Arctic Observation:

Contribution from Asian Forum for Polar Sciences (AFoPS)

AFoPS Secretariat
on behalf of
AFoPS Arctic research community

Introduction

The Asian Forum for Polar Sciences (AFoPS) established in 2004, is a non-governmental organization set up to encourage and facilitate cooperation for the advance of Antarctic and Arctic sciences among Asian countries. The AFoPS currently consists of five Members - China, India, Japan, Malaysia, and the Republic of Korea - with a growing number of observers from Thailand and many more.

Towards the end of the first decade, the AFoPS has become an important medium of collective endeavors in human and information exchange, research collaboration, and logistics cooperation among the Asian polar science institutions.

Research infrastructures of AFoPS members now encompass much of the Arctic, both oceanic and terrestrial realms. Ice breaking or ice strengthened research vessels from China, Japan and Korea regularly sail the Arctic waters. Four members maintain research stations in Svalbard and many more observation posts around the Arctic. These facilities can be well connected and offered for international collaboration.

Logistic capabilities of AFoPS are reaching a level that can make significant data contribution to a circum-Arctic perspective. Human expertise and enthusiasm are also growing. It is timely to offer this possibility to the wider polar community in contribution to a sustained Arctic observing system.

Current activity and research infrastructure of AFoPS Members

Xuelong, the powerful Chinese research icebreaker, sails every other year to Pacific Arctic waters mid-summer, usually August to September. The Chinese program undertakes a fairly extensive, multi-disciplinary survey in areas such as oceanography, biology and geology. Reaching out to the northernmost edge of the sea ice to survey deep in the icy Arctic waters was often attempted in the Chinese research voyages. A number of focused investigations in hydrographical/biogeochemical processes and biodiversity were conducted in a number of locations in the Arctic Ocean including the Canada Basin and the Bering Basin. Chinese Arctic station Yellow River in Svalbard also support a range of observational activities.

The first Indian Arctic expedition in August 2007 has marked a beginning of long-term scientific research by Indian scientists in yet another arena of global scientific collaborative research in the Polar Regions. In 2008, a research base 'Himadri' station was established in Ny-Alesund to mark the IPY and to give a thrust to our endeavor in Polar Science. Recent deployment of IndARC, the country's first underwater moored observatory in the Kongsfjorden fjord, half way between Norway and the North Pole, represents another milestone in India's scientific endeavors in the Arctic region.

In response to the rapid change of the Arctic environment, the Japanese ministry to support science and technology, MEXT, started the Arctic Climate Change Research Program in 2011 as one of the new national projects, "Green Network of Excellence (GRENE)". In order to strengthen Arctic research and contribute to the international community, MEXT initiated the next 5-year program called "Arctic Challenge for Sustainability (ArCS)". This program focuses on 1) understanding changes in the Arctic holistically as well as its global impacts through comprehensive and integrated research, 2) understanding causes and mechanism of these changes, 3) predicting future changes and assessing the subsequent socio-economic impacts, and 4) delivering robust scientific information to stakeholders.

Korea Polar Research Institute (KOPRI), the lead agency of the Korean national polar program, undertakes Arctic observations supported by some of its major research projects. Oceanography and remote sensing group conduct multi-disciplinary research survey every summer in the Pacific side of the Arctic waters, mostly in Chukchi Sea and further north. Its research icebreaker Araon has been used as a deployment platform for ocean and sea ice buoys and moorings of many international partners. The terrestrial program focuses on permafrost ecosystem and greenhouse gas dynamics, running observation posts at a number of Arctic locations including Svalbard and Alaska. KOPRI's field observation data will be incorporated into modelling efforts that have already begun to determine the climate linkages between the Arctic and mid latitude.

Malaysian polar program, yet to possess its own field infrastructure, has taken a great deal of interest in understanding the climatic connection between the changes in the polar region and lower latitude phenomenon. It also dispatches some of its scientists to Arctic field sites to observe and collect specimens and samples with support of AFoPS Members and other partners.

Concluding remarks

After marking the tenth anniversary in 2014 as well as a chairmanship transfer, the AFoPS is now gearing for a big leap in the next decade. This is also the time when we see a large expansion in research infrastructure and investments among the Asian polar programs. The AFoPS pursues elevated and more sustained Arctic observations by concerted use of its research infrastructures in both land and ocean. The AFoPS members have so far accommodated a number of foreign researchers on board or at stations as opportunities develop and will continue to do so.

A regional alliance with a global perspective has every good reason to become a network of active cooperation hubs for other members of the Arctic observing community. The AFoPS secretariat aims to coordinate this process and is prepared to receive expressions of interest and facilitate consultation as such cooperation is better mediated and implemented with collective effort. Please write to international@kopri.re.kr.

Permafrost Action Team: Short statement for ASSW 2016

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Overview: The Arctic is warming rapidly (IPCC, 2013) causing permafrost to thaw and exposing massive stores of organic matter to microbial decomposition (Schuur *et al.*, 2015). Degradation of near-surface permafrost (perennially frozen ground) caused by modern climate change is adversely affecting human infrastructure, altering arctic ecosystem structure and function, changing the surface energy balance, and has the potential to dramatically impact arctic hydrological processes and increase greenhouse gas emissions. The Permafrost Action Team (AT) as one component of the Study of Environmental Arctic Change (SEARCH) addresses critically important knowledge gaps about the causes and consequences of degradation and loss of near-surface permafrost. The Permafrost AT objectives are: 1) improve observation and prediction of the nature, timing, and location of permafrost thaw; 2) improve prediction of how degradation of near-surface permafrost will influence the dynamics of the Arctic landscape; 3) improve prediction of how permafrost degradation will influence fish, wildlife, and human communities. The planned activities span the broad context of permafrost research, including changes in permafrost temperature, extent, and landscape evolution. In addition the Permafrost AT is aimed at facilitating connections between new knowledge generation and potential stakeholders including community leaders, industries, nongovernmental organizations, and governmental decision makers. There is growing realization of the strong interactions between degradation of near-surface permafrost the dynamics of ecosystems, and that these interactions together influence local and global environmental, economic, and social systems.

Science Synthesis: The Permafrost Action Team is focusing its efforts to develop new knowledge about the impacts of permafrost degradation through research synthesis. This framework of synthesis builds on activities of the Permafrost Carbon Network (PCN) (www.permafrostcarbon.org), which is now a subcomponent of the Permafrost AT. This network is an international scientific effort that links biological carbon cycle research with networks in the physical sciences focused on the thermal state of permafrost. Approximately 1330-1580 billion tons of soil carbon is stored in soils of the northern circumpolar permafrost zone, about twice as much carbon as currently contained in the atmosphere (Hugelius *et al.*, 2014, Schuur *et al.*, 2015). Sustained and substantial carbon release from the Arctic is a wildcard with the potential to alter the future trajectory of climate change. While modern climate change is largely due to human activities, the future path also depends on the responses of terrestrial and ocean systems. A key societal question is whether there are *tipping points*, global carbon cycle surprises that will make climate change effects such as sea-level rise, extreme weather, droughts, and impacts on agriculture occur faster than currently projected by models. Recently, attention has been drawn to permafrost thaw as a mechanism that could move significant quantities of Arctic carbon into the atmosphere in response to a changing climate. This vulnerable carbon pool has been identified to be susceptible to both the direct and indirect effects of climate change, but the level of risk and timescale of change is currently highly uncertain. The critical question centers on how fast this process will occur. Abrupt releases of methane forecast to cause trillions of dollars of economic damage to global society contrast with predictions of slower, sustained carbon gas release that would give society more time to adapt

Yet, the picture is complicated by limited information on the quantity and form of carbon sequestered in permafrost, by inadequate knowledge of cryospheric biogeochemistry, and by insufficient understanding of the interactions between the terrestrial cryosphere, hydrology and vegetation in northern high latitudes in a warming climate. The activities within the PCN to address these knowledge gaps and to promote synthesis and outreach include: 1) organization of an interrelated sequence of meetings and working groups designed to synthesize existing permafrost carbon research, and 2) formation of a consortium of interconnected researchers to disseminate synthesis results about permafrost carbon to other scientific networks and activities. There are five working groups organized around the linked themes of Carbon Pools, Carbon Quality, Thermokarst, Anaerobic/Aerobic Issues, and Upscaling & Modeling Integration. These working groups are producing synthesis products both within and among individual groups. Over the last five years, the network has produced new knowledge through multiple synthesis products within each of these working groups (e.g. Harden *et al.*, 2012, Hugelius *et al.*, 2014, Hugelius *et al.*, 2013, Olefeldt *et al.*, 2013, Schädel *et al.*, 2014, Strauss *et al.*, 2013, Treat *et al.*, 2015). Individual synthesis products have then been linked in crosscutting activities designed to address the highest level question about the permafrost carbon feedback to climate change (Schuur *et al.*, 2015). The current estimated amount of carbon vulnerable to release to the atmosphere in a warming climate is between 5-15% of the 1330-1580 Pg carbon pool, which is of similar magnitude to other historically important biospheric carbon sources. This synthesis also concluded that carbon release is likely to be a gradual, long-lasting process over many decades rather than an abrupt pulse.

Science synthesis produced by the PCN, in turn, has led to publications aimed at broader audiences designed to bring information to a wide array of stakeholders. Activities and people within this network have informed, for example, the Intergovernmental Panel on Climate Change Working Group I Fifth Assessment 'Chapter 6: Carbon and Biogeochemical Cycles' (Ciais *et al.*, 2013) and a United Nations Environmental Program report 'Policy implications of warming permafrost' (Schaefer *et al.*, 2012), among other documents. These types of articles that are designed to reach broader audiences have been made possible with the integration and synthesis of individual primary science publications, the core activity of the network. In turn, the knowledge within these publications has been widely disseminated to the public by the media through interviews by PCN scientists. The sheer size of the Arctic carbon pool, the rapid changes observed in the permafrost region, and the potential tipping-point impacts on both local and global stakeholders warrant focused attention on these remote landscapes. This process of knowledge delivery and use was facilitated by the networking efforts of the PCN to bring the best science available on this topic to a wide range of stakeholders.

This example of the PCN that is focused on the global climate impacts of thawing permafrost was the first step, and an ongoing effort, of the Permafrost AT. The next goal is to enable this science synthesis and networking approach for understanding local impacts of changing permafrost. Knowledge of the impacts of changing permafrost on wildlife, ecosystems and the services they provide to human society is critical for residents of the permafrost zone. The Permafrost AT will be making use of data sets from the two components of the Global Terrestrial Network for Permafrost (GTN-P), the Thermal State of Permafrost (TSP) and the Circumpolar Active Layer Monitoring (CALM) initiative in synthesis studies. The carbon cycle synthesis of the Permafrost AT is already promoting the use of these data sets in the benchmarking of coupled carbon-permafrost-climate models, and there is great potential for these data sets to contribute to syntheses involving infrastructure and ecosystem services.

The Permafrost AT has developed a steering committee of scientists and other stakeholders in the realm of local and global impacts of permafrost thaw with the intent of replicating the PCN science synthesis and network approach to focus on other critical aspects of changing permafrost. Individuals with interest in these topics are invited to join this process aimed at creating knowledge and finding solutions for impacts related to changing permafrost in a warmer world.

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White Paper for the 2016 Arctic Observing Summit
Submitted to Theme 5: Arctic Observations in the Context of Global Observing Initiatives
(This paper also has direct relevance to Theme 6: Interfacing Traditional Knowledge, Community-based Monitoring and Scientific Methods for sustained Arctic observations)

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Advancing Arctic observing within the Global Earth Observation System of Systems (GEOSS) through Community-Based Monitoring

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Abstract

The intent of this paper is to advance the discussion on the complementarity of, and the existing connections between, the Sustaining Arctic Observing Networks (SAON) process and the Group on Earth Observations' (GEO) effort to develop the Global Earth Observation System of Systems (GEOSS). Better coordination may be achieved through an explicit focus on pan-Arctic observing networks, with particular attention to community based monitoring (CBM), which is gaining attention in deliberations associated with the U.S. Chairmanship of the Arctic Council (2015-2017). Community-based monitoring (CBM) has many definitions, but is here recognized as a process of systematic or *ad hoc* observing of environmental phenomena in a social context that is co-led and implemented by Arctic residents, typically in partnership with external collaborators and/or with the support of visiting researchers, government agencies, and non-governmental organizations. The increasing coherence of CBM in the Arctic, along with growing recognition of the utility of community-based observing network systems (CBONS), provides an opportunity to strategically work toward a template and best practices for CBM to be applied to other GEO regions worldwide. We recommend the formation of a CBM Community of Practice (CoP) within GEO, preceded by an organized effort to gather expressions of shared interests from across the GEO community. Such an effort will result in improved interoperability and the application of local and ground-based data, as well as, advance understanding of how and where traditional and local knowledge can best interface with scientific monitoring to improve our understanding of social-ecological systems.

