Science summit for the G7 2026

S7 Academies joint statement

The Global Arctic: Unprecedented Change, Global Stakes

Executive Summary

The global Arctic: unprecedented change, global stakes

The Arctic is undergoing some of the fastest and most wide-ranging environmental transformations on the planet. Over the past decades, this region has become a hotspot of global change, where warming has occurred nearly four times faster than the global average over the last 40 years. These rapid changes are reshaping landscapes, ecosystems, climate feedbacks, and the ways of life of Arctic societies—particularly Indigenous communities who have stewarded these lands for millennia. The consequences of Arctic change are felt most strongly locally, but it is now understood that they extend far beyond the Arctic region, with implications for climate stability, sea-level rise, biodiversity and weather patterns globally. In this context, the Arctic must be viewed as a sentinel region for Earth's stability, where anticipating, understanding of, and responding to abrupt and potentially irreversible shifts is of critical importance.

The S7 urges the G7 to consider the 5 recommendations, which are summarised below:

1. **Mitigate Arctic and global change** through immediate reductions in greenhouse gas emissions, consistent with internationally recognized temperature goals, including those reflected in the Paris Agreement. Rapid mitigation must also be paired with stronger efforts to limit pollutants and reduce high-impact activities, as well as a strong focus on regional adaptation actions that consider human rights, limits, and sustainable development goals.
2. **Strengthen international scientific cooperation** through mission-based research, open data and sustained observation networks.
3. **Advance evidence-based adaptation** with early warning systems and locally tailored resilience strategies.
4. **Deepen research** on tipping systems and potential high impact events as well as systemic Arctic risks.
5. **Ensure Indigenous and Local Knowledge** and leadership are ethically and equitably engaged in international governance and environmental decision-making.

The future of the Arctic—and the global climate—depends on action taken now.

Statement

The global Arctic: unprecedented change, global stakes

The Arctic: A Region Undergoing Rapid and Multifaceted Transformation Caused by Humans

The Arctic is currently undergoing profound and accelerated environmental change. Due to Arctic amplification, the region has warmed at nearly four times the global average of anthropogenic warming over the past four decades. This exceptional rate of change is driving a series of interconnected processes: the rapid loss of sea ice and glaciers, thawing of permafrost, coastal erosion, droughts and increasing frequency and intensity of wildfires, and major biogeochemical and ecological disruptions on land and in the sea. These dynamics are the result of complex feedback mechanisms involving ocean-atmosphere interactions, changes in albedo, and variations in cloud and aerosol behavior - all in response to anthropogenic activities, particularly the burning of fossil fuels. There are increasing reports of significant ecological shifts, including climate induced migration of species, changes in food webs, and threats to endemic species. The rapid transformation of the Arctic has significant societal, economic, and geopolitical implications, with infrastructure damage and knock-on effects for industry and human settlements via changes in transportation, energy and supply chains. Understanding the mechanisms of Arctic amplification and its implications is essential to anticipate and mitigate cascading effects—both within and beyond the Arctic region.

Global Impacts and Tipping Systems: Arctic Change as a Driver of Climate Instability

Changes occurring in the Arctic are not confined to the region: they have significant implications for the global weather and climate system, as well as for societal development. Wildfires and the thawing of permafrost, which stores vast quantities of organic carbon, release large amounts of CO_2 and methane—greenhouse gases that accelerate global warming. Similarly, the accelerated melting of the Greenland Ice Sheet is projected to contribute substantially to sea-level rise, threatening low-lying coastal regions worldwide. In parallel, these Arctic changes may disrupt the Atlantic Meridional Overturning Circulation (AMOC) and the North Atlantic Subpolar Gyre (SPG), further unbalancing global ocean heat distribution, weather patterns, and regional climates beyond the Arctic region. These developments underscore the Arctic's central role in regulating planetary equilibrium and the urgency of monitoring thresholds that, if crossed, may lead to irreversible shifts and global consequences for planetary health and humanity.

Pollution in the Arctic: Emerging Pressures from Local and Global Sources

The Arctic is increasingly impacted by environmental pollution, originating from outside the region via long-range atmospheric and oceanic transport or from industrial activities within the region that are expanding as maritime access improves. Pollutants such as mercury, persistent organic pollutants (POPs), and plastics can accumulate in Arctic ecosystems, where cold temperatures and slow degradation exacerbate their persistence compared to other regions. These contaminants cascade through the food web to pose risks to wildlife and human health, particularly among Indigenous communities relying on subsistence practices for food security and livelihoods. Contaminants and pollutants are associated with endocrine disruption, neurotoxicity, birth defects and other chronic effects. Some may also serve as vectors for pathogens or promote antimicrobial resistance with consequences well beyond the Arctic region. Yet, significant knowledge gaps remain regarding their sources, distribution, and long-term impacts—highlighting the need for enhanced research, risk assessment and governance frameworks.

