A REPORT TO

Scientific and Community Stakeholders

BERING STRAIT ENVIRONMENTAL OBSERVATIONS

A SCIENTIFIC NEEDS ASSESSMENT

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Alaska Ocean Observing System

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Background

A large expansion of process-based marine research occurred in the Arctic during the past decade. This work included many new efforts in the North American Arctic gateway with significant research initiatives led by Japan, the Republic of Korea, China, Canada, as well as the countries on either side of the Bering Strait, the United States and Russia. Despite acceleration of these efforts during the International Polar Year of 2007-2008, the long-term continuous observation record in the Arctic is thin. Among researchers, there is widespread recognition that the existing observational network is insufficient to understand the impacts of climate change on the overall freshwater balance of the Arctic, altered biogeochemical cycles and how biological communities will respond to climate change. Without the ability to observe, it is not possible to understand or predict. Another uncertainty is how local communities in the region will adapt to, and mitigate, changes to traditional subsistence economies.

In the United States, these scientific observational needs led to the development of science initiatives such as the Study of Environmental Arctic Change (SEARCH) and the associated Arctic Observing Network (AON). These programs have developed plans and priorities for augmenting Arctic observations. Data products will constrain environmental changes and illuminate impacts on the Arctic System.

The expense and physical impossibility of monitoring the entire expanse of the Arctic Ocean forces a focus on critical points to leverage the value of the observations. Bering Strait is the single gateway that governs physical, chemical, and biological exchange between the Pacific-influenced Bering Sea and the Atlantic-influenced Arctic Ocean. Time series observations of the primarily northward flow through the strait sets one of the primary boundary conditions for the Arctic Ocean.

This report to the scientific community, to the people living in the Bering Strait region, and to other stakeholders is the culmination of a workshop process with international and multidisciplinary contributions. Our aim was to identify the critical observations needed in the Bering Strait region. The need for a coordinated and cohesive approach to environmental observations in Bering Strait facilitated a science planning process that included building scientific community consensus on an appropriate scope and scale of environmental observation efforts. The overall objective of the environmental observation system to be developed is to meet local needs in the Bering Strait region as well as provide supporting data for integration into global ocean observation efforts.

Introduction

Bering Strait is the Northern Hemisphere connection between the Pacific and Atlantic Oceans. When normalized to a salinity of 34.8, the volume of freshwater flowing through Bering Strait is at least equivalent to the combined direct river runoff from the four largest Eurasian rivers, the Yensiey, Lena, Ob, and the Pechora (Aagaard and Carmack 1989), and probably more (Woodgate and Aagaard. 2005). Clearly this 80 km-wide strait is a key point for monitoring physical, chemical, and biological processes of the Arctic Ocean. An observation record for the Pacific inflow offers that opportunity. The high nutrient content of the water, flowing predominantly northward through this shallow (50 m) strait results in biological productivities that are higher than any other Arctic seas, and seasonally rival any location in the world ocean (Sambrotto et al. 1984; Springer et al. 1996; Macdonald et al. 2004). This relatively low-salinity water also contributes to the formation and maintenance of the Arctic Ocean's cold halocline that separates the warm (>0°C) Atlantic Water in the deep Arctic Ocean from the freshened surface waters with seasonal and multiyear sea-ice (Bauch et al. 1995; Ekwurzel et al. 2001; Steele et al. 2004). Although salinities in the Bering Strait inflow exceed those of ambient Arctic Ocean surface waters, they are low compared to the Atlantic layer.

The study committee report on designing an AON (National Research Council, 2006) identified 17 variables and 13 indicator variables that should be measured across the Arctic Ocean basin. These critical parameters were selected to characterize both marine and terrestrial systems. Among these are salinity, ice cover, biomass, concentrations of carbon, dissolved oxygen and nutrients, land cover, biodiversity, contaminant concentrations, phenology, health, cultural diversity, education and economic indicators. Despite planning to collect a broad, comprehensive suite of biological, chemical, and physical observations along with cultural and economic data, it is clear that the sum of all international efforts will leave substantial observation gaps. Limited resources force prioritization of objectives. The biogeographical, hydrological and oceanographic importance of Bering Strait to Arctic and global ocean processes make it clear that special attention should be accorded to the Bering Strait region. The goal of the science planning process that led to this report was to gather expert scientific and local community opinion on the most effective mix of measurements that should be implemented in the Bering Strait region. This guidance was integrated with knowledge of the optimal mix of sensors and platforms that would address societal and scientific needs in the Bering Strait region in the context of the larger AON effort.

Workshop Structure and Information Gathering Process

Funding from the National Science Foundation, the National Oceanic and Atmospheric Administration and the Alaska Ocean Observing System made it possible to convene two workshops to discuss the design of an environmental observation system in the Bering Strait region. The first workshop was held at the University of Washington's Center for Sustainable Forestry (Pack Forest) in Eatonville, Washington, USA, near Mt. Rainier National Park on May 12-14, 2009 (see Appendix I for agenda). This meeting was structured to solicit expert scientific opinion on the scientific observational requirements in Bering Strait. Attendees included agency representatives, observational scientists, modelers who could specify data validation needs, specialists in ocean observation systems, local (Bering Strait region) community representatives, and experts on the exchange of water and biogeochemical cycling in the Bering Strait region (Appendix II). International participation was successfully sought from Russia, Sweden, Japan, Korea, and China. A number of early career scientists were also engaged in the workshop effort. Each participant was asked before the meeting to prepare a short written summary on environmental observation needs in the Bering Strait, taking into account their own disciplinary backgrounds and perceptions of the international needs for integrating observations in the Bering Strait region with pan-Arctic scientific needs. These 1-2 page summaries are available in this report as Appendix III.

The second workshop was held in Nome, Alaska, USA on January 25-26, 2010. It was hosted by the Northwest Campus of the University of Alaska Fairbanks. This workshop included representatives from five Bering Strait region villages: Shishmaref, Wales, Diomede, Gambell, and Savoonga (representatives of Brevig Mission were unable to participate because poor visibility prevented their air travel). A small number of scientists and agency representatives also attended (full attendee list is Appendix II) this second, more community-oriented workshop. The focus of this workshop was to identify the observations of primary importance to local residents of the Bering Strait region (agenda included in Appendix II). The intent was to integrate local community needs with scientific recommendations for observational infrastructure so that the developing observation system will serve both community and scientific needs.

Both workshops built on knowledge exchange between individual scientists and community representatives. Each presentation focused on the speaker's areas of expertise. Short panel summaries and breakout groups continued dialogs begun with the talks. Background information was provided on the state of technology in ocean observation instrumentation, as well as the current implementation of observation infrastructure in the Bering Strait region (Figure 1).

An important point of discussion during each workshop was the identification and prioritization of the variables that participants thought were most important to measure in the marine system. In the Eatonville workshop, participants also used available information to rate the readiness of specific sensor technologies in a challenging environment such as Bering Strait, using standard criteria that are being used in development of the Ocean Observatories Initiative (OOI; Table 1).

Table 1. Categorization of sensor technologies ocean observations. Adapted from a presentation by Mike Harrington at the Ocean Observatories Initiative Instrumentation Workshop I.

SENSOR CATEGORY	DESCRIPTION
1. Proof of Concept	Lowest Level, speculative (not currently deployed)
2. Research Prototype	Basic components integrated, prototype sensors used to collect data
3. Research Proven	Not commercialized but clearly beyond prototype, successful collection of data
4. Commercial	Proven to work in environment as expected, commercial production
5. Operational	In final form, proven to work under sustained operational conditions

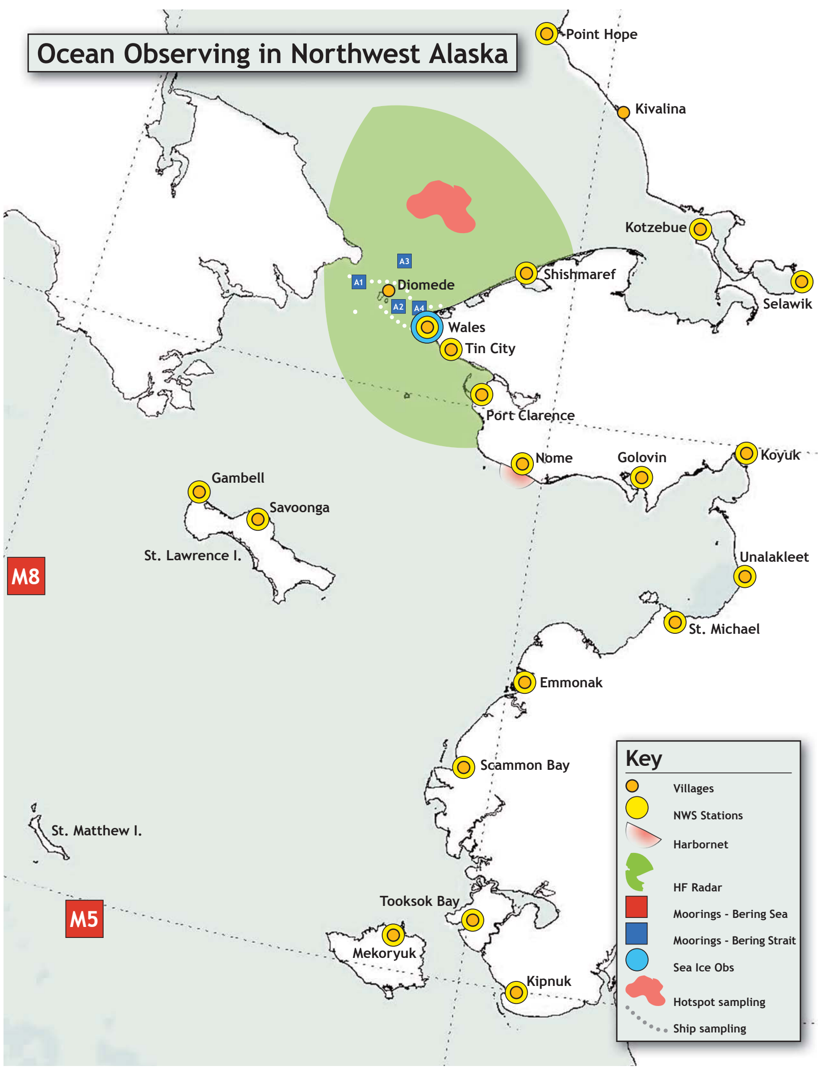

Figure 1. Current and plausible near-future ocean observing systems in Bering Strait region, as well as community locations. Graphics courtesy of Molly McCammon, Alaska Ocean Observing System.

A final consideration in the prioritization discussions was to rate the practicalities of several categories of observation platforms for each of the important measurement parameters. Specifically, potential sensor platforms that were considered included cabled systems, shipboard sampling, moorings, coastal observatories, community-based observations, satellite-based remote sensing, and autonomous underwater vehicles and gliders. Examples of these potential observation platforms as they are deployed or might be deployed in the Bering Strait region are discussed briefly below to provide some additional information on the basis for the workshop discussions. (Community-based observations are treated as a separate section to follow).

Cabled Seafloor Observatory. For workshop discussions, this platform was defined as a series of instruments connected by cable to shore providing real-time data collection of undersea conditions. As currently envisioned, instrumentation would include a range of physical and geophysical sensors, including current speeds, salinity, temperature, benthic imagery, acoustics, seismic activity and almost any parameter that can be electronically measured. Compared to moored instrumentation arrays, cabled sensors are less restricted by power and data rate limitations. Cabled sensors also enable continuous real-time data recovery. Disadvantages are initial high capital costs and possible hardware vulnerabilities from ice gouging of the buried seafloor cable. The likely eventual degradation of sensor performance due to biofouling and the need for maintenance of sensors are additional concerns. There are no cabled observatories currently operating in the Arctic, but demonstration systems are being deployed in several locations including Monterey Bay (http://www.mbari.org/mars/) and in the northeast Pacific (http://www.interactiveoceans.washington.edu). Initial workshops have also been convened to explore the feasibility of a cable observatory based in Barrow that would address scientific question relevant to environmental observations in the North American Arctic (Chayes et al. 2005, 2006). Proposals to develop fiber optic infrastructure within Alaskan waters (e.g. Figure 2) will reduce initial capital costs.

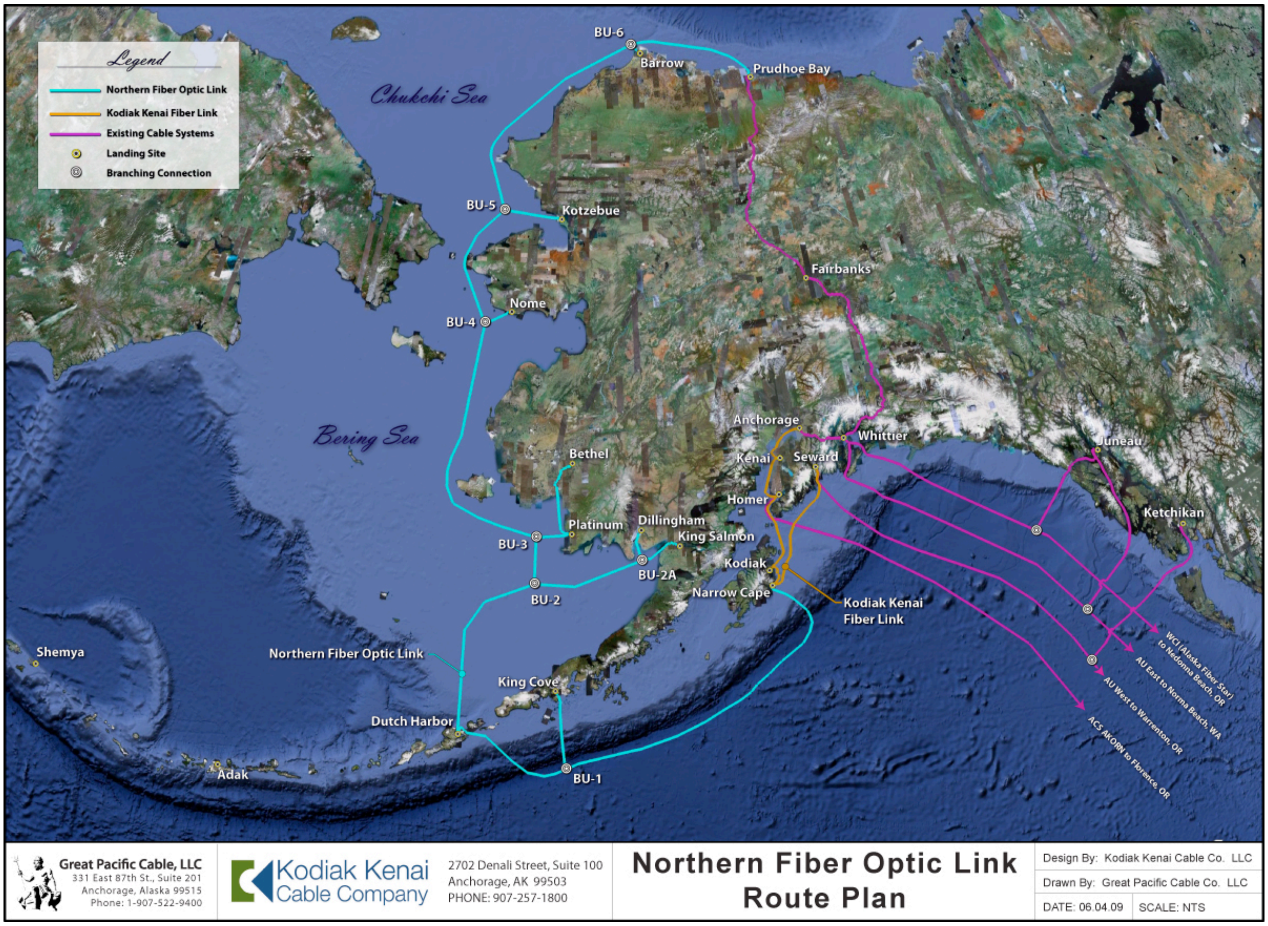

Figure 2. Proposed fiber optic link for northern Alaska that could be adapted to support a cabled observatory in northern Alaska. Graphics courtesy of Kodiak-Kenai Cable Company.

