

**The 2nd Arctic Science Ministerial**

**Science Summary**

The second Arctic Science Ministerial (ASM2) aimed to promote the results of the projects presented at the first ASM and to foster further scientific cooperation among a wide number of countries and representatives of Indigenous Peoples and international organisations with Arctic interests. The ASM2 focused on three themes where an improved and better-coordinated international scientific effort can provide clear opportunities to advance the understanding of the impact of rapid Arctic changes and to respond to major societal challenges in the Arctic and globally. A significant note of progress from the ASM1 meeting is the increased participation of the Arctic Indigenous Peoples and international science organizations that provided important content and discussions to the ASM2. The themes for ASM2 were:

1. Strengthening, Integrating and Sustaining Arctic Observations, Facilitating Access to Arctic Data, and Sharing Arctic Research Infrastructure;
2. Understanding Regional and Global Dynamics of Arctic Change; and
3. Assessing Vulnerability and Building Resilience of Arctic Environments and Societies.

**About This Document**

This Science Summary presents a synopsis of the contributions provided by the following: Canada, China, Czech Republic, Denmark, Faroe Islands, Finland, France, Germany, Greenland, Iceland, India, Italy, Japan, the Netherlands, Norway, Poland, Portugal, Republic of Korea, Russia, Singapore, Spain, Sweden, Switzerland, United Kingdom, United States of America, European Union (EU), Gwich’in Council International (GCI), Inuit Circumpolar Council (ICC), Russian Association of Indigenous Peoples of the North (RAIPON), Saami Council, Association of Polar Early Career Scientists (APECS), Group on Earth Observations (GEO), International Arctic Science Committee (IASC), International Arctic Social Sciences Association (IASSA), International Council for the Exploration of the Sea (ICES), Arctic Council Indigenous Peoples Secretariat (IPS), Sustaining Arctic Observing Networks (SAON), University of the Arctic (UArctic), UN Environment (UNEP) and the World Meteorological Organization (WMO). It is based on the input describing both the progress achieved after ASM1 and new research activities in relation to the themes of ASM2. The documents received from countries and Indigenous and international organisations were analysed and initiatives categorised within the three themes of ASM2 by the Science Advisory Board. This categorisation is not univocal and countries and organisations may have a different opinion. Contributions and initiatives proposed ranged from small localised and concentrated short-term efforts of a few researchers to large multi-national multi-agency long-term programmes with several hundred professionals involved. This document is a higher-level summary of these contributions including summary tables and word clouds highlighting key words across all contributions. It is not exhaustive but rather aims to provide an overview to identify areas of major interests and to help catalyse further cooperation aiding in the advancement of Arctic science. For the sake of transparency all the inputs provided to the ASM2 are available for consultation by the ASM2 participants.

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**Theme 1. Strengthening, Integrating and Sustaining Arctic Observations, Facilitating Access to Arctic Data, and Sharing Arctic Research Infrastructure**

Research and observations are essential for predicting the evolution of changes in the Arctic and their impacts on regional to global scales. The Arctic is a complex system, and it remains a challenge to monitor it – even more so due to its vastness, low population density, and extreme conditions. Costly research infrastructures are usually required to observe the processes in the Arctic. Costs can be reduced by sharing research infrastructure and observing systems, but also by making data freely and openly available in a timely manner. Cooperation among countries, research institutions and communities is therefore mutually beneficial for the partnering entities.

Existing national and international observing and research efforts are not yet fully able to meet the demand for comprehensive and integrated information on the Arctic. There is a need to enhance coordination and collaboration on Arctic observations ranging from those by an individual to high-tech autonomous systems. The demonstration of the benefits and the value of an integrated Arctic observing system is essential to justify the required long-term investments. Significant advances from the first ASM have happened in this realm.