Introduction

The Group on Earth Observations (GEO) has concluded its first ten years (2005-2015) of implementing the Global Earth Observation System of Systems (GEOSS)[1], which is an observation-to-information value chain derived from multiple interoperable Earth observation systems, highly dependent on the foundational elements of *user engagement* and *capacity building*. GEOSS has relied on the voluntary contributions from Member States and Participating Organizations, which have been inventoried and coordinated through the GEO Work Plan. The *Information Services for Cold Regions* Component Task[2], which was intended to support and facilitate the archival, management, and accessibility of *in-situ* and remote observations of the Arctic, Antarctic, and high mountain regions, was included within all previous Work Plans and represents the clearest intention of GEO to integrate Arctic observing. However, Arctic observations are also connected to GEO in other ways; for example, the Circumpolar Biodiversity Monitoring Program (CBMP) contributes via the GEO Biological Observing Network (GEOBON). GEO's membership is open to all member states of the United Nations and to the European Commission. As of January 2016, GEO has 102 members, which include all eight Arctic states and the majority on high-mountain states.

In 2014, GEO renewed its commitment to GEOSS for another decade and accordingly developed the *GEO Strategic Plan 2016-2025*[3], which was released in September 2015 for deliberation at the GEO XII Plenary in Mexico City held in November 2015. *Information Services for Cold Regions* remains present in GEO's 2016 Work Programme[4], and is highlighted as one of 21 *GEO Initiatives*.. In the Work Programme, the Sustaining Arctic Observing Networks (SAON) process is listed as a key contribution to GEO Cold Regions. Importantly, SAON became a Participating Organization within GEO in 2014 to serve as an "Arctic extension" for GEO/GEOSS. This, together with a GEO Cold Regions Side Event at the GEO-X Plenary in January 2014, represents significant progress, especially following a long period of relative inactivity in GEO's efforts to engage the *Cold Regions*[5]. In addition to SAON, GEO Cold Regions has made connections with the World Meteorological Organization's Global Cryosphere Watch (GCW) portal, the Svalbard Integrated Arctic Earth Observing System (SIOS), the Year of Polar Prediction (YOPP), and other cryospheric focused initiatives[6].

SAON, however, is unique in its ability to document and coordinate Arctic observing activities including community based monitoring (CBM) and community-based observing network systems (CBONS). SAON was conceived during the International Polar Year (IPY) 2007-08 and formally established in 2012. Its purpose is to support and strengthen the development of multinational engagement for sustained and coordinated pan-Arctic

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[1] Ad hoc GEO (February 16, 2005) *GEOSS 10-Year Implementation Plan*. Third Earth Observation Summit, Brussels.
[2] GEO's past Work Plans were divided into Tasks, which were sub-divided into Components. *Information Services for Cold Regions* was a component within GEO's Task for Integrated Water Information.
[3] GEO Implementation Plan Working Group. GEO Strategic Plan 2016-2025: Implementing GEOSS. Document MS4, GEO X-II, November 11-12, 2015.
[4] Beginning in 2016, GEO has shift from a Work Plan toward a Work Programme.
[5] Fifth GEOSS Evaluation Team (June 2104) *GEOSS Evaluation of Water, Weather and Climate Societal Benefit*.
[6] GEO 2016 Work Programme (version 4), 22 December 2015.

observing and data sharing systems that serve societal needs, particularly related to environmental, social, economic, and cultural issues. SAON was established on the initiative of the Arctic Council and the International Arctic Science Committee (IASC). SAON has worked with the Arctic research and operational communities and Arctic Indigenous Peoples organizations to evaluate the state of Arctic observing (e.g., through national inventories), assess observing needs, and support cross-community discussions (e.g., co-organizing the Arctic Observing Summit series). Starting in late 2014, this work is continuing through two committees: the Arctic Data Committee (ADC) and the Committee on Observations and Networks (CON). These committees are actively working to move SAON forward in its mission. This includes further developing the Atlas of Community Based Monitoring project (www.arcticcbm.org) led by the Inuit Circumpolar Council, which is described below, as well as continuing work by the Conservation of Arctic Flora and Fauna (CAFF; www.caff.is), which has led the way in supporting CBONS. SAON is working to understand the state and user requirements of Arctic observing, however the body will not directly undertake science planning, policy setting, observations, data archival, or funding of these efforts.

Opportunities for Operational Linkages

GEO has made significant progress in establishing an operational system of systems. The Summative GEOSS Evaluation[7] found that GEO, during its first 10 years, was largely successful in including satellite-based programs, while relatively falling behind in efforts to integrate *in-situ* or ground-based observations. The Evaluation also concluded that GEOSS is far from realizing its vision of being *user-driven*. A multi-pronged approach from across the GEO community will be needed to address these challenges moving forward. A focus on CBM could represent one element to such an approach, and would serve to engage a cross-section of the in-situ and ground-based observing communities that are not yet represented within GEO.

CBM has many definitions, but is here recognized as the process of systematic or *ad hoc* observing of environmental and/or social phenomena that is co-led and implemented by Arctic residents, typically in partnership with external collaborators and/or with the support of visiting researchers, government agencies, and non-governmental organizations. CBM, unlike other forms of observations, often incorporates "user-contexts" within the process of making observations. CBM refers to a broad range of approaches and can serve many purposes, including contributing to CBONS, which are distributed networks of community residents throughout a region who regularly observe their environment, typically in context of local livelihood activities that may include hunting, fishing, and traditional forms of travel across land or water[8]. CBONS rely on observations being systematically documented and shared beyond a single community, guided and informed by an overarching purpose and organizing framework. CBONS are primarily distinguished from instrument-based monitoring by their paramount focus on variables of greatest

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[7] Sixth GEOSS Evaluation Team. Report on the Sixth and Summative Evaluation of GEOSS Implementation. Document 6, GEO X-II, November 11-12, 2015.

[8] Alessa, L., et al. (2015) Bering Sea Sub-Network II: Sharing Knowledge, Improving Understanding, Enabling Response - International community-based environmental observation alliance for a changing Arctic. Conservation of Arctic Flora and Fauna, 61 pp.

interest and impacts to communities[9]. It has been noted that the results from this form of observing are variably shared beyond the community[9], often by design through data protections reflecting cultural concerns and the potential for misuse by outside users.

Coalescing the strengths of SAON and GEO will establish a significant contribution toward developing a sustained, integrated Arctic observing system that is part of the larger global system. In this context, the increasing coherence of CBM in the Arctic, facilitated in part by relationships formed during the recent IPY between community members and researchers, both from the social and physical sciences, provides an opportunity to develop a template for CBM for elsewhere around the globe. Furthermore, the unprecedented climate and environmental changes being observed in the Arctic, together with the new suite of stakeholders and societal concerns that arise with these changes, provide areas where CBONS may significantly contribute, such as disaster preparedness, monitoring threats to food security, or understanding shifts in phenology. The rate and scale of change in the Arctic is unique to the region; however, the types of change are not.

The GEOSS vision and approach may, in turn, provide added-value to SAON and Arctic CBM projects by linking their observations and information (e.g., that which is available through the Atlas of Community Based Monitoring) to the GEOSS Portal and other global databases. Such linkages, which often serve to connect seemingly disparate communities, may provide opportunities to explore new applications for CBM, for example, through tailored approaches to inform or integrate with scientific modeling. As new international, collaborative polar initiatives get underway a closer connection between SAON and GEO, framed, in part, in the context of advancing CBM, will serve to propagate forward lessons-learned and partnerships formed during the IPY. For example, it may be worth exploring whether CBONS could contribute to the verification and user-engagement priorities of the YOPP, which aims to improve environmental prediction capabilities in the Polar Regions, including sea ice and weather predictions on various time scales.

This opportunity comes at an appropriate time in the evolution of GEOSS. The GEO Strategic Plan 2016-2025 has shifted GEO's societal benefit areas (SBAs) toward more information-user domains. These proposed new SBAs include Biodiversity and Ecosystem Sustainability, Disaster Resilience, Energy and Mineral Resources Management, Food Security and Sustainable Agriculture, Infrastructure and Transportation Management, Public Health Surveillance, Water Resources Management, and Sustainable Urban Development. Within all of these areas, Arctic CBM could play a role in defining user needs at local to regional scales and demonstrating the societal value of utilizing local observations and/or traditional knowledge together with satellite-based or instrument-based observations at larger scales. Specifically, the potential observational contributions from CBM should be assessed as GEO establishes key or essential variables for the cold regions[6]. CBM approaches and CBONS should also be considered for their ability to engage local communities in ways that are broader than local and traditional knowledge contributions. New technologies (e.g., inexpensive and easily deployable unmanned aerial and underwater vehicles) and social media platforms provide emerging opportunities for local residents to partner with science. These opportunities, in turn, may highlight key prospects for capacity building to support

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[9] Johnson, N., et al. (2015) The Contributions of Community-Based Monitoring and Traditional Knowledge to Arctic Observing Networks: Reflections on the State of the Field. Arctic, Vol. 68, Suppl 1.

lasting and mutually beneficial relationships that underpin most sustained joint-observation campaigns.

Mapping the Arctic's Community-Based Observing Networks

There is an urgent need to assess and evaluate Arctic CBM. Significant progress has been made toward this goal through the development of the Atlas of Community Based Monitoring & Traditional Knowledge in a Changing Arctic. The Atlas was designed to showcase the many CBM and traditional knowledge initiatives across the circumpolar region. A full report analyzing the different types of CBM included in the Atlas, how they are being implemented, and their respective strengths is complete and currently under review (see Johnson et al. AOS statement). It currently contains close to one hundred examples of environmental focused CBM projects. Funding has been applied for to allow Polar Knowledge Canada to add terrestrial biodiversity CBM projects to the atlas; however more will be required to grow and maintain the resource. This globally-oriented project is also working to link to other regional or local initiatives that are focused on CBM, bridging the range of approaches from, for example, the Community Based Observing Network for Adaptation and Security (CONAS) to the Inuvialuit Settlement Region Community-based Monitoring Program (ISR-CBMP) to the Local Environmental Observer (LEO) health program. SOAN's continued work on the Atlas is listed as a contribution to the Information Services for Cold Regions Initiative within the GEO 2016 Work Programme, yet it remains to be seen how such a contribution may integrate with the GEOSS Common Infrastructure[10].

Recommendations for Integrating Arctic CBM into GEO

1. We recommend the formation of a CBM Community of Practice (CoP)[11] within GEO, with an initial priority focus on the Arctic. This would most appropriately follow an organized effort by the GEO Community (e.g., coordinated by the GEO Secretariat) to gather expressions of shared interests from GEO Member States and Participating Organizations. A CoP could leverage and integrate the critical mass that now exists in Arctic CBM with observing systems that are within the scope of GEOSS. Here, SAON efforts to understand and document the state of Arctic observations, particularly CBONS, would be a valuable contribution for the CoP to understand how CBM can develop and support shared interests. Established best practices and applications could then be transferable to regions outside the Arctic, especially where GEO's local community engagement and capacity building efforts have shown significant progress, such as the regions served by the SERVIR Program and its growing number of regional hubs[12]. Such an effort could address shared resources and efforts to create an infrastructure that unites data generators and users. This

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[10] https://www.earthobservations.org/gci_gci.shtml

[11] GEO defines a CoP as "a user-led community of stakeholders, from providers to the final beneficiaries of Earth observation data and information, with a common interest in specific aspects of societal benefits to be realized by GEOSS implementation" (https://www.earthobservations.org/cops.php).

[12] SERVIR (The Regional Visualization and Monitoring System), a joint initiative of the National Aeronautics and Space Administration (NASA) and United States Agency for International Development (USAID), works with regional organizations around the globe to assist developing countries in using Earth observing information in managing climate risks and land use.

will result in improved interoperability and the application of local and ground-based data. A CBM CoP may also advance understanding of how and where traditional and local knowledge can best interface with scientific monitoring to improve our understanding of social-ecological systems.

2. Toward this end, we propose a discussion on this topic at the 2016 Arctic Observing Summit in Fairbanks, Alaska, focusing on: (a) characterizing and understanding shared interests in CBM in the Arctic; (b) exploring opportunities for new CBM applications and new linkages to international, collaborative polar initiatives, such as the Year of Polar Prediction (YOPP); and (c) the continued need to develop and document best practices, both for improved local benefits to Arctic communities and to support the transferability of approaches to regions outside the Arctic[13].

[13] This was the topic of the Workshop on Best Practices for Community Based Observing Networks and Systems (CBONS), held October 2015 in Seattle, WA, for which a workshop report should be available in early 2016.

A Brief Introduction to the Alaska Ocean Observing System: A Presence in the Arctic
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The Alaska Ocean Observing System (AOOS) is the IOOS Regional Association (RA) responsible for coordinating statewide monitoring for Alaska's nearly 44,000 miles of coastline and offshore environments. The Alaska coastline is larger than that of any of the other RA territories as well as the combined seaboard of the rest of the United States. AOOS is not only unique for its geographic scale, but also for being the only regional observing system that encompasses the Arctic. AOOS also nests within national and global observing networks, collaborates to build observing and forecasting capacity, delivers information to stakeholders and provides data management support to programs operating around the region, including international programs in the Arctic.

AOOS has three strategic priorities within its mission: 1) to sustain marine ecosystems and fisheries, and track climate change and trends; 2) to promote safe marine operations; and 3) to mitigate natural hazards and their impacts on coastal communities. Alaska is the canary in the coalmine with respect to climate change, as evidenced in the steady decline of Arctic summer sea ice extent and concentration, increased wildfires, thawing permafrost, increasing ocean acidification (OA) and ecosystem shifts. However, climate change is only one of the drivers currently affecting Alaska and the Arctic. Others include an upswing in marine traffic especially through the Bering Strait, groundbreaking industrial activities, escalating coastal erosion and inundation affecting many coastal subsistence communities, and the dramatic retreat of sea ice. These factors all heighten the need for sustainable, reliable and accessible marine information.