Shipboard Sampling and Distributed Biological Observatories. While shipboard sampling does not necessarily introduce any new observational technology, repeated shipboard sampling of specific locations (Figure 3) has been advanced as a mechanism to develop distributed biological observatories in the North American Arctic. This planned sampling by an international array of ships passing through Bering Strait and coordinated by the Pacific Arctic Group would provide biological time series data that cannot be obtained by other means (Grebmeier et al. 2010; see also http://soa.arcus.org/side-meetings/distributed-biological-observatory). Successful implementation of this ship-based sampling concept also was supported for modeling efforts (e.g. see Jin workshop abstract), for integration with remotely sensed observations (see Smagin workshop abstract), and for better understanding of water mass variation (see Zhao abstract).

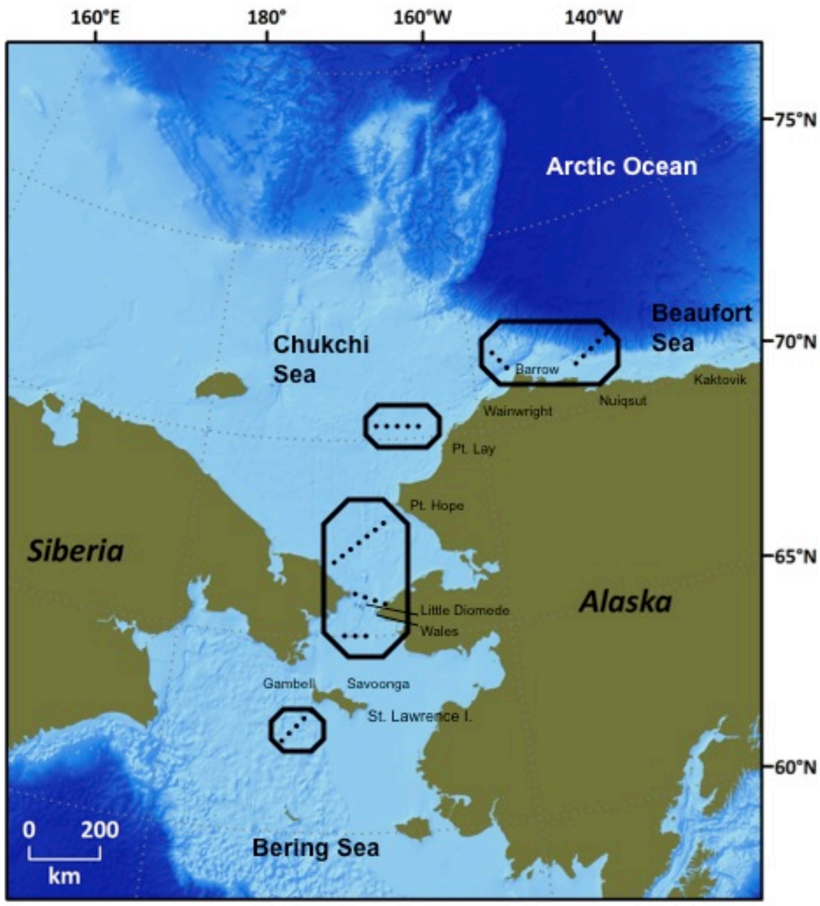

Figure 3. Proposed transect lines proposed to be occupied by ships transiting Bering Strait, including research vessels of Canada, China, Korea, the United States and Russia.

Moored observatories. Moorings are defined as arrays of instruments anchored to the seafloor. Oceanographic sensors that provide salinity, temperature, ice thickness, and current speed are more reliable than more recent developing technology to measure bio-geochemical parameters such as nutrients. Overall, moorings are a mature, robust observational technology employed throughout the World Ocean, including within Bering Strait (example shown in Figure 4). Data collected from the Bering Strait moorings that

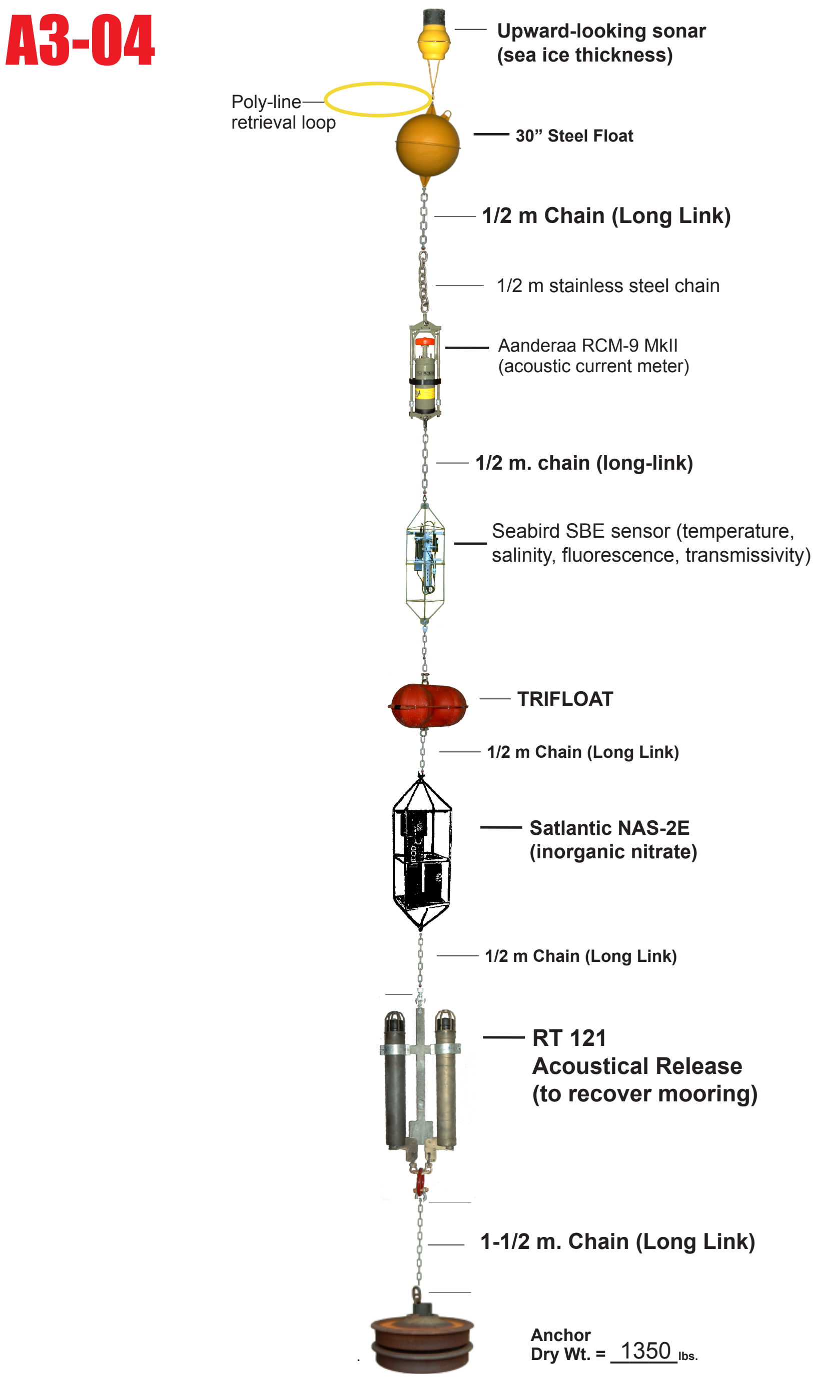

Figure 4. Arrangement of typical mooring deployed in Bering Strait to measure salinity, temperature, transmissivity, fluorescence, ice thickness, and nitrate. For additional information, see http://psc.apl.washington.edu/HLD/Bstrait/bstrait.html

have been continuously recording data for a period approaching two decades have been used in a number of physical oceanographic studies (e.g., Roach et al. 1995, Woodgate et al. 2005a, b, 2006, 2010; Aagaard et al. 2006). More recent innovations in the Arctic have included acoustical sensor systems for detecting marine mammals (see Moore workshop abstract) and profiling systems that can provide vertical water column data, which are needed to achieve more accurate estimates of freshwater fluxes through Bering Strait and for use in modeling exercises (see workshop abstract by Maslowski and Kinney). Ice coverage ultimately limits how close to the surface moored observations can be made and has an impact on capabilities to estimate freshwater flow and heat fluxes (see workshop abstract by Woodgate et al.) The workshop abstract by Woodgate et al. also discusses possible future strategies that would integrate satellite-based observations, including altimetry, and overall wind fields with analysis of the optimal position and number of moorings that should be ultimately required.

Coastal observatories. Coastal observatories are shore-based installations that support sample and data collections from adjacent coastal waters. Marine biological laboratories with seawater intake systems are the closest comparable institutions, but there are very few coastal observatories in polar regions and none in any ice-covered seas in the United States. If such facilities were available in the Bering Strait region, a wide variety of biological and chemical sampling that cannot be easily collected from other platforms except ships would be feasible on a more continuous basis. This sampling might include such observations as phytoplankton and zooplankton species or chemical tracers that require large volumes of water or post-collection processing. Pilot-scale water sampling from Little Diomede Island in Bering Strait has demonstrated that the concept of pumping large or perishable water samples onshore for sampling is feasible (Cooper et al. 2006; see also Figure 5). Radar observation systems for sea ice and automatic identification systems for vessels transiting Bering Strait are additional useful observation technologies that should be incorporated into any developing coastal observatory in this region. Coastal observatories also have been viewed as important components of the AON to assess permafrost degradation and related arctic coastal dynamics,

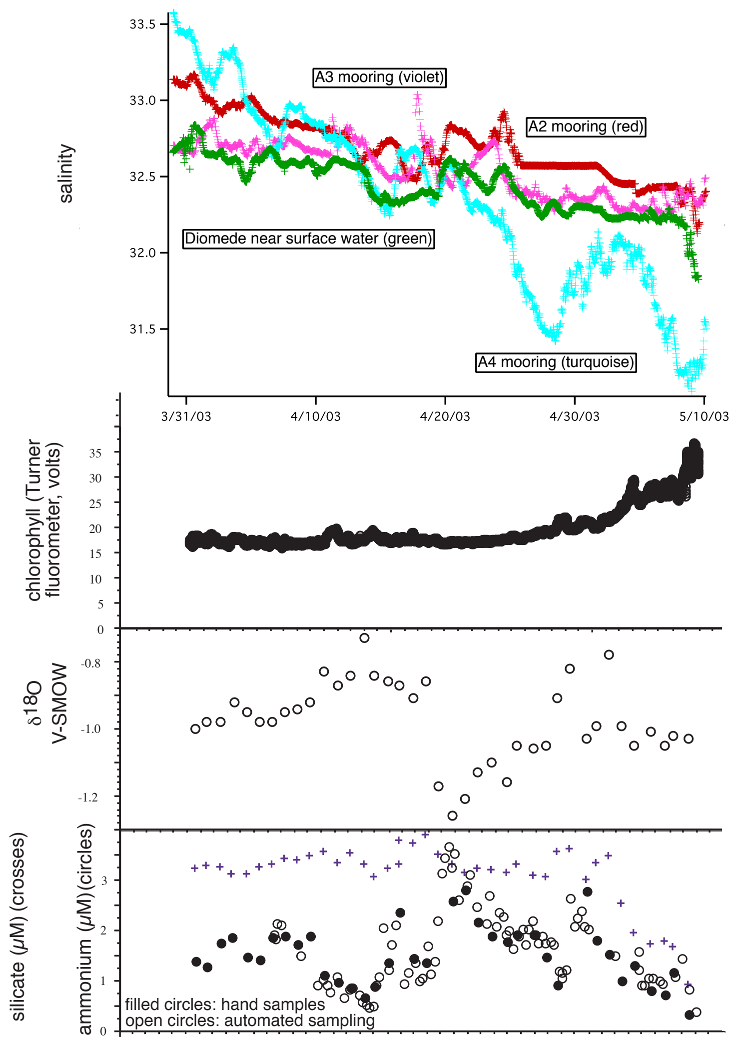

Figure 5, top panel. Comparison of salinities measured in Bering Strait region, April-May 2003 from Bering Strait moorings A2, A3, A4 simultaneously with pumped water collections made at Diomede (green data points) from 4 m depth. Mooring data courtesy of Rebecca Woodgate, University of Washington. Diomede data from Cooper et al. (2006). Figure 5, Lower three panels: Selected other data that were possible to collect simultaneously at Diomede, specifically in-situ chlorophyll, $\delta^{18}O$, silicate and ammonium, phosphate and nitrate + nitrite (data not shown) also declined to low levels by early May. The relatively small variation in the stable oxygen isotope composition of the water sampled was interpreted to indicate that the change in salinity was largely driven by melted sea ice rather than a water mass change, simultaneously with nutrient consumption during the early spring bloom (Cooper et al. 2006) led by the International Permafrost Association (http://ipa.arcticportal.org/). Nevertheless optimal study locations for permafrost and coastal dynamics do not necessarily coincide with ideal locations for water sampling from land-based infrastructure. Efforts to incorporate a seawater sampling system into the Barrow Arctic Research Center infrastructure and/or any cabled observatory to be developed in Barrow also have not been initially successful. Simply for equivalency, an important goal for the AON should be to improve coastal and near-shore research infrastructure so that the networks that are developing as data resources in terrestrial and freshwater systems (e.g., the Circumarctic Environmental Observatories Network; http://www.ceon.utep.edu) will also develop organically to support coastal research, whether specifically in Bering Strait, or more generally in the Arctic.

