Scientific Statement on Cryosphere of the Paris Call for Glaciers and Poles

8-10 november 2023

INTRODUCTION

The cryosphere of mountain and polar regions is critically important for the energy balance of the planet, the water cycle, climate feedbacks, biodiversity and human societies. But with continued human-caused global warming, ice sheets and glaciers are shrinking, sea-levels are rising, permafrost is thawing, snow cover is decreasing, sea-ice is melting, and the polar oceans are warming. Two billion people and two thirds of irrigated agriculture depend on runoff contributions from mountains, often originating from glaciers. By 2050, one billion people in the low-lying coastal zones will be exposed to the consequences of sea level rise generated in a large part by melting ice sheets of Greenland and Antarctica.

The latest IPCC reports and subsequent scientific studies highlight the fast and slow, partially irreversible responses of the cryosphere to global warming. There are substantial gaps in risk assessments, and in global and local mitigation and adaptation, notably for water management. The loss of cryosphere components is accompanied by local hazards and amplified regional and global extremes. The consequences have major implications for the social cost of carbon emissions or insurability. It is imperative to identify and where possible prevent self-reinforcing processes with cascading impacts that cannot effectively be halted or reversed.

Thus, cryosphere scientists call for international stewardship in risk management. This refers to long-term committed and ambitious international coalitions to alleviate risks from melting ice. 2023 saw an exceptionally low cover of sea ice around Antarctica (-17% in June 2023 compared to average). It saw a failure of reproduction of emperor penguins. Disturbances related with wildfires have increased in the Arctic compared to the mid-20th century. In 2021-2022, based on 37 reference glaciers, glacier mass loss was around 20% higher than the average of the last decade, with particular extremes in the European Alps, high-altitude regions of Asia, the North American west, South America and parts of the Arctic. New studies reveal that today's 1.2°C warming could trigger losses of part of the West Antarctic ice sheet, even with no additional warming beyond current temperatures. Such observations call for immediate action and coalitions to limiting ice loss, to remain in manageable spaces on our planet.

The following statements on glaciers, sea ice, polar oceans and permafrost summarize the perspectives of international science as discussed at the One Planet – Polar Summit, November 8th and 9th, 2023. The scientists call for urgent political and socioeconomic action, and for new ambitious international and interdisciplinary approaches to reduce uncertainties and tackle unknowns in feedback mechanisms between the cryosphere and planetary health:

- **Ice sheets, glaciers, water cycle and sea level**

With the loss of glacier masses over continents, global sea level will inevitably pursue its increase with a pace particularly depending processes around Greenland's ice melt, and especially the interface between the austral ocean and huge ice shelves floating on the ocean. These need to be understood. Mountain glaciers are major sources of water in downstream regions. With their loss, billions of people face the risk of lack of important water resources for agriculture during the dry season, with a risk of increased tensions or conflicts.

- **Ocean, sea ice, life and atmosphere**

As the world's largest carbon and heat sink, the polar oceans play a vital role for Earth's biogeochemical cycles, ecosystems and the livelihood of millions of people. The loss of sea ice strongly impacts the energy balance between the Earth and outer space, reducing its thermostat effect and amplifying the ongoing warming. It also impacts unique polar ecosystems (in addition to other stressors such as fisheries, noise, and persistent chemicals), bringing in particular existential threat to many indigenous communities in the North and to irreversible biodiversity loss. Mountain and polar terrestrial life is at its limits, with nowhere to migrate to as conditions warm, thus facing extinction.

- **Permafrost and georisks**

Boreal and Arctic permafrost contains about twice as much carbon as in the current atmosphere. Confidence is low in the timing, amount, trend and partitioning between CO_2 or CH_4 greenhouse gas fluxes being caused by its future thaw, in a context where wildfire disturbances have increased. Permafrost thaw in polar and high-altitude environments poses increasing geo- and biohazards, affecting infrastructures, people, heritage sites and wildlife.