Work of this nature is challenging in Alaska, which has a largely remote coastline with limited infrastructure and few assets sitting ready to assist in emergency response situations, such as oil spills, shipping incidents, storm surges and coastal inundation events. From an observing standpoint, AOOS is collaborating with all entities concerned with marine systems to not only fill critical gaps in ocean and coastal monitoring data needs, but to foster collaborations between existing and new monitoring and research activities across all sectors, including private industry, academia, state and federal agencies, local communities and non-governmental organizations. AOOS works with already established and ongoing activities, and carefully balances the challenges of providing real-time observations in Alaska in order to use limited resources wisely. The mere size of the region alone requires extensive collaboration and leveraging with other programs to accomplish the AOOS mission.

To augment these efforts, AOOS pursues additional funding opportunities, and offers data management, synthesis and visualization services to other organizations, which enhances data sharing and integration into the AOOS website data portal while adding value to separate activities managed by other organizations. Similar to most projects in remote Alaska, many AOOS supported activities are successful due to these collaborations between multiple partners.

AOOS Observing Build-Out Plan for the Alaskan Arctic

As part of the national Integrated Ocean Observing System (IOOS) program, AOOS has developed a statewide 10-year observing build out plan as well as a more focused observing strategy for the Alaskan Arctic, based on a decade of stakeholder and scientist input. The effort considers Alaska's stakeholder needs in a national context and outlines a bare bones implementation plan with potential for enhancements. The plan assumes existing federal assets, including availability of satellite data products, will continue, and that leveraging oil & gas industry assets will continue. Recent developments with the departure of Shell Oil from the Arctic are currently being assessed in terms of their impact on observing capability in the Arctic. AOOS funding supports key observing assets including shore-based radar stations, wave buoys, weather stations, ecosystem moorings, and ship and glider surveys.

AOOS Ocean Data Explorer and Arctic Data Portal

One key effort by AOOS since its inception has been to develop and provide the infrastructure necessary to support an operational observing system data network by building a centralized regional data assembly center (DAC) with web-based analytical and visualization tools and products. The AOOS Website (www.aoos.com) hosts not only AOOS funded data streams, but also serves as the data portal exchange for the entire region, serving data assets from international, federal, state, and regional governmental programs, research and observing activities conducted by private industry (oil and gas, shipping and fishing), non-governmental organizations and international research cooperatives, and community based observing groups including those incorporating traditional knowledge.

The AOOS website hosts the Ocean Data Explorer, a central portal that catalogs, archives, visualizes and integrates many different types of data from across the state, including real-time sensors observations, model forecasts, GIS layers, satellite data and high definition video footage. The Ocean Data Explorer currently provides access to all real-time environmental observations, over both land and sea. It serves as a one stop shop for environmental and oceanographic data, both current and historical. Providing access to the numerous data assets collected throughout the state is one of the hallmark products AOOS is well known for. A subset of this data system is contained in the Arctic Data Portal, accessible as well through the AOOS website. In addition to data access, the AOOS website hosts a secure data management and sharing system to support large-scale integrated research programs, and provides participating researchers a direct pathway for archiving and publicly sharing their data. The website also serves to archive and provide public access to private industry data as well.

Summary

The AOOS motto "*Eye on Alaska's coasts and oceans*" reflects the vision of a network of critical ocean and coastal observations, data and information products that aid our understanding of the status of Alaska's marine ecosystem and allow stakeholders to make better decisions about their use of the marine environment. For more information on the AOOS program, the website www.aoos.org provides a valuable resource to any entity working in the state and surrounding seas and oceans by providing access to numerous coastal and ocean and some terrestrial data assets, reference and literature resources and visualization products.

The Year of Polar Prediction

White Paper submitted to the Arctic Observing Summit 2016

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Executive Summary:

The Year of Polar Prediction (YOPP) has the mission to enable a significant improvement in environmental prediction capabilities for the polar regions and beyond, by coordinating a period of intensive observing, modelling, prediction, verification, user-engagement and education activities. The YOPP Core Phase will be from mid-2017 to mid-2019, flanked by a Preparation Phase and a Consolidation Phase. YOPP is a key component of the World Meteorological Organization – World Weather Research Programme (WMO-WWRP) Polar Prediction Project (PPP).

The objectives of YOPP are to:

1. Improve the existing polar observing system (better coverage, higher-quality observations);
2. Gather additional observations through field programmes aimed at improving understanding of key polar processes;
3. Develop improved representation of key polar processes in coupled (and uncoupled) models used for prediction;
4. Develop improved (coupled) data assimilation systems accounting for challenges in the polar regions such as sparseness of observational data;
5. Explore the predictability of the atmosphere-cryosphere-ocean system, with a focus on sea ice, on time scales from days to seasons;
6. Improve understanding of linkages between polar regions and lower latitudes and assess skill of models representing these linkages;
7. Improve verification of polar weather and environmental predictions to obtain better quantitative knowledge on model performance, and on the skill, especially for user-relevant parameters;
8. Demonstrate the benefits of using predictive information for a spectrum of user types and services;
9. Provide training opportunities to generate a sound knowledge base (and its transfer across generations) on polar prediction related issues.

The PPP Steering Group provides endorsement for projects that contribute to YOPP to enhance coordination, visibility, communication, and networking. This White Paper is based largely on the much more comprehensive YOPP Implementation Plan (WWRP/PPP No. 3 – 2014), but has an emphasis on Arctic observations.

1. Introduction

There has been growing interest in the polar regions in recent years due to the opportunities and risks associated with anthropogenic climate change. Increasing economic, tourism, transportation, and scientific activities in polar regions are leading to more demands for enhanced environmental prediction capabilities to support decision-making. Furthermore, there is increasing evidence that weather and climate in the polar regions have a substantial influence on the lower latitudes. However, forecasting capabilities in the polar regions are lagging behind compared to mid- and low-latitude predictions. The probably most important reason for this is the sparseness of polar observations (Figure 1), posing challenges to data assimilation, forecast initialization, process understanding, model development, and forecast verification.

Figure 1: Conventional observations that were assimilated by the operational forecasting system at ECMWF on 15 April 2015. Different colors are used for different observation types (see legend). The strinking observational gap in the Arctic exists also for other important data types, in particular Argo floats in the ocean. Figure from Jung et al. (2016).

Recognizing this, the World Meteorological Organization – World Weather Reasearch Program (WMO-WWRP) has decided to embark on a decade-long Polar Prediction Project from 2013 to 2022. The key element of PPP is the Year of Polar Prediction (YOPP) with a Core Phase taking place between mid-2017 and mid-2019.

The YOPP Mission is to:
Enable a significant improvement in environmental prediction capabilities for the polar regions and beyond, by coordinating a period of intensive observing, modelling, prediction, verification, user-engagement and education activities.

In other words, YOPP is an extended period of coordinated intensive observational and modelling activities, aimed at improving prediction capabilities for the Arctic, the

Antarctic, and beyond. This concerted effort will be augmented by research into forecast-stakeholder interaction, verification, and a strong educational component. Being part of the Polar Prediction Project, YOPP concentrates on time scales from hours to seasons. With its clear focus on polar prediction rather than a very broad range of polar science topics, YOPP is quite different from IPY (the International Polar Year 2007-2008). Prediction of key variables such as visibility, wind, precipitation, and in particular sea ice, is central to YOPP. The presence of linkages between polar and non-polar regions suggests that the benefit of YOPP will extend beyond the polar regions.

Extra observations will be crucial to YOPP in order to (i) optimize the polar observing system, (ii) generate the knowledge necessary to improve the representation of key polar processes in models, and (iii) provide ground-truthing that it is so important to exploit the full potential of the space-borne satellite network. YOPP will provide an opportunity for testing new observational activities, and will encourage research, development and employment of innovative systems.

Another important aspect of YOPP will be a strong virtual component through involvement of the numerical modelling community, encompassing models of the atmosphere, ocean, sea ice, and land. Operational model runs will cover time scales from hours to seasons. A particular focus will be on sea ice, since for polar regions this medium is both a critically important environmental variable to be predicted, and a strong modulator of other weather-related predictands (Figure 2).

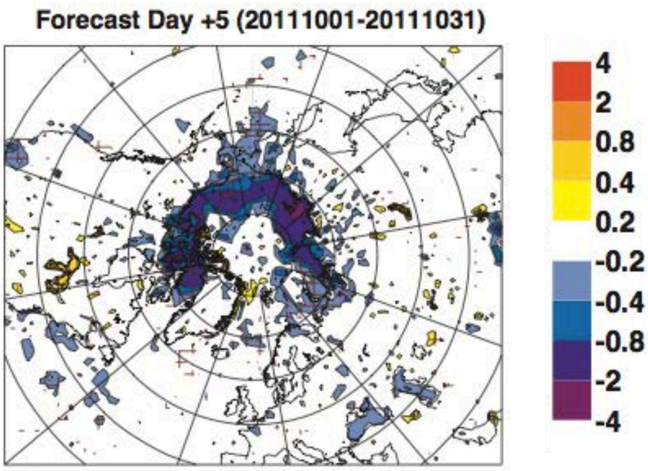

Figure 2: Mean 2-m temperature difference (in K) between hindcast experiments using observed and persisted sea ice and sea surface temperature at 5 days lead time with the ECMWF forecasting system for October 2011. The large errors along the ice edge highlight the importance of coupled processes even for near-term prediction in polar regions. Figure from Jung et al. (2016).

Striving to improve polar predictions, the additional observations collected during YOPP will be utilized in several ways. The observations will be used (i) in data assimilation systems to improve forecast initialization, assess the relative merits of different observation types, locations, and frequencies (by means of observing system (simulation) experiments, i.e., data denial experiments), and further develop coupled data assimilation techniques, (ii) as basis for forecast verification, and (iii) to study processes that are key to improved polar predictions, for example processes related to the stable boundary layer, sea ice, mixed-phase clouds, and polar lows. YOPP-related data from observations and models will be shared using standardised interfaces and documentation standards, also enabling long-term data preservation. A dedicated YOPP Data Portal will provide a unified framework of the data hosted by the data centres contributing to YOPP.

YOPP will also explore largely uncharted territory in the area of polar forecast verification; YOPP will contribute to our understanding of the value of improved polar prediction capabilities; and YOPP will help to educate the next generation of scientists. YOPP will be carried out in three phases: a Preparation Phase from 2013 to mid-2017, a Core Phase from mid-2017 to mid-2019, and a Consolidation Phase from mid-2019 to 2022 (Figure 1). Each of these phases is discussed in the following Sections.

In order to achieve the research objectives listed in the executive summary, strategic aspects of YOPP are to:

A. Strengthen linkages between academia, research institutions and operational forecasting centres;
B. Establish and exploit special research data sets that can be used by the wider research community and forecast product users;
C. Establish a common virtual data archive through integration of contributing archives;
D. Link with space agencies;
E. Promote YOPP with funding agencies;
F. Develop strong linkages with other initiatives;
G. Promote interactions and communication between research and stakeholders;
H. Foster education and outreach.

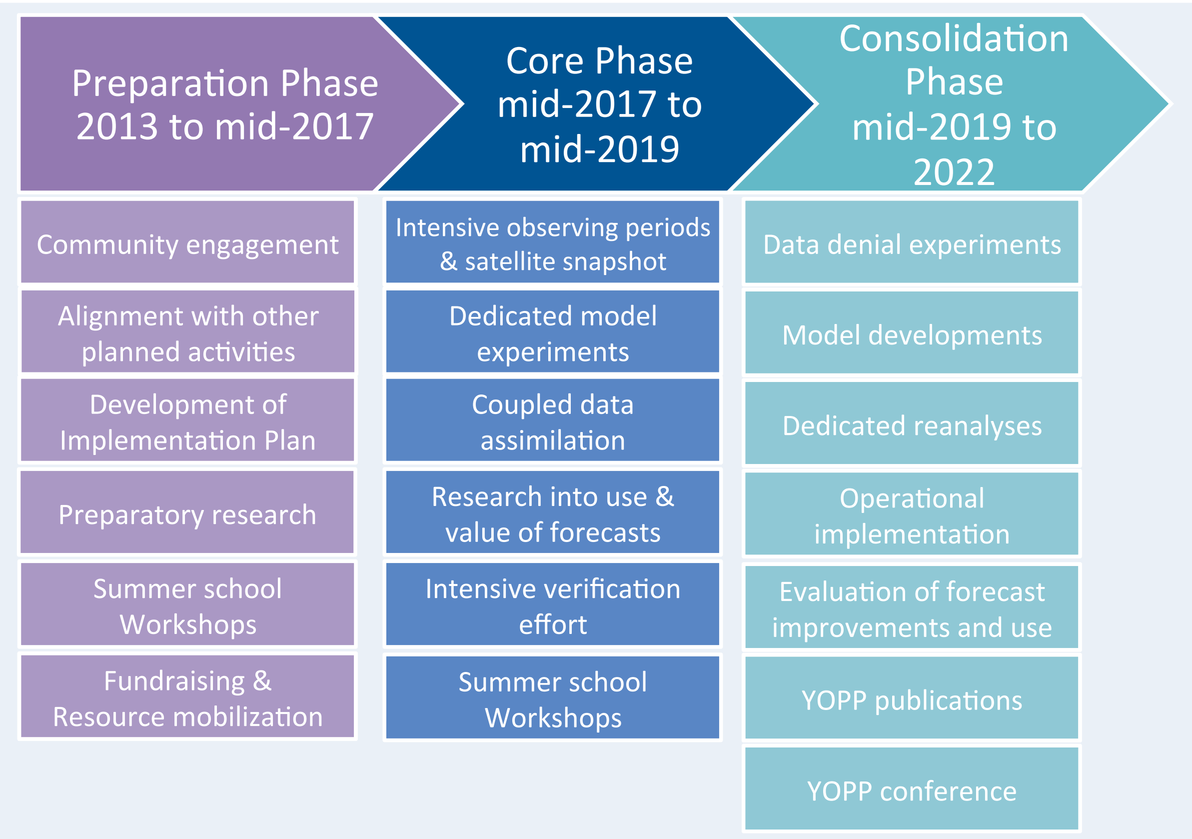

Figure 3: The phases of YOPP and key activities therein

2. YOPP Preparation Phase (2013 to mid-2017)

The current Preparation Phase is crucial for the success of YOPP. It involves a number of aspects – overall planning, engagement with stakeholders, coordination of observations and related field programmes, promotion of modelling activities, establishment of data archive systems, preparatory research, and involvement of funding agencies.