Remote Sensing for a Bering Strait Observatory: Satellite remote sensing offers an opportunity to extend the *in situ* observations from within or near the strait to the surrounding region while placing them in a broader context. An observatory database and web site would benefit from near-real-time updates from satellite sensors so that local users and scientists alike could obtain the most up-to-date information about the surface conditions in the region. While the surface is often obscured by clouds there are also frequent breaks in the clouds that permit piecing together a mosaic of the surface over time. This is helped by the fact that polar orbiting satellites offer frequent views of the polar regions. Useful remote sensing data include: AVHRR visible and thermal images (1 to 4 km), MODIS visible and thermal images (0.25 to 1 km, Figure 6), SSMI sea ice concentration (25 km), AMSR-E sea ice concentration (6.25 km), and MODIS SST (4 km, 8 day^{-1}). Additional derived products that could be produced regularly include the sea ice motion from AMSR_E brightness temperatures, the normalized difference vegetation index (NDVI) over land from MODIS (0.5 to 1 km), and sea surface chlorophyll-a concentration from ocean color measurements by SeaWiFS or MODIS (4 km, 8 day^{-1}). Ideally the Observatory database would have easy access to near-real-time regional subsets of the data for each of the selected sensors and products. Frey, Hong and Ahn, and Smagin (workshop abstracts, Appendix III) provide some other details on how satellite remote sensing products are being used, or could be used to assess recent changes in Bering and

Chukchi Sea ice coverage and biological productivity.

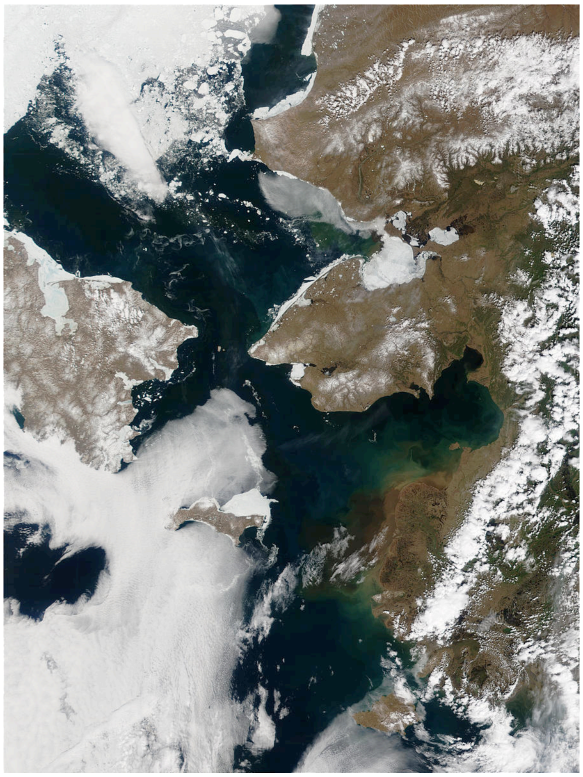

Figure 6. MODIS image of the Bering Strait region taken on 4 June 2002 showing the strait, pack ice, fast ice, clouds, and snow on the mountains (MODIS Rapid Response System, http://rapidfire.sci.gsfc.nasa.gov/gallery).

Autonomous underwater vehicles and gliders Autonomous underwater vehicles are a relatively new class of technologically advanced platforms that are being used in many marine systems, including the Arctic (Curtin et al. 1993, Bellingham and Rajan, 2007). These devices have been developed for long endurance (months) autonomous deployments to depths as great as 1000 m under low power consumption. Over time and at relatively slow speeds (< 1 m s^{-1}) these vehicles can make large scale synoptic physical measurements, and transfer data as needed via satellite or following shipboard or land-based recovery. At the Eatonville workshop, there was some skepticism expressed whether these instrument packages were practical for use in the Bering Strait region due to high currents, but clearly technology development should be monitored for possible incorporation into Bering Strait observatory networks.

Consensus Observation Recommendations

A major element in each workshop was an interactive discussion leading to development of a list of priorities for environmental observations in the Bering Strait region (Table 2). Observations were rated as being critical (A), secondary (B), or less important (C). Following prioritization, on a scale of 1-to-5, and using standard Ocean Observatories readiness criteria (Table 1), the capabilities for each potential platform (ship-based sampling, mooring, etc.) were rated. Some differences in terminology should be noted; for instance, Eatonville workshop participants considered trace elements and tracers to include contaminants, but participants in Nome treated contaminants as a separate category with particular interest in the connections to human health regarding subsistence food consumption. In a similar manner, while participants in Eatonville acknowledged the importance of human health issues, there was a consensus that human health was probably beyond the scope of what the workshop report could be reasonably be expected to recommend to the funding agencies supporting the science planning effort. One obvious concern is that the choice of measurements is heavily weighted toward the critical (A) category. One critique evaluating this prioritization states,

> “Just as some legislators never saw a tax they don't like, so scientists rarely see an observation/measurement they don't like! Resources ($) are limited, so the scientific community needs to make difficult decisions and improve prioritization, or the agencies will do it and not always to the satisfaction of the scientific community.”

In defense of the process, however, the discussions that led to this prioritization were highly interdisciplinary and assumed that a broad range of biological, chemical and physical measurements should be made. For instance, the appended abstract by Codispoti argues that the technology for more automated measurement of dissolved nitrogen species has improved and these measurements fulfill a critical need because the adjacent Arctic shelves are important in the global nitrogen cycle through their affect on denitrification. Anderson, in his workshop abstract, also details some of the important scientific questions that could be addressed with a better understanding of how nutrients are affected as bottom waters interact with the sediments. These questions, such as what proportion of the organic matter is mineralized by microbial activity, what is recycled from the sediments, what proportion of that contributes to new production, and how production of high nutrient water at the salinity of the upper halocline can be geographically partitioned implies a much more ambitious observation network than currently exists or is envisioned to exist in the near-term. For these reasons, it should be acknowledged that the limited financial resources for Arctic observations challenge our ambitions, but perceptions of the value of ocean observations could shift in the future in unexpected ways. For example, the millions of people who have watched the live underwater video feed (http://www.nytimes.com/2010/05/27/us/27spillcam.html) of the 2010 Gulf of Mexico oil spill via the internet suggests that as ocean observations become more operational unanticipated audiences may develop. A parallel phenomenon was the unlikely development of a 24-hour weather network as weather observations and instant communication capabilities both improved, chronicled in Frank Batten's 2002 book "The Weather Channel: The Improbable Rise of a Media Phenomenon" (Harvard Business School Press).

One related complexity is that the suite of critical measurements are at different states of readiness for ocean observations. Some observations, such as salinity and temperature determinations are robust and have been undertaken for a number of years, while others such as observations of variation in phytoplankton and zooplankton populations are much less automated and have only been attempted sporadically. Long-term changes in biological communities can have momentous consequences for ecosystem structure, fisheries, subsistence, and ecological services. On the other hand, small, but significant and measurable changes in salinity and temperature will not necessarily have an impact on ecological systems, even if all biological change is ultimately linked to physical changes. So despite the accuracy, resolution, and volume of data that are available from physical measurements, workshop participants recognized that it is appropriate to consider physical, chemical, and biological observations as having differing development trajectories. Some observation technologies are mature and robust, but it does not make them any more critical for Bering Strait specifically or for the Arctic in general. In response to the critique that too many variables were deemed critical, several principles can be articulated in response:

1. To support our objectives, a more diverse set of observations is required in the Bering Strait region. Many of the observation activities that are currently operational predate the SEARCH and AON programs, so expanding observational capabilities remains an unmet goal.

2. Marine observations that are limited to electronic signals that document physical processes are insufficient to document the scope of the changing Bering Strait ecosystem and the impacts on the greater Arctic system.

3. Measurements that are routine to acquire should be routinely supported. One mechanism to support routine measurements would be to provide for transition support to agencies that have a monitoring mandate. Any successful transition would expand the funds available to support other needed ocean observations that are less well developed.

Table 2. Consensus recommendations for observation priorities. A=Must measure; B=Secondary priority; C=Less important. These ratings were generated independently at each workshop. Numbers for each observation platform category correspond to the measurement capabilities of the specific platform, given available technology for the particular measurement, rated on a scale of 0-5, and specifically using the Ocean Observations technology criteria provided in Table 1 (Zero or no rating means that the measurement cannot be obtained from the observational platform). These numerical ratings were generated at the first workshop at Eatonville. *Measurement not considered at first workshop in Eatonville, but proposed by participants at Nome meeting. †Rating of 5 for selected applications. ‡ See Iverson abstract for more information about the Ocean Tracking Network (ITN)

Priority Workshop Eatonville (left)	Workshop Nome (right)	Measurement	Cabled observatory	Shipboard sampling (1-2 yr^{-1})	Mooring (recovery 1-2 yr^{-1})	Flowing seawater (daily to continuous)	Community-based observations	Satellite remote sensing	Autonomous underwater vehicles and gliders
A	C	Salinity	5	5	5	5	5		4
A	A	Temperature	5	5	5	5	5	5	4
A	A	Water velocity	5	5	5	0			4
A	A	Meteorology (weather)	0	5	0	0	5	4	
A	?	Nitrate + nitrite	4	5	4	4	4		
B	?	Phosphate	3	5	3	4	3		5
B	?	Silicate	3	5	3	4	3		0
A	?	Ammonium	3	5	3	4	3	3	0
B	A	pCO_2/pH	4	5	4	4	4		
C	?	Trace elements	0	5	3	2	0		0
B		Dissolved oxygen	4	5	4	2	0		0
C	A	Contaminants & tracers	0	5	5†	5	5		4
*	A	Human health					5		
A	A	Species inventories	1	5	0	5	4	2	1
A	A	Ice coverage	0	4	3	0	4	5	3
A	A	Ice thickness	5	2	5	0		2	

B	B	Turbidity	5	5	5	3	0	4	
A	C	Chlorophyll fluorescence	5	5	5	5	2	4	
A	C	Productivity (sensors) based)	1?	5	3	3	0	3	4
A	B	Benthic communities biomass biomass production species includes use of video	3	5	0	3	1	0	
AB	B	Phytoplankton species (includes ice and water)	0	5	5	5	5	2	
A	B/ B+	Zooplankton abundance/ species	0	5	5	5	5	2	
A	A	Mammal observations (visual)	0	5	0	0	5		
A	A	Mammal tissues	0	0	0	0	5	0	5
A	A	Mammal acoustics	5	5	5	0	5		0
A	A	Fish distribution (OTN) ‡	5	0	5	0	0		0
A	A	Fish abundance diversity	2	5	0	0	5		
*	A	Plastics/ debris							
*	A	Trash disposal							
A	A	Seabirds	0	4	0	0	5	0	0
A	A	Ship traffic					4		

Balanced Observation Platform Deployments

Another insight that developed from workshop discussions that prioritized variables that need to be observed in the Bering Strait region was the recognition that no one observation platform, (e.g. moorings, community observations, satellite imagery, etc.) met all observation needs effectively. For example, shipboard work is expensive and occasional and limited seasonally, but it is unequalled for evaluation of long-term biological community changes that require water or sediment sampling. At the same time, new technologies such as are being implemented by the Ocean Tracking Network (see abstract by Sara Iverson and http://oceantrackingnetwork.org/) promise improvements in following biological migrations, and the potential for community-based observations should also not be underestimated. Nevertheless, for the foreseeable future, "old-school" sampling such as can be accomplished from ships must be considered a necessary component of a broader, well-integrated Bering Strait observation system. The initiative of the Pacific Arctic Group, a working entity of the International Arctic Science Committee (see abstract by Jackie Grebmeier; Grebmeier et al. 2010) to help coordinate sampling locations and sampling strategies for biological communities is one mechanism to bring international ship-based resources forward to help satisfy those needs.

Although the workshop efforts were primarily directed towards improving observations in the Bering Strait region from a marine perspective, it was widely recognized that there are linkages between marine observations, local community observations and land-based climate and hydrological observations. The abstract by Cherry appended to this workshop report describes the efforts of a nascent Bering Strait Research Consortium (http://www.beringstraitresearch.org) that aspires to integrate hydrological and climatic observations on the Seward Peninsula with observations being made in the marine system.

International Challenges

Several workshop participants pointed out in their one page abstracts (e.g. Anderson, Maslowski and Kinney, Springer) that the international boundary between the United

States and Russia complicates obtaining coordinated observations across the region. The support by US agencies, particularly NOAA through the RUSALCA program (http://www.arctic.noaa.gov/aro/russian-american/), for the Bering Strait mooring system has resulted in development of much better coordinated observations in Bering Strait. It is hoped that the participation of Russian investigators in RUSALCA can serve as a model for future efforts. A longer-term goal therefore should be to expand routine deployment and servicing operations achieved in recent years for moorings in Bering Strait to observations that would be more effectively achieved from other platforms.

The challenges of obtaining permission to sample from ships in the Russian sector of the Bering Strait is not a new problem. It was explored in a joint US - Russian workshop supported by the US NSF and the Russian Foundation for Basic Research in 2005. Then, the needs for higher-level agreements between US and Russian authorities were recognized as necessary to improve scientific research opportunities within the Russian sector of the Bering Strait. These needs remain even as ambitious plans are put into place by East Asian nations such as China and Korea to expand their Arctic field research programs.

The Pacific Arctic Group, which includes membership from China, Japan, Korea, Canada, Russia and the USA, was organized under the auspices of the International Arctic Science Committee to provide a forum for coordinating international research activities in the Pacific sector of the Arctic Ocean. In particular at the Eatonville workshop, where international representation was sought to provide guidance on Bering Strait regional observations, the workshop participants agreed that international support for improved environmental observations in the Bering Strait seems well established. The ten PAG research themes for example (http://pag.arcticportal.org) coincide well with the specific needs and priorities identified during the workshops:

•Theme 1: Undertake seasonal and interannual ocean observations in the Pacific Arctic Sector where recent maximum sea ice retreat is occurring

•Theme 2: Understanding oceanic and atmospheric processes in the Pacific Arctic, including the feedback loops, are critical to mid-latitude climate variability.

•Theme 3: Monitoring fresh water input via precipitation, riverine input, oceanic input, glacial and sea ice melt in the Pacific Arctic sector will improve our understanding of mid-latitude climate variability and provide additional information to support theme 1.

•Theme 4: Identify and monitor ecosystem and biological indicators (ice, water column, benthic, higher trophic organisms) of climate change in the Pacific Arctic.

•Theme 5: Investigate sea ice thermodynamics including sea ice thickness, extent, and its interactions with ocean and atmospheric forcing in the Pacific Arctic region. Investigate sea ice dynamics such as sea ice drift, interactions between different ice packs.

