The Distributed Biological Observatory: Linking Physics to Biology in the Pacific Arctic Region

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Introduction

In 2009, in response to dramatic seasonal sea ice loss and other physical changes influencing biological communities, a Distributed Biological Observatory (DBO) was proposed as a change detection array to measure *biological responses* to physical variability along a latitudinal gradient extending from the northern Bering Sea to the Beaufort Sea in the Pacific Arctic sector (Grebmeier et al. 2010). By design, DBO sampling was focused on five regions of demonstrated high productivity, biodiversity and rates of change (http://www.arctic.noaa.gov/dbo/). The DBO concept was vetted at numerous scientific meetings and has been included in various US arctic research planning documents, including the National Oceanographic and Atmospheric Administration (NOAA) Arctic Strategic Plan, the United States Geological Survey (USGS) 'Science Needs' Report, the Bureau of Ocean Energy Management (BOEM) Alaska Region Research Plan, the Interagency Arctic Research Policy Committee (IARPC) 5-Year Research Plan, the National Ocean Policy Strategic Plan, and the National Strategy for the Arctic Region (NSAR).

Pilot Phase, 2010-2014

In 2010, a pilot DBO program was initiated focused on developing standardized sampling in regions 3 and 5. International participation was coordinated by the Pacific Arctic Group (http://pag.arcticportal.org/) and national participation was coordinated by NOAA (http://www.arctic.noaa.gov/dbo/). In 2012, the National Science Foundation/Arctic Observing Network (NSF/AON) program awarded a 5-year research grant to a collaborative team from the University of Maryland Center for Environmental Science (UMCES), Clark University and the Woods Hole Oceanographic Institution (WHOI) to provide support for standardized sampling in all five DBO regions. That same year, the IARPC developed a 5-year plan focused on seven research themes (http://www.iarpccollaborations.org/plan/index.html). The DBO Collaboration Team (CT) was formed under the first theme, *Sea Ice and Marine Ecosystems* and has been meeting via teleconference to complete ten milestones intended to guide the DBO from a pilot phase to the implementation of decadal-scale sampling; more details at: http://www.iarpccollaborations.org/teams/Distributed-Biological-Observatory - milestones.

International Cruise Planning and Reporting

Support from the Pacific Arctic Group (PAG) has been essential to the success of the DBO pilot phase. PAG is a consortium of international institutions and individuals having a Pacific perspective on Arctic science (http://pag.arcticportal.org/). Organized under the aegis of the International Arctic Science Committee (IASC), the PAG has as its central mission to serve as a Pacific Arctic regional partnership to plan, coordinate, and collaborate on science activities of mutual interest. The PAG meets each spring and autumn and has taken a leadership role in coordinating international and industry-based contributions to DBO sampling, including the provision of ship time at no-cost. These international contributions to DBO sampling have provided an unprecedented capability to track inter- and intra-annual variability in DBO regions. An annual listing of DBO cruises is developed each year at the PAG spring meeting and is available on both the PAG and NOAA DBO websites (http://www.arctic.noaa.gov/dbo/cruise-data). The results of each year's sampling are reported at the PAG autumn meeting and form the basis for national and international science presentations given at various national and international forums.

US Interagency, Academic and Industry Partners
The DBO CT has benefitted from strong support and collaboration from a number of US agencies and academic partners. An abbreviated listing of contributions is provided below, accompanied by web links to sources of additional information.

NSF **AON:** Conduct standardized sampling in all five DBO regions, 2012-2017 http://arctic.cbl.umces.edu/; also, contributions to DBO sampling from other AON-supported projects, various NSF-research platforms and the provision of a physical oceanographic data portal at WHOI

see Lee Cooper presentation to the DBO CT
http://www.iarpccollaborations.org/members/documents/2164

UCAR: Provision of a DBO Data Agreement and Data Archive at the University Corporation for Atmospheric Research (UCAR), Earth Observing Laboratory (EOL)
https://www.eol.ucar.edu/field_projects/dbo

see Jim Moore presentation to the DBO CT
http://www.iarpccollaborations.org/members/documents/1576 *and*

see Don Stott presentation to the DBO CT
http://www.iarpccollaborations.org/members/events/2319

NASA The development of DBO-focused satellite visualizations products as part of the Cryosphere Science Research Portal
http://neptune.gsfc.nasa.gov/csb/index.php?section=270

see Joey Comiso presentation to the DBO CT
http://www.iarpccollaborations.org/members/documents/1318

NASA also contributed to DBO sampling during the 2010 ICESCAPES program
http://www.nasa.gov/topics/earth/features/icescape2010.html

NOAA OAR: Coordination of international contributions to the DBO, via the PAG, and contributions to DBO sampling during the RUSALCA program - the only program to sample in the Russian Exclusive Economic Zone http://www.arctic.noaa.gov/rusalca/

NMFS: Chair of the IARPC DBO CT, and contributions to DBO sampling during various multidisciplinary research programs in the northern Bering and Chukchi seas, e.g.
BASIS: http://www.afsc.noaa.gov/abl/mesa/mesa_basis.php,
Arctic Eis: https://web.sfos.uaf.edu/wordpress/arcticeis/

NOS: Opportunistic contributions to DBO sampling via NOAA ship *Fairweather* and coordination of the Arctic Marine Biodiversity Observing Network (AMBON). NOTE: AMBON is co-supported by BOEM through the National Oceanographic Partnership Program (NOPP) and by industry partner Royal Dutch Shell. http://ambon-us.org

BOEM Alaska Environmental Studies Program: Contributions to DBO sampling, via support of research projects conducted by NOAA OAR and NMFS, in the Chukchi and Beaufort Seas (e.g. CHAOZ, ArcWest), and via awards to numerous academic partners in support of studies such as ANIMIDA, cANIMIDA, ANIMIDA III, COMIDA, Hanna Shoal, AMBON;

see Dan Holiday presentation to the DBO CT
http://www.iarpccollaborations.org/members/documents/1956

for research project summaries, see DBO 2nd Data Workshop final report
http://www.arctic.noaa.gov/dbo/sites/default/files/atoms/files/2nd%20DBO%20data%20workshop%20report_Final-2.pdf

also see BOEM Alaska Region Environmental Studies page:
http://www.boem.gov/About-BOEM/BOEM-Regions/Alaska-Region/Environment/Environmental-Studies/Index.aspx

Future contributions to sampling in DBO Beaufort Sea regions are anticipated, via the Marine Arctic Ecosystem Study (MARES) program
see Guillermo Auad presentation to the DBO CT
http://www.iarpccollaborations.org/members/documents/2533

AOOS Provision of web-based assets mapping and a password-protected DBO Data Workspace
https://workspace.aoos.org/group/23134/projects

AOOS also provides link to the IOOS, including with both national (17 Fed agencies) and global (GOOS) outreach http://www.aoos.org/

Partial support for long-term biophysical mooring (UAF) in the NE Chukchi Sea, and potential for future support for moorings in the N. Bering and Beaufort seas as 'anchors' to DBO transect lines.

NPRB Support for long-term biophysical mooring (UAF) in the NE Chukchi sea, and potential for future contributions to sampling in DBO Chukchi Sea regions, via the Arctic Program http://www.nprb.org/arctic-program

Key Products: Workshops, Data Agreement, Data Archive, Presentations and Papers
There have been numerous special sessions and presentations on the DBO at multiple science and policy venues since the inception of the pilot phase. While a full-listing goes beyond the scope of this document, some of the key meetings (including two DBO Data Workshops) are provided here: http://www.arctic.noaa.gov/dbo/workshop-products. Several significant products have resulted from these meetings, including:

• DBO Data Policy and Release Guidelines: http://dbo.eol.ucar.edu/data_policy-dbo.html
• UCAR/ACADIS DBO Data Archive: https://www.eol.ucar.edu/field_projects/dbo
• Satellite products for the DBO: http://neptune.gsfc.nasa.gov/csb/index.php?section=270
• AOOS DBO Workspace https://workspace.aoos.org/group/23134/projects
• Presentations: AGU & OSM Meeting(s) 2012, 2014 & Alaska Marine Science Symposiums
• Peer-reviewed publications: Itoh et al. (2015); Grebmeier et al. (2015); NOTE – planning is underway for DBO Special Issue of *Deep Sea Research II*.

Decadal Implementation Phase, 2015-2024

Expansion to Eight DBO Sampling Regions: 2 Bering + 3 Chukchi + 3 Beaufort
In 2013, increasing interest in the DBO led to the initiation of discussions within the IARPC CT to extend DBO sampling to regions in the Beaufort Sea. Primary contributors to these discussions were NSF/AON-UMCES, BOEM/Alaska Region, NOAA/NMFS & OAR and Canada Department of Fisheries and Oceans. To the extent possible, Beaufort Sea sampling transects and regions were centered on areas of high productivity and biodiversity, as in the Chukchi Sea. Other factors considered in selection of the new regions included: (i) availability of long-term data; (ii) linkages to other programs; and (iii) willingness of IARPC CT and other partners to participate in DBO sampling and data sharing. In 2014, draft maps of provisional DBO sampling sites were prepared and circulated among the IARPC CT and other interested colleagues for discussion and revision. By 2015, three new DBO regions were agreed upon for the Beaufort Sea, with locations embedded in a web-accessible map, (http://www.arctic.noaa.gov/dbo/dbo-stations). The IARPC DBO CT agreed that expansion of standardized sampling into the Beaufort Sea was a significant step in the process of developing a decadal-scale implementation plan.

Annual Cycle for Field Season Planning, Data Sharing and Reporting: 5 steps
Since the inception of the DBO, the PAG semi-annual meetings have been essential to field season planning, provisional data exchange and collaboration on science products on an international basis. The annual cycle for of DBO activities proceeds in five steps:

(i) PAG Spring Meeting: coincides with the Arctic Science Summit Week (ASSW) of IASC, and includes a review of ongoing studies in the Pacific Arctic region and the initiation of the annual DBO Sampling Table where *planned* DBO sampling is tabulated and auxiliary research projects that can provide DBO-related data are identified.

(ii) DBO Cruises: ship-based sampling is completed on various cruises from July-October, and DBO-related sampling is completed on various auxiliary projects.

(iii) PAG Fall Meeting: often coincides with related arctic science meetings and provides an opportunity to report *actual* DBO cruise sampling and related outcomes from auxiliary projects. During the implementation phase, a new goal of submission of metadata to the UCAR/ACADIS website will be established.

(iv) DBO Data Workshops: two DBO Data Workshops have provided an opportunity for presentation of provisional results, multi-disciplinary discussions and planning for the data archiving (http://www.arctic.noaa.gov/dbo/workshop-products). During the implementation phase, an annual DBO Data Workshop has been identified as a key activity in support of data integration, analysis and archiving.

