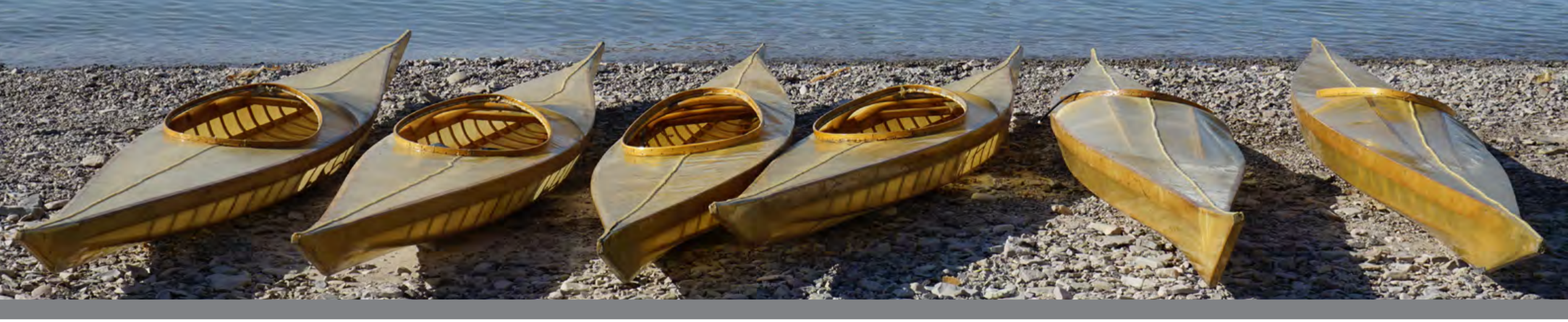
IASC

The International Arctic Science Committee's

2020 STATE OF ARCTIC SCIENCE REPORT



What is this Report & Who is it For?

The State of Arctic Science 2020 aims to be a cohesive synthesis of international Arctic research activities and priorities, as gathered from the Arctic research community itself.

Arctic science is moving faster than ever, and so this report is aimed at Arctic science agencies, Arctic science managers, and Arctic science users including a wide range of decisionmakers and policymakers, to help all Arctic science stakeholders stay up to date on Arctic research.

Arctic Lands Acknowledgement

The circumpolar Arctic is the contemporary home to many different Indigenous Peoples. As researchers and others who are working in, or reside in, the Arctic we recognize these lands and waters as the mostly unceded traditional homelands of Indigenous Peoples. Wherever you may be reading this report, IASC honors and recognizes the place-based knowledge of Arctic Indigenous Peoples, and their ancestral and contemporary stewardship of their homelands. IASC welcomes the Arctic science community to do the same.

It is the responsibility of each of us individually to learn, read, and gain better understanding of the Indigenous Peoples and cultures with which we engage. IASC encourages the Arctic research community to use your greater understanding to enhance engagement, partnerships, and co-production of knowledge with Indigenous Peoples.

IASC is also committed to recognizing that Traditional Knowledge, Indigenous Knowledge, and "Western" scientific knowledge are coequal and complementary knowledge systems, all of which can and should inform the work of IASC.

COVER PHOTO: BENJAMIN HELL
A helicopter lands on the sea ice - Tunu, Greenland.

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Terminology Note: Science & Research

IASC is an international and interdsciplinary organization which encourages and facilitates cooperation in all aspects of Arctic research, in all countries engaged in Arctic research and in all areas of the Arctic region. Rather than defining human and environmental boundaries, IASC tries to bridge those boundaries. The term 'research' is considered by some to be more inclusive than 'science' as it covers more of the Humanities. With 'Science' in IASC's name, this report uses these terms interchangeably in this report.

ABOVE PHOTO: VICTORIA BUSCHMAN
Students learn about traditional qajaq revitalization, building, and maneuvering as part of the Canadian Students on Ice Expedition Program - Croker Bay, Tallurutiup Imanga National Marine Conservation Area, Nunavut.

Introduction

IASC, the International Arctic Science Committee, was founded in 1990 with a mission of encouraging and facilitating cooperation in all aspects of Arctic research, in all countries engaged in Arctic research, and in all areas of the Arctic region. IASC is a connector – connecting scientists across international, disciplinary, and cultural boundaries and connecting with those who do research with those who seek the outcomes of that research.

One way in which IASC does this is by providing a collective voice to the international Arctic research community. Decadally, this is addressed through the International Conference on Arctic Research Planning process (*e.g.*, ICARP-III's "Integrating Arctic Research - A Roadmap for the Future;" *https://icarp.iasc.info/*). However, with rising temperatures, geopolitical interests, the initiation of the Arctic Science Ministerial meetings, and an increasingly active landscape of international Arctic (science) organizations, Arctic science is moving faster than ever.

IASC is grounded in our community of scientists and aims to provide a consensus voice – by reaching out to their national communities, connecting internationally, and reporting out. This report presents a synthesis of a breadth of input, but it is not exhaustive, as input came only through the IASC Working Groups. Indeed, there are many other NGOs, IGOs, institutions, non-profits, Indigenous Peoples' Organizations, companies, countries, and more working in the Arctic knowledge space. Nevertheless, this report comes from scientists themselves.

Each of the 23 countries represented in IASC's scientific Working Groups (Atmosphere, Cryosphere, Marine, Social & Human, Terrestrial; https://iasc.info/working-groups) was asked to submit a summary detailing the research priorities and activities in their country. This corpus of content was compiled by each Working Group's leadership. These were condensed into this report here, then reviewed by the IASC Executive Committee and Council with an eye towards interdisciplinary connections. For national and/or disciplinary breakdowns, please contact IASC Working Group members directly (contact information is available at *https://iasc.info*).

Following an internal recommendation, this report, *IASC's 2020 State of Arctic Science Report* is aimed at Arctic science agencies, Arctic science managers, and Arctic science users including a wide range of decisionmakers and policymakers – *e.g.*, national research councils and scientific foundations, Arctic ministers and ambassadors, international science bodies, and more. It will also be delivered to the organizers of the 3rd Arctic Science Ministerial. It is exciting to be able to learn from the insights of the Arctic science community, so please read on and also join IASC in thanking the community for their time and input.

PHOTO: MARIASILVIA GIAMBERINI
A braided river flows from a valley on Spitsbergen, depositing sediment and nutrients into the ocean.

Current Arctic Research Priorities

Climate change is the predominant driving force for national research interests in the Arctic.

Research priorities can mostly be distilled into the following topics, with strong overlapping themes identified between nations. As organized below, IASC's research priorities are aligned with those outlined in ICARP-III's "Integrating Arctic Research - A Roadmap for the Future." It is notable that themes are highly interdisciplinary not just at this summary level, but also at the Working Group level. With the accelerating speed of natural and social changes in the Arctic, the research areas presented here update the ICARP-III pillars to 2020.

