A Call for a Research Clearinghouse in Alaska

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Three recent working groups sponsored by the state of Alaska have all called for coordinated clearinghouse functions to ensure scientific research and monitoring in Alaska meets the needs of Alaskans. These include the most recent Alaska Arctic Policy Commission report and implementation plan (January 2015); the Northern Waters Task Force report (January 2012); and the Research Needs Work Group report to the Alaska Climate Change Sub-Cabinet (June 2009). They are reinforced by recommendations from Alaska Governor Bill Walker's Transition Team on Climate Change and the Arctic (November 2014).

The recommendations are taken directly from the entities' final reports. They highlight the need identified by multiple groups of Alaskans for a more coordinated research and monitoring agenda for Alaska, especially in light of a rapidly changing Arctic. Given that these recommendations have maintained their currency since 2009, they should be considered a high priority for discussion by the Arctic research community.

Alaska Climate Change Sub-cabinet's Research Needs Work Group

http://climatechange.alaska.gov/

Through Administrative Order 238 then-Governor Sarah Palin established, a Sub-cabinet on Climate Change in 2007 to advise her on the preparation and implementation of an Alaska climate change strategy. The Sub-cabinet established four advisory groups:

- Immediate Action Working Group (IAWG) focusing on near term actions needed in Alaska;
- Mitigation Advisory Group (MAG) to identify and propose measures to mitigate Alaska's greenhouse gas emissions;
- Adaptation Advisory Group (AAG) to identify and propose methods to adapt to the impacts of climate change on Alaska; and
- Research Needs Work Group (RNWG) to recommend research strategies for mitigating greenhouse gases and adapting to the impacts of climate change.

The RNWG was established to assist the Sub-cabinet in identifying needed research to implement mitigation and adaptation strategies identified by the Advisory Groups, and ultimately, the Sub-cabinet. Research needs were broadly defined and included measures to implement or encourage: data collection and management; monitoring; addressing workforce needs; scientific research; the development of engineering standards, practices and other support tools; infrastructure needs and improvements; technology development; the assembly of traditional knowledge; and, modeling.

In describing climatic changes in Alaska and acknowledging that the impacts could be both potentially negative as well as beneficial, nearly everyone unanimously laments the paucity of data, analyses, information infrastructure, and decision-support and sharing tools necessary for effective assessment and response to such changes. They also acknowledge that there is no single agency, organization, or collaborative association within Alaska that is tasked with systematically coordinating the identification, collection, compilation, analysis, and publishing of climate change data and research. This important task is required to ensure the quality necessary to effectively support decision-making and evaluate and manage multifaceted risks and threats such as those associated with climate change in Alaska. However, there are many scientific agencies and organizations collecting and interpreting natural and economic data in Alaska that can be used in an overall climate change response strategy. The challenge is to coordinate the many different data sets, identify the information and data gaps for climate related policy and mitigation/adaptation efforts, and make sure sufficient funding is available and distributed to do the work.

As part of its vision, the RNWG envisioned an integrated research and knowledge management infrastructure supporting multi-disciplinary systematic analyses and decision- making as an integral part of the climate change strategy that will allow Alaska to effectively, economically, and sustainably adapt to and mitigate the consequences of climate change.

As a general strategy, the RNWG members recognized that addressing the impacts to Alaska from climate change and the value of efforts to mitigate greenhouse gases will be most effective through a systematic approach. That approach includes establishing mechanisms to ensure communication and coordination among State agencies and with federal agencies and with stakeholders to provide research-derived information to address multi-jurisdictional needs in mitigating greenhouse gas emissions and adapting to climate change.

In its report, the RNWG encourages the leaders of the Executive Branch, the Legislature, and the University to assume a more proactive and collaborative role in planning, developing, and clarifying a strategic vision, goals, and performance measures for State government in promoting sustainable communities and addressing climate change in Alaska. The strength and effectiveness of this integrated strategic planning will be a function of the specificity of the state's roles, focus on long-term sustainability, and extent of collaboration with stakeholders. The RNWG believes that this strategic planning is necessary for, and will be the most effective way to prioritize the research needs identified herein. There is a general consensus that a systematic approach within a multi-disciplinary research strategy will provide the best science-based decision making tools for proactive solutions. It takes time, however, to transform research data to useful information. Identifying research today, with particular attention to the cross cutting needs, will support better decisions in a shorter time frame and ensure that Alaska leads the nation in successfully adapting to the impacts of climate change, while mitigating the greenhouse gas emissions as part of our national role.

Alaska Northern Waters Task Force

http://housemajority.org/coms/anw/pdfs/27/NWTF_Full_Report_Color.pdf

In 2010, the Alaska State Legislature established the Alaska Northern Waters Task Force (ANWTF) to identify opportunities to increase the state's engagement with these issues. On both the state and federal level, the task force has found many urgent needs. The following are its topmost recommendations:

1. Statewide public testimony gathered by the task force made it clear that the state and federal governments must provide Alaskans with meaningful opportunities to participate in Arctic policy and Outer Continental Shelf development decisions. Many local government officials, tribal government representatives, and individuals expressed a need for timelier, more frank, and more thorough information from state and federal authorities regarding policies and activities off Alaska's coasts. The task force believes that consistent, structured communication and consultation—particularly with those Alaskans likely to be most impacted by evolving conditions—is the best way to build consensus, advance responsible policies, and stimulate broadly beneficial economic development.

2. The state of Alaska has only just begun to grapple with the challenges and opportunities developing in the far north. It is imperative the state be strategically involved and in a leadership role in the development of policies affecting the state, its communities, and citizens. It is therefore among the task force's highest priorities to press for the creation of a commission to develop a comprehensive state strategy for the Arctic. As the Arctic changes, the decisions Alaska faces will continue to evolve and grow in complexity. An Alaskan Arctic Commission will enable Alaska to more effectively respond to unfolding developments and will jumpstart Alaska's preparations to ensure that the interests of the state and its people are protected.

Research

Worldwide climate change is already having an impact on the Arctic, where temperatures are rising twice as quickly as those in more southern latitudes. Profound transformations are underway in its complex ecosystems. These changes are expected to trigger unprecedented degrees of human activity in the region. As a consequence, transformation in the far north will accelerate all the more, not just environmentally, but also on socioeconomic levels. Under these circumstances, the need for wide-ranging scientific research and monitoring in the Arctic has never been more pressing. We must continue to gather essential baseline information about the environment and its dynamics in order to become better able to discern shifting conditions. In turn, our understanding of the implications of changes there will increase, and we will improve our ability to prepare for and mitigate impacts.

1. The ANWTF recommends that the state of Alaska and the federal government identify priorities for Arctic research. By ranking priorities funding can be targeted more effectively and research can be better coordinated. Major knowledge gaps will be closed far more quickly.

2. The ANWTF recommends improving the exchange of research information and

integration of data management. Faster and more extensive integration of data collected by state and federal agencies, academics, and industry would yield enormous benefits for all stakeholders.

3. The ANWTF recommends increased long-term monitoring of the Arctic, including routine surveys of key chemical, physical, and biological parameters of the Beaufort and Chukchi Seas and associated coastal plains. In order to better understand, quantify, and predict the effects of changes in both marine and terrestrial Arctic ecosystems, Alaska must increase our long-term monitoring of a wide range of environmental characteristics.

Alaska Arctic Policy Commission Final Report & Implementation Plan
http://www.akarctic.com/wp-content/uploads/2015/01/AAPC_Exec_Summary_lowres.pdf

Policy Statement #4: Value and strengthen the resilience of communities, including efforts to:
- Recognize Arctic indigenous peoples' cultures and unique relationship to the environment, including traditional reliance on a subsistence way of life for food security, which provides a spiritual connection to the land and the sea;
- Build capacity to conduct science and research and advance innovation and technology in part by providing support to the University of Alaska for Arctic research consistent with state priorities;
- Employ integrated, strategic planning that considers scientific, local and traditional knowledge;
- Safeguard the fish, wildlife and environment of the Arctic for the benefit of residents of the state;
- Encourage more effective integration of local and traditional knowledge into conventional science, research and resource management decision making.

Arctic Policy Implementation Plan: Strengthen Science and Research
Alaska should pursue strategies to broaden and strengthen the influence of its agencies, its academic experts and its local governments and associations. Alaska's future prosperity largely depends on the scientific, technological, cultural and socioeconomic research it promotes in the Arctic in the coming years and its ability to integrate science into decision-making. Ongoing and new research in the Arctic must be designed to help monitor, assess and improve the health and well-being of communities and ecosystems; anticipate impacts associated with a changing climate and potential development activities; identify opportunities and appropriate mitigation measures; and aid in planning successful adaptation to environmental, societal and economic changes in the region.

The vast amount of science and research conducted in the Alaskan Arctic encompasses a broad spectrum of interests, from the public to the private sector including non-governmental organizations, the state University system and many others. It is crucial that the state of Alaska be involved in the various forums that build the information base available to policy makers. In addition, while local and traditional knowledge and subsistence activities inform many of the above entities' research priorities, activities and findings, regional traditional knowledge must receive a higher level of consideration.

How researchers can better collaborate with local people and include traditional knowledge into their projects is receiving more attention. Observational systems are among the most effective means for monitoring and documenting change, improving inputs to models and informing permitting decisions. They are also a valuable way to meaningfully involve Arctic communities in research activities. Process studies can add to this knowledge and help reveal the forces influencing ecosystem structure and function. In addition, the transfer of findings from process studies to models can reduce uncertainties and improve the accuracy of projections.

While models have practical use in developing strategies for managing wildlife and for sustainable and adaptable communities, civil and economic development infrastructures, it remains necessary to clearly identify the limitations of models that are developed to aid in decision-making. Even as baseline data and component parameterizations improve, awareness of these limitations assists the evaluation of contingencies and determination of proper levels of precaution in management and strategic approaches.

State government priorities pertaining to the Arctic are influenced by state objectives. Establishment of these priorities will ensure organized state input to federal, local and institutional decisions on Arctic research and monitoring needs.. As the state's engagement with Arctic issues increases, the executive branch will play an important role in improving coordination of state agencies' positions in Arctic research and associated matters. Alaska should pursue strategies to broaden and strengthen the influence of its agencies, its academic experts and its local governments and associations. Benefits include an increase in the knowledge available to decision makers in both the public and private sectors; strengthening and refining of findings through data synthesis; reducing duplicative research; and enhancing the effectiveness of interdisciplinary research efforts. More coordinated research efforts driven by state of Alaska priorities would have significant impact for policy makers and decision makers, allowing them to address opportunities and challenges in the emerging Arctic.

- Ensure state funding to, and partnership with, the University of Alaska for Arctic research that aligns with state priorities and leverages the University's exceptional facilities and academic capacity.
- Increase collaboration and strengthen capacity for coordination within the Arctic science and research community.
- Strengthen efforts to incorporate local and traditional knowledge into science and research and use this community-based knowledge to inform management, health, safety, response and environmental decisions.
- Improve, support, and invest in data collaboration, integration, management and long-term storage and archiving.
- Support monitoring, baseline, and observational data collection to enhance understanding of Arctic ecosystems and regional climate changes.

- Invest in U.S. Arctic weather, water and ice forecasting systems.
- Update hydrocarbon and mineral resource estimates and mapping in the Alaskan Arctic.

Alaska Governor Bill Walker 's Arctic Policy and Climate Change Transition Team Report

http://gov.alaska.gov/Walker_media/transition_page/arctic-policy-and-climate-change_final.pdf

Recommendation # 3: Developing a better understanding of our changing climate, oceans, and environment.

Effective management, sustainability, and responsible development depend on understanding affected environments and how those environments are changing. The changes occurring due to warming and ocean acidification are not limited to only the Arctic—they will affect all Alaskans and all parts of Alaska. While increased attention to the Arctic has brought with it new research, the State can and should play an active role in identifying research and monitoring priorities, ensuring that decisions are based appropriately on science, and coordinating among the various scientific entities. Developing and using a better understanding our oceans and terrestrial ecosystems, including the effects of changing climate and ocean acidification, is key to sustainable choices for the future.

Success Elements Considered to be Agreeable by Most Alaskans

- Coordination of Arctic science/LTK (Local and Traditional Knowledge) priorities by an entity like the State Committee for Research (SCoR) to help focus investments
- Science sufficiently informs solutions
- Research funding based on merit, objectivity, and Arctic priorities (rather than special-interest agendas)
- Centralized Arctic policy development that draws in all regions
- Expertise is coordinated, including through a sharing center
- Alaska leadership in addressing climate change and ocean acidification

Possible Actions to Achieve Agreed Success Elements

- Either reinvigorate and/or revamp purpose of SCoR or create a new entity—like a State Arctic Research Commission—charged with coordinating research and establishing priorities
- Begin scoping with stakeholders to identify priorities
- Identify baseline research and monitoring needs
- Coordinate with USARC (Arctic Research Commission) and Arctic Council working groups
- Ensure support of decision-makers in identifying research needs and increasing stronger role of science in decision-making
- Centralize data and research results

- Create a coordination/sharing center works that functions as a clearing house for research

Recommendation #4) Improving intergovernmental collaboration, transparency, and participation.