Arctic Societies and Knowledge Systems: Human Dimensions of Environmental Change

Approximately four million people live permanently in the Arctic, including numerous Indigenous groups and communities whose livelihoods, cultures, and identities are closely tied to a habitable land, ice, and healthy sea. These populations are disproportionately affected by rapid environmental changes, which threaten their livelihoods, infrastructure, and cultural heritages. Yet, Arctic societies also hold valuable knowledge systems, grounded in long-term intergenerational stewardship, sustainability, and observations of environmental variability that make them highly resilient to change. Their participation is thus critical to understanding the land–sea continuum, a zone of intense interaction between the cryosphere, biosphere, ocean, and human systems and in identifying robust solutions to cascading impacts and risks of environmental, socio-economic, and geopolitical change, in line with the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP[48]). Ensuring Indigenous knowledge and academic science are valued and connected—through co-produced research,communication and inclusive governance approaches—offers vital pathways toward more resilient and adaptive responses to ongoing Arctic transformations and threats.

Recommendations

The S7 urges the G7 to consider the 5 recommendations below:

1. **Mitigate Arctic and Global Change through Immediate Greenhouse Gas Emission Reductions**

   Scientific evidence indicates that minimizing the pace and magnitude of Arctic climate change—and its global consequences—requires rapid and sustained reductions in greenhouse gas emissions. Assessments of pathways consistent with internationally recognized temperature goals, including those reflected in the Paris Agreement, involves rapid and deep reductions. Recognizing that countries may pursue differing national approaches, the G7 is well positioned to play a critical role in advancing these efforts. Given the level of scientific knowledge, the potential environmental and ethical risks and the absence of essential international governance, the G7 could consider supporting a moratorium on large-scale field experimentation or deployment of Arctic geoengineering options at this time.

   Efforts should also target pollution and high-impact activities, by:
   - Phasing out emissions of mercury, POPs and other persistent chemicals;
   - Strengthening regulations and increasing policy incentives supporting energy, transportation and other infrastructure transitions in the Arctic;
   - Restricting industrial and extractive expansion that would exacerbate environmental degradation and would be at risk by thawing and warming.

2. **Strengthen International Scientific Cooperation**

   Enhanced cooperation is critical to understand, monitor, and predict the rapid changes unfolding across the Arctic. This requires:
   - Strategic collaboration and open, transparent data sharing across nations and disciplines;
   - Sustained investment in long-term, multi-scale observation networks, especially in remote and transboundary areas;
   - Support for mission-based science and international joint project funding;
   - Joint development of holistic modeling tools that couple physical, ecological, and social processes to better project Arctic system dynamics and global feedbacks.

   Improved communication of scientific findings—through accessible, open-access policy relevant outputs and clear articulation of uncertainties—is essential to support evidence-based decision-making under rapidly changing conditions.

3. **Advance evidence-based adaptation**

   As changes accelerate, Arctic communities, ecosystems, and economies need actionable knowledge to adapt effectively. Governments must therefore fund and support:
   - Early warning systems for key risks such as wildfire outbreaks, deterioration in air quality, different forms of extreme weather;
   - Enhanced risk assessment tools for infrastructure integrity, industry and business investment, biodiversity and ecosystems, health and food security;
   - Development of locally tailored adaptation strategies, particularly for Indigenous and remote communities most exposed to environmental hazards;
   - Attention to quantifying limits to adaptation (including effectiveness and feasibility), residual risk, loss and damage, and the cost of inaction.

   Adaptation must be grounded in collaboration, integrating both scientific insights, Indigenous and Local Knowledge systems, and community-based experience.

4. **Deepen Research on Systemic and High-Impact Risks**
   Understanding and anticipating systemic Arctic risks is vital for global stability. Research priorities include:
   - The dynamics of key trends and potential tipping elements, such as sea-ice behavior, permafrost carbon feedback, Greenland Ice Sheet stability, and AMOC variability, but also irreversible ecological shifts;
   - Improved modeling of interacting cryospheric, oceanic, and biospheric thresholds, which may co-occur and amplify one another;
   - Identification of early warning indicators for cascading or compound tipping events to inform global mitigation and adaptation practices and policies.