(v) DBO Products: this has included science presentations and community outreach at various annual science meetings (e.g. AGU, OSM, AMSS) and during informal discussions with agency and academic leaders. During the implementation phase, the goal of augmenting community outreach to include active participation by local observers of biological change will be sought, via linkages with established community observing networks (e.g. CONAS, ELOKA, C2O2, A-OK).

This annual cycle of DBO activities has proven very effective during the pilot phase and is anticipated to foster success during the DBO implementation phase. As noted above, three important additions to the cycle for the implementation phase include: (1) a requirement for all DBO contributors to upload metadata to the ACADIS DBO data archive before or immediately after the PAG autumn meeting; (2) the conduct of an annual DBO Data Workshop, and (3) the goal of building connections with existing community-based observation programs, as described below.

Building Connections with Existing Community-based Observation Programs
The development of a decadal implementation plan seems an opportune time for the DBO to foster connections to existing community-based observation programs in an effort to link offshore observations of biological change to local observations and traditional knowledge. One approach to this goal would be to identify communities close to existing DBO transect lines where local observations are already underway: e.g., Gambell, Savoonga, Wales, Diomede,

Point Hope, Point Lay, Wainwright, Barrow and Kaktovik. A second step would be to initiate dialog with existing local observing programs to explore areas of synergy between coastal and DBO sampling, which could be identified and acted upon.

Over the past decade of rapid environmental change, several community-based programs have been initiated to foster the inclusion of local knowledge and observations in assessments of shifts in Arctic ecosystems (e.g., Sigman, 2015). Three examples include the US-based CONAS and ELOKA programs, and the Canadian-based CACCON program:

• The Community Based Observation Network for Adaptation and Security (CONAS) consists of systematic observations made by subsistence hunters, fishermen and other leaders from eight coastal communities in the Bering Sea (http://www.bssn.net). The existing network is comprised of 3 villages in Chukotka and 5 in Alaska, including Gambell and Savoonga on St. Lawrence Island (near DBO regions 1 and 2). The CONAS is funded by the NSF, and is now planning to expand northwards, to include coastal villages along the Chukchi and Beaufort seas, and has expressed an intention to partner with the DBO and AOOS.
http://www.uidaho.edu/caa/programs/research/crc/research/conas

• The Exchange for Local Observations and Knowledge of the Arctic (ELOKA) was launched during the 2007-09 IPY, with funding from NSF/Arctic Social Science program, to facilitate the collection, preservation, exchange, and use of local observations and knowledge of the Arctic. ELOKA continues to support a number of community-based observations and includes a long list of partner organizations including AOOS (http://eloka-arctic.org/).

• The Circumpolar Arctic Coastal Communities Observatory Network (CACCON ~"Catch-ON") is a new initiative aiming to build knowledge hubs to support, sustain and share adaptation for coastal communities (http://caccon.org/).

There are many other community-based programs (e.g., LEO, SIWO, C2O2 etc.) where synergistic connections to the DBO might be fostered. In particular, a new initiative to support community observations and information sharing is the Alaska Arctic Observatory and Knowledge Hub (A-OK). This 5-year program will focus initially on the cryosphere and likely include aspects of several local observation programs already underway in the Alaskan arctic. The upcoming Arctic Observing Open Science Meeting (17-19 November 2015; http://www.arcus.org/search-program/meetings/2015/aoosm) might provide an opportunity to discuss steps toward developing synergistic connections between existing community-based observations and the DBO.

Periodic Assessment of the State of the Pacific Arctic Marine Environment
The overarching goal of a decadal-scale DBO implementation plan is to establish guidelines for the *periodic assessment of the physical and ecological state of the Pacific Arctic marine*

environment (ref: Milestone 3.1.3h). The DBO was launched in 2010 with just such a goal in mind; that is, to assess how bio-diverse 'hotspots' of marine organisms are responding to rapid physical changes in the Pacific Arctic region. As mentioned earlier, an annual DBO workshop is considered an essential activity in support of this goal. Annual workshops would serve as forum where assessment guidelines could be developed, discussed and approved. All US agencies involved in the DBO effort should explicitly recommend and financially support the participation of their Principal Investigators in this annual DBO workshop.

A general timeline for steps in the development of a periodic Pacific Arctic Regional Marine Assessment (PARMA) are provided here for discussion and revision:

PRODUCT	**Target Date**
Annual DBO Workshop	2016-2023
PARMA Guidelines: development & vetting	2016-2017
Special Issue of DSR II: "the DBO – results since 2010"	2017
Produce the 1st Pacific Arctic Regional Marine Assessment	2018
Revise PARMA @ 3-year intervals	2021, 2024
Long-term Future of the DBO – National and International Linkages	2019
IARPC-IASC Panel Review @ 3-year intervals	2020, 2023

Some ideas on how the DBO Implementation phase might be supported include:

US Agency Contributions

• **NSF** – continue support of DBO sampling in all regions, *and* support of the DBO Data Archive; initiate a DBO Program Office &/or as a DBO-LTER (Long Term Ecological Research) framework.

• **NASA** – further refinement of DBO Cryosphere products, as needed. Note that satellite sea surface height and sea surface salinity are currently being added to augment existing data products. Also, NASA may provide coordination of sampling from shipboard programs (e.g. Arctic-COLORS), which may be developed over the next decade.

• **NOAA** –continue DBO sampling during the RUSALCA and AMBON cruises, on AFSC cruises *and* with NOS-charting assets (e.g. *Fairweather*) whenever possible; support and host an annual DBO workshop; publish the Executive Summary of the PARMA as a contribution to the Arctic Report Card.

• **BOEM** – continue support of DBO sampling during all research programs in the Pacific Arctic whenever possible.

• **AOOS** – continue support of long-term biophysical mooring in the NE Chukchi Sea and initiate support for biophysical moorings in the Beaufort and northern Bering Seas; enhance DBO Workspace and linkages to DBO Data Archive; assist in the development of visualization products; support State of the PAME assessment.

• **NPRB** – continue support of long-term biophysical mooring in the NE Chukchi Sea, as part of the Long-Term Monitoring Program; initiate DBO sampling during research programs funded via the Arctic Program.

• **ONR** – initiate DBO sampling during physical research programs in the Pacific Arctic whenever possible.

• **Industry Contributions**
NOPP – following the AMBON example, development of an inter-agency + industry call for a 10-year program of DBO support, in response to Integrated Ecosystems Assessment (IEA) goals common to all contributors.

• **Academic Contributions**
Universities – research & provision of peer-reviewed science, via support from US Agencies; streamline funding processes through programs such as the NOPP, LTER, and NOAA/Cooperative Institutes.

• **International Support and Coordination**
PAG – continued support of semi-annual meetings
IASC – initiate inclusion of DBO review @ annual meeting of IASC-Marine Working Group
Arctic Council – CAFF/CBMP, PAME, other WGs

Contributions to the National Strategy for the Arctic Region
The National Strategy for the Arctic Region (NSAR) Implementation Plan[1] identifies three lines of effort, **two** of which are particularly germane to the implementation phase of the DBO, specifically: *Pursue Responsible Arctic Region Stewardship*, and *Strengthen International Cooperation*.

The DBO directly supports responsible stewardship of the arctic region by providing science-based observations as a basis for effective management and policy decisions. Activities of the DBO are summarized in the NSAR report under the 'Stewardship' line of effort, demonstrating the key nature of systematic observation of biophysical properties to the goals of integrated ocean resource management.

The DBO also strengthens international cooperation by providing the foundation for countries to engage in a common approach to oceanographic observations. The activities of the DBO, coordinated by the PAG, directly support the 'One Arctic' theme, at the foundation of goals established by the US during the Chairmanship of the Arctic Council. In addition, the fact that DBO regions are 'embedded' in the US contribution to the Arctic Council CAFF/CBMP program further strengthens international cooperation.

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[1]www.whitehouse.gov/sites/default/files/docs/implementation_plan_for_the_national_strategy_for_the_arctic_region_-_fi....pdf

Title: air Pollution in the Arctic: Climate, Environment and Society (PACES)

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Arctic air pollution, including aerosol particles such as black carbon and trace gases such as tropospheric ozone, has impacts on climate change, ecosystems, regional air quality, and human health. Rapid changes to and complex interactions within the Arctic environment due to global warming and socio-economic drivers mean that there is an urgent requirement to improve understanding of sources of Arctic air pollutants, which both contribute to and are driven by Arctic environmental change. Changes in atmospheric aerosol particles and tropospheric ozone have likely contributed substantially to recent rapid warming of the Arctic (Shindell and Faluvegi, 2009). The balance between Northern Hemisphere mid-latitude pollution sources and local Arctic sources is changing, the latter being already important in some regions, and likely to grow rapidly in the future. Reducing sea-ice is leading to increased accessibility and local emissions from activities such as oil and gas extraction or shipping. Improved quantification of the relative contributions of different pollutant sources is needed to provide a sound scientific basis for sustainable solutions and adaptive strategies. Deficiencies in predictive capability and a lack of observations at high latitudes present major challenges to advancing this understanding, and to making credible near- and long-term projections of Arctic environmental change. This Short Statement describes a new international initiative - air Pollution in the Arctic: Climate Environment and Societies (PACES) (see www.igacprojects.org/PACES), recently launched under the auspices of the International Global Atmospheric Chemistry project (under Future Earth) and the International Arctic Science Committee (IASC/Atmosphere WG). PACES addresses several AOS themes, aiming to promote and spin-up new observational efforts to reduce uncertainties in process-level understanding and improve predictive capability of impacts related to Arctic air pollution. In particular, PACES addresses Theme 1 (international strategies), Theme 6 (citizen-based science), Theme 5 (links to global programs), and Theme 2 (e.g. development of miniaturised sensors).

Despite recent progress in understanding sources, processing, fate and impacts of Arctic air pollution, through extensive and unprecedented observations from aircraft, surface and satellites during the International Polar Year (IPY) (Law et al., 2014), there remain important uncertainties and unknowns regarding processes controlling Arctic air pollution and its impacts. Models display diverse and often poor skill in simulating pollution enhancements at the surface and throughout the depth of the troposphere in the Arctic (Monks et al., 2015; Eckhardt et al., 2015), suggesting deficiencies in diagnosing pollutant contributions from local and remote sources. Long-term Arctic surface observations provide information on seasonal cycles and pollutant trends, however these are most sensitive to local and Eurasian emissions. Pollution from North American and Asian sources enters the Arctic at higher altitudes but regular vertical profile information is severely lacking. Poor understanding of pollutant deposition fluxes is a likely driver of poor model skill. There are significant uncertainties associated with sources and impacts of local emissions from e.g. oil and gas extraction and shipping (e.g. Stohl et al., 2013). An understanding of how natural processes will be modified by pollution in a changing Arctic is also essential. Moreover, projections of Arctic air pollution must account for ever-changing human activities and evolving governance and socio-economic responses. Partnership between Northern communities and atmospheric scientists to expand and exchange knowledge about Arctic air pollution will be invaluable, through community-based observations and benefiting from local knowledge to improve assessment of air pollution risks and explore sustainable solutions in Northern communities.