Thus, science calls for sustained coordinated action to avoid highly adverse and irreversible impacts of a disappearing cryosphere:

1. Strongly and urgently decrease global greenhouse gas emissions, phase out new fossil fuel investments, and close the gap to achieve the goals of the Paris Climate Agreement.

2. Advance knowledge relevant for gradual risks and extremes resulting from cryosphere loss. Address the cryosphere feedback mechanisms for physical, biological and social tipping points that pose risks to planetary and human health. Doing so requires major collaborative efforts to monitor and evaluate the processes at work, to quantify and forecast them, and to inform policy-makers. This needs secured long-term support.

3. Include the cascading socio-economical dimension of melting ice, and mitigate them by improved risk management. Doing so must involve the perspectives of indigenous and other communities inhabiting high-altitude and high-latitude regions. There is a need for solidarity mechanisms to address residual risk, leading to loss and damage.

4. Accelerate the political processes enabling the protection of cryosphere ecosystems to reduce pressure on high latitude and high mountain ecosystems and enhance their resilience.

5. Support integrative international scientific initiatives and missions to improve cryosphere knowledge as developed by the scientific communities.

6. Improve the environmental footprint and sustainability of cryosphere observations, infrastructure and data sharing, for all communities working in polar and high-mountain environments.

Ice sheets, glaciers, water cycle and sea level

CONTEXT

The polar regions and mountain areas are the home to Earth's major ice fields, which are now responding to our increasingly warming climate. The polar regions, especially the Arctic, are warming up to four times the global average and are now the largest contributors to sea level rise. The Antarctic ice sheets hold close to 58 m (West Antarctic Ice Sheet ~6 m, East Antarctic Ice Sheet ~52 m) of potential global sea level rise, and the Greenland ice sheet ~7m.

The ice sheets also contain a rich store of past climate data on the response of the ice to past periods of climatic change. Bubbles of air captured in ice cores yield a unique record of CO_2 and other greenhouse gas fluctuations over the past 800,000 years. From this record we have established that CO_2 levels never rose above 280 parts per million during the past 800,000 years. Since the 1800's, carbon dioxide levels have risen 50% above pre-industrial levels, to our current level of around 420 parts per million. This extraordinary record has provided us with important information about cycles of ice sheet behaviour in the past, and particularly about the pattern of ice sheet retreat in past periods of warmth.

Satellite observations indicate that the ice sheets of Greenland and Antarctica are clearly responding to both atmospheric and oceanic warming. Ice shelves fringing Antarctica are vulnerable to warm ocean waters that are forced beneath them by strengthening winds, melting the ice shelves from below. The loss of ice shelves, which protect glaciers from the surrounding ocean, has already started to destabilise ice at the Antarctica Peninsula and in West Antarctica, and this alone could cause >1 metres of global sea level rise by 2100 if climate warming persists unheeded. Similarly, Greenland glaciers that terminate in the Arctic Ocean are being impacted by warming Atlantic Ocean waters and surface melting, adding to sea level rise. Altogether, there has been more than a fourfold increase in the rate of ice loss from Antarctica and Greenland since the 1990s.

The Greenland and West Antarctica ice sheet losses result in irreversible and self-sustaining changes that could continue for many generations, even if global warming is stopped or reversed. The massive East Antarctic Ice sheet, once thought to be stable for many years into the future, shows signs that some glaciers have thinned and retreated. Recent research on tipping points addresses further fundamental risks of accelerated mass loss.

Melting of the vast ice sheets in the polar regions is causing global sea level rise that will affect billions of people who live in coastal regions across the planet. Every centimetre of sea level rise brings an extra

2-3 million people into a state of annual flooding. The reduction of uncertainties in the projections of global sea level rise (rate and extent) is critical for risk evaluation and actions to protect people and their livelihoods, major cities and industrial supply chains, many situated in coastal regions. Better understanding of the processes affecting Antarctic ice sheet instability is required to more accurately forecast sea level rise; some models predict up to 2 metres sea level rise by 2100.