Inclusion of Alaskans' expertise, experience, and perspective in the decision-making process is critical to ensuring that good decisions are made about our lands, waters, and communities. For example, we need to provide opportunities for affected communities to have a seat at the table when state-wide decisions are made, and we need to ensure that the State's voice is heard when the federal government makes decisions. Openness, transparency, and an inclusive process are key.

Success Elements Considered to be Agreeable by Most Alaskans
· Special adviser to State government on Arctic issues
· Arctic policy and implementation plan adopted by the State and resources allocated to implement it
· Established public process for decisions related to the Arctic
· All Alaskans included in decisions
· Governor and cabinet informed on challenges and opportunities in the Arctic

Possible Actions to Further Agreed Success Elements
· Review and prioritization of existing State Artic policy resources, including looking back at climate change sub-cabinet working group recommendations
· Create a venue for dissemination of information and feedback from the public
· Create "Arctic Portal" clearinghouse that includes information from all sources, including Tribes, nonprofits, corporations, and others

Arctic Observing Summit 2016 - White paper contribution

TOWARDS AN INTERNATIONAL SCIENTIFIC OBSERVATORY AT THE NORTH POLE

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AOS Themes: (1) International and national strategies for sustained support of long-term Arctic observing;
(5) Arctic Observations in the Context of Global Observing Initiatives

ABSTRACT: We advocate the establishment of a North Polar international station and observatory as a valuable scientific workspace and tool for studying the evolution of the Arctic environment and ecosystems, as well as a mechanism, entirely consistent with the United Nations Convention on the Law of the Sea (UNCLOS) and with the Ilulissat Declaration (Arctic Ocean Conference, 2008), for enhancing stability and peace through international collaboration in the Arctic.

1. The Arctic Climate

The past three decades are likely the warmest period of the last millennium in the Northern Hemisphere (Fig. 1). Global anthropogenic CO_2 and other greenhouse gas emissions have risen from less than 10 gigatonnes (Gt) per year in 1950, to almost 40 Gt annually in recent times, with atmospheric CO_2 levels unprecedented in the last 800,000 years (IPCC 2014). The impact of increased atmospheric CO_2 is most pronounced at high latitudes, with complex positive feedback effects that exacerbate and accelerate the changes in climate and environments locally and globally. The Arctic climate is changing most rapidly: the permafrost is thawing, releasing carbon and methane in the process, and snow and ice cover are shrinking on land and especially at sea, decreasing the albedo effect of these regions (solar radiation that is reflected back to space). The impact is felt on coastlines eroded by enhanced wave and storm activity, on animal populations depending on ice cover, and on the people who live in the region.

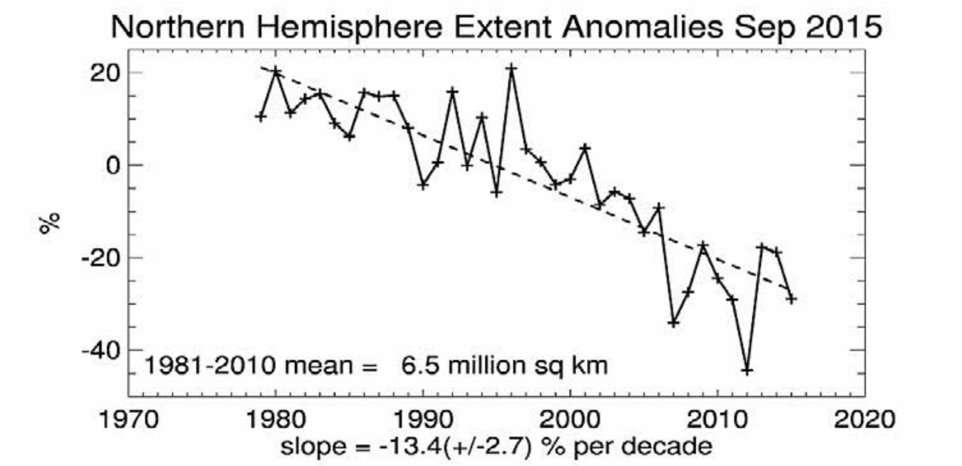

Figure 1. *Monthly sea ice extent anomalies in the Northern Hemisphere from 1979 to 2015. Image courtesy of the National Snow and Ice Data Center, University of Colorado, Boulder (https://nsidc.org/data/seaice_index/).*

Based on the rapid rate of decay of Arctic ice cover (e.g. Fig. 1), the Arctic would be expected to be ice free in September (the month of minimum coverage) by 2070, or even sooner, within the middle (IPCC 2014) or the early part of the 21st century (Overland and Wang, 2013). There would still remain considerable ice coverage in the central Arctic with a peak in March.

2. Opportunities

What is seen as a major ecological disruption by some is perceived as an opportunity by others, who hope to benefit from easier access to the Arctic basin's mineral and biological resources, on land and at sea. The reduced ice cover is already allowing easier passage through the Canadian archipelago and north of Siberia. Trans-arctic shipping routes linking Europe and Asia across the North Pole are already seriously contemplated (Smith and Stephenson, 2013).

3. Territorial Claims

The opening of the Arctic Seas promises unprecedented access to natural resources and has attracted extensive territorial claims by circum-Arctic nations[1]. Byers (2013) has presented a comprehensive discussion of claims within the framework of the United Nations Law of the Sea (UNCLOS), focusing mainly on the extensive Arctic continental shelf areas. Through the 2008 Ilulissat Declaration (Arctic Ocean Conference, 2008), the coastal Arctic states (Canada, Denmark, Norway, Russia, and the USA) declared that they saw “no need for a new comprehensive international legal regime to govern the Arctic Ocean,” but reaffirmed their commitment “to this legal [UNCLOS] framework and to the orderly settlement of any possible overlapping claims,” an attitude likely to bring the benefits of mutual cooperation (see Nowak and Highfield, 2011).

However, some unresolved claims remain sources of bilateral irritation (for example, Hans Island, between Canada and Denmark). There have also surfaced, more recently, aggressively competitive claims to the North Pole, seeds of further conflicts. In this paper, we examine more closely the meaning of a claim to the North Pole and suggest means of avoiding conflicts over its possession.

4. Where is the North Pole?

By definition, the North Pole is the intersection of the Earth's axis of rotation with the planet's surface: ideally, a fixed geometrical point, without area. In a pinch, national pride might be satisfied by sharing immediate proximity to that point. However, because of its oblateness, the Earth wobbles, a motion predicted by Leonard Euler in the 18th century and verified by Seth Carlo Chandler in the 19th. The Chandler wobble is complicated by seasonal variations in the Earth's moment of inertia related to atmospheric and oceanic motions, which are also thought to be responsible for the wobble's persistence against attenuation by internal friction. Gradual shrinking of the Greenland ice cap is also held to be responsible for a gradual drift in polar location. As a result, the pole describes a clockwise path with a radius of about 10 m over a period of about 433 days. The combined effect (polar motion), is estimated at 30 to 100 ft. per century (~ 9 to 35 m; Hutton and Eagle, 2004), but may vary (Fig. 2), and indeed, ice melting may have even expedited an abrupt eastward turn of the mean pole position since 2005 (Chen et al., 2013).

What ownership of the North Pole implies is possession of a rather small area -- under today's conditions, a radius of 100 m about the average pole position would suffice for centuries. Is possession of such a small area of sufficient economic importance and national prestige to engage in a conflict with neighbouring countries?

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[1] Some recent claims by the Kingdom of Denmark include extensions to continental shelf areas off Greenland and the Faroe Islands, including the North Pole itself (e.g. see Continental Shelf Project of the Kingdom of Denmark, http://a76.dk/lng_uk/main.html). The recent December 2014 claim by Denmark overlaps with claims by Norway, USA, Canada and Russia (http://a76.dk/greenland_uk/north_uk/index.html).

We offer a solution that we believe will avoid conflict over the North Pole and prove of benefit to all Arctic nations and indeed the whole North Hemisphere: a North Pole International Observatory, established within an area left outside national claims or any new legal regime: the "high seas" on a very small scale.

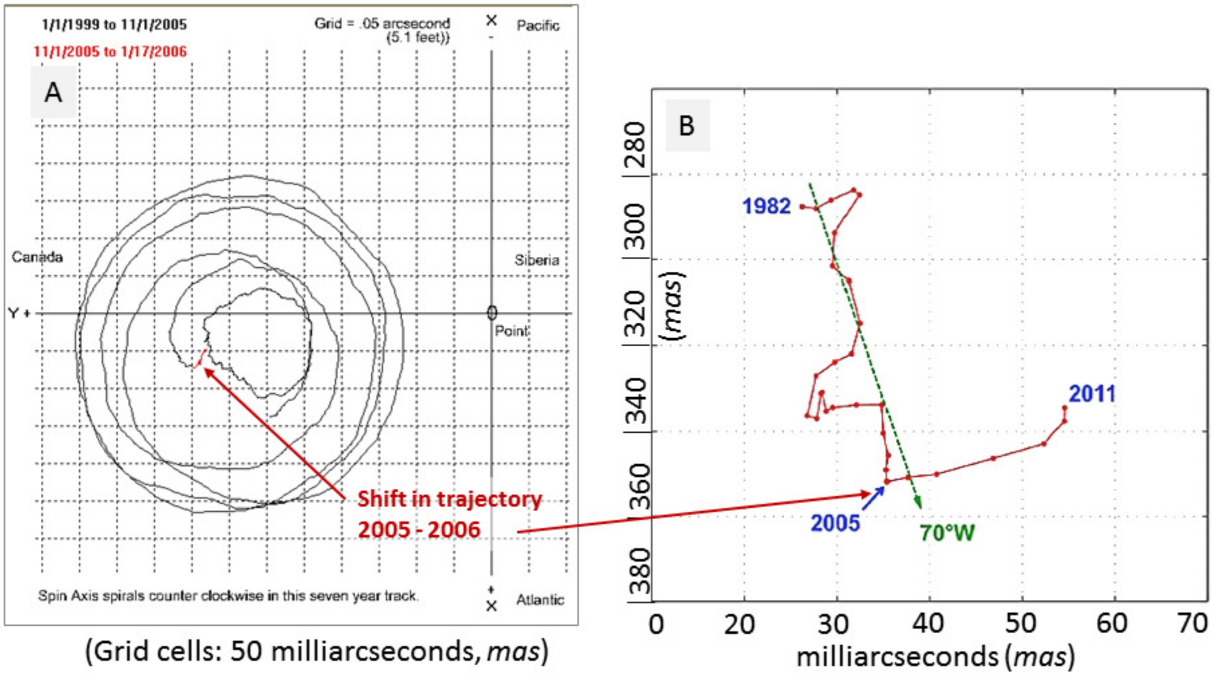

Figure 2. *Recent path of the North Pole as noted by Michael Mandeville (Mandeville, 2006; panel A), including the initial shift in trajectory starting in late 2005, and average annual pole position by year as calculated by Chen and colleagues from 1982 to 2011 (Chen et al., 2013; panel B). Figures modified from Mandeville (2006) and Chen et al. (2013). (One millarcsecond is equivalent to approx. 3 cm of motion on the Earth's surface near the pole; 50 mas, the length of a grid cell in panel A, measures approx. 5.1 feet).*

5. POLARIS Station

The POLAR International Science Station and Observatory (POLARIS, for now, Fig. 3) would be an observatory of polar areas and of much of the northern hemisphere. It would provide direct atmospheric and oceanic information from a data-poor part of the world, data that would contribute to a better understanding of the Arctic and the whole Northern Hemisphere circulation and improve weather predictions in the north. Enhanced ocean observations would help to better understand flows in and out of the Arctic and the contribution to the climate that they make in transferring heat between the Atlantic to the Pacific.

Situated at the pole, **POLARIS** would be ideally located for astronomical observations and observations of auroras, and would contribute to a better understanding of upper atmospheric conditions over the North Hemisphere, with benefits to ground and satellite radio communications. Because of its equidistance from equatorial areas, the poles are privileged observations points for Schumann resonances, another indicator of global ionospheric conditions.

