International Arctic Science Committee (IASC)
Cryosphere Working Group

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IASC Cryosphere Working Group Strategy and Work Plan

The remit of the Cryosphere Working Group (CWG) includes all scientific and engineering research related to the Arctic and sub-Arctic cryosphere. All components of the cryosphere are represented, namely glaciers, sea ice, snow, permafrost, seasonally frozen ground, and lake and river ice. Increasingly, research is focussing on the interactions between the cryosphere and other components of the Arctic system such as the atmosphere, the ocean, land , as well as the biosphere and Arctic communities, and how changes in the cryosphere are affecting them. This naturally leads to cross-disciplinary research areas and facilitates cross-cutting activities with other IASC Working Groups. The CWG has developed this Work Plan to be aligned with, and feed into, international planning goals such as those identified by the ICARP IV process, IPY 2032-33, and U.N. Decade of Action for Cryospheric Sciences (2025-2034).

The CWG expects to revise this Work Plan during the first half of 2026 to align with the outcomes of the ICARP IV process (report to be published in March 2026).

CWG Scientific Foci

The CWG has identified four core scientific foci associated with the priorities above and that address major unknowns in the Arctic System. Research centered on these topics will contribute to an integrated and predictive understanding of the Arctic cryosphere, a fundamental component of the Arctic and Earth System. The four foci are to:

- **Improve knowledge of the past, current, and future states of the Arctic cryosphere across wide-ranging spatial and temporal scales**
- **Strengthen predictive capabilities for extreme cryospheric events**
- **Advance understanding of cryospheric interactions with atmospheric, terrestrial, marine, and biological systems**
- **Enhance understanding of the societal impacts of cryospheric change**

Draft Working Group Plan, 2024-2028

This CWG Work Plan is designed to contribute to the IASC strategy and is intended to align with ICARP IV and IPY 2032-2033 directions within the Arctic cryosphere communities (including research and indigenous communities). The Work Plan is structured along four scientific foci, complemented by additional scientific themes. For each focus, we briefly describe its targets as a set of research questions and highlight its linkages with the strategic goals of IASC, as per the current IASC Strategy (2023-2026), which extends the scientific priorities of ICARP III. It is the aim of the CWG that all research foci should use innovative methods and approaches including

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the integration of in-situ observations, remotely-sensed measurements, numerical models, artificial intelligence and/or machine learning (AI/ML), and participatory research approaches.

1. Past, Current, and Future States of the Arctic Cryosphere

- How, and on what timescales, does the Arctic cryosphere respond to climate change?
- What is the effect of climate warming and Arctic amplification on individual and/or linked cryospheric components (e.g., glaciers and ice caps, sea ice, snow, permafrost)?
- What are the Arctic cryosphere tipping points associated with ongoing and future climate change, and how can we best monitor and predict these?

This research theme seeks to understand changes in all components of the Arctic cryosphere in the context of historical variability, the current state of the system, and cryosphere-climate evolution under future climate change. This includes variability and changes in Arctic glaciers and ice caps, sea ice, snow, permafrost, and river and lake ice. All these cryospheric components are sensitive to climate warming and Arctic amplification, which may lead to climate system 'tipping points' At present, some key physical processes relating to the Arctic cryosphere are imperfectly represented or not represented in Earth System Models (ESMs) (or their feeder ice/ocean/atmospheric physics-based models) used for accurate projections of the Arctic system under future climate scenarios. There is a need to recognise and fill knowledge gaps on several physical processes and their feedbacks (e.g., iceberg calving, firn processes, sea-ice thermodynamics and albedo evolution) that are important for climate simulations, and to refine their representation in ESMs and at-the-same-time quantify model uncertainties. Understanding the impacts of changing environmental conditions (e.g., temperature, precipitation, ocean and air mass circulation, albedo) on specific cryosphere components (e.g., snow, sea ice, river/lake ice, permafrost, surface runoff and subglacial meltwater discharge, ice-ocean interactions, glacier mass balance) and across spatiotemporal scales are priority knowledge gaps. A major priority is to standardise and harmonise datasets from Earth Observation (EO; i.e., satellite observations) plus *in situ*, autonomous, airborne, and on-the-ground observations to provide optimal formats and uncertainty/bias quantification for models.