PACES aims to advance Arctic air pollution research over the coming decade. Longer-term goals are being addressed in the short-term (2016/17) via a series of planning and discussion workshops to identify specific PACES actions and to foster new collaborative efforts that will be developed for the mid/longer term and contribute to the PACES Implementation Plan. PACES makes the following key recommendations:

1) Advancement of Arctic air pollution research should be trans-disciplinary exploiting collaborative platforms for observations across linked aspects of the Earth system (atmosphere, cryosphere, ocean, land surface, society), foster community-based monitoring approaches, and take account of societal and economic drivers and responses to Arctic change.
2) Improve process understanding via developments in regular long-term monitoring and intensive field observations (surface/vertically; in-situ/satellite). Use of commercial transport platforms (shipping and aircraft) and new technologies (e.g. unmanned aerial vehicles) should be explored.
3) Improve predictive capability across a range of scales to diagnose impacts of Arctic air pollution on regional/global climate and air quality and the wider Earth system exploiting new capabilities in Earth system modelling, and coupled regional-scale modelling.

Quantification of impacts on societies and economic response requires development of physical models informed by social and economic drivers.

Following a recent workshop, several actions have been identified and Working Groups are being developed to plan for coordinated airborne & modelling activity on transport of (Asian) pollution to the Arctic (2018-2020 timeframe) and to improve observational capacity in the Russian Arctic. A further workshop is planned at ASSW to discuss natural-social science initiatives.

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FRENCH ARCTIC INITIATIVE

French Arctic Initiative (*Chantier Arctique*): contribution to an Arctic Observing System

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The French Arctic Initiative (FAI), the *Chantier Arctique* (see http://www.chantier-arctique.fr/en), started in 2012, but was launched in 2014, with its first call for proposals, for an initial duration of 10 years. It is a multi-agency initiative led by CNRS, also including CNES, MétéoFrance, Ifremer, CEA, BRGM, IPEV and participation from government research and foreign affaires ministries. The FAI goals contribute to the French national Arctic Roadmap and to EU PolarNet and are represented via participation in international bodies such as IASC, SAON, EPB, the Arctic Council working groups. This French national research program has its main objective to foster new research in the Arctic that is transdisciplinary in nature and which builds on already existing French expertise. In this respect it covers not only environmental sciences but also societal aspects. Ten cross-disciplinary priorities are detailed in the Science Plan (see http://www.chantier-arctique.fr/en/uploads/Prospective_february2015.pdf) together with 2 transverse themes on modeling and observations.

Considering that the Arctic region is undergoing rapid changes in all its major components, most of them still poorly documented, **the FAI recommends that national strategies focus effort on designing a collaborative, interdisciplinary and sustainable strategy for observing the Arctic environment**. This strategy warrants a better understanding of key processes underpinning Arctic evolution and continuous monitoring of changes in different key components. An important issue identified by the FAI is the need to maintain, and to build on, already existing observational capacity in the Arctic that is supported by French agencies (often in collaboration with international partners), and to make use of existing French expertise in terms of developing new instrumentation, contributing to observational networks, participation and analysis of data from, for example, satellite missions, and joint initiatives with local communities (citizen-based science). **This Short Statement summarizes recommendations from the FAI science plan (section on Observations) that are the result of community wide consultations**. We primarily address issues of relevance to *Priority 1* (national strategies) and *Priority 5* (synergies with global observing systems) but also including *Priority 2* (new observational opportunities) and *Priority 6* (community-based observations and Traditional Knowledge). This document provides a basis for discussions related to sustained support of and improvements to a coordinated Arctic Observing System (AOS) that builds on national and international strategies.

Considering that:

(1) Changes currently observed in the Arctic involve complex interactions between all the components of the Arctic environment, with impacts of utmost importance in terms of ecological, societal, economical and political aspects, at the regional and global scale,

(2) Current changes must be understood in the context of longer term variability that is only beginning to be tackled (especially with regard to ubiquitous natural climate variability) due to lack of suitably long time series of key variables,

(3) Improved quantification of impacts of human activities on the Arctic environment constitutes one of the major challenges needed to better predict future change in the Arctic,

The French Arctic Initiative considers that it is urgent that national strategies, in conjunction with international initiatives, combine their efforts by:

a) **Encouraging observation-based research, by increasing national and international efforts to maintain and develop perennial instrumented networks and ground-based infrastructures in**

key instrumented or multi-disciplinary research sites. Such sites currently exist but their spatial distribution must be enhanced and their access secured at the national/international level. Similar solutions are encouraged for the (ice-covered) ocean since instrumented sites mainly exist on land, at present. France is already involved in several of such infrastructures in the context of international cooperation (AWIPEV/SiOS in Svalbard, observatories in Siberia, UMI Takuvik in Québec), instrumented networks (e.g. NDACC) or via national platforms (aircraft, balloons). France is unfortunately lacking a national ice-strengthened sea-going research vessel which might have hindered nationally led observational initiatives, stressing the need for international coordination and trans-national access to optimize observationally-based polar research.

b) **Fostering close interactions at the international level between observational initiatives, on one hand, and scientific communities involved in remote sensing (through various agency polar missions) and regional modeling, on the other hand**. In this latter respect, a coordinated approach should be encouraged, aiming to improve the reliability of data-assimilation or operational/predictive regional systems for one or several components of the Arctic system and their interaction (e.g. through improvements in coupled modeling). This should be developed with the framework of international initiatives (e.g. YOPP, CMIP…).

c) E**xploring national, bilateral or international funding strategies to support the development of new instrumentation, including dedicated technologies, miniaturizing or integration of new sensors, capable of sustaining the challenges of reliability, autonomy, robustness imposed by polar conditions**. These initiatives, which already have support at the national level (e.g. IAOOS, CLIMCOR) should make a significant contribution to sustained international efforts concerning arctic observations and should contribute to enlarging the existing global observational systems (GOOS, GCOS, GEOSS) often restricted to the extra-polar regions due to instrumental limitations.

d) **Promoting interdisciplinary approaches with the aim to foster new research topics at the interface between disciplines or components of the Arctic system**. This would require specific actions within funding programs, such as shared multi-instrumented platforms, gathering a wide range of expertise needed to address questions of special relevance to the Arctic.

e) **Supporting involvement of Arctic native populations in international research efforts, in particular, promoting their participation in observational initiatives, and benefiting from specific local knowledge to increase understanding about past and present Arctic change and future evolution**. This should build on and expand already existing initiatives.

f) **Insuring proper management of the diverse range of data that will be gathered at different levels and scales, making data accessible to the international community through consistent quality controlled datasets and real-time access for assisting observational strategies and model implementation.** The success of AOS will depend on the capacity of all nations to coordinate their initiatives in terms of data processing, storage and delivery to all Arctic related communities and stakeholders.

In application of the above recommendations, to date the FAI has:

- **finalized a White Paper in 2015** outlining **future challenges for multidisciplinary Arctic research** and the technical/financial support required for **the national community to contribute efficiently to the international initiatives leading to improve Arctic knowledge;**
- **implemented** a regular national "**Call for Proposa**l", launched in 2015, encouraging cross-disciplinary **national research collaborations and multi-agency support** in order to foster **comprehensive multi-approaches projects** answering the above challenges; similar calls should be launched on a regular basis;
- **communicated information about scientific initiatives at the political level** through involvement in science diplomacy (Ministry of Foreign Affairs, Ministry of Research) in the French government initiative for better management of the Arctic.

The FAI is in its **early stages. Its success will depend on the fruit of these actions** and on continued implementation and development of this national program.

The Role of EU-PolarNet in sustaining Arctic Observations

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Introduction

The rapid changes occurring in the Arctic are significantly influencing global climate and vice-versa with consequences for global society. Arctic observational networks have contributed critical knowledge to identifying the processes behind these rapid changes but, in contrast to lower latitudes, datasets from the Polar Regions are still insufficient to fully understand and more effectively predict the effects of change on our climate (to effectively forecast weather and runoff , chart sea-ice, etc.), ecosystems and society. This situation can only be improved by a higher degree of coordination of observational sites, a closer cooperation between all relevant actors on an international level and by sustaining research oriented observations by shifting them into operational ones.

Additionally Earth Observations will provide a major contribution to support in situ observations and to understand the complexity of the different processes taken place in the Arctic. Since satellite technologies are very efficient and practical tools to provide consistent, year-round observation, as well as communication and navigation support in the harsh polar environment, a collaboration and interaction of the in-situ observations with relevant space based observations by ESA, NASA, Canadian Space Agency etc. and operational services (e.g. Copernicus) will provide benefit to the understanding of the Arctic.

Most Arctic and several non-Arctic countries have conducted regular environmental observation and monitoring programmes for several decades. The over-arching Sustaining Arctic Observing Networks (SAON) process, co-sponsored by the Arctic Council and IASC, aims to facilitate and support multi-national engagement in sustained and co-ordinated pan-Arctic observing and data-sharing systems, particularly in relation to environmental, social, economic, and cultural issues. Each of these Arctic programmes are intended to facilitate the inclusion of the Arctic population in observing activities by promoting community-based monitoring.

What is EU-PolarNet?

EU-PolarNet is a five-year, European Commission-funded Coordination and Support Action that brings together 22 of Europe's internationally respected, multidisciplinary research institutions. A total of 17 countries are represented in the consortium, making it the largest network of expertise and infrastructure for polar research in the world. The overall goal of EU-PolarNet is to develop an Integrated European Polar Research Programme that includes both space based and ground based observations and that is co-designed with all relevant stakeholders and international partners. This will be achieved by establishing an ongoing dialogue between policymakers, business and industry leaders, local communities and scientists to increase mutual understanding and identify new ways of working that will deliver economic and societal benefits. This European Polar Research Programme will include a realistic and feasible infrastructure implementation plan to allow the implementation of the research that has been prioritised in the Polar Research Programme.

Data management is recognized as a priority area for Arctic science and quality controlled observational data as well as easy access to the data are required to help address urgent global environmental issues.

What EU-PolarNet can do for Sustaining Arctic Observations?

Within the lifetime of the project, EU-PolarNet will perform a strategic analysis of the existing observation programmes, and the infrastructures used to deliver them. The ultimate goal is to identify strengths and weaknesses in all fields and to determine where additional support may be needed to ensure the adequate collection of data to achieve sustainable Arctic observations. EU-PolarNet will also focus on an analysis of how scientific data from the Arctic are managed and made accessible to a wide range of users. On this basis, recommendations will be made to improve and optimise interoperability and inter-calibration of observational data and exploring the interplay between both space- and ground based techniques. Furthermore, a scheme for improvement of observational and data infrastructure use will be developed.

