AMAP/EU-PolarNet Stakeholder Workshop on Research Needs on Climate-related Effects on the Arctic Cryosphere and Adaptation Options

Reston, VA, USA, 28 April 2017

Final Report

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Executive Summary: Compiled research

Based on the presentations and discussions at the AMAP/EU-PolarNet Stakeholder Workshop on Research Needs on Climate-related Effects on the Arctic Cryosphere and Adaptation Options, a number of priority research issues were identified.

There is a critical need to estimate the ***economic cost of adaptation*** at both the Arctic scale and the global scale. Strong links to global connections are needed because changes in the Arctic are so large that they will feed back into changes in atmospheric circulation and global sea-level rise that will have major effects globally, implying very large and expensive requirements for adaptation on a global scale. An economic assessment of Arctic changes needs to be connected to the economic cost of the consequences.

In addition to the identification of research needs, ***coordination of research*** is needed. Coordination is important to manage limited time and money, and different competencies and strengths. An aspect of this is the need for a forum to address transdisciplinary research issues. Single-discipline silos need to be broken down and natural sciences and social sciences need to be brought together with stakeholder input to broaden the recommendations for research. Better means and instruments of attracting the input from a wider audience of stakeholders should be investigated and tested.

Monitoring climate-related changes in the Arctic cryosphere at the system level and across disciplines is very important and requires a consistent commitment from funding agencies for long-term monitoring, which is vital given the rapid changes in these systems owing to changing stressors. Funding for the development and maintenance of interdisciplinary networks is also crucial.

Making existing knowledge available in a form that can be used in the context of decision-making is at least as important as identifying research needs and filling scientific knowledge gaps. There is a need to investigate how natural sciences and knowledge intersect with social sciences and ***how natural science feeds into social science, policy development***, and other needs so that there is a better understanding of the need for funding and so that the scientific information provided will be appropriate to its intended use. There is a mismatch between organizational structures and funding structures. An institutional analysis should be conducted to determine whether the underlying social structure helps or hinders utilization of scientific information and the funding of adaptation options.

To ***increase the societal relevance and uptake of Arctic research***, knowledge should be obtained on how scientific research is applied in practice and how it feeds back into the trajectory of the multiple systems (e.g., geophysical, ecological) that are the focus of Arctic research. There is a need to engage with the relevant diverse communities (e.g., of knowledge holders, scientists, policy-makers, managers) at the outset when formulating research questions and designing research programs. Insights are provided by systems science, and by social and political science.

Recommendations for scientific research on the various components of the cryosphere often address narrow questions, resulting in a mismatch between consideration of narrow scientific issues and their relation to broader social systems. Extrapolating from the complexity of physical or ecological systems to global impacts also needs to be addressed.

In order to understand ecosystem services, and how we can manage for their continued provision including in an economic context, ***good understanding is needed of the geophysical, ecological, and social systems involved and how they are coupled***. Ecosystem services are numerous and relevant across scales; they are provided by nature and valued by people, so in essence they are co-produced in social-ecological systems. This is relevant at various scales as the drivers, including environmental, governance, and influencing actors are often different across these scales.

Information on and understanding of the physical sciences is very important to climate-related adaptation measures. There is a large ***need for knowledge regarding climate adaptation in the Arctic*** as well as on the global scale, given that the effects will be felt outside the Arctic region.

Research is needed to develop action plans for small-scale industrial development and extra knowledge is needed of the economy and how to develop economic activities. There is need for a framework for helping communities to diversify their activities and take advantage of any opportunities presented by climate change. In considering local adaptation actions, experience from scientific assessments is available but there is also a need for the involvement of representatives from industry, shipping, mining and local residents. There is a need to test ways and means that local communities can use to adapt to climate change, including both short-term and long-term changes, so that this information can be used to teach university students about adaptation to climate change.

Capacity building and policy-making are important at the local level as well as in broader regional areas. This should include the enhancement of education and training opportunities and job possibilities with good working conditions to develop these Arctic communities.

The need for ***early inclusion of Indigenous people and use of Indigenous knowledge in scientific studies*** and the development of climate-adaptation actions in the Arctic is vital. Indigenous people and communities need to be included more closely in scientific research. Indigenous knowledge gained over many centuries should be captured now while it still exists so that we can understand and utilize this thousand-year-old knowledge. There is need for developing priorities on using different kinds of knowledge and understanding; this requires a framework for implementation.

1 Background

The Arctic cryosphere is experiencing rapid change as a consequence of the rapidly changing climate. The sea-ice cover is decreasing rapidly, snow cover duration is decreasing, the melting of glaciers and the Greenland ice sheet is increasing, and permafrost is thawing in a number of areas. The Arctic Monitoring and Assessment Programme (AMAP) has studied these changes over the past 25 years and prepared assessment reports documenting the changes and their impacts. In 2017, the fourth assessment of physical changes in the Arctic cryosphere was completed, entitled *Snow, Water, Ice and Permafrost in the Arctic 2017*(SWIPA2017) (AMAP, 2017a). In parallel, AMAP coordinated the Adaptation Actions for a Changing Arctic (AACA) process, which assessed the impacts of climate change and other stressors on the ecosystem services, human societies and socio-economic conditions of several regions in the Arctic (AMAP, 2017b, c, d), providing parallel, complementary information to SWIPA 2017. The results of these four assessments and other recent AMAP work were presented at the AMAP-organized event “International Conference on Arctic Science: Bringing Knowledge to Action”.

AMAP, as a partner in the Horizon 2020 coordination and support action EU-PolarNet, is responsible for promoting trans-Atlantic research activities between EU countries and the USA and Canada and, as one aspect of this, to hold international stakeholder workshops to determine common research needs that can be provided as input to the central EU-PolarNet requirement, namely, to develop an Integrated European Polar Research Programme together with an implementation plan. An important aspect of EU-PolarNet is “connecting science with society”, under which dialogue and cooperation with relevant Arctic stakeholders will ensure their input to the formulation of this research programme. The AMAP/EU-PolarNet Stakeholder Workshop on Research Needs on Climate-related Effects on the Arctic Cryosphere and Adaptation Options is the third of four AMAP-organized stakeholder workshops to identify and formulate key Arctic research needs over the five years of the project. The central theme of this workshop was the identification of research needed to obtain a better understanding of the dynamic processes, linkages and feedbacks of the climate-related changes in the Arctic cryosphere and potential options for adaptation to such changes by residents, communities and regions in the Arctic.

