary targets and strategies to limit greenhouse gas, black carbon emissions, and reduce local human disturbances.

“This work substantially furthers our understanding of how cryosphere changes are threatening the stability and resilience of life-supporting conditions of the Earth system,” said Centre cofounder Johan Rockström, director at the Potsdam Institute for Climate Impact Research (PIK) and co-chair of the Earth Commission. “As cryosphere risks unfold before our eyes – most recently with the floods in Nepal – the report’s arrival at COP31 issues an important reminder for global leaders of the significance of cryosphere governance.”

The study proposes a potential uptake of the cryosphere in the planetary boundaries framework to better understand and mitigate mounting risks given the cryosphere’s profound contribution to maintaining life-supporting conditions on Earth.



View of a research expedition in Antarctica in January 2026, organized by Alfred Wegener Institute. Photo: Susa Niiranen/Stockholm Resilience Centre

“This timely, integrated update on the state of cryosphere decline, its impact on the Earth’s environment and the impacts on humanity’s prosperity and survival issues a clear warning on the emergency of cryosphere collapse that global policymakers must heed at COP31 and beyond,” added Dr. John Pomeroy, Chair, Strategic Management Committee for the UN Decade of Action for Cryospheric Sciences, UNESCO Chair in Mountain Water Sustainability, and distinguished professor at the University of Saskatchewan. “The paper makes an important contribution to delivering on the ambitions of the UN Decade of Action for Cryospheric Sciences (2025-2034), while reinforcing the need for coordinated international action on preserving our cryosphere, and the irreplaceable freshwater, ocean and ecosystem services it provides.”

The report arrives amid the UN Decade of Action for Cryospheric Sciences (2025–2034) and COP31 in Antalya, Türkiye (November 9-20), offering a comprehensive scientific springboard for unprecedented

opportunities for coordinated international action.

Citation

Su, B., Rockström, J., Chen, D., Fetzer, I., Feng, H., Hugelius, G., Winkelmann, R., Norström, A.V., Xiao, C., Hanna, E., Alverson, K., Box, J.E., Qin, D., Sommerkorn, M., Andreassen, L.M., Heil, P., Yao, T., Richardson, K., Lade, S.J., Bai, X., Gupta, J., Stewart-Koster, B., Zheng, Z., Pomeroy, J., Mackintosh, A., OKI, T., Mukherji, A., Jackson, M., Rocha, J.C., Donges, J.F. & Wang-Erlandsson, L. 2026. The cryosphere beyond a planetary safe operating space. *Science*

doi.org/10.1126/science.aef5636

Use of AI in our web news

The creation of our web news is supported by the use of generative AI. We use AI tools to help edit, draft, translate and spellcheck parts of our web news. The final text has been read and approved by one of the involved researchers.

Read more about how we use AI in communications »