•Theme 6: Understanding the connectivity of warm Atlantic inflow to the Pacific sector, heat flux throughout Arctic, and associated biodiversity/invasion of Atlantic-species into the region. Physical gateways should be mapped and monitored, including outflow through the Canadian Arctic Archipelago.

•Theme 7: The Arctic Ocean is very poorly mapped from the seafloor to the ice above. Significant information gaps include the bathymetry, biodiversity, and knowledge of ocean currents and their over space and time. Exploration of the unknown Pacific Arctic region is essential for the construction of base maps necessary for the planning of future monitoring efforts.

•Theme 8: The Pacific water inflow through the Bering Strait region is a key conduit for heat, salt, nutrients, and biological material (including genetic material) to the Arctic basin that influences sea ice cover, formation, and the carbon cycle.

•Theme 9: Nearshore coastal processes and subsea permafrost dynamics are important processes in the shallow Pacific shelf areas are subject to climate change impacts.

•Theme 10: The open and closing of the Pacific gateway has occurred over geological time periods with dramatic impact on the Arctic system. The paleorecord provides a long-term record for comparative evaluation of climatic processes relative to contemporary studies in prior themes.

While the environmental observation needs were discussed during these workshops and other science planning activities did not address all Pacific Arctic Group science themes (e.g., Paleoclimate), clearly international partners are interested and available to improve observations in the Bering Strait region.

Canada's Three Oceans Research (C3O) program was initiated during the International Polar Year in 2007-2009. It provides an example of the potential for improved observations through international partnerships. The goal of C3O is "to observe North Pacific, Arctic, and North Atlantic waters, and establish a scientific basis for sustainable, long-term monitoring. " Canadian Coast Guard icebreakers transiting the Bering Strait are used as part of this goal, and Fisheries and Oceans Canada has hosted scientists of a number of countries using these research platforms with measurements along 15,000 kilometers between Victoria and Halifax, including measurements of ocean temperature, salinity, oxygen, nutrients, tracers, sediments, viruses, bacteria, plankton, birds, and whales.

Similarly, biennial Chinese Arctic expeditions have also hosted international participants in the interest of improving international cooperation in the Bering and Chukchi Seas. These expeditions have also occupied stations that were identified during the US Shelf-Basin Interactions program as being critical to understanding how biogeochemical processes originating in the Bering Strait region have an impact on "downstream" portions of the Arctic.

The interest in the Bering Strait region of countries as distant as Korea was tied to global climate predictions by a Korean participant in the Eatonville workshop, Dr. Gi Hong of the Korea Ocean Research and Development Institute:

> "None of the climate prediction models listed in IPCC reports have closely simulated climate changes occurring in the Bering Strait Region. We do not have mitigation and adaptive capacities because accurate scientific understanding is lacking. Therefore we need to develop a field program to actively observe the symptoms of the climate change in the region to better inform the global climate models to improve simulations of the current climate and to better predict the future climate in the region. These observation programs should be separate from the current passive trend surveillance (monitoring) programs on the marine environment administered by the federal and local administrations, and should coordinate the current and planned research activities at both national and international scales to maximize synergies in the US Arctic."

Local Community Needs

Communication Among Villages and Needs for Smaller-scale Observations. One of the key desires expressed at the community-oriented meeting in Nome was the need for more locally-based observations that can be directly collected and used within local villages, as well as shared with neighboring villages. At the Eatonville meeting, while the orientation was much more conventionally scientific, several participants emphasized the importance of observations that can only be collected by local residents (see workshop abstracts by Eicken, Springer, and Sugai).

In Nome, the value of environmental observations being made available for local use was emphasized. While environmental observations that are available through the National Weather Service (NWS) are probably as well developed and robust as any component of the AON, local users in the Bering Strait region pointed out that forecast areas are large. One consequence is that sea ice coverage predictions and weather are often locally incorrect.

Many hunters in Bering Strait villages integrate internet-served NWS forecast data with traditional knowledge of local meteorology. Sharing of information among villages about upcoming changes in weather, sea ice distribution, and hunting opportunities is communicated via traditional communication devices such as telephones. While NWS weather data are helpful, publicly available sea ice imagery is not typically of high enough resolution and quality to aid subsistence hunting. Discussions at the Nome workshop revolved around the potential for stepwise improvements in open source sharing of subsistence hunting information using brief internet-based communication forums such as Twitter to share up-to-date information on local conditions that would be relevant to hunting success. Use of Twitter in the Bering Strait region is not without precedent. Bering Air, one of two local air carriers serving the six villages represented at the Nome workshop uses Twitter to update villages on flight departures.

Ice imagery available from satellite sources such as MODIS and Radarsat have also been shared during spring cruises since 2008 from scientists aboard US Coast Guard icebreakers and the Saint Lawrence Island villages of Savoonga and Gambell. These satellite images have been posted in public locations such as IRA Council tribal government offices (personal communication, Gay Sheffield, Alaska Department of Fish and Game). Other ship-based ice observations of sea ice and marine mammal populations are sources of information that are valued within these two villages (personal communications, Branson Tungiyan, Native Village of Gambell; George Noongwook, Savoonga Whaling Captains Association)

Another new initiative to better share available satellite-based ice coverage imagery is underway as a cooperative outcome of an Arctic Observing Network project based at Wales involving University of Alaska Fairbanks faculty member Hajo Eicken and Winton Weyapuk, Jr. of Wales. Building on this collaboration, which also includes ice observations made in Gambell by Paul Siluk Apangalook and others, the Nome workshop participants discussed improved communication and forecasts of ice conditions and weather in the Bering Strait region. Input provided on the draft plans for a pilot project that involves the NWS, NOAA and other agencies as well as the Eskimo Walrus Commission (EWC), were very helpful in developing a viable strategy for improved ice and weather forecasts based on a cooperative approach. This pilot project is now underway under the auspices of the Study of Environmental Arctic Change (www.arcus.org/search/siwo). Local ice and weather experts compare 10-day forecasts and ice advisories produced by the NWS (Figure 7) with their observations to provide comments to help improve standard NWS products. At the same time, local observations of ice conditions provide critical information on ice developmental history and key aspects of the ice cover important for the Bering Strait ecosystem. For example, the first installment of the ice outlook includes input by Native experts such as Winton Weyapuk Jr., Paul Siluk Apangalook as well as dispatches from researchers aboard the USCG Healy.

A Local Perspective: What observations should be made?

Observations should be made by any scientists regarding marine - land - migratory bird paths. We as Inupiaq use for human consumption these routes, paths that should be recorded to see the differences from the past to this date. All these things should be passed to our Elders in our communities. They are the ones who see climate change, and effects on animals and bird routes in our regions. Climate changes plays a big role in our subsistence lifestyle; go to our Elders in our communities to see what they see in their lifetime. Seems like the scientists are working with college students for information in our own communities. Our best resources are our Elders in our respective communities. Local residents can help because they are our hunters/food gatherers who see the changes in the ice conditions, and timing of plant and berry harvest in the seasons. Important observations should be made by local community members who see changes in marine mammals such as oogruks, walrus, seals, beluga, fish in our oceans and rivers. It is very important for us human consumers from the sea, land, mammals, plants, fish etc. We depend on a subsistence lifestyle. We also should know the level of contaminants we consume from the sea; mammals, fish and plants, berries that grow in our regions. Scientists should be onboard ships traveling along the Northwest Passage to record up to date information on the bearded seal, walrus, beluga, and whale migration routes we depend on. Scientists should come to our communities about their findings. They should also come to our communities to see preparations for early harvest of plants, berries, fish, marine mammals in the surrounding communities. The scientists should communicate with the communities they are involved with, and give detailed findings that they come up with. ----**Stanley Tocktoo, Shismaref**

Another approach to involving local residents in observations is exemplified by the Bering Sea Sub-Network (http://www.bssn.net). This is an evolving program that provides a mechanism for involving local communities in environmental observations. The goal of this project is to stimulate development of a community-based monitoring network in the Bering Sea, empowering village residents within Russia as well as the United States to provide their environmental observations as part of the overall suite

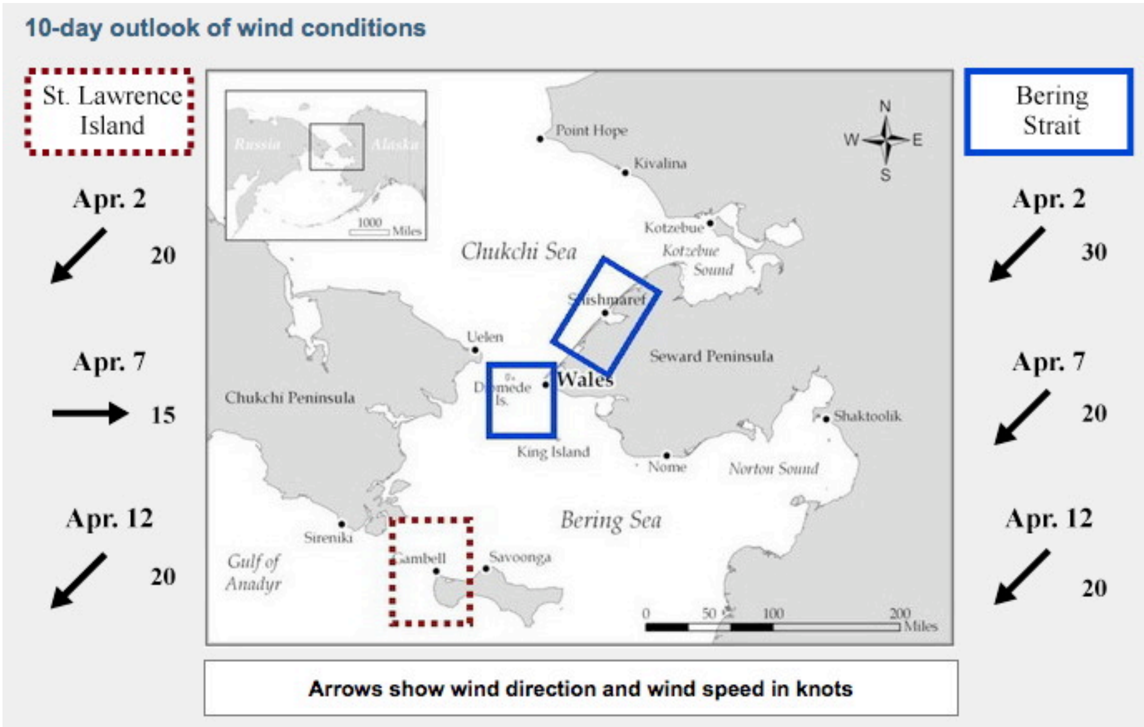

Fig. 7: Map from Sea Ice for Walrus Outlook (SIWO) website (www.arcus.org/search/siwo) showing 10-day forecast of wind conditions. The site also posts local ice experts' opinions on ice conditions, links to satellite imagery for coastal villages and other relevant information.

of work to be accomplished within an integrated network. Along with the unusual international nature of the village network, the observation methodologies are focused on traditional knowledge and higher trophic levels, so the results of this effort could provide unique perspectives unavailable elsewhere, both for biological species with economic and subsistence value, as well as enriching knowledge available through more typical scientific endeavors. The project is using two approaches, specifically 1) structured interviews to identify recent important changes from the perspective of individual village residents in addition to 2) the development of a network of observers who will report on on-going changes they observe from their communities and neighboring areas.

One of the key points to consider in any environmental observation design, which was clearly articulated by local residents at the Nome workshop, as well as in other discussions is the very high degree of interest by local communities in the Bering Strait region in scientific research and observations that are being conducted in local waters (see inset comments by Stanley Tocktoo of Shishmaref). For example, at a community meeting in Savoonga following the Nome workshop, almost 30 people in a community with a population of ~800 came to listen to a presentation of recent scientific results in the Saint Lawrence Island polynya region (Figure 8). If a similar level of community interest was achieved in a major city, major sports facilities would be filled. The deep interest in current research stems directly from the subsistence economy that supports the villages of the Bering Strait region and the need to anticipate how local communities will adjust to climate changes that are widely assumed by local communities to be underway.

Figure 8. Jackie Grebmeier of the University of Maryland Center for Environmental Sciences explains recent scientific results in the Saint Lawrence Island polynya region to a community meeting in Savoonga, Alaska in January 2010.

Conclusions

The workshop findings included a consensus that an integrated environmental observation system in the Bering Strait region needs to include a broad suite of physical, biological and chemical observations. Those observations identified and enumerated as critical by the US National Academy Study Committee on Design of an Arctic Observing System in 2006 remain relevant guideposts. These observations are at varied states of development and readiness. For example, moored observations of salinity, temperature, currents and seasonal sea ice pre-date the AON and have sufficiently matured so that the scientific value of these observations is clear. Other technologies such as remote sensing are also becoming widely and routinely used. These types of observations should be continued in a sustained manner and transitioned to agencies that are prepared to provide long-term support. At the same time, other more experimental measurements should be encouraged and appropriate sampling platforms made available. These sampling platforms should include standard ship transects, but the potential for less traditional sampling systems such as coastal and undersea cabled observatories should also be seriously explored. One clear workshop finding was that no one observation platform will meet all observation needs. A strong program of observation will be based on balance among available sampling platforms so that a broader suite of observations can be sustainably made with appropriate tools. The end result of a broadly based program will be a better understanding of how physical, biological, and chemical processes interact in this changing Arctic ecosystem.

Cooperation and involvement of local residents is also required for many of these observations to succeed. Empowering local residents to incorporate community-based observations into the larger AON and enabling them to benefit from network development themselves should be seen as necessary improvements. Without a strong commitment on the part of agencies and scientists to incorporate the observations that can be made from communities in the Bering Strait, it is unlikely that a broadly supported and scientifically robust Arctic environmental observatory system in the Bering Strait will be established.

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Appendix I (Workshop agendas)

Agenda, Eatonville Workshop

Bering Strait Observations Workshop,

Center for Sustainable Forestry (Pack Forest), Eatonville Washington, USA

Day 1, Tuesday May 12, 2009

7:30 Breakfast

8:30 a.m. Welcome and Overview, Lee Cooper

Bering Strait Observations Status and Implementation, Introductions, Meeting logistics, etc.

8:45 a.m. Remarks from the National Science Foundation representative, Dr. Martin Jeffries

SEARCH, AON, and the Need for Science-Driven Observing Systems in the Bering Strait

9:00 a.m. Remarks from National Oceanic and Atmospheric Administration representative, Dr. John Calder, Environmental Observations Perspectives from NOAA's Climate Observations Office

9:10 a.m. Remarks from the Executive Director, US Arctic Research Commission, Dr. John Farrell

9:20 a.m. An Overview of Bering Strait as a Key Observation Point for the Arctic Ocean, Dr. Knut Aagaard, University of Washington

9:50 Questions and Discussion

10:00 Break

10:15 The Potential for Cabled Observatories in the Arctic System, Dr. Bernie Coakley, University of Alaska Fairbanks.