The stakeholder workshop was held immediately following the AMAP International Conference on Arctic Science: Bringing Knowledge to Action so that it could use the presentations and discussions at the conference as a basis for consideration of knowledge gaps and research needs at the workshop.

The format of the workshop, after the introductory presentations setting the background and aims, comprised presentations by several experts from around the Circumpolar North on a specific theme followed by discussion by the participants of the ideas presented and identification of research needs requiring further work. The workshop participants, as a group, then considered all material presented to identify key themes and approaches.

2 Opening and welcome

The Co-Chairs of the Workshop, Morten Skovgaard Olsen (Danish Ministry of Energy, Utilities and Climate) and Jim Overland (NOAA Pacific Marine Environmental Laboratory) opened the meeting and welcomed the participants.

Representatives of the two co-sponsors of the workshop, the AMAP Secretariat and EU-PolarNet, then provided the overall background for the workshop.

Lars-Otto Reiersen, AMAP Executive Secretary, welcomed the participants to the workshop. He noted the significance of this workshop to identify research needs relating to climate impacts on the Arctic cryosphere and adaption options for Arctic communities that can be provided to the European Commission in relation to their funding activities. The results should also be useful to AMAP and other organizations coordinating or conducting international or national investigations in the Arctic.

3 Context of the workshop: Research needs defined for EU-PolarNet work

Nicole Biebow, Project Manager of EU-PolarNet, the other co-sponsor of the workshop, presented a brief overview of this activity. She stated the European Union and its executive body, the European Commission (EC), attribute an increasing importance to science and innovation in the high latitudes. As a result, the EC launched a five-year coordination and support action œEU-PolarNet ï Connecting Science with Societyö, which is working in close cooperation with the EC to shape Europeøs polar research and policy agenda. EU-PolarNet is the largest consortium of expertise and infrastructure for polar research, comprising 17 countries represented by 22 of Europeøs internationally respected multidisciplinary research institutes.EU-PolarNet is working closely together with the EC, providing support and advice on all issues related to the polar regions.

An important aim of EU-PolarNet is to develop an Integrated European Research Programme for the Antarctic and the Arctic; this will be co-designed with all relevant stakeholders and coordinated with the activities of many other polar research nations beyond Europe, including Canada and the United States, with which consortium partners already have productive links. The AMAP/EU-PolarNet Workshop on Research Needs on Climate-related Effects on the Arctic Cryosphere and Adaptation Options is one important step in obtaining input from researchers and stakeholders for the Integrated European Polar Research Programme.

EU-PolarNet is also designing a resource-oriented European infrastructure access and usage plan for polar research. It is working to improve and strengthen international cooperation and implement the Trans-Atlantic Ocean Research Alliance between the EU, Canada and the USA. EU-PolarNet will continue to assist the EC in defining calls for the 2018ï 2020 H2020 program, which will allocate a significant amount of funding to Arctic and Antarctic research.

An early activity of the project was to determine the polar research priorities in European countries. Based on an extensive compilation of national and institutional priority issues, ten research themes were chosen that reflected research strategies in most of the plans. These were then related to societal goals. The next step is to develop six white papers to promote urgent polar research questions. This will build on a public online consultation to enable scientific and non-scientific stakeholders to indicate what they consider are the most important topics in the polar regions that should be tackled by future research questions and key issues of societal relevance. The white papers will be developed jointly by stakeholders and scientific experts during a five-day meeting near Madrid. Further information can be found on http://www.eu-polarnet.eu/.

4 Aims and outcome of the workshop

The workshop organizer and meeting rapporteur, Janet Pawlak, AMAP Deputy Executive Secretary, emphasized the importance of this workshop as one of the stakeholder contributions to the further development of prioritized objectives for Arctic research and ultimately the Integrated European Research Programme for the Arctic. As climate-related effects on the Arctic cryosphere and adaptation options represent only one of many research topics for the Arctic, this workshop should aim to identify the most important research needs on this topic. These research needs will be included in the report to be prepared based on the presentations and discussions at the workshop for submission to EU-PolarNet as a stakeholder contribution on these issues. The report is also a project deliverable to the European Commission for its information and use.

5 Research needs on climate-related effects on the Arctic cryosphere

5.1 Summary of research needs from the AMAP conference

Ross Brown, Environment Canada, gave an overview of the research needs on climate-related effects on the Arctic cryosphere that he heard articulated at the AMAP conference. These include:

1. There is a need for improved understanding of dynamic processes, linkages and feedbacks in the climate system. Currently, models are developed in ósilosô without looking at interfaces between systems. Important knowledge gaps are that critical processes are not covered and small-scale processes are not represented in the models. There is also a need to reduce the current large spread in model outcomes. Model Intercomparison Projects (MIPs) tend to be silos, covering each separate component of the cryosphere; there is a need for a more integrated approach and data sets need to be made available for that process. Users have not been taken into account in the conduct of MIPs.
2. There is a need to narrow uncertainties in observed trends and variability in the amount of seasonal snow cover and for the development of realistic gridded values of historic precipitation. Multiple data sets are needed to establish uncertainties in Arctic precipitation; surface snow depth and precipitation observing points are needed.
3. An improved understanding of the impacts of the transition of the Arctic to a rain-dominated precipitation regime is needed; this requires a multidisciplinary research framework.
4. An improved understanding of the risk of abrupt cooling events in the Northwest Atlantic from a shutdown of the subpolar gyre is needed. There is an estimated 45% chance of a shutdown in the 21st century. There is a need to improve the quantification of the freshwater system.
5. Northern community needs for environmental information for decision making are not being met; special attention is needed to improve this information, also in close collaboration with each particular community.