   Interdisciplinary, mission-based, and international programs should be prioritized to address these complex, cross-system dynamics.

5. **Engage Indigenous and Local Knowledge and Ensure Inclusive Governance and Leadership**
   The future of the Arctic depends on governance that is both inclusive and grounded in the knowledge of its people. This entails:
   - Co-production of knowledge that fully respects scientific processes and freedoms, local expertise and Indigenous perspectives, languages, and monitoring systems;
   - Equitable participation of Indigenous representatives in policy and decision-making processes;
   - Assessment of political and social factors that hinder Indigenous peoples' engagement and equitable participation and leadership in the knowledge economy;
   - Capacity-building initiatives to strengthen Indigenous involvement and leadership in research, adaptation planning, and environmental stewardship.

   Recognizing and supporting Indigenous rights and knowledge as we support and protect scientific integrity and prevent real or perceived political interference in science is essential not only for Arctic sustainability but for the legitimacy and effectiveness of all evidence-based policy responses in this globally important region.

Advancing these recommendations will require strong coordination through upcoming scientific frameworks and established governance structures. The current UN Decade of Ocean Science for Sustainable Development (2021–2030), the new UN Decade of Action for Cryospheric Sciences (2025–2034), and the Fifth International Polar Year (IPY-5, 2032–33) offers a major opportunity to mobilize large-scale, collaborative research efforts that match the pace and complexity of Arctic change. The Fourth International Conference on Arctic Research Planning (ICARP IV) - led by the International Arctic Science Committee (IASC), with its final report published in March 2026 - provides a strategic roadmap for Arctic research priorities and international scientific cooperation (ICARP IV Final Outcomes Report, 2026). These scientific initiatives must be supported by international alliances and new partnerships between public and private funding. The Arctic Council and its bodies and committees remain a central framework for fostering dialogue, cooperation, and evidence-based decision-making across the Arctic. The G7 should offer a coherent foundation for aligning research, policy, and action in response to accelerating, human-driven Arctic transformations.

Scientific background

The global Arctic: unprecedented change, global stakes

1. The Arctic: A Region Undergoing Rapid and Multifaceted Transformation Caused by Humans

Context and Challenges

The Arctic is undergoing a rapid and persistent transformation, with regional surface temperatures rising nearly four times faster than the global average over the past 40 years[1,38]. This Arctic amplification is driven by strong feedbacks between sea ice, snow cover, the ocean, and the atmosphere, fundamentally reshaping the region's physical and ecological systems. The most recent observations confirm that the Arctic has entered a phase of system-wide reorganization, with accelerated change across marine, cryospheric, and terrestrial domains[1].

Sea ice decline has become a signature indicator of Arctic and global climate change. Summer sea-ice extent has decreased by approximately 12–13 % per decade since 1979, and the remaining ice is younger, thinner, and more mobile[1]. The 90% loss of thick multiyear ice has profoundly altered ocean–atmosphere heat exchanges and reduced surface albedo, amplifying regional and global warming[40]. Model projections indicate that nearly ice-free Arctic summers could occur as early as the 2030s, even under moderate emissions scenarios.

The Arctic Ocean is changing in structure and chemistry. Reduced ice cover and greater light penetration increase biological activity in surface waters, while growing freshwater input from melting ice and rivers strengthens stratification and reduces vertical nutrient flux[1,34]. These changes affect plankton productivity and the Arctic Ocean's capacity to act as a carbon sink. At the same time, ocean acidification progresses faster in the Arctic due to low buffering capacity, with pH declines of up to 0.3 units since pre-industrial times in some regions[1,36]. This threatens calcifying species such as pteropods and benthic shell-formers, with cascading effects on food webs and biogeochemical cycles.

On land, permafrost degradation and changing snow cover are reshaping the Arctic surface. Warming and deepening of the seasonally unfrozen active layer destabilize terrain, lead to substantial coastal erosion, and expose previously frozen organic matter to microbial decomposition, producing carbon dioxide and methane emissions[1,46]. Earlier snowmelt and shorter snow seasons increase solar energy absorption, further warming soils and altering vegetation phenology. Freshwater resources in the Arctic are under increasing threats from climate change as well as multiple anthropogenic stressors[5]. Where coastal sea-ice declines, protections against storm and wave surges are missing, with substantial consequences for coastal habitats and settlements.