10:35 Questions and Discussion

10:45 An Overview of the State of the Art in Chemical Oceanographic Observations, Dr. Lou Codispoti, University of Maryland Center for Environmental Science

11:00 Questions and Discussion

11:10 Bering Strait Observations in the Context of the Developing Alaska Ocean

Observing System, Molly McCammon, Alaska Ocean Observing System

11:30 Bering Strait Observations in the Context of the Ocean Observing Initiative, Dr. Mario Tamburri, Alliance for Coastal Technologies and University of Maryland Center for Environmental Sciences

11:45 Questions and Discussion

12:00 Lunch

Individual Short Presentations from Participants (2-3 Powerpoint slides, ~10 minutes each)

13:00 Community-based Observations, Human Dimensions, and Local Needs

Herter, Sugai (also chemical oceanography), Metcalf, Gofman

13:40 Physical observations, hydrology and climate

Woodgate, Zhao (also Chinese national interests), Cherry

14:10 Sea ice and Remote Sensing

Eicken, Frey, Lindsay, Hong

14:50 Break

15:10 Chemical observations

Anderson (also European Union perspective), Kelly (also technology development), Smagin (also Russian national interests)

15:40 Biological observations

Grebmeier, Iverson (also Canadian national interests), Springer, Moore

16:20 Modeling Needs

Maslowski, Jin

16:40 A "Vision" panel for Bering Strait observations and integration into the larger Ocean Observations Initiative; short keynote type presentations by panel members to set the stage for discussion and to stimulate discussion of the first day presentations. Panel members: Mario Tamburri (ACT), Molly McCammon (AOOS), Jackie Grebmeier (UMCES)

17:30 Adjourn for Day

18:00 Dinner

19:00 After dinner reception, Pack Hall (wine and soft drinks)

Day 2, May 13, 2009

7:30 Breakfast

8:30 Meeting logistics and announcements (Lee Cooper)

8:40 A "Priorities" panel for observations in Bering Strait: Implementation of appropriate physical, chemical, and biological observations. Short keynote type presentations by panel members to set the stage for discussion. Panel members: Rebecca Woodgate (UW, physical oceanography), Lou Codispoti (UMCES, chemical sensors), Hajo Eicken (UAF, sea ice), Sara Iverson (Dalhousie University, biology and Ocean Transport Network)

10:00 Break

10:20 A "Communications/Synergies" panel to put forward a vision of how to involve local communities, and how to approach operational status for envisioned observations in the context of international needs. Short keynote type presentations by panel members followed by open discussion; Panel members: Vera Metcalf (Eskimo Walrus Commission), Susan Sugai (UAF), Sue Moore (AFRC).

12:00 Lunch

13:00 Plenary Discussion of Appropriate Workshop Breakout Groups, identification of potential steering committee members for science plan development, organization and appointment of leadership to steer discussions and development of written products; charge to breakout groups

14:00 Break

14:20 - 16:30 Initial meeting of working groups to discuss scope of efforts.

16:30 Plenary Discussion

17:30 Adjourn for Day

18:00 Dinner

19:00 After Dinner Reception, Pack Hall (wine and soft drinks)

Day 3, May 14

7:30 Breakfast

8:30 Short plenary meeting to follow-up on initial working group discussions and organizing committee discussions; adjustments as needed; address any issues in new working group charges

9:00 to 12:00 Working group deliberations and development of written and graphical products for presentation

12:00 – 13:00 LUNCH

13:00 Plenary Presentation of working group written and graphical products
Potential gaps and how to fill them

Discussion of International coordination issues

Discussion of local community involvement and outreach

Discussion of integration with national and regional ocean observation networks

15:00 Break

15:20 – 16:00 Meeting wrap-up and outline of post-workshop tasks

16:00 Adjourn meeting

18:00 Dinner

19:00 Post-meeting reception, Pack Hall (wine and soft drinks)

Agenda, Nome Workshop

Bering Strait Observations Workshop,

Northwest Campus UAF, Nome Alaska, USA

Day 1, Monday January 25, 2010

Morning flights to Nome

Pickup at Airport

Light food and refreshments available, UAF Northwest Campus

1:00 PM

Welcome and Overview, Lee Cooper

Bering Strait Observations, Introductions, Meeting logistics, etc.

1:15 PM

Outcomes from the science workshop held near Mt. Rainier, May 2009

Panel discussion with participation from Vera Metcalf, Heidi Herter, Jackie Grebmeier, Hajo Eicken

1:45 PM

A vision for how the Alaska Ocean Observing System would mature and operate; discussion and informal presentation by Molly McCammon and Darcy Dugan, Alaska Ocean Observing System with questions and answers

Individual perspectives from villages with discussion and questions as needed.

Examples of questions: What observations should be made, how can local residents help and participate, what kinds of facilities or equipment are needed locally to assist scientists and local residents in making important observations. What are the important observations that need to be made and recorded? How can scientists on ships or on land and local residents engaged in subsistence food gathering activities communicate and exchange information better?

Presentations from individual villages; a written version (1-3 pages) of the presentation covering questions above would be very helpful but is not required. We are leaving time to develop written summaries from each village represented on the second day; please consider telling us about your individual community and how it differs from others in the region, including hunting patterns over the seasons, what has changed recently, what has gotten harder/easier about subsistence hunting and food gathering; what kinds of observations should be made that would support the continued health of subsistence food gathering activities, the health of the ecosystem and community life in the region.

2:15 PM

Gambell

Savoonga

2:45 PM

Brevig Mission

Wales

3:15 PM

Diomede

Shishmaref

3:15-3:30 Coffee break

3:30-4:00 PM

An overall perspective for environmental observations in the Bering Strait region, including concerns that may not have surfaced in the individual community discussions. Discussion led by Kate Stafford, Lee Cooper and Gay Sheffield; Questions and Discussion

4:00 – 5:00 PM

Development of a list of critical observations that need to be made in the Bering Strait region to fully understand environmental changes and prepare for the future; once those observations have been identified, prioritizing them by importance, as well as practicality. In other words, for the most important observations, how easy will it be to implement them.

5:00 – 5:30 PM

Additional discussion as needed; Adjourn for the day

7:00 Hosted Workshop Dinner at Airport Pizza or possibly other venue

Day 2, Tuesday, January 26

Continental breakfast 08:00 to 08:30 AM

08:30 AM

Talk about how well we did yesterday; what is still needed or missing. Adjust schedule as needed.

09:00 AM

Continue development of list of priorities for observations. Comparison of the results of this workshop with those developed by the more science oriented workshop last year.

10:30 AM

Production and/or editing of written summaries by the individual village representatives that can be incorporated into the overall workshop report. We will make enough laptop computers available to facilitate this.

12:00 PM

Complete the workshop effort, plan for follow-up and communication after the workshop with and within local communities. Arrange transportation to airport and errands needed in Nome before departure on afternoon and evening flights. Continue work into afternoon as needed.

Appendix II

List of Workshop Participants

Eatonville workshop

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*The two representatives from the Native Village of Brevig Mission were unable to reach Nome for the workshop because of weather problems that cancelled their flight.

Breakfast discussions at Eatonville, left. Kate Stafford and Patrick Omiak at Nome meeting, above

From left Jackie Grebmeier, Victor Smagin, Susan Sugai, and Karen Frey

Group photo at Nome workshop

Appendix III

Abstracts of Talks from the Eatonville Workshop

Carbon transformation, sources and sinks

Leif Anderson

The Bering Strait region is very dynamic from a carbon perspective. A substantial transport passes through from the Pacific Ocean to the Arctic Ocean over the Bering and Chukchi seas. During this transit extensive primary (and secondary) biological production occurs, which together with cooling of the water contribute to an uptake of CO2 from the atmosphere. The produced organic matter is a source for marine life and contributes to the traditional life of the native people.

Furthermore part of the organic matter is mineralized by micros, mainly at the sediment surface of these shallow continental seas, and the resulting chemical products is transferred back to the overlying waters. The resulting high nutrient, low oxygen water, can either mix back into the photic zone and contribute to new primary production, or flow off the continental margin and penetrate a matching density surface. The latter is seen as a maximum at around a salinity of 33.1 in the so called Upper Halocline (UH). The source of this UH water has been postulated to be the Chukchi Sea, but lately it has shown that the East Siberian Sea also contributes to the UH. One question is to what degree these two shelf seas add to the UH water. A second question is what the seasonal timing of this outflow of nutrient rich water occurs? A third question is the source of the organic matter that is mineralized at the sediment surface? It is obvious that marine produced organic matter is a major source in the Chukchi Sea, but in the East Siberian Sea there is extensive coastal erosion as well as input of terrestrial organic matter from river runoff.

In order to add to the answer of the above questions field studies of different seasons are needed within the Russian EEZ. Making a study of the East Siberian Sea also opens the possibility to investigate the very topical issue on release of methane from the sediment, including the source of this methane.

Study of Hydrology and Climate Drivers in the Bering Strait Region: Science for Society and Research Capacity Building

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While the residents of Beringia have adapted to their highly variable environment over thousands of years, the rapid, climate-induced changes in sea ice concentrations, permafrost distributions, and coastal erosion are presenting new challenges. These climate changes have occurred over precisely the same period when remote villages on the Seward Peninsula and Chukotka have transitioned to market-based economies and utilities such as diesel-generated electricity and municipal water storage. New, informed resilience strategies must be developed to deal with rapid climate change and its impact on both traditional and market-based socio-economies. The intent of this proposed project is to support development of new resilience strategies by determining the drivers of physical changes and their impacts on water and other community re- sources. The proposed research will employ observations (including those from UAF's longterm hydroclimate station network) and modeling to determine the role of sea ice concentrations in the Bering and Chukchi Seas on modulating temperature, precipitation, and permafrost distributions on the Seward Peninsula in Alaska. The relative roles of regional feedbacks and large-scale atmospheric dynamics will also be tested.

In addition to this proposed research, efforts have begun to build a consortium for the Bering Strait Region to increase the capacity for data sharing and communication of research results to the public and among researchers. While the organization of the Bering Strait Research Consortium (BSRC) is still in its infancy, it currently stands as a partnership of the University of Alaska Fairbanks, the National Park Service, local Native corporations, and other interested parties who have agreed to share information, logistics, and data to improve the quality of natural and social science research in the Bering Strait Region. More information on BSRC can be found at http://www.beringstraitresearch.org/.

Collaboration between the investigators associated with a Bering Strait Observatory and those associated with this consortium are strongly encouraged.

Our group has the following specific expertise, resources, and interests: * We maintain an expanding network of meteorological, permafrost, and hydrologic stations through out the Seward Peninsula for which we are looking for ongoing support * Our group and its collaborators have considerable experience studying the connections between climate physics, land-atmosphere interactions, and water resources

The Need for Chemical Time-Series Observations in the Bering Strait Inflow

Lou Codispoti, University of Maryland Center for Environmental Science, Horn Point Laboratory: Codispot@hpl.umces.edu

I have a longstanding interest in how the Bering Strait inflow modulates oceanic chemical distributions. Although, the inter-ocean water mass exchange via this connection is probably less than 5% of the total exchange between the Atlantic and the Pacific, the concentration differences are much higher in the north. These concentration differences significantly amplify the importance of Bering Strait in the inter-ocean trading of salinity, silicate, N*, etc.

More recently, I have been impressed with the importance of the Bering Strait inflow to the ecosystem structure of the Pacific influenced portions of the Arctic. It is, therefore, important for us to better understand the chemical fluxes in the Bering Strait inflow in order to improve predictions of both the Arctic Ocean ecosystem, and global oceanic chemistry.

My major research interest is the global nitrogen budget, and the Bering Strait inflow cannot be neglected in studies of this problem because this inflow carries an important denitrification signal (negative N*) into the Arctic that is significantly increased by denitrification within the Arctic

These scientific issues interface with my interest in improving our ability to obtain chemical observations on relevant time and space scales, an interest that motivates my research on autonomous determination, processing and telemetry of nutrient concentrations.

At this workshop, I wish to make the case for the importance of the chemical transports in Bering Strait, and to suggest that we now possess the technology to obtain data on these fluxes on meaningful time and space scales.

A Meeting Organizer's Perspective on Observation Needs in Bering Strait

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Having the opportunity to organize a workshop on science observations in the Bering Strait gives me a somewhat different perspective from most attendees. In order for the workshop and science plan or report to follow to have credibility and to be of use to the science community, local stakeholders and agencies that will use our recommendations, I have a responsibility to:

1) Bring in a representative cross-section of international experts to deliberate on the evolving needs that must be anticipated for addressing new emerging research issues, including marine biodiversity, ocean acidification, and freshwater balance as changes in the Bering Strait region have an impact on the larger Arctic system.

2) Utilize past science planning efforts such as SEARCH, AON, and the results of relevant scientific research projects such as PROBES, ISHTAR, SBI, BEST, and the many single investigator-led projects in the Bering Strait region to take advantage of the scientific knowledge base.

3) Incorporate a wide range of perspectives and needs, including those of local communities and modelers, and an interdisciplinary range of observational scientists, yet provide a pragmatic plan that can be implemented in the context of national and international resources.

These are not insignificant challenges, but I am pleased that we have been able to assemble in one place a set of workshop participants (in other words, objective 1) with sufficient breadth in experience and international perspective to accomplish the longer- term objectives articulated in points 2 and 3. I thank all of the participants for taking the trouble and effort to come to Pack Forest to address these important scientific needs.

I feel privileged to provide a few observations that stem from my own experiences, which include service on the (US) National Academies panel on designing an arctic observing system, my management of the Russian-US project office for RAISE from 2000-2005, my work in a remote, local Bering Strait community to develop prototype ocean observation systems, and my service as chief scientist on a number of multidisciplinary research icebreaker cruises in the Bering and Chukchi Seas. Briefly, I think we need to move towards more genuine involvement of local communities in environmental observation efforts. Incorporating traditional ecological knowledge is one element, but we also need to set the stage for eventually bringing a next and locally raised generation into the scientific enterprise. Second, the Arctic Observation Network has in the marine environment so far not significantly expanded biological observations, and this is a particularly important need in the Bering Strait region. Finally, in Bering Strait, the US government needs to work in better partnership with the Russian government, as well as other international partners to insure that scientific needs are met and coordinated for the best interests of understanding the role of the Bering Strait in affecting the Arctic system.