The past CO_2 accumulation has already committed 30—60 centimetres of sea level rise. Sea level will continue to rise quickly as further warming impacts the stability of the ice sheets in future. With global mean sea level more frequent extreme weather events will cause greater damage and costs to coastal zones and populated areas, with more coastal erosion, landslides, groundwater inundation, saltwater intrusion and contamination of aquifers.

Mountain areas, such as the Alps, Andes, Himalayas and Rockies, are losing their ice cover. These glaciers and snowfall provide meltwater during dry seasons, sustaining a sixth of the global population and a quarter of the GDP. Two-thirds of irrigated agriculture depends on runoff contributions from these ice masses. Over the next 30 years they are projected to lose 10-40% of their snow, equating to hundreds of cubic kilometres of water supply. By the end of the century, mountain glaciers will lose 20-60% of their ice.

This poses a global threat to secure water, food, energy and livelihood for hundreds of millions of people. However, how much water the mountain cryosphere provides and how its role will change, remains remarkably uncertain. Although this is seen as a matter of greatest importance *(WMO high mountain call to action, 2019)* there has yet to be a global initiative to measure mountain water resources.

Ice covered areas in both polar regions and high mountains are shrinking, revealing newly exposed ground in which plant species are colonising and growth rates are increasing, even in Antarctic terrestrial sites. Extreme weather events, drier conditions and warming events are causing turnover in plant species such as mosses and lichens. Ice-free areas are also being increasingly colonised by sea birds and seals in polar regions. Non-native species have become established in some newly exposed areas in cold regions, although far more monitoring is needed to fully understand the changes in terrestrial systems as glaciated landscapes shrink. Are we losing glacial microbiomes that we still know little about?

Mountain glaciers and the seasonal snow cover in their surroundings are heritage sites of unparalleled scenic beauty, areas of intense tourism and winter sports use, guaranteeing financial resources and maintaining the local population's way of life. These assets are already suffering the impact of glacier melting and retreat to higher elevations.

PRIORITIES

1. **Sea level projections.** The major threat from melting polar ice sheets is the rise in global sea levels and the impact on coastal populations and infrastructures. It is crucial and urgent that these threats

are reduced, and that projections of sea level rise are improved, both in terms of timing and amount. To achieve this objective, international modeling efforts need to be supported both in term of computing infrastructures, model development and human ressources. The management of sea level rise impacts and risks for coastal communities, requires regular updates. Actions to address challenges from migration of displaced populations from inundated low-lying regions are critical.

2. **Ice-ocean interactions.** To improve future projections of Greenland and Antarctic ice loss, it is necessary to understand better ocean-ice interactions, the oceanic circulation and related melt rates below the ice shelves, the ice dynamics through the grounded zone, the marine ice sheet instabilities. This requires both better observations with innovative technologies to monitor and measure changes in the field, sustained and enhanced satellite observations, and improve physics of ocean-ice coupled numerical and artificial intelligence models to provide updates of future sea level rise for policymakers and practitioners.
3. **Past climates.** Ice sheets, glaciers and sediments are important archives of past climates. Further observations from these palaeoclimate records (ice and sediment cores) are urgently needed to help understand whether past ice sheet retreat was a gradual process or characterized by more abrupt and intermittent events. This is needed to improve the physics of icesheet dynamics, atmosphere-ice sheet interactions, ocean-ice sheet interactions and ice-sheet instablities in the models used for future projections.
4. **Water resources.** Better understanding of the water supplies provided by ice and snow in mountain regions is needed, requiring more monitoring, field research, satellite observations and improved modelling. It is critical that this is undertaken in collaboration with local communities, practioners, and policymakers to ensure that future changes in water resources are embedded in risk management and adaptation strategies.
5. **Hazards.** It is essential to monitor and evaluate the risk of natural disasters due to the melting of mountain glaciers, such as the rupture of glacial lakes, and rock and landslides.
6. **Ecosystems.** The impact of ice loss on ecosystems, both in high mountains, coastal regions and oceans, has yet to be fully understood. Newly exposed areas require monitoring to assess what and how new ecosystems develop in freshly exposed areas, which needs special management and protection from invasive species.
7. **Collaboration.** Working in remote and challenging polar and high mountain regions to undertake these observations is expensive, energy and time-consuming and difficult. Research is most efficiently, effectively and safely undertaken through large multi-skilled research teams, sharing infrastructures and costs.
8. **Action.** International action is key to tackling these major challenges; their urgency demands large teams of complementary expertise working together to collect new data sharing major infrastructures. Antarctica InSync is a new proposal that will bring together the polar community to plan and deliver a programme of synchronous measurements of many aspects of the Antarctic environment to understand how the continent and its ocean is being impacted by climate change and provide better forecasts that benefit the whole planet. For the Arctic large scale land-ocean interactions programs in the planning. International capacity building needs better support to develop the next generation of international cryosphere scientists.