***Progress towards an integrated Arctic observing system***

* ***Arctic Observing Summit*** - The international Arctic Observing Summit (AOS) [[1]](#footnote-2) is an avenue for providing guidance for an international network of Arctic observing systems. A significant improvement in Arctic observation and monitoring has already been achieved through major programmes by different nations, but the key messages from AOS need to be considered for the future. For example, at the AOS in June 2018, participants from 26 countries and several Arctic Indigenous People’s organisations highlighted the societal benefits of accessible data and sustained observing systems. They submitted a call to action to the Arctic Science Ministerial that can be considered a basis for improving Arctic observation systems:
	+ There is an urgent need to progressively shift key observing system components – including community-based observations – from short-term research funding to sustained, operational infrastructure support;
	+ A properly resourced, comprehensive effort is needed to identify strengths and gaps in the current set of systems, sensors, networks, and surveys used to observe the Arctic;
	+ Observing and data systems, at different spatial and temporal scales, should emerge from co-design, co-production, and co-management processes with relevant stakeholders and rights-holders embracing free, ethical, and open data sharing, adhering to the “FAIR” data principles (Findable, Accessible, Interoperable, Reusable); and
	+ To build an Arctic Observing System that is comprehensive, coordinated, sustainable, and fills current observational gaps, all existing assets and activities, including indigenous knowledge, must be leveraged to the greatest extent.
* ***Sustained Arctic observing*** - Since ASM1, the Sustained Arctic Observing Network (SAON) and the US lead a group of experts from multiple sectors to develop the Arctic Observations Assessment Framework which is a value-tree framework for future assessments of the societal benefits of Arctic observations and the development of a pan-Arctic observing system consisting of 12 societal benefit areas, 41 sub-areas, and 163 key objectives. The EU’s Impact Assessment on a Long-Term Investment on Arctic Observations (IMOBAR) project builds on this framework and will provide policy makers with evidence to support long-term investments in Arctic observing systems by analysing the costs and societal benefits of Arctic observing systems of a selected number of essential variables. The Arctic Observations Assessment Framework will be of benefit to the many countries contributing to the SAON process. Germany, Switzerland, Greenland, Demark, France, Russia, Iceland and China, among other countries, have increased their efforts in supporting SAON. The Group on Earth Observations (GEO) is working to connect the demand for sound and timely environmental information with the supply of data and knowledge about the Earth so that decisions and actions, for the benefit of humankind, are informed by coordinated, comprehensive, and sustained Earth observations. Their polar efforts are concentrated in the GEO Cold Regions Initiative, which SAON is part of.
* ***Regional observing*** - Many regional observation programmes continue to evolve and lead to important discoveries. This includes the Distributed Biological Observatory[[2]](#footnote-3) and the Svalbard Integrated Arctic Earth Observing System (SIOS)[[3]](#footnote-4). Many countries already contribute to these regional programmes and more being invited to join, such as the invitation for Russia’s Barentsburg Station to become part of SIOS. The EU is helping to coordinate regional efforts with their INTAROS project aimed at developing an integrated Arctic Observation System (iAOS) by extending, improving and unifying existing systems in the different regions of the Arctic. WMO has many efforts working toward coordinating global Earth observations relevant for the Arctic, such as the Global Cryosphere Watch which provides authoritative, clear, and useable data, information, and analyses on the past, current and future state of the cryosphere, or the Polar Challenge which is working to stimulate new technological advances for under ice observations.
* ***National observing*** ***activities*** - There is a noticeable increase in national monitoring and observing programmes. The new US National Science Foundation initiative "Navigating the New Arctic" is a major commitment to accelerating the pace of research in order to tackle the challenges and opportunities associated with wide-scale, rapid Arctic change by fostering innovation in observing and data sharing. It is guided by the co-production of knowledge between local and indigenous communities and partnerships at the local and state government, interagency and international levels. The German project “Frontiers in Arctic Marine Monitoring” (FRAM) is a modular network of fixed-point and mobile sensor platforms in the Fram-Strait and Central Arctic Ocean contributing new capacities for year-round ocean observations. Multidisciplinary observatories tethered to ice-floes of the German MIDO project provide freely available, real-time data on atmosphere, sea-ice and ocean. Spain is creating a Spanish Arctic Observatory. The Czech Republic has been monitoring ice-free regions of Svalbard since 2007 looking at factors impacting vegetation cover and how that influences ground temperature. The Faroe Islands have several monitoring programs helping to better understand their marine environment. The Republic of Korea’s Arctic Ocean Observing System (K-AOOS) aims at strengthening international collaboration and access to data and their Circum-Arctic Permafrost Environment Change Monitoring (CAPEC) project has added new observational node sites in Iceland and Russia. Poland is expanding its oceanographic, meteorological and glaciological observations at Hornsund with the RV Oceania. A new Norwegian centre focusses on observing the aurora, ionosphere, and the coupling of Earth with space. Russia’s Ice base “Cape Baranov” and Tiksi station carry out comprehensive monitoring of a variety of earth system components. Two new tasks have emerged within the suite of US observing activities to support sea ice forecasting and wildfire detection. Many other countries, such as China, India, the Netherlands and Sweden, are also increasing their observation efforts.
* ***Community-based observing*** - Community observing and training activities are also gaining momentum. The US-lead Local Environmental Observer (LEO) Network is a group of 2500 local observers and topic experts in 552 communities worldwide who share knowledge about unusual animal, environment, and weather events using an innovative software tool. The US is also supporting the EyesNorth effort to develop a set of best practices for community-based observing. Canada established the Rangers Ocean Watch and the new Biodiversity Rangers programme and has just launched a new effort to include Indigenous Peoples, particularly youth, in community-based monitoring activities.
* ***Indigenous Knowledge*** - Incorporating Indigenous Knowledge into scientific observation frameworks is increasingly important and necessary. To keep track of the work being done in this area, the Inuit Circumpolar Council (ICC) and partners have created a web-based atlas infrastructure[[4]](#footnote-5) to inventory and map community-based monitoring and Indigenous Knowledge initiatives across the circumpolar North and has expanded the atlas to include an Inuit Mental Health and Wellness map. The Indigenous Peoples Secretariat (IPS) of the Arctic Council also works to coordinate activities with respect to indigenous knowledge.

***Enhanced cooperation and new activities from Space Agencies***

Data from past, current and future satellite missions are critical to better understanding the Arctic and to provide much needed input for modelling of Arctic processes.

* ***Satellite data tools and uses*** - To help access, analyse and share that data, the European Space Agency has established the Polar Thematic Exploitation Platform allowing for easier discovery and access to large volumes of Copernicus Sentinel satellite data and comprises toolboxes, provisioning of virtual machines, processing resources, plus functionality to allow deployment of user defined workflows and processing environments. COPERNICUS, the EU Earth observation programme, is developing an Arctic dedicated webpage aimed at supporting scientists in finding adequate products and information with direct links to the portfolios of the Copernicus Services or Sentinels products. The Finish Arctic GEOSS satellite data centre plans to give Arctic research actions a sufficient level of free to use data capacities to accelerate knowledge production from Arctic observations. An example of practical use of this data is the collaboration between Chinese and Greenlandic researchers who completed the latest high-resolution (30m) Greenland remote sensing image map (2014-2015) which is used in local resource management, research and improved welfare of the Greenlandic people.
* ***New and follow-on missions*** - The next generation of Canada's RADARSAT-1 and RADARSAT-2, the RADARSAT Constellation Mission will launch in late 2018 for three main uses: maritime surveillance (ice, surface wind, oil pollution and ship monitoring); disaster management (mitigation, warning, response and recovery); and ecosystem monitoring (agriculture, wetlands, forestry, permafrost monitoring related to climate change, and coastal change monitoring). The US and Germany launched the Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) mission in Spring 2018 to continue tracking Earth’s water movement including ice sheets and glaciers, and sea level rise. The US NASA IceBridge airborne science mission is collecting altimetry, radar, and other geophysical data to monitor and characterize the Earth’s polar sea ice, glaciers, and continental ice sheets with the primary goal of extending the record of ice altimetry begun by NASA’s Ice, Cloud and land Elevation Satellite (ICESat-1, 2003-2009). ICESat-2 was launched in September 2018 and will continue to measure changes in the height of the Earth’s polar land and sea ice that aides in assessing ice elevation changes and sea ice thickness; the measurements are also relevant for forest height assessments e.g. in permafrost regions, Arctic cloud studies, and measurements of ocean topography for sea level changes.

***International access to infrastructure***

Expensive research infrastructures are usually required for observations in the Arctic. Costs can be reduced by sharing research infrastructure and observing systems. Cooperation among countries, research institutions and communities is therefore mutually beneficial for the partnering entities.