The frequency and severity of wildfires in boreal forests and tundra have increased, driven by higher summer temperatures, longer dry periods, and reduced soil moisture[1,17,43]. Fires release vast amounts of carbon into the atmosphere, they modify surface albedo, permafrost insulation, and vegetation composition, affecting local ecosystems and atmospheric carbon fluxes.

Ecosystems are rapidly responding to these physical transformations. Longer growing seasons, shifts in vegetation composition, and northward migration of shrubs and boreal species are altering tundra landscapes and energy fluxes[1]. In aquatic systems, changes in ice cover, salinity, and nutrient flux alter habitat structure, plankton communities, and food web composition[7]. The redistribution of species—including boreal fish and zooplankton moving northward—reflects a broader reorganization of Arctic ecosystems with uncertain implications for productivity and resilience[3].

Together, these coupled processes indicate an Arctic entering a new state characterized by retreating glaciers, thinner sea ice, warmer soils, fresher and more acidic waters, more frequent wildfire activity, and rapidly transforming ecosystems. The interactions among these changes highlight the profound and multifaceted nature of Arctic climate change[1].

Knowledge Gaps

Despite major advances in observations (eg.,[37]) and modeling, crucial uncertainties remain in predicting the pace and extent of Arctic transformations. The interactions between declining sea ice, surface albedo, and cloud formation, amongst other issues, are incompletely understood, particularly during the polar night, where data on moisture, aerosols, and longwave radiation are limited.

Ocean stratification and biogeochemical processes remain a key uncertainty. Increased freshwater input strengthens surface stratification but reduces vertical nutrient flux, with poorly constrained effects on plankton communities, primary production, and the Arctic Ocean's role as a carbon sink[1,34]. Similarly, the regional impacts of acidification on calcifying species and early life stages are not fully quantified, and few long-term datasets link carbonate chemistry changes to broader ecosystem responses[1,36].

Terrestrial feedbacks are also complex. The combined effects of permafrost thaw, snow decline, vegetation shifts, and wildfire disturbances on soil carbon, surface energy fluxes, and albedo as well as terrestrial networks of life remain difficult to quantify. Current models often underestimate the biophysical feedback associated with vegetation–albedo interactions and fire dynamics[1,43].

Finally, integrating across system components—atmosphere, ocean, cryosphere, and biosphere—remains a challenge. Many models and observational networks still operate independently, limiting our ability to capture the full complexity of Arctic amplification and its cascading effects on global climate[1].

Research Needs

Maintain and expand year-round Arctic observation networks to monitor atmosphere–ocean–ice interactions, wildfire activity, marine carbonate chemistry, and ecosystem responses. Advance coupled process studies linking cryosphere changes, ocean acidification, wildfire dynamics, and biological productivity.

Improve model resolution and coupling to capture feedback among energy, carbon, nutrient, and fire cycles across Arctic domains.

Promote open data and international collaboration to enable cross-disciplinary Arctic climate assessments.

2. Global Impacts, Tipping Systems and High Impact Events: Arctic Change as a Driver of Climate Instability

Context and Challenges

The transformations underway in the Arctic are not confined to the high latitudes. They are increasingly recognized as drivers of global-scale climate feedbacks that can modify Earth's energy balance, ocean circulation, and atmospheric dynamics[28]. As some Arctic thresholds are approached, the risk of triggering tipping systems and potential high impact events - abrupt, potentially irreversible shifts in the climate and/or ecological systems - has become a central concern for both science and policy.

One of the most critical feedbacks involves permafrost carbon release. The Arctic permafrost region contains roughly 1 500 Pg of organic carbon, nearly twice the amount currently in the atmosphere[18]. As permafrost thaws, organic matter becomes available for microbial decomposition, releasing carbon dioxide and methane[8,39]. While gradual thaw produces a sustained, long-term emission, abrupt thaw events—such as thermokarst collapse or coastal erosion—can rapidly unlock and mobilize deep carbon stocks and transport them into rivers and the coastal ocean. The resulting greenhouse-gas fluxes could offset terrestrial and oceanic carbon sinks, reinforcing global warming and complicating mitigation targets under the Paris Agreement[30].

The Greenland Ice Sheet represents another major source of concern. The ice loss over the past decade is five times higher than in the 1990s, contributing 0.63 mm per year to sea level rise between 2006 and 2018[15] contributing around one quarter of observed global sea level rise. About half of this acceleration comes from faster coastal glacier flow, with the other half due to increasingly extensive and prolonged surface melting[41]. Continued ice loss is expected to accelerate as regional temperatures rise. Model projections indicate that sustained warming beyond a few degrees Celsius above pre-industrial levels could trigger irreversible mass loss[33], committing the planet to up to 7 meters of long-term sea-evel rise.