YOPP was devised following the first meeting of the PPP Steering Group in Switzerland in December 2011. The initial concept for YOPP is outlined in the PPP Implementation Plan (WWRP/PPP No. 2 – 2013). The International Coordination Office (ICO) for Polar Prediction, hosted at the Alfred Wegener Institute in Germany and responsible for the overall management of PPP, is also in charge of the overall management of YOPP.

YOPP Planning Meetings involving members of the WWRP-PPP Steering Group as well as participants representing important partners (Table 1) were held 2013 in the UK, 2014 in Finland and Canada, and 2015 in Switzerland. The last of these – the YOPP Summit - was special in that about 120 scientists, stakeholders, and representatives from operational forecasting centers, international bodies, and funding agencies were assembled to make major progress in the planning of the approaching YOPP Core Phase. The outcomes of extensive discussions held at the YOPP Summit are the basis for a final revision of the YOPP Implementation Plan which will be published ahead of the Arctic Observing Summit 2016.

Table 1: Selected YOPP Partners (coordinating bodies; acronyms are explained in the appendix of the YOPP Implementation Plan).

Group	**Role**
APECS	Implementation of educational component of YOPP
CBS / Integrated Observing Systems	Facilitating the improvement of polar observing systems
EC-PHORS	Overall policy perspective
EUCOS	Additional observations over northern polar regions
GASS	Coordination of polar model intercomparison projects
GCW	Cryospheric observations, and potential use of the GCW portal
GODAE Oceanview	Development and implementation of the intensive modelling campaign (ice-ocean)
IASC	Planning of YOPP for northern polar regions
IASOA	Contributing observations and research based on pan-Arctic atmospheric observatories
IICWG	Coordination of operational ice services
MOSAiC	Gathering data from and around the drifting observatory to improve coupled models and coupled data assimilation, and for ground

	truthing of satellite data
PCPI	Close coordination of related activities
PSTG	Supporting the exploitation of satellite data (“satellite snapshot”)
S2S	Sub-seasonal to seasonal aspects of polar predictions
SAON	Coordination of Arctic Observations
SCAR	Planning of YOPP for southern polar regions
Sea Ice Prediction Network	Collaboration on Arctic sea-ice prediction
SOOS	Coordination of Southern Ocean Observations
WCRP/CliC	Close coordination of related activities of CliC and its working groups
WGNE	Development and implementation of the intensive modelling campaign (atmosphere)
WGSIP	Encouraging institutions with prediction capability to use initial conditions that take advantage of the new available data from YOPP to rerun some sub-seasonal and seasonal predictions

The identification of, and engagement with, key partners for YOPP is an important element of the Preparation Phase (Table 1). Another crucial element at a slightly different level is the excitation of, support for, and coordination of individual projects and initiatives that fill YOPP with life. In the past, a number of scientists seeking funds from different funding agencies for projects potentially contributing to YOPP have been supported with individual letters of support. At the YOPP Summit it was decided to establish an endorsement process that fulfils these tasks in a more systematic manner. For projects and initiatives to be endorsed, criteria include, among others, the contribution to the general YOPP objectives, willingness for close coordination with other YOPP activities, and open data sharing. Requests for endorsement are reviewed by the PPP Steering Group. During the first four weeks, more than 10 projects and initiatives have requested YOPP endorsement. Among the earliest endorsed are for example: a project contributing additional upper air soundings from Neumayer Station (Antarctica) and RV Polarstern; the Forum for Arctic Modelling and Observational Synthesis (FAMOS); a project conducting an Arctic Earth Observation Impact Assessment; and the Group on Earth Observations Cold Regions Initiative (GEO-CRI). Details on the endorsement process and an up-to-date list of endorsed projects and initiatives is given at <http://www.polarprediction.net/yopp/yopp-endorsement.html>.

A number of important science workshops has already been co-organized by PPP, for example a Polar Prediction Workshop held in the UK (2013), a PPP Science Workshop held in the US (2013), a Polar-Lower Latitude Linkages Workshop held in Spain (2014), a SERA Workshop held in Canada (2015), and a Workshop on the Dynamics of Atmosphere-Ice-Ocean Interactions in the High-Latitudes held in Norway (2015).

Another important outcome of the YOPP Summit was the establishment of additional sub-committees that take the lead in fostering certain aspects of YOPP. The existing sub-committees on (i) Sea-Ice Prediction, (ii) Societal and Environmental Research and Applications (SERA), and (iii) Education are complemented with committees on (iv) Southern Hemisphere aspects, (v) Coordinated Model Experiments, (vi) the YOPP Data Component, and (vii) Arctic Observations and Intensive Observing Periods. Most of these are now in the process of being established (as of November 2015). A substantial part of the further YOPP planning will take place within these sub-committees and on pre-YOPP workshops they are organizing, focussed on their respective themes.

3. YOPP Core Phase (mid-2017 to mid-2019)

The main YOPP activities are planned to take place during the period mid-2017 to mid-2019 – centred on the year 2018. The YOPP Core Phase encompasses four major elements: an intensive observing period, a complementary intensive modelling and forecasting period, a period of enhanced monitoring of forecast use in decision making including verification, and a special educational effort. Here we only sketch aspects of observational activities in the Arctic.

YOPP will take advantage of the existing operational data gathered under WMO auspices for the globe, including polar regions. Additional observations promoted during the YOPP Preparation Phase will fall into the following categories: (i) comprehensive reference stations, (ii) field campaigns, (iii) aircraft campaigns, (iv) shipping, (v) free troposphere, (vi) sea ice and upper ocean, (vii) open ocean, (viii) deeper ocean, (ix) autonomous sensor systems, (x) snow, (xi) land, (xii) boundary layers and clouds, and also (xiii) stakeholders. All of these categories are discussed in detail in the YOPP Implementation Plan.

It has been realized that maintaining certain types of Polar observations (e.g., four radiosonde launches daily) over two full years is not feasible. Therefore, extra observations will concentrate on Intensive Observing Periods (IOPs) within the YOPP Core Phase. Taking into account operational feasibility, physical processes, benefit for data assimilation systems, and socio-economic relevance, the timing of Arctic IOPs has tentatively been determined as follows.

There will probably be two Arctic IOPs, with one covering a full open-water season (June to November 2018) and one focusing on winter (January to March 2019). The start of the Arctic summer IOP well before the sea-ice minimum is required to ensure that long-term predictions for the economically relevant late summer/early autumn season can be well initialized. To improve predictions on shorter time scales (hours to days) for the same target period, on the other hand, it will be important to enhance observations in late summer and early autumn. Furthermore, it was strongly argued for extending the IOP to late autumn to capture the time of year when atmosphere-sea ice-ocean interactions are most vigorous. The shorter Arctic winter IOP will take place in operationally more challenging conditions and will be targeting phenomena such as Polar lows, snow, cold-air outbreaks, and stable boundary layer processes.

It is important to note that the temporal focus on IOPs does not imply that observations taken outside IOPs but within the YOPP Core Phase, or even in the late Preparation Phase or early Consolidation Phase, would not be useful for YOPP. For example, some observation types will be more continous in nature (e.g., extra automatic weather stations and floats), and some relevant observational campaigns will not be able to comply with IOPs for practical reasons (e.g., MOSAiC).

Given the strong involvement of operational forecasting centers, YOPP will not only benefit from additional observations *per se*, but also from additional efforts to provide observational data in (near-)real-time via the WMO Information System / Global Telecommunication System (WIS/GTS). The revised YOPP Implementation Plan will include a "How-To" chapter to facilitate real-time data provision for the research community.

4. YOPP Consolidation Phase (mid-2019 to 2022)

The Consolidation Phase will be as important as the earlier phases in that it will ensure to provide a legacy of YOPP. Beside the holding of synthesis workshops and conferences, implementation of YOPP findings into operational forecasting systems, and evaluation of forecast improvements and their use by stakeholders, it will be crucial to ensure proper archiving, availability, and traceability (Digital Object Identifiers) of the additional observational data generated during YOPP. To this end, a YOPP Data Portal, building on the experience of the Global Cryosphere Watch (GCW) Portal, will be implemented to enable an efficient exploitation of YOPP data. GCW data management is based on achievements in distributed data management systems during the International Polar Year and alignment of these achievements with relevant WMO activities like WMO Information System (WIS) and WMO Integrated Global Observing System (WIGOS) as well as the combined SAON/IASC Arctic Data Committee and SCAR Standing Committee on Antarctic Data Management (SCADM). The foundation of this is standardised documentation of datasets using metadata describing who measured/modelled/analysed what, where and when, as well as the access mechanisms to data and potential constraints. Integration of YOPP data management with WIS ensure that YOPP data are exposed through the GEOSS Common Infrastructure as well as for other WMO programmes (e.g., the emerging Polar Regional Climate Centre). WIGOS metadata describes instrumentation, procedures and facilities used to collect observational data and ensures proper understanding of quality, comparability and how representative data are. It is also the basis for WMO programmes network design.

The additional data collected during YOPP will be used during the Consolidation Phase to evaluate the benefit of extra observations for polar predictions. This includes data denial experiments which will provide guidance for optimizing the polar observing system. Furthermore, the extra observations along with the high-resolution numerical experiments will benefit model development and the enhancement of value of satellite data in a prediction context.

In order to synthesize the available YOPP data and to exploit them in models, it will be desirable to carry out special (high-resolution) reanalyses for the Arctic (as for the Antarctic). This will be an ongoing activity during the Consolidation Phase. Such reanalyses along with the availability of reforecast data sets will provide the basis for probabilistic forecast calibration and for diagnostic and verification studies that are expected to advance polar prediction across a wide range of time scales. Finally, in particular the strongly involved of observational centers will enable a seamless legacy of

YOPP by utilizing an optimized polar observing network and improved forecasting systems for better polar predictions beyond 2022.

5. Final Remarks

This White Paper has barely touched on some aspects that are important ingredients for a successful YOPP, including coordinated model experiments, education and outreach efforts, funding aspects, verification, data assimilation, satellite data, and more. If you want to learn more, and want to stay informed, about YOPP, the website of the International Coordination Office for Polar Predicion at <http://www.polarprediction.net> hosts all relevant information, including workshop and meeting reports, the PPP and YOPP Implementation Plans, a frequently updated news section, and information on upcoming events (including the pre-YOPP workshops) and on the endorsement process. Another way to get more information is to follow @polarprediction on Twitter, and/or to subscribe to the polar prediction mailing list by sending an email to <office@polarprediction.net>.

The remaining one and a half years of the Preparation Phase are crucially important to making YOPP a fruitful endeavor. Ultimately, the success of YOPP depends on the enthusiasm and willingness of scientists to contribute with their projects and initiatives. The Arctic Observing Summit 2016 is a prime opportunity to inform on YOPP, discuss Arctic observations needed for YOPP, and to excite corresponding contributions to YOPP. We invite requests for YOPP endorsement not only for already funded projects to maximize coordination and mutual benefits, but also to support planned projects in their efforts to obtain funding.

Selected publications:

PPP Steering Group and Coauthors: Implementation Plan for the Year of Polar Prediction, WWRP/PPP No. 3, 2014 (newer version available by the time of the Arctic Observing Summit 2016)

Goessling, H. and Coauthors: Paving the Way for the Year of Polar Prediction, Bull. Am. Met. Soc., 2015

Jung, T. and Coauthors: Advancing polar prediction capabilities on daily to seasonal time scales, Bull. Am. Met. Soc., 2016

Jung, T. and Coauthors: Polar-lower latitude linkages and their role in weather and climate prediction, Bull. Am. Met. Soc., 2015

Title: **The Arctic Vegetation Archive as the basis for a Canadian arctic terrestrial ecosystem classification: Application to establishing arctic terrestrial ecosystem monitoring**

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Introduction

The Arctic Vegetation Archive (AVA) initiative has the critically important goal of locating, rescuing and consolidating existing arctic relevé data, and using these data to coordinate pan-Arctic vegetation classifications (Walker et al 1994, Walker and Raynolds 2011, Walker et al 2013, 2014). The AVA takes a 'network of networks' approach, and the Canadian contribution to the AVA is coordinated through the Canadian National Vegetation Classification (CNVC), which represents a partnership of provincial and territorial vegetation classification practitioners in Canada (http://cnvc-cnvc.ca/). Until recently, CNVC work focussed on forest ecosystem classification, but funding provided under the International Polar Year (IPY) created the opportunity to collect and develop draft classifications for both subarctic and arctic vegetation communities in the Canadian North (Levesque et al 2014, Mackenzie 2014).