* ***International agreement*** - Since the ASM1, at the Arctic Council's ministerial meeting in May 2017, the Foreign Ministers of the Arctic states, including the Ministers of Greenland and the Faroe Islands, signed an agreement where the Arctic countries commit themselves to enhanced cooperation in the areas of research, education, data, sample and personnel exchange, access to research facilities and access to Arctic areas. The legally binding “Agreement on Enhancing International Arctic Scientific Cooperation” entered into force on May 23, 2018 and Denmark holds the responsibility for initiating follow-up activities.
* ***Icebreakers*** - The new EU Arctic Research Icebreaker Consortium (ARICE)[[5]](#footnote-6) project will develop strategies for the optimal use of existing Arctic research icebreakers to share and jointly fund operational ship time, provide trans-national access to six research vessels, and improve research services by partnering with the maritime industry on a “ships and platforms of opportunity” programme. The UK is building the new RRS Sir David Attenborough icebreaker which should be ready for the 2019 field season.
* ***INTERACT*** - The International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT)[[6]](#footnote-7), supported by the EU, aims for a geographically comprehensive compilation of terrestrial research infrastructure throughout the Arctic and adjoining forest and alpine regions. Now with 79 research stations under the INTERACT umbrella it is a fundamental building block and one-stop-shop for research projects, programmes and organisations requiring access to northern lands, data and services, and includes a rapid response capability to potential hazards.
* ***EU-Polar-Net*** - The EU-PolarNet[[7]](#footnote-8) project has launched an online European Polar Infrastructure database which includes detailed information on European stations, vessels and aircraft, and an up to date inventory of European logistical capabilities in the polar regions.
* ***National activities*** - In addition to the larger international efforts of sharing infrastructure, many nations have their own programmes to enhance cooperation. The Netherlands contributes internationally by hosting the European Polar Board[[8]](#footnote-9). Canada is working to establish the Experimental and Reference Area of the Canadian High Arctic Research Station (CHARS ERA) as a Flagship Monitoring Observatory Site, and as a hub for interdisciplinary research open to international researchers.
* ***National funding*** - Since ASM1 many countries have increased their Arctic research budgets. Sweden raised its climate research budget by 13 million Euro, increasing funding for polar research infrastructure and the icebreaker RV Oden and its planning for a new fleet of vessels. In 2018, for the first time, the Italian Budget Law included specific resources for Arctic research and establishes the 2018-2020 Arctic Research Programme. Denmark has launched a call for projects for: 1) monitoring and mapping of long-range transport pollution in Arctic ecosystems and human health 2) biodiversity and sustainable exploitation of living resources and 3) development of the knowledge base on national and international environmental regulation. Portugal extended its PROPOLAR call for Antarctic research in 2013 to include Arctic research campaigns.
* ***International funding*** - To enhance international collaboration efforts specific funding calls and sources are needed. The EU has committed 28 million Euro for projects dealing with the topics of Polar Climate, GEOSS[[9]](#footnote-10) Initiatives in the Arctic Region, and Coordination of European Polar research. The "LC-CLA-07-2019: The changing cryosphere: uncertainties, risks and opportunities" call it will provide an additional 41 million Euro. There are also important bilateral efforts such as the new Arctic Bursaries Programme between the UK and Canada, which fosters UK participation in Canadian projects. ASM 2 is intended to stimulate additional opportunities for leveraging and cooperative investments.

***Increased data access and cyberinfrastructure***

Many nations have increased their efforts to share data and develop new cyberinfrastructure to support Arctic research.

* ***National data efforts*** - Denmark's user-driven web-portal, Isaaffik, provides information and support for use of infrastructure and vessels, assistance on arctic travel, enhancement of safety during fieldwork, and an overview of Arctic educational programmes. The Italian Arctic Data Center has recently set up a user interface with visualization and download of atmospheric data. Japan expands its Arctic Data Archive System with web services for search and download capability, data visualization in quasi-real time and plans to include geographic information systems into the platform by 2020. Sweden is working to digitize older data including 100+ years of land-based and marine research data since 1980. The US National Environmental Satellite, Data, and Information Service (NESDIS) Arctic mission is to provide data for Arctic waters, land, and atmosphere including delivery and evaluation of imagery and products from satellites for research and operational needs; it contributes to a range of international data portals and networks. The Chinese Earth Big Data Science Project launched in February 2018 aims to establish an international Earth big data science centre committed to promoting and realizing Earth big data technology innovation and providing comprehensive one-stop macro decision support; it includes focal research areas for the Arctic, the Antarctic and the Qinghai-Tibet.
* ***International data efforts*** - International activities to share data across national and disciplinary boundaries include the Arctic Spatial Data Infrastructure project of the eight Arctic countries aiming to modernize the use and reuse of existing data and it has created an internationally harmonized basemap that provides a unified topographic view over the entire Arctic. SAON and the International Arctic Science Committee (IASC) will develop a blueprint for a structure or “architecture” to better connect existing data resources. Their goal is to set the foundation for a fully developed Arctic data system that will use an open data policy and standards to allow users to find, access, and reuse data critical for research and for mitigating risk to humans and infrastructure.

***Increased cooperation on new observation technology and methods***

The need to continue to develop innovative technological tools and new methods for advanced observation in the remote and harsh Arctic environment is increasingly recognized with many nations at the forefront of creating such tools.

* ***New technology*** - A new technique of solar-sky-moon photometry for monitoring atmospheric aerosols has helped to constitute the first comprehensive dataset with respect to aerosol properties from remote sensing at the AWIPEV base in Ny-Ålesund. As a result of international collaboration, Chinese researchers led the development a new method for the measurement of meltwater runoff on the Greenland ice sheet surface, showing that current regional models overestimated the actual runoff on the ice surface. US researchers are developing an Autonomous Underwater Vehicle (AUV) that can travel long distances with sensors that have the capability of surveying oil spills at high latitudes and under ice and are helicopter-portable, allowing rapid response to incidents. They plan to refine sensors, develop new underwater gliders, improve the engineering of floats to maximize operations for the Arctic and develop the capability of under ice navigation. Japanese researchers have developed the Continuous Soot Monitoring System (COSMOS) which is now regarded as the standard measurement technology for black carbon and have initiated research on a new Autonomous Underwater Vehicle (AUV) for observations under sea ice.
* ***Harmonised methods*** - In addition to developing new approaches, the need to standardize methods and protocols between institutions and various disciplines also requires efforts to reconcile differences. The Italian-led Monitor and invEstigate Arctic along Longitudinal Transects (MELT) project is working to standardize measurements, methodologies, and terminology for the research of boundaries of different environmental components (e.g. ocean-atmosphere interface). The US has a national effort to enhance multi-agency participation in new and existing activities to improve best practices, coordination, and synthesis of Arctic observations.