Besides observing the impact of climate change on species of special concern and of particular interest to Arctic communities, such as polar bears, marine mammals and fish, biological monitoring at the North Pole would document the evolution of deep ocean primary productivity as the ice cover shrinks and thus form a basis for understanding a new ice-free Arctic marine ecosystem and food webs, from invertebrates to migratory species. The potential location of **POLARIS** would be ideal also for studying the physical, chemical and biological components of the environments spanning from sea level to ~4000 m depth adjacent to the Lomonosov Ridge, and the slow-spreading Gakkel Ridge (Fig. 3), including novel hydrothermal vent ecosystems (Edmonds et al., 2003; German et al. 2011).

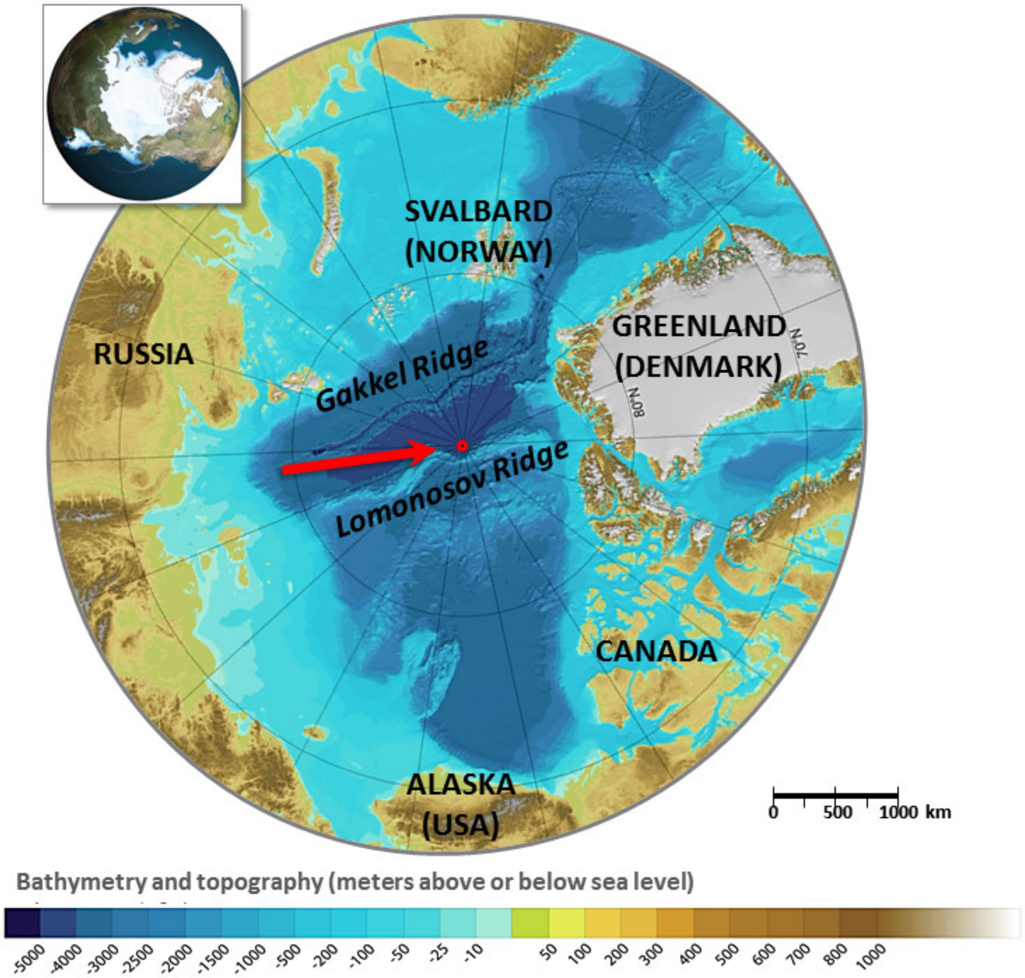

Figure 3. *Bathymetry under Arctic ice at 90° N and approximate location of the Geographic North Pole (red point and arrow). The POLARIS International Station and Observatory could be located at or near the Geographic North Pole and could serve as an invaluable site to investigate the atmosphere and the heterogeneous marine physical, chemical and ecological environment within 50 to 100 km from the Lomonosov Ridge, from sea ice to depths over 4000 m, and the ultraslow-spreading Gakkel Ridge. (Image data sources and information: Johnson et al. 2009; Jakobsson et al. 2012; Edmonds et al. 2003).*

Along with other existing drifting, ship-based and land-based stations, and those that already participate in international collaborative networks such as INTERACT (INTERACT - International Network for Terrestrial Research and Monitoring in the Arctic; http://www.eu-interact.org/en/), CNNRO (Canadian Network of Northern Research Operators, http://new.cnnro.org/about-cnnro/), and others, POLARIS would complement research and monitoring as part of such station networks, and be ideally situated to serve as a hub for basic emergency response and as a communications relay site.

POLARIS would eventually pay for itself through the broad, long-term benefits that it would bring to the nations of the North Hemisphere, and especially of the Arctic. It would also pay for more than itself by eliminating onerous expenses associated with the management of international disputes, bringing substantial budgetary savings to Arctic states. Peace pays! For some research activities, the cost of ship-based surveys may be reduced and survey time could be complemented where **POLARIS** could serve as a hub for shorter, more focused surveys. Costs of operation for **POLARIS** could be supported in part from occasional tourism activities and for use by the private sector with a review system for the approval and oversight of such activities, with the goal of setting high standards for environmental stewardship and sustainability in Arctic environments.

The role of scientific collaboration in ensuring stability and peace in the Arctic has been stressed by others, namely by Berkman (2012, 2014) and most prominently in the words of Mikhail Gorbachev (as quoted by Berkman): "**Let the North Pole be a Pole of Peace**."

6. Obstacles

Perhaps the **POLARIS** concept may elicit skepticism and objections initially: '*A research station at the pole doesn't make any sense! It's a deep ocean, heavily ice-covered area, which is likely to continue to have some ice for quite a few years!', or, 'Too expensive, and technologically idealistic!'.*

As a first step, there would be a need to develop international agreements. For the small area proposed directly around North Pole, establishing a cooperation agreement may be feasible, at least compared to the complex Arctic claims that are currently under review. Cooperation will be needed to allow access via international waters and national jurisdictions. However, an agreement could be modelled in part following the *Antarctic Treaty* (http://www.ats.aq/e/ats.htm), implemented in 1961, and ratified by 53 countries at present, outlining scientific research, cooperation and knowledge exchange, and limiting activities to peaceful purposes only. In 1991, the Protocol on Environmental Protection to the Antarctic Treaty further strengthened the establishment of Antarctica for peaceful scientific purposes only and identifying Antarctica as a reserve. An agreement among collaborators in the POLARIS observatory could be designed to satisfy the requirements of the Ilulissat declaration.

Aside from cost, logistic and design challenges, establishing a scientific presence at the North Pole will certainly encounter other potentially serious problems. However, one may reflect on what early polar explorers like Robert F. Scott, Roald E. G. Amundsen, or Ernest H. Shackleton would have thought of a research station at the South Pole one hundred years ago. Within half a century the international community has collaborated extensively to overcome extreme challenges and participated in co-development and co-design of advanced bases capable of adapting to the most extreme Antarctic conditions, such as the Amundsen–Scott South Pole Scientific Station, Halley VI, and Princess Elisabeth Antarctica, a zero-emissions building. What might become possible over the next hundred years?

7. Robust Design and Advanced Engineering

If **POLARIS** is to be the focus of scientific presence at the North Pole, what kind of structure will it be? Most likely a structure which will evolve from simple beginnings, as has the South Pole station. It may start as did the many former Ocean Weather Stations, on a ship -- an ice breaker, of course --keeping position at the pole.

A more advanced structure would have to maintain its position against wind, current and ice, either dynamically like a modern drill-ship, or through an anchoring system. Currently, the deepest drilling platform, Perdido, operated by Shell Oil in the Gulf of Mexico, works in a depth of 2,450 m, still well-short of the 4,000 m depth at the pole. Perdido is of course not equipped to handle ice pressures. The Hibernia platform, located on the Grand Banks of Newfoundland, was built to resist the impact of icebergs and sits on a massive anchoring base, but sits in relatively shallow water (80 m). There is obviously no existing platform that would fit the bill. We hope that the idea will soon challenge the imagination of the cleverest of engineers.

8. Recommendation

We bring the concept of a North Pole international scientific observatory to the attention of the Arctic Observing Summit in the hope that it will germinate in the minds of some of the participants. We recommend to the participants and Thematic Working Groups of the Summit that a Study Group be considered to explore international interest and input for such an observatory, including discussion of a potential agreement to support international cooperation and to pave the way for peaceful resolution of ownership of the Geographic North Pole. The Study Group would act as a forum for international discussion of the idea and engage in detailed assessments of the challenges and benefits of such an observatory.

In addition to an important role as a symbol of peace and international collaboration, *POLARIS* would be ideally located where a vast polar area remains largely unexplored and where travel and research are still limited by logistic and environmental challenges. As outlined above (Section *5. POLARIS Station*), from a scientific perspective, exploration, monitoring, and experimental approaches build our fundamental knowledge base about polar ecosystems that remain understudied. Ultimately, the potential benefits of such knowledge can include applications such as filling gaps in coverage and scope, and improving our ability to detect or even predict extreme events, understand circulation patterns, improve ecosystem and environmental monitoring for better management, and for detecting shifting species distributions. Such knowledge may even help refine indicators and sustainability limits to guide emerging economies with eyes on the Arctic, such as the large number of bioprospecting companies searching for the next generation of pharmaceuticals in polar regions (Hoag 2009). From a geographic perspective, *POLARIS* can potentially serve as a communications relay center or to serve as an important satellite site for emergency response in the future. This northernmost observatory could bring benefits to diverse sectors, communities, and nations within and beyond the Arctic. As part of existing station and observatory networks, *POLARIS* could contribute to global observing initiatives by expanding the geographic reach and focus towards more comprehensive Earth observation efforts.

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DOCUMENT

White Paper

Polaris: User Needs and High-Level Requirements for Next Generation Observing Systems for the Polar Regions

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1 EXECUTIVE SUMMARY

The demand for environmental information in the Arctic region is evolving rapidly influenced by a multitude of drivers, including climate change science, exploration of natural resources, environmental sustainability, shipping, local communities etc. Developing appropriate next generation observation systems therefore require a holistic approach where all drivers and stakeholders' interest are fully taken into account and consolidated into priority actions with high socio-economic impact.

Space based solutions are clearly at an advantage in the Polar Regions, given the remoteness, lack of ground-based measurements, and the excellent repeat coverage provided by polar orbiting satellites. Even though space proven technology and access to space is becoming more reliable and affordable, building, launching and operating space based infrastructure remains a significant investment of substantial risk. Sharing the risk and investment amongst the different stakeholders would be desirable and probably necessary to ensure the need for long term monitoring. In this context the European Space Agency Polaris initiative is establishing next generation space based mission concepts for satellite remote sensing systems. In doing so, gaps in Arctic environmental information requirements are identified via close dialog with a wide range of national and international user community representatives, which is being fed into mission concepts studies. This white paper is presenting the Polaris initiative and initial results.

2 INTRODUCTION

There has been a growing interest in the Polar Regions in recent years, fuelled by concerns about amplification of anthropogenic climate change. Increased economic and transportation activities are leading to greater demands for sustained and improved availability of integrated observations and predictive weather, climate and water information to support decision-making, on all time scales. Whilst polar-orbiting remote sensing satellites already play an important role in providing observations of the polar regions, new environmental, political and socio-economical factors are creating a demand for more detailed and frequent monitoring than is presently available.

This White Paper defines the ESA activities being be executed in establishing user and high-level mission requirements for the next generation of satellite Earth observation systems covering the Polar Regions and preliminary analysis of mission concepts to meet these information requirements. Other coordinated activities will cover the architectural and technical definition of space systems candidate to implement those concepts.

3 BACKGROUND

The Polar Regions are key drivers of the Earth system and changes in these regions will have a significant impact on global factors such as weather systems and sea level. Conversely, the Polar Regions are known to be especially vulnerable to on-going climate changes, largely as a result of polar amplification.

The Intergovernmental Panel on Climate Change (IPCC) reports that over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide and Arctic sea ice has continued to decrease in extent (IPCC Fifth Assessment Report, chapter 13.4). Satellite EO derived measurements played an essential role in arriving to these conclusions. Furthermore, the IPCC fourth assessment identified the contributions of ice from glaciers and ice sheets as the major remaining uncertainty in projections of sea level changes (IPCC Fifth Assessment Report, chapter 13).

