U.S. Senate Committee on Energy and Natural Resources
March 5, 2015 Hearing: Arctic Opportunities

Questions for the Record Submitted to Dr. Bitz
from Senator Maria Cantwell

Arctic Research

Question 1: What types of ocean observation data do we currently have access to in the Arctic? What types of data and analysis are needed to fully understand, map and communicate changes in sea ice in the Arctic?

Observing the Arctic environment requires a suite of measurements due to the interconnected nature of the system. Sea ice is highly responsive to changes in the ocean and atmosphere, while it also amplifies changes across all components. Hence, sea ice, ocean, and atmosphere need to be observed simultaneously to understand processes that control Arctic change.

Arctic observing systems need infrastructure in the Arctic to collect, store, and deliver data to users. Infrastructure and a skilled workforce are needed at research institutions to analyze and interpret the data, produce data products, and store the data.

The Arctic is observed by instruments on satellites and in the field (known as *in situ*). Satellite measurements offer a whole-Arctic perspective and are important for understanding the range of Arctic change and dynamical interactions that occur on the scale of many miles. Unfortunately few satellites are able to provide measurements of the Arctic Ocean owing to the presence of sea ice. Hence, *in situ* observations are necessary for nearly every variable in the ocean. At the same time many traditional *in situ* observing methods are difficult or impossible in the presence of sea ice (see Figure 1). While new methods are making remote observations easier, intensive field campaigns of the sea ice, ocean, and atmosphere are still key to understanding the local processes that cause climate change and to validating satellite measurements.

Satellite and *in situ* measurements are indispensable to developing Earth System Models and evaluating their behavior. In turn, such models deepen our understanding of the past and allow us to make projections of future change to improve decision-making about our future.

Sea ice is a composite of ice floes that are separated by open water. A sea ice covered region is described by the fraction of the area (or concentration) that is covered by ice floes. The sea ice concentration is observed through clouds and both day and night at present by two satellites: (i) the Special Sensor Microwave Imager (SSM/I) satellites from NASA and (ii) the Advanced Microwave Scanning Radiometer (AMSR-2) from the Japan Aerospace Exploration Agency. These same satellites also distinguish multiyear ice (floes that first grew over open water more than a year ago) from first-year ice. These data are among the most valuable in part because measurements are available since 1979, and thus provide the longest continuous record of sea ice in the whole-Arctic.

Sea ice thickness is a vitally important variable for prediction and monitoring sea ice change. Sea ice thickness strongly influences the sea ice conditions in summer, with unusually thin ice in spring leading to more open water in summer. Further, sea ice thickness anomalies tend to persist for a few months to a few years. Thickness is less well observed than concentration. A patchwork of *in situ* thickness measurements is available since the late 1950s from a range of methods, including submarines, buoys, and stake measurements made by hand. Satellites have been used to measure thickness in the last two decades. In orbit at present is CryoSat-2, operated the European Space Agency, with sea ice thickness measurements available about a month after the data are sent back to Earth. The accuracy of the measurements relies on the accuracy of snow depth measurements of the snow that lies on top of the sea ice, but measurements of snow depths are incomplete at this time. At present, a U.S. satellite that can measure sea ice thickness is planned for 2017. It will be NASA's second generation Ice Cloud and Land Elevation Satellite (ICESat2). In the meantime, NASA's IceBridge aircraft mission is making sea ice thickness and snow depth measurements on flight tracks for a few weeks in spring each year. These data are prized because of their accuracy, and they offer a rare survey of snow depths and sea ice thickness simultaneously.

The Gravity Recovery and Climate Experiment (GRACE) is a satellite operated by NASA that can be used to interpret changes in the mass of the ocean. It has been used successfully in the Arctic to aid in measuring seawater properties that vary with changes in ocean circulation and runoff from land.

Aside from GRACE, ice breaking ships and buoys have been the primary sources of ocean measurements in the Arctic. New technologies are permitting remotely operated or self-operated vehicles, such as sea gliders, to be programmed to make profiles under the sea ice and to pop up periodically in brief windows of open water to send data by satellite phone. These instruments can make measurements for weeks before returning to have their batteries refreshed. Sea gliders can measure temperature, salinity and seawater chemistry, thereby allowing measurements of conditions important for ecosystem studies as well as physical changes. Sensors attached to seals are another efficient means of measuring seawater properties in regions important to fish and seals.