Additionally, EU-PolarNet will support the optimisation and data accessibility of existing observational sites by:

1) Better coordination of the European observational sites in the Arctic, (terrestrial, marine, atmospheric, space-based) like INTERACT; SIOS; FRAM etc. and by developing an open access platform for interaction,

2) Facilitating cooperation between these initiatives and linking them with international ones (SAON, GEOSS, WMO, ESA etc.),

3) Facilitating cooperation with community based observations and industry partners within its stakeholder workshops,

4) Facilitating the development of a roadmap for optimisation and standardisation of the observation networks, identifying gaps in the system and recommending improvement,

5) Supporting the development of a governance structure that ensures coordination, support and improvement of selected sites,

6) Interacting with funding agencies (at national and European level) to shift research based observation to operational observation that get long-term funding.

Conclusions:

Sustained observations of the Arctic system are critical input for advancing our understanding of the ongoing Arctic change and its effects on the Northern Hemisphere. Interested countries and organisations need to cooperate to develop a plan to ensure comprehensive and sustained Arctic observations. As already stated by ESA and CLIC in their paper on “Earth observation and Arctic science priorities ”, the creation of a network for Arctic supersites (key regions) ensuring coordination of co-located in situ, airborne and satellite observations could sustain research driven observations by making them routine operational observations. Supersites shall be identified based on jointly scientifically agreed criteria, like e.g. the location of the sites to investigate regional and Arctic-wide changes, the interest to many different research disciplines and the availability of observational infrastructure already in place or easily to be installed.

EU-PolarNet recommends to establish an ESFRI-type of distributed infrastructures of such selected supersites linked to a determined governance structure and a joint international funding system. This would guarantee access, interoperability, data sharing and sustained long-term observations. EU-PolarNet also recommends to cooperating with local communities by including community-based observations into the observing system and to interact with industry as one of the main users of the data and models. The Sustaining Arctic Observing Networks (SAON) implemented by the Arctic Council and IASC has to be involved at any stage of this process.

Monitoring Arctic Sustainability: International Experiences and Agenda to Develop Arctic Sustainability Indicators

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The Belmont Forum project *"ASUS: Arctic SUStainability: A Synthesis of Knowledge"* brings together an international team of experts from seven Arctic countries to develop an interdisciplinary synthesis and assess the state of knowledge about Arctic sustainability and sustainable development. A special domain of this ASUS project is "Monitoring of sustainability and sustainable development". The aim of this activity is to assess what has been already done in monitoring Arctic sustainability and sustainable development at different scales, what approaches and methods were implemented to delineate and monitor trends, both positive and negative on the way towards sustainability in the Arctic. The focus on creating knowledge infrastructure for multi-scale socially-oriented observations and assessments of Arctic socio-ecological systems sustainability and resilience in changing natural and living environments is of great importance. A design of the suitable monitoring frameworks of sustainable development and resilience of complex socio-ecological systems is one of the project's goals. In this case sustainable development should be viewed as both the *process* and as an *outcome*.

ASUS monitoring sustainability domain is built on existing knowledge infrastructure by linking with multiple research projects and networks including IPCC, U.S. (*Arctic-FROST*; *Arctic-COAST, NSF AON*); Canadian (*ReSDA, ArcticNet, CACOON*); Nordic (*ARCSUS*, *NCM Arctic Cooperation Programme*), and Russian (IASOS), as well as integrative Arctic Council projects (*ASI, AHDR, ARR, AMAP*).

ASUS will synthesize knowledge pertaining to biophysical and social observations under an overarching umbrella of social-ecological monitoring. This transdisciplinary, integrated approach is best suited for understanding and managing coupled human-environmental systems. Many biogeophysical, social and integrative observation systems have been established in various Arctic regions under SAON and other long-term monitoring programs. However, attempts to assimilate social and biogeophysical monitoring frameworks with a focus on sustainability indicators are limited. We will develop principles for an integrated monitoring framework of sustainability indicators by combining existing physical, ecological and social observations and by completing methodological and substantive syntheses of these observations. We will consider data interoperability, accuracy and availability and develop strategies to enhance continuous observations and develop suitable frameworks for incorporating community-based monitoring.

One of the main results of the IPY was the start of the local and regional observing projects and networks. Several of them are focused on the land-based resources and social processes: Traditional Indigenous Land Use Areas in the Nenets Autonomous Okrug (*MODIL-NAO*), Circum-Arctic Rangifer Monitoring and Assessment Network (*CARMA*), Reindeer Herders Vulnerability Network Study (*EALAT*), and Monitoring the Human-Rangifer link (*NOMAD*). Some of them such as Sea Ice Knowledge and Use (*SIKU*), Exchange for Local Observations and Knowledge of the Arctic (*ELOKA*), and the Bering Sea Sub-Network (*BSSN*) are oriented toward the sea, ice, marine and coastal resources. The Community Adaptation and Vulnerability in Arctic Regions (*CAVIAR*) has a number of land-focused case studies of reindeer herding and terrestrial resource use, but also incorporates coastal fisheries and other marine resources. Nevertheless, most of these monitoring networks are concentrated on changes in different components of natural environment and their impacts on indigenous people and only few put primary attention to "socio-economic" factors impacting human capacities (health, demography, education, etc.) and well-being.

A substantial post-IPY progress in social monitoring human conditions resulted in a set of regional and circumpolar studies. We envision using the established indicators framework developed by the Arctic Social Indicators and IASOS projects. ASI indicators measure six domains:(1) Fate control and or the ability to guide one's own destiny; (2) Cultural Wellbeing and Cultural Integrity or belonging to a viable local culture;(3) Contact with nature or interacting closely with the natural world; (4) Material Well-being; (5) Education; (6) Health and Population. Integrated Arctic Socially Observation System (IASOS) network that is developing and practicing the methodology of socially-oriented observations (SOO) putting main focus on quality of life, human and social capital development in the Arctic.

ASUS may significantly add to Arctic observing and assessment processes, and will ultimately produce a list of indicators targeting current and near-term priorities for observing networks and systems. It will help to identify societally significant socio-economic environmental variables to assess the capacity of observational networks in the Arctic. The data from key socially-oriented observation sites will help to identify key indicators for on-going observations at the local scale. The synthesis of local and regional observation frameworks will be critical in developing the instruments for socially significant observations at the national circumpolar and global scales.

The International Arctic Buoy Programme (IABP) – A Model for Sustaining Arctic Observing Networks

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Introduction

Our ability to predict weather and sea ice conditions requires *in situ* observations of surface meteorology and ice motion. These observations are assimilated into Numerical Weather Prediction (NWP) models that are used to forecast weather on synoptic time scales, and into the many long-term atmospheric reanalyses (e.g., NCEP/NCAR and ERA Interim Reanalyses) that are used for innumerable climate studies. The impact of these *in situ* observations can be seen in Fig. 1, in which *Inoue et al*. (2009) report that the standard deviation in gridded sea level pressure (SLP) reanalyses fields over the Arctic Ocean was over 2.6 hPa in areas where there were no buoy observations to constrain the reanalyses, and this uncertainty in the SLP fields spreads to cover the entire Arctic when the observations from buoys are removed from the reanalyses. The buoy observations also help constrain estimates of wind and heat. *In situ* observations of sea ice motion are also important for estimating the drift of various areas and types of sea ice, and for understanding the dynamics of ridging and rafting of this ice, which changes the thickness distribution of sea ice. **Over the Arctic Ocean, this fundamental observing network is maintained by the IABP.**

This network of drifting buoys was recommended by the U.S. National Academy of Sciences in 1974. Based on this recommendation, the Arctic Ocean Buoy Program was established by the Polar Science Center, Applied Physics Laboratory (PSC/APL), University of Washington in 1978 to support the Global Weather Experiment. Operations began in early 1979, and the program continued through 1990 under funding from various agencies. In 1991, the IABP succeeded the Arctic Ocean Buoy Program, but the basic objective remains – to maintain a network of drifting buoys on the Arctic Ocean to provide meteorological and oceanographic data (e.g., Fig. 2) for real-time operational requirements and research purposes including support to the World Climate Research Programme, the World Weather Watch Programme, and the Arctic Observing Network (AON).

The IABP is composed of 32 different research and operational institutions from many countries (http://iabp.apl.washington.edu/Participants.htm). The IABP is funded and managed by the participants of the program. Management is the responsibility of the IABP Executive Committee, and operation of the program was delegated to the IABP Coordinator Ignatius Rigor.

Contributions to the IABP from each country vary widely, some countries contribute buoys through research projects, others provide substantial logistics support, many contribute both equipment and logistics. The United States contribution to the IABP is coordinated through the USIABP, which is managed by the PSC/APL and the NIC. The USIABP is a collaborative program that draws operating funds and services from many U.S. government organizations and research programs, which include the Office of Naval Research (ONR), Coast Guard (CG), Department of Energy (DOE), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), National Science Foundation (NSF), Naval Oceanographic Office (NAVO), National Ice Center (NIC), and Shell Exploration and Production Company (SEPC). From these contributions the USIABP acquires and deploys buoys on the Arctic Ocean, and supports the research, coordination, data management and enhancement of the IABP by the PSC/APL.

Contributions to the IABP from Europe range from research driven deployments by the Alfred Wegener Institute in Germany, to contributions of buoys from the European Meteorological Network which are deployed by logistics of opportunity provided to the IABP, for example, deployments by the German R/V Polarstern, and the Russian R/V Akademik Treshnikov during the primarily U.S. funded Nansen and Amundsen Basin Observing Network cruises.

Research Highlights of the IABP AON

Dramatic changes in Arctic climate have been noted during the past two decades. It should be noted that many of these changes were first observed and studied using data from the IABP, which are analyzed and made available to the research community by the PSC/APL. For example, IABP data were fundamental to Walsh et al. (1996, e.g. Fig. 3) showing that atmospheric pressure has decreased, Jones et al. (1999) and Rigor et al. (2000) showing that air temperatures have increased (e.g. Fig. 4); and to Proshutinsky and Johnson (1997), Steele and Boyd, (1998), Kwok, (2000), and Rigor et al. (2002) showing that the clockwise circulation of sea ice and the ocean has weakened (Fig. 3).

The integrated affect of all these changes were studied by Rigor and Wallace (2004), who showed that the average age (thickness) of sea ice has decreased dramatically, which may help explain the recent run of record low summer sea ice extents. All of these results relied heavily on IABP data. And, as such, maintaining and enhancing the IABP has been identified as a priority for the Study of Environmental Arctic Change (SEARCH).

In addition to supporting these studies of climate change, the IABP observations are also essential for:

1. ***Forecasting weather.*** Observations of SLP, which may not be obtained by any other means except by *in situ* drifting buoys, are critical for forecasting weather by the National Weather Service. Estimating the strength and trajectory of Arctic storms would be difficult to predict without observations from the buoys.
2. ***Forcing, assimilation and validation of global weather and climate models.*** For example, the sea level pressures and temperature fields from the IABP were used as forcing, and IABP ice motion data were assimilated by Zhang et al. (2003) to improve model estimates of sea ice thickness, and the IABP data has been used to validate the IPCC AR4 model simulations (e.g. Liu et al., 2007). These data are also assimilated from the World Meteorological Organization

(WMO) Global Telecommunication System (GTS) into the weather and forcing fields produced by Naval Research Laboratory (NRL) to force the Polar Ice Prediction System (PIPS), and are used to validate the ice motion fields from PIPS.