Despite considerable research progress in understanding the Polar Regions over the last decade [RD17], many gaps remain in observational capabilities. These gaps limit present numerical weather prediction capabilities and sub-seasonal and seasonal forecasting in Polar Regions, thereby hampering reliable decision-making. The goal of the WMO Global Cryosphere Watch (http://globalcryospherewatch.org/) is to improve the integrated observing system capabilities at high latitudes, while the complementary goal of the WMO-WWRP Polar Prediction Project (http://www.polarprediction.net) is to promote development of improved weather and environmental prediction services for the polar regions on time scales from hours to seasonal. However, whilst both of these endeavours are expected to improve representation of polar atmosphere, land, ocean and cryosphere processes in models, there remains a clear demand for both initiatives to be sustained in the future by basic improvements to existing satellite observation capabilities.

Over the last decade a much more variable and unpredictable sea-ice regime has been observed in the Arctic and Southern Oceans. Velocities of some major Greenland glaciers are accelerating, causing increased iceberg calving rates. Both the new Arctic sea-ice regime and increased glacier/iceberg calving are creating new challenges for operations in polar waters. The need for tactical real time snap shots and forecasts for sea-ice and icebergs is increasingly becoming a priority to operate safely and efficiently in ice-infested waters, as is the need for reliable and timely information on the sea state and local winds and other meteo parameters, which are known to be naturally more challenging in polar regions. Coastguards executing search and rescue missions, shipping companies planning trans Arctic passages, engineers building new infrastructure, and oil and gas companies undertaking exploration/production operations will all need this type of information, which can only be derived from EO satellites in an efficient manner.

All Arctic nations are providing satellite-based ice monitoring services as part of their national weather forecasting services. The International Ice Charting Working Group (IICWG) was formed in October 1999 to promote cooperation between the world's ice centres on all matters concerning sea ice and icebergs. Over the last years IICWG has played a key role in establishing a global user community able to formulate operational standards and provide ESA and other satellite operators clear and consolidated requirements for satellite missions such as RADARSAT-2, Sentinel-1, etc. In their 2014 IICWG included the following statement in their annual press release “Accurate, timely analyses and forecasts of ice conditions are essential for safe and efficient navigation in polar waters” [RD16]

According to the US Geological Survey (2009), the Arctic holds 13% of undiscovered oil and 30% of undiscovered gas supplies. A significant part of these oil and gas is located offshore Greenland in waters where sea-ice and icebergs pose challenges in terms of accessibility and safety. Supporting oil and gas tactical operations in ice-infested waters will require satellite based information products, which are currently not yet available. Conversely, oil and gas prospection, exploration and production operations imply very high environmental risks for local ecosystems that are known for their fragility. Space EO is the primary choice for extending environmental monitoring to the Polar Regions with an approach that is adapted and optimised for the specific characteristics of the polar environment.

As the Arctic sea-ice extent is shrinking year by year there is also an increased interest for new shipping routes from Europe to Asia with the potential of reduced sailing times (Smith and Stephenson, 2013). In 2009, Beluga Shipping became the first shipping company to transport goods through the 'Northeast Passage' escorted by a pair of Russian icebreakers, travelling from South Korea to Siberia. The prospect of an ice-free Arctic sea during the summer months is definitely attractive, but also extremely challenging due to the freeze over during the winter months. A seamless trans-Arctic sea-ice and iceberg navigation satellite-based service is still not available, but will have to be developed to support safe navigation of vessels through these future routes.

In 2012 the European Commission and the High Representative issued a Joint Communication on “Developing a EU Policy towards the Arctic Region: progress since 2008 and next steps”. This communication sets out the case for increased EU engagement in Arctic issues and proposed to further develop EU’s policy towards the Arctic. With the EU having invested over €1.14 billion in the European Arctic since 2007, the EU is also a key investor and actor in the Arctic region.

Space Weather, the physical and phenomenological state of natural space environments, should also be taken into consideration when discussing the Polar Regions. In general, the associated discipline aims, through observation, monitoring, analysis and modelling, at understanding and predicting the state of the Sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them, and also at forecasting and nowcasting the potential impacts on biological and technological systems. The effects of Space Weather are observed in the degradation of spacecraft communications, performance, reliability, and lifetime. In addition, it leads to enhanced risks to human health on manned space missions. Space weather also has numerous effects on the ground including damage to aircraft electronics, enhanced radiation dose for air passengers and crew, damage and disruption to power distribution networks and pipelines and degradation of radio communications as well as errors of GNSS signals.

The ability to predict Space Weather (SWE) impacts on Earth, thus allowing users to enact the measures needed to protect critical infrastructures, is one of the key goals of the ESA SSA-SWE program. To this end, a number of measurements are needed. Observation of the auroral oval, measurement of the radiation and plasma environment and the local magnetic and electric fields in geo-space supports the monitoring and prediction of space weather impacts for the benefit of end users. These observations are feasible from high inclination LEO, MEO and HEO orbits [RD18]

The provision of environmental information products and services responding to these drivers and challenges will not be possible without the appropriate exploitation of other space based systems, like; GNSS, telecommunication and Automatic Identification System (AIS) services.

For Global Navigation Satellite Systems (GNSS), presently GPS and Glonass but in the future also for Galileo, the performance in the Polar Regions is reduced compared to the performance obtained by users at mid latitudes. The reasons are mainly the satellite-receiver geometry and the ionospheric effects on the satellite signals. High reliability navigation through the European Geostationary Navigation Overlay Service (EGNOS) is presently also not possible in the Arctic because of the inability of geostationary satellites to reach high latitudes. On-going developments, like the Arctic Testbed and second generation EGNOS, are exploiting Satellite-based augmentation systems (SBAS) based on accurately-located reference stations and the future introduction of Dual Frequency Multi-Constellation navigation services to compensate for these limitations. EGNOS delivers navigation services with guaranteed integrity of position that could make a valuable contribution to safe navigation in the region.

Geostationary telecommunication satellites do not cover the Polar Regions at all or only partly with reduced efficiency. A number of satellite constellations that are in a low-Earth orbit such as Iridium, Globalstar, OrbComm and Gonets, are serving the Polar Regions with low data-rate and/or messaging services. There are presently no broadband communications solutions available for defence or military users; all European forces currently use U.S. systems.

The Canadian and Russian governments have initiatives to develop high elliptical orbit solutions, respective PCW (Polar Constellation for Communication and Weather) and ARKTIKA systems. The Canadian PCW system is planned to offer broadband services only to certain areas of the Arctic. The Russian ARKTIKA system is planned to offer low data rate communications for government and aeronautical communications with a navigation signal overlay, and broadband communications. The planned coverage is more extensive than the Canadian, but for the moment mainly targeting government and institutional use.
ESA supports a Private-Public Partnership with Inmarsat called ICE (Inmarsat Communication Evolution). This initiative will redefine the provision of mobile satellite communication services though innovative ground, space and user segments and will include the provision of truly global coverage, including polar areas.

Automatic Identification Systems (AIS) is an automatic tracking system used on ships and by vessel traffic services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites. Due to the lack of land based AIS infrastructure in the Polar Regions, satellite based AIS is essential. The availability of satellite based AIS in the Polar Regions is increasing rapidly, especially due to commercial telecommunication operators adding AIS to the payloads.

This study shall consider these and other relevant issues and establish the needs and requirements for the next-generation integrated environmental information products and services for the Polar Regions, and associated high-level requirements for space based systems responding to these.

Current and planned polar-orbiting EO space systems (e.g. MetOp, CryoSat-2, Sentinel-1 and ICESat-2) are and will be providing important data sets and services addressing some of the challenges, but the demand for new information as well as better detail and timeliness of information requires enhanced monitoring capabilities for the Polar Regions. In considering these, the concept of integrated observing systems shall be applied, i.e. data sets from different techniques (possibly not only spaceborne), missions and different sources are collected and combined in a coordinated manner to address information needs. These data sets can be integrated to obtain a more complete and comprehensive picture of the Earth system and underlying processes that would be beyond the capabilities of single satellite missions.

ESA has traditionally engaged in addressing scientific issues related to the Polar Regions, e.g. with the CryoSat mission. Now, wider European EO operational capabilities are being rapidly put in place, starting with the first Sentinel mission (Sentinel-1A), launched in April 2014. The missions that shall provide long-term stable, robust streams of EO data in a reliable manner include:

- The Copernicus Sentinels
- The meteorology/climatology missions part of the International Joint Polar System, namely the MetOp series of satellites
- The Copernicus contributing missions
- Earth Explorer follow on missions that may be realised in other frameworks from the ones above.

These operational missions will provide a solid basis from which the next-generation operational satellite missions can be designed. These additional missions would provide rich and valuable synergetic EO measurements resulting in novel synergetic data products and complementary data sets, which would be able to respond to scientific and operational needs not addressed thus far.

A separate EO system study is anticipated for start later in 2015 based on the results of this study, as they become available, in order to elaborate detailed mission concepts analysis

4 POLARIS OBJECTIVES

The objectives of the Polaris study are to:

- Review, identify and consolidate user community environmental information requirements for the polar regions,
- Establish consensus and endorsement for these requirements via close dialogue with key user representative bodies across the user categories in scope
- Identify information gaps considering existing and planned EO and integrated (EO/nav/telecom) systems, space and non-space based
- Consolidate and prioritize information gaps together with key user representatives bodies
- Establish a set of endorsed, high-level mission requirements reflecting the gaps in connection and dialog with stakeholders
- Identify potential new integrated information services possibly provided by synergetic use of space assets (EO, navigation and telecommunications etc.)
- Perform a preliminary assessment of the high-level operations requirements for supplying these integrated services.

In the long-term the project aims at stimulating the development of novel space mission concepts for the Polar regions that may exploit new and existing European operational capacity in order to address in a cost-effective manner new scientific and operational information needs.

5 RELEVANT DOCUMENTS

5.1 Reference documents

RD1	Earth Observation Science Strategy for ESA: A new Era for Scientific Advances and Societal Benefits (ESA SP-1329, 2015)
RD2	Sea-Ice monitoring, GLOBAL SATELLITE OBSERVATION REQUIREMENTS FOR FLOATING ICE by John Falkingham (http://nsidc.org/noaa/iicwg/docs/IICWG-2014/Global-Satellite-Observation-Requirements-for-Floating-Ice-Final.pdf)
RD3	ESA EO Convoy Studies: Earth Observation Capabilities, Gaps and Opportunities, EOSC-ASU-RP-001 Issue 3 Revision 0 (http://congrexprojects.com/2013-events/13m12/measurement-gap-analysis)
RD4	Snow Monitoring White paper prepared by the Group of European Satellite Snow Monitoring Perspectives), http://www.globsnow.info/docs/White_Paper_European_Satellite_Snow_Monitoring_25062014.pdf
RD5	IGOS-P Cryosphere Theme requirements document, WMO/TD-No. 1405, Aug 2007. (http://globalcryospherewatch.org/reference/documents/files/igos_cryosphere_report.pdf)
RD6	2014 SCAR Antarctic and Southern Ocean Science Horizon Scan (http://www.nature.com/news/polar-research-six-priorities-for-antarctic-science-1.15658)
RD7	Final Report - Workshop on Future Directions for Arctic Research (http://www.arcus.org/logistics/2013-workshop/report)
RD8	A community white paper in response to the WMO Polar Space Task Group (PSTG), Requirements for Monitoring of Permafrost in Polar Regions (https://www.dropbox.com/s/w6i6dlmt1b3kiw8/WMO_PSTG_permafrost_recommenadtions_final-1.pdf?dl=0)
RD9	Lloyd's, Arctic Opening: Opportunity and Risk in the High North, Chatham House, (http://www.chathamhouse.org/publications/papers/view/182839)
RD10	Laurence C. Smith and Scott R. Stephenson (2013), New Trans-Arctic shipping routes navigable by midcentury, PNAS, (www.pnas.org/cgi/doi/10.1073/pnas.1214212110)
RD11	Outline of a Technical Solution to a Global Cryospheric Climate Monitoring System, (http://www.nr.no/en/nrpublication?query=/file/4403/Solberg_-_Outline_of_a_Technical_Solution_to_a_Global_Cryosp.pdf)
RD12	Strategic Arctic Impact Assessment of Development of the Arctic (http://www.arcticinfo.eu/en/sada)
RD13	ESA-CliC Cryosphere Workshop on snow (http://www.congrexprojects.com/2014-events/14c19/workshop-report)
RD14	The Polar Communication and Weather Mission: Addressing remaining gaps in the Earth Observing System, by Louis Garand, Alexander P. Trischenko, Larisa Trischenko, and Ray Nassar
RD15	WWRP Polar Prediction Project Implementation Plan WWRP/PPP No. 2 – 2013 – (http://www.polarprediction.net/fileadmin/user_upload/redakteur/Home/Documents/WWRP-PPP_IP_Final_12Jan2013_v1_2.pdf (see pg. 38 – link to space agencies))
RD16	2014 Meeting of the IICWG (http://nsidc.org/noaa/iicwg/meetings.html#iicwg-15)
RD17	WMO PSTG reports (http://www.wmo.int/pages/prog/sat/pstg_en.php)
RD18	SSA-SWE-RS-RD-0001, I1r4 (http://swe.ssa.esa.int/DOCS/SSA-SWE/SSA-SWE-RS-RD-0001_i1r4.pdf)

6 SCOPE

6.1 User communities

The following key polar user community categories are within the scope of the Polaris study (non exhaustive examples):

User community category	Community member examples	User representative bodies (examples)
Scientific research groups (Earth science and climate research)	Universities, science laboratories, national institutes etc.	WMO-WWRP PPP, WCRP-CliC, Global Cryosphere Watch
Governmental organizations and working groups	Coast guards, Navies, civil protection, national meteorological and hydrological services/institutes, etc.	Arctic Council working groups (PAME, AMAP), International Maritime Organization (IMO), International Ice Charting Working Group (IICWG), European Maritime Safety Agency (EMSA), European Fisheries Control Agency (EFCA)
Industry	Oil and Gas, Mining, Shipping, Tourism etc.	OGP, IAATO, AECO
Non-governmental organisations involved with polar environment	Environmental interest groups, foundations, UN bodies etc.	TBD

6.2 Geographic scope

In this study the Polar Regions shall for the purpose of this study include all regions at latitudes greater than 55 N and 55 S latitude, which are considered to be outside of the regions of coverage provided by geostationary satellites.