**Theme 2. Understanding Regional and Global Dynamics of Arctic Change**

Recent years show a continual decline of summer sea ice and snow extents, and also increasing net loss of mass from Greenland's ice sheet. In the absence of sea ice and snow, solar energy is not reflected but rather absorbed at the exposed land and sea surfaces. The absorbed energy contributes to delayed ice growth in fall and earlier ice melt in spring and so amplifies temperature increases. Thawing of permafrost leads to potential further increases in greenhouse gas emissions. All these changes - and their dynamics - affect ocean and atmospheric circulation, thereby impacting the global climate. Even a small increase in air temperature can thereby trigger greater system warming over time, making the Arctic among the most sensitive areas to climate change on Earth.

The full impacts of a warming Arctic, including deep ecosystem changes (both on land and the ocean), have not yet been fully assessed and quantified. Understanding and responding to this challenge requires joint efforts of the global community.

***Increased predictive capabilities and skills***

Improved predictions of Arctic changes are prerequisite for developing adaptation measures. Several major international projects are underway with the aim to better predict future Arctic changes.

* ***MOSAiC*** - The international Multidisciplinary drifting Observatory for the study of the Arctic Climate (MOSAiC) is the first year-around expedition in the central Arctic with the focus to explore the mechanisms acting in the coupled climate system and investigate environmental wintertime conditions in the Arctic Ocean. Its goal is to improve regional and global climate models and weather forecast models. Much progress has been achieved since ASM1 and the drift of the German R/V Polarstern across the Arctic Ocean is planned from September 2019 until September 2020; the programme will involve 60 institutions from 16 nations. Russia and China will contribute to the research and provide fuel and key logistical support to R/V Polarstern. Among the many US contributions to MOSAiC are a suite of instruments that will be installed on R/V Polarstern to study the atmospheric boundary layer and its interactions with the sea ice surface. The UK, Norway, Japan, Netherlands, Sweden and further countries (in total 17 countries), will participate by sending researchers at various points during the expedition, contributing with science projects and processing data.
* ***YOPP*** - As one of the WMO's Polar Prediction Projects, the Year of Polar Prediction (YOPP) is an internationally coordinated period (mid-2017 to mid-2019) of intensive observing, modelling, prediction, verification, user-engagement and education activities that will contribute to the knowledge base needed for managing the opportunities and risks that come with Arctic environmental transitions. The EU APPLICATE programme is a main contributor to YOPP by developing enhanced predictive capacity for weather and climate in the Arctic and beyond. In 2018, China’s Ninth Arctic Scientific Expedition will contribute observations of atmospheric sounding and buoys and transmit its atmospheric sounding data to WMO in real time. As a contribution to YOPP, Canada launched the Canadian Arctic Prediction System (CAPS), a high-resolution atmospheric model that enables enhanced services to mariners through improved predictions of weather, ice and ocean conditions, including sea state in Arctic waters. The International Arctic Systems for Observing the Arctic (IASOA) Observatories have been identified as the locations at which there would be enhanced radiosonde launches during the YOPP Special Observing periods that will improve the quality of weather and sea ice forecasts, the prediction of weather phenomena over the Arctic Ocean and the accuracy of cold wave forecasts for Japan and the North American East Coast. The US also has a number of organisations and researchers involved in projects supporting YOPP including efforts for improved sea ice forecasting, short-term weather forecasts and data processing support. In total more than 22 countries are contributing to the YOPP.
* ***Other prediction efforts*** - In addition to MOSAiC and YOPP, there are a number of activities on the international organization and national levels that are working toward improving our understanding of climate processes, mid-latitude atmosphere connections and general improvement of prediction. These research activities will develop and deliver improved climate products and services and valuated information for decision making and societal benefit. The WMO, for example, is in the early stages of implementing an Arctic Regional Climate Centre (ArcRCC) to provide climate scale (monthly and seasonal) information for temperature, precipitation and sea ice for all of the circumpolar Arctic. Many national and regional projects, such as Russia’s efforts in the North Eurasian node of the Pan-Arctic Regional Climate Outlook Forum, already make strong contributions to this Centre. Other efforts are posed to contribute such as the EU's Blue-Action project is improving the ability to describe, model, and predict Arctic climate change and its impact on Northern Hemisphere climate, weather and their extremes. The Copernicus Arctic Regional Reanalysis project will combine all available surface and atmospheric observations with a simulation model of the atmosphere (Numerical Weather Prediction model) to produce as accurate as possible estimates of the time evolution of the state of the atmosphere. The Norway-led Arctic Climate Predictions: Pathways to Resilient, Sustainable Societies (ARCPATH) project is working internationally to address gaps and uncertainties that can improve the development of local and international adaptation measures. Germany's Transregional Collaborative Research Centre (AC)³ will investigate key processes contributing to Arctic Amplification and the major feedback mechanisms. The US, Norway, Republic of Korea, Russia and Japan also have a number of modelling groups and projects working to enhance climate prediction.
* ***Mid-latitude linkages*** - Arctic change has the potential to affect millions of people through shifts in mid-latitude weather, but occurrences are intermittent. The US is leading an international effort with various organisations, including the Arctic Monitoring and Assessment Programme (AMAP), to foster workshops and symposia over the next 3 years to increase our understanding of the linkages between Arctic Change and mid-latitude weather. The US, Republic of Korea, India and the UK all have active research groups working on improving our understanding of these linkages.

***Increased Cooperation on Understanding the Arctic System***

Major changes in the Arctic, with consequences for ecosystems, societies and the global climate system, are driven by the reduction of sea ice, glacial melt, permafrost thaw, alteration of ocean circulations and changes to the hydrological cycle. Understanding of these changes is also highly relevant for economic developments.