It is interesting to note, though, that these priorities do not always flow from defined national Arctic research strategies. While some countries do have strategic plans, others do not have stated national Arctic research priorities or indeed are forbidden by law from doing so.

ICARP-III Pillar 1: The Role of the Arctic in the Global System

- Improving understanding of connections between Arctic changes and mid-latitude & tropical weather, weather extremes, climate variability, and environmental processes
- Observing, understanding, and forecasting Arctic (environmental) change – especially using coupled computer models
- Climate change, including impacts on ecosystems (*e.g.*, biodiversity, food webs, biogechemical cycling, ocean acidification, permafrost thaw, etc.)
- Developing new approaches to monitoring ecosystem changes in the Arctic region
- Arctic energy, water, and carbon budgets – in particular, coupling between atmosphere, land, ice, and ocean
- Contributions of Arctic glaciers to regional and global sea level
- Studying past environmental changes through the study of climate and environmental records (*e.g.*, ice cores, lake and sediment records, *etc.*)
- Use of ecological and biological indicators to understand current and past Arctic changes
- Resources (including minerals, energy, fish, subsistence, and more)
- Geopolitics, security, international law, and international relations in the Arctic

ICARP-III Pillar 2: Observing and Predicting Future Climate Dynamics and Ecosystem Responses

- Observing, understanding, and forecasting Arctic (environmental) change – especially using improved numerical, coupled computer modelling
- Sustaining and developing long-term data sets to validate Arctic predictive models
- Monitoring Arctic trace gasses and aerosol-cloud interactions, motivated by the need to improve understanding of Arctic amplification and Arctic climate feedbacks
- Monitoring long-distance pollution transport in the Arctic (metals, NOx, SOx, organic pollutants, *etc.*)
- Developing new observing systems and capabilities, including improving coordination with Earth Observation programs (see New & Novel section)
- The future of the Central Arctic Ocean
- Greening & browning of the Arctic (large-scale, as well as microhabitats)
- Life in (extreme) Arctic environments – disappearing ecosystems, resurrected ecosystems, and invasive species

ICARP-III Pillar 3: Understanding the Vulnerability and Resilience of Arctic Environments and Societies and Supporting Sustainable Development

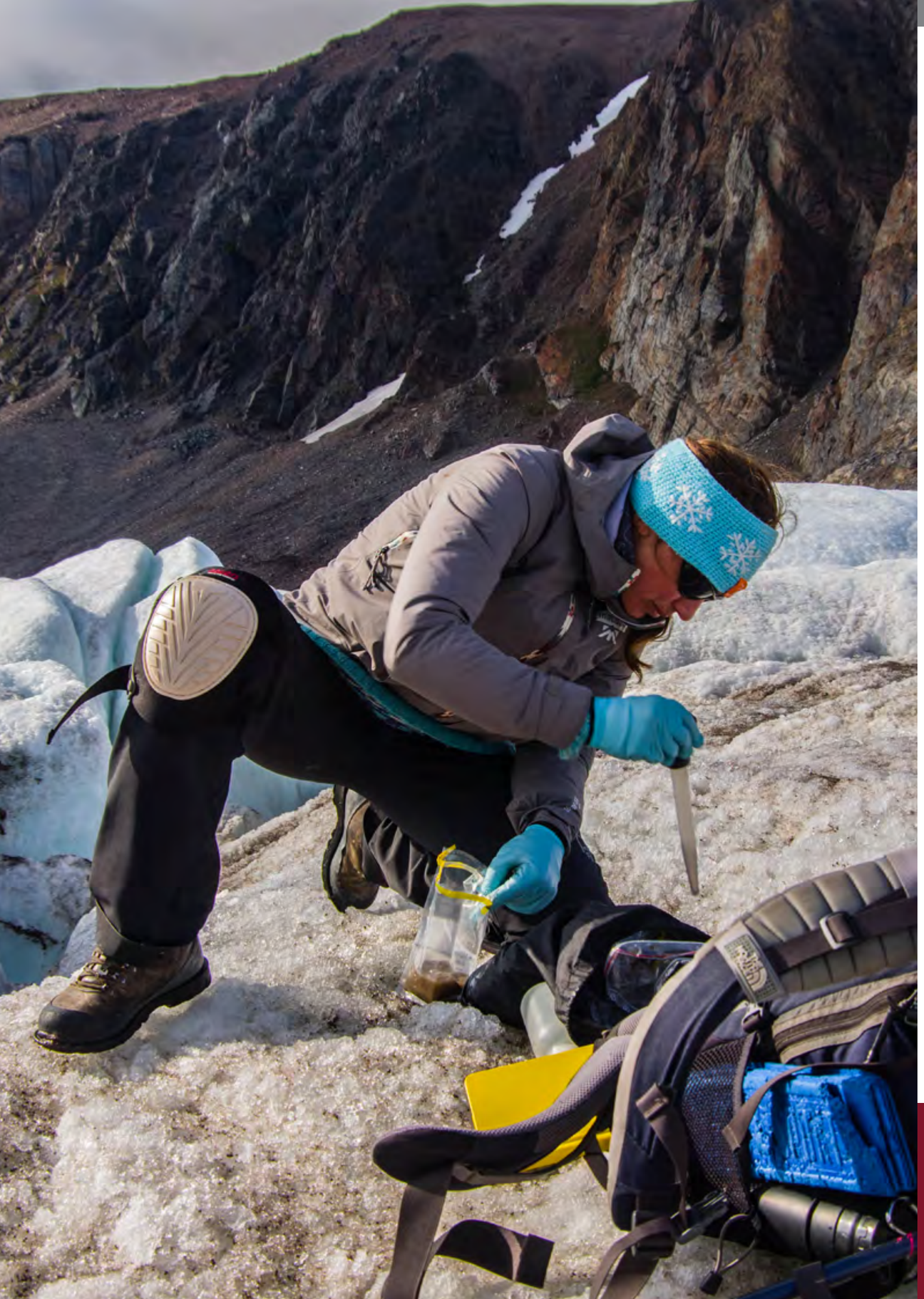
- Initiatives to better integrate Indigenous and Traditional Knowledges in research efforts and co-design/co-produce Arctic research strategies with northern and Indigenous communities
- Monitoring contaminants and pollutants (including plastics) in all parts of Arctic human-environment systems
- Improving understanding of the Arctic water cycle and its response to climate change
- Understanding natural hazards and extreme weather (associated with climate change)
- Environmental sustainability, maritime technology, and shipping safety
- Climate change, resilience, and adaptation
- Health problems – community vitality, adapting to a new Arctic, (new) parasites, and holistic human-environment approaches
- Gender and equality
- History and archaeology
- Coastal erosion and impacts on carbon cycling, infrastructure, communities, ecosystems, and more

Major Ongoing & Upcoming Projects

International coordination is key for building impactful initiatives. Such collaborative projects include, but are by no means limited to, the following:

- The MOSAiC (Multidisciplinary drifting Observatory for the Study of Arctic Climate) Arctic drift is a major multinational field experiment. It will provide unprecedented multi-season datasets on high Arctic energy budgets, clouds, atmospheric composition, sea ice, ice-atmosphere interactions, biogeochemistry and more.
- T-MOSAiC (Terrestrial Multidisciplinary distributed Observatories for the Study of Arctic Connections) extends the activities of MOSAiC to coordinate complementary activities relevant to coastal connections, terrestrial sciences, and Arctic communities.
- INTERACT (the International Network for Terrestrial Research and Monitoring in the Arctic) builds capacity and access to Arctic research stations.
- INTAROS (INTegrated ARctic Observation System) aims to increase temporal and geographic coverage and usefulness of observational data in the Arctic.
- The GLACE (Greenland Circumnavigation Expedition) is an ambitious international, interdisciplinary research expedition which has been postponed 2020.
- New international ice coring activities in Arctic and western Canada as well as Greenland provide deep climate change knowledge; these complement new projects in Antarctica, as well.
- Joint research cruises in the Russian Arctic are giving insight into under-studied areas.
- EU H2020 KEPLER aims to prepare a roadmap for Copernicus (the European Union's Earth Observation Programme) to deliver improved capacity for monitoring and forecasting in the polar regions. Relatedly, EU-PolarNet is the world's largest consortium of expertise and infrastructure for polar research.
- Several nations are undertaking model simulations for the forthcoming IPCC-AR6 as well as AMAP (the Arctic Monitoring & Assessment Programme) reports (*e.g.*, projections of the whole Arctic region, Greenland Ice Sheet mass budget, atmosphere-ice-ocean interactions, and more). Many projects are also building insightful process-based studies to inform these models.
- Nunataryuk is a major project studying coastal catchments in permafrost areas, coastal erosion and impacts on carbon cycling, and science for socioeconomic adaptation.
- The International Tundra Experiment studies effects of warming on vegetation and soil.
- The Year of Polar Prediction (YOPP) aims to enable improvements in environmental prediction capabilities for the polar regions and beyond.
- The Synoptic Arctic Survey (SAS) and the Distributed Biological Observatory (DBO) are projects coordinating Arctic marine observations for international and interdisciplinary benefit.

PHOTO: ARCTIC & ANTARCTIC RESEARCH INSTITUTE / SERGEY NIKOLAEV
Taking oceanographic measurements during the TRANSARCTICA 2019 expedition



Major Ongoing & Upcoming Projects (continued)

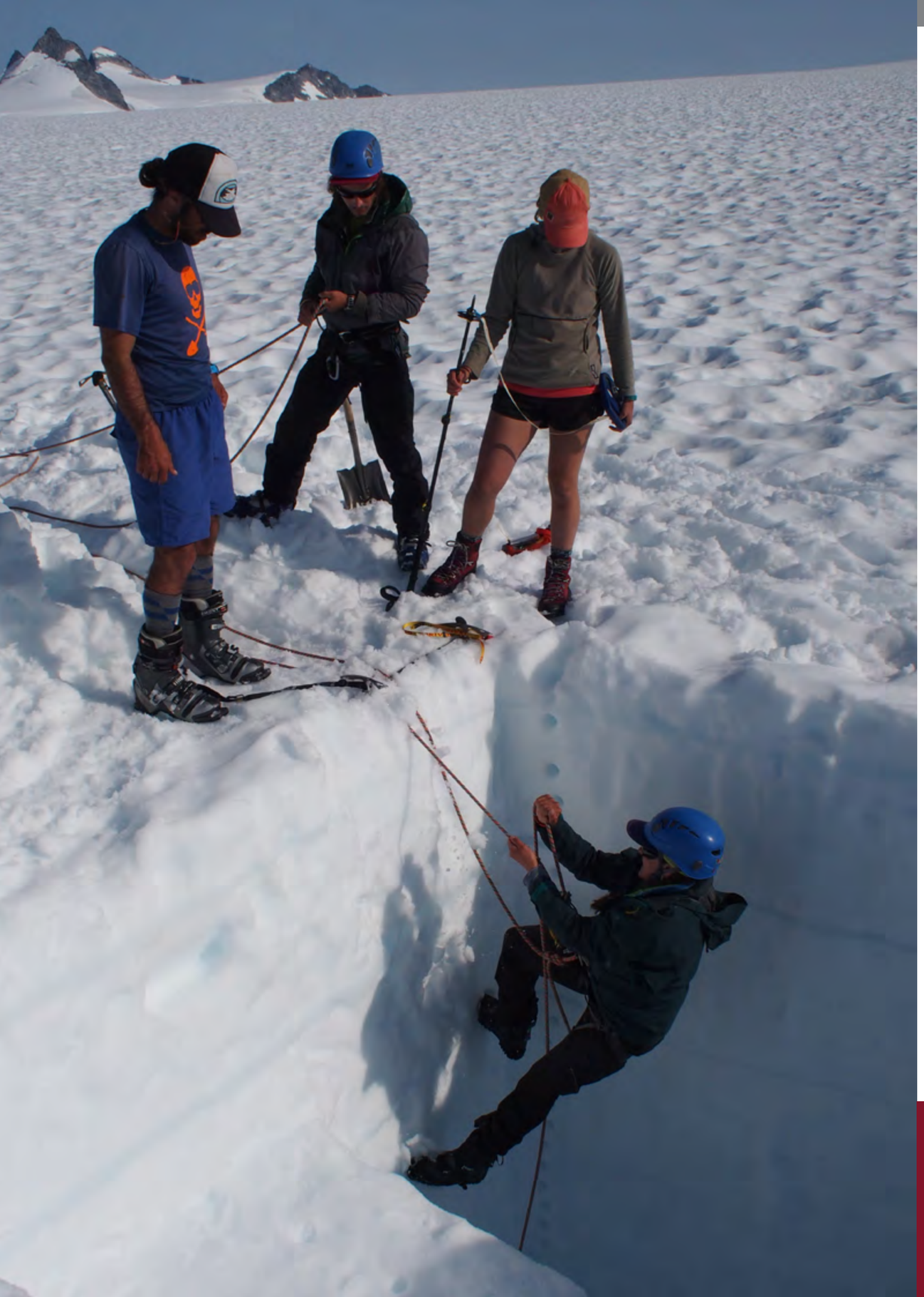
Long-term monitoring continues to be crucial to building improved understanding of the Arctic, and yet monitoring initiatives are still unique in Arctic science. For example:

- Several programs at Ny-Ålesund, Cambridge Bay, Zackenberg Station, RIF Field Station, and other similar stations are studying atmospheric, ecosystem, and climate variables.
- A special ice platform for long-term studies of atmosphere, sea-ice, and ocean interactions in the Central Arctic Basin is under development.
- Projects are monitoring migratory and native bird populations around the Arctic (*e.g.*, Greenland, Svalbard, and Siberia) and around the world (*e.g.*, Arctic Migratory Bird Initiative).
- The Circum-Arctic Vegetation Map (CAVM) is an international effort to map the vegetation and associated characteristics of the Arctic using a common base map, as an important point of reference for comparisons across the Arctic.
- Many monitoring projects in the Arctic harness polar orbiting, globally observing satellites, this includes airborne and field calibration efforts at several Arctic test sites.