6.3 Thematic scope

The following environmental information parameters are within the scope of the Polaris study

- Ocean parameters (sea surface temperature, salinity, currents and circulation, roughness, sea state, colour etc.)
- Sea-ice parameters (marginal ice zones, ice edge characterisation, ice motion, freeze thaw cycles, etc.)

- Atmospheric parameters (chemistry, composition and meteorology e.g. clouds, water vapour, atmospheric motion, ozone, aerosols etc.)
- Land surface parameters (land surface type, snow cover, albedo, permafrost, etc.)
- Ice sheet parameters (ice elevation, thickness, surface type, albedo, surface temperature etc.)
- Ice shelf parameters (ice front position, thickness, calving rate, etc.)
- Interaction and coupling between geophysical parameters
- Vessel and oil spill monitoring
- Space weather and its impact on activities in the polar region.

7 POLARIS TASKS

7.1 Task objectives

The overall objective of the tasks include the identification and consolidation of environmental information needs and priorities within relevant Polar user communities, current state of the art in term of EO use and of utilisation of supporting space techniques for navigation and telecommunications, gaps analysis, PEST analysis for future needs identification, and elaboration of high level observation requirements that could fill these information gaps.

Both scientific challenges [RD1, RD5, RD6, RD7, RD8], and operational needs derived from governmental, non-governmental and industrial organizations [RD 2, RD4] shall be considered. The socioeconomic impacts realized by closing information gaps shall also be analysed.

The objectives of each task are as follows.

Task 1: Information needs gathering

Establish a clear and credible description of the current and future environmental information needs for key user communities in the Polar Regions including operational, institutional, research users of both Artic and Antarctic regions. This task will involve close dialogue with key individual users to document their current and future information needs. Structured individual input will form the basis for a needs consolidation exercise. Key user representative bodies shall be engaged in establishing a clear and consolidated consensus for what represents key needs for different user sectors

Task 2: Gaps and impact analysis

Based on the consolidated needs identified in Task 1, Task 2 shall define the gaps taking into account existing and planned observation systems (space and non-space). Previous studies [e.g. RD 3] have addressed this issue and shall be thoroughly taken into account as part of the analysis. The main output of this task will be a preliminary set of new (EO based) products and innovative integrated services, which cannot be realized with current and planned future satellite missions. In this context an integrated service shall be considered as a solution combining space based EO observations with in-situ measurements, modelling tools etc., in addition to exploiting other space based capabilities such as telecoms, navigation, AIS etc. in order to meet user requirements. These new services shall become the input for defining preliminary high-level operations requirements for future space missions as part of Task 3. Key in this analysis will be to identify which gap-fillers will provide the highest socioeconomic benefit and impact given trends and drivers in the Polar Regions.

Task 3: Preliminary observation requirements analysis
Based on the gap analysis, and identified products and integrated services, high-level observation requirements shall be identified and analyzed. Preliminary data products shall be defined in-line with most promising integrated services for further development in a separate system study.

8 PRELIMINARY STUDY FINDINGS

8.1 Information Gaps

Table 1 identifies the primary gaps in existing environmental information in meeting user needs (i.e. existing products/services do not fully address needs) that were found from the literature review and consultations. These are broken down by parameter theme (along the left of the table) and parameter type (across the top of the table). Highlighted cells show where there is a shortcoming in the existing information (for example, in terms of spatial or temporal resolution), or where there are concerns about data continuity or coverage.

Information deficiencies can be addressed in two ways: i) by providing more capable earth observation technology (mission concepts), and/or by improving how well the overall information acquisition and delivery systems works (system concepts). These are examined in the following sections.

The key environmental information gaps can be summarized in the following way:

- Environmental information Gaps supporting Polar earth sciences

  Despite considerable research progress in understanding the Arctic region over the last decade, many gaps remain in observational capabilities and scientific knowledge. These gaps limit present ability to understand and interpret on-going processes, prediction capabilities and forecasting in the Arctic region, thereby hampering evidence-based decision-making. Amongst these sea-ice and ice sheet mass balance were identified as high priority gaps, both hampered by uncertainties represented by the difficulty in estimating varying snow cover and snow properties. Sea-ice thickness influences the heat flux between the atmosphere and the ocean surface and ice sheet (in particular Antarctica) mass balance measurements are key to understanding and predicting sea level fluctuations. Improving the knowledge of terrestrial snow, lake ice dynamics, permafrost extent and biodiversity were also highlighted as areas were significant gaps exist.

- Environmental information Gaps supporting Polar operations

The dominant information gaps in operations are mainly driven by the need to have improved sea-ice and iceberg information for tactical operations. This will require more detailed sea-ice and iceberg classification products at a higher temporal resolution than currently available. Sea-ice thickness, stage of development, structure, motion, extent and topography were identified as parameters were significant gaps exist. In addition, having more accurate sea-ice snow information will be required to reliably establish these information parameters. The ability to detect and forecast iceberg motion is another capacity which is key to the communities carrying out Polar operations, and linked to this is of course the issue of improved Polar weather predictions (especially wind).

8.2 Mission Concepts

A number of aspects of earth observation missions can be varied in order to better meet the needs of polar data users. Some examples of mission concept attributes that have emerged from the study include:

Sensors

- Active Microwave
    - Multi-frequency (a combination of C,L,X,Ku)
    - Multi-polarization, cross polarization (H, VV, HV, VH, consider circular)
    - Integrated AIS
- Altimeter
    - Radar, Lidar
- Radiometer
- Gravity
- Optical
- Hyper/Multi-Spectral

Table 1: Polar Information Gaps

Parameter Type

Parameter Theme	Ice Thickness	Extent	Structure/Age	Snow Depth	Freeze-Thaw	Topography	Mass Change	Motion	Iceberg Calving	Surface State/Albedo	Grounding Line	Elevation Change	Snow Water Equivalent	Location	Size	Ice Dammed Lakes	Salinity	Wind	Waves	Chemistry/Particulates	Biota	Temperature	Precipitation/Clouds/Humidity	Vegetation/Land Cover
Sea Ice	■	■	■	■	■	■		■		■														
River and Lake Ice	■	■	■		■																			
Ice Sheets	■			■			■	■	■	■	■													
Glaciers	■	■	■	■		■	■	■	■	■						■								
Snow		■	■	■	■					■			■											
Icebergs		■						■	■					■	■									
Permafrost		■			■				■	■		■								■				
Ocean																	■	■	■		■	■		
Land										■											■			■
Atmosphere																		■		■		■	■	

Performance

- Spatial resolution – (high resolution plus wide swath)
- Low Revisit time (at least daily)
- Vary revisit time of day
- Low Latency
- Complete coverage
- Mission continuity
- Operational systems

Orbits

- Tandem (active + passive, along track and cross track)
- Constellation (small sats)
- True polar coverage

8.3 System Concepts

However, an end-to-end data service value chain includes much more than just data acquisition by an earth observation satellite. The value of the end-product may also depend on the attributes of data analysis, discovery, access, and dissemination. Such issues mentioned in the consultations include:

- Better integration of data parameters (space, in-situ, analysis)
- Better discovery and dissemination of information
- Integration of data with computation capacity
- Data visualization
- Delivering data over low bandwidth channels (such as to ship bridges)
- Reducing latency (the time from acquisition to delivery) and near-real-time delivery of products
- Vessel identification & tracking integration
- Indication of the uncertainty/quality of information
- Open web service links to data
- Data archive access
- Licensing agreements to make more EO data available to the community at lower cost
- Better metadata
- Training and education

8.4 Product and Service Concepts

Many end users are not in a position to work directly with earth observation data. Rather, they need products and services that provide the processed information that they require. Examples of such products that are not currently available or do not fully meet user needs include:

- Ice thickness at high spatial resolution
- Ice age and stage of development
- Snow depth on ice
- Melt and freeze onset for lake ice and river ice
- Detection of icebergs in sea ice
- Detection of iceberg calving
- Weekly mass balance changes for glaciers and ice sheets
- Snow water equivalence
- Consistent vegetation information – structure, biomass, health

9 FUTURE WORK

The remaining tasks in the project are:

- **Impact Analysis**: Assess the socioeconomic and environmental implications of implementing the most promising systems.

- **Legal and Political Implications**: Assess the potential legal and political implications of implementing the most promising systems.

- **System Analysis**: Define preliminary integrated systems for further development in a separate system study.

AOS 2016 - Short Statement

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Designing a Regional Seas Arrangement for the Arctic Ocean: Legal, Scientific and Observational Support

Regional Seas arrangements (RSAs) exist for over a dozen of the world's marine regions but not yet for the Arctic.[i] Legally binding conventions form the basis for many of these RSAs, which rely on science input to help member states fulfill their legal obligations to monitor and assess the state of the marine environment in their region. In May 2015 the Arctic Council established a Task Force on Arctic Marine Cooperation (TFAMC). The Task Force's mandate includes assessing the need for a mechanism to "coordinate efforts to improve scientific understanding of Arctic marine areas."[1] An RSA may prove the most politically acceptable platform for such cooperation. Alternatively, an independent science coordination agreement could emerge as a more likely platform for science cooperation.

This paper proposes substantive and structural elements of a negotiating draft for a possible science coordination agreement, either related to or independent of an RSA

Designing an Arctic Ocean RSA presents a prime opportunity to better coordinate observational, monitoring and assessment science from around the Arctic, for use in policy and management decisions. A scientific advisory body to the Arctic RSA would not create a new science body but rather be a forum for existing Arctic and ocean science groups to share information and advise Arctic Council members, Permanent Participants and Observer states. The advisory body could draw on the work of IASC, the ocean science organizations ICES and PICES[ii] and the Sustained Arctic Observing Network (SAON).

Other RSAs offer good models for promoting ocean science and basing decisions on it. The North-East Atlantic and the Baltic are relevant models and supported by legally binding agreements known respectively as the OSPAR and HELCOM Conventions.[iii] OSPAR, to which all five of the Scandinavian Arctic States are party,[iv] includes clear environmental conservation goals and mandates, and covers a significant portion of the Arctic Ocean.[v] HELCOM activity includes monitoring and evaluating environmental indicators.

OSPAR and HELCOM cooperate on a range of scientific matters including biodiversity indicators,[vi] Marine Spatial Planning, Marine Protected Areas,[vii] and Ecosystem Based Management.[viii] Monitoring protocols for marine pollution developed under OSPAR's Joint Assessment and Monitoring Program (JAMP) could serve as best practices for Arctic RSA members. Such inter-treaty cooperation offers structures with which an Arctic RSA could network and substantive areas for scientific cooperation to inform Arctic Ocean policy around the Noth.

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[1] Arctic Council, Iqaluit Declaration, Ninth Ministerial Meeting of the Arctic Council, Iqaluit (Canada), 24 Apr. 2015, p.4, available at http://www.arctic-council.org/index.php/en/document- archive/category/604-declaration-sao-report, at p. 5.

A 2013 study of Europe's four regional seas conventions – HELCOM, OSPAR, the Bucharest Convention (Black Sea) and the Barcelona Convention (Mediterranean)[ix] –identified Integrated Monitoring and Assessment, and Data Collection and Reporting as two areas in which strong mechanisms exist internally that are also prime candidates for greater governmental support to create a robust and consistent protection of the larger marine region. This focus on monitoring, assessment and reporting also provides a logical link to science bodies active in the region.