* ***Sea ice*** - The Republic of Korea is leading a 5-year project with the US, Norway, and Japan to improve our understanding of Arctic sea ice using satellite data. Norway is investigating interactions between Arctic sea ice cover and the sensitivity of the Greenland Ice Sheet; recent results showing that it could have major impacts on global ocean circulation. Spain, China and the US have projects to improve modelling of sea ice behaviour. The recently completed EU ICE-ARC project investigated the rapid loss of Arctic sea ice along with shifts in atmospheric and oceanic conditions and estimated the global economic and societal costs of sea ice loss. In partnership with Inuit, Canadian scientists together with Germany, UK and the US explore strategies and management options to protect the most likely last permanent ice-covered region in the Arctic Ocean, an area essential to ice-dependent species such as polar bears, beluga, narwhal, seals, walrus as well as the Inuit communities that depend on them for food. China is monitoring sea ice dynamics in key areas of north, east and west shipping lanes in the Arctic to understand the impact on Arctic shipping.
* ***Marine ecosystems*** - As sea ice changes in the Arctic, so does the behaviour of the Arctic marine ecosystem, yet we are still only beginning to understand life cycles of Arctic marine organisms. Several national and international efforts are underway to address these gaps. Norway has launched the Nansen Legacy project which aims to establish a holistic understanding of a changing Arctic Ocean and ecosystem which is needed for future sustainable resource management in the Barents Sea and the adjacent Arctic Basin. Russia has several projects looking at climate impacts on seals, walrus, beluga and other key fish species. In 2019, Switzerland will lead the GreenLAnd Circumnavigation Expedition (GLACE), a complete circumnavigation of Greenland looking at marine, terrestrial, atmosphere and cryospheric environments. Spain is starting a number of projects to understand the life cycle of main Arctic fish species as well as invasive crab species. The UK has new projects focusing on productive seasonal sea ice areas, the food web and whole ecosystem changes. To bring national level efforts together, the US held an international workshop to develop a shared, high-level conceptual model of the functioning of the Arctic Ocean considering key processes controlling the responses of Arctic marine ecosystems to current pressures and changes.
* ***Arctic Ocean seafloor*** - We know relatively little about the bottom of the Arctic Ocean, but efforts are ongoing to increase our understanding. The Republic of Korea, Norway and France are working together to collect a deep sediment core from the Svalbard fjords to provide insights into past, present and future climate changes. Canada and the US are mapping the Arctic Ocean seafloor. Italy is using samples collected from the Fram Straight to understand climate and environmental changes controlling the evolution of living organisms in the deep sea. Iceland has launched a new effort to map the ocean floor to aid in understating the ocean’s natural resources and the protection of fragile ecosystems. Russia also has a project trying to better characterise the Arctic Ocean bottom including its geologic structure and gas hydrates reserves. The Republic of Korea, Denmark and the UK are looking at fossils from North Greenland to understand the evolution of life moving from sea to land. The Czech Republic is working to better understand the formation of dense algal mats in fjords around Svalbard that are thought to be over a billion years old. Germany collects data to establish a Pan-Arctic benthic biology baseline and to model potential ecosystem changes.
* ***Ocean circulation*** - Changes in the earth's temperature and associated changes in freshwater run-off have the potential to change Arctic ocean circulation patterns which can impact the whole planet. Freshwater discharge from the Arctic has thus been and continues to be an important area of study by many nations over recent decades. For example, since 2010 India has been gauging the impact of fresh water discharge from the Kongsfjorden on the North Atlantic circulation and the global fresh water balance for better model prediction of the Atlantic current and its connection to Indian summer monsoon rainfall. Norway, Italy and Poland are also actively engaged in better understanding ocean circulation and the impacts of melting ice.
* ***Terrestrial ecosystems*** - With warmer temperatures, thawing permafrost and increased human activity come changes in the Arctic terrestrial ecosystem and research in this area is working toward understanding the impacts. Belgium, Germany, Norway, Switzerland and Spain have created the multidisciplinary, multi-scale project CLIMARCTIC to integrate the knowledge of Arctic terrestrial ecosystems from microbes to landscape scales. Poland is working to harmonize various snow sampling methods to help advance our understanding of the impact of snow changes on Arctic biology. The Czech Republic studies new soils that form after glaciers retreat and their colonization by microbes and plants. India extends their research on terrestrial biodiversity and the potential human impact on flora and fauna. Norway’s Climate-ecological Observatory for Arctic Tundra (COAT) is a large ecosystem-based research and monitoring programme that addresses the impact of climate change on biodiversity and ecosystem services in the arctic tundra; it adopts a food web approach and considers biodiversity and ecosystem services of global concern as well as local human dimension because Arctic people themselves are parts of arctic food webs. Russia has launched a new project looking at plant adaptation strategies in response to climate change. The US and Canadian supported Arctic Boreal Vulnerability Experiment (ABoVE) and Next-Generation Ecosystem Experiment-Arctic (NGEE Arctic) are large, multiyear field campaigns in Alaska and western Canada to understand processes driving changes to terrestrial ecosystems in the Arctic and boreal region. Portugal, Spain and Canada propose the Terrestrial – Multidisciplinary distributed Observatories for the Study of Arctic Climate (T-MOSAiC) in permafrost environments, which is supported by the International Arctic Science Committee.
* ***Freshwater ecosystems*** - Changes in freshwater ecosystems, catchments and rivers will have direct influences on societies, tourism, fisheries and peoples of the Arctic. Finland has an interdisciplinary, Pan-Arctic programme to better define processes governing freshwater resources, improving our ability to model and predict basin-scale hydrologic interactions and historical ecohydrology. The Saami Council has a wetland inventory project in Sweden that has the ambition to integrate indigenous knowledge to the work conducted within the Arctic Council; it identifies knowledge gaps regarding wetlands, aims to strengthen the communities depending on wetlands, and to build resilience to changes in wetlands and wetland use. Noting the area of Arctic whitefish production has decreased by 90% in the past 10 years, the RAIPON have begun a project based on indigenous knowledge and modern technologies to contribute to the recovery of this culturally important food source. The US has teams and projects with goals to advance an integrated, landscape-scale understanding of Arctic terrestrial and freshwater ecosystems and the potential for future change.
* ***Wildlife*** - Wildlife is another area of importance to Arctic peoples and there is an array of research as well as regulatory and political activity driving wildlife management. As an example of research efforts, the Czech Republic have attached geolocators to Arctic terns allowing for the study of the longest migration paths of any bird, some 90,000 km from pole to pole. One of Russia’s new research foci is on issues surrounding the protection of Arctic mammals such as elk, brown bear, shrews and walrus. From the cultural and societal perspective, the ICC leads a circumpolar Inuit Wildlife Management Summit which has developed an implementation strategy for circumpolar Inuit wildlife management that moves away from single species management and focuses on a holistic approach. This considers that animals are migrating across international borders and also focusses on the strong connection between components within systems, including how changes impact Inuit, their culture, the biodiversity or wildlife that sustains them culturally, physically, spiritually, and economically.
* ***Permafrost and Methane*** - The thawing of Arctic permafrost has many impacts from coastal erosion to collapsing infrastructure to the increased release of the powerful greenhouse gas methane into the atmosphere. The EU’s Nunataryuk project aims at quantifying organic matter, sediment and contaminant fluxes from thawing coastal and subsea permafrost and at assessing the implications for the indigenous populations, the local coastal communities and environment as well as the global climate; a major goal is also to develop targeted and co-designed adaptation and mitigation strategies. The US has several permafrost projects and has recently created a Permafrost Coastal Erosion Research Coordination Network to further investigate the impacts of coastal erosion and identify solutions to this problem that many Alaskan communities face. Several other groups are looking into the fate of carbon stored in the permafrost to better understand methane release. Singapore's researchers are working on permafrost geochemistry dynamics and predictions of changes in carbon pools and greenhouse gas fluxes from Arctic ecosystems. Italy is leading the EU-funded Arctic Critical Zone and Carbon Dynamics in Permafrost-thawing Environments Project on ecosystem impacts of permafrost thaw and on plant species composition. Italy, Sweden, Russia, US, UK, and the Netherlands are investigating carbon release from sediments in the East Siberian Arctic Ocean, an area with fast rates of climate warming and vast reservoirs of vulnerable carbon. Russia is also working with Germany on studying the fate of permafrost carbon in the Lena River Delta region of West Siberia. Russia also has projects looking at permafrost loss in the Yakutia coastal lowlands and the potential for a mega-pool of sub-sea permafrost carbon. The Republic of Korea's AMAGE field programmes in the East Siberian Sea (2016) and in the Canadian Beaufort Sea (2017) collected data on sub-surface geology, permafrost, and gas hydrates using an autonomous underwater vehicle (AUV) and a remotely operated vehicle (ROV).
* ***Ice sheets, glaciers and sea level*** - The rate of loss of land ice, such as the Greenland Ice Sheet and coastal Arctic glaciers, is of great importance to global sea level and many groups are working to better understand how these massive ice bodies formed and better predict their melting rates. Denmark is leading several international efforts with China, France, Germany, Japan, Republic of Korea, Sweden, Iceland, Italy, Norway, Switzerland and the US to recover ice cores from various parts of Greenland to understand past climate conditions and ice dynamics. Iceland’s researchers are studying causes and impacts of the rapid loss of their glaciers. India and Norway are measuring snow thickness of glaciers and looking at its impact on melting rates. Poland, China, Spain, Japan and the US support several projects to better understand the dynamics between glaciers and oceans and improve our estimation of the contribution of small glacier and ice cap melting to sea level rise. These projects together produce important information for countries like Singapore who plan to assess the vulnerability of the Asian region to sea level change.
* ***Economic drivers*** - Presently, global economic interests in the Arctic are on the rise and are driving new areas of scientific research. Greenland has established the Arctic Oil & Gas Research Centre to examine the social and economic impacts of oil and gas activities in the Arctic with a focus on Greenland. Singapore, for example, used existing climate change models to investigate the impact of future sea ice changes on commercial transarctic shipping routes. The Republic of Korea is planning a new project for 2020 on Arctic accessibility and the potential for general resource development, based on predictions of changes in the Arctic cryosphere including impacts of diminishing sea ice and thawing permafrost on subsequent business opportunities and potential safety and pollution threats. Several other countries have similar projects in various stages of development.