3. ***Validation of satellite retrievals of environmental variables.*** For example, the buoy data are used to validate satellite estimates of sea ice motion (e.g. Kwok, 2008; Lindsay and Stern, 2003), and surface temperatures (e.g. Comiso, 2003).
4. ***Predicting sea ice conditions.*** Our ability to accurately forecast sea ice conditions depends on observations of sea level pressure, surface air temperature and sea ice motion over the Arctic Ocean.
5. ***Assimilation into atmospheric reanalyses.*** The Arctic also plays an important role in the global climate system, primarily through its role in the global heat balance and by its effect on the global thermohaline circulation (Aagaard and Carmack, 1994). Therefore, data from the IABP are also critical for global assessments of the atmosphere and ocean, and are thus assimilated into the global reanalyses, e.g. Inoue et al. 2009 (Fig. 1), and NCEP/NCAR Reanalysis (Kalnay et al. 1996).

The data collected by the IABP support both research and operations, i.e. the data are posted on the WMO GTS (e.g. Fig. 2) where operational weather and ice forecasters may collect the data and assimilate this information into their weather and ice forecasts, and into the forcing fields used to drive numerical models such as PIPS.

Over 800 papers have been written using data from the IABP (A growing list of these citations can be found at http://iabp.apl.washington.edu/publications.html.). This number does not include the countless papers that have used the various reanalyses products (e.g the NCEP/NCAR reanalysis, Kalnay, et al. 1996). Needless to say, the observations and datasets of the IABP data are one of the cornerstones for environmental forecasting and research in the Arctic. For example, the decrease in SLP over the Arctic shown by Walsh et al. (1996) using IABP data is probably the first indication of Arctic climate change (Fig. 3), and recently Inoue et al. (2009) showed the impact of the buoy observations on the SLP field reanalyses (Fig. 1).

Evolution of the IABP Arctic Observing Network

The Participants of the IABP observe the Arctic Ocean to forecast weather and sea ice conditions, and to understand the Arctic and global climate system. Towards these goals, the Participants are actively involved in the research and development of new instruments to monitor the Arctic. For example, given the retreat of Arctic sea ice, the IABP has been deploying Surface Velocity Program (SVP) buoys which are routinely deployed in all the other worlds “wet” oceans. These buoys follow ocean currents and are designed to measure sea surface temperature and air pressure. The IABP started deploying these buoys in the Arctic in 2006, and continues to analyze the observations from these buoys in comparison to the traditional weather stations that the IABP deployed which measure air temperature. The IABP has also been developing buoys which are designed to survive in the increasing area of seasonal ice such as the Airborne Seasonal Ice Beacon (AXIB).

When possible, the meteorological buoys are collocated with buoys, which monitor the temperature, salinity and currents of the upper ocean. For example, Ice Mass Balance (IMB) buoys deployments by the Canadian CCGS Louis St. Laurent, and German R/V Polarstern are collocated with ocean buoys provided by the Japan Agency for Marine-Earth Science and Technology Center and the Woods Hole Oceanographic Institute forming "Automated Drifting Stations", which monitor a myriad of geophysical variables at the air, ice and ocean interface. These enhanced data sets are collected as part of the data management tasks of the IABP (i.e. the IABP strives to collect all data collected by buoys deployed in the Arctic); this data are made available to the operational and research communities through the WMO/IOC GTS, the IABP web pages, and through various external data archives.

Arctic Observing Experiment (AOX)

Accurate observations of the fundamental meteorological parameters: temperature, air pressure, and wind are critical for the AON. The USIABP/IABP continually assesses the accuracy of the instruments that we deploy, but given the increased heterogeneity and seasonality of the Arctic the IABP has had to quickly adapt to these changes by developing the AXIB buoy and by deploying buoys typically deployed in the "wet" global oceans, e.g. the SVP buoy. But how accurate are these instruments in the polar environment, and how do measurements of air temperature (Ta, the primary temperature variable that the IABP historically strived to measure), compare to the surface temperature (Ts) measurements of an SVP buoy? Accurate temperature measurements are also necessary to validate and improve satellite measurements of surface temperature across the Arctic. As we deploy more AXIB buoys, which measure both Ta, and Ts, we will be able to answer this question. And in 2013, the USIABP established the IABP AOX test site at the DOE Atmospheric Radiation Measurement, and NOAA Climate Monitoring and Diagnostics Laboratory in Barrow, Alaska to assess our ability to measure these fundamental parameters. The AOX is primarily funded using contributions from U.S. DOE, NOAA and NSF, Environment Canada, and the Alfred Wegener Institute.

Summary

Sustaining the Arctic Observing Network to collect the fundamental observations of sea level pressure, air temperature and ice motion that are required by the operational and research communities for a myriad of purposes is a challenge that requires a well coordinated program to manage all the disparate pieces. These pieces include: 1) funding to purchase equipment; 2) logistics to deploy buoys; 3) manpower to coordinate the pieces, to assure the quality of the data and produce the research databases; etc. Thus maintaining the network requires interagency and international support and collaboration, since no single agency or country has the resources to maintain the whole network. The Participants of the IABP work together to maintain the fundamental observations what we all need from the Arctic Observing Network.

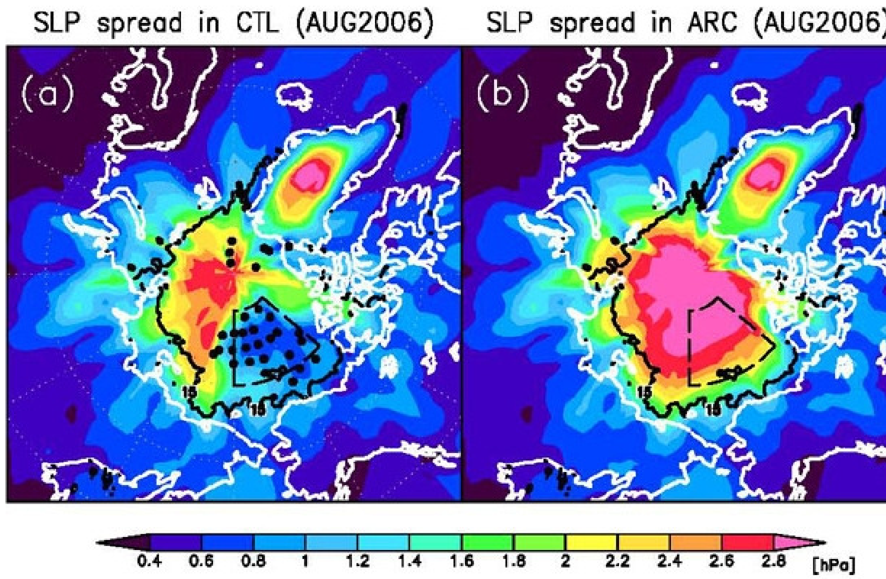

Figure 1. Standard deviation (SD) of sea level pressure measurements from various atmospheric reanalyses. The SD is low in areas where there are buoy observations (left). The spread increases to cover the whole Arctic when the observations from the buoys are removed from the reanalyses (right). Adapted from *Inoue et al*. (2009).

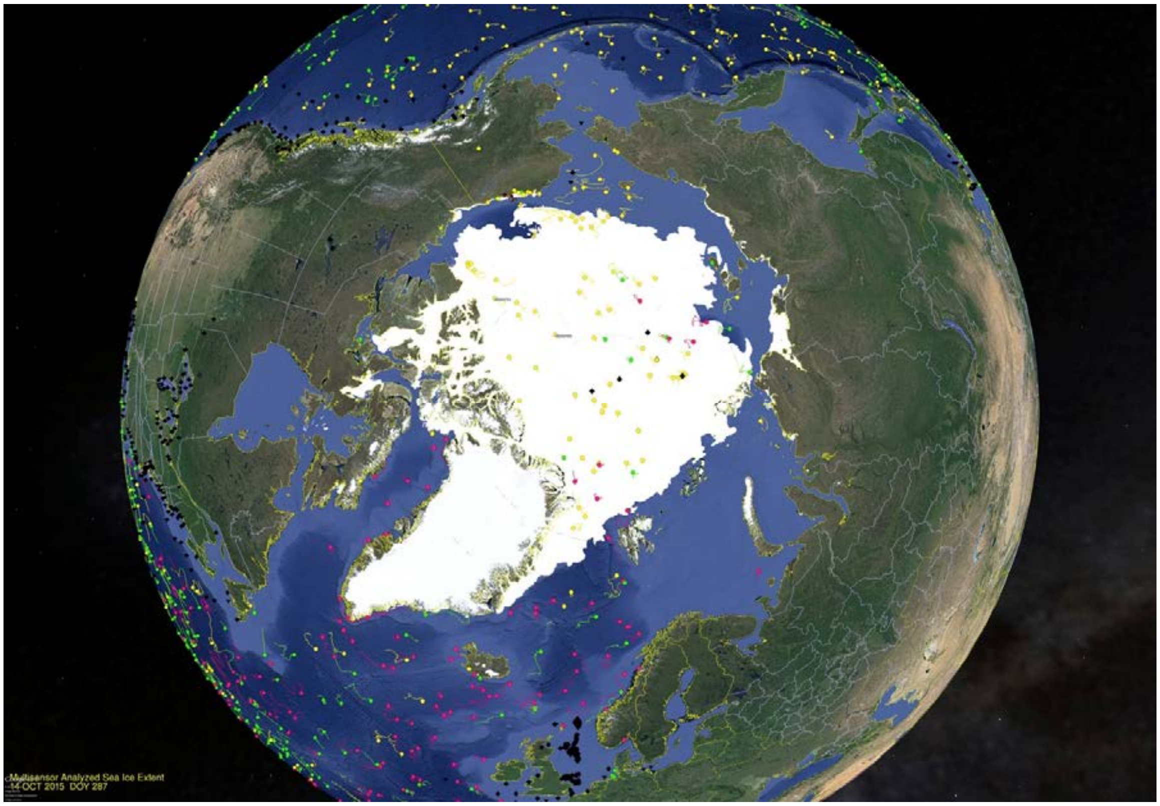

Figure 2. Map of IABP buoys reporting on the World Meteorological Organization (WMO) Global Telecommunications System (GTS) on October 15, 2015 as reported by the Meteo France. The U.S. National Ice Center's (NIC) Multisensor Analyzed Sea Ice Extent (MASIE) denotes areas of sea ice on the Arctic Ocean. The pink dots show buoys contributred to the IABP by the European Meteorological Network (EUMETNET), while the yellow dots show other buoys which report pressure, and the green dots are buoys without barometers. Black diamonds denote subsurface moorings. This map shows over 200 buoys reporting on WMO/GTS over the Arctic Ocean. Automated drifting stations (ADS) with clusters of ocean buoys, ice mass balance and other buoys are shown only by the USIABP/IABP meteorological buoy in these ADS.