<u>Question 2</u>: Understanding Arctic sea ice is important for a number of reasons, including safe transportation. What types of data and analysis does the United States need to have the capacity to deliver real-time information on ice cover, flow and thickness?

Producing sea ice forecasts is a promising new activity that research scientists and operational forecast centers have taken-on since 2008. Weather forecasting has about a four-decade lead on sea ice forecasting. In theory skilful sea ice forecasts are possible a few weeks to a few years in advance. At this time, a few basic quantities have been evaluated, such as whole-Arctic sea ice areal coverage, to provide a metric of Arctic-wide sea ice conditions. However, local quantities and higher-level properties would be more useful to forecast, in order to identify optimal shipping routes or warn coastal communities of impending danger. These quantities include sea ice thickness, orientation of openings between sea ice floes, amount of meltwater ponding on the surface, and where sea ice is broken and piled up.

Sea ice is very sensitive to atmospheric and oceanic conditions, so sea ice prediction systems must simultaneously forecast the ocean and atmosphere. Earth System Models are an appropriate tool. Prediction systems will likely need observational data assimilated in all physical components at once, and many ensemble members (possible instances to produce probabilistic information) will likely be needed. Software and computing resources do not yet exist to meet these needs.

Many of the same observations that are valuable for understanding and recording Arctic sea ice change also benefit sea ice prediction. However, generally finer spatial resolution of sea ice conditions and ocean heat content will permit better forecasts. Ocean heat content near the sea ice edge in summer is most important for predicting the sea ice during fall freeze-up. Further, observations need to be available rapidly and reliably. The infrastructures to gather data in the field need to include methods to collect and transmit the data to research institutions rapidly.

The greatest need at this time is for sea ice thickness with better accuracy than the CryoSat-2 satellite offers today. Further, if thickness measurements were available in a week, rather than a month, sea ice forecasts 2-4 weeks in advance would be possible, and this is the range when forecast skill is expected to be greatest. Further, data need to be available year round, so forecasts can be made year round.

The planned NASA ICESat2 mission should, in theory, produce more accurate measurements than those from the current CryoSat-2 satellite. However, the accuracy of snow depth estimates influences the accuracy of sea ice thickness data from satellite. At this time, no satellite produces satisfactory measurements of snow on all sea ice types. The current NASA IceBridge aircraft mission is giving the first accurate across Arctic view of snow depths on sea ice. However, the flight tracks are still limited to the North-American sector, about 1/4 of the Arctic Ocean, each year, and flights only take place for a few weeks in spring. The mission was conceived to provide ice thickness data that "bridge" the gap between ICESat and ICESat2. However, the sea ice thickness measured by ICESat2 will be more accurate with continued snow depth measurements from IceBridge. The IceBridge mission needs to be the IceSustained mission. Flights are needed over a larger region and for a longer period each spring. Continued sea ice thickness measurements from IceBridge also provide a valuable confirmation of satellite measurements.

Question 3: Ocean observation data is also used in weather forecasting and prediction, though we have significantly less Arctic data compared to other areas. How accurate are our weather forecasts in the Arctic? How is weather supposed to change over time in the Arctic?

The Arctic is one of the most sparsely observed parts of the globe for weather forecasting purposes. Weather balloons launch sites are sparse in the Arctic compared to in mid latitudes, and no weather radar exists anywhere north of 65N in North America. Buoys resting on the sea ice provide essential routine measurements of surface pressure and temperature, but only at the surface. Most other observations that inform weather forecasts are from satellites, and many weather satellites are geostationary (perched above the same point on the equator), with a poor view of the Arctic. Further, satellites observations of temperature and humidity structure of the atmosphere are made difficult by the very cloudy nature of the Arctic. Ships on Arctic research voyages often take special observations that are sometimes transmitted to the weather services. A study of the great Arctic cyclone in August 2012 proved that observations from even one ship considerably improved the prediction (Yamazaki et al, 2015). Dropsonde measurements from US scientists from US Coast Guard aircraft in the Beaufort Sea provide such measurements during the summer but only at intermittent intervals.