**Theme 3. Assessing Vulnerability and Building Resilience of Arctic Environments and Societies**

Communities and ecosystems around the Arctic are already experiencing the impacts of global change. Not all changes are perceived to have negative effects, because a warmer Arctic may also present opportunities in terms of resource utilisation, transport routes, tourism and regional growth. It is however increasingly clear that environmental, ecological and social changes are happening faster than ever, affecting ecosystems and the way people live. People’s lives are also changing, in particular for indigenous and non-indigenous Arctic residents regarding new livelihoods, new technologies, increasing global connections, and new forms of Arctic governance.

Science will contribute to identifying and minimizing the risks, reducing exposure, improving resilience and adaptation, and form a vital basis for decision-making. Understanding how these changes interact with one another, and what they mean for people and ecosystems alike, requires holistic and trans-disciplinary approaches that look at human and natural dynamics together.

***Identifying risks and minimizing impacts of climate and global changes***

As the Arctic climate changes, there are many risks to the residents and the ecosystems, as well as risks to the global community. Many countries have projects to help identify these risks and create plans to deal with potential damaging impacts.

* ***Pollution*** - France proposes a new project studying the distribution and impact of various pollutants (e.g. mercury, per- and polyfluoroalkyl substances [PFASs]) and local and remote sources of black carbon. India and Norway are working together on monitoring organic contaminants in Svalbard and quantifying microplastics in the Kongsfjorden sediments. The Italian-lead iCUPE project plans to improve our knowledge of presence and environmental cycling of persistent organic contaminants, mercury and other elements in the Arctic environment. The EU “Black Carbon in the Arctic” project aims to contribute to the development of collective responses to reduce black carbon emissions in the Arctic and to the reinforcement of international cooperation to protect the Arctic environment. Aiming for a 2021 delivery, AMAP has begun a comprehensive assessment of the state of science on Arctic short-lived climate forcers (SLCFs) with the aim of improving the understanding of black carbon and methane emissions, emission inventories, Arctic climate and public health effects, and policy options. The trans-disciplinary consortium of EU GRACE includes experts from Europe and Canada and focuses on developing, comparing and evaluating the effectiveness and environmental effects of different oil spill response methods in a cold climate. Singapore aims to analyse ship traffic characteristics and to estimate ship emissions in the Arctic.
* ***Food security*** - The aim of Norway's BESS is to monitor the status and changes of the Barents Sea Ecosystem and to support scientific research to evaluate the status of and changes in marine commercial stocks, their habitat and environment, and potential for sustaining marine living resources. In addition, the Nordic ReiGN Center of Excellence will establish a Scandinavian interdisciplinary multi-site research centre for holistic understanding of drivers connected to globalization and climate change that affect reindeer husbandry in Fennoscandia, and how these drivers are linked to ecological, social and political differences between the countries. The Arctic Council’s EALLU Project focuses on Indigenous Traditional Knowledge of food as a foundation for diversification of local economies and new approaches to adapt to Arctic change. It focusses on indigenous youth involvement and engagement based on the work of the UArctic’s EALÁT Institute. Through their food security project of ICC, Inuit throughout Alaska developed a report that provides an Inuit understanding of food security which describes the Arctic as a puzzle made up of multiple interconnecting pieces including culture, language, sharing, as well as marine mammals, oceanography and other aspects. The indigenous-led climate change work to help restore the Atlantic Salmon populations in Finland and Norway is making great progress with the physical restoration of lost habitats and in 2017 saw the first new trout spawning. The International Council for the Exploration of the Sea (ICES) has groups working on integrated ecosystem assessments including the Norwegian Sea, Barents Sea, and a joint collaboration with the Arctic Council’s Protection of the Arctic Marine Environment (PAME) Working Group and the North Pacific Marine Science Organization (PICES) on the Central Arctic Ocean. In addition, the US, ICES, and PICES are undertaking a management/sharing pilot study under the remit of the Scientific Experts on Fish Stocks in the Central Arctic Ocean (FiSCAO).
* ***Marine traffic*** - Increased economic interest in the Arctic also means more ship traffic and projects are underway to help mitigate those risks. The EU “Safe maritime operations under extreme conditions: The Arctic case (SEDNA)” project is developing an innovative and integrated risk-based approach to safe Arctic navigation, ship design and operation, to enable European maritime interests and to harness the Arctic’s significant and growing shipping opportunities, while safeguarding its natural environment. With increased ship traffic comes a need for more safety procedures and the US is helping by working to build and deploy two CubeSats that will detect distress beacons in the polar regions, as well as two ground stations for the Mobile CubeSat Command and Control ground network.
* ***Hazards*** - Russia is working to minimize risks from a diminishing Cryosphere by developing new methods and technologies to remotely monitor icebergs, glacier movement, areas of potential landslides, explosive methane emissions and other hazards.