Members of the IASC Social & Human Working Group, in particular, highlighted a wide range of interdisciplinary projects (even more so than their colleagues in other Working Groups), although it was noted that funding is still not commensurate with the degree of importance of social sciences research:

- They observe a shift in research project solicitations and funding streams towards more multi- and interdisciplinary scholarship (*e.g.*, Sustainable Cryospheres, Horizon2020, and Navigating the New Arctic).
- International, interdisciplinary projects focus on topics like resource extraction, tourism, cross-border mobility, youth development, community & environmental sustainability, traditional economies, the roles of institutions in the Arctic, and more.
- A notable project is Resource Extraction and Sustainable Arctic Communities (REXSAC), which focuses on extractive resource industries in the Arctic as cultural, social, economic, and ecological phenomena, including what opportunities exist for transitioning toward post-extractive futures.

PHOTO: MARTIN LULAK
A scientist takes sediment samples from cryoconites - small pits on the surface glaciers which are full of microscopic life - Ebbabreen, Svalbard.



New & Novel Arctic Research

The most prevalent theme in novel Arctic research is the emergence and development of new technologies and capacities which facilitate more interdisciplinary efforts. For example:

- Using modern metagenomic and proteomic approaches to build better ecosystem and biodiversity understanding (both marine & terrestrial)
- Polar tree-ring dating and climate studies are emerging tools which give insight into modern impacts of extreme weather events on terrestrial environments.
- Development of autonomous vehicles and observing platforms, like autonomous (under-ice) ocean monitoring with passive and active acoustics, gliders, and saildrones
- The Arctic in winter can serve as a proxy for the frozen moons of Jupiter and Saturn.
- Novel isotopic measurement methods for trace elements such as mercury and osmium provide new insights for ice core climate studies as well as quantifying modern pollution.
- New, modern research stations in areas of northern Canada (CHARS), Russia (special ice platform, Snowflake Station) will soon provide local logistical and laboratory support.
- Bioprospecting and biotechnology approaches are being applied to the Arctic.
- In Finland, the Aalto Ice Tank has been renovated to study wave propagation through sea-ice cover.

Remote sensing (both satellite and airborne) technology and techniques were highlighted:

- Historical archive data is being combined with current data to understand past changes.
- There is broad support for further development and use of unmanned airborne vehicles.
- Airborne laser ranging and high-resolution satellite stereo imagery are enabling studies of glacier mass balance and snow cover.
- Many countries are investing in new satellite platforms to improve observational and processing capabilities, which are complemented by on-the-ground measurements.
- Remote sensing of land- and sea-ice properties, in particular, were widely noted.

PHOTO: ALLEN POPE

Students on the Juneau Icefield Research Program measure annual snow accumulation and glacier health on the Taku Glacier in Southeast Alaska (on Lingit Aaní - the traditional lands of the Tlingit peoples).

New & Novel Arctic Research (cont.)

New methodologies and techniques are also enabling new science. For example:

- Methodologies for knowledge co-production in the Arctic: Arctic social sciences in collaboration with Indigenous knowledge holders and communities are best positioned to address this challenge and pioneer new, transdisciplinary and postdisciplinary ways of thinking and knowing. (Note: due to lack of representation, there has been minimal Indigenous engagement in this report, which should be remedied in future versions.)
- Convergent research: deeply interdisciplinary work focusing on addressing grand challenges and broad questions yields profound discoveries.
- Uncertainty (emulation) statistical model analysis is being used to identify key weaknesses and uncertainties in climate modelling capabilities. This has applications, for example, to understand changes in the Arctic coastal environments and their relevance for safety and resilience of Arctic maritime transportation, offshore energy production, and fisheries; to improve prediction products; and to understand the value of additional Arctic data on quality of Arctic forecasts.

Emerging research themes include:

- OneHealth: a cross-cutting, interdisciplinary initiative recognizing the interconnection of human, animal, and environmental health that has a great deal of traction in the Arctic, especially within a context of sustainable development.
- Plastics in the (marine) environment
- Research focusing on sea ice, particularly the shift from multi-year to first year ice – and more generally, research on other transitioning systems
- Investigations of the role ocean circulation plays in the ice sheet mass loss in Greenland and its consequences for sea level rise
- An emphasis on interdisciplinary approaches to understanding human-environment relations in the Arctic, with emphasis on assessments concerning economic systems
- Air pollution in the Arctic, both as a driver of Arctic climate change and from the point of view of local sources and impacts - broadening the research on potential drivers of Arctic change and impacts on local communities
- Intersectionality: focus on different/multiple experiences of marginalization to help elicit social inequalities in the Arctic
- The role of extractive industries in society and resource extraction and sustainability
- Arctic Socioeconomic Amplification: feedback, amplification and loop effects between empowerment of Arctic actors & increased geopolitical/economic interest in the Arctic
- Diverse social science topics, including sustainable tourism, mobility, human rights, globalization, science diplomacy, and climate change effects on health in the Arctic

PHOTO: ALFRED WEGENER INSTITUT / ESTHER HORVATH
After lots of planning and preparation, the 11 meter high metrological tower at Met City was raised. From the tower, MOSAiC researchers will get a collect a range of atmospheric and surface measurements and samples.

Emerging Arctic Research Issues

Many of the areas of emerging Arctic research are nuancing and expanding upon the broadly stated priorities (above / ICARP-III). Scientists are on the cutting edge, defining areas within the ICARP-III umbrella items.

Coupled Arctic Systems

Several emerging issues are centered around improving our understanding of interactions between components of the Arctic system, including using interdisciplinary approaches.