The consistent availability of sea surface temperatures and sea ice thickness is severely limited in the Arctic and the quality of those measurements is still in question. Yet studies show that both variables are important predictors of the atmosphere surface conditions. Sea surface temperature can be measured from satellite, but only where the ocean is free of sea ice. Conventional *in situ* measurements of sea surface temperature are rarely used when sea ice encroachment may be eminent (see Figure 1). Sea ice thickness in weather prediction systems is usually prescribed to be an average of previous years because thickness measurements are not available in time to make weather forecasts.

Weather in the Arctic is highly dependent on wind direction (Jung and Leutbecher, 2007). Projections from global climate models indicate that the storm track will shift northward, with a significant influence on the frequency and strength of high latitude storms, including the likelihood of extreme wind events in parts of the Arctic. The combination of an Arctic Ocean with more frequent open water and extreme winds is a serious issue for higher waves and coastal erosion. Arctic storms tend to be strongest in the fall, precisely when diminished sea ice has the greatest impact on the Arctic atmosphere. Greater open water coverage cause a warmer and moister atmosphere, which can strengthen storms and increase storm frequency. The Bering Sea Storm of November 2014 had the lowest surface pressure in the North Pacific for the past 45 years. This storm had an extreme drop in pressure once it entered the high northern latitudes, suggesting the local conditions were a major factor in deepening the storm.

Global warming is expected to increase precipitation in the Arctic. Local Arctic warming increases the likelihood that precipitation will fall as rain, increasing the frequency of freezing rain and rain on snow events, both of which inhibit transportation and injure wildlife.

References:

Jung, T. and M. Leutbecher (2007) Performance of the ECMWF forecasting system in the Arctic during winter, Quarterly Journal of the Royal Meteorological Society 133: 1327-1340.

Yamazaki, A., J. Inoue, K. Dethloff, M. Maturilli, and G. König-Langlo (2015) Impact of radiosonde observations on forecasting summertime Arctic cyclone formation. Journal of Geophysical Research, doi:10.1002/2014/JD022925.

Question 4: How does changing ice cover impact larger weather patterns, including patters impacting the lower 48 states?

Greater surface warming in the Arctic relative to the globe – known as Arctic amplification – decreases the pole to equator temperature differences over mid latitude regions, like the lower 48 states. The strength of winds in the jet stream derives from north-south temperature difference throughout the atmosphere, so Arctic amplification in a warming world may weaken the jet stream. However, a thinner and less extensive sea ice cover causes warming that is mostly surface trapped. Warming above the surface in the Arctic has been associated more with remote surface warming (Screen et al, 2012; Perlwitz, 2014). Some scientists have connected a warming Arctic with a slowing of the mid latitude jet stream and greater excursions in atmospheric waves (e.g., Francis and Vavrus, 2012). Arctic amplification is highest in fall and winter when storminess is normally the highest. The long-lived meteorological conditions observed across the lower 48 states in the last two winters, colder than normal in the east and warmer than normal in the west, resemble the proposed pattern.

However, there are many other factors that affect the jet stream and storm track besides the north-south temperature difference. For example, a consistent northward shift in the storm track is seen due to greenhouse warming, which should also shift the jet stream northward (Yin, 2005).

Researchers are vigorously analyzing observations and conducting modeling studies to investigate polar-mid latitude weather and climate linkages. We are limited by the shortage of observations in the Arctic, especially in the past. Nonetheless, there are wellestablished theoretical and observed impacts of the Arctic climate on the mid latitude atmosphere and ocean. The connection between Arctic warming and changes in the mid latitude is still debated (e.g., see Barnes and Screen, 2015).