The injection of freshwater from melting ice and increased precipitation also alters the salinity balance of the North Atlantic, with potential implications for the AMOC and for the North Atlantic Subpolar Gyre (SPG) — two key components of the global climate system. Arctic and sub-Arctic freshening will reduce the formation of dense deep waters, weakening oceanic heat transport toward higher latitudes[47]. Freshening can also destabilize the SPG itself by shifting it toward a weaker, cooler, and more stratified state, reducing the northward transport of heat and salt into the subpolar Atlantic[45]. Such a transition would not only precondition further AMOC weakening but could also trigger rapid regional climate shifts, including colder conditions around Greenland and altered storm tracks across the North Atlantic basin. While a complete AMOC collapse remains unlikely this century, even moderate slowdowns could modify regional temperature and precipitation patterns worldwide[13].

Further, Arctic sea-ice loss, SPG and AMOC changes influence planetary-scale atmospheric circulation. The reduction in pole-to-equator temperature gradients can alter jet-stream position and waviness, potentially contributing to persistent mid-latitude weather extremes[9]. Although the strength and spatial expression of these teleconnections remain debated, they illustrate how Arctic changes can propagate through the climate system via both dynamic and thermodynamic pathways.

Knowledge Gaps

Although the mechanisms linking Arctic processes to the global climate system are increasingly well identified, significant uncertainties remain regarding their magnitude, thresholds, and interactions. One major uncertainty concerns the magnitude and timing of carbon emissions from permafrost. Current models still diverge on how much carbon may be released this century and on the relative importance of gradual versus abrupt thaw processes. Methane fluxes from sub-sea permafrost and thawing coastal zones are particularly poorly constrained, reflecting the scarcity of year-round observations and the need for process-based modeling across spatial scales.

Another critical source of uncertainty lies in the stability of the Greenland ice sheet and its contribution to future sea-level rise. The nonlinear dynamics of surface melt, subglacial hydrology, and ice–ocean interactions remain among the largest challenges for global projections. Improved coupling between ice-sheet models and regional climate simulations is needed to better capture feedback involving surface albedo, snow accumulation, and oceanic heat inflow.

The sensitivity of the AMOC to freshwater fluxes from the Arctic is also not yet fully understood. Observations of salinity, temperature, and current structure in key gateways such as the Fram Strait and the Labrador and Irminger Seas remain limited. Sustained monitoring and data assimilation into ocean–atmosphere models are essential to assess whether changes in Arctic freshwater inputs could trigger threshold behavior in large-scale circulation.

Uncertainties also persist regarding the representation of teleconnections between the Arctic and mid-latitudes. The causal pathways linking Arctic amplification to climate anomalies in Eurasia and North America remain debated, in part because of the limited temporal span of satellite records and the complexity of internal climate variability[6]. Robust attribution studies are required to disentangle Arctic forcing from other drivers of atmospheric circulation.

Finally, the integrated risk of cascading tipping systems and potential high impact events is only beginning to be explored. Interactions among cryospheric, oceanic, and biospheric thresholds are rarely assessed in combination, even though their co-occurrence—such as between permafrost thaw, accelerated Greenland melt, and a weakening AMOC—could amplify global impacts beyond the sum of individual effects. Identifying early-warning indicators for such compound tipping dynamics has emerged as a key research priority for the coming decade.

Research Needs

Quantify Arctic feedback to global climate. Strengthen coordinated observations and model integration for permafrost carbon, Greenland melt, and Arctic–Atlantic freshwater fluxes.

Develop early-warning indicators of tipping behavior. Use high-resolution monitoring and Earth-system modeling to identify threshold proximity and potential cascade effects.
Enhance coupled climate–cryosphere simulations. Improve representation of non-linear feedback between ice, ocean, and atmosphere to reduce uncertainty in global projections.

Climate Geoengineering in the Arctic

Geoengineering refers to intentional, large-scale manipulation of Earth system processes to offset warming and/or its effects without reductions in greenhouse gas emissions. One form of geoengineering (carbon dioxide removal, CDR) involves the removal of CO_2 from the atmosphere by either nature-based or engineering methods, thus reversing some anthropogenic emissions. However, other ideas for geoengineering attempt to mask the effects of increased greenhouse gas concentrations, either by affecting climate using solar radiation modification (SRM) or by addressing individual impacts such as those affecting ice sheets.