Sea ice in the Bering Strait Region: Integrated observations in a focal area for marine life and people

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Bering Strait is an important pathway for water and sea ice entering or exiting the Arctic Ocean; it also experiences substantial transport of marine life and vessel traffic. Comparatively little is known about the volume transport of sea ice through Bering Strait. Its narrow width and the short-term variability of ice transport (forced both by wind and the surface ocean) through the Strait render satellite-derived estimates of areal fluxes difficult. Data from upward-looking sonar suggest that the ice-associated freshwater flux is directed towards the South and more than one order of magnitude smaller than the northward directed freshwater transport (Woodgate and Aagaard, 2005). Observations by indigenous experts in the Bering Strait Region (Weyapuk et al., unpubl. observations, 2006-2009) indicate that ice movement varies locally with the currents and prevailing wind patterns.

Sea ice in the Bering Strait region is of great importance through its use as a platform for marine mammals such as walrus or bearded seal, its role in providing access to marine mammals to hunters from a number of coastal communities, and its importance in reducing ocean wave action which aids hunters and reduces rates of coastal erosion. The annual migration of walrus, seals and whales through Bering Strait is con- strained by the drift and seasonal retreat patterns of sea ice. Anomalous conditions, such as stoppage of ice in the Strait or anomalously rapid retreat experienced in 2007, can have significant impacts on animals and people (Eicken et al., 2009). It is presently unclear, how exactly changes in the large-scale distribution of sea ice are impacting communities in the Bering Strait region, though some observations suggest that link- ages are more complicated than suggested by a simple analysis of summer minimum ice extent (Noongwook et al., 2007; Krupnik and Ray, 2007; Eicken et al., 2009).

Increases in maritime traffic through the Strait (Brooks, pers. communication, 2008) in recent years and growing industrial activity are likely to result in an increase in the conjoined uses of the ice environment in this region. These potentially conflicting activities concentrated into a confined area by the geography of the Strait and the resulting information needs by different stakeholder groups need to be considered in addition to improving fundamental understanding of ice transport when designing an observing system.

Such an observing system likely will include measurements of ice draft and ice velocity from ice-profiling sonar from moorings deployed in the Strait, augmented by remote-sensing observations of ice dynamics. With limited access to SAR data of sufficient sampling rates, AMSR-E passive microwave data may be the only reliable, open-access tool for satellite remote sensing of ice drift. Recent deployment of a coastal radar has demonstrated the potential of this method for monitoring ice movement in the Strait, but also identified logistic challenges.

Community-based ice observations (entering into a database) have helped improve the value of sea-ice data to different stakeholder groups, may enhance operational products by, e.g., the National Weather Service Ice Desk, and document uses of the sea-ice environment by marine mammals and people. A key challenge and opportunity for the Bering Strait region will be to build an integrated observing system that balances interests by the scientific community and different stakeholders, and integrates the different data streams and observations to help with adaptation in a focal area for a range of activities.

Satellite Remote Sensing of Sea Ice and Ecosystem Dynamics in the Bering Strait Region Karen Frey (kfrey@clarku.edu; Tel: 508.793.7209) Graduate School of Geography, Clark University, Worcester MA

Satellite remote sensing can provide daily, long-term observations (up to ~30 years) of sea ice and ecosystem dynamics in the Bering Strait region, providing significant spatial and temporal extrapolation of field measurements. However, field measurements of these parameters are absolutely critical for the validation, calibration, and interpretation of satellite observations that will in turn enable the continuation of accurate satellite measurements into the future. In the case of the Bering Strait region, satellite observations have shown that recent declines in sea ice cover have been associated with some of the most significant increases of chlorophyll biomass in the entire Pacific Arctic region (Figure 1). Thus, it is critical that regular field observations of sea ice and ecosystem dynamics in the Bering Strait region are instigated in order to further explore the accuracy of these satellite-derived trends. Once satellite measurements can be accurately tuned to field measurements, this will provide the spatial and temporal extrapolation necessary to understand the biophysical complexities of climate change impacts in this region.

Ecosystem Dynamics: In the ocean water column, optical properties and total absorption of light are a linear combination of the absorption of phytoplankton, detritus, sediment, water, and chromophoric dissolved organic matter (CDOM). Although it can be difficult to tease apart these parameters in optically complex waters such as in the Bering Strait region, the development of theoretically- and empirically-derived algorithms based on satellite ocean color data can allow separation of these individual components. These algorithms ultimately allow the determination of such parameters as chlorophyll-a concentrations, CDOM concentrations, primary production rates, and organic/inorganic particulates. Global algorithms for these parameters currently exist, but can lead to significant inaccuracies when applied to high-latitude regions. Field measurements of these individual parameters (chlorophyll-a concentrations, CDOM concentrations, primary production rates, and concentrations of organic/inorganic particulates) within a Bering Strait Observatory are therefore critical to ground-truth ocean color data and develop new, regionally-specific algorithms that can be accurately utilized.

Sea Ice Dynamics: Field validation of sea ice dynamics (melt onset, concentration, and thickness) is also critical in the context of satellite remote sensing. While satellite-derived sea ice concentrations (derived through passive microwave satellite data) may be based on more widely accepted methodologies, field validation of satellite laser altimetry-derived sea ice thickness and satellite radar scatterometer-derived sea ice melt onset may be even more critical.

Temperature measurements in the vicinity of sea ice would allow for estimates of the timing of sea ice melt onset. Sea ice thickness (and snow depth measurements) would be critical for calibration of data from laser altimetry platforms (e.g., the Ice, Cloud, and land Elevation Satellite (ICESat) that has been collecting measurements since 2003).

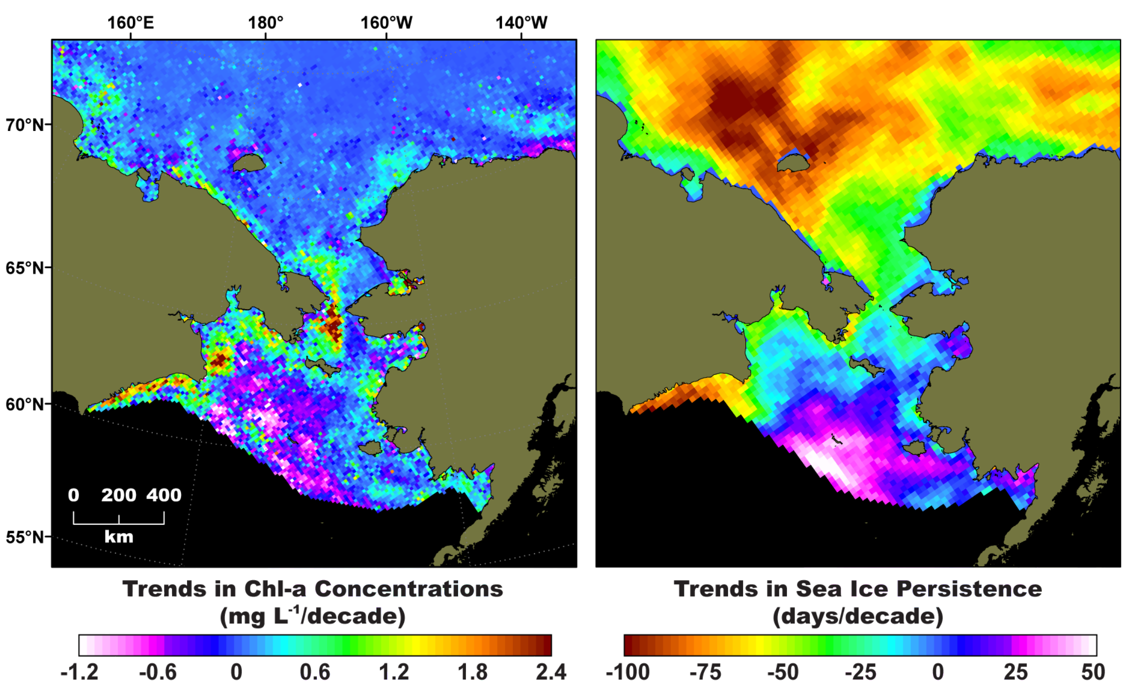

Figure 1. Trends in SeaWIFS-derived chlorophyll-a concentrations and SSM/I passive microwave-derived annual sea ice persistence over the years 1998–2008.

Biological Time Series Observations in the Bering Strait Region

Jackie M. Grebmeier

Ecosystem changes currently occurring on the shallow shelves of the northern Bering and Chukchi Seas are directly linked to the hydrographic nature of the marine systems both to the south and north of Bering Strait. The shallow continental shelves support large populations of benthic infaunal organisms that are excellent integrators of physical and biological processes in the region. High biological productivity in the Bering Strait region is maintained by high nutrient Pacific water inflow. The high cascading potential between lower to higher trophic organisms in the region can provide an important mechanism for rapid translation of biological change to higher trophic organisms that are important subsistence food sources to local coastal communities. With the recent reduction of sea ice in the Bering Strait region, increased seawater warming, and the potential for a rapid ecosystem reorganization, it is essential to include a suite of biological measurements in an Arctic observation network in this critical gateway region.

There is a need for time-series observations in the Pacific Arctic sector to track the status and change in this marine system. Limited benthic biological time-series sites in the northern Bering Sea indicate a change in species composition and decline in biomass of the dominant bivalve species coincident with declines in diving seaduck populations over the last few decades (Grebmeier et al. 2006, Science 311; Lovvorn et al. 2009, Ecol. Appl., 19: 1596-1613). In addition, declining benthic amphipod populations in the Chirikov Basin south of Bering Strait has occurred coincident with movement of migrating gray whales that have recently expanded their range northward with reduced sea ice extent (Coyle et al. 2007, DSR 54; Moore and Harrington 2008, Ecol. Appl. 18). Variability in hydrographic conditions influencing water column productivity, low seawater temperature, and low zooplankton populations in the spring in the northern Bering Sea result in rapid export of labile organic carbon to the sediments (Grebmeier and Barry 2007, Elsevier Oceangr. Ser. 74). The time-series sites in this region indicate that the dominant bivalve, polychaete and amphipod populations vary depending upon water mass structure and sediment type, but that the observed decline in benthic biomass likely results from changes in the timing of ice retreat and its impact on spring ice algal phytoplankton production.

Select time series sites in regions where benthic fauna form a key prey base for benthic-feeding apex predators would be ideal sites to collect a standard suite of physical, biogeochemical and biological measurements to evaluate status and trends in the marine biological system. Time-series observations of key biological components and environmental parameters at select time and space scales could form the basis of a distributed biological observational network. The increasing interest by national and international science efforts in the region, along with resource extraction support activity, could provide a timely opportunity to develop and maintain a collaborative marine observational network into the future.

Ocean Color and Top Predator Monitoring in the Bering Strait Region

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We would like to report our experience on Ocean Color studies in the Arctic Ocean and to introduce the Korean Stationary Satellite equipped with Ocean Color Observing modules scheduled to be launched in June 2009, and a hypothesis on the feasibility of using bones of top predator for ecosystem wide changes in the Workshop on the Instrumentation and Observation Infrastructure to Support a Cohesive Set of Marine Environmental Observation Systems in the Bering Strait Region as our contribution.

Calibration of MODIS Aqua observation using in situ measurements. We have visited 3 summers from 2006 to 2008 coastal ocean near Ny-Alesund, Spitsbergen, to measure various optical properties of seawater. Our observation indicated that current (1) standard atmospheric correction, (2) correction of chlorophyll concentration due to the dissolved organic matter and suspended particulate matter, and (3) overestimated Lw caused by high latitude in MODIS Aqua appeared to be responsible the discrepancies in Chlorophyll concentration. We have subsequently devised empirically new algorithm for chlorophyll a concentration for the region.

GOCI (Geostationary Ocean Color Imager) will be launched in June 2009. The northern boundary of the coverage is about 50°N; however, the satellite observation on the North Pacific will be indirectly useful for the Bering Strait Region. GOCI has relatively high ground resolution to be sufficient for coastal monitoring, very long focal length and relatively high SNR in the spec. level with low deviation.

Radionuclide concentration (^{210}Pb) in bones of local marine mammals as proxy to the food chain structures in the Bering Strait. We propose a hypothesis on the presence of any particular natural radionuclide as a proxy to determine the ecological changes in the coastal marine environments of the Bering Strait region. Based on our earlier study on the ^{210}Pb concentrations in the sea otter skull collected in Amchitka Island, Aleutian, the hypothesis may be added to the observation item in the region because the top predators of marine mammal (sea otters, seals, etc) are regularly harvested in the region by the local people.

Key issues

Sara Iverson, Scientific Director of OTN Canada, Dalhousie University

In summary, I believe a key requirement for the Bering Strait region should be to become involved in and partnered with the Ocean Tracking Network (OTN) and to benefit from methodologies and research programs that are being put in place elsewhere.

Led by Dalhousie University, an international research and technology develop- ment consortium called the global Ocean Tracking Network (OTN Global), aims to revolutionize the way oceans are viewed and understood, which will contribute to a more sustainable use of the world's oceans. With Canadian Foundation for Innovation (CFI) support ($35 M) via its International Joint Venture Project (IJVP), made-in-Canada technology will be installed in 14 oceans across 7 continents to record the structure and movement of the Earth's oceans. At the same time, the behaviours, movements and interactions of hundreds of at-risk and commercial species of marine life will be tracked for up to 20 years. Part of the rationale for creating OTN as a part of the Global Ocean Observing System (GOOS) was the economy of letting oceanographic observers, who routinely collect and manage vast amounts of data, add a relatively small amount of information of high economic value about animal movements to their collections. Historically oceanographers and animal trackers operated independently and focused on specific local problems. The OTN provides large-scale arrays at areas of biological and physical interest, thus providing added value to many smaller scale electronic sensing and tagging projects. OTN Canada is the initiation of a 7-year $10 M integrative research program (funded by the Natural Sciences and Engineering Research Council, NSERC), which makes use of OTN Global technologies and infra- structure to understand changing marine ecosystems across Canada's three oceans – Atlantic, Arctic and Pacific. The paramount objective of this Network, which is just now starting up, will be to better understand changing ocean dynamics and their impact on ocean ecosystems, animal ecology and movements, and ocean resources, with the aim to address critical issues in resource management and implications for ocean gov- ernance. This work is also aimed to serve as a template for research implementation in other countries and regions.

The immediate goals of OTN are: (1) to create a global network of compatible underwater receivers that record oceanographic observations, as well as the presence or absence of animals carrying uniquely coded acoustic tags that last for many years, consistent with animal size; (2) to establish a global network of users who put their information in a common database, so that animals that travel long distances can be tracked systematically; (3) to demonstrate technologies that couple animal locations to the oceanographic conditions they experience, including for instance the emerging capacity to link several trophic levels with a new concept called Business Card Tags, allowing larger animals to act as "bioprobes". The longer term goals of the OTN are: (1) to integrate the data collected by the receiver network with data collected and stored archivally by tags as the animals move freely in the ocean and (2) to make these data available to the oceanographic community for modeling and other purposes through GOOS.