There are initiatives under way for weather and climate model improvement as well as successful models for moving knowledge to action that can be implemented on a broader basis.

A comment to this presentation indicated the importance of linking biodiversity and ecosystem functions to community needs.

5.2 Research needs on climate-related effects on the Arctic cryosphere: marine systems

David Barber, University of Manitoba, Winnipeg, Canada, noted that motivating principles for research into the effects of changes in the Arctic cryosphere on marine systems include that the Arctic Ocean and its regional seas are now open for development. Furthermore, there is increasing evidence that the Arctic plays a role in lower latitude climate and weather processes. Teleconnections and high-frequency processes (e.g., storms) are poorly understood, and thus poorly modeled. Sea ice is a critical habitat for marine organisms to succeed. Changes in the Arctic are causing changes in predator-prey interactions, and we do not know what influence climate change will have on marine productivity, biomass or biodiversity. Ocean acidification is occurring but is still poorly understood and we do not know whether the Arctic Ocean will become an overall source or sink for carbon dioxide.

Sustainable solutions to these issues will require true northern engagement with science and policy and there is a growing recognition that international coordination is required to address these major issues at pertinent scales, both in time and space.

David Barber highlighted the need for research on the following topics:

- The double gyre pattern for movement of sea ice in the Arctic Ocean, which is based on atmospheric circulation, needs study; if there is a change in the gyre pattern, there will be a change in the atmospheric circulation.
- The various ice forms have not been studied adequately and this affects their interpretation in satellite images; for example, rotten ice shows up as multi-year ice in satellite images. Ice also changes from dark to light periods and this needs studying.
- There is a need to better understand freshwater coupling with the marine system; there is much more freshwater in the Arctic now and this affects physical and biogeochemical parts of the system. The coupling between fresh and marine waters is complex, and freshwater flows under the ice, changing conditions for marine organisms.
- There is a need to work with industry to develop better observing and measurement resources. In Canada, marine transportation corridors are developing through the Arctic but baselines and bathymetry maps do not exist for some of these areas. Environmental data from the coast guard, defense, regulatory agencies, Indigenous organizations and industry need to be merged to create a broader picture of these new corridors.
- Baselines for sea-ice habitats need to be established; the biological aspects of marine science in the Arctic are poorly known and there is no knowledge about bacteria in sea ice.
- It is important to apply emerging technologies to the development of autonomous systems for observations in the Arctic and sustained observing systems need to be established for long-term observations. This should include technology development and integrated data systems. Indigenous community monitoring programs are also important in this regard.

Economic development is now also driving much research in certain regions, such as in northern Canada.

In the discussion, it was considered that more research is needed on carbon processes and the connection between the marine and terrestrial environments as well as freshwater processes and their connection with sea ice. Another poorly understood topic is the coupling between the atmosphere and sea ice; their interactive processes are not understood well. Different views have also been expressed concerning the potential risk of the shutdown of the North Atlantic circulation; however, it was noted that there is a large amount of freshwater stored in the gyres in the Arctic Ocean. The Beaufort Gyre has been storing water for over ten years and a release could occur. Observations also indicate that the Atlantic meridional overturning circulation is slowing down.

5.3 Research needs on climate-related effects on the Arctic cryosphere: terrestrial systems

Vladimir Romanovsky, University of Alaska Fairbanks, noted that three key priorities from the International Arctic Science Committee (IASC) third International Conference on Arctic Research Planning (ICARP III) serve as a useful framework for the consideration of research needs. These key science priorities are: 1) the role of the Arctic in the global system; 2) observing and predicting future climate dynamics and ecosystem responses; and 3) understanding the vulnerability and resilience of Arctic environments and societies and supporting sustainable development.

Regarding the role of changes in the terrestrial cryosphere in a changing global system, these include a) changes in the snow amount, timing and distribution, which influence changes in global albedo, hydrology, vegetation, etc.; b) changes in the amount and distribution of land-based ice masses, which influence changes in global sea level, albedo, hydrology, etc.; and c) changes in permafrost and coastal erosion, which result in changes in the carbon cycle, hydrology, vegetation, etc. Although these changes may not seem so significant to scientists who are not involved in Arctic studies, in reality changes in snow amount, timing and distribution under a warmer climate affect the complex interplay and interrelation with changing air temperature, precipitation, wind, topography and micro-topography, vegetation, etc. Changes in the other terrestrial components of the cryosphere similarly affect the complex interplay with the various relevant systems. The major priority is to emphasize interactions among these systems. While many of these interactions and internal feedbacks are known, they are not adequately understood and often not included in the global or even the regional Earth System Models (ESMs). For this reason, recent ESMs do not produce good results in modeling snow, terrestrial ice masses, and permafrost. As an example, there is such a wide range of model results for permafrost extent that they are useless. Changes to the terrestrial cryosphere give feedbacks to the global climate, but there is a need to model them correctly to determine how important these feedbacks are.

With regard to observing and predicting future climate dynamics and ecosystem responses and understanding the vulnerability and resilience of Arctic environments and societies, there is an urgent necessity to make measurable progress in studying, understanding, and successfully modeling the internal interrelations and feedbacks in the terrestrial cryospheric components of the Arctic system. This needs to be done at relevant smaller scales, which requires very high resolution measurements and modeling. Furthermore, the variability of all components is so large that there may be different conditions only 50 m away. This requires a large amount of data and raises the question of how this variability should be expressed in our research and how knowledge of variability can be made useful.

It is also necessary to be able to provide scientifically sound projections of changes in these components into the future to enable the relevant stakeholders to plan all necessary measures that will ensure sustainable development of Arctic communities. The challenge in making progress in this direction is also associated with the high degree of spatial variability in the related natural processes and environmental characteristics of terrestrial cryospheric components.