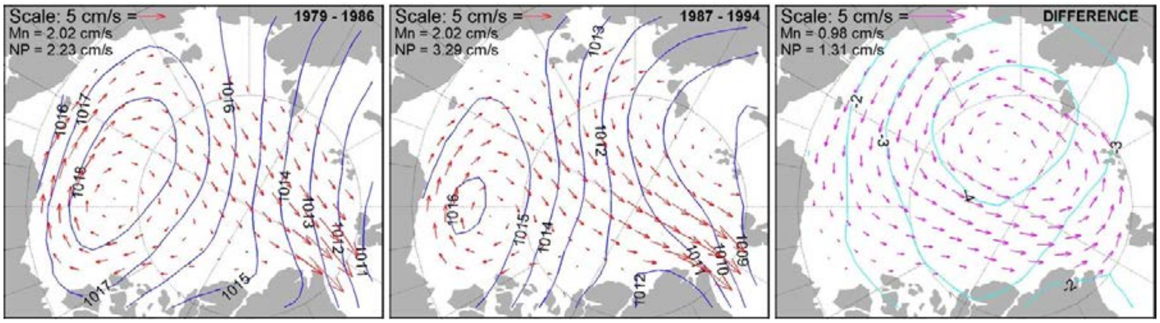

Figure 3. Using IABP data, Walsh et al. (1996) showed that sea level pressure (SLP) over the Arctic Ocean decreased by over 4 hPa (right), when he took the difference between SLP from 1979 – 1986 (left), and 1987 – 1994 (middle). These changes in SLP (winds), drive a cyclonic anomaly in ice motion (vectors), e.g. Rigor, et al. (2002).

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Broad Coordination Needed to Address Atmospheric and Coupled-system Gaps in the Central Arctic

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With increased global focus on Arctic sea ice and its dramatic recent changes, there is a growing community recognition of the need to improve coupled system understanding in the central Arctic. Moreover, it is becoming clear that the most impactful deficiencies in this domain are related to atmospheric processes. While there are many stakeholders for an improved Arctic coupled-system understanding, the modeling community is one of the strongest drivers of this need. Coupled system numerical models are the new frontier, with major efforts underway in many countries to develop fully coupled models for numerous forecasting applications. In light of the broad global interest in sea-ice forecasting, sea ice is a particularly good example of these primary deficiencies. Sea ice is an integrator of energy in the central Arctic system. Variability in the sea ice mass budget cannot be understood without also understanding energy fluxes from the atmosphere and ocean, energy exchange processes at crucial interfaces, interseasonal processes of heat storage and release, precipitation on sea ice, momentum transfer, ice deformation, and other processes. Simply observing sea ice in isolation does not provide the foundation needed to improve predictive skill for sea ice.

In recent years, some lines of disciplinary research have found great success in the Arctic Ocean domain, with significant advances in autonomous observations that allow for year-round, routine measurements of numerous ice and ocean properties (e.g., ITP and IMB buoys and others). These measurements are sometimes made together in clusters, facilitating studies of some aspects of the coupled system. However, similar advances have not been made in the realm of autonomous atmospheric measurements. While buoy-based systems exist for basic surface meteorology and some atmospheric gases, robust autonomous measurements are not currently available for the surface energy budget nor the processes responsible for its variability such as clouds and atmospheric thermodynamic profiles. These measurements are exceedingly difficult to make in an autonomous fashion due to extreme conditions, riming, the sophistication of necessary instruments, and other issues. Ultimately the atmosphere is the driver of most variability in the Arctic cryosphere; it is involved in most climate feedbacks, and atmospheric greenhouse gases are the root cause of climate change. To understand the central Arctic climate system, and improve sea-ice forecasting, requires an improved ability to obtain long-term atmospheric measurements in the central Arctic domain and to conduct the inter-disciplinary research that will provide a coupled system understanding.

Due to the complexity, expense, and scale of the deficiencies outlined here for the central Arctic system a legitimate attempt to address these issues requires significant national and international cooperation. There are two current promising pathways for progress where investment and coordination will lead to substantial advancement in both the short- and long-term.

1) *The Multidisciplinary drifting Observatory for the Study of Arctic Climate* (MOSAiC, www.mosaicobservatory.org). To make large advances in understanding many aspects of the coupled central Arctic system requires comprehensive, interdisciplinary observations, some of which use sophisticated instruments that cannot currently be operated in an autonomous fashion. While the movement towards autonomous sensors is important for continuity (see below), the scale of our current deficiencies and urgency with which they must be addressed warrant intensive, manned observations.

MOSAiC will be a drifting, manned station to facilitate coupled system observations of the atmosphere, ice, ocean and ecosystem in the central Arctic, surrounded by a constellation of autonomous sensors to capture spatial heterogeneity and variability. These assets will be installed in the newly forming autumn sea ice and drift for a full year with that ice, supporting coupled system observations over the annual cycle. Observations of many critical parameters such as cloud properties, surface energy fluxes, atmospheric aerosols, biological processes in the ice and ocean, and others have never been made in the central Arctic in all seasons, and certainly not in a coupled system fashion. The international scientific community recognizes that, if manifested, MOSAiC will provide an unprecedented step change in coupled system understanding and a foundation for coupled system research and modeling for the foreseeable future.

MOSAiC is an example where the scientific drivers are exceedingly strong and the potential for scientific advancement is high. As a result, there has been substantial excitement throughout the community on the potential it holds. The International Arctic Science Committee (IASC) has adopted MOSAiC as a key international activity, the German Alfred Wegener Institute has made the huge contribution of the icebreaker Polarstern to serve as the central drifting observatory for this yearlong endeavor, and the US Department of Energy has committed a comprehensive atmospheric measurement suite. MOSAiC will be an observational centerpiece for the WMO-sponsored Year of Polar Prediction (YOPP), which will bring together numerous enhanced observational and modeling activities over a multi-year period towards the advancement of polar prediction capabilities. Many other nations and agencies have expressed interest in participation and in gaining access to the unprecedented observational datasets that MOSAiC will provide. However, international coordination is not yet sufficient to support this groundbreaking endeavor and it likely will not be possible without substantially more US leadership and formal engagement from additional nations.

2) *Development of autonomous atmospheric systems.* To develop a longer-term understanding of the central Arctic coupled system that represents multiple years and diverse conditions also requires making sustained autonomous atmospheric measurements along with those that are currently made in the Arctic ocean and sea ice. Prior attempts to routinely measure atmospheric radiation faced difficulties related to riming and leveling, but these are solvable problems. Profiling atmospheric thermodynamic and dynamic structure, and observing cloud properties are substantially more difficult, but obtaining some estimate of how these interact with the surface is critical for understanding the current and evolving Arctic state. Various groups are currently working on buoy-based atmospheric observations, with leadership from the French and Norwegians. Further investment in robust technologies for obtaining reliable atmospheric measurements in the central Arctic are needed, and international coordination is imperative to provide the requisite financial backing, system development, network deployment and logistics support, and integration with other autonomous measurement systems. Manned campaigns like MOSAiC can serve as an important platform for development of such systems by providing a platform for all-season, in-the-field testing and adaptation of equipment.

To manifest MOSAiC and long-term autonomous atmospheric measurements, and maximize their benefit for stakeholders, these significant activities must rely on national and international coordination. To date there has been little coordination on “coupled system” observations in the central Arctic with an emphasis on better integrating atmospheric measurements. As a result these are the most significant gaps that inhibit shared priorities like sea ice forecasting. With a wealth of experience and capability, and the potential for strong collaborations with many nations, the US should provide leadership in this direction. Organizations such as the US Interagency Arctic Research Policy Committee (IARPC) must stand up to its mandate and develop truly interagency coordination on these important topics, rather than providing simply a collection of disparate individual agency contributions to Arctic research. Through IARPC, US agencies can and should formulate a cross-agency plan for committing specific resources to the MOSAiC and YOPP initiatives; moreover, this plan must take shape in 2016 to provide ample time for planning and coordination. Internationally, nations must develop the ability to more effectively coordinate their contributions through joint funding mechanisms and formalized leveraging of resources. Prioritization of joint research on key Arctic themes can capitalize on guidance from international organizing bodies such as IASC.

A multi-disciplinary and multi-institutional approach to long-term and high-resolution Arctic marine monitoring

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Advances in instrument technology now allow us to autonomously sample the marine ecosystem from the vantage of multiple disciplines and across multiple trophic levels. A coordinated set of co-located subsurface moorings on the northeastern Chukchi Sea shelf is making observations with high temporal resolution throughout the year, including the under-sampled and poorly understood seasons when sea ice inhibits ship-based sampling. We describe here our approach to mustering and maintaining the resources sufficient for operating this highly instrumented Arctic marine observatory. Through formation of a multi-institutional consortium we are able to achieve as a group far more than any single partner could alone. Led by the University of Alaska's School of Fisheries and Ocean Science, other academic partners include researchers from the University of Washington and Université Laval; Olgoonik-Fairweather is an industry partner; and agency partners are the Alaska Ocean Observing System (AOOS) and the North Pacific Research Board (NPRB).

The success and future resilience of our Chukchi Ecosystem Observatory hinges on:

- Coordinated collaboration of multiple consortium partners
- Sustained financial support over many years - but at moderate levels annually
- Surpassing some critical mass of measurements and activity beyond which new partners want to join and fuel new growth
- Selection of site and measurement parameters that will be important to many stakeholders
- A data policy based on open sharing and rapid dissemination
- Partnering with other programs for observatory servicing through shared ship operations
- Attracting new partners by offering leveraging opportunities for new applications

By achieving a certain "critical mass" of observations at the observatory site, we have been able to attract new partners and measurements that had not been associated with the initially proposed and funded project. Although still in our build-out phase, the fully outfitted observatory will simultaneously record ocean and sea ice physics, nutrient and carbonate chemistry, suspended and sinking particulate matter, phytoplankton, zooplankton, fisheries, and marine mammal data sets, thereby providing an unprecedented view into the mechanistic workings of the Chukchi shelf ecosystem. The observatory site - on the southeastern flank of Hanna Shoal and northwest of the head of Barrow Canyon - is well situated to monitor the shelf's nutrient and carbon cycles and how changing wind, wave, and ice affect the regional oceanography.

Another important aspect of securing the operating funds for the observatory is through the recognition that the observatory data are valuable to multiple stakeholders having many disparate applications. The data provide researchers and resource managers with a broad-spectrum and multi-year set of reference observations that can be applied to evaluating and improving regional and global-scale biogeochemical, ice-ocean circulation and ecosystem models. Sea ice data are important to industry and shipping interests. Data spanning multiple trophic levels are important to an ecosystem approach to resource management.