A workshop was held in September 2013 by the National Academy of Sciences to review the current understanding of Arctic-mid latitude weather and climate linkages and made recommendations to move forward to close important knowledge gaps. A report is available at http://www.nap.edu/catalog/18727. A follow-on international workshop was held in December 2014 by the Polar Prediction Program and the Polar Climate Predictability Initiative. A series of documents about the workshop is available at http://www.polarprediction.net/linkages.html

References:

Barnes, E.A., and J.A. Screen, 2015: The impact of Arctic warming on the midlatitude jet-stream: Can it? Has it? Will it?, WIREs Clim Change, doi.10.1009/wcc.337.

Francis, J. A., and S. J. Vavrus, 2012: Evidence linking Arctic amplification to extreme weather in mid-latitudes. Geophys. Res. Lett., 39, L06801, doi:10.1029/2012GL051000.

Perlwitz, J., M. Hoerling and R. Dole, 2014: Arctic tropospheric warming :Causes and linkages to lower latitudes, Journal of Climate, 28, 2154-2167.

Screen, J.A., C. Deser, and I. Simmonds, 2012: Local and remote controls on observed Arctic warming. Geophys. Res. Lett., 39, L10709

Yin, H. J., 2005: A consistent poleward shift of the storm tracks in simulations of 21st century Climate. Gephysical Research Letters, 32, L18701: doi:10.1029/2005GL023684.

Question 5: Please describe how the University of Washington is using an interdisciplinary approach in their Arctic program. What has the University of Washington learned that could be applied on a national scale as the United States builds a more robust federal Arctic research program?

In 2013, nearly 100 scholars in three vibrant centers of polar study and across many parts of the University Washington combined forces to create the UW Future of Ice Initiative, to further leverage and cross-fertilize existing disciplinary and interdisciplinary strengths on polar studies. The goal of the initiative is to train a new generation of polar scholars and citizens and to invest in new research that answer scientifically and societally relevant questions demanding the integration of a broad range of disciplines, from physics to biology to people and policy. With unprecedented levels of interest in the changing Arctic region, the stakes are high for those who claim, protect, and use the region. The Future of Ice Initiative is our effort to apply our expertise collectively to these and related issues.

The UW has a long history of interdisciplinary research in the Arctic and Antarctic. For the past 45 years, the UW Quaternary Research Center has engaged in the study of polar glaciology, geomorphology, permafrost, climate change, ecosystem dynamics, and human-environmental interactions from the past to the present. For over 40 years, the UW Polar Science Center has maintained leadership in areas of Arctic and Antarctic coupled atmosphere-ocean-ice-ecosystem dynamics. For decades, the Canadian, Russian and East European, and European Studies Centers within the UW Jackson School for International Studies (JSIS) has focused on the social science, humanities, and policies of the Arctic regions and nations. Scholars in other corners of the University have been engaged in the study of Arctic law, public health, fisheries management, forestry, engineering and related subjects.

In a year and a half, the Future of Ice Initiative has made several significant steps towards achieving our goals. We founded the Arctic Minor—a program giving undergraduate students a broad background in Arctic social and natural sciences. A related pilot program for graduate students last year led to several published papers combining research in the natural and social sciences. We are hiring interdisciplinary-oriented faculty to strengthen the connections between disciplinary departments and expand university research teams' abilities to study such issues as the resilience of arctic ecosystems and people to climate change, resource extraction, and transportation. In those areas where we still lack local expertise, we are recruiting visitors though the Arctic Fulbright chairmanship (housed in the Canadian Studies Center and in its second year) and by hosting conferences and workshops that bring the national and international expertise to the UW campus to help us explore a broader range of issues (e.g., the Arctic Encounter policy and law symposium in January 2015; the Ecosystem Studies of Subarctic Seas conference in June 2015). Students educated in the undergraduate Arctic Minor and through our graduate programs will gain degrees and enter the workforce knowledgeable about and prepared to contribute their creative talents to polar issues, ensuring the best possible future for the polar regions and the most equitable and sustainable policies for those invested in the burgeoning opportunities and risks of the future.