- Humans are a key component of coupled Arctic systems, both as drivers of change and as beings vulnerable to the effects of Arctic change.
- Coupled Arctic systems include biogeochemical cycles and natural emissions; terrestrial-atmosphere carbon fluxes; relationships between atmospheric processes, ice, and ocean; coupling between the stratosphere and lower atmosphere; and understanding the role of complex Arctic biological systems. Understanding how these interactions will respond in a warming Arctic is a priority.
- A better understanding of Arctic amplification is also emerging, both in the present Arctic and during past warming, as well as societal impacts of rapid warming.
- Improving knowledge of coupling between the Arctic and the large-scale global climate system, including mid-latitude – Arctic linkages, ocean and atmospheric heat fluxes, and tropical-Arctic linkages with respect to climate variability and via teleconnections
- Improved representation of interactions across system boundaries in regional and global models with a focus on the coastal zone
- Understanding interplay of the biological pump, the marine food web, ecosystem stressors, and fish stocks (in the Central Arctic Ocean)
- Integrated ecosystem assessments - examining linkages between biodiversity and environmental change through space and time
- Studying other processes like:
  - Cryospheric controls on tundra nutrient cycling
  - Fjord and ocean productivity
  - Shifts in primary production in response to sea-ice and climate change
  - Drivers and impacts of ocean acidification
  - Drivers and impacts of permafrost thaw

Pollution: Sources, Sinks, and (Societal) Impacts

- Arctic aerosol and trace gases: Several nations have identified emerging issues around improving knowledge of Arctic aerosol sources and impacts in particular, including aerosol-cloud interactions, and in the context of local pollution sources and associated societal impacts. Wildfires as sources of Arctic pollution are also identified, as well as issues around the impacts and processing of mercury in the Arctic.
- In addition, the emerging issue of plastic contamination and litter in the Arctic and evaluation of the impact of plastics, emerging pollutants (such as UV filters and pharmaceutical products), and pathogens were also mentioned by multiple countries.
- There are some small projects for air quality observation of small particulate matter (PM2.5).
- Expanded research in unique aspects of Arctic public health (*e.g.*, pathogens & climate change).

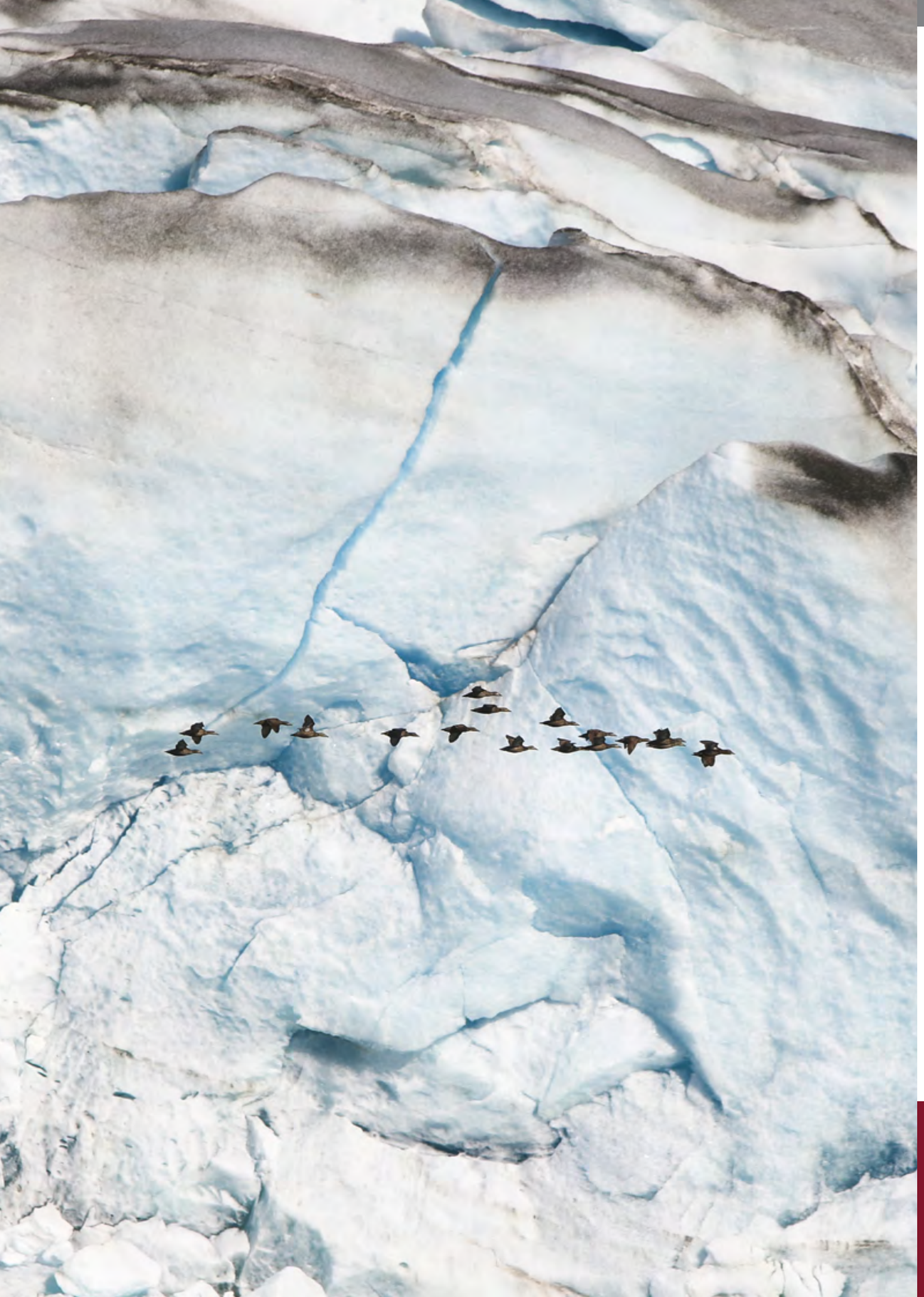
Observing, Forecasting, Prediction, and Predictability

- Prediction of sub-seasonal to seasonal processes in the coupled Arctic system
- Supporting new and diverse Artic research teams and participating in establishing new Arctic observing networks
- Arctic scientists are making significant efforts to integrate different monitoring approaches and observing systems. Important coordination is happening via the Sustaining Arctic Observing Networks and the Arctic Observing Summit.

Societally Relevant Arctic Research

- The IASC Social & Human Working Group has a work plan that identifies scientific foci including Arctic residents and change; histories perceptions and representations of the Arctic; securities, governance and law; natural resource(s)/ use/ exploitation and development: past, present, future; and human health and well-being.
- Research ethics related to Arctic research – as well as data and metadata management
- Reconciliation, decolonization, and restorative justice, especially for Indigenous Peoples
- Geopolitics and circumpolar governance, as well as Arctic legal governance
- Gender equality and quality in Arctic research
- Arctic infrastructure
- Arctic economic and technological futures
- Sustainability: Arctic sustainability in a global context, the UN Sustainable Development Goals and the Arctic, the politics of sustainability, and sustainable Arctic cities
- A large amount of societally relevant Arctic research is fed into the working groups of the Arctic Council, their programs, and their assessment reports.
- Building better dissemination channels of Arctic information to the public: for example, a growing number of citizen science projects with Arctic focus can help lead to a deeper understanding of the causes and consequences of climate and environmental change beyond the typical diffusion of scientific knowledge.

PHOTO: BARUN MAJUMDER
Northern Lights shoot across the sky above a research station - Trail Valley Creek, Inuvik, NWT, Canada.



Current Gaps in Research and/or Data

There is a recognized need to develop an integrated observing network for the Arctic and to make Arctic data and metadata more easily available internationally. There is a need to design or refine monitoring programs with clear objectives on shared Arctic variables.