Ocean, sea ice, life and atmosphere

CONTEXT

Sea ice is an integral part of the high latitude oceans and a key Earth system indicator for climate change. Sea ice is frozen seawater, it expands during each hemisphere's winter; and melts in the summer. The white surface of sea ice reflects solar energy (albedo), cooling the planet. Sea-ice strongly influences ocean-air momentum, heat and gas exchange. When it melts, the darker ocean absorbs more heat, amplifying the cycle of melting sea ice. Sea ice is also a habitat to huge diversity of life, from microbes to whales, and an immense variety of birds, many of which are endemic. Losses of sea ice, especially multi-year ice and coastal sea ice, are endangering polar life. Sea ice transports matter, builds a barrier against glacial ice loss, and protects coastlines against waves and erosion. It supports human mobilities and has been part of hominid expansion and culture even before the emergence of *Homo sapiens*, and remains a key element of human cultures and livelihoods today.

Polar oceans drive the ocean's conveyor belt. The Southern Ocean is especially critical as a global sink for heat and CO2. When cold polar water sinks, it brings oxygen and dissolved organic matter, but also pollutants to the deep-sea. Fluxes of radiative heat and freshwater from enhanced precipitation, runoff and melting sea ice and ice sheets are increasing, thereby enhancing surface stratification. The ocean warming has far-reaching climatic implications for melt of Greenlandic marine-terminating glaciers and Antarctic ice shelves and ice sheet, thereby enhancing sea level rise and possibly ocean overturning at lower latitudes. Complex and poorly understood processes include oceanic eddies, tropical-polar interactions, interior warming and stratification changes, and future ability to take up CO_2 by the physical and biological carbon pump.

At times present at much lower latitudes over Earth history, sea ice is conceivably a hotspot for evolution of microorganisms on Earth, and potentially harbours life on extraterrestrial ocean worlds. The role of sea ice as a major biome on Earth, and an integral part of polar ecosystem functioning remains to be understood. Establishing a baseline in the state of sea-ice related ecosystems constitutes a race against time in the face of the speed of transformations affecting the polar sea ice, particularly the oldest one. In losing old sea ice in the Arctic, we may lose our best analogue of conditions prevailing during past ice ages and in other ocean worlds.

As to polar ocean productivity, the lack of time series with adequate seasonal and regional resolution has limited our understanding as to the effect of warming. Satellite observations show mainly increases in phytoplankton biomass in the Arctic and Southern Ocean over the last 20 years, because the shrinking sea ice enhances light penetration. However, concurrent stratification changes, including increased air-sea momentum transfer enhancing ocean mixing, and it impacts nutrient supplies, thus future projections are highly uncertain.

The key drivers of polar productivity, the diatoms, get replaced by smaller algae as a result of ocean warming, changing the food web and potentially reducing the carbon pump. Loss of sea ice endangers krill, fish, marine mammals and seabirds as they find their prey there and use it as a platform to reproduce, leading to alarming massive breeding failure in emperor and Adélie penguin colonies. Loss of sea ice also affects microbial life and thereby the entire food web. While northward expansion of new species into the Arctic Ocean from the Pacific and Atlantic has been documented at all trophic levels, the actual causes (e.g. changes in water mass distribution, currents, seawater properties or sea ice dynamics) remain unclear, and therefore our capacity to make any prediction about marine ecosystems are limited.