In order for the full potential of this unique dataset to be realized, we have implemented an important open data policy. Raw data are made public immediately following each recovery cruise to enable time sensitive analyses and applications; fully processed data are published as soon as practical after recovery given the requisite time lags associated with post-season factory calibrations and other unavoidable laboratory/processing bottlenecks.

A single mooring was deployed in September 2014 and recovered in August 2015, comprising the first year of the observatory in the water. The parameters recorded included: currents, temperature, salinity, pressure, significant wave height and direction, ice thickness and keel depth, chlorophyll *a* fluorescence, beam transmission, photosynthetically available radiation and acoustic backscatter at 38/125/200/455 KHz. The 2015 deployment consisted of three co-located moorings carrying an expanded set of instrumentation including a dissolved oxygen sensor, a colored dissolved organic matter sensor, a sediment trap, a passive acoustic recorder, and water column photography. Future deployments will also measure particle size spectra and concentrations as well as several carbonate chemistry parameters. We provide an overview of the CEO consortium and our approach, objectives and observatory design, and highlights from the first year's worth of data returns.

Arctic Observing Summit (AOS)

Statement: Circumpolar Biodiversity Monitoring Programme (CBMP)

Relevant to all themes: but especially for themes 1 and 4

By*:* Tom Christensen, CBMP Co-Chair, John Payne, CBMP Co-Chair or Courtney Price, CAFF Secretariat

Facilitating more rapid detection, communication, and response to the significant biodiversity-related trends and pressures affecting the circumpolar world.

The Conservation of Arctic Flora and Fauna[a] (CAFF) is the biodiversity working group of the Arctic Council [b] and has a mandate to address the conservation of Arctic biodiversity, and to communicate its findings to the governments and residents of the Arctic, helping to promote practices which ensure the sustainability of the Arctic's living resources. It does so through various monitoring, assessment [c] and expert group [d] activities. CAFF's projects provide data for informed decision making to resolve challenges arising from trying to conserve the natural environment and permit regional growth. This work is based upon cooperation between all Arctic countries, Indigenous Organizations, international conventions and organizations.

As the Arctic continues to experience a period of intense and accelerating change, with climate change at the forefront, and as changes in polar regions impact environments, migratory species and communities globally, it has become increasingly important to effectively and sustainably manage Arctic ecosystems. CAFF operates at the interface between science and policy and as such is positioned to develop common responses on issues of importance. In order to deliver informed policy advice to decision-makers, it is important that accurate, credible and timely information on current and predicted changes in the Arctic's ecosystems are made available. To efficiently address this information CAFF created the Circumpolar Biodiversity Monitoring Program (CBMP – www.cbmp.is [1]), an international network of scientists, government agencies, Indigenous Organizations and local resource users working together to enhance Arctic biodiversity monitoring to improve detection, understanding, prediction and reporting of important changes facing Arctic biodiversity. Community well-being, health, food security, fisheries and other economies depend on the successful and sustainable management and monitoring of biodiversity and ecosystem health.

The CBMP is collecting information from the existing extensive and varied monitoring efforts across the Arctic to provide more robust and timely information on what is happening in the Arctic environment. Harmonizing and integrating efforts to monitor the Arctic's living resources will allow decision makers to develop responses to challenges facing the Arctic environment in a more efficient and effective manner.

The CBMP coordinates marine[e], freshwater[f], terrestrial [g]and coastal[h] monitoring activities while establishing international linkages [i]to global biodiversity initiatives including the UN Convention on Biological Diversity (CBD) and the Group on Earth Observations Biodiversity Observation Network (GEOBON). The CBMP emphasizes data management (through the Arctic Biodiversity Data Service[j]), capacity building[k], reporting[l], coordination and integration [m] of Arctic monitoring, and communications, education and outreach[n].

[1] *The CBMP is a response to Arctic Council recommendations that have called for improved and better coordinated, long-term Arctic biodiversity monitoring e.g. from the Arctic Climate Impact Assessment (ACIA) and reinforced by the recommendations of the Arctic Biodiversity Assessment and other Arctic Council projects. The development and implementation of the CBMP has been further highlighted as an Arctic Council priority in the Kiruna (2013), Tromso (2009), Salekhard (2006), Reykjavik (2004), Inari (2002), Barrow (2000) and Iqaluit (1998) Declarations.*

Experts are currently developing and implementing coordinated and integrated Arctic Biodiversity Monitoring Plans to help guide circumpolar monitoring efforts. Results will be channelled into effective conservation, mitigation and adaptation policies supporting the Arctic. These plans represent the Arctic's major ecosystems: 1) marine[o]; 2) freshwater[p]; 3) terrestrial[q]; and 4) coastal[r]. The Coastal Plan is currently under development while the other Plans are being implemented. These umbrella Plans work with existing monitoring capacity to facilitate improved and cost-effective monitoring through enhanced integration and coordination.

Implementation activities include the collection and aggregation of existing monitoring information and capacity across the Arctic, identifying opportunities to fulfill gaps in monitoring, and working towards the publication of the State of the Arctic Marine, Freshwater and Terrestrial Biodiversity reports in 2017, 2018 and 2019. Work also continues to make data available through the Arctic Biodiversity Data Service (ABDS)[s], an online, interoperable data management system that serves as a focal point and dynamic source for up-to-date circumpolar Arctic biodiversity information and emerging trends. Satellite data is underutilized in the Arctic. There is a desire among the various science disciplines to use remote sensing to support ongoing biodiversity assessments and monitoring. In addition, remote sensing data also has value for site-specific and regional applications. CAFF, through the CBMP is creating a framework to harness remote sensing potential for use in Arctic[t] biodiversity monitoring and assessment activities and to produce a series of satellite-based remote sensing products focusing on the circumpolar Arctic. MODIS satellite products of relevance to Arctic processes are being converted to a more Arctic-friendly projection, facilitating a top-of-the-world analysis perspective. Satellite products are being developed for use by different stakeholder groups and products will be organized by terrestrial, marine, coastal, and freshwater disciplines. Landsat images will be used to generate additional remote sensing products at a finer scale.

It is important that monitoring programs develop the most effective reporting strategies if they are to inform decision making. To facilitate effective and consistent reporting, the CBMP has chosen a suite of indices and indicators [u]that provide a comprehensive picture of the state of Arctic biodiversity – from species to habitats to ecosystem processes to ecological services. These indices and indicators are developed in a hierarchical manner, allowing users to drill down into the data from the higher-order indices to more detailed indicators. Indicators available or under development include Arctic Species Trend index; Arctic Migratory Bird index, Protected Areas index, Land Cover change; and Linguistic diversity.

Enhanced coordination of Arctic biodiversity monitoring via the CBMP is yielding an improved ability to detect important trends, link these trends to their underlying causes, predict future trends and scenarios for Arctic biodiversity, and thereby provide more timely and credible information to support responsible decision making at multiple scales (local, regional, national and global). It is anticipated that this increased coordination will result in reduced costs, compared to the cost of multiple, uncoordinated approaches that stop at regional or national boundaries. While most Arctic biodiversity monitoring networks are, and will remain, national or sub-national in scope, there is immeasurable value in establishing circumpolar connections among monitoring networks. In addition, this coordination is resulting in more rapid uptake of new technologies and methodologies through increased dialogue.

The CBMP has been endorsed by the Arctic Council and the UN Convention on Biological Diversity. It is the biodiversity component of the Sustaining Arctic Observing Networks (SAON[v]) and the official Arctic Biodiversity Observation Network of the Group on Earth Observations Biodiversity Observation Network (GEOBON[w]).

Information from the efforts of the CBMP will flow through national processes as well as through appropriate international venues such as the Arctic Council and the UN Convention on Biological Diversity. This not only provides the best information to the most relevant policy actors, but also creates cost efficiencies in reporting activities. The continued implementation of CBMP comes at a critical time. The recent Conference of the Parties to the Convention on Biological Diversity (CBD) resulted in a strong recognition of the importance of Arctic biodiversity and of the Arctic Council work.

For more information please visit: www.cbmp.is or contact caff@caff.is.

Recent updates and reports:

- Arctic Freshwater Biodiversity Monitoring Plan
- Arctic Terrestrial Biodiversity Monitoring Plan
- Arctic Marine Biodiversity Monitoring Plan
- Arctic Biodiversity Data Service (ABDS)
- Land Cover Change Index [x]
- Arctic Species Trend Index[y]
- Arctic Migratory Bird Index
- Protected Areas
- Linguistic Diversity[z]

Sign up for the CBMP Newsletter[aa] and read past issues[bb].

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[a] http://www.caff.is/
[b] http://www.caff.is/arcticcouncil
[c] http://www.caff.is/assessments
[d] http://www.caff.is/expert-group
[e] http://www.caff.is/index.php?option=com_content&view=article&id=499&Itemid=1014
[f] http://www.caff.is/index.php?option=com_content&view=article&id=508&Itemid=1015
[g] http://www.caff.is/index.php?option=com_content&view=article&id=557&Itemid=1016
[h] http://www.caff.is/index.php?option=com_content&view=article&id=524&Itemid=1017
[i] http://www.caff.is/index.php?option=com_content&view=article&id=470:about-the-cbmp&catid=385:about-the-cbmpnew&Itemid=1011
[j] http://www.abds.is/
[k] http://www.caff.is/cbmp-capacity-building
[l] http://www.caff.is/cbmp-reporting
[m] http://www.caff.is/cbmp-coordination
[n] http://www.caff.is/cbmp-communications-and-outreach
[o] http://www.caff.is/marine/marine-monitoring-plan
[p] http://www.caff.is/freshwater/freshwater-monitoring-plan
[q] http://www.caff.is/terrestrial/terrestrial-monitoring-plan
[r] http://caff.is/coastal
[s] http://www.abds.is/
[t] http://caff.is/indices-and-indicators/land-cover-change-index
[u] http://caff.is/indices-and-indicators
[v] http://www.arcticobserving.org/
[w] http://geobon.org/
[x] http://www.caff.is/indices-and-indicators/land-cover-change-index
[y] http://www.caff.is/asti
[z] http://abds.is/index.php/explore-indicies/linguistics

[aa] http://visitor.r20.constantcontact.com/manage/optin/ea?v=0013J7BZf17TJUwvedPSUdU0w==
[bb] http://www.caff.is/cbmp-newsletter

New Japanese Arctic Research Project "Arctic Challenge for Sustainability (ArCS)" and related activities

Headquarter of ArCS Project (Masao Fukasawa[2, 1], Hiroyuki Enomoto[1] , Sei-ichi Saito[3] and Takeshi Kawano[2])

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It has become a well-known fact that changes in the Arctic environments are closely connected to the weather /climate system in regions other than the Arctic. Also, the rapid environmental changes in the Arctic raise new socio-economic activities on a global scale fumbling a new and appropriate relationship among Arctic and non-Arctic states. Now, issues arising in the Arctic environment are nothing other than global issues.