This paper outlines how a coordinated arctic vegetation classification under the AVA and CNVC can be used to calibrate a Canadian terrestrial ecosystem classification (TEC) covering both Arctic and Sub-arctic landscapes, using approaches well developed in southern Canada (Ponomarenko and Alvo 2001). As a demonstration of system applications, we discuss how the TEC can provide an ecosystem-based template for designing and coordinating terrestrial monitoring objectives across the Canadian North, and across the circumpolar Arctic.

From Vegetation Classification to Ecosystem Classification

The key application of the AVA/CNVC explored in this paper is the use of a pan-arctic vegetation classification as the standardized, correlated basis for linking plant communities to ecological sites to calibrate a useful TEC for the Canadian Arctic and Sub-arctic. TEC has a long history of development, with its roots in Russia and northern Europe, and many variations in Canada and the United States. Over the last 25 years there has been a consistent effort by all Canadian provinces to develop provincial forest ecosystem classifications, many of which are similar in structure, and include similar concepts (although different terms) of ecological site, plant community, plant association, and ecological community. Following the early approaches of Hills and Pierpoint (1960) and Krajina (1959, 1965), more modern examples are Meades and Moores (1996) in Newfoundland, Neily et al. (2003) in Nova Scotia, Mason and Power (1996) and Zelazny et al. (1989) in New Brunswick, Bergeron et al. (1992) and Saucier et al. (1998) in

Quebec, Lee et al. (1998) and Sims et al. (1989) in Ontario, Zoladesky et al. (1995) in Manitoba, Beckingham et al. (1996a) and McLaughlan et al. (2010) in Saskatchewan, Beckingham et al. (1996b) and Corns and Annas (1986) in Alberta, Pojar et al. (1987) in British Columbia, and more recently Flynn and Francis (2011) for the Yukon Territory.

At the heart of a northern TEC is the marriage of the biotic (plant community) and abiotic (ecological site) components of arctic and sub-arctic landscapes. Krajina (1960) initiated these ideas for forest ecosystems in British Columbia based on the Russian concept of the biogeocoenose (Sukachev 1960, Sukachev and Dylis 1964), i.e., areas of a landscape that are relatively homogenous in terms of species composition and vegetation structure, in hydrologic, atmospheric and soil conditions, and in the type and matter of energy exchange and interactions among all components (also adapted from Teplyakov et al. 1998).

Biogeocoenose can be thought of as a synonym for the more modern term – (terrestrial) ecological community (Ponomarenko and Alvo 2001) which we will use here. A terrestrial ecological community includes all of the biota on a site, from soil microbes and invertebrates, through to the plants, pathogens, herbivores and predators. The concept also includes the environmental factors that in part control biotic composition, abundance and productivity, and the interactions between all abiotic and biotic components. It is impossible of course to account for the myriad of individual ecosystem components and interactions, even in relatively simple arctic ecological communities. For practical purposes, in the course of terrestrial ecosystem classification, we describe and classify ecological communities using the co-distributions of plant communities (using relevés), and the ecological sites [using standardized site and soil description methods such as MOELF (1998)] on which they occur. Similar ecological communities typically repeat themselves in a predictable pattern across the landscape, recurring in similar environmental settings. Boundaries between ecological communities may be abrupt, as at the margin of a wetland or floodplain, or they may change gradually, as along an even slope, where downslope seepage is the driving ecological factor.

The functional linkages between the biotic and abiotic components of ecological communities provide the basis for assessing and extrapolating the role of ecological processes in determining their nature and distribution across an Arctic landscape. Typically, these processes are inferred from an analysis of the ecosystem data collected in the field, e.g., soil depth, texture, coarse fragment content, depth to permafrost, and the presence of soil mottling or gleying for mineral soils, or the nature and depth of organic strata and water tables in organic soils. Site factors are also part of the overall description and include assessments and measurements of slope angle and slope position (e.g., upper, mid, lower, toe, depression), site aspect and exposure to sun and wind, elevation, landform, as well as observations and assessments of other relevant factors such as the presence, frequency and duration of riverine or estuarine flooding, sedimentation and erosion, snow bed persistence, or soil instability [see MOELP (1998) for standardized methods].

Field data are integrated and interpreted to develop a qualitative understanding of the key driving processes that control vegetation composition, structure and productivity in each ecological community. Taken together for all ecological communities in a given landscape, we develop a comprehensive and integrated understanding of regional terrestrial ecosystem pattern and process that provides ecological rationale for establishing more quantitative ecosystem monitoring and research, for developing interpretative classifications such as habitat suitability or risk of permafrost degradation, for developing effective, ecosystem-based land use strategies and impact assessments, and as the basis for process-based modelling of ecological change.

To develop the TEC for pan-arctic ecological communities we propose to implement the mature approaches developed under the Biogeoclimatic Ecosystem Classification (BEC) System in British Columbia (Pojar et al. 1987), and more recently by Flynn and Francis (2011) in the Yukon. The BEC approach uses established functional relationships between ecological communities and key environmental drivers to organize and classify terrestrial ecological communities in order to classify and map regional bioclimates, and within bioclimates, to organize and classify constituent ecological sites and communities along predominant ecological gradients (Meidinger and Pojar 1991, MacKenzie and Moran 2004).

To classify and identify the ranges of regional bioclimates, Pojar et al. (1987) use the zonal concept, also utilized in other areas of Canada and the Arctic, e.g., Saucier et al. (1998), Ecosystems Working Group (1998), Walker et al. (2005), Gould et al. (2003), Flynn and Francis (2011). The concept of zonal ecosystems flows from the early work in Russia attributed to Dokuchaev, that linked broad patterns in soil types to regional climatic gradients – a concept brought to North America by early soil scientists, e.g., Marbut (1935). Zonal ecological sites have a list of defining physical characteristics such as being positioned on moderate slopes, and having well-drained soils of at least medium depth with loamy texture and low coarse fragment content. As a result, zonal ecological sites and communities are assumed to best represent regional climates, in that climate at the site level is least modified by local-scale site factors (Pojar et al. 1987). Late seral plant communities situated on zonal ecological sites form the zonal ecological communities that typify and are used to locate the boundaries of regional bioclimates (for example see https://www.for.gov.bc.ca/hfd/library/documents/treebook/biogeo/biogeo.htm). A zonal plant community classification, e.g., Klinka et al. (1979, 1991), can be developed to identify, classify, and map biogeoclimatic subzones – the regional scale ecosystems of the biogeoclimatic classification in the TEC. Biogeoclimatic subzones are the basic unit of the TEC regional ecosystem, and can be agglomerated into biogeoclimatic zones defined by the same vegetation Order, or by the next hierarchical level in the vegetation classification system. In practice, the zonal concept may need to be adapted to account for distinct differences in late-seral zonal ecological communities within the same regional climate due to differences in predominant parent material, e.g., calcareous versus non-calcareous substrates (Walker 2000), or by dominating successional drivers such as high frequency fire (Payette and Delwaide 2003, Girard et al. 2008). A correlated pan-arctic vegetation classification such as the AVA initiative is fundamental to developing and implementing this regional scale, biogeoclimatic classification level of the TEC.

All ecological sites and communities within a biogeoclimatic zone or subzone that are not zonal are termed 'azonal', because they lack the defined characteristics of zonal sites. In azonal ecological communities and sites, environmental drivers such as excessive soil drainage or persistent downslope seepage, persistent soil waterlogging (wetlands), direct exposure to desiccating and abrasive winter winds, accumulations of deep, persistent and protective snow blankets, or seasonal flooding, sedimentation and erosion along rivers, lakeshores and estuaries, modify the effects of regional climates and result in distinctive azonal ecological communities comprised of a suite of species co-adapted to each set of recurrent ecological site conditions. Zonal and azonal ecological communities thus make up the repeating pattern of tundra and semi-forested ecosystems that we see when travelling across or flying over tundra or sub-arctic landscapes.

To classify ecological sites and communities within bioclimates, we propose to use the concept of ecological equivalence – a concept that comes from the original work of Cajander (1926) and Bakuzis (1959), and has been successfully applied in the BEC System in British Columbia (Pojar et al 1986, Meidinger and Pojar 1991, Klinka et al 1996), and in Quebec (Saucier et al. 1998). It states that all ecological sites that have the same late seral plant community will have similar ecological potential or productivity. The strong correlation between the site index of major commercial tree species and the ecological site classification in British Columbia presents strong evidence for the usefulness of this approach (http://www.for.gov.bc.ca/hre/sibec/). The concept of ecological equivalence is useful for ecosystem classification in that it permits the field identification of ecologically-equivalent, enduring ecological sites that are affected by similar driving ecological processes, have similar ecosystem productivities, and consequently provide a similar range of ecological services. As for the zonal classification of regional bioclimate, the classification of equivalent ecological sites and communities across the arctic also requires the kind of coordinated classification of vegetation communities proposed under the AVA initiative.

Concepts outlined above to develop a TEC link mature plant communities to ecological sites, and assume development under conditions of relative climatic stationarity, as witnessed by stability of North American and Eurasian treelines for the last 3,000 to 4,000 thousand years (Lavoie and Payette 1996, MacDonald et al 2000, Payette 2006). This has permitted the creation of distinctive terrestrial ecological communities under relatively constant environmental conditions, so that correlative relationships between ecological communities and regional climates and other driving site factors can be clearly established, e.g., BEC climate and site units in British Columbia (Pojar et al. 1986, Klinka et al 1996), forest management units in Quebec (Saucier et al 1998). Clearly, this overall consistency in climate and related drivers, e.g., mean summer temperature, snow regimes, ground ice processes, active layer depths, is changing, and it is to be expected that arctic and sub-arctic plant communities will change in response (ACIA 2005, SWIPA 2011). For example, the *in situ* relative dominance of species is already changing on many ecological sites across the Arctic (Henry et al 2012, Hudson et al. 2011), and we can expect that vegetation community composition will eventually change as well, with southern species slowly replacing arctic and sub-arctic obligate species from south to north. In that these changes are only beginning to happen, long-term monitoring of plant communities on similar ecological sites along a south to north gradient can provide a standardized approach to help document climate-driven ecosystem changes.

Applications of Terrestrial Ecosystem Classification and Mapping to Northern Terrestrial Monitoring Objectives

The amplification of climate warming at more than double the global average in northern latitudes (ACIA 2005, IPCC 2007, Serreze et al 2009) means that abiotic and biotic components of Canada's sub-arctic and arctic ecosystems are changing, and will continue to change in ways that are highly complex and difficult to predict with any certainty (Francis et al 2009, Derksen et al. 2011). It is because of this high uncertainty that many summary reports on climate-driven change at sub-arctic and arctic latitudes have recommended the immediate establishment of coordinated and integrated monitoring networks that can generate timely information on how ongoing climate change is driving ecological change in northern Canada (ACIA 2005; SWIPA 2011; Bidwell et al 2013). Recently the European Commission called for proposals that will contribute to an improved Arctic Observation System, stating that '… an integrated and multi-disciplinary Arctic observation system is becoming essential for studying, forecasting and assessing changes that support the region's sustainable development.' Here we discuss how a vegetation-based TEC that captures ecological variability at regional to local scales could provide a fundamental tool for producing an effective national and international monitoring sample design that would underlie coordinated sub-arctic and arctic monitoring.

Under the Arctic Council's Conservation of Arctic Flora and Fauna (CAFF) Working Group, monitoring programs have been developed for marine, freshwater and terrestrial ecosystems, as 3 components of the CAFF Circumpolar Biodiversity Monitoring Program. General monitoring questions identified in the development of the CAFF CBMP Terrestrial Biodiversity Monitoring Plan (http://www.caff.is/terrestrial/terrestrial-monitoring-plan) provide coordinated direction to inform local monitoring questions. Through the CBMP Terrestrial Expert Monitoring Group process, *Essential* and *Recommended* Focal Ecosystem Components (FECs) of terrestrial ecosystems were selected by a team of specialists in terrestrial ecosystems, creating an internationally agreed on set of monitoring indicators that can be used to summarize the condition of terrestrial biodiversity across the circumpolar North. An approach outlining design options for plot layout and transect locations is thoroughly described in the Arctic Regions Essential Components (*AREC*) Integrated Monitoring Design (Ibarguchi et al 2015). The arctic–subarctic TEC proposed in this paper would provide a standardized nomenclature for ecological communities across all sample sites, would summarize the key drivers controlling ecosystem composition, structure and productivity, will provide a standardized approach for scaling up regionally using remote sensing tools, and will provide the basis for comparing monitoring results across different biomes.