As Arctic warming accelerates, producing profound local impacts and cascading effects on global climate, some scientists have explored whether such non-CDR geoengineering options deployed in the Arctic might slow ice loss or buffer regional and global changes. However, the unique physical and seasonal characteristics of the Arctic create specific challenges for these approaches, such as low insolation during winter and sensitive feedbacks involving sea ice and ocean circulation. While geoengineering concepts have been proposed for the Arctic region, their effectiveness, environmental risk, feasibility, and governance have been questioned [42].

Proposed Concepts

Increasing Solar Reflectivity through Stratospheric Aerosol Injection: This method aims to deposit reflective particles (e.g., sulfate aerosols) in the stratosphere to reduce incoming solar radiation[24]. Large-scale deployment would require extensive logistics (e.g., specialized aircraft) and continual injection to maintain effects.

Marine Cloud Brightening: A second form of SRM involves increasing the reflectivity of low-lying marine clouds, by spraying sea salt or other aerosol particles, to serve as additional cloud condensation nuclei, with the aim of causing marine cloud brightening (MCB). The effects of MCB on cloud properties and regional climate are still poorly understood.

Diverting Ocean Circulation Patterns: Concepts such as underwater barriers or “sea curtains” have been proposed to block warm water from reaching ice-sheet grounding lines, potentially reducing ocean-induced melting[20]. These structures would need to span vast and harsh marine areas, posing enormous engineering, cost, and ecological challenges.

Increasing Sea Ice Albedo or Thickness: Enhancing surface reflectivity using reflective materials (e.g., glass beads) or actively pumping seawater onto ice surfaces to thicken ice have been proposed[11,14]. However, materials could harm ecosystems, and the scale of deployment needed to meaningfully influence ice mass balance is likely infeasible.

Slowing Ice Sheet Flow: Drilling to remove basal water under major ice streams has been proposed to reduce ice flow to the ocean[29]. Yet limited understanding of subglacial hydrology and the potential for rapid refilling or unintended consequences makes practical implementation highly uncertain.

Assessment

Across these concepts, several major limitations and risks have been identified[42]. Many proposed geoengineering approaches are expected to have limited effectiveness in the Arctic. In addition, environmental hazards pose serious concerns, as the introduction of aerosols or particulate materials could generate unintended ecological consequences, alter atmospheric or oceanic circulation, and disrupt nutrient and weather patterns. Significant technical and logistical barriers further complicate deployment: the Arctic’s extreme conditions, remoteness, and vast spatial scales make installation, maintenance, and continuous operation costly and uncertain. Beyond these physical constraints, governance and ethical challenges present major obstacles, given that the Arctic spans multiple national jurisdictions and international waters, and no legal framework exists across these different areas to regulate large-scale atmospheric deployments or safeguard the rights and interests of Indigenous communities who would be directly affected.

Far more research is needed before any of these approaches can be considered safe and effective on Arctic-wide scale. In addition, a governance framework would be needed given that the effects of deployment would cross borders. For these reasons, at the present time, deployment of geoengineering (including large-scale field experiments that might be similar to deployment) should be avoided.

3. Pollution in the Arctic: Emerging Pressures from Local and Global Sources

Context and Challenges

Once viewed as pristine and isolated, the Arctic Ocean and lakes is now significantly impacted by human caused pollution. Contaminants transported over long distances by rivers, ocean currents, and the atmosphere from northern industrial regions accumulate in the Arctic, where they harm ecosystems, wildlife, and human health. Some are transformed by microorganisms into even more toxic compounds. Furthermore, in the long term, the retreat of sea ice and portions of the Greenland ice sheet will generate ambitions regarding mining, transport and development. This will have unprecedented environmental, social and geopolitical impacts that are yet to be understood and governed.

Among the most concerning pollutants are mercury, plastics, and persistent organic pollutants (POPs). Methylmercury bioaccumulates and biomagnifies through food webs, reaching toxic levels in top predators and Indigenous communities. Plastics, from nano- to macro-plastics, are now found in all Arctic compartments and species[4]. Once ingested, they can cause physical and toxicological damage through the release of associated chemicals, leading to endocrine disruption and risks of neurological, reproductive, and cardiovascular disorders[22]. Plastics also host microorganisms and antibiotic resistance genes, acting as potential new transport vectors[16]. POPs, both legacy and emerging, persist in Arctic environments, resisting degradation and posing chronic toxicity risks[2]. In addition, local sources of pollution—fuel use, poor waste management, wastewater, mining, shipping, and tourism—are rising sharply. Despite major risks to biodiversity, ecosystems, and Arctic societies, knowledge gaps remain large, especially regarding contaminant origins, transformations, and climate feedback.