***Developing adaptation and resilience-building strategies***

Many Arctic residents, particularly the Indigenous Peoples, are proactively working to build strategies and systems that will help them adapt to the rapidly changing Arctic environment. The health and well-being of Arctic residents is an important area of scientific interest and needs to be considered when looking into adaptation and resilience strategies.

* ***Building resilience*** - In the most biologically productive region north of the Arctic Circle, the ICC initiated the Pikialasorsuaq Commission to build resilience of Arctic communities in a region where global dynamics have caused immense changes to the marine ecosystem that is integrally linked with culture, health, local economies, infrastructure, and Inuit lives overall. The Saami have projects developing research methods and skills to conserve species, enhance biological diversity and reduce pasture degradation in reindeer herding regions globally, while sustaining resilience of ecosystems and the livelihoods of reindeer herding communities. This includes the Saami "RIEVDAN: Rapid change - challenges or opportunities for sustainable reindeer husbandry?" project that is investigating the cultural capabilities in Saami reindeer husbandry and the opportunities embedded in indigenous and scientific knowledge with focus on adaptation to change and reconciliation engaging both Russian and Norwegian researchers and students. Another Saami project is assessing the impacts of operational wind farms in Northern Sweden on reindeer, habitat and reindeer husbandry. RAIPON's project "Arctic Children - Pre-school educational practices" aims to promote the sustainable development of Russian Indigenous Peoples, particularly their integration into modern society while maintaining their traditional way of life. Gwich’in Council International has several initiatives working towards strengthening and preserving their culture, protecting and managing traditional tribal land and resources, and promoting healthy living. The US has a group working to help strengthen coastal community resilience and various other groups working with local communities to provide environmental data and predictions that can be helpful for adaptation planning. Canada will address the topic of coping with a changing environment at local and regional levels by examining case studies of capacity building and partnership development with ‘Big Science’. Sweden has a University-based research centre on building resilience and assessing vulnerabilities of Arctic environments and societies. Norway's TriArc (The Arctic Governance Triangle: Government, Indigenous Peoples and Industry in change) project is examining how large development projects like mining, aquaculture and production of electric power challenge traditional resource use and management, subsequently to examine the types of governance arrangements established to regulate the relationship between traditional land use and large industrial development.
* ***Health and well-being*** - The Faroe Islands have long-term monitoring and research into the health risks to children and adults caused by contaminants in animal foods, including whales. The US has several groups addressing responses to societal challenges such as strengthening systems of care to prevent suicide and improve mental health through the promotion of indigenous knowledge, research, evidence-based early intervention, and primary prevention efforts; it includes maximising the health benefits of in-home running water and sanitation services in rural Alaska. The Czech Republic also has a research focus looking at the life cycle of Arctic parasites and viral pathogens and their impact on human health.

***New technologies for improving sustainability of the Arctic***

In many regions of the Arctic, communications and sustainable sources of energy pose technological challenges. Several efforts are underway to help identify issues and gaps as well as develop solutions.

* Finland and Denmark are leading the Arctic Council's Task Force on Improving Connectivity in the Arctic which is expected to develop recommendations with regards to a range of specific challenges, such as the identification of geographical areas that would benefit from common, pan-arctic communication-solutions, gaps in the current coverage, how investments and public-private partnerships are sufficiently stimulated and the identification of prospects for future technological solutions. Italy is participating in the Arctic Renewable Energy Atlas project, an activity launched by the Arctic Council's Sustainable Development Working Group (SDWG) by mobilizing national expertise and experience in renewable energy, identifying trade associations and industries interested in contributing to and discussing the improvement of renewable energy use in the Arctic. The US Remote Alaska Communities Energy Efficiency Competition provides an effective means to empower remote Alaskan communities to develop reliable, affordable solutions using energy efficiency and renewable energy technologies. Norway's Sustainable Arctic Marine and Coastal Technology Centre is developing robust technology necessary for sustainable exploration and exploitation of the valuable and vulnerable Arctic region. The Czech Republic is focusing efforts on low temperature biotechnology by exploring biotechnological potential of polar and other low temperature adapted microalgae in partnership with 5 EU countries.

***Increasing awareness and building adaptive capacity***

Interest in learning about the Arctic region is increasing as global economic interests are raising. Many projects are aimed at sharing information about the Arctic region, organisations and universities have developed exchange programmes with other countries and science focused conferences, workshops and assessments bring people together to learn about the Arctic. Arctic policy discussions are of increasing importance and many countries are creating and updating their Arctic plans and inviting international feedback.