As an example, IASC CWG leadership in pan-Arctic glacier mass balance processes led to the well-developed IASC Network on Arctic Glaciology (https://nag.iasc.info/). Similar targeted activities are needed for the other components of the Arctic cryosphere.

This research focus links to IASC strategic goals via:

- ***Role of the Arctic in the Global System:*** Glacier and ice-sheet contribution to sea-level rise; role of albedo changes in Arctic climate amplification; effect of snow and ice cover on atmospheric patterns and their impacts on mid-latitude weather and climate; effects of freshwater runoff on the strength of local and larger-scale ocean circulation; impacts of sea ice and glacier changes on the marine ecosystem; greenhouse gas emissions due to thawing permafrost.

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- ***Observing and Predicting Future Climate Dynamics and Ecosystem Responses:*** Enhance EO monitoring capabilities of lake ice, sea ice, and snow conditions; improve uncertainties and integration of in-situ and EO products; further develop the representation of cryospheric processes in different type of models and across spatiotemporal scales, including process operational forecast and ESMs.

2. Extreme Cryospheric Events: Understanding and Predicting Hazards

- How will changes in snow and ice conditions related to climate change impact the frequency and type of extreme cryospheric events in the Arctic?
- What are the main climatic or environmental drivers of these events and the associated hazards?
- How can we best monitor the Arctic cryosphere to improve predictions of these events?

As our climate warms, the frequency and intensity of extreme cryospheric events are likely to increase. This research focus aims to understand the drivers of such events including, but not limited to, heavy snowfalls, icings, avalanches, ice-jam floods, glacial lake outburst floods, landscape instabilities (slope failures, rockfall, detachments, slumps) triggered by permafrost thaw and glacier retreat, coastal erosion from permafrost thaw, rapid sea-ice loss events, increased storm-wave heights in sea ice-free waters, and thin-ice conditions where rivers, lakes, and coastal seas have traditionally supported thick, stable ice for seasonal transportation and mobility. Many of these extremes are rapid and episodic events with the potential to impact people and infrastructure. The World Meteorological Organization (WMO) call for "Early Warning Systems for All" by the end of 2027 requires greater understanding and integration along the full chain of cryospheric monitoring, modelling, process understanding, and services (i.e., assessment and communication of hazards). In addition to rapid events, extreme cryospheric events can occur on daily to seasonal timescales, often associated with specific circulation anomalies in the atmosphere and ocean (e.g., intrusion of warm air and water masses from outside the Arctic). Research into this topic requires observations, modelling, AI and services to support hazard warning systems and climate change risk assessments.

This research focus links to IASC strategic goals via:

- ***Role of the Arctic in the Global System:*** Improve understanding of how cryospheric extremes are formed and developed; impacts of cryospheric extreme events on hemispheric- to global-scale atmospheric and oceanic circulation. This supports broader WMO disaster risk reduction efforts for weather- and climate-related hazards.

- ***Understanding the Vulnerability and Resilience of Arctic Environments and Societies and Supporting Sustainable Development:*** Provide knowledge on snow and sea-ice extremes for long-term planning; land cover change implications of permafrost degradation especially thermokarst, including geomorphological, ecological, and hydrological disruptions and their impacts on infrastructure; dynamics of coastal erosion and changing ice thickness and impacts on transportation, economic activity (e.g., shipping, fishing, tourism), and connectivity of northern communities. Improve monitoring

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and modelling of hazards related to extreme floods from ice caps (jökulhlaups), glacier lake outburst floods, ice-jam floods, and peak river flows related to extreme snow and ice melt and extreme runoff that can result from heavy rainfall on frozen ground or refrozen ice crusts within a snowpack.

3. Coupled Cryosphere-Biosphere Processes

- What are the main ecological and biogeochemical processes that are affected by changes in the Arctic cryosphere?
- How will cryospheric changes impact Arctic ecosystems, food webs, and biodiversity and what are the potential corresponding impacts on Arctic communities?
- What are the feedbacks between the Arctic cryosphere, biological and ecological processes, and Arctic amplification and how can we best represent these in ESMs?