Knowledge Gaps

Research must clarify how contaminants are stored and released by the cryosphere, particularly permafrost and sea ice, and how thawing affects their biogeochemical cycling and availability to food webs. Understanding long-range transport from lower latitudes via atmospheric and oceanic routes and the potential role of organisms as biological vectors is critical[23]. Further work is needed on persistence, degradation, and combined (cocktail) effects of contaminants under multiple stressors such as warming, parasitism, and food-web reorganization. Emerging concerns also include micro- and nanoplastics, pathogens, biological invasions facilitated by Arctic “Atlantification” and shipping, and acoustic pollution. These factors demand integrated monitoring and mitigation strategies.

Despite global attention, plastic pollution in the Arctic remains poorly characterized. A synthesis of over sixty studies revealed plastics in virtually all Arctic environments, including deep-sea sediments and the central basin[4], though nanoplastic data remain scarce[26]. Sources include local fishing, landfills, wastewater, and long-range atmospheric or oceanic transport. With global plastic production expected to triple by 2060[32], it is crucial to understand long-term dynamics of micro- and nanoplastic accumulation and release, particularly from melting sea ice. Once in the water column, particles enter food webs with largely unknown toxicological consequences. Developing reliable biomarkers is needed to assess exposure in Arctic fauna.

The Arctic Ocean and lakes exhibits distinct mercury dynamics, with elevated surface Hg and shallow methylmercury (MeHg) maxima compared to other ocean basins, enhancing entry into marine food webs[2,21]. It receives Hg from atmospheric deposition, rivers, erosion, and Atlantic and Pacific inflows. Despite global emission controls, permafrost thaw could release vast mercury stocks, potentially enhancing microbial methylation and bioaccumulation. Seasonal dynamics, currently under-sampled, and the role of sea-ice loss in Hg exchange processes require urgent study. Toxicity thresholds, mostly based on temperate species, must be revised for Arctic organisms.

Although banned since 2001, legacy POPs such as HCH, DDT, and PCBs remain at high Arctic concentrations in the Arctic[2], owing to changes in transport routes and slow degradation in cold environments. They continue to threaten wildlife and Indigenous communities dependent on marine resources. Per- and polyfluoroalkyl substances (PFAS)—notably PFOS, PFOA, and PFHxS—are increasingly detected in Arctic biota[44]. PFAS accumulates in marine mammal livers and seabird eggs, causing immunotoxic and endocrine effects[19]. Thousands of unregulated PFAS remain understudied, suggesting current monitoring underestimates total exposure.

Atmospheric pollution—both local and transported—affects Arctic ecosystems and communities. Expanding industrial activity, shipping, and resource extraction increases local emissions of soot, nitrogen oxides, and aerosols, compounded by imported pollutants from lower latitudes. Stable boundary layers trap contaminants near the surface, producing high local concentrations. Warming also intensifies natural emissions from boreal wildfires and biogenic sources. Understanding interactions between anthropogenic and natural aerosols, clouds, and radiative forcing is essential for predicting regional and global climate feedback.

Research Needs

Continuous, autonomous Arctic-wide monitoring. Develop year-round observation systems—instrumented buoys, autonomous vehicles, drifting platforms, and satellite integration—to capture seasonal and spatial variability. Combine chemical data with biological indicators and ecotoxicological monitoring for a holistic view of contamination patterns and trends.

Understand impacts on Arctic biota and societies. Conduct long-term, multi-stressor studies linking chemical contamination to biological and health outcomes across species and human populations. Establish toxicity thresholds for both single compounds and realistic contaminant mixtures. Involve Indigenous communities to align research with local needs and perspectives.

Advance numerical modeling. Improve models to simulate long-range transport, deposition, re-emission, and interactions between contaminants, aerosols, and cryospheric processes. Incorporate climate-change and socio-economic scenarios to forecast future Arctic pollution dynamics and feedback.