Among the challenges is the need for permafrost science to become truly multidisciplinary and interdisciplinary. There is also a need to develop new, advanced observational methods that include both ground-based methods and remote sensing, as well as a combination of the two, to optimize the observational network and to upscale the point observations. A 30-m resolution is possible from Landsat images with some ground measurements for a list of ecotypes; this knowledge can be used to organize a measurement system and determine where to place measurement stations with the aid of an ecotype map. This strategy has been used in Alaska by which measurement stations in a specific area of the state were chosen according to ecotype, and various simple and inexpensive measurements were taken to determine how the different ecotypes respond to temperature changes. The area studied contains about 20 common ecotypes as well as a few uncommon ecotypes. The measurements covered approximately 90% of all ecotypes in that area. They showed that permafrost characteristics are similar for similar ecotypes; for example, tussock tundra permafrost is the same for upland and lowland areas. Moss cover is very important for the presence of permafrost. Thus, an ecotype map can be converted to a permafrost map. These measurements could also be used to upscale the point information; this has worked well for permafrost and it may also be possible for snow and other components. A description of the system used in Alaska can be found at www.permafrostwatch.org.

5.4 Discussion: Research needs on climate-related effects on the Arctic cryosphere

It was noted that for all cryospheric components, there is a question of how the Arctic affects the global system. There is a gap between looking at complexities on a regional level and in the broader climate models. This raised the question of how EU-PolarNet can start to bridge the gap between regional complexities and global issues.

It was pointed out that the U.S. Department of Energy is developing a model to handle this complexity for the terrestrial areas in Alaska. It is not a grid model, but a coarser scale model of watersheds. It is possible to do more if not limited by classical grids. The next phase of this work will broaden it from only Alaska to the circumpolar North and will work with other modeling and measurement communities in one to five years. This project covers many components and makes use of a number of other projects.

Regarding upscaling complexity for the Arctic marine areas, high-resolution general circulation models and regional models are being used, but some processes are not understood well enough to model and the system is changing very quickly making it even more difficult.

Furthermore, it was noted that it is very difficult to understand complex systems. We can look at some components and determine how they relate to other components; for example, in relating temperature to elevation and to radiation feedbacks, one can approach feedback by going from coarse resolution to high resolution. However, it was pointed out that the marine system is much too dynamic to obtain a high resolution and it is also changing very rapidly.

The question was raised as to whether there is a need to scale to the pan-Arctic level. There are audiences for different scales as well as many important questions at much smaller scales.

The NOAA model gives incorrect results for snow cover, but it is still being used in publications. A collaborative project should compare the different models and determine the most accurate for each cryosphere component. There is a need for commonly defined protocol to improve performance. As an example, the SnowPEX project was an intercomparison and validation of hemispheric and global satellite snow products.

6 Research needs on adaptation options for climate-related effects on the Arctic cryosphere

6.1 Summary of research needs from the AMAP conference

Larry Hinzman, University of Alaska Fairbanks, stated that he had requested a number of participants at the conference to provide input on this topic from the presentations and discussions at the sessions they had attended. He had received a great deal of input and expressed his appreciation to all who had contributed.

Larry Hinzman noted that Arctic human development (or Arctic social well-being) is defined across the domains of health and population, material well-being, education, cultural vitality, contact with nature, and self-determination, but we are lacking the systems and support for maintaining on a regular basis the data necessary to feed indicators within these identified domains. The obstacles primarily relate to data access, costs, and privacy issues.

There is a need to address methodological and knowledge gaps in evaluating adaptation actions over time and to obtain a better understanding of how adaptation actions may set up path dependencies by either facilitating or constraining future action. There is also a need to better understand the cumulative impacts of climate change, industrial development and societal change. Explanatory social science approaches to adaptation are needed that should include behavioral sciences and institutional and policy analysis. There is a knowledge gap in relation to interdisciplinary work that could better engage the social sciences in adaptation research, especially in relation to psychology, communication and decision sciences. However, making existing knowledge available in a form that can be used in the context of decision-making is at least as important as identifying research needs and filling scientific knowledge gaps.

There is a need for more research across scales and on engaging the changing economic opportunities associated with shipping and resource development, in addition to impacts on Indigenous practices. Furthermore, longitudinal studies are required to assess the effectiveness of adaptation actions and for international comparisons with other regions.

The scientific community working on climate change and adaptation issues should help to improve the education systems for northern populations so that they can better take charge of their adaptation strategies. The impacts of changes in the cryosphere on ecosystems and their living resources, particularly the traditional and country food sources, need further study. The role and effects of contaminants in local foods and the impacts of climate change on health also need greater investigation. There is a need to understand the role that climate warming plays in the release of contaminants and disease vectors in the environment, as well as the risk associated with the transmission of disease vectors from the environment to animals and ultimately to humans, and where climate warming will exacerbate these problems. Further research is needed on how risk communication on contaminants is practiced in Arctic countries and on appropriate methodologies for developing and deploying risk communication messages and evaluating the effectiveness of the communication strategies.

Specific to the Bering/Chukchi/Beaufort region is an identified need for innovation in the process of conducting scientific research that genuinely engages and partners with Indigenous communities in a way that substantively builds adaptive capacity to multiple stressors and achieves locally defined goals.

Multiple stressors are interacting in the Arctic today: rapid change (environment, climate, socio-economic conditions), the latter driven by industrial developments (extractive industries), tourism, migration, urbanization, new technologies, economic challenges and opportunities. Climate change may not be the main challenge, but it exacerbates existing challenges. Adaptation to these challenges is context-dependent and a social process, but it also involves all levels of management and decision-making.

The suite of Arctic indicators is seriously deficient in biological and economic indicators at scales from community to regional level. There is a need for indicators that integrate the effects of multiple stressors, i.e., integrative indices of stress on communities in Arctic regions. Integration can be across physical (climate), social and economic domains. There is a need for better metrics or indicators of cumulative impacts of change, with cumulative meaning over time and/or over climate change, industrial development and societal change.