- The two scientific international organizations especially relevant to the Arctic Ocean are ICES (North Atlantic) and PICES (North Pacific). All eight members of the Arctic Council are among ICES' twenty-state membership, as are the six Arctic Council Observer states.[x]
- ICES' cooperation with PICES includes their first joint working group in 2009 on the climate change impacts on fish and fisheries, and collaboration on Arctic Ocean issues, including integrated ecosystems assessments. [xi] ICES maintains working relationships with the AMAP, CAFF and PAME Arctic Council Working Groups, as well as the decadal International Conference on Arctic Research and Planning (ICARP) and the International Arctic Science Committee (IASC).
- An Arctic RSA that coordinates national measures for protection of the marine Arctic could also work with its member states to coordinate their participation *as Arctic States* in each of these scientific forums. An eventual role for an Arctic RSA could be to serve as a similar science cooperation body for the Arctic Ocean; an Arctic ICES, so to speak. This would provide geographic coverage not only of the Arctic Ocean but also, by linking with PICES and ICES, of the two oceans that connect it to the world ocean. In addition, ICES already uses strategic partnerships to extend its work into the Arctic, the Mediterranean Sea, the Black Sea, and the North Pacific Ocean.[xii]
- The ongoing negotiations of a science cooperation agreement under the auspices of the Arctic Council, as mandated at the 2013 Kiruna Ministerial, will also need to inform any scientific cooperation role for an Arctic RSA.

ENDNOTES

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[i] Tullio Treves, "Regional Approaches to the Protection of the Marine Environment", in M. H. Nordquist/J.N. Moore/ S. Mahmoudi, eds, The Stockholm declaration and law of the marine environment (2003), 137-154.

[ii] International Arctic Science Committee (IASC), the International Council for the Exploration of the Seas (ICES), and the North Pacific Marine Science Organization (PICES).

[iii] The Oslo/Paris (OSPAR) Convention on the Protection of the Marine Environment for the North-East Atlantic, and the Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea, which created the Helsinki Commission or HELCOM as its governing body. Through HELCOM all nine bordering states and the European Union work together to prevent and reduce pollution in the Baltic Sea. Six states are either Arctic Council members: Denmark, Finland, Russia and Sweden; or Arctic Council observers: Germany and Poland. The EU's membership in HELCOM indirectly encompasses five more of the Arctic Council observer states: France, Italy, The Netherlands, Spain, and the United Kingdom.

[iv] Denmark, Finland, Iceland, Norway, and Sweden. The OSPAR Secretariat is in ongoing discussions with the Russian Federation about closer collaboration. According to Molenaar: "While no such accession has yet occurred, the OSPAR Commission has had some discussions on accession by the Russian Federation," Erik J. Molenaar, Current and Prospective Roles of the Arctic Council System within the Context of the Law of the Sea, in *The International Journal of Marine and Coastal Law 27 (2012) 553–595,* at 568.

[v] OSPAR Region 1, Arctic Waters, encompasses the east coast of Greenland, the Russian/Norwegian boundary in the Barents Sea and all of Iceland, the Faroe Islands and Svalbard. http://www.ospar.org/content/content.asp?menu=00420211000000_000000_000000.

[vi] ICES background paper on OSPAR/HELCOM biodiversity indicators project https://portal.helcom.fi/meetings/CORESET%20II%2022014%20joint/Meeting%20documents%20joint%20meeting/2-3%20ICES%20background%20information.30.09.2014.pdf

[vii] JOINT MINISTERIAL MEETING OF THE HELSINKI AND OSPAR COMMISSIONS (JMM), BREMEN: 25 - 26 JUNE 2003, Agenda item 6 JMM 2003/6-Rev.1-E, Joint HELCOM/OSPAR Work Programme on Marine Protected Areas.

[viii] Milieu Law and Policy Consulting, Analysis of Regional Sea Convention needs ensuring better coherence of approaches under the Marine Strategy Framework Directive, Final Report, 8 November 2013, p. 24, available at https://webgate.ec.europa.eu/maritimeforum/sites/maritimeforum/files/Final%20Report_RSC%20needs.pdf.

[ix] Convention for the Protection of the Mediterranean Sea against Pollution, signed in Barcelona 16 February 1976, in force 12 February 1978, revised in Barcelona, Spain, on 10 June 1995 as the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean.

[x] Arctic Council Observers who are also ICES members: France, Germany, the Netherlands, Poland, Spain and the United Kingdom.

[xi] Molenaar, Arctic Fisheries and International Law: Gaps and Options to Address Them, Carbon and Climate Law Review, CCLR 1|2012, 63-77, at 71 in footnote 71, adds that the two convened the “PICES/ICES Workshop on Biological Consequences of a Decrease in Sea Ice in Arctic and Sub-Arctic Seas” in May 2011. The Report of this Workshop is available via the ICES website on the Internet at <www.ices.dk> under Doc. ICES CM 2011/SSGHIE:14 (last accessed on 15 February 2012).“ See also ICES Science Plan 2009-2013, http://ices.dk/community/Documents/SCICOM/ICES%20Science%20Plan%202009-2013%20formatted.pdf, at 15**;** ICES/PICES Symposium on "Ecological basis of risk analysis for marine ecosystems" 2-4 June 2014, Porvoo, Finland (Scientific justification available at http://www.ices.dk/news-and-events/Documents/Symposia/20113SSGSUE02%202014%20Ecological%20basis%20of%20risk%20analysis%20for%20marine%20ecosystems.pdf.

[xii] See http://www.ices.dk/explore-us/who-we-are/Pages/Who-we-are.aspx.

White Paper
Arctic Observing Summit, Fairbanks, March 2016

CACCON and Partner Knowledge Networks:
Arctic Coastal Engagement Network of Future Earth Coasts

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Abstract

The Circumpolar Arctic Coastal Communities Observatory Network (CACCON) functions as the Arctic Regional Engagement Network for Future Earth Coasts. In partnership with other Arctic knowledge networks and programs, including the Exchange for Local Observations and Knowledge of the Arctic (ELOKA) and Arctic-COAST, CACCON promotes consensus and collaboration to advance local knowledge availability and accessibility for adaptation planning and sustainable development in Arctic coastal communities and regions. Components of the CACCON agenda include: integrative analyses of sustainability challenges in Arctic coastal communities using co-developed situational and sustainability indicators; solutions-oriented research for actionable, proactive adaptation policies in Arctic coastal communities; sharing insights among existing community-based research and resilience programs; responding to community-based agendas and building resilience by growing local and regional knowledge co-production and dissemination capacity. These activities support the Global Coastal Futures initiative of Future Earth Coasts, rooted in the Future Earth principles of co-design and co-production of knowledge involving a broad cross-section of stakeholders and consensus-building on pathways for transformation to more sustainable strategies for enhanced present and future well-being on Arctic coasts.

Introduction

This paper addresses the challenges of rapid environmental and social change in the Arctic coastal zone and the information needs of residents and other stakeholders for effective decision-making that supports sustainability goals. It reports on a number of interrelated initiatives that seek to support transitions to more sustainable pathways in the circumpolar Arctic and global coastal zone. A common thread is the recognition that access to critical knowledge synthesizing information from multiple sources at appropriate scales can enhance the ability of individuals and institutions to respond to or proactively prepare for coastal change.

Arctic Coasts and Coastal Communities

The circum-Arctic coastal zone is the locus of complex interactions among marine, terrestrial, and atmospheric processes. It is a key interface in the Arctic environment, a focus of human habitation and activity, a rich band of biodiversity, high productivity, and critical habitat, and among the most dynamic components of the northern landscape. Thus the coast and residents who depend upon it are particularly sensitive to ongoing and projected environmental change, exacerbated by anthropogenic stressors[1].

Arctic and sub-Arctic Inuit communities are almost exclusively located in coastal settings that provide access to marine and terrestrial food resources, transportation and communication corridors, and culturally significant landscapes. These coastal communities and their critical infrastructure are also exposed to a range of coastal and marine hazards in addition to other landscape hazards common throughout the permafrost regions of the circumpolar Arctic. Combined with challenges of economic and social development, demographics, globalization, mixed cash and non-cash economies, maintenance of linguistic and cultural integrity, health, and well-being, the already-noticeable effects of environmental change are an added source of uncertainty and concern. Food security in many communities is dependent on access to country food, the harvesting of which entails interaction with the changing physical environment in ways that depend, for example, on the continued viability of travel on ice. There are direct connections between environmental change and measures of well-being such as fate control and food security. Communities and industrial operators in the north are also sensitive to ice and weather conditions and require timely and accurate observations and forecasts to conduct activities in a way that maximizes opportunity while minimizing risk. In the near-absence of road connections, northern communities are particularly affected by impacts on aviation and sealift operations. Coastal archaeological sites in Arctic Canada are also under threat, with important knowledge of the region's history and prehistory potentially lost to erosion. Climate change will exacerbate existing coastal hazards, leading to more rapid loss of archaeological resources and culturally significant sites in the future. All of these factors represent potential vulnerabilities and challenges to health and safety, community resilience, cultural integrity, sustainability, and well-being.

The *State of the Arctic Coast 2010* report[1] included the following recommendations:

- The need for an integrated approach to Arctic coastal change;
- The value of recognizing Arctic coasts as complex social-ecological systems;

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[1] Forbes, D.L. (ed.), 2011, *State of the Arctic Coast 2010 – Scientific Review and Outlook* (www.arcticcoasts.org).

- The value of combining western science and traditional ecological knowledge for enhanced understanding of change;
- The importance of integrating co-produced knowledge into Arctic policy and decision-making.

This vision paper is based on the conviction that an integrated, collaborative, and holistic approach to monitoring, understanding, and managing the many sources of change in northern communities, working closely with community researchers and knowledge-holders, is a key to local empowerment and sustainable development for present and future generations

CACCON

The Circumpolar Arctic Coastal Communities Observatory Network (CACCON) was initiated in 2014 as an ICARP-III[2] activity of the International Arctic Science Committee (IASC) and a regional engagement initiative of LOICZ (now Future Earth Coasts). It was launched as a pilot in Canada in 2015 with funding from the ArcticNet Network of Centres of Excellence. CACCON aims to foster a web of community-engaged, locally directed, multifaceted, and integrative coastal observatories (knowledge production centres and hubs). It is founded on the premise that co-designed and co-produced knowledge in the hands of decision-makers is the key to successful adaptation and resilient communities. The challenge is to determine what knowledge is required, where and how it can be sourced (including local traditional and purpose-developed knowledge), and how it can be made readily available when and as needed.

An important opportunity arises when knowledge can be shared with partners across the network to enhance co-learning and realize the benefits of this collaborative effort (see *SmartICE* example below). In recent years, there has been a rapid expansion of interest and activity in community-based monitoring (CBM) in the Arctic. Residents, northern communities, researchers, and policy-makers have increasingly come to appreciate the strengths of CBM in local resolution and detail, potential for continuity, integration of traditional knowledge, capacity-building and, above all, relevance to community knowledge-gap priorities. However, as noted in a recently published review of Arctic CBM for the 2013 Arctic Observing Summit, “CBM initiatives remain little-documented and are often unconnected to wider networks, with the result that many practitioners lack a clear sense of the field and how best to support its growth and development” (Johnson et al., 2015)[3]. CACCON specifically aims to build capacity through sharing experience between stakeholder peers across the circumpolar world, to help identify information needs and transformational insights.

The CACCON agenda includes the following:

- Integrative analyses of sustainability challenges in Arctic coastal communities using co-developed situational and sustainability indicators;
- Solutions-oriented research for actionable, proactive adaptation policies in Arctic coastal communities;
- Sharing insights among existing community-based research and resilience programs;

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[2] Third International Conference on Arctic Research Planning, Toyama, Japan, April 2015

[3] Johnson, N., Alessa, L., Behe, C., Danielson, F., Gearheard, S., Goffman-Wallingford, V., Kliskey, A., Krümmel, E.-M., Lynch, A., Mustonen, T., Pulsifer, P. and Svoboda, M. 2015. The contributions of community-based monitoring and traditional knowledge to Arctic observing networks: reflections on the state of the field. *Arctic*, 68, Supplement 1, 28-40.

- Responding to community-based agendas and building resilience by growing local and regional knowledge co-production and dissemination capacity – thematic pilot focused on landfast ice;
- Serving as an Arctic Regional Engagement Network for Future Earth Coasts.