4. Arctic Societies and Knowledge Systems: Human Dimensions of Environmental Change

Context and Challenges

The Arctic is undergoing profound transformations that extend far beyond physical and ecological systems. These changes directly affect the region's societies, economies, and knowledge frameworks. The accelerating impacts of climate warming—manifested in sea ice decline, permafrost degradation, and shifting ecosystems—are reshaping the living conditions, mobility, and cultural continuity of Arctic peoples[2,8].

Indigenous and local communities are among the most exposed to these transformations. Traditional subsistence practices such as hunting, fishing, and herding are disrupted by unstable ice and snow conditions, unpredictable weather, and changing animal distributions[2]. Permafrost thaw and coastal erosion endanger settlements and infrastructure, while sea-level rise and the retreat of glaciers - such as the accelerated ice loss observed in Greenland and the Canadian Arctic[31,41] - further threaten habitability and safety in low-lying areas.

At the same time, global economic interests are expanding in the region. Extractive industries, shipping, and tourism bring both opportunities and risks, intensifying pressures on ecosystems and governance systems. These developments interact with pollution and contaminants that continue to accumulate in northern environments and food webs, raising health and food security concerns[2].

Beyond immediate physical risks, these transformations are reshaping knowledge systems and governance. Indigenous knowledge and local observing practices have long supported adaptation to Arctic variability, yet they are often undervalued in formal policy frameworks. Strengthening the integration of local observations, long-term monitoring, and scientific data is critical to improve collective understanding and response to change.

Knowledge Gaps

Although scientific understanding of Arctic physical systems has advanced significantly, substantial gaps remain in how knowledge is generated, integrated, and mobilized across disciplines.

Co-production of knowledge is still uneven and often insufficiently resourced, with many initiatives limited in duration or scope and rarely integrated into long-term monitoring frameworks. As a result, community-led observations, oral histories, and Indigenous knowledge systems are not consistently incorporated into environmental assessment or modelling efforts, even though they provide critical insights into socio-ecological dynamics. These dynamics—linking environmental change with cultural practices, mobility, food systems, and community resilience—remain poorly captured in current approaches[2,8]. Strengthening durable and well-supported co-production efforts is therefore essential for understanding the full complexity of Arctic change.

At the same time, policy and scientific decision-making processes often marginalize Indigenous and local perspectives, despite the fact that governance in the Arctic is increasingly fragmented by geopolitical tensions, expanding economic activity, and diverging national priorities. Without fair and equitable participation, decisions risk lacking legitimacy or failing to reflect local priorities and lived experience. This is particularly evident in domains where key risks remain insufficiently quantified, such as health impacts from pollution exposure, the stability of food systems, or the availability of culturally important species[2]. Ensuring fair and equitable participation is thus fundamental for developing policy responses that are coherent, effective, and socially grounded.

Finally, supporting Indigenous and local leadership and capacity in research and policy activities is necessary for building long-term resilience. Current observation systems remain heavily weighted toward physical and biogeochemical parameters, with limited inclusion of social, cultural, or community-defined indicators. This imbalance constrains the ability of communities to assess risk, plan for change, or meaningfully shape adaptation strategies. Sustained investment in Indigenous-led monitoring, training, and institutional support is therefore crucial—not only to correct existing asymmetries in research and governance, but also to enable more just and durable forms of environmental stewardship across the Arctic.

Research Needs

Reinforce community-based observation: Expand year-round monitoring networks combining local and scientific knowledge to track environmental and societal change.

Integrate human dimensions into Arctic assessments: Ensure that future AMAP and IPCC assessments include robust analysis of social impacts, adaptation, and cultural resilience.

Support adaptation and infrastructure planning: Develop policies that account for permafrost thaw, coastal erosion, and local safety, in partnership with Arctic communities.

Enhance governance coordination: Strengthen cooperation under the Arctic Council to link national adaptation strategies with regional knowledge frameworks.

Secure long-term funding for data integration: Support open, sustained, and interoperable systems that link environmental, health, and socio-economic datasets across the Arctic.

Acronyms

AMAP : Arctic Monitoring and Assessment Programme

AMOC : Atlantic Meridional Overturning Circulation

CDR : Carbon Dioxide Removal

DDT : Dichlorodiphenyltrichloroethane

HCH : Hexachlorocyclohexane

ICARP : International Conference on Arctic Research Planning

IPCC : Intergovernmental Panel on Climate Change

MCB : Marine Cloud Brightening

PCB : Polychlorinated Biphenyls

POP : Persistent Organic Pollutants

SPG : Subpolar Gyre

SRM : Solar Radiation Modification

UNDRIP : United Nations Declaration on the Rights of Indigenous Peoples

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