In the discussion of this presentation, it was considered that the overarching issue with relation to adaptation is to determine what is needed to maintain everyday life and develop a good quality of life in the Arctic. Cultural adaptation and social adaptation are strongly linked and the preservation of culture is strongly linked with the preservation of life. A loss of culture leads to a loss of life. There is a need to develop models for sustainable communities in the Arctic.

6.2 Research needs on adaptation options for climate-related effects on the Arctic cryosphere: risks to food security and human health

James E. Berner, Alaska Native Tribal Health Consortium (ANTHC), Anchorage, Alaska, stated that climate-mediated environmental threats to human health comprise major threats to circumpolar communities (Figure 1). Increased transport of environmental contaminants to the Arctic, resulting in increased tissue levels of contaminants in Arctic wildlife, may increase their susceptibility to active infection with endemic or new pathogens. This, in turn, would likely result in mortality of these species and possibly increased risk of exposure of human consumers to zoonotic (animal-borne) diseases as well as increased levels of contaminants. Increased tissue levels of contaminants in subsistence species will decrease their immune response to endemic zoonotic diseases, such as Brucella and Toxoplasma. This immunosuppression may also affect humans.

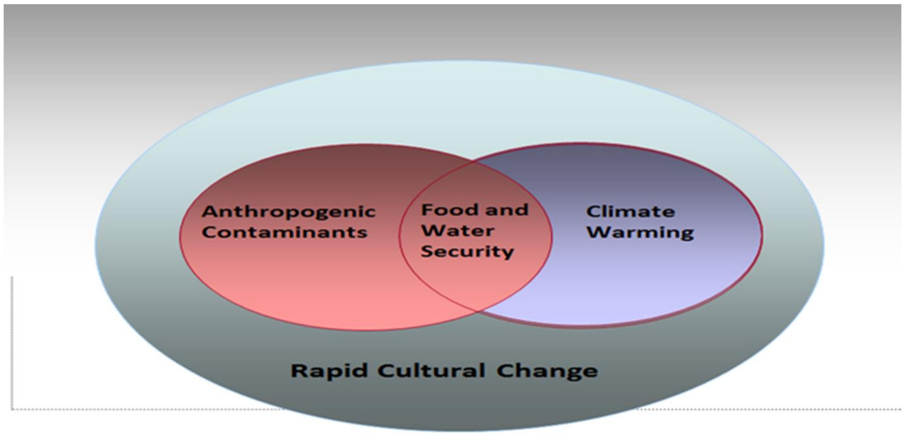

Figure 1. A confluence of changes affects rural Arctic communities.

The Arctic influences ocean circulation and north-flowing currents carry contaminants from more densely populated regions south of the Arctic, where marine organisms are also exposed to higher concentrations of contaminants. Concentrations of contaminants in Pacific salmon returning to Alaska are mirrored in their human consumers.

Local sources of contaminants also occur in the Arctic. This is particularly the case in Russia, where old drums that have contained PCBs are rusting and leaking contaminants into the soil and waterways. This results in very large concentrations of PCBs in walrus meat that has been treated by traditional methods of fermentation in a ground pit in Chukotka. Continued use of DDT also has an influence on soil sources of contamination.

Consumption of marine mammals from the Bering Sea is a source of contaminant exposure for Arctic residents, with concentrations of contaminants particularly high in ribbon seals. To determine levels of exposure to contaminants, two Alaska native biomonitoring programs (the Alaska Native Maternal Organics Monitoring (MOM) and the Rural Alaska Monitoring Program (RAMP) Study) and one village-based observer (the Local Environmental Observer (LEO)) program have been established to gather data in rural Alaska. All three are supported by the U.S. Environmental Protection Agency.

The MOM study is part of a circumpolar network of maternal monitoring programs and is sponsored by the Arctic Council. The objectives are to systematically collect and interpret information on contaminants, follow trends in exposure and provide data for risk reduction strategies. The detection of emerging threats is also important, as well as creation of a specimen bank for retrospective analyses.

The RAMP biomonitoring initiative enables communities to monitor contaminants in their own specimens. The residents operate the monitoring program and metrics are based on the assessment of environmental change by the individual village. RAMP focuses on food and water security in rural Alaska and uses a ‚One Healthô framework, which assumes that all parts of the ecosystem and environment are related and are affected by changes in any other part. This program started with monitoring antibodies in terrestrial and marine mammal blood collected by soaking filter paper in blood of hunter-killed animals to show exposure to zoonotic diseases, i.e., diseases that can infect both animals and humans. Blood levels of mercury, selenium and stable isotopes of carbon and nitrogen are now also being measured in these samples and organic contaminants will be tested in the future. There is a growing problem of harmful algal blooms (HABs) in the Arctic, so the program tests the stomach and intestinal contents of marine mammals for the HAB toxins saxitoxin (paralytic shellfish poisoning, PSP) and domoic acid (amnesic shellfish poisoning). Tests for these toxins are also performed in local freshwater sources, as thawing permafrost can release nitrogen and phosphorus into the water and stimulate HABs. With climate warming, beavers, muskrats and rabbits have moved farther north with the expansion of the tree line, carrying ticks and mosquitos that may host the bacteria that cause the tularemia infection. RAMP tests for these bacteria.

Five zoonotic diseases are increasingly prevalent in Arctic wildlife: toxoplasmosis (in about 50% of harbor seals); trichinosis (very common in polar bears and walrus); brucellosis (10ï 25% of caribou); tularemia (beaver, muskrat, snowshoe hare); and Q-fever (*Coxiella burnetti*) (75% of fur seals).

Shellfish, particularly clams and mussels, are a subsistence resource harvested from the beaches in Northwest Alaska; they have historically been free of PSP but they are vulnerable to changing ocean conditions. However, now algal toxins are prevalent on all coasts of Alaska and both saxitoxin and domoic acid have been detected in a wide range of species of marine mammals harvested or stranded on the coast.