At a regional scale a biogeoclimatic classification based on the distribution of zonal, late seral ecological communities will provide a first level of national and international ecological stratification. In Canada the Walker et al (2005) CAVM Team map can be used identify climatically uniform areas in the arctic component, and the Ecoclimatic Zones (Ecosystems Working Group 1989) can be used to stratify sub-arctic areas – providing an ecosystem basis ensuring that monitoring will be representative of the complete range of arctic and sub-arctic climates. Using this approach, a first criterion for establishing a network of monitoring sites will be to ensure, as much as possible, that stations are selected to represent sub-arctic and arctic biogeoclimatic zones. This representation is critical for ensuring that the monitoring network can report on ecological change across the range of arctic and sub-arctic biogeoclimatic variability, and can capture this variability in scaling up exercises to apply local, place-based monitoring results to representative eco-regional areas.

At each site where monitoring is established, a recommended approach would be to use the TEC to design the locations of question-based monitoring experiments (Lindenmeyer and Likens 2010). Question-based (or hypothesis-based) monitoring is essentially a series of replicated long term experiments that measure changes in important ecosystem indicators, and the abiotic drivers that control them, against hypothesized outcomes. For example, key environmental drivers such as air and soil temperature, precipitation and soil moisture, active layer depth, and snow depth and duration are co-located with measures of vegetation response, and changes in nutrient cycling, arthropods, small mammals, and shorebirds to provide an assessment of how and why terrestrial ecosystems are changing, and to permit modeled projections of how the indicators may change in the future under different climate scenarios. This approach was also recommended in Ibarguchi et al (2015) where capacity exists to implement the experiments. Work ongoing under the International Tundra Experiment (ITEX) meets many of the criteria for question-based monitoring (http://www.geog.ubc.ca/itex/about.php). Over time, model predictions can be compared against monitored outcomes to improve the models and can be extrapolated across representative eco-regional areas.

A conceptual ecosystem model is developed for each monitoring experiment to link vegetation (and other terrestrial biotic) indicators to the environmental drivers that determine change, and the monitoring questions that frame the experiments. Monitoring questions are central to the development of the experiments and should be developed through a consultative process involving the range of local and regional stakeholders involved in establishing the monitoring program.

In an ideal world we would want to establish question–based monitoring at all ecological communities at each monitoring site, but in practice this will be prohibitively expensive given the number of ecological communities and the considerable costs of establishing and replicating monitoring experiments that integrate a suite of monitoring measures and ecological drivers. So it will be necessary to select certain ecological communities for monitoring, or to combine communities, e.g., all wetland communities, all snow protected communities, and sample across them. To prioritize local ecological communities for monitoring one approach that utilizes the TEC would be to select:

- <u>zonal ecological communities</u> at all monitoring sites to provide a co-ordinated basis for assessing and comparing changes across regional, national and international scales, and:
- <u>azonal ecological communities</u> based on international to local priorities, e.g., ecological communities that are important habitat for focal species such as caribou or muskoxen, climate refugial or snow bed communities important for conservation objectives, communities potentially impacted by resource development, communities expected to change quickly such as moist, rich sites with a vigorous shrub component, or estuarine communities that act as important migration staging areas. Other priorities may flow from ongoing research, so it may be a local priority to monitor ecological communities where net ecosystem carbon flux or cryosphere change is being measured.

The selection of ecological communities to establish this question-based monitoring at each research station will be constrained by logistical issues such as site access, spatial orientation of ecological communities, and replication requirements. The site selection process can be facilitated using a large scale map of ecological communities generated from high resolution satellite imagery or aerial photography. The map will delineate distributions of ecological communities within the sample area, and will provide the information required to optimize the location of potential monitoring sites, given monitoring priorities and logistical constraints. Such detailed maps of local scale ecological communities would support the monitoring transect approaches proposed in Ibarguchi et al (2015), with the additional benefit of providing information on identified ecotonal areas between ecological communities.

A high resolution map of ecological communities can also be used to monitor areal change at the landscape scale, e.g., expansion or shrinkage of ecological communities, changes in vegetation biomass or shrub cover, or changes in important wildlife habitat, and to link the results of the question-based monitoring to broad areas through remote sensing approaches (Zhang et al 2013, Fraser et al (2011). By agglomerating site units or ecological communities, local scale monitoring and derived models can be scaled-up from detailed ecological community maps using high resolution imagery (e.g., 1 m WorldView of QuickBird) to maps based on regional scale imagery such as SPOT 4/5 or Landsat 8 to cover ecologically-representative regional areas, i.e., TEC subzones.

Whatever ecological communities are selected for monitoring, the point here has been to demonstrate how the TEC acts as an ecological template providing a clear rationale for selecting sites to monitor, and for linking monitoring results across northern monitoring sites in different areas of the Canadian and circumpolar Arctic and Sub-arctic. By contributing the baseline information that informs the TEC, the AVA is fundamental for the development of long-term monitoring and other ecosystem based management systems for the Arctic.

Summary

This paper has presented the important role that a correlated AVA could play in providing a strong biological basis for developing an TEC for Arctic and Sub-arctic terrestrial ecosystems and has proposed how such a TEC would provide a strategic ecosystem-based foundation for implementing monitoring across the vast areas of Canada's North. The international nature of the AVA also means that monitoring and research in the Canadian North can be linked across the circumpolar area to help coordinate the implementation of the CBMP Terrestrial Ecosystem Monitoring Program (Christensen et al 2013).

Although applications to pan-Arctic monitoring are explored here, a similar argument can be made for the role of a correlated arctic TEC in developing a strategic approach for implementing coordinated research across the Arctic and Sub-arctic. For example, a key five year research priority for POLAR is to develop an understanding of terrestrial cryosphere change as it affects northern ecosystems, communities, and industrial activities. A strategic approach to implementing cryosphere research could utilize an arctic-subarctic TEC in the same way presented here for monitoring. Similarly, impact assessments and other land use management, e.g., road locations, pipeline issues, priority conservation areas, and terrain trafficability, can be informed by ecosystem maps linked to the arctic-subarctic TEC.

For all of these applications, a Canadian Arctic-Subarctic TEC, grounded by a correlated AVA initiative, can provide an ecosystem-based template for framing issues across this vast area, for developing strategic experimental designs, for extrapolating point based observations through remote sensing approaches to broad geographic areas, and for communicating monitoring and research results nationally and internationally.

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Research Data for a Changing World

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> ***"Why should we care? Because, just as the World Wide Web has transformed our lives and economies, so this new data wave will matter eventually to every one of us, scientist or not."***
> *- The Data Harvest, RDA Europe, 2014*

1. Introduction

Global environmental change is one of the most pervasive concerns of the 21st century. Scientists throughout the world are undertaking research to determine the nature and extent of these changes, and their impacts on humans and the environment. Global change research enables scientists to understand and predict how our planet functions and evolves and to investigate responses to those changes. This research increasingly requires integrating large amounts of diverse data across scientific disciplines to deliver the policy-relevant and decision-focused knowledge that societies require to respond and adapt to global environmental change and extreme hazards, to manage natural resources responsibly, to grow our economies, and to limit or even escape the effects of poverty. To carry out this research, data need to be discoverable, accessible, usable, curated and preserved for the long-term. This needs to be done within a supporting data intensive *e-infrastructure* framework that enables data exploitation, and that evolves in response to research needs and technological innovation. Without such data and the supporting e-infrastructure, policy makers and scientists will be forced to feel our way into the future without the benefit of new scientific understanding, unfocused and ill-prepared.

Environmental change is most rapidly occurring in the Arctic, where additional pressures for development and commerce are speeding the need for informed decision making. Data committees, such as the Arctic Data Committee of the Sustaining Arctic Observing Networks, are working quickly to craft policy for the Arctic that would provide measured access to information – "ethically open data" – while giving careful consideration to both the potential benefit and harm that data could cause to northern communities. The Arctic also leads the way for valuation of local knowledge and community or citizen science, creating opportunities for new data management approaches that connect users with knowledge holders.

Gaining support for these data initiatives requires the concerted efforts of many organizations involved in the funding, implementation, and evaluation of data and data management. Over the past two years, a team of domain experts and representatives from international data governance bodies came together under the Belmont Forum auspices to forward a set of global data principles. These principles target not only best practices for open access, but also communication, training, and stewardship to grow an informed community of data providers and users. These principles were adopted by the Forum in October 2015. Many of the members in the Forum hail from Arctic and Arctic-interested nations; thus, the implementation of these principles has the potential to meaningfully improve data transparency in all regions, including the Arctic.

The Belmont Forum seeks to establish a cooperative approach to developing **sustainable practices within the global change research community** for data discovery, management and curation. The goal is to streamline the dissemination of global environmental change information and maximize the opportunities for effective action.

1.1 About the Belmont Forum

Established in 2009, the Belmont Forum[1] comprises the world's major funding agencies of global environmental change research and also international science councils. It is guided by the Belmont Challenge, which aims: ***"to deliver knowledge needed for action to avoid and adapt to detrimental environmental change including extreme hazardous events.*** [2] The Belmont Forum serves as a round table for these agencies to address issues related to global environmental change collectively. To meet the goals of the Belmont Challenge, the Belmont Forum coordinates funding for Collaborative Research Actions (CRAs), which are high-priority research activities designed to improve the way funding agencies collaborate with each other and develop opportunities for multi-national research. Initially, priority focus has included Arctic observing and science for sustainability, coastal vulnerability, freshwater security, food security and land use change, mountains as sentinels of change, biodiversity and ecosystem services, and climate predictability.

1.2 E-Infrastructures and Data Management Collaborative Research Action

Accurate and reproducible science requires comprehensive and verifiable data that are appropriately documented and accessible. As researchers strive to understand the vast and varied systems comprising the global environment, a large factor determining their success is access to robust and reliable data as a foundation and reference point for their own conclusions. The Belmont Forum initiated the E-Infrastructures and Data Management CRA to collectively develop achievable and sustainable e-infrastructures and data management practices in recognition that:

> ***"…the need to address global environmental challenges requires a more coordinated approach to the planning, implementation, and management of***

[1] For more information on current membership, please visit http://www.belmontforum.org .
[2] The Belmont Challenge: A Global, Environmental Research Mission for Sustainability, (March 2011) http://belmontforum.org/sites/default/files/documents/belmont-challenge-white-paper.pdf

data, analytics and e-infrastructures through international collaboration."

— Belmont Forum, New Delhi, February 2013

A report with priorities was one output from the CRA, and is now being implemented. This is the result of activities conducted over an 18-month period by an international Assembly of more than 120 domain scientists, computer scientists, information scientists, social scientists and legal scholars. Their task was to survey the state of current practices and establish recommendations on how the Belmont Forum can leverage existing resources and investments to foster a more coordinated, holistic and sustainable approach to the funding and support of open and effective data management practices. The Assembly was guided by an international Steering Committee which consisted of experts from research and user communities from participating Belmont Forum member countries. Members of the Steering Committee were responsible for leading one or more Assembly working groups (Work Packages) in order to collectively assess existing international e-infrastructure capabilities, identify gaps and overlaps, prioritize challenges, and provide recommendations on how to best address the Belmont Challenge. Logistical and administrative support was provided by a joint US-UK Secretariat.

1.3 E-Infrastructures and Data Management CRA Members

The main sections of the report were written by the project Secretariat with guidance and significant input from the Steering Committee, with review and edits from the Assembly. This final report is a synthesis of;
1) Comprehensive reports by each Work Package on the state of the art, barriers, gaps and best practices;
2) Steering Committee contributions from a series of in-person and virtual meetings, and;
3) Feedback from meetings of national delegations of the participating Belmont Forum countries.

This report prioritized actions best suited for the Belmont Forum collaboratively to address *interoperability* and organizational challenges in data management and e-infrastructure, and to identify existing national and international initiatives which demonstrate good practice to create a global momentum toward thoughtful data management. Therefore, this report aimed to:

- Identify strategic science policies, outlining what can be done better, in a multilateral way, to support global change research;
- Clearly express global e-infrastructure needs, barriers and gaps;
- Inform stakeholders;
- Prioritize actions to address interoperability challenges.

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2. Report Summary

An e-infrastructure that supports data-intensive, multi-disciplinary research is needed to facilitate new discoveries and accelerate the pace of science to address 21st century global change challenges. Data discovery, access, sharing and interoperability collectively form core elements of an emerging shared vision of e-infrastructure for scientific discovery. These elements further depend on building relationships among data sets, people, systems, organizations and networks. However, the pace and breadth of change in data and information management across the *data lifecycle* means that no one country or institution can unilaterally provide the leadership and resources required to use data and information effectively, or to establish and maintain the relationships needed to support a coordinated, global e-infrastructure.

The Belmont Forum represents many of the world's largest and most influential funders of environmental and social science research. It is uniquely capable of catalyzing international collaboration and leveraging existing national programs to effectively initiate and guide best practice in data stewardship, data sharing and e-infrastructure development to meet global change research needs. Furthermore, alignment of international and cross-domain efforts in interoperability will promote new interdisciplinary and international scientific understanding relevant to the Belmont Forum research agenda. As such, ***the Belmont Forum is ideally poised to play a vital and transformative leadership role in establishing a sustained human and technical international data e-infrastructure to support global change research.*** This *Community Strategy and Implementation Plan* (CSIP)[3] proposed an initial path forward.