The map attached represents the anticipated scope of the OTN project, showing existing partner equipment in red, and tentatively funded deployments in other colors. The Bering Strait region has been considered an extremely important area to include, as it represents the gateway between the Pacific and Arctic and many key Arctic species move/migrate through it. It became lost on the radar and is not currently in the OTN budget – but this could readily be changed with additional funding sources. Together with POST (Pacific Ocean Shelf Tracking project), OTN already has a huge investment in Alaskan waters, with lines planned for Prince William Sound, Icy Strait, and Unimak Pass. Despite challenging logistics for the Bering Strait in particular, OTN feels these could be dealt with and the Bering Strait should be added.

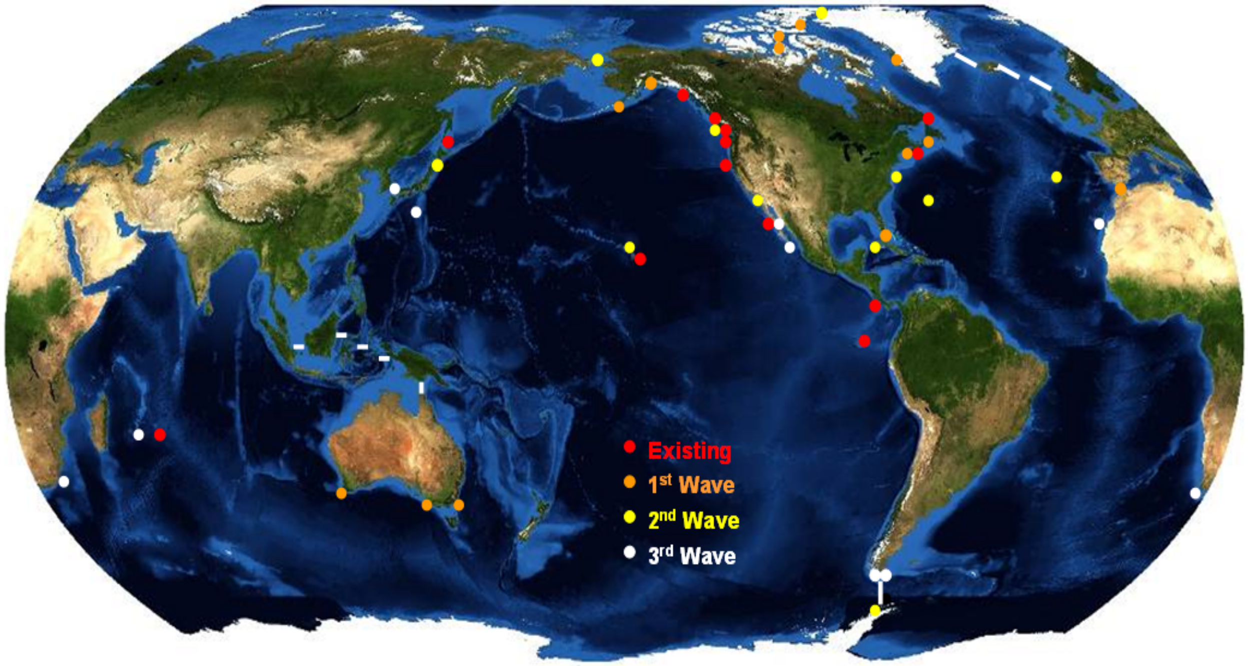

Figure 1. The anticipated global scope of the OTN project, showing existing partner equipment in red, tentatively funded installations for the next three years in orange and possibly yellow, and larger scale deployments under consideration in white.

Arctic Observing Network (AON), SEARCH & Environmental Observing in the Bering Strait

Martin O. Jeffries National Science Foundation, Office of Polar Programs, Division of Arctic Sciences

Introduction

• AON is a USG inter-agency program that is an integral part of SEARCH - Study of Environmental Arctic Change. • In May 2007, IARPC (Inter-agency Arctic Research Policy-Committee) directed agency staff to develop AON as part ofthe implementation of SEARCH and as a lasting legacy of IPY.

NSF and NOAA co-lead this effort. • NSF has been supporting long-term observing projects since~2000, has issued two AON solicitations (2006, 2008) and is committed to supporting Arctic environmental system observing activities for the foreseeable future. • SEARCH categories • Atmosphere • Human Dimensions • Hydrology & Cryosphere • Ocean & Sea Ice • Palaeo-environment • Terrestrial Ecosystem • Data & Information Management

SEARCH- Study of EnvironmentalArctic Change: Observing(AON)-->Data Analysis, Data Synthesis & Computer Modelling--> Understanding--> Responding SEARCH: http://www.arcus.org/search/index.php 1. Is the Arctic system moving to a new state? 2. Is the Arctic system predictable? 3. Do recent and continuing changes reflect natural variability and/or anthropogenic forcing? 4. What is the direction and relative importance of regional feedbacks? 5. How are terrestrial and marine ecosystems and ecosystem services affected by environmental change and human activities? 6. How are cultural and socio-economic systems affected by environmental system changes? 7. What are the most consequential links between the Arctic and global systems?

CADIS Cooperative Arctic Data& Information Service

• AON Cyberinfrastructure • ISO 19115 for inter-operability • http://www.eol.ucar.edu/projects/aon-cadis/

AON encompasses physical, biological and human observations, including local/ indigenous knowledge, of the land, ocean and atmosphere. AON projects will have a scientific rationale as to why the proposed activity, data (including frequency and duration of observations) and geographic location are essential to research that will advance the understanding of Arctic environmental system change.

NSF & AON: A Few Essentials AON projects will conform to the SEARCH data policy: data will be fully, freely ..and openly available as quickly as possible after collection and quality control, and metadata, data and documentation will be submitted to an appropriate national archive or repository. AON projects will be informed by the current understanding of Arctic environmental system change and will contribute data essential to understanding change research and related activities.

NSF & Bering Strait A Bering Strait observing system should have a strong scientific rationale. Broader impact: contribute to local needs. The scientific rationale should be grounded primarily in SEARCH, i.e., Bering Strait observations should contribute to understandingArctic environmental system change. The Bering Strait region is interesting in its own right, but it is also a gateway that connects the Pacific Ocean to the Arctic Ocean and the Atlantic Ocean. Consequently, a Bering Strait observing system should serve not only local needs, but also serve regional and global needs. Resources ($$) are limited, thus observing priorities will need to be established. Observing priorities should be guided by scientific priorities. Need to avoid parochialism. Observing system implementation guided by observing system design, e.g., location, frequency and duration of observations.

A report that will guide the US and international scientific community, and advise US and overseas government agencies, in the development of an integrated, coordinated and sustained Bering Strait observing system that will contribute to the understanding of Arctic environmental system change. The development of the observing system will be based on science-driven observing priorities and observing system design exercises.

Building a time series of physical and biological observations at the Bering Strait

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From a modeler's perspective, I think the following requirements are important for the observation system at the Bering Strait: Design some critical locations that most national and international cruises would agree to observe so that data from different cruises are comparable and possibly a time series of observations can be accumulated. A long time series of observations is important for data analysis to gain better understanding of both seasonal and interannual variability and derived climatology for model initial conditions or validation. Locations are chosen to have good representation of the Bering Strait and can be use to calculate various physical and biological flux across Bering Strait.

In coupled physical-biological models, the physical and biological variables are tightly constrained by each other. One difficulty to synthesize different observations for model development is that the variables of observations during different cruises area were different and incomplete due to different purpose of the cruise, time, and scientists aboard etc. To better estimate model parameters and validate the model results, it is important to have both physical and biological variables measured at the same time and the list of variables as complete as possible (e.g., measurements including atmo- spheric variables wind, air temperature, cloud etc.; physical oceanography variables T, S, current, light intensity, etc.; and biological variables nutrients, phytoplankton, zoo- plankton, etc.; and sea conditions if present).

Personally, one of my goals is to use the observations to set up a database to validate the model in a way that we can compare how much errors are in the atmospheric forcing, physical ocean variables and biological outputs and their impacts on each other. Another is to investigate the influence of nutrients flux through Bering Strait on the phytoplankton blooms in the Chukchi and Beaufort Seas using a coupled physical and biological model.

Bering Strait Observatory in Support of Arctic and Global Climate Modeling and Prediction

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One of the main goals of a Bering Strait Observatory should be to quantify the long-term mean and variability of the circulation, mass and properties transport at time scales from daily to decadal across the data-limited northern Bering Sea and through Bering Strait. Estimation of flow through Bering Strait presents several challenges to both observational and modeling studies. This strait is narrow and shallow and it is the only communication passage between the Pacific and Arctic Oceans. From the observational point of view, the political boundary between the U.S. and Russia divides the strait and restricts access to potential investigators. Also, ice floes with deep drafts are a threat to moorings placed in the upper 40m of the strait. More importantly, extrapolation of velocity measurements from one or few points to total transport is of uncertain validity due to substantial horizontal shear and seasonal stratification. Spatial variability of fluxes of freshwater / salt and biochemical properties across the strait further complicates long term measurement approach. However, the use of multiple current meters and regression techniques increases confidence in transport estimates.

From the modeling point of view, the representation of the flow and its variability across this narrow and shallow strait with a large ocean to the north and south is challenging as it requires a combination of high resolution and large domain to realistically represent the time-dependent and highly variable flow. So far, most of global ocean circulation models either close Bering Strait or instead use some type of prescribed conditions. Each of these approaches has a significant impact on model results, including position of sea-ice edge upstream in the Bering Sea and oceanic and sea ice export through Fram Strait and freshwater budget in the Nordic Seas downstream. Improved understanding of ocean circulation and sea-ice conditions in the Bering Strait region will facilitate more realistic GCM simulations and predictions both in Bering Strait and over the larger pan-Arctic region. This goal has been central to some high-resolution modeling studies however, additional observations are necessary to further validate those model results

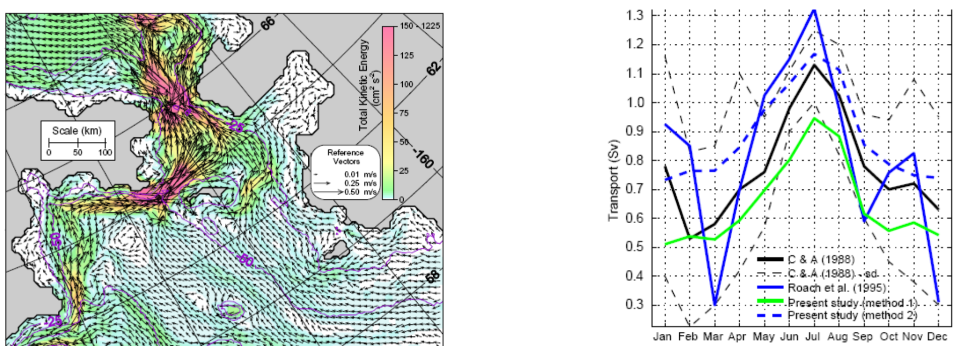

Figure 1. (a) Modeled mean velocity averaged over the upper 50 m. Color shading represents the total kinetic energy (cm2 s-2); (b) Bering Strait annual cycle transport (monthly means) from various studies. The NPS model estimates were made via two methods. The first method (in green) utilizes the entire strait in both the horizontal and vertical directions and is the method used for other calculations in this paper. The second method (in dashed blue) is done by using only the near-bottom velocity in the eastern channel multiplied by a cross-sectional area.

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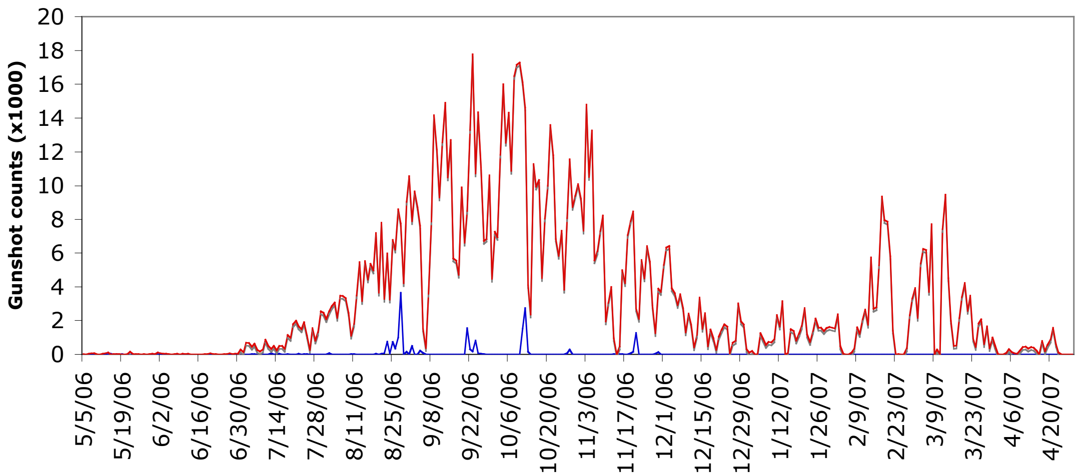
ACOUSTIC DETECTION OF MARINE MAMMALS AT BERING STRAIT

Sue E. Moore, NOAA/Science & Technology-PMEL

Year-round passive acoustic sampling of marine mammal calls in waters offshore Alaska has been conducted for a decade1. Sampling has relied on battery powered long-term recorders, deployed on biophysical moorings or autonomously. Surprising results have included: (1) the detection of gray whale calls (a temperate species) in the Beaufort Sea over-winter 2003-042, (2) seasonal tracking of critically endangered North Pacific right whale calls in the SE Bering Sea from May through November 3, and (3) the increase and persistence of fin whale calls in the Gulf of Alaska (4) and the SE Bering Sea from autumn through winter (see Figure).



Whale calls detected at mooring M2 in SE Bering: fin (red) and right whale (blue).

Passive acoustic observation capability at Bering Strait, via development of a fiber optic cable at Little Diomede, Alaska, would provide an unprecedented opportunity to detect and monitor movements of vocal marine mammals at this key Arctic gateway. Marine mammals are top predators in the marine ecosystem and the harvest of several species is essential to the well being of Alaskan Native subsistence communities. Call recognition algorithms developed to aid data analysis from the long-term recorders could be applied to a data stream from a cabled acoustic observatory. The capability to detect calls from both arctic-adapted and sub-arctic species5 in real time would address immediate questions raised by ecologists and subsistence hunters regarding how climate-related ecosystem variability is affecting marine mammal phenology.