At the current level of global warming of 0.2°C per decade, sea ice loss in the Arctic observed since 1978 is 3% per decade in wintertime, and 13% in summertime. The majority of multiyear sea ice has been replaced with annual, thinner and more dynamic sea ice. There is a close relationship between changes in Arctic summer sea ice, cumulative CO_2 emissions, and global surface temperature - translating into around 3 square metre loss of Arctic sea ice for each ton of CO_2 emitted. In Antarctica, no significant sea ice trend was discernible from 1979 to 2020 (summer or winter), due to large internal variability and contrasting regional trends. However, we have now seen two years of an exceptionally low cover of sea ice, (in June 2023 -17% compared to average)..

Human influence is the main driver of Arctic sea ice retreat. As greenhouse gas emissions and their atmospheric concentrations have continued to increase, the Earth warms. 91% of this excess heat accumulates in the ocean, of which half sinks into the Southern Ocean. 3% leads to cryosphere melt, 5% to land warming and 1% to lower atmosphere warming. Thus, the warming ocean will be an increasing threat to the future of sea ice. Several additional amplifying feedback loops act on sea ice and involve surface albedo, water vapor, clouds, snow precipitation, air-sea fluxes, altogether causing polar amplification. The extent to which stabilizing feedback loops driven by physical and biological processes may dampen amplification is however not well constrained, adding to uncertainties. For instance, the production of climate active gases such as di-methyl sulfide, or aerosolized microbial ice nucleating particles, both favoring cloud production during newly ice-free areas, have been put forward. Especially in the Arctic, long-range contaminants, notably black carbon transported from intensifying industrial regions at lower latitude, do contribute to reduction in sea ice albedo and, therefore, to melt.

In the past 40 years, Arctic warming was 4 times faster than the global average. In scenarios and pathways assessed in the IPCC AR6 2021 report, there is a likelyhood already by 2030-2035 for a first ice-free (<15% ice-cover) summer for the Arctic Ocean, and at least once prior to 2050, linked to cumulative CO_2 emissions reaching 1000 gigatons. Recent variations are related to atmospheric circulation patterns, with persistent consequences due to a warmer ocean and possibly a new Antarctic sea ice state. Heat uptake in the Southern Ocean accounts for >50% of the global ocean heat uptake.

Gaps in scientific knowledge concern especially land-ocean, ice-atmosphere-ocean, ocean-glacier and sea-ice-life interactions. It is important to better understand future changes in precipitation in a warming world associated with an intensification of the water cycle and its variability, including snow, and changes in the dynamics in atmospheric circulation and winds. Changes in large scale water mass distribution, notably between Atlantic and Arctic Oceans, in the connection between fresh and cold surface waters and warm and salty deeper ones, including ocean mixing, and in sea ice growth/melt cycle and dynamics (advection, ridging, leads, melt ponds) further complexify the impact of global warming on polar ice. The lack of long-term time series with adequate regional resolution to achieve circumpolar assessments of change is critical to advance confidence in projections. Key needs are forecasts of the role of decadal dynamics and teleconnections of phenomena like El Nino, North Atlantic Oscillation and of the stability of the Atlantic Meridional Overturning Circulation, the Antarctic Circumpolar Current and their links to sea ice. The fate of sea ice directly and indirectly affects food-webs and biological interactions from microbial life to krill, fish, whales and birds, as well as to benthic life including the deep-sea. Gaps in knowledge remain large as to the total diversity of polar life and its dynamics, its interactions with ocean chemistry, i.e., aerosol formation, dissolved matter, particle fluxes, and its implications for economic development, human health and well-being.

IMPACTS AND RISKS

→ Polar oceans are experiencing climate change impacts with large magnitudes and will be profoundly different by 2050.

→ The impacts of shrinking polar sea ice may be felt globally, including in weather patterns.