2.1 Recommendations

The Belmont Forum was presented with the overarching and synergistic recommendations listed below, through its unique role in global research collaboration, to: fill critical global e-infrastructure gaps; improve data management and exploitation; coordinate and integrate disparate organizational and technical elements; share best practices; and foster new *data literacy* to enable actionable and societally beneficial science. These recommendations have the potential to transform the way data are used and research is conducted by accelerating discovery, increasing the value of research in decision-making, and catalyzing changes throughout the economy and society that are of value to all citizens.

The five recommendations are:

1. **Adopt Data Principles** that establish a global, interoperable e-infrastructure with cost-effective solutions to widen access to data and ensure its proper management and long-term preservation. Researchers should be aware of, and plan for, the costs of data intensive research.
2. **Foster communication, collaboration and coordination** between the wider research community and the Belmont Forum, and across Belmont Forum projects through a Data and e-Infrastructure Coordination Office established within a Belmont Forum Secretariat.
3. **Promote effective data planning and stewardship** in all research funded by Belmont Forum agencies to enable harmonization of the *e-infrastructure data layer* through enhanced project data planning, monitoring, review and sharing.

[3] Available online: http://www.bfe-inf.org/sites/default/files/doc-repository/A_Place_to_Stand-Belmont_Forum_E-Infrastructures__Data_Management_CSIP.PDF

4. **Determine international and community best practice** to inform e-infrastructure policy for all Belmont Forum research, in harmony with evolving research practices and technologies and their interactions, through identification and analysis of cross-disciplinary research case studies.
5. **Support the development of a cross-disciplinary training curriculum** to expand human capacity in technology and data-intensive analysis methods for global change research, and increase the number of scientists with cross-cutting skills and experience in best practice.

These recommendations have been adopted by the Belmont Forum, and the remainder of this paper describes what has been adopted and agreed.

2.2 Motivation

2.2.1 A New Data Literacy for the 21st Century

The United Nations noted that the world needs a new data literacy that enables actionable and socially-beneficial science to address environmental change affecting disaster mitigation, resilience, water and other natural resources.[4] Broader and more effective development of best practice in data stewardship, sharing and cross-disciplinary use are pillars of the new data literacy and the basis of *Open Science* and, more generally, of the direction of science itself. Global access to data will change the ways we address environmental change problems and also change our behavior; mastery in the management and exploitation of data is key to successful collaboration and future research.

2.2.2 Unique Challenges in Global Change Research

Global change research is a crucible for shaping e-infrastructure technologies and research practices. Free and open exchange of data, methods and results, as well as effective data stewardship, are central to advancing scientific enquiry in all fields but there are particular challenges and needs in cross-disciplinary research areas. Challenging multi-disciplinary research questions relating to the Earth system span physical (e.g. atmosphere, land, and oceans), political, social and geographical boundaries, requiring data and information to be interoperable and exchangeable worldwide. Global change research also integrates diverse observations, data-intensive analytical methods and numerical models across numerous scientific domains. It requires extensive data storage and movements, including emerging capacities in *cloud computing* and *High Performance Computing*. In addition, there is a need to preserve historical, often “small” and disparate data, as much of global change research relies on observations that by definition cannot be repeated. Both the public and commerce have a high level of interest in the results, leading to an increasing demand for veracity, dissemination and citizen involvement.

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[4] A World That Counts: Mobilizing The Data Revolution for Sustainable Development. *undatarevolution.org/report/*.

2.2.3 Importance of Overcoming Historical Barriers to Interoperability

Major regional, national and international e-infrastructure efforts[5] have noted that cultural, social and organizational barriers to global data sharing and interoperability generally exceed technical barriers. These non-technical aspects are easily overlooked or considered outside the scope of domain and of information and communication science and technology programs. Funding strategies by research agencies have also inadvertently bolstered these barriers by supporting investigator- or discipline-generated projects that are generally disconnected from each other and are typically independent of an overarching, integrated framework that would contribute to a coordinated e-infrastructure. Similarly, policy has often focused independently on particular segments of the data lifecycle (such as data acquisition, storage and distribution or data-intensive High Performance simulation) whereas a policy which bridges the whole data lifecycle is required for a healthy data-intensive e-infrastructure environment. Thus, the emphasis in this report is to integrate across the technical and non-technical aspects of interoperable data and e-infrastructure.

2.2.4 Reproducibility in Science

In October 2014, the Belmont Forum Principals requested that this CRA consider issues regarding reproducibility in science. Elements of reproducibility underpin all science, including global change research. They include: reuse of data and code; need for data repositories and sharing platforms; standards required for sharing code and data effectively and accurately; citation, *provenance*, *metadata*, tools and incentive mechanisms; capture and sharing of workflows; and ensuring domain-specific statistical reproducibility in the computational and data science software stack. Accurate capture and free exchange of data and information is inherent in this. Reproducibility is thus not drawn out separately but is interwoven into its conclusions and recommendations. The term "reliability" of data is emerging as a possible alternative descriptor of the issues involved in reproducibility of science.

2.3 Findings and Recommendations

2.3.1 Vision

The Belmont Forum vision is of high quality, reliable and multidisciplinary global change research enabled by a sustained human and technical, internationally coordinated and data-intensive e-infrastructure able to process a continuous increase in the diversity and volume of data generated. In such a research-driven e-infrastructure, data should be discoverable, reusable, open and accessible by default as far as possible. In addition, the data's fitness-for-purpose should be assessed using transparent metadata relating to trustworthiness and quality. To realize this vision and maximize the return on public investments in research, all stakeholders need appropriate incentives to contribute to and support this vision. ***The Belmont Forum can blaze a path towards achieving this vision by implementing the recommendations outlined below.***

[5] COOPEUS, RDA, ICSU-WDS, DataONE, DIAS, ESIP, EarthCube, GBIF, GEOSS, iCORDI, INSPIRE and OneGeology.

- Adopt Data Principles and Policy

The Belmont Forum has adopted a common data policy and the following principles to widen access to data and promote its long-term preservation in global change research; help improve data management and exploitation; coordinate and integrate disparate organizational and technical elements; fill critical global e-infrastructure gaps; share best practices; and foster new data literacy.

The Belmont Forum recognizes that significant advances in open access to data have been achieved and implementation of this policy and these principles requires support by a highly skilled workforce. The Belmont Forum recommends a broad-based training and education curriculum as an integral part of research programs and encourages researchers to be aware of, and plan for, the costs of data intensive research. The Belmont Forum's ambition is that this policy and these principles will take positive steps toward establishing a global, interoperable e-infrastructure based on cost-effective solutions that can help enable actionable and societally beneficial science.

Data should be:

- **Discoverable** through catalogues and search engines
- **Accessible** as open data by default, and made available with minimum time delay
- **Understandable** in a way that allows researchers—including those outside the discipline of origin—to use them
- **Manageable** and protected from loss for future use in sustainable, trustworthy repositories

The Belmont Forum and its members will support and promote this data policy and principles with the intent of making these data principles enforceable over time.

The development of these principles was informed by data principles generated and recommended by many international programs, such as the G8. These principles underpin the recommendations in this report as they inform the nature of the data plans and help identify best practice.

- II. Foster Communication, Collaboration and Coordination

An appropriate organizational and community-building environment is necessary to: resolve barriers and gaps in global data sharing and interoperability; build relationships; distill information from data; and align incentives for effective and collaborative data management. Otherwise, the current trend of competing or conflicting technology development and agency policies will endure. While this work is, and will continue to be, undertaken largely in a national context, the Belmont Forum can place it into a global context by fostering the appropriate coordination and collaboration environment. ***The Belmont Forum can and must champion the organizational, community-building and***

technical framework needed to facilitate the international and interdisciplinary exchange of global change information through its member organizations, both individually and collectively.

- III. Promote Effective Data Planning and Stewardship

Communicating best practice in data and information stewardship and sharing will not only help to improve collaborative efforts but also reduce the associated risks and costs of data management. This involves: paying attention to the full lifecycle of data use and the rates at which information is gleaned from data; changing policies to promote better and more effective data planning; adopting data stewardship principles; and implementing incentives for their adoption, similar to the ways in which scientists are incentivized to publish research results. Establishing good practice is fundamental to improving data availability and interoperability. It will enable co-evolution of research needs with e-infrastructure, increase data usefulness, build trust among stakeholders, and reduce overall costs resulting from ineffective data management. ***The Belmont Forum is ideally positioned to achieve significant impact by collectively changing grant funding policies and reward systems to promote more effective data planning and stewardship.***

- IV. Determine International and Community Best Practice to Inform Belmont Forum Research e-Infrastructure Policy

Individual research domains successfully exchange best practice, either through scholarly publishing or increasingly through exchanging information via the Internet using a variety of mechanisms and applications. While there are beacons of good practice, there are inconsistencies in the exchange of information and the shaping and sharing of data-intensive e-infrastructure between nations and across domains and users. The rapid pace of change in technology and its adoption makes the normal development of good practice difficult and it is unclear whether the market will produce suitable solutions without intervention. Environmental and social sciences have a strong need to preserve and exchange information globally and all Belmont Forum members have examples of good practice to share. ***The Belmont Forum is uniquely placed to review worldwide and discipline-specific current practice and to foster best practice (in data sharing stewardship, analysis, modeling and workflows, and in the implementation of e-infrastructures) to promote efficiencies and trust in data and e-infrastructure solutions.***

- V. Support the Development of a Cross-Disciplinary Training Curriculum to Build Capability

E-Infrastructures globally lack enough skilled people who understand data management and data intensive methods in environmental, social and health sciences, and in engineering to effectively drive this area forward. While training exists in a number of domains, it is frequently restrictive in scope. In addition, formal training is typically aimed at university students and early career researchers but there is a strong need for established scientists to become more data-enabled and data-proficient. Significant progress in building this capability can be achieved through cataloguing, accrediting and enhancing existing training efforts, filling critical gaps in a nascent global curriculum, and sharing methods for interdisciplinary and transdisciplinary exploitation of data.

The Belmont Forum is well placed to stimulate new ways of thinking and working amongst distributed and diverse researchers, data and information scientists and data-enabled domain scientists, enabling them to better address global change research challenges.

2.3.2 Leveraging the Power of the Belmont Forum

If the planet were a patient in a modern intensive care hospital unit, there would be a coordinated set of sophisticated monitors and instruments, rapid analysis and presentation of test results, a team of medical professionals coordinating diagnosis and treatment according to proven medical principles and best practices, and a set of available experts from different specialties drawing on the best available medical research and data. The Belmont Forum is in a unique position to develop key pieces of a comparable global e-infrastructure. It can act as a catalyst for promoting dialogue and collaboration, and leverage - but not replace - existing national programs. It also provides a synergistic, top-down approach that complements bottom-up activities carried out by individual nations and organizations across the globe.

Implementation of these recommendations could include adopting internal actions and policies to align Belmont Forum efforts with external developments, influencing research investments judiciously, targeting limited resources where they are uniquely or best suited, or issuing funding calls (such as a networking or community-building action, a call to run a summer school or develop training materials, small-scale priming activities, large-scale research activities, or whatever is most appropriate to address the issue in question). For some actions, the Belmont Forum could identify that a CRA or invitation to tender would be the best funding mechanism to address an issue.

The challenges and opportunities in creating coordinated, global and interoperable e-infrastructure are complex but addressing them will result in tremendous benefits to stakeholders at all levels. These challenges are also clearly outside the ability of any single entity to attempt to control or implement, both in terms of resources and authority. Development of an e-infrastructure capable of supporting the existing and emerging global change research agenda has been, and will likely continue to be, organic with many aspects unpredictable and disruptive. It must therefore be agile and adaptable to meet changing research needs and technology development. Shared responsibilities are a key to success.

2.3.3 Shared Responsibilities

We have described the rationale for the Belmont Forum to undertake the recommended actions but have not discussed what the larger research and computing communities should do for Belmont Forum e-infrastructure and data management actions to be successful. Do individual Belmont Forum members take independent action? What should external entities and funding agencies do to support these activities? How does the Belmont Forum respond to external dynamics?

Globally, researchers and governments alike are recognizing the importance of data discovery, access, information sharing and interoperability. These collectively form core elements of an emerging shared vision of e-infrastructure for scientific discoveries, governance and resource management. There are numerous challenges to achieving these ambitious goals, many of which have been identified through existing Earth and related science informatics community initiatives. This broad, loosely-coupled community has identified many of the technical and social challenges to e-infrastructure but developing solutions that are adopted and collectively enhanced by the scientific community is still difficult. By building a cohesive international community committed to this e-infrastructure vision, the Belmont Forum can create opportunities for shared and more sustainable efforts toward removing barriers to interoperability on a global scale. GEO is one of the key international organizations involved with this initiative, together with ICSU and Future Earth, and the Research Data Alliance. This collaboration means that this initiative will build on the excellent work already in progress, including in the Arctic, and ensure no loss of momentum and engagement with the wider scientific community.