Our collective experience working in and on issues of Arctic scholarship can be applied on a national scale, as the United States builds a more robust federal Arctic research program with regard to the following points:

- Understanding the interconnected Arctic system requires a focus on the inter-relations among physical, biological, and social processes. Programs with a narrow research scope or expertise lead to disciplinary research that is insufficient to address questions about the relationships among climate change, ecological responses, human use of the environment, and the social dynamics at scales from families to international economics and politics. Managing for sustainability and adaptation requires research that can cross traditional boundaries of disciplines, cultures, spatial and temporal scales.

- At UW we have been successful in reducing the barriers to collaboration and integration, in part because our scholars are free to pursue research beyond the bounds of specific disciplines or narrowly drawn mandates. Centers and initiatives that bridge disciplines are effective ways to bring scholars together with expertise to tackle complex problems.
- Because the Arctic is a remote and expensive place to work for the majority of researchers, it is critical to coordinate projects that make the most efficient use of resources by bringing interdisciplinary teams into the field to study different dimensions of the interconnected systems we seek to understand. By working together we can solve more complex problems, minimize the logistical and ecological footprint of our work, and reduce costs. By collaborating with research partners in Arctic communities we can gain access to year round data collection, tap into local expertise, and build mutually reinforcing relationships with northern residents, many with decades of local knowledge and some inheriting generations of traditional knowledge.
- We need to balance field and remote data collection. Some remote observations are now easier, and monitoring technologies such as bouys drifting on top of sea ice, animal borne instruments, remotely operated or self-operated ocean gliders and aircraft, are becoming increasingly viable sources for some kinds of information previously unimaginable (e.g., variability of clouds and sea ice over the Arctic Ocean, three-dimensional ocean temperature and chemistry profiles, life histories of fish, polar bear migration patterns, narwhal diving behaviors). Some of these approaches require large coordinated initiatives at the national and international levels (e.g., satellite based platforms). Others are being developed locally and at increasingly efficient costs (animal tags and ocean gliders).
- Indigenous communities in the Arctic have a long history of sustainable adaptation in the Arctic. Yet, the last 150 years have been hard on these communities as they have been displaced from traditional territories and subjected to exploitative practices and policies. Establishing more secure and healthy futures for these communities in the context of environmental change and the burgeoning pressures of industrial development requires a reversal of historical tendencies to ignore the input and insights of these communities. At UW, we are trying to move away from colonialist legacies of research in which Southern scientists parachute into the Arctic with research questions and methods that are of little interest to northerners. We strive to avoid seeing our research conclusions used in support of policies that actively undermine the sustainability of Arctic communities. Instead, we are embracing collaborative approaches and seeking to increase the numbers of Arctic

residents that we enroll at UW. By recognizing community voices, expertise, and sensitivities, we hope to be able to provide more balanced understandings of the challenges faced in the Arctic and offer possible solutions.

Question 6: How do you see research institutions, like the University of Washington, playing a role in the emerging Arctic? How can the United States best leverage research with the academic and private sector as we increase research focus on the Arctic?

A central role of Universities is in the emerging Arctic is to generate ideas, understanding, and technology that will enable government agencies, NGOs and the private sector to effectively protect and manage the increasing access to this region. University researchers are findings ways to predict the complex interactions of the environment and human activity.

One of the most effective ways universities can take a lead in Arctic research is to facilitate and coordinate inter-disciplinary and multi-institution collaborations (at state, national, and international scales). Universities can provide the intellectual and structural flexibility and leadership to connect and integrate studies that bridge disciplines, agencies, industries, and governments.

A close interaction of scientists with industries and government entities that depend on scientific information is important in the formulation of research questions that have socio-economic impact and to disseminate the results. Centers that can establish and guide dialogue with users need to be integrated with research programs. Universities can house these centers and provide scholars with diverse knowledge of the relevant physical, economic, social, and geopolitical issues to undertake this dialogue. In turn, users would be more aware of what researchers could offer and would be more apt to form partnerships to take on the significant challenges and opportunities in the Arctic.

Research in the Arctic is critical to tracking, understanding, and managing change in the Arctic. The training of researchers working in the polar regions has lagged behind other regions of the world. The federal government should invest in universities around the country to facilitate the training of the next generation of citizens and scholars who can tackle the important problems that are only now coming into focus.