The RAMP and LEO programs are being expanded in North America and beyond and will be useful for observing the spread of disease and contaminants and how that relates to climate change. Community biomonitoring allows for many more specimens to be analyzed, improved local risk-appraisal, correlation with climate and oceanographic data, collection of regional data on pathogen movement trends in a species disease exposure, detection of emerging infectious and contaminant threats, and the creation of specimen biobanks. The most immediate application of RAMP data is the creation of a community-specific adaptation plan, allowing residents to reduce exposure to the subset of vulnerable residents, including pregnant mothers, infants, the elderly, residents suffering from immunosuppression owing to chemotherapy or other reasons, and those with chronic diseases.

Research needs include:

- Continued monitoring of maternal contaminant exposure and long-term monitoring to detect health effects; this will be needed for the foreseeable future as contaminants continue to be distributed by riverine, oceanic and atmospheric transport;
- Continued testing of appropriate marine mammal matrices for HAB toxins. Saxitoxin forms in ice seals in the different parts of the Arctic should be investigated using high-performance liquid chromatography to determine whether the toxin is being formed by the same plankton species in all regions of the Arctic;
- Investigations of effects of HABs on marine mammal genes should be conducted.

6.3 Research needs on adaptation options for climate-related effects on the Arctic cryosphere: natural hazards

Katia Kontar, University of Alaska Fairbanks, stated that the Arctic is prone to many natural hazards that could result in natural disasters. Natural hazards are physical phenomena caused by rapid or slow onset events that could potentially cause a severe threat to humans and their welfare; autumn storms are a rapid onset hazard that increases erosion of the coast. Climate change is a slow onset hazard affecting many other hazards. A disaster is a disruptive and destructive event that results from a hazard, and overwhelms the affected communities and their ability to cope with the consequences.

Since the 1980s, the number and severity of disasters has been increasing, with the number of disasters more than doubling (Figure 2).

Climate change and natural hazards need to be considered together because currently they are the subject of two different multidisciplinary communities of research and practice. Climate change increases the magnitude and frequency of some natural hazards, including floods, erosion, permafrost thaw and slope instability. In Alaska, 86% of Alaska Native villages are affected by flooding and erosion, part of which is caused by rising temperatures.

The goal is to minimize the negative impacts of climate change and natural hazards. This can be done through mitigation, including structural measures on buildings and non-structural measures such as building codes; preparedness, including monitoring and warnings; and as a last resort relocation, which is very difficult and not satisfactory. An example of this is the need to relocate the village of Kivalina in Alaska, which is heavily affected by coastal erosion. Climate change and natural hazards are complex natural and social phenomena: human activities, such as emissions of greenhouse gases and building houses in vulnerable areas, are key causes behind the negative impacts of natural events and humans continue to suffer from these negative impacts.

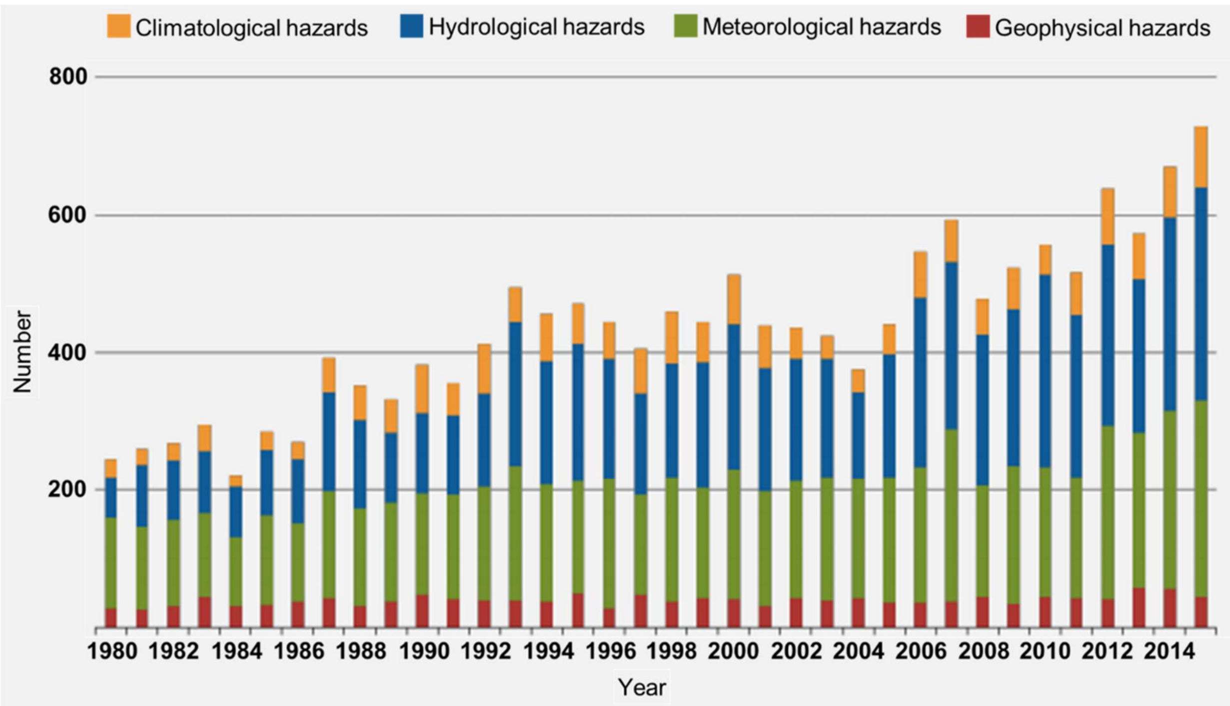

Figure 2. Disaster events, 1980ï 2015. The number of disasters caused by climatological and meteorological events has more than doubled since 1980. Source: Münchener Rückversicherungs-Gesellschaft (MünichRe), 2016. NatCatSERVICE: Loss events worldwide 1980ï 2015.)

There is a need for more interdisciplinary research to identify the most appropriate options to address each hazard; every hazard and every at-risk community should be addressed individually. There is a need to identify the natural and socio-economic drivers of each hazard to be able to identify solutions. Increased engagement of all stakeholders is also needed to identify the best solutions. The negative impacts of climate change and natural hazards can be lessened through holistic policy solutions. These policies should be based on assessments of both physical sciences and social sciences and applying interdisciplinary research and stakeholder collaboration.