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Observation systems in the Bering Strait region

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There are many observing initiatives including Sustaining Arctic Observing Networks (SAON), and Arctic-HYCOS as parts of SAON, Integrated Arctic Ocean Observing System (iAOOS), the Alaska Ocean Observing System (AOOS) that all correspond to meeting ocean observation needs. The main purpose of these programs is the creation of stable, sustainable observing systems with ground, sea and space based monitoring of the overall environment, extreme events, and scientific maintenance of long-term observations in Arctic regions. One important source of ocean monitoring is remote sensing. Satellites substantially compensate for the lack of ground measurements. For this reason the World Meteorological Organization recommended development of a legacy data set compiled from multiple space agency satellite data portfolios to provide a broad range of "polar snapshot" products. An extension of this effort was a proposed cooperative arrangement among major satellite agencies to ensure coordination of polar observations beyond IPY through a future structure that would achieve a "Polar Satellite Constellation."

Expedition observations are a complex blend of physical, chemical, and biological data and other parameters that include observations of the atmosphere, sea surface, water column, and seafloor. Expeditions should be carried out during all seasons, when all manner of measurement can be undertaken, including measurements of the water column and bottom structure and key vertical fluxes and transport processes (i.e., salinity, temperature, currents, oxygen, nutrients, chlorophyll, plankton, suspended particulate matter).

Shipboard work must be complemented and extended via remote time-series measurements from both one-year and multi-year seafloor observatories equipped for basic measurements of conductivity, temperature and depth (CTD meters), as well as other biogeochemical sensors, Acoustic Doppler Current Profilers (ADCPs), water samplers, and sediment traps (continuous and event-driven).

The National Data Buoy Center operates Coastal-Marine Automated Network stations with locations along coastlines throughout the US including 7 in Alaska. The network typically provides hourly observations of air temperature, barometric pressure, wind speed, wind direction, and wind gust. Some stations also provide obser- vations of sea water temperature, water level, waves, relative humidity, precipitation, and visibility. These categories of stations should be also be implemented along the Russian coastlines of the Chukchi Sea.

What are the key research questions that can be addressed with this integrated observing system? I think the European Seas Observatory Network (ESONET) provides some helpful guidance through their Science Objectives: To what extent do seabed processes influence ocean circulation, biogeochemistry, and marine ecosystems? For example, my understanding is that offshore permafrost zone processes may be responsible for the main silica input to the Arctic Basin.

How are physical and biogeochemical processes that occur at differing scales related? What aspects of physical oceanography and biogeochemical cycling will be most sensitive to climate change? What will the important feedbacks of potential ecological change be on biogeochemical cycles? What are the factors that control the distribution and abundance marine life and what will the influence of anthropogenic change be? Overall and regional changes in productivity as affected by changes in meteorological, oceanographic, hydrological, and biogeochemical boundary conditions.

Some things to think about Alan Springer, University of Alaska Fairbanks and Alaska SeaLife Center ams@ims.uaf.edu

A. What are the questions? Is this program intended to simply observe the flux of properties from the Pacific to the Arctic through Bering Strait, or in addition, to monitor regional ecosystem processes important to the maintenance of this world class biological hot spot? The latter in the contexts of science, conservation, management? e.g., are there long term changes in:

1) volume transport in the Anadyr and Alaskan Coastal currents? 2) nutrient inventory of Anadyr Water? 3) physical characteristics of the water masses (Anadyr Water, Alaskan Coastal Water)? 4) primary and secondary production in the Bering Strait region? 5) biomass of zooplankton advected in the Anadyr and Alaskan Coastal currents? 6) abundance of seasonally resident vertebrates (fishes, birds, mammals)? 7) predator-prey relationships?

B. Geography is everything—a comprehensive observation program for the Bering Strait region must observe all of the ecoregions. 1) The overall spatial domain of the "Bering Strait region" must be defined. In important ways it lies from St. Lawrence I. to the southern Chukchi Sea, and from coast to coast. 2) The program must be international, as arguably the most important, certainly the most prominent, ecoregion—the Anadyr Current system—lies largely in Russian waters. It simply is not possible to adequately monitor transport and properties of the AC from east of the convention line. A great proportion of marine mammal and seabird populations live in and move through the western part of the region. 3) Appropriate pulse points must be identified. E.g., inflow through Anadyr Strait and Shpanberg Strait, out flow through Bering Strait, the ISHTAR Pt. Hope line extended to the Chukotka Peninsula. There must be an accounting approach to estimate the real contribution of Pacific stuff to the Arctic/Atlantic—all that enters the system through Anadyr Strait and Shpanberg Strait does not pass through Bering Strait, and all that passes through Bering Strait does not enter the Arctic Basin. But, there is also aug- mentation, e.g., POC. 4) The flow of Anadyr Water is a big deal but not the only deal. The Alaskan Coastal Current dominates the inner shelf—species and food webs there are important to coastal residents. Physical and biological variability in both regions matters to biomass yield.

C. What matters most to people who live there? 1) marine mammals; 2) seabirds; 3) other

D. What tools do we have? e.g.: 1) chemical biomarkers, such as isotopes, fatty acids, combinations that can tell us about carbon sources, connectivity in food webs, response to environmental change. 2) upper trophic level species that can tell us about ecosystem variability and change? e.g.: a) walruses – diet and fecundity as indicators of benthic production and foraging strategies b) least auklets – diet as indicator of transport of oceanic zooplankton. c) seabirds as indicators of ACW food web productivity d) pinniped and cetacean distribution, abundance, and diet as indicators of changing pelagic and benthic production regimes and community structure.

Bering Strait Observations Workshop: Need for community-based observations in the face of climatic and ecological change

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A comprehensive environmental observation system in the Bering Strait region must involve a robust community-based observation system. Human populations in the Bering Strait region have been almost entirely dependent upon marine mammals, in particular walrus, and have learned to maintain a sustainable balance with their food supply. As such, these communities have already demonstrated that they possess the "infrastructure" needed for implementation of a sustained, long-term Bering Strait environmental observing system. Community-based monitoring programs will be able to provide meaningful data on factors such weather (sea state), sea-ice conditions, and marine ecosystem health as documented through subsistence harvest of bowhead whales, walrus, ice seals, and fish.

CIFAR, the NOAA-supported Alaska regional cooperative institute, administers 5 of the "Russian-American Long-Term Census of the Arctic (RUSALCA)" projects. We also administer several NOAA projects that seek to improve NOAA's forecasting capacity in coastal regions in Alaska with regard to waves and extreme winds from storm events.

Because of CIFAR's position within UAF and our focus on two-way education and outreach between coastal communities and University-based researchers and state and federal managers, we hope to entrain local observers including high school students as part of the Bering Strait Observations network. We expect to begin modestly by purchasing one or two free-floating buoys to measure real-time wave parameters and train a community teacher and interested students in maintaining the instrument, making concurrent observations (for example, documenting with digital photographs bluff or beach erosion or uplift of sea ice accompanying major storm wave actions), and interpreting the data.

Unlike most research projects that have funding durations of several years, community-based projects can become fiscally self-sustaining providing the implementation stage is well-planned and sufficiently funded for an adequate duration to allow two-way communication between the community observers and University researchers to be firmly established on both ends. University researchers need to actively solicit input on the design of the monitoring project so that it fits within the time line of other necessary community activities and meets community concerns. Community observers will need to be willing to make a long-term commitment to maintaining observations that will be valued both locally and regionally in the face of climatic and ecological change. Resilience and adaptation to change must be based on knowledge and Bering Strait communities have a record of sustained observations that can augment ongoing research programs in the Bering Sea.

An Ocean Observing System for the Bering Strait, the Pacific Gateway to the Arctic – an integral part of the Arctic Observing Network Rebecca Woodgate, Tom Weingartner, Terry Whitledge, Ron Lindsay"

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Background: The narrow (~ 85 km wide), shallow (~ 50 m deep) Bering Strait is the only ocean gateway between the Pacific and the Arctic Ocean. The throughflow, although small in volume (~ 0.8 Sv northwards in the annual mean), has a startlingly strong impact on the Arctic system:

- it provides ~ 1/5th of the oceanic heat input to the Arctic, is a driver of the seasonal melt-back of ice in the Chukchi/western Arctic, and is a subsurface heat source for over half the Arctic Ocean; - it is a highly variable source of freshwater, contributing 1/3rd of the freshwater input to the Arctic; and

- it carries the most nutrient-rich waters entering the Arctic Ocean, fueling Arctic ecosystems.

Draining the Bering Sea Shelf to the south, the throughflow provides an integrated measure of Bering Sea change, dominates the hydrography of the highly productive Chukchi Sea, and (models suggest) influences the North Atlantic overturning circulation and possibly world climate.

Recent measurements of the Bering Strait fluxes find strong seasonal and interannual variability, so far unpredictable – the heat flux increase from 2001 to 2004 is enough to melt an 800 km by 800 km area of 1 m thick ice, and the internannual variability in freshwater is likely ~ 30%. Yet, our understanding of what sets the properties and variability of the throughflow is still rudimentary, and our ability to measure these fluxes accurately is constrained by lack of data, both from the most nutrient-rich western half of the strait (which lies in Russian waters), and from the upper water column (due to potential ice-keel damage to instrumentation), where stratification and coastal boundary currents (especially the Alaskan Coastal Current in the eastern channel) contribute significantly to freshwater and heat fluxes.

Given the significant role of Pacific waters in the Arctic, quantifying the Bering Strait throughflow and its properties is essential to understanding the present functioning of the Arctic system, and the causes and prediction of present and future Arctic change. This makes a Bering Strait monitoring system a vital component of the Arctic Observing Network (AON). We have currently under review at NSF as a proposal for an international project to:

1) measure the velocities and water properties of the Bering Strait throughflow, and quantify oceanic fluxes of volume, freshwater, heat and nutrients through the strait; 2) design (and calibrate) an optimum monitoring system for oceanic fluxes through the Bering Strait on daily to interannual time scales, using in situ, satellite, and numerical weather prediction results; 3) utilize the system design to improve and extend previous Bering Strait flux estimates back several decades and provide uncertainties estimates for all fluxes.

To obtain the necessary data to design and calibrate an effective, efficient monitoring system for the strait, the project focuses on a 3-year deployment (2010-2013) of an 8- mooring array, supported by annual CTD surveys, satellite data, and model winds. The array includes upper and lower layer temperature, salinity and velocity measurements in both channels of the strait and at one "climate" site to the north, and across-strait pressure measurements.

A Future monitoring scheme: All indications at present are that a monitoring system for the strait needs to include in situ moorings. For velocity, we suspect a few moorings will be sufficient, since the flow is well correlated within the strait. (Note that inferring the flow from winds alone frequently misses the large flow events and underestimates southward flow events. Also, use of satellite altimetry only gives the variability of the flow, and that only in ice-free months.) Further analysis is needed to determine an optimum strategy for temperature and salinity, although we suspect this will require both deep and shallow in situ measurements possibly supplemented with satellite surface temperature data, with likely mooring(s) dedicated to the Alaskan Coastal Current. Such moorings would also provide an excellent platform for other measurements, such as measurements of nutrients and pCO_2.

Impact of Polynya and cold water mass in North Bering Sea on the Bering Strait throughflow

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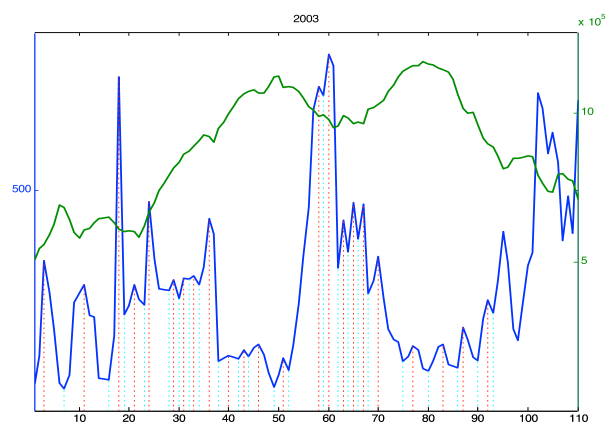
The Bering Strait throughflow is a key factor in influencing the ice cover and upper ocean of the Arctic, which brings the Pacific-originated water with higher temperature and special components. The pacific water is with multiple origins, complicated structure, and intraseasonal variation. Our interests are focused on following three aspects. Winter polynyas in north Bering Sea is important to the heat flux through air-sea interface, vertical convection, and cold water mass formation, and provides the habitat for some sea birds. Although satellite remote sensing provides continuous images to reflect spatiotemporal variation of polynyas, the quantified description for their varying position, area, and concentration is still difficult. The concept of "equivalent open water" was proposed to describe the polynyas. The total area of ice covered area is divided into two parts, one is the compressed ice with ice concentration 1, and the other is the open water with ice concentration 0. The latter is defined as the equivalent open water (EOW). The area of EOW is the same with that of the real polynyas. Usually, the ice concentration makes it difficult to distinguish the polynya and pack ice if the ice concentration is higher. EOW, however, can display the absolute area of all polynyas, which is significant in estimating the physical and ecological action of polynya. EOW clearly describes the seasonal variation and annual difference of the Bering Sea polynyas.

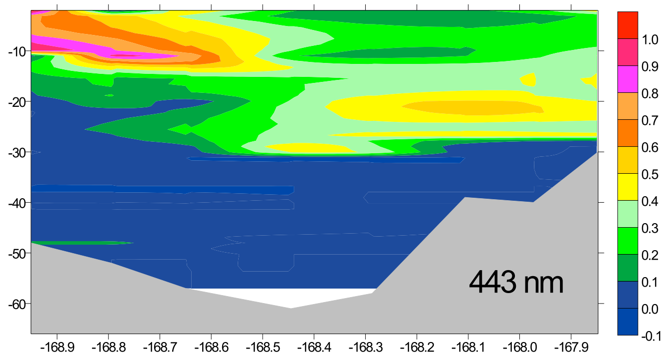
Cold water masses in summertime is a typical phenomenon in North Bering Sea. It appears at depths of 50 m or more and covers a large of area on the deeper part of the continental shelf. The cold water mass originates from the winter polynyas as a vertically uniformed water column. In the ice melting season, the upper part of the cold water is modified significantly, and the cold property of the water in deeper waters is retained. The cold water mass is a component of the Pacific-origin water and has an influence on water masses in the Arctic Ocean. In recent years, frequent observations in the north Bering Sea provides information on this cold water mass and its seasonal variation.

Optical properties are also useful observation parameters. Waters with the same temperature and salinity might have different optical properties, as affected by chemical components and suspended particles. These optical differences can be used to distinguish water masses. Also these observations can reveal the modification of water mass property caused by biological processes as they respond to solar radiation.

China will conduct Arctic cruises in 2010, 2012, and 2014. We have opportunities to undertake observations in the Bering Strait area when we enter and exit the Arctic, which is satisfactory for measuring summertime variation. We would like to join other cruises in spring and autumn to gain a more complete understanding of intraseasonal variation of Pacific origin water.



Variation of EOW area (blue) and compressed ice area (green)



The optical section across the Bering Strait along 64°20′N