Interactions between the cryosphere and biosphere are an emerging area of focus that has been historically understudied due to its interdisciplinary nature. There are unique ecological and biogeochemical processes associated with snow, permafrost, glaciers, ice shelves, and sea ice that have significant implications for Arctic biodiversity and productivity, ecosystem functions, and biogeochemical cycle dynamics including carbon, particularly in the context of a changing climate. These include, but are not limited to, algal growth changes and feedbacks with light transmission, increased meltwater and nutrient fluxes from melting glaciers and ice caps, decline in Arctic sea ice, snow and glacier extents and associated primary productivity and vegetation changes, increasing precipitation and river discharges in the Arctic, and permafrost decline and related carbon release and soil movement/vegetation change. This focus seeks to illuminate how changes in the Arctic cryospheric elements affect biological processes and ecosystems, and how these may continue to change in the future. Numerous links and feedbacks between other environmental "spheres" (e.g., terrestrial, atmosphere, marine, human) also exist and this focus is naturally cross-cutting with the other IASC WGs.

This research focus links to IASC strategic goals via:

- ***Role of the Arctic in the Global System:*** Snow and sea ice covers support specialized ecosystems that are sensitive to fluctuations or declines in the global cryosphere. This applies to biological scales ranging from microbes to apex predators such as polar bears. Biogeochemical changes resulting from ecological shifts also have implications for global carbon fluxes and sinks.
- ***Observing and Predicting Future Climate Dynamics and Ecosystem Responses:*** There are numerous examples of snow and ice impacts on surrounding marine and terrestrial ecosystems. For instance, Arctic rain-on-snow events can lead to ice layers that affect the mobility and grazing of reindeer and caribou, while meltwater discharged from marine-terminating glaciers supplies nutrients to the ocean, affecting primary producers and biogeochemical cycles. The physical and chemical states of the snowpack and sea ice affect vegetation and primary productivity (e.g., frost and wind

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protection; light availability), animals (e.g., mobility), and pollution propagation (e.g., volatilisation of persistent organic pollutants).

- ***Understanding the Vulnerability and Resilience of Arctic Environments and Societies and Supporting Sustainable Development:*** Ecological integrity underpins traditional ways of life and food security across the Arctic. The changing Arctic cryosphere is opening up new economic opportunities such as expansion of fisheries, shipping routes, tourism, and resource extraction, while also presenting challenges related to Indigenous self-determination, environmental sustainability, and geopolitical dynamics.

4. Impacts of the Changing Cryosphere on Humans

- How can we elevate local, community, and Indigenous values and knowledge systems into research and monitoring of the Arctic cryosphere?
- What are the most important cryospheric components to northern communities and where do the knowledge gaps exist relating to how they are changing?
- What cryosphere services are required to best inform northern communities of predicted changes to their local cryosphere?

The changing Arctic cryosphere has myriad direct and indirect impacts on northern peoples and communities. Some of these are captured in foci 1-3, with clear impacts on infrastructure, transportation, local economic activity, traditional livelihoods, and food security. This theme is therefore integrative, with a focus on community engagement and northern capacity building to co-develop research priorities and to monitor cryospheric change. Within this, there is also an imperative to develop the concept of “cryosphere services” for northern communities, which includes information on recent trends in the different components of the cryosphere (e.g., sea ice, permafrost, snow cover) as well as projections of cryospheric change and the associated impacts on the livelihoods of northern peoples. Integrating their communities into cryosphere monitoring programmes and research is essential to ensure knowledge exchange on historical cryospheric and environmental change and that a participatory approach is followed, and to enable instrumentation and cryospheric monitoring across the populated Arctic.

This research focus links to IASC strategic goals via:

- ***Role of the Arctic in the Global System:*** Arctic communities include numerous Indigenous peoples who have rights to self-determination and to weather, climate, and hydrological services under the U.N. Declaration of the Rights of Indigenous Peoples.
- ***Understanding the Vulnerability and Resilience of Arctic Environments and Societies and Supporting Sustainable Development:*** Changing snow, ice, and permafrost conditions have direct impacts on Arctic communities and traditional livelihoods. Social dimensions of climate and cryospheric change need further study and prioritization in this context.

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Building resilience also applies to development of scientific capacity within Arctic and Indigenous communities, which requires a deeper commitment to knowledge co-development, diverse ways of knowing, and community empowerment.