→ Sea-ice loss, warming and acidifying oceans reduce available habitats for many polar marine species, including many shellfishes, fish species and marine mammals, while opening the way to invasive boreal species. Exposure to old (e.g. fisheries) and new stressors such as plastics and persistent chemicals and noise could worsen the negative effects for polar marine species.

→ Sea ice decline leads to more opportunities but also growing risks from expanding and intensifying shipping, fisheries, tourism, resource development, and other industries - including intensification of geopolitical tensions.

→ Sea-ice loss and extreme events arising from climate warming affect the lives and livelihoods of Arctic communities. Amplified climate changes increasingly threatens many aspects of Arctic lifestyles (culture, heritage, identity, health, including mental health, safety), especially for indigenous peoples.

GOVERNING PRIORITIES

1. Science calls for a new international ambition in reducing greenhouse gas to limit global warming as close as possible to 1.5°C, and reach net zero CO_2 emissions as soon as possible and with the smallest cumulative emissions until this is reached. This is an essential goal to avoid further large declines of sea ice cover, and to reduce weather extremes globally, thereby avoiding the escalation of losses and damages, and costs of adaptation and adaptation limits.
2. International collaboration for the protection of polar oceans (for example as voiced in the Helsinki Declaration on Climate Change at the Antarctic Treaty Consultative Meeting (2023)) is essential to reach the goals of the Paris Agreement and Kunming Montreal frameworks.
3. To reduce the pressure on polar life due to intensifying and expanding human activities, marine and terrestrial protected areas are key actions and need a new international ambition supported by science. In their planning and maintenance collaboration and support for self-determination among indigenous communities is important.
4. Closing gaps in cryosphere education and literacy, information and forecasting is critical for society. It needs support for better process understanding, modeling tools and frontier research, including implications for habitability, water, food, and human security, unique ecosystems and biodiversity, equity, economy including eg. insurability.
5. The cryosphere perspective should be included in estimates of the cost of carbon emissions, costs of adaptation, adaptation limits, and the planning of loss and damage funds.
6. Local infrastructure to enhance resilience to climate change / sea ice loss, especially including self-determination of indigenous peoples.

SCIENTIFIC PRIORITIES

1. Long-term support of international sea-ice, ocean, biosphere and atmosphere programs in the Arctic and Antarctic, considering infrastructure (e.g. international sea ice buoy and Argo float programs, polar research vessel fleet, research aircrafts and stations) as well as large international missions (e.g. Tara Polar Station, Antarctica InSync, International Polar Year), nested into and coordinated with international observing networks and initiatives.
2. Strongly reinforced cooperation among space, ocean and polar agencies to initiate polar orbiting satellites, consistently distribute Earth observation data for polar regions, develop new missions, new products and algorithms, and conduct dedicated field expeditions for ground truthing. Improve FAIR data accessibility.
3. Regional cooperation, multi-scale biodiversity & marine protection networks (monitoring and governance), increasing science-based resources to reinforce resilient and sustainable development trajectories.
4. More research capacity, with new cutting-edge scientific expertises for exploring the sea ice biodiversity.
5. Funding of capacity building developed by, and co-developed with local communities, to serve both local and global science needs, and maximize regional collaborations and activities for more sustainable, year-round polar science
6. Transformation of polar infrastructure to develop lower carbon and ecological footprint solutions for research, and allow for near real-time data transmission.
7. Accessible, context-specific sea-ice information products and tools, regional forecasts and projections to support decision-making

8. Complex interactive, data – enabled model (Digital twin) of polar seas, including risk management modules (adequate and appropriate emergency responses and adaptation) and guiding observation strategies.

Permafrost and georisks

CONTEXT

About one fifth of the land surface of the Northern Hemisphere is underlain by permafrost. It extends beneath great portions of Alaska, Canada, Russia, and the Qinghai-Tibet Plateau, and is also found in northern Scandinavia, Antarctica, and high mountain regions around the world. The most densely populated and developed landscapes with permafrost are in the European Alps. Many permafrost regions contain valuable mineral resources, and people urging their development. Most infrastructure design and construction in permafrost terrain is predicated on the ground remaining frozen.