6.4 Discussion: Research needs for adaptation options for climate-related effects on the Arctic cryosphere

In the discussion of this presentation, the difference between mitigation and preparedness was noted: community preparedness involves becoming aware and informed about the potential hazards, while mitigation involves long-term preparation for hazards. Estimates have shown that the cost of investments in mitigation and proactive measures amount to approximately 10% of the cost of a disaster if it occurs. For example, the cost of coastal erosion in Alaska is very high.

7 Panel discussion – Research needs for Arctic climate-related effects

In the overall discussion of issues raised at the workshop, a number of points were made regarding research and other needs in relation to studies of climate-related changes in the Arctic cryosphere:

- In AMAP, there is an emphasis on the importance of monitoring at the system level and across disciplines; however, there is a problem for agencies to make a commitment to fund long-term monitoring. There is a need to maintain the funding for long-term monitoring because scientists are trying to describe systems while these systems are changing owing to the changing stressors.
- It is important to develop and maintain networks. The International Polar Year created networks across disciplines, but these networks have not been maintained because they need funding.
- There are some global institutions that conduct monitoring, such as the WMO Global Climate Monitoring System; however, there is still a need for national monitoring of physical parameters. The aim should be that modeling and observations at the national level will fit into the international system.
- There is a mismatch between organizational structures and funding structures. An institutional analysis should be conducted to determine whether the underlying social structure helps or hinders utilizing scientific information and funding adaptation options.

Issues mentioned in relation to the application of scientific information by society and communities for the development of adaptation options include:

- The SWIPA2017 chapters each contain recommendations for scientific research on the various components of the cryosphere; however, these recommendations address narrow questions from the report. There is a mismatch between addressing narrow scientific questions and bringing them together in relation to social systems. It is also difficult to extrapolate from the complexity of the system to global impacts. Furthermore, the best means of bringing science into society is often not clear.
- Information on and understanding of the physical sciences is very important to climate-related adaptation measures. For example, for the village of Kivalina, Alaska to receive funding for relocation, they need to know that the place where they want to move will still be stable in 20 to 30 years.
- Natural sciences are distinctly different from social sciences; it would be useful to investigate how natural sciences and knowledge intersect with social sciences.

- There is science available that focuses on how the knowledge that our scientific research produces is actually applied and feeds back into the trajectory of the multiple systems (e.g., geophysical, ecological) that much research in the Arctic is focused on. Insights are provided by systems science, and by social and political science; and if we want to increase the societal relevance and uptake of Arctic research, we should consider this body of knowledge and engage with the relevant diverse communities (e.g., of knowledge holders, scientists, policy-makers, managers) at the outset when we formulate research questions and design research programs.
- Science is needed on how knowledge passes through social systems and feeds back to ecological science; how does science feedback to social science, policy, and other needs so that it gives a better understanding for funding? As an example, if a policy issue is to increase resilience, social science can ask how this should be done.
- In order to understand ecosystem services, and understand how we can manage for their continued provision including in an economic context, we need good understanding of the geophysical, ecological, and social systems involved and how they are coupled. Ecosystem services are provided for by nature, but valued by people, so in essence they are co-produced in social-ecological systems. This is not only relevant at the local scale but also at the sub-regional scale (e.g., national, AACA regions, LMEs) as the drivers, including environmental, governance arrangements, and influencing actors, are often different across these scales.
- In considering local adaptation actions, experience from scientific assessments is available but there is also a need for the involvement of representatives from industry, shipping, mining and local residents.
- There is a need to test ways and means that local communities can use to adapt to climate change, including both short-term and long-term changes, so that this information can be used to teach university students about adaptation to climate change. These results currently do not exist, so universities have no teaching materials on climate change adaptation solutions.

The issue of scale is important for both scientific understanding and adaptation actions:

- An issue regarding societal questions is the ability of societally posed questions to look at the scale of actions. When the issue of scale has been determined, decisions can be made on the level of the model to be used and on how information from other activities can be used. This process aids a thoughtful use of resources.
- There is a large need for knowledge regarding climate adaptation in the Arctic as well as on the global scale, given that the effects will be felt outside the Arctic region. Nonetheless, climate change may present opportunities within the Arctic region for communities struggling with economic capacity and limitations in the region.
- For the AACA assessment of the Baffin Bay/Davis Strait region, much work was conducted to describe and make models and projections, but the long-term downscale projections were not adequate. It was not possible to inform communities relying on hunting and fishing on what will happen several decades from now. There is a need to encourage small-scale industries in these communities. Research is needed to develop action plans for small-scale industrial development and extra knowledge is needed of the economy and how to develop

economic activities. There is need for a framework for helping communities to diversify their activities.

- Capacity building and policy-making are important at the local level as well as in broader regional areas. This should include the enhancement of education and training opportunities and job possibilities with good working conditions to develop these Arctic communities.
- The need for understanding ecosystem services is not only relevant in a local community context (e.g., small-scale subsistence hunting), but also in a much broader context, as ecosystem services are numerous and relevant across scales, including addressing their monitoring, governance and management needs.