The seed network for CACCON includes communities in Canada, Greenland, Norway, Russia, and the USA. As specific funding has thus far been available only in Canada, the Canadian component of CACCON is currently underway as a pilot with support from the ArcticNet Network of Centres of Excellence. CACCON activities in Canada include community-science initiatives in Nain (Nunatsiavut), Pond Inlet (Nunavut), and Arviat (Nunavut). CACCON partners are engaged with independent community-based knowledge initiatives in the Inuvialuit Settlement Region (ISR) (Northwest Territories and Yukon) and Clyde River (Nunavut), among others. Community-defined sustainability issues range from coastal hazards and shore protection in the ISR and Hall Beach (Nunavut) to safe and healthy homes in Nunatsiavut, community infrastructure planning and decision-making in Arviat (Nunavut) and Nunatsiavut, and safety of travel on landfast ice in Nain (Nunatsiavut) and Pond Inlet (Nunavut). These issues among others resonate in other communities and with territorial government agencies focused on climate-change adaptation, health, and community planning and engineering services.

Two examples of CACCON prototype activities

SmartICE

Arctic climate change will result in landfast ice that is thinner, forms later and breaks up earlier than before, resulting in increasingly more dangerous over-ice travel and less reliable traditional knowledge of safe routes based on past climatic conditions. Considering that the majority of residents in Arctic communities use sea ice to access country foods and maintain cultural and family activities, increased risk or fear of travelling on the ice has severe repercussions for food security and physical and mental health. At the same time, changes in sea-ice conditions are creating longer shipping seasons while natural resource economics are driving the demand for winter shipping. Consequently, there is an urgent need to understand the emerging implications of changing shipping trends for local communities and local sea-ice users.

SmartICE (Sea-ice Monitoring and Real-Time Information for Coastal Environments) is a community-academic-government-industry collaboration that seeks to address the limitations in technologies and services currently used to map coastal sea-ice conditions. Most importantly, through technological innovation and science, the initiative strives to integrate and augment *Inuit Qaujimajatuqangit* (Inuit knowledge and values) about local sea-ice conditions, not replace it. The overall goal of *SmartICE* is to develop an integrated, near real-time monitoring and dissemination system that informs decisions about coastal sea-ice travel and shipping, thereby improving safety. We are currently piloting *SmartICE* technologies and operations in Nunatsiavut (Nain) and Nunavut (Pond Inlet). Although primarily designed to support ice-travel safety, *SmartICE* observations may also inform winter fishery and harvesting programs, search-and-rescue operations, climate change adaptation planning, ecosystem monitoring, and sea-ice technology validation. *SmartICE* directly involves northern partners and communities in all aspects of the project including Inuit training Inuit across the project regions.

Adverse marine weather in the eastern Beaufort Sea – Gathering community and end-user input

The Marine Environmental Observation, Prediction and Response (MEOPAR) Network of Centres of Excellence and Transport Canada are funding a three-year project focused on weather impacts and their associated adverse effects on marine transport in the Eastern Beaufort Sea region. Transportation in this context includes travel in all sizes of vessels, from small craft used for subsistence activities to sea-lift barges and cruise ships supporting tourism. The objective is to have coastal communities, industrial/marine shippers, and operational/emergency response groups identify specific occurrences of problematic weather or wave events that have interfered with their activities. These occurrences are linked to broader atmospheric patterns, to make that large-scale to local-scale connection that national forecast services are interested to see and challenged to address.

Three communities in the Inuvialuit Settlement Region (Sachs Harbour, Tuktoyaktuk, Ulukhaktok) are participating in the study. It is hoped that this project will help to develop community resilience in the face of longer-term changes in the weather and will contribute to an understanding of how local weather relates to larger-scale climatic trends.

Future Earth Coasts[4]

Future Earth Coasts (formerly LOICZ[5]) is a core project of Future Earth. Future Earth is a new global research platform designed to provide the knowledge needed to support transitions toward sustainability, enabling people to thrive in a sustainable and equitable world. To support a human population of ~9 billion by 2050, we will need a globally shared vision and pathway to this more sustainable world, facing up to the challenges and knowledge needs that it will entail. The core project Future Earth Coasts is responding to the need to co-design and co-produce a new type of science that links disciplines, knowledge systems, and societal partners to tease out and reproduce the ingredients of success and confront inhibitors that promote adoption or continuation of unsustainable practices at the coast.

- *The 2050 agenda of Future Earth Coasts is to institutionalise a process for assessing the global status of our coasts and identifying innovative solutions for policy makers, practitioners, the market place, and civil society to enhance stewardship, well-being, and sustainability in our relationship with the coastal zone.*

This is undertaken in the context of the recently adopted Sustainable Development Goals (SDGs)[6]. These define many aspects of a more secure, just, and liveable future, but have fallen short of articulating the specific risks and opportunities of living on the coast. Bridging this gap between the

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[4] Much of this section is taken directly from an overview document *Future Earth Coasts – Setting the Agenda*, 2015, (Future Earth Coasts IPO, Cork, Ireland), authored by Martin LeTissier, Val Cummins, Bruce Glavovic, Ramesh Ramachandran, Michelle Mycoo, Mark Pelling, and Donald Forbes.

[5] Land-Ocean Interactions in the Coastal Zone (LOICZ) was a core project of the International Geosphere-Biosphere Program (IGBP) and the International Human Dimensions Program for Global Environmental Change (IHDP), both of which have now been superseded by Future Earth.

[6] See https://sustainabledevelopment.un.org/sdgs

ambition of the SDGs and the lived experience, political realities, and biophysical limits of the coast is an opportunity and responsibility that Future Earth Coasts aims to meet.

As a global coastal research platform, Future Earth Coasts supports a web of regional engagement networks from East and South Asia to West Africa, South America, the Caribbean and the Pacific. CACCON has been nominated as the regional engagement network of Future Earth Coasts in the Arctic. This calls for a collaborative engagement and co-learning relationship with northern residents and the many other players in the Arctic observing community. Acknowledging SDG 11 ("*making cities and other human settlements inclusive, safe, resilient and sustainable*"), CACCON aims to foster conversations and research on the components and processes that need to be encouraged, developed, and in place to move toward this goal in the Arctic coastal zone. It is our conviction that local ownership and accessibility of relevant data and knowledge are two of these key components.

The '*Global Coastal Futures*' process envisaged by Future Earth Coasts will play out in a number of ways, not least of which will be a focus on the documentation and sharing of solutions strategies (ingredients of success or failure) in the pursuit of sustainable or transformative development in coastal communities around the globe. The Coastal Futures approach also aims to deliver sharp science and policy messages of regional and multi-sectoral relevance, as well as speaking to specific local sustainable development questions. It goes beyond the description of the state of the coast ('status') to define:

- A process of inquiry that is as important as the product.
- An approach rooted in the Future Earth principles of co-design and co-production of knowledge involving a broad cross-section of stakeholders.
- Tools to develop capacity to roll out methodologies for replication at all scales.
- Consensus-building on pathways for transformation.

Obviously the Arctic is an important component of such a global initiative and may stand to gain insights from an engagement network in the circumpolar North as well as from parallel efforts in other parts of the world. This is a logical extension and application of CACCON as well as a follow-up to the *Arctic Human Development Report* and activities of the IASC Social and Human Working Group, the Exchange for Local Observations and Knowledge of the Arctic (ELOKA), the anticipated Coastal Permafrost in Transition (CPiT) working group of the International Permafrost Association, the *Arctic Resilience Report* of the Arctic Council, and the Arctic-COAST project.

Exchange for Local Observations and Knowledge of the Arctic (ELOKA)

ELOKA facilitates the collection, preservation, exchange, and use of local observations and knowledge of the Arctic. ELOKA works with community partners around the circumpolar Arctic, a network of technical practitioners, and academia to co-produce locally appropriate and effective methods and technology for sharing local observations and Indigenous knowledge. Established during the International Polar Year 2007-2008, ELOKA promotes sharing within and between Arctic communities and fosters collaboration between resident Arctic experts and visiting researchers. This work includes engaging in dialogue on how to appropriately share across knowledge domains. Most recently, the results of an ELOKA workshop were presented during the

International Polar Data Forum[7] as a summary statement which has been expanded as an Arctic Observing Summit white paper[8]. As stated, CACCON aims to foster a web of community-engaged and directed coastal observatories and knowledge hubs. ELOKA activities will complement CACCON and members, particularly in making information and knowledge readily available when and as needed. Members of each network are working to establish practical ways of collaborating and sharing knowledge, best practices and technology through hands on projects.

Arctic-COAST

This recently launched US National Science Foundation Research Coordination Network (RCN) shares goals with the CACCON and Future Earth Coasts agendas outlined above, with a specific focus on building sustainability in the Russian Arctic coastal zone.

Arctic-COAST develops the transdisciplinary science-policy-community interface between the academic domains of biophysical, socio-economic, and decision-making research and policy applications to address the resilience of coastal social-ecological systems. By integrating data-rich regional case studies, developing data management tools, and presenting information through an educational web-based portal, the network will contribute to research cyberinfrastructure in the circumpolar Arctic. Using a resilience framework as an overarching concept, Arctic-COAST will be instrumental in closing knowledge and policy gaps to foster sustainable development of Arctic ecosystems and communities.

Arctic-COAST will synthesize and disseminate knowledge about the state, dynamics and resilience of Arctic coastal SESs. To bridge existing knowledge gaps, Arctic-COAST will (1) provide systematic, synthetic knowledge about Eurasian and North American Arctic coastal SESs; (2) compile spatial, systems-based understandings of SES resilience for different geographical scales and regional contexts; (3) craft future research directions for Arctic SES resilience and ecosystem stewardship, focusing on governance issues; and (4) foster a new generation of scientists, policy and decision makers capable of adaptive management. Arctic-COAST will fund regular meetings and workshops to promote exchange, collaboration, training and educational opportunities for scientists, early career and indigenous scholars, students and local community members.

Arctic-COAST comprises five working groups:

1. Monitoring Change in Social-Ecological Systems;
2. Resilience of Arctic Communities;
3. Governance and Adaptation;
4. Arctic Futures (Scenarios);
5. Young Arctic Leaders in Research and Policy.

Key questions driving the network include the following:

- What are the major changes and drivers within coastal social-ecological systems in the western Russian Arctic vis-à-vis other Barents and polar regions?
- What are the most important elements to measure or monitor to understand impacts and responses within coastal social-ecological systems and assess their resilience?

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[7] http://www.polar-data-forum.org/

[8] Original statement: http://bit.ly/1Ow9TMF [insert reference to AOS white paper when available]

- What experience is available in the Russian Arctic with respect to observations and community-based monitoring?
- What are viable avenues to connect data and knowledge with governance, particularly on the Russian Arctic coast?

Next steps

We aim to facilitate face-to-face and virtual meetings among CACCON communities at neighbouring, regional, national, and pan-Arctic (network-wide) scales. A prime objective is the encouragement of peer-to-peer capacity transfer, exemplified by the Nain to Pond Inlet connection under *SmartICE*. Opportunities for such interaction will arise in conference side meetings, such as at the Arctic Observing Summit (AOS) in 2016, and future AOS, Arctic-COAST, ELOKA, CpiT, or other meetings.

More directly, through targeted network development, regular voice and video-link communications, a network web hub, and the establishment of local or regional working groups, we hope to promote the CACCON goals of co-designed and co-produced knowledge acquisition and sharing to support sustainable development practices in northern settlements. This includes the identification and plugging of critical knowledge gaps through collaborative research involving local and/or indigenous leads, community research champions and teams, and collaboration with external researchers and data sources such as satellite imagery, census data, circumpolar compilations, or other publicly available data.

As the Arctic regional engagement network for Future Earth Coasts, CACCON and partners will provide a platform for the exploration of community, institutional, or governance challenges for adaptation planning and decision-making. One objective would be to identify ‘bright spots’ (and perhaps ‘grey spots’ or even instructive ‘dark spots’), around which small working groups, largely composed of local knowledge-holders, can be organized to tease out the enablers and inhibitors of success. Understanding the strengths and weaknesses of innovation will be a major goal. A range of approaches may be applied as appropriate, from indicators to social/institutional/decisions mapping to narrative insights, with parallel co-produced documentation on the social and biophysical context and challenges in various locations or regions. A key goal is to work out and share solutions strategies that show promise in one or several locations and may be replicated, or further developed, in others.

The CACCON objectives and those of Future Earth Coasts, as noted earlier, call for collaborative engagement with northern residents and the many other players in the Arctic observing community. Working with knowledge-network partners ELOKA and Arctic-COAST, community-based observing networks such as the Alaska Arctic Observatory and Knowledge Hub (A-OK), the Bering Sea Sub-Network, or other key players such as the Inuit Circumpolar Council, Inuit Qaujisarvingat (Inuit Knowledge Centre), and the Coastal Expert Monitoring Group (Coastal Biodiversity Monitoring Program), CACCON promotes consensus and collaboration to reach common goals of local knowledge availability and accessibility for informed decision-making and improved well-being in northern coastal places.