The polar environments are experiencing climate changes several times greater than most of the world. The changes are apparent in temperature and are becoming evident in precipitation. The rates of climate change track or exceed the highest rates projected 20 years ago. Permafrost is essentially climate in the ground, so permafrost temperatures are rising throughout the polar and high mountain regions and near-surface permafrost is thawing.

In the last decade, the occurrence and risk of geo- and biohazards in thawing ground such as coastal erosion, landslides, oil spills, release of buried industrial wastes and natural contaminants such as mercury, ancient viruses, and emissions of methane and CO_2 from organic material now entombed in permafrost have all increased. Such regional carbon emissions have a magnitude with global implications. Thawing has accelerated following wildfires in the forests that cover about one half of our permafrost environments, and which are annually burning larger areas than ever before. Of direct importance to northern Indigenous peoples are physical threats to heritage sites and wildlife populations because the permafrost biome contains limited biodiversity, making ecosystems fragile when disturbed. For people in high mountain regions, the loss of water supply as permafrost thaws and surface water infiltrates into the ground is a serious concern.

Permafrost science and engineering is a challenging endeavor, in part due to the high cost of working in remote areas. In the past, people resident in the permafrost regions have played relatively minor roles in research. This must be better balanced in all phases of program development if policy and politics emanating from the Arctic are to be fully informed by scientific progress. The peoples and private and public agencies of the permafrost realm face deterioration of built infrastructure and access to the land, emergent risks and unaccustomed rates of environmental change, and a need for mitigation and adaption tailored to a local context that promotes economic development.

PRIORITIES

1. We must recognize the inevitability of significant adjustments to permafrost environments and their ability to support infrastructure as it is currently designed. Efforts to advance adaptation of infrastructure design and construction techniques to thawing ground are urgently needed. To secure permafrost monitoring, data sharing and regular updates of reports is essential to reduce the risk of damage to people and infrastructure, particularly in high mountain regions.
2. The timing and rate of projected CO_2 and methane emissions from thawing permafrost requires priority attention from the scientific community. We must improve dynamic modelling of emissions from permafrost under a range of potential future climate trajectories, critically including the role of the microbiological activity. Geopolitical solutions must be found to facilitate comprehensive scientific assessments of this existential issue for all permafrost regions.
3. Socio-economic aspects of anticipated losses and damages from, and adaptation to, a thawing cryosphere and the associated ecological shifts need greater emphasis in research, particularly the financial consequences of permafrost thaw for public agencies, actuaries, and the private sector. Similarly, aspects of the environment that influence the health of people and the wildlife on which they depend are critical, particularly the distribution and density of species key to ecological and food security.
4. Greater involvement of Indigenous and other people of the cryosphere regions is essential in all aspects of research and deliberations regarding adaptation to and management of climate change impacts. Education and training must be enhanced to enable such engagement.
5. Emissions from wildfires and other disturbances, including coastal erosion, are now persistent and are compromising society's efforts to reach net zero carbon emissions. Enhanced thawing of permafrost from these disturbances accelerates permafrost carbon emissions over decades. We require dedicated research on methane and CO_2 emissions from burned and coastal areas, including those only accessible through remote sensing.
6. The expense of field research in remote areas and its essential role in validating theoretical progress and remote sensing observations must both be recognized. Some costs may be mitigated by greater involvement of agencies and institutions located in the permafrost regions.
7. Finally, international efforts to archive, manage, and make data regarding the changing permafrost state openly available, including the wealth of data from remote sensing, must be supported on a permanent basis.

The content of the scientific statement had been produced by the following scientists, with support from participants to the One Planet – Polar Summit:

Science advisory board

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Session moderators :

In addition to Antje Boetius, Jefferson Simoes and Nicole Biebow who also moderated scientific sessions :

Dame Jane Francis, paleoclimatologist and paleobotanologist, Director of the British Antarctic Survey, United Kingdom

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