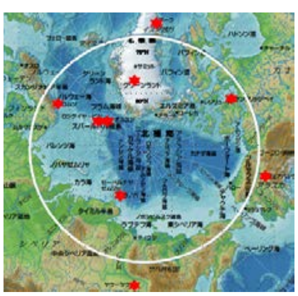
New Japanese Arctic research project "Arctic Challenge for Sustainability (ArCS)" started in the summer of 2015. The gist of the project is as follows;

1. To enhance research system of Arctic science in order to assess the rapidly changing environment in the Arctic through projections with least ambiguity as possible under strong and close international collaboration.
2. To provide necessary and sufficient information, not only from the viewpoint of natural science but also of social science, to domestic and international policy-makers actively for tackling to "Arctic problems" and also to strengthen Japan's contributions to the Arctic and the international community.

These points will provide a scientific basis for Arctic policies of national and international responding by helping to grasp the present state of the Arctic environment and to improve future projections of various items, which enables sustainable development in the Arctic and contributes to secure the resilience of the Arctic.

Aiming at the gist, ArCS has started. The ArCS project is composed three pillars, namely, "Reinforcement of research base on foreign countries", "Dispatching experts to Arctic meeting and human resource development", and "Enforcing international research cooperation". At the same time, ArCS is aiming to have much dialogue as possible with stakeholders (government officials, private sectors, mass-media, etc.) who make advices concerning the possible research direction of the project. Also, ArCS has a plan to organize International Advisory Board in near future.

Reinforcement of research base/stations



Improving the basic research facilities for long-term stay and/or monitoring studies, which can be used by inter- national collaborative studies.

Dispatching experts and young scientists and Human resource development

Long-term research cooperation through the exchange of young researchers. Interdisciplinary human resource development. Sending experts to International committees and meetings.

Enforcing international research cooperation

Carrying out the international joint research project in the Arctic. Considering the social and cultural impacts, providing information appropriately.

New Japanese initiative ArCS project will integrate the current ability of research and international collaborations. ArCS is also willing to give the idea to fill the gaps of observation networks of weather/ocean, technologies of sensing/platforms and simulating, and data interoperability.

Some trials have been already initiated: JAMSTEC is developing automated vehicle to conduct observations efficiently in the Arctic Ocean, especially under the sea ice. Micro-satellite technologies are also waiting their missions for low-cost and focused Arctic observing systems. Ocean Observation Camera (OOC) was developed as one of the scientific instruments installed on micro satellite RISESAT by Hokkaido University, Tohoku University, National Taiwan Ocean University, and other research and corporate partners. The lunch of RISESAT planed next year, and start providing new Arctic data. Arctic Data archiving System (ADS) initiated by GRENE Arctic project will look for the requirement from Arctic scientific partners and possible improvement to respond them.

Statement for the 2016 Arctic Observing Summit

Statement on the GEO Cold Region Initiative (GEOCRI)

Yubao Qiu[1], Hannele Savela[2], Jeffrey R. Key[3], Massimo Menenti[4], Vito Vitale[5], Xiao Cheng[6], Julie E. Friddell[7], Jan René Larsen[8], Hiroyuki Enomoto[9], Xuejun Guo[10], Stein Sandven[11], Jun She[12], Hanna Lappalainen[13], Basanta Raj Shrestha[14], Bob Su[15], Carolina Gabarró[16], Xin Li[17], Terry V Callaghan[18], Richard Lawford[19], Dominique D. Bérod[20], and the GEOCRI Group[21]† *(The affiliation list is in Appendix I)*

More than one hundred countries around the world have cryospheric elements, where frozen water in various forms dominates the earth's changing systems. These are the "Cold Regions" that include the Arctic, Antarctic, high-latitude oceans, the Himalaya-Third Pole region, high-altitude alpine (mountain) areas, and even some parts of the mid-latitudes. They are the most ecologically and environmentally sensitive areas to global and regional environmental change. The changes to these areas comprehensively affect the dynamic Earth system, impacting many aspects of society in all parts of the world. Recent scientific research is making it increasingly clear that "What happens in the poles doesn't stay in the poles"[1, 2, 4].

GEOCRI sketch scheme: An Arctic focus with its main networks

The Group on Earth Observations (GEO) was launched in response to calls for action by the 2002 World Summit on Sustainable Development, which recognized that international collaboration is essential for exploiting the growing potential of Earth observations to support decision making in an increasingly complex and environmentally stressed world.

†This statement was based on the GEO Cold Regions Initiative proposal to the GEO XII Plenary, the authors listed above drafted this statement. Contact: Yubao Qiu, qiuyb@radi.ac.cn, and Dominique D. Bérod, dberod@geosec.org.

GEO aims to build a comprehensive Global Earth Observation System of Systems (GEOSS). A dominant feature of the Cold Regions is frozen water in its various forms, which is relevant to GEOSS through its Water, Ecosystem, Biodiversity, Health, Energy, Disaster, Climate, Weather, and Agriculture societal benefit areas.

With its strong link to user communities, GEO is developing a user-driven approach to Cold Regions that will complement the current science-driven effort [4]. A global, comprehensive Cold Regions Information Service will strengthen synergies among the activities of the Environmental, Climate, and Cryospheric communities. In particular, it will support the efforts of scientists, experts and decision makers to ensure the sustainability of these environmentally stressed areas in an increasingly complex political and economic context.

The GEO Cold Region Initiative (GEOCRI) is an emerging initiative that aims to identify, address and fill observational gaps and improve networks through coordinated observation practices and information services worldwide. Its goal is "*Promoting Earth observations data sharing and cooperation, enabling improved information services for the inter-continent cold regions, informing the stakeholder and decision makers*".

GEOCRI's vision, objectives and actions are to,

- Build a global **network** to archive, manage, and provide access to in-situ and remotely-sensed earth status data (especially the Cryosphere, Ecosystem/Biodiversity, Environment, etc.) and social and economic data for monitoring the global cold regions through appropriate national, regional and global systems, centres and programs.
- Provide sustained observations and information **exchange mechanism**, advocate open data policy, and free access to the earth observations data over Earth's Cold Regions, enhance the interoperability capacity between the existing and emerging international distributed data sharing networks.
- Establish a **proactive framework** for the development of information and related services, the Global Cold Regions Community Portal, to underpin the Global Earth System of Systems implementation by expanding the outreach of, and maximizing synergies among, thematically wide GEO activities and thematically deep participant activities, thereby exploiting their complementary roles.
- Strengthen the **partnerships and synergies** with scientific communities, policy-makers, stakeholders, and funders over the cold regions' ecological and engineering fields to address the fragile ecosystem and environmental challenges and societal influences, and improve the public awareness through the capacity building.

Under the GEO umbrella, GEOCRI is open to participation by existing international organizations and networks, national and international programmes, national and regional GEOSS, individual projects and experts, observation stations and facilities, and the private sectors. Participation is voluntary. A comprehensive list of contributions is given in Table 1.

Table 1: GEO Cold Regions Partnership (Qualitative Rating)

GEO Cold Regions Partnership (Qualitative Rating)

Catg.		Dimenssion	GEO Cold Regions	CEOP AEGIS	GCW/WMO	INTERACT	PEEX	Polar View	PSTG/WMO	SAON	SIOS	SOOS	TPE	SwissEX	Other National Projects
Geographic area		Global													
	Regional	Arctic													
		Svalbard													
		Antarctic													
		TP(Third Pole)													
		Mountains													
Themes		Cryosphere													
		Ecosystem													
		Environment*													
		Biodiversity													
		Others(WA/CL/HD/AG, etc.)													
Obs.		Space Observations													
		In-Situ													
		Model(Simulation)													
Functions		Implementation													
		Coordination													
		Network													
		Information(Data Portal)													
		Services													
		Capacity Building													
		Resource Mobilization													
		User Engagement													

* Environment: comprehensive sets, eg. Black Carbon, Atmoshphere and etc. WA: water CL: climate HD: Human dimension AG: Agriculture
* Qualitative Rating based on the mandate, there is no any comparison with each other
* Coordination : managerial function to making different people or things work together
* Capacity Building : approach to development that focuses on understanding

Intl. Program/projects National Program/Projects

(Dec, 2013)

Through GEO's members and its platforms, the Plenary and Ministerial Summit, GEOCRI raises awareness and overall requirement, and provides support to individuals and programs for resource and financial mobilization at a national or international level.

Partner contributions to GEOCRI for the near-term include the Second Asia Global Cryosphere Watch (GCW) CryoNet Workshop in Russia and the Second South America CryoNet Workshop; SAON's sustained documentation and data activities; SIOS implementation on a full-fledged establishment of the knowledge centre in Longyearbyen in 2016; capacity building for research and in-situ observations throughout the pan-arctic station network INTERACT; launching a comprehensive PEEX metadata collection and building a Modelling Demo; activating the "metadata elements" project of the IASC/SAON Arctic Data Committee in 2016, which is to identify the minimal set of metadata fields to facilitate automatic interoperability between polar data centers and repositories around the world by Canadian Cryospheric Information Network/Polar Data Catalogue; establishment of flagship stations within the Third Pole region for observation and monitoring through Third Pole Environment (TPE); harmonizing and collecting observations in Greenland and surrounding waters by Denmark; compiling the ESA – MOST Dragon 4 Hydrology and Cryosphere Theme; improvement to the Italian Arctic Data Centre (portal of the Italian research activities); improving the Snow Observations over Tibetan Plateau (SOTP); improving the Cryosphere Monitoring Programme (CMP) and Cooperative Research Activities (CRA) of the Arctic Observing and Research for Sustainability and of the Mountains as Sentinels of Change; promoting the joint observations of ocean, land and atmosphere in the Arctic region and promoting Arctic Data Archive System (ADS) by Japan, and the project "Modelling Freeze-Thaw Processes with Active and Passive Microwave Observations" (SAMP Freeze/Thaw) supported by the Netherlands Organisation for Scientific Research; enhancing the Ny Alesund observation super-site in the Arctic; launching a Chinese cubesat named TW-1A for polar sea ice observation(has been launched at Oct., 2015); promoting a Chinese Water Cycle Mission (WCOM) by China; *(Note: All the contributions are listed in the new work programme 2016-2025, version 3.0)*

Acknowledgment: thank all the contributors who we did not list as co-authors, we cannot achieve this without their contributions, they are Ellsworth LeDrew (Canada), Dag Anders Moldestad (Norway), David Hik (Canada), Jenny Baeseman(Norway), Emilio Garcia Ladona (Spain), Nicholas Dawes (Switzerland), Marco Tedesco (USA), Cunde Xiao (China), Manfred Gottwald (Germany), Mark Drinkwater (ESA), Barry Goodson (Canada), and Tandong Yao(China), and etc. in the past time of GEOCRI.

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