White Paper
on
The Need for Sustaining Observations in the North Pole Region

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North Pole as an Indicator of the Changing Arctic Ocean

Sustained observations of environmental conditions in the North Pole region, nominally north of 84°N, are critical to understanding changing Arctic Ocean sea ice and circulation and their connections with global climate. The Transpolar Drift is the main conduit of sea ice and freshened upper ocean waters across the Arctic Ocean. It passes over the North Pole region just before passing through Fram and Nares straits on its way to the North Atlantic. The exported ice and freshened water stratifies the sub-Arctic seas and limits the vertical convection of heat that is a key element in global climate change. As a result conditions in the region of the Pole are sensitive indicators of changes over the whole Arctic Basin and how these affect the global ocean. The average ice thickness near the Pole is highly correlated with the basin-average ice thickness [*Lindsay and Zhang*, 2006]. Ocean

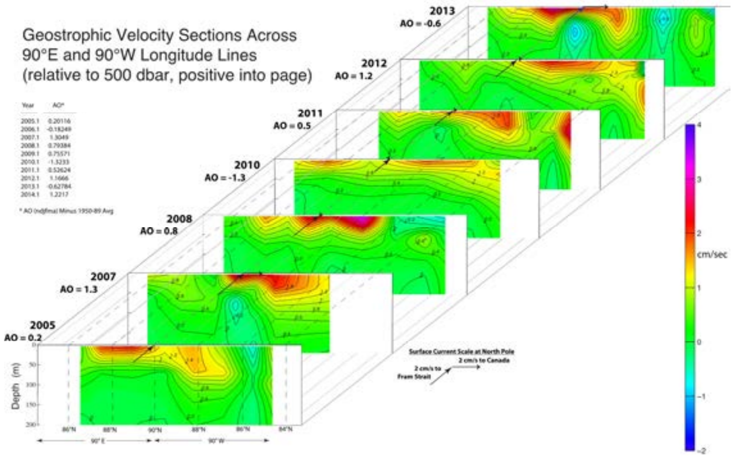

Figure 1. Geostrophic velocity across 90°W and 90°E longitude lines for years from 2005 to 2013. These are computed from dynamic heights relative to 500 dbar derived from Switchyard, NPEO, and NABOS CTD profiles. Positive velocities are into the page, nominally toward Fram Strait. Transpolar drift in the ocean is the positive lens in the upper 100-m centered near the North Pole (90°N on x axis). The winter (NDJFMA) AO index minus the average winter AO 1950-89 is also shown for each year. Arrows show surface geostrophic current at the Pole into and along the section.

bottom pressure (OBP) measured at the North Pole is highly correlated with dominant mode of Arctic Ocean mass change [*Peralta-Ferriz et al.*, 2014b], which appears to be forced by northward winds in the Nordic Seas and Fram Strait in what is arguably a lower frequency expression of the sub-monthly mass variation that dominates wintertime Arctic Ocean bottom pressure [*Peralta-Ferriz et al.*, 2011].

Annual repeat hydrochemistry stations at the Pole reveal the contributions from sea ice melt, runoff and precipitation, and the Pacific Ocean to freshwater flux in the Transpolar Drift toward the North Atlantic [*Alkire et al.*, 2015].

The position and orientation of the Transpolar Drift provide a strong indication of whether the Arctic Ocean circulation is in an anticyclonic (clockwise) state dominated by a large Beaufort Gyre or a cyclonic (counterclockwise) state in which the anticyclonic Beaufort Gyre is balanced against cyclonic circulation on the Eurasian side of the Arctic Ocean [*Sokolov*, 1962]. The cyclonic mode has been associated with a counterclockwise shift in the orientation of the Transpolar Drift, diversion of Eurasian runoff to the Canada Basin, and high levels of the wintertime Arctic Oscillation index [*Morison et al.*, 2012].

Hydrographic stations at one degree intervals over the Pole along 90°W and 90°E made by the US National Science Foundation Switchyard, North Pole Environmental Observatory (NPEO) and Nansen and Amundsen Basin Observing System (NABOS) project reveal changes in the geostrophic water velocity of the Transpolar Drift (Fig. 1) that cannot be resolved by buoys moving with the Drift. These sections from 2005 to 2013 indicate a current core of about 2 cm s^{-1} magnitude roughly centered on the North Pole, but with significant structure and interannual variability. The position of the velocity core is shifted towards Canada along 90°W when the previous winter (NDJFMA) AO index is high (e.g., 2007, 2008, 2011, 2012) in qualitative agreement with the cyclonic-anticyclonic paradigm (*Morison et al.*, [2012]). The velocity core tends to shift toward the 90°E side of the Pole when AO is low (e.g., 2005, 2010, 2013) as we expect under an expanded anticyclonic Beaufort Gyre in the Canada Basin.

Drifting buoys installed in the North Pole region address what would otherwise be a nearly complete lack of near-surface ocean, ice, and atmosphere observations in the Central Arctic. The International Arctic Buoy Program (IABP) is the source of many of the buoys measuring surface atmospheric properties and ice drift. Data from these have contributed to countless successful studies. However, the IABP usually depends on shorter-term projects for buoy deployment, commonly along with new buoys measuring a wider range of variables. These efforts have a distinctly international character. Examples include drifting Polar Ocean Profile Systems from Japan and Canada [*Kikuchi et al.*, 2004; *Kikuchi et al.*, 2005] and Ice Tethered Profilers, Ice Mass Balance, and Arctic Ocean Flux buoys from the US [*Timmermans et al.*, 2011]. Investigators from the France's University of Pierre and Marie Curie (UPMC) have been deploying a new type of ice-mass and ocean flux buoy (Vivier) and an Ice, Atmosphere, Arctic Ocean Observing System (IAOOS) (Gascard), (http://iaoos.ipev.fr/index.php?option=com_content&view=article&id=47&catid=29&lang=en&Itemid=179) in collaboration with investigators from the Norwegian Polar Institute and Scottish Association for Marine Science deploying advanced ice-mass balance and radiometer buoys. The Polar Science Center in the US works with the IAOOS group deploying NPEO Web-Cam buoys that give visual evidence of the seasonal ice melt progression [*Inoue et al.*, 2005; *Perovich et al.*, 2008].

An international suite of satellite remote sensing tools such as ICESat from the US, GRACE from the US and Germany, and CryoSat2 from the EU extend the conclusions from Central Arctic Ocean in situ observations to other regions. Furthermore, even though all satellite systems have a data hole of some size at the Pole, the high concentration of satellite passes through the larger North Pole region provide many opportunities for ground truth comparisons between satellite remote sensing and in situ observations. For example, satellite altimeter derived dynamic ocean topography can be validated versus hydrography-determined dynamic heights in the North Pole region [*Kwok and Morison*, 2011] (ICESat) [*Kwok and Morison* 2016] (CryoSat2). The hourly in situ ocean bottom pressure measurements at the North Pole extend the frequency range and validate the monthly average OBP from GRACE [*Peralta-Ferriz et al.*, 2014a].

Need for International Effort Sustaining Observations in the North Pole Region

Nearly all the research efforts noted above are aimed at understanding the role of the Arctic Ocean in climate variability. The North Pole region data have been a regular contribution to the NOAA/BAMS State of the Climate Report (https://www.ncdc.noaa.gov/bams). Process studies and detection of interannual changes are helpful in this. However, detecting and understanding climate change absolutely requires observations at decadal and longer scales. And this is now the crux of the problem that our Arctic Ocean research community is facing. The investigations described above were nearly all conducted with the support of basic research funding agencies around the world. They were funded under grants and programs typically extending a few years.

In the future, national funding efforts such as the US National Science Foundation Arctic Observing Network (https://www.nsf.gov/news/news_summ.jsp?cntn_id=109687) and the EU Integrated Arctic Observing Network (http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/5122-bg-09-2016.html) are positioned to support long-term observations. However, these agencies are under some obligation to fund new investigators with new projects. Thus it can be difficult for them, particularly given the large logistics costs of operating in the North Pole region, to sustain consistent repeat observations there over the decades required for climate science. Given this fundamental problem, how might we build a program of sustained observations in the North Pole region out of what has been 20 years of basic research observations?

In this white paper, we propose that an international program is a key element in sustaining observations in the North Pole region at decadal and longer time scales. Examples of such programs are the International Arctic Buoy Program (IABP) providing support to the World Climate Research Program (WCRP) and the International Arctic Systems for Observing the Atmosphere (IASOA) circumarctic network of meteorological observatories. With this white paper we hope to begin establishing endorsements and links with governmental organizations such as the Arctic Council and existing programs devoted to international Arctic research such as Sustained Arctic Observing Networks (SAON) and the International Study of Arctic Change (ISAC).

An international program can help build a sustained North Pole observing program in at least four ways. The first is by facilitating financial sharing of the burden of long-term measurements among several nations. If we can agree on what measurements absolutely have to be continued, the sanctioning of these by an international body could be a compelling rationale for individual countries to participate.

Second, international coordination of field efforts would reduce the logistics burden of sustaining observations through economies of scale; the cost of a helicopter flight to the North Pole for deployment of several buoys from several countries is the same as for one buoy from one country. We need a way to share logistics costs among participating countries. Also this type of logistics sharing, which already happens a great deal at the investigator level, would be better recognized and appreciated by the individual funding agencies. Arguably, the help we now provide our international partners investigator-to-investigator may be unknown at the higher levels of our funding agencies.

Third, international support provides a buffer against funding or logistics difficulties in any one program. If one national group has a shortfall for a period of time, partners from other countries can ensure that the critical measurements are maintained.

Finally, the establishment of an international program of sustained observations in the North Pole region by a strong international body would give the observational effort greater robustness, and ideally immunity, in the face of changing geo-politics. To understand the role of the Arctic Ocean in global climate, we need it fully recognized that, at least for climate science, the North Pole region is in international waters. Endorsement by an established international body could give a program of sustained observations in the North Pole region that recognition.

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Arctic Observing Open Science Meeting

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Significant investments in Arctic observing during the IPY and beyond have produced a broad, multi-disciplinary data set of unprecedented spatial and temporal scope spanning land, ice (ice sheets and sea ice), ocean atmosphere and human systems. The 2015 Arctic Observing Open Science Meeting provided the research community a forum to discuss the advances supported by these sustained, broad, contemporaneous observations and to identify areas for improved integration into an Interagency Arctic Observing Network. Specific goals were:

- Present and document new understanding achieved through Arctic observing.
- Illustrate the breadth and scope of existing Arctic observing activities.
- Strengthen the goals, identity and activities of an integrated Interagency Arctic Observing Network.

Keynote speakers provided examples of scientific objectives and advances in understanding that are achievable only through sustained observing collected by a network. Thematic sessions focused on specific research areas, including the Terrestrial Arctic, Arctic Atmosphere, Community Based Monitoring, Marine Ecosystems, the Fate of Sea Ice, Ocean Circulation and Mixing, Robust Autonomous Observations, Human Dimensions, Applications to Global Climate Modeling, Ice Sheets and Glaciers and Meeting the Needs of Managers and Decision Makers. Each session was asked to address the following questions:

1. What scientific or operational advances have been facilitated by the network(s) of Arctic observations?
2. How have observing activities contributed to the science needs of mission agencies or stakeholders?
3. What opportunities exist to address new science questions, operational challenges, or questions of Arctic communities through enhanced collaboration and a robust interagency observing system?

Presentations and discussions highlighted achievements of the existing network. Broad, sustained atmospheric measurements have led to an understanding of the sources, sinks and seasonality of trace gasses and found consistent variability in cloud properties across sites and different moisture, energy and aerosol conditions, pointing to paths for consistent representation in models. Distributed measurements in the Arctic Ocean, combined with sustained observations at the three primary gateways, has documented variability in freshwater storage and release, and provided a basis for understanding the underlying mechanisms. Large advances in understanding the processes that govern sea ice variability stem from a loosely-organized network of individual projects. Terrestrial networks span both science and the provision of useful products to decision makers. Networks increasingly include measurements collected by community-based observers, as the interface between communities and research endeavors strengthens.

Open Science Meeting participants also identified important opportunities for the observing network. With increased human activity, decision makers will need data for planning responses to environmental change, such as storm surge, coastal erosion and permafrost melt, and to disasters such as spills. These needs will drive design for some elements of the network. Advances in autonomous platforms and sensors should deployed to complement existing network elements, providing a path to extend temporal and spatial coverage in a cost-effective manner. A comprehensive evaluation of atmospheric reanalyses could be used to define the core atmospheric measurements needed by the larger observing network. Scaling issues were common to many domains, as participants discussed the balance between distributed observing and more concentrated efforts at ‘super-sites’, and the need to understand how to upscale from these. Other common concerns included network optimization, production and delivery of useful products and the establishment of funding models capable of supporting critical, sustained measurements.