The Arctic Horizons Report (a community workshop report funded by the NSF Arctic Social Sciences Program) points out that, "The Arctic is a testbed for interdisciplinary research, a 'critical region of inquiry.' … This research takes place at multiple scales ... and requires that we work across disciplines and regions; the local and the global both need to be supported, and the places of their intersection located."

Spatial (and Temporal) Coverage

- While field stations facilitate research, research infrastructure also bounds Arctic science. Cross-site comparisons are needed to determine if findings are generalizable.
- Spatial coverage in ground-based network measurements is lacking. Data coverage and sharing in the Russian Arctic and Siberia are particularly lacking.
- Research gaps include the Central Arctic Ocean (and the related potential for fisheries), as well as other areas of the Arctic with limited data coverage, such as the East Siberian Sea and the Canadian Arctic.
- The longer-term need to develop year-round sampling capabilities and sampling of the land-sea interface was also mentioned by multiple countries.
- Widespread and regular atmospheric vertical profile information is severely lacking.
- Limited coverage of some satellite observations at high latitudes: in particular there is a paucity of remote sensing methods for widespread study of permafrost (*e.g.*, ground ice content).
- There is a lack of cloud and lower atmosphere measurements (*e.g.*, energy budget, aerosols) outside the summer 'fieldwork' season.
- It is important to bring consistency to the study of the heterogeneity of physical ground properties (soil, water, snow etc.), which increases the uncertainties of future projections of permafrost.
- There is a need for reliable measurements in order to sub-seasonal-to-seasonally predict sea-ice thickness at high resolution over large spatial scales.
- In glaciology, data are very limited for constraining ice motion at high elevations on the Greenland Ice Sheet, submarine melt rates at tidewater glacier termini, densification of firn, and seasonal cycles of snow mass.
- Long term observations, research continuity, and comparative analyses in all disciplines are needed.
- Improved understanding of the spatiotemporal patterns of Arctic climate change, including meteorological observations, paleoclimate data, reanalysis products and climate models, is needed to quantify regional patterns (and drivers), as well as the impact of Arctic changes on global climate.

PHOTO: MATTHEW AYRE
A flock of female eiders give scale to the terminus of a glacier in West Greenland.

Interdisciplinary Data Exchanges

- There is a lack of cross-disciplinary understanding and exchange of data across many disciplinary boundaries. Problematic interfaces include atmospheric and cryospheric research, oceanographic and cryospheric science, sea-ice science and biogeochemistry, permafrost science and microbiology, and observations and numerical simulations, to name a few.
- It is important to improve collaboration of research groups studying (High) Arctic landscape system transformation related to climate change; coordinated ecological, cryospheric, atmospheric, and hydrological monitoring are necessary to improve understanding of Arctic change (*e.g.*, tundra greening/browning and climate change).
- There are few hard-rock geoscientists in many Arctic science collaborative communities.
- There is a need for multi-component (land, ice, ocean, atmosphere) integrated observations and models of coupled coastal zone dynamics and processes.
- Research that is multi-, inter-, or transdisciplinary needs more time to mature than standard disciplinary projects. This is also true for projects that involve Arctic communities or other stakeholders.
- Information, data curation, and management are key. There is a need to save legacies of polar science and make them accessible by ensuring access to documents and data, developing databases of scholarship and scholars, and respecting data sovereignty.

International Data Sharing

- Special attention is needed for supporting international efforts to make Arctic data and metadata easily accessible, with the implementation of web portals and archives (*e.g.*, within international networks such as INTERACT) to facilitate data access.
- There is a lack of consistency and one-point access for meteorological archive data.
- Data sharing and in-situ data access are not universally available across the Arctic.
- Remoteness also hinders data collection and sharing.
- There is a lack of strategic coordination of efforts (regionally, nationally, and internationally), although this is not preventing an active and diverse array of research.
- There are many efforts working to coordinate and align data (*e.g.*, the Arctic Data Committee) but only minimal funding and personnel to be able to support implementation and follow-through.

Research Approaches & Infrastructure

- International scientific cooperation is underway in many research areas and there are numerous examples of joint and multi-lateral programs, but the need for infrastructure support (*e.g.*, innovative technologies, new icebreaking platforms, etc.) remains clear.
- There is a lack of base funding, funding stability, and prioritization of sustained, baseline monitoring.
- Arctic scientists should further build cross-disciplinary, interdisciplinary, and convergent research practices.
- There is a further need for increased emphasis on co-producing research with Indigenous, traditional, and local knowledge holders. This will require a commensurate emphasis on research ethics and data sovereignty.
- There is a need to better follow the priorities of northern residents and communities.
- There is limited engagement of scientists in Arctic community vulnerability assessments.
- Often, there is limited Northern infrastructure and capacity; many research projects still require equipment, labs, personnel, and training from “southern” institutions.

Focus on Transitions in Arctic Natural and Human Systems

- Ongoing environmental change is a feature of the (modern) Arctic, and it can be anticipated that all of its spheres will be dramatically transformed within this century. It is an enormous challenge just to document these transformations – let alone to act on them in a manner informed by science. Although many countries prioritize Arctic research, the current levels of monitoring and research are clearly insufficient to meet these challenges.
- Increased connectivity in the Arctic transforms the research Arctic scientists can do, as well as the lives of Arctic residents (*e.g.*, relate to mobility or telemedicine).
- Long term ecosystem monitoring and sustainability impact assessment of natural resources in a changing environment are important in the Arctic in order to understand the roles and functions of resources in supporting sustainable development and resilience in Arctic.
- What impacts do new influences or technologies (*e.g.*, expanded tourism, renewable energies, multimedia, digital communication) have in the Arctic? What is the impact of increased regional autonomy and Indigenous empowerment? How should these changes be contextualized by colonial pasts and present? What does a just transition to sustainability look like in Arctic communities?

PHOTO: GEORGIA MURRAY
Snow-dusted mountains tower over a fjord in Svalbard.

Emerging Issues Concerning International Science Cooperation

International cooperation is absolutely key to studying Arctic systems, many of which know no boundaries. Whether atmosphere or ocean, wildlife or parasite, Inuit or Sámi - geographic distances are certainly distorted at the top of the world. Arctic research does and should continue to involve extensive international collaboration, and Arctic researchers can continue to work together to work across and reduce political barriers and socioeconomic disparities.