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3. Actions to Catalyze Recommendations[6]

- **Action Theme 1: Coordination Office**

Foster communication, collaboration and coordination through the establishment of a Data and e-Infrastructure Coordination Office

- **Action Theme 2: Data Planning**

Promote effective data planning and stewardship in all research funded by Belmont Forum agencies

- **Action Theme 3: e-Infrastructure**

Determine international and community best practice in order to inform e-infrastructure policy for all Belmont Forum research

- **Action Theme 4: Human Dimensions**

Support the development of a cross-disciplinary training curriculum to build capability

> ***"Too often, development efforts have been hampered by a lack of the most basic data about the social and economic circumstances in which people live... We must also take advantage of new technologies and access to open data for all people."***
> *- Bali Communiqué of the High-Level Panel, March 2013*

[6] Please see Appendix 1: References for supporting documentation

3.1 Broader Impacts

3.1.1 Benefits of Acting

This proposed set of initiatives will enable the Belmont Forum to fulfill its charge better to "*to deliver knowledge needed for action to avoid and adapt to detrimental environmental change including extreme hazardous events."* In addition, through internal adoption by individual Belmont Forum members, these recommendations will have much broader impacts for disciplines and programs outside of environmental change research and for organizations engaged in scientific and technical research and operations worldwide.

Accelerate the Pace of Scientific Discovery

The recommendations have the potential to transform the way research is conducted by accelerating discovery, increasing the value of research decision-making, and catalyzing changes throughout the economy and society that are of value to all citizens. New scientific discoveries and socio-economic innovation will emerge from tackling the large increase in diversity, volume and rate of growth of multidisciplinary data. Establishing and enabling a cross-disciplinary framework and data-intensive e-infrastructure, with network and computational elements, will allow scientific knowledge to transcend disciplines and address new environmental change problems. Acting now, at a stage early in the development of distributed network solutions and similar elements of e-infrastructure, means that the Belmont Forum can have extraordinary influence on those specialized developments.

Broaden Dissemination of Best Practice

Actions to adopt and use best practices for research data and e-infrastructure planning and development will ultimately benefit current and future Belmont Forum-funded research, and the general research landscape. This could foster greater trust in research outputs, because data are available for validation and reuse.

Enhance Coordination

Developing coordinated and interoperable data and e-infrastructure includes mapping relevant activities in and among organizations. Mapping will enhance collaboration and general practice within the Belmont Forum, across activities within member agencies and countries, and in institutions involved in the global coordination of environmental and social science information. It will harmonize efforts and organizations, lessen volunteer fatigue, reduce redundancy and duplication of effort, and increase the impact of funding initiatives.

Build Capability

Facilitating international, cross-disciplinary training will increase the potential for broader, global participation in research, and expand human capability and competitiveness. This will result in products and publications of greater benefit to the international community. Students and researchers, especially from developing nations, will also benefit from the opportunity to present their research problems and materials, compare best practice, and network with contemporaries in other countries and disciplines. In itself, this will be an important legacy of the investments described here. Taking all these investments together, they will be transformative.

3.1.2 Consequences of Not Acting

Impaired Ability to Respond to Detrimental Effects of Environmental Change

Global change research is extremely time-critical. Given the immediate and long-term risks of environmental change, together with the ever-increasing amounts of research data being generated, much damage would be done to the field of study (Earth) and our ability to start formulating meaningful evidence-driven actions if delays force us to start again or backtrack. Not acting may limit our options and ability to respond to crises, since avoidable errors in decisions occur daily. Decision makers may not know about reasonable options for adaptation and mitigation because data and knowledge were not shared, or Earth system models will incorrectly assess impacts because they did not incorporate realistic or current data. We can also lose visibility of existing data if they are not curated and made accessible to modern e-infrastructures. Avoiding such errors and loss of data by promoting better access, preservation and use of existing data would yield significant financial savings, reduce distress and save lives.

Lost Opportunities and Squandered Valuable Resources

Not acting will create lost opportunities, delays in achieving Belmont Forum goals, squandering of valuable resources in the form of increased costs to retrofit incompatible data, software and scientific results, and losing data irretrievably. Not acting could also result in losing momentum in the application of globally integrated e-infrastructure for research, which has potentially profound economic and societal consequences. Not acting also means that, in the void of truly globally accepted agreements, special interest developers may be the only option and may drive solutions that are incompatible with environmental and social science research needs.

Appendix 1: References

The following references support the recommendations described in the Community Strategy and Implementation Plan:

A. Action Theme 1: Communication, Coordination, and Collaboration

Deese, B. C. and J. P. Holdren. 2014. Memorandum for the heads of Executive Departments and Agencies: Science and Technology Priorities for the FY 2016 Budget. Executive Office of the President of the United States. whitehouse.gov/sites/default/files/microsites/ostp/ostp_public_access_memo_2013.pdf

European Commission, Commission to the Council and the European Parliament. 2012. On the Experience Gained in the Application of Directive 1003/4/EC on Public Access to Environmental Information. eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2012:0774:FIN:EN:PDF

Holdren, J., T. Dickenson, G. Paulson, et al. 2014. National Plan for Earth Observations. National Science and Technology Council, Executive Office of the President. 71 pp. whitehouse.gov/sites/default/files/microsites/ostp/NSTC/2014_national_plan_for_civil_earth_observations.pdf

Office of Science and Technology Policy. 2013. Memo: Increasing access to the results of federally funded research. whitehouse.gov/sites/default/files/microsites/ostp/ostp_public_access_memo_2013.pdf

President's Council on Advancing Science and Technology (PCAST) 2011. Working Group on Biodiversity Preservation and Ecosystem Services. In: Sustaining Environmental Capital Report. whitehouse.gov/sites/default/files/microsites/ostp/pcast_sustaining_environmental_capital_report.pdf

B. Action Theme 2: Data Planning

1. OECD Principles and Guidelines for Access to Research Data from Public Funding (OECD, June 2007) oecd.org/sti/sci-tech/38500813.pdf

2. Riding the wave: How Europe can gain from the rising tide of scientific data (EU, October 2010) cordis.europa.eu/fp7/ict/e-infrastructure/docs/hlg-sdi-report.pdf

3. The Data Harvest: How sharing research data can yield knowledge, jobs, and growth (RDA, December 2014) europe.rd-alliance.org/sites/default/files/report/TheDataHarvestReport_%20Final.pdf

4. Science as an open enterprise (The Royal Society, UK, June 2012) royalsociety.org/~/media/Royal_Society_Content/policy/projects/sape/2012-06-20-SAOE.pdf

5. Increasing Access to the Results of Federally Funded Scientific Research (US OSTP, February 2013) whitehouse.gov/sites/default/files/microsites/ostp/ostp_public_access_memo_2013.pdf

6. Making Open and Machine Readable the New Default for Government Information (US White House, May 2013) whitehouse.gov/the-press-office/2013/05/09/executive-order-making-open-andmachine-readable-new-default-government-

7. G8 Open Data Charter and Technical Annex (G8, June 2013) gov.uk/government/publications/opendata-charter/g8-open-data-charter-and-technical-annex

8. Today's Data, Tomorrow's Discoveries (US NSF, March 2015) nsf.gov/publications/pub_summ.jsp?ods_key=nsf15052 9. Increasing Access to the Results of Scientific Research (US NASA, November 2014) science.nasa.gov/media/medialibrary/2014/12/05/NASA_Plan_for_increasing_access_to_results_of_federally_funded_research.pdf

1. ncbi.nlm.nih.gov/pmc/articles/PMC3817176/

2. datapub.cdlib.org/2014/03/03/finding-disciplinary-data-repositories-with-databib-and-re3data/

3. docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1001&context=lib_fspres

Relevant work on data publishing has been conducted by RDA/WDS and CODATA working groups, amongst others, which can easily be adapted and updated. The following texts were additionally identified as relevant evidence of the need for this action;

1. Costas, R., Meijer, I., Zahedi, Z. and Wouters, P. (2013). The Value of Research Data - Metrics for data sets from a cultural and technical point of view. A Knowledge Exchange Report, available from knowledge-exchange.info/datametrics.

2. Mooney, H, Newton, MP. (2012). The Anatomy of a Data Citation: Discovery, Reuse, and Credit. Journal of Librarianship and Scholarly Communication 1(1):eP1035. dx.doi.org/10.7710/2162-3309.1035. (Motivates reward structures to encourage data publication).

3. Klump, J. (2012), Offener Zugang zu Forschungsdaten: Open Data und Open Access to Data – Die ungleichen Geschwister, in Open Initiatives: Offenheit in der digitalen Welt und Wissenschaft, edited by U. Herb, pp. 45–53, universaar, Saarbrücken, Germany. [online] Available from: nbnresolving.de/urn:nbn:de:bsz:291-universaar-873

C. Action Theme 3: e-Infrastructure

1. A Science Plan for Integrated Research on Disaster Risk, 2008: wcdrr.org/uploads/Sendai_Framework_for_Disaster_Risk_Reduction_2015-2030.pdf The ICSU Priority Area

Assessment on Environment and its Relation to Sustainable Development (2003) and the ICSU Foresight Analysis (2004) both proposed 'Natural and human-induced hazards' as an important emerging issue. Responding to this proposal, the Science Plan of Integrated Research on Disaster Risk (IRDR) aims to generate new information and data, and leave a legacy of coordinated and integrated global data and information sets across hazards and disciplines, with unprecedented degrees of access.

2. GEOSS Data Sharing Action Plan, 2010: earthobservations.org/documents/geo_vii/07_GEOSS%20Data%20Sharing%20Action%20Plan%20Re v2.pdf The "GEOSS Data Sharing Principles" is one of the first accomplishments of the Group on Earth Observations (GEO). It states: a. There will be full and open exchange of data, metadata and products shared within GEOSS, recognizing relevant international instruments and national policies and legislation; b. All shared data, metadata and products will be made available with minimum time delay and at minimum cost; and c. All shared data, metadata and products should be free of charge or no more than cost of reproduction will be encouraged for research and education.

4. Future Earth 2025 Vision, 2014: futureearth.org/sites/default/files/future-earth_10-year-vision_web.pdf. The vision of Future Earth is for people to thrive in a sustainable and equitable world. It says that Future Earth is contributing to improved modes of sharing data about environmental change and progress towards sustainability in order to support policy and practice at different levels. The outputs include science-based data, tools and resources to support improved resilience of people, communities and economies, including disaster risk reduction.

5. The Road to Dignity by 2030: un.org/disabilities/documents/reports/SG_Synthesis_Report_Road_to_Dignity_by_2030.pdf Ending Poverty, Transforming All Lives and Protecting the Planet, 2014 calls for inclusive, agile and coordinated action to usher in an era of sustainable development for all. Secretary-General Ban Ki-moon presented the United Nations (UN) General Assembly with this document, which will guide negotiations for a new global agenda centered on people and the planet, and underpinned by human rights. It emphasizes the role of data in the new agenda by saying that the world must acquire a new 'data literacy' in order to be equipped with the tools, methodologies, capacities, and information necessary to shine a light on the challenges of responding to the new agenda.

6. A World that Counts, 2014: undatarevolution.org/wp-content/uploads/2014/11/A-World-That-Counts.pdf. This document was published by the UN Secretary-General's Independent Expert Advisory Group (IEAG) on a Data Revolution for Sustainable Development. It emphasizes that data are the lifeblood of decision-making and the raw material for accountability and that effective policies become almost impossible without high-quality data providing the right information on the right things at the right time.

7. Sendai Framework for Disaster Risk Reduction 2015-2030: wcdrr.org/uploads/Sendai_Framework_for_Disaster_Risk_Reduction_2015-2030.pdf Representatives from 187 UN member states have adopted the first major agreement of the Post-2015 development agenda, a far

reaching new framework 'Sendai Framework for Disaster Risk Reduction 2015-2030', for disaster risk reduction with seven targets and four priorities for action. It also promotes and enhances, through international cooperation (including technology transfer), access to and the sharing and use of non-sensitive data, information, communications and geospatial and space-based technologies and related services.

8. Sustaining Domain Repositories for Digital Data: A White Paper 2013: datacommunity.icpsr.umich.edu/sites/default/files/WhitePaper_ICPSR_SDRDD_121113.pdf This paper addresses some of the common needs of domain repositories across the natural, social, and health sciences, though not explicitly the issue of how to fill gaps between/across domains.

D. Action Theme 4: Human Dimensions

UK: “Most Wanted II - Postgraduate and Professional Skills Needs in the Environment Sector’ nerc.ac.uk/skills/postgrad/policy/skillsreview/2012/

UK: Employer Engagement - enhancing HEI engagement with the Satellite Industry Final Report hestem.ac.uk/resources/outputsprojects?keys=Space&x=0&y=0&field_author_date_value[value][year]=&field_discipline_value_many_to_o ne=All&field_activity_project_nid=All) ≺ A1-24 ≻ Appendix 1, Action Theme 4: Human Dimensions

E. EU: (SIM4RDM produced an EU landscape report in 2013, which describes the need for data management plans and how researchers said they would benefit from face-to-face support and training sim4rdm.eu/documents/project-outputs)

Schmidt, B., Gemeinholzer, B., Treloar, A (2016): Open Data in Global Environmental Research: The Belmont Forum's Open Data Survey. PLOS One, DOI: 10.1371/journal.pone.0146695

The Open Data Survey (completed as part of this CRA) with the responses of more than 1000 global participants, cites only 23% of respondents having any awareness of data publishing guidelines of any type. The report strongly recommends the support of training activities in this area, noting particularly, “Support and training activities should be supported in concerted ways, targeting researchers as well as current and future data and information professionals.” Crucially, all evidence identifies the global shortage of researchers who are literate in cross-cutting and interdisciplinary skills - environmental and social scientists who are also skilled in informatics, or information technologists who have environmental and social science expertise.