* ***Raising awareness*** - EU’s EDU-ARCTIC first offered its innovative online tools aimed at students aged 13-20 in 2017 with almost 900 teachers from 48 countries participating using more than 200 online lessons in 7 languages. Iceland has several programmes dealing with climate education with particular focus on the impacts of the loss of Iceland's glaciers using methods to teach problem solving. Greenland’s Climate Research Centre provides opportunities for capacity building and training for young people. Singapore has been actively generating awareness of Arctic issues by holding events that inform and engage students, academics, researchers, government officials, business professionals and the public. In July 2017, Finland sponsored an international expedition through the Northwest Passage where participants discussed the future management of operations in diminishing sea ice conditions, the meaning of Arctic expeditions for Finland and Canada, as well as the means to ensure pluralism and diversity in the process of planning the Arctic futures. The “Narwhal: Revealing an Arctic Legend”, a US exhibition running from August 2017-2019, presents Inuit perspectives on their connections to narwhals as well as the latest scientific knowledge about these fascinating animals. The US also leads the annual international peer-reviewed publication of the “Arctic Report Card” describing the state of the Arctic aimed at a wide audience, including scientists, teachers, students, decision-makers, and the general public. To help communicate and illustrate the most critical, connected environmental challenges with Arctic and global relevance, UN Environment and GRID-Arendal are producing a set of maps and graphics, accompanied by short narratives.
* ***Exchange programmes*** - 220 graduate students have been exchanged through the Japanese-Russian programme for nurturing professionals that play leading roles in creating a sustainable future in the Russian Far East and the Arctic Circle. Canada, Denmark, Sweden and Finland have started a new exchange programme to support early career scientists, particularly those who are northern-based and/or Indigenous, to conduct research at a partner country research station. Along with collaborative research projects and sharing analytical instruments and methods, the Russian-German Otto Schmidt Laboratory (OSL) provides training for many young scientists in the fields of polar and marine science. The US Fulbright Arctic Initiative brings scholars together to address policy challenges faced by the Arctic Council and Arctic States creating interdisciplinary dialogue and diversifying international perspectives on solutions to pan-Arctic problems. A central research activity of Norway's ARCEx multi-disciplinary research centre is to provide essential knowledge and methodology for eco-safe exploration in the high north, developing and utilizing the best available technology and practices in order to minimize impacts and risks to the Arctic environment. Sweden has several university programmes dedicated to Arctic issues such as Umeå University’s focus on understanding of how the lives of Arctic residents are impacted by changing conditions. The University of the Arctic maintains a catalogue listing over 2000 Arctic courses available and has taught over 2000 students in their online “Introduction to the Arctic: Climate” class.
* ***Conferences and assessments*** - AMAP brought the international science community together to produce the 2017 Snow, Water, Ice and Permafrost in the Arctic Assessment (SWIPA 2017) meant for policy makers to gain an overview of the changes coming to the Arctic and the major consequences for ecosystems and society. Finland and the US are planning an international Arctic STEM Summit to sustain the excitement of and commitments to using Arctic science and local and traditional knowledge to enrich formal and informal education. The 4th International ICES/PICES/IOC/FAO Symposium entitled "The effects of climate change on the world’s oceans" held in June in Washington D.C. is another example. APECS regularly organizes workshops and panel discussions worldwide bringing international early career researchers together with mentors to discuss research and develop skills. IASSA brings together social scientists sand humanities scholars from around the world every 3 years for their International Congress of Arctic Social Sciences.
* ***Policy*** - China has recently released their 13th 5-year plan for Arctic activities. The Polar Regions have been integrated in the scientific agenda of the Atlantic Interaction Initiative, an intergovernmental framework led by Portugal, acknowledging the importance of the Poles to the Global System and aims to stimulate the exchange of ideas between the scientific and business community. Singapore, Norway, Canada, and the Netherlands are working together to enhance legal debates on the Arctic, particularly dealing with Arctic Shipping Governance issues.

***Protocols for equitable, ethical engagement and involvement of Indigenous Knowledge and communities in research***

Indigenous Peoples have been living in the Arctic Region for thousands of years and their cultures and livelihoods are being impacted by environmental changes. Elders have passed down knowledge from generation to generation and this Indigenous Knowledge is very valuable culturally and scientifically. However, there is still a gap in connecting different ways of knowing and it is critical that researchers working in the Arctic region engage with communities. Many national programmes have adopted ethical codes of conduct to guide their research to respect the lands, peoples and cultures.

* ***Indigenous Knowledge*** - Many Indigenous Peoples are working to set expectations and practices that researchers should consider when dealing with indigenous knowledge. In March 2018, the Inuit Tapiriit Kanatami (ITK) released the National Inuit Strategy on Research for Canada which promotes a shared understanding of the legacy of Inuit Nunangat research and connects this legacy to current research practices, defines Inuit expectations for the role of research in their regions and communities, and identifies areas for participation and action between Inuit and the research community. Beginning in November 2018, the ICC will bring together Inuit from across Nuunat (homelands), which spans Chukotka, Alaska, Canada, and Greenland, and facilitate discussions to develop Circumpolar Inuit principles/protocols for equitable, ethical engagement and involvement of Indigenous Knowledge and communities which will be used to develop a proposed process and outline for the Arctic Council.
* ***Ethical principles*** – The EU’s INTERACT project has developed information on ethics of research in Indigenous Peoples’ communities, coordinated by the International Centre for Reindeer Husbandry. The US is revising its 1990 "Principles for the Conduct of Research in the Arctic" with the goals to strengthen the Principles around a set of core fundamental and mutually beneficial concepts, ensure broad stakeholder participation on the review and revision process, and ensure wide dissemination and practice of the Principles. Denmark is in the process of developing a set of guidelines/ethical recommendations for researchers performing fieldwork in the sphere of arctic research and hope to launch them in Summer
1. http://www.arcticobservingsummit.org [↑](#footnote-ref-2)
2. https://www.pmel.noaa.gov/dbo/ [↑](#footnote-ref-3)
3. https://sios-svalbard.org [↑](#footnote-ref-4)
4. http://www.arcticcbm.org/index.html [↑](#footnote-ref-5)
5. https://www.arice.eu [↑](#footnote-ref-6)
6. https://eu-interact.org [↑](#footnote-ref-7)
7. https://www.eu-polarnet.eu [↑](#footnote-ref-8)
8. http://www.europeanpolarboard.org [↑](#footnote-ref-9)
9. https://www.earthobservations.org/geoss.php [↑](#footnote-ref-10)