Science Planning & Coordination

- International cooperation is critical in developing widespread networks of comparable measurements. However, outside of the main long-term surface observatories, international cooperation often remains largely opportunity driven and less strategic.
- Institutionalized cooperation is rare and information about it is hard to find.
- Improved collaboration between Eastern and Western nations, both Arctic and non-Arctic, is valuable in order to maximize joint benefits and avoid duplicated efforts.
- Support for bilateral connections between non-Arctic institutions and field stations in Arctic countries is a promising place to start.
- MOSAiC is an important success story in developing a major multi-disciplinary and international field project to deliver unprecedented data and science from bottom-up, but ensuring that international critical mass and momentum is maintained following the large YOPP and MOSAiC international collaborations may be a major challenge.
- There is growing cooperation in international research initiatives via H2020 projects. INTERACT and the Arctic Research Icebreaker Consortium (ARICE) connect researchers around the Arctic. The Pacific Arctic Group is also an effective mechanism for improving international cooperation. Yet, other means of providing for cooperation between institutions in different countries are needed.
- The new Roadmap for Arctic Observing and Data Systems (ROADS) process was designed and developed by SAON as an approach to coordinate observations based on shared societal benefits and provide clear inputs to Funding Agencies as well as policymakers.
- Coordination organizations and research infrastructure bodies (polar clusters, polar boards, the Forum of Arctic Research Operators, IASC, *etc.*) are important for engaging the breadth of the Arctic research community and reduce the risks arising from fragmentation.

Funding

- It is challenging, but crucial, to align national funding mechanisms to enable large multi-national efforts. International collaborations are limited when there is a lack of international funding vehicles. EU framework and Svalbard Science Forum are examples of international programs. Joint funding calls from two or more national funding councils would be very helpful. However, overly complex and elaborate funding procedures (*e.g.*, Belmont Forum) can limit participation in an unequitable fashion.
- The nascent forum of Arctic science funders, an outcome of the 2nd Arctic Science Minsterial, is a multilateral discussion platform to coordinate, enhance, and initiate new collaborative scientific activities in the Arctic; it also aims to be a gateway for information about international funding calls for Arctic research.
- Participation in strong international research networks has been and will continue to be essential for small nations and countries with developing Arctic research programs.
- Bilaterial programs (like a UK-Canada Arctic Bursary program, introduced in 2017) have been highly successful in stimulating research and collaboration.
- Recruiting and retaining diverse researchers is a critical issue for Arctic science. One approach is creating knowledge exchange opportunities, such as Fellowship programs.
- Funding remains tight for the maintenance/continuation of (long term) observational networks.
- There is a lack of funding for and inclusion of Indigenous epistemologies.
- The most acute issue for many social scientists is the funding gap between social and natural sciences in the Arctic, as well as the lack of funding programs and streams within Arctic research funding structures that support international collaborations in social sciences, humanities, and/or interdisciplinary work. Without addressing this gap, advancing social sciences, health research, and humanities scholarship in the Arctic will be, at the very least, challenging.
- There is a need to continue to support excellence in scientific research, on Arctic/polar topics, as well as in related areas. This can be done by encouraging emerging sound practices, such as the sharing of data, field methodologies, and access to research stations, but most importantly by funding national and international projects based on open calls to which a broad array of research groups can apply and which can be evaluated based on scientific criteria and merit.
- Apart from some topics that require major investments, it is vital to support small to medium-size projects that enable the development of innovative research questions.

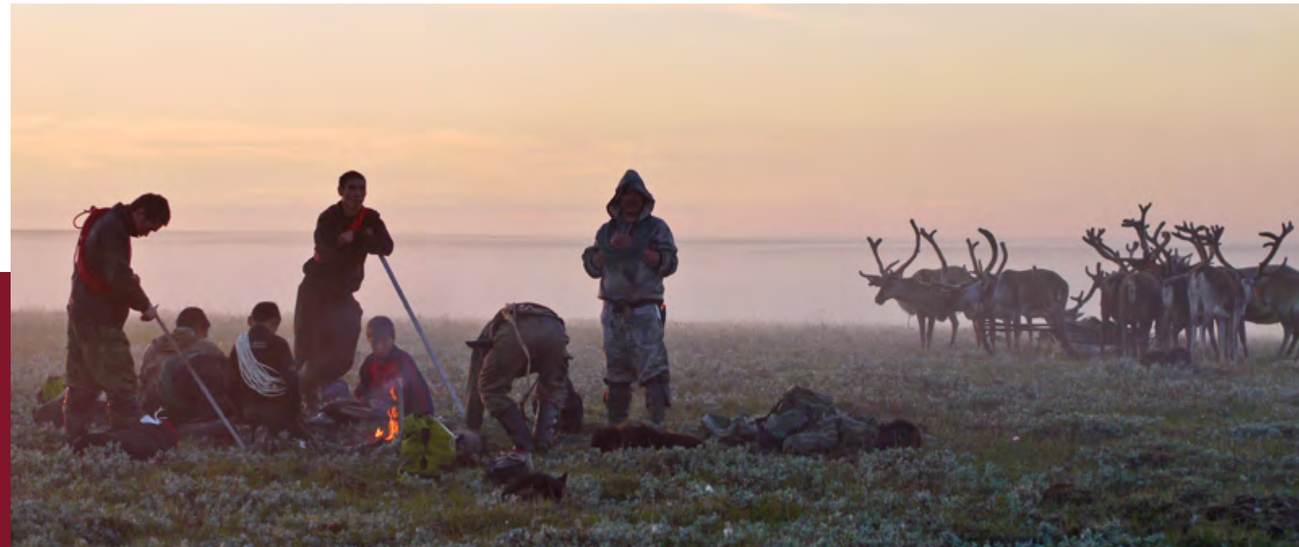


PHOTO: ILYA ABRAMOV
Reindeer herders gather around a fire in the Russian Arctic.

Access

- Access to data and objects, including acquisition, collection, transportation and repatriation of data, information, historical materials, archaeological artefacts, etc. is another key issue. Cross-border and sometimes intra-country mobility of data and objects can be difficult or impossibl, which impedes knowledge discovery.
- Physical access to communities, and frequently a long-term presence, are necessary for most social science research; this remains difficult in many current funding structures.
- Open and timely data sharing is growing and critical. Yet, data management remains challenging. It is important to ensure common data policies & practices across nations, as well as to provide funding and resources to make this happen.
- Providing platforms and protocols for scientific cooperation, including data and metadata sharing, facilitates research across the Arctic.
- The important roles of research infrastructure, networks, and field stations have been discussed earlier in this report.