The need for early inclusion of Indigenous people and use of Indigenous knowledge in scientific studies and the development of climate-adaptation actions in the Arctic received considerable discussion:

- In the Inuit community, people are considered part of the ecosystem and the cumulative impacts that are occurring. Communities have a sharing society and are all part of global interconnected systems. These communities have a great capacity and should receive greater empowerment; they have a great deal of experience with adaptation. They also have a need to receive scientific information on physical conditions and changes but owing to the way the scientific research is currently conducted, they are not receiving this information quickly enough. Indigenous people and communities need to be included more closely in scientific research. In the past, the typical way that small communities were included in multi-million dollar research projects was that the community received a 300-page research proposal several days before the deadline for its submission, meaning that there was no chance for the community to read and comment on it. There is a need to scale down from large scientific proposals to the people living in a small village who have long-term Indigenous knowledge of that area.
- However, scientists engaged in Arctic research are becoming better connected to local communities and there are more examples of new approaches to scientific research that bring in local knowledge and association with local communities.
- Indigenous knowledge is important; the first observation of regime change in the Bering Sea came from Indigenous studies of the contents of seal stomachs. Nonetheless, despite the importance of Indigenous knowledge, it cannot easily tackle new climate-related threats such as the changes affecting infrastructure in communities.
- Indigenous knowledge gained over many centuries should be captured now while it still exists so that we can understand and utilize this thousand-year-old knowledge.
- One problem is to bring together many different people to address the questions. Indigenous people are an important part of this. There is an urgency to include the people in the Arctic directly affected by the climate-related changes. The AMAP conference involved mainly scientists talking to scientists with very few Indigenous representatives or other stakeholders.
- Indigenous knowledge is very valuable, but owing to the major changes in the Arctic that will occur in future decades, a system should be developed so that Indigenous knowledge can be supplemented. However, most people do not understand Indigenous knowledge and how scientists and Indigenous knowledge-holders can work together. There is a scientific decision chain that involves many different types of people; there is need for developing priorities on

using different kinds of knowledge and understanding. This requires a framework for implementation.

General points discussed included:

- Humans are part of the ecosystem and cumulative effects are both economic and environmental. Estimating the economic cost of adaptation at both the Arctic scale and the global scale is very important.
- There need to be strong links to global connections, and global stakeholders should be considered; for example, quantitative data exist on global sea-level rise. Sea level is important and sea-level rise is already locked into the system, particularly after 2050. While temperatures in mid-latitudes may stabilize at about 2°C, in Alaska a temperature increase of 4 to 5°C is projected. These changes are off scale and will feed back into changes in atmospheric circulation that will have major effects globally. They imply very large needs for adaptation on a global scale, which will be very expensive. There is a need to connect the economic assessment of Arctic changes to the economic cost of the consequences.
- We should decide what the most critical areas are that we should focus on.
- In addition to the identification of research needs, there are needs for coordination of research. There are different types of research, and on the coordination side there are different levels and skills of coordination. We need to evaluate what we are doing well and what we are not doing well.
- Different countries face different situations. When one country develops solutions to climate adaptation, efforts should be made to try to utilize them in other countries. An example is the cooperation between Russia and Alaska on natural hazards.
- Although this is a workshop intended to obtain ideas for research needs from a wide variety of relevant Arctic stakeholders, most participants were from the scientific community. This is indicative of the problem of attracting other types of stakeholders to such workshops. For example, industry representatives have not attended these workshops, perhaps because they are not interested in the subject or do not have the time. There are so many different priorities and they are difficult to address. This raises the question of what type of instruments could be used to attract a wider audience of stakeholders.
- How to foster broader engagement is both a practical and a social research question; there is need for both analysis and practice and the need for a bridge between the community level and higher scales comes into play.
- Coordination is important, both to manage limited time and money as well as to manage different competencies and strengths. There is need for a forum in which transdisciplinary issues can be addressed for research needs.

8 Final remarks and closing of meeting

On behalf of EU-PolarNet, Nicole Biebow thanked the workshop participants for their insights on the many topics discussed.

She noted that we currently often work in single-discipline silos; we need to ensure that we have representation of people who can contribute to all of these topics. In its white paper process the EU-

PolarNet will move beyond this because the EU wants to include economic, societal, and technological issues all in one topic. Silos need to be broken down and technology needs to be considered also.

Nicole Biebow stated that the report that will be prepared based on this workshop will feed directly into the research development process and the white paper conference, which will develop recommendations on a much broader scale than that discussed at this workshop. The aim is to integrate physical and social sciences and to bring natural science and social science together with stakeholders to broaden the recommendations for research.

The Co-Chairs thanked the speakers and all the participants for their valuable insights and suggestions, and then closed the meeting.

AMAP/EU-PolarNet Stakeholder Workshop on Research Needs on Climate-related Effects on the Arctic Cryosphere and Adaptation Options

Reston, VA, 28 April 2017
Hyatt Regency Reston

Co-Chairs: Morten S. Olsen (Denmark), Jim Overland (USA)

Time	
8:30 ï 8:50	**Opening and welcome** *Lars-Otto Reiersen, AMAP Executive Secretary* **Context of the workshop: Research needs defined for EU-PolarNet work** *Nicole Biebow, AWI, Project Manager EU-PolarNet* **Aims and outcome of the workshop** *Janet Pawlak, AMAP Secretariat – Rapporteur*
8:50 ï 10:00	**Summary of research needs on climate-related effects on the Arctic cryosphere from the AMAP conference** *Ross Brown, Environment Canada* **Research needs on climate-related effects on the Arctic cryosphere: marine systems** *David Barber, University of Manitoba, Winnipeg* **Research needs on climate-related effects on the Arctic cryosphere: terrestrial systems** *Vladimir Romanovsky, University of Alaska Fairbanks* **Discussion**
10:00 – 10:30	Coffee Break
10:30 ï 11:40	**Summary of research needs on adaptation options for climate-related effects on the Arctic cryosphere from the AMAP conference** *Larry Hinzman, University of Alaska Fairbanks* **Research needs on adaptation options for climate-related effects on the Arctic cryosphere: risks to food security and human health** *Jim Berner, Alaska Native Tribal Health Consortium* **Research needs on adaptation options for climate-related effects on the Arctic cryosphere: natural hazards** *Katia Kontar, University of Alaska Fairbanks* **Discussion**
11:40 ï 12:30	**Panel discussion – Research needs for Arctic climate-related effects**
12:30 ï 12:45	**Final remarks and closing of meeting**

AMAP/EU-PolarNet Stakeholder Workshop on Research Needs on Climate-related Effects on the Arctic Cryosphere and Adaptation Options

Reston, VA, 28 April 2017

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