Legal Framework

- Arctic researchers welcome efforts by IASC, IASSA, and UArctic to promote the recently adopted Agreement on Science Cooperation in the Arctic. The main leitmotif of this Agreement is to improve access to data, places and information, as well as to remove procedural obstacles to Arctic research. Scientists are especially interested in how the Agreement will be applied to researchers from non-party states.
- Current best practices entail reaching out to Arctic countries and organizations to create memoranda of understanding and collaborative partnerships. Agreements to share infrastructure and logistical support could help to remedy some of the obstacles above.
- Given the diversity of the Arctic regions, cultures, and environments, Arctic scientists achieve the best results by working in international teams and consortia with scholars from multiple Arctic and non-Arctic jurisdictions, who bring together interdisciplinary experiences, expertise, and funding. Therefore, the Arctic research community places high hopes in the implementation of the Agreement.
- The marine research community emphasizes the importance of international access to exclusive economic zones, particularly in data-sparse Arctic regions, as a priority.
- The Agreement provides a unique opportunity to promote and find support for inter- and transdisciplinary international research for understanding complex Arctic problems.
- There is a lack of attention in some Arctic and non-Arctic jurisdictions to ethical practices related to Arctic research, with no national or international policies/ethics/guidelines for research engaging with local and/or Indigenous issues/communities.
- The Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean is also seen as an important milestone for Arctic environmental protection as well as an impetus for expanded research in the Central Arctic Ocean. It is protective of the Arctic as well as being a mechanism to stimulate additional internationally coordinated research.
- Nevertheless, the current political tension between some of the Arctic (and non-Arctic) countries is presently felt as an obstacle to cooperation by some.

PHOTO: LUCA BRACALI
Waves crash against the coastline of Hamnøy, Norway.

Conclusion

The Arctic – a unique and globally important region – is also a quickly changing region. More than ever before, we need to continue to build our understanding of the Arctic, its systems, and their connections. Bigger than any one discipline or country can ever hope to address, IASC leads with science rather than nationality.

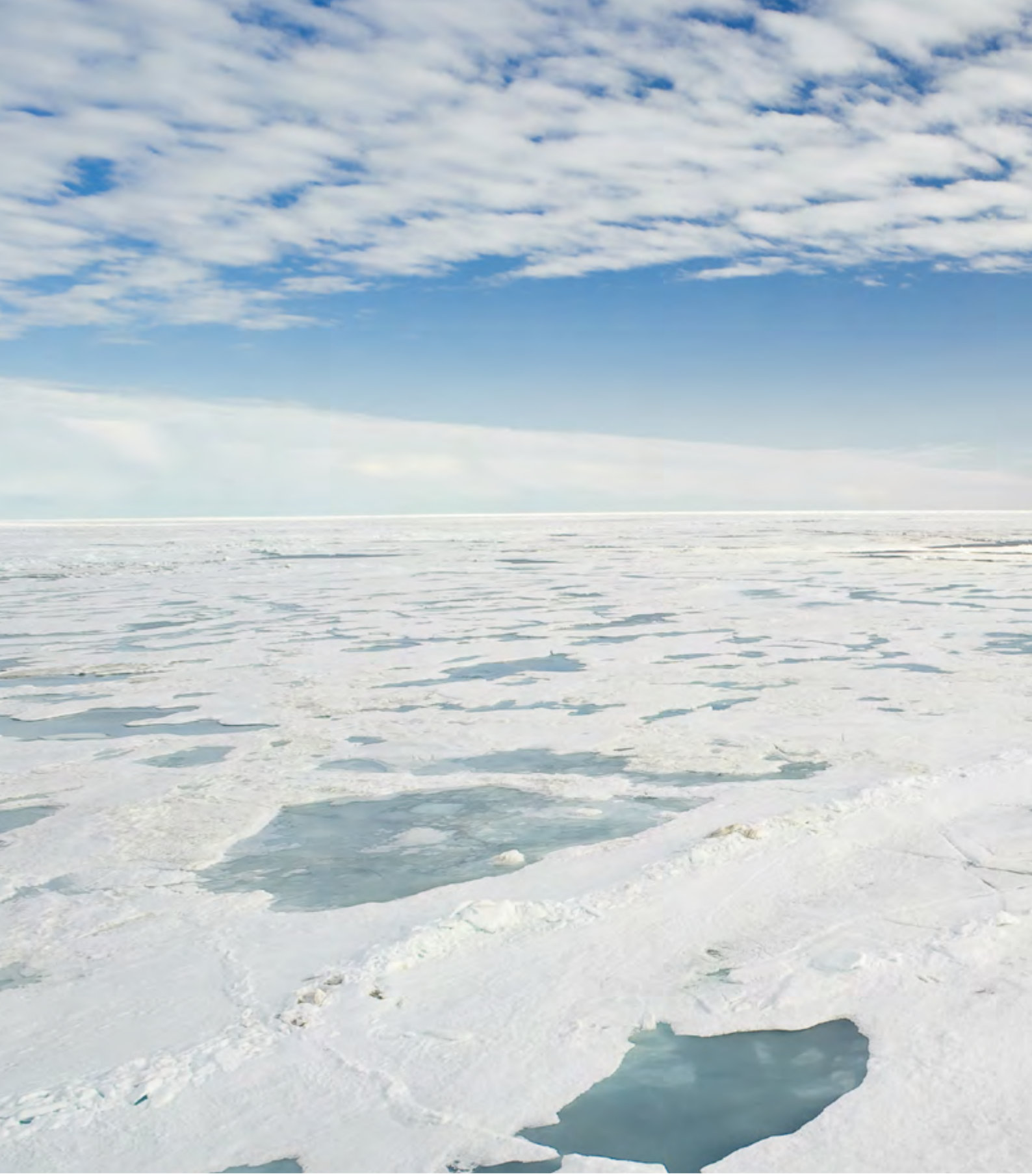
In this way, IASC hopes that the State of Arctic Science 2020 identifies priorities, linkages, and gaps in the current work of the international Arctic research community. For example:

- Arctic research must be truly interdisciplinary, and indeed convergent, in order to meet both Arctic and global challenges.
- The Arctic research community must improve on its efforts to center the priorities, voices, and contributions of Arctic residents and Indigenous Peoples.
- International and interdisciplinary cooperation are absolutely key to studying Arctic systems and should be encouraged and expanded.
- Arctic data sharing, discoverability, access, and re-use continue to be difficult challenges, but work in these areas will be crucial for future success.
- Current levels of Arctic monitoring and research are insufficient to meet these challenges, despite the hard work and investments of both Arctic and non-Arctic countries.

The State of Arctic Science 2020 was a first attempt. Building on a foundation of ICARP-III, IASC has compiled this report out of broad, bottom-up contributions from the IASC community. Nevertheless, Arctic change is accelerating and Arctic science is vast, and so this report attempts to summarize - but just barely scratches the surface of - the tapestry that is Arctic research.

IASC firmly believes that this report adds value and is a useful contribution for researchers, policymakers, and all research stakeholders by setting out the state of Arctic science. While this report is static, Arctic research is vibrant and evolving. Therefore, IASC will review how this report is received and consider how best to take it forward in the future. Please do let IASC know what you think, how you might have used this report, or how IASC might improve it! Email *info@iasc.info* and find out more about IASC at *www.iasc.info*.

PHOTO: VITALIY ZEMLYANSKIY
Huperzia arctica (Tolm.) Sipliv. - also known as Arctic firmoss - documented in central Yamal.



IASC 2020 State of Arctic Science Report
Electronic version available at *https://iasc.info/iasc/publications*

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