

extrapolation, since the practice of log linear extrapolation also assumes that reentrainment is negligible.

The examples shown here demonstrate that the process of colloid filtration during transport through environmental porous media is surprisingly complex, requiring direct visualization, measurement, and simulation techniques to investigate pore-scale processes governing filtration under environmental conditions.

Acknowledgments

This work was funded by a grant from the U.S. National Science Foundation's (NSF) Hydrologic Sciences Program (EAR 0087522). Any opinions, findings, conclusions, or recommendations expressed in this material are

those of the authors and do not necessarily reflect the views of NSF

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MEETINGS

Objectives for a Cabled Observatory in Alaska's Beaufort Sea

PAGES 177, 182

Study of the Arctic Ocean is limited by the sea ice and harsh weather that prevent access through much of the year. These constraints have restricted data acquisition in the past and obscured understanding of events, processes, and variability of the environment of the Arctic Ocean. Breaching this isolation can be achieved through the use of new technologies and the adaptation of existing instrumentation to monitor the shelf and basin independent of surface conditions.

Through much of its history, Arctic oceanography has been dedicated to the study of large-scale seafloor structure, ocean circulation, and hydrographic structure. Recently, expedition-based observations have been augmented by moored or ice-tethered instruments that provide year-round observations during the span of their deployment. With increased knowledge collected over an extended period, variability has become apparent but is not well understood. Permanent seafloor instrumentation is the only way to understand this variability (seasonal and annual) in the context of what may be rapid climate change (annual to decadal).

The scientific potential of a cabled seafloor observatory in the Arctic was explored by participants of a U.S. National Science Foundation (NSF)-funded open workshop, "Science and Education Objectives for a Seafloor Cabled Observatory on the Beaufort Shelf, Alaska," held early this year. Thirty-two people representing academia, government, private industry, and citizens of Barrow, Alaska, participated.

Discussions of what permanently installed seafloor instrumentation could accomplish for science and for Barrow ranged widely

across the broad spectrum of disciplines including chemical, biological, and physical oceanography; geology and geophysics; and marine mammal and ice canopy studies. The key questions and problems addressed included, How would a cabled observatory for Arctic studies be designed? Where and how it should operate? What are the current engineering and science constraints for this facility in the Arctic? What are the science and education objectives for such a project?

The Beaufort Sea Shelf is a Key Location

Barrow, Alaska, which is located at the juxtaposition of the Chukchi and Beaufort seas, is ideal for investigating oceanographic processes pertinent to basin-scale and regional processes. The Beaufort and Chukchi shelves are heterogeneous environments, characterized by complex oceanography that dramatically affects the local ecosystem. Because this region is particularly sensitive to climatically driven environmental changes, understanding the variability and the linkages between and within the atmosphere and the ocean are necessary to constrain change, to predict how it will evolve over time, and to develop plans to mitigate the consequences to local communities.

The regional oceanography sets the stage for this facility. The shelf environment is heterogeneous and highly variable, dictated by the interaction between shelf, slope, and basin currents. These currents include flow through Barrow Canyon, complex and poorly understood boundary flows along the continental slope, and the Beaufort Gyre, which dominates circulation in the Canada Basin.

The connections among these current systems result in mixing and exchanges between the shelf and the basin. This complex interaction is influenced by water mass modification processes associated with the annual freeze/melt cycle, by winds, and by the steep and complicated bathymetry. The various currents transport organic material and nutrients between regions, which affects ecosystem structure, function, and chemical cycling. Very little is known about these ecosystems, particularly with respect to seasonal variation. Observing these changes beneath the ice, and through the fall and spring seasons, is not now possible. Permanent installation of oceanographic sensors on the seafloor would make study of these complex processes possible.

From the science and instrumentation talks at the workshop, three scientific foci emerged as priorities for the cabled observatory location:

- Barrow Canyon is a conduit for water and marine mammals into the deep Arctic Ocean. Monitoring of the transport of water and sediment, and of animal migration, through the canyon was seen as necessary to understanding the regional shelf-slope transfer.
- Hanna Shoal, east of Barrow Canyon and north of Point Barrow on the Beaufort Shelf, is a relatively shallow portion of the seafloor. Flow separation between the eastwardly flowing Pacific Ocean water and the much larger Beaufort gyre shifts across the shoal. Sea ice also advances and retreats across the shoal. Both of these complex events can be difficult or dangerous to observe from the surface.
- Canada Basin, the deep water north of the Beaufort Shelf, would make it possible to monitor the Beaufort Gyre and provide a quiet location for seismometers and cross-basin acoustic tomography.

A suite of oceanographic instrumentation was proposed that would provide valuable insights into a wide range of physical, biological, chemical, and geological properties, and that would take advantage of the infrastructure capabilities of a cabled observatory (kilowatts of power and gigabit-rate data transmission).

For example, passive acoustic monitoring would support comprehensive and continuous

surveys of marine mammal populations and various tomographic studies. Active acoustic instruments would enable study of the seabed, currents, plankton distribution, and the underside of the ice canopy, including ice thickness. Sophisticated chemical (e.g., nutrient analyzers) and biological (e.g., flow cytometers, video and optical plankton recorders, and benthic samplers) sensors that require high power and collect large volumes of data could be deployed, as well as more traditional biological sensors (e.g., pH, oxygen, fluorescence, and light). Perhaps the greatest potential for this facility is the variety of synoptic measurements that could be made to study coupling between the various oceanographic processes and marine life.

Observing these complex processes cannot easily be done even with access to unlimited ship time. Addressing the critical science issues raised by the heterogeneous processes seen in the Arctic Ocean and observing ongoing climate change throughout the four seasons will only be accomplished with a cabled seafloor observatory.

Continuous real-time observations of the shelf environments off Barrow would also create a wide range of formal and informal educational opportunities. These could support innovative education projects with native Alaskan populations and open a window on the Arctic Ocean to the world. Also, from a practical perspective, real-time information regarding oceanographic conditions off Barrow (e.g., currents, wave height, ice cover) would enable local residents to make informed decisions about the weather and ocean conditions.

This facility would augment ongoing programs and other projects in development. The Western Arctic Shelf-Basin Interactions Project (SBI; <http://sbi.utk.edu/>), sponsored by NSF and the U.S. Office of Naval Research, has conducted extensive oceanographic surveys across the northern Alaskan shelf over the last three years, and would be enhanced by year-round access. A cabled seafloor observatory

literally would open our eyes to how the water column and seafloor are changed by variability of currents and the annual formation and loss of sea ice. The Study of Environmental Arctic Change (SEARCH; <http://psc.apl.washington.edu/search/>) multi-agency initiative led by NSF would also be augmented by this facility, which would extend the program's monitoring into the water column.

The Ocean Observatories Initiative (OOI; <http://www.orionprogram.org/OOI/default.html>), developed by NSF's Ocean Sciences Division, is moving forward to develop a plan for ocean observatories throughout the U.S. exclusive economic zone (EEZ) and beyond. As a part of that process, the OOI management has solicited Request for Assistance (RFA) letters and proposals for particular cabled seafloor installations to establish the scope of the project. An RFA letter has been submitted requesting the technical support of the OOI program in adapting observatory technology to the Arctic environment.

Barrow, Alaska and the Beaufort Shelf

Barrow is an exceptional place to support an exceptional facility. The existing instrumentation, much of it permanent, installed and operated by U.S. government and research groups, daily generates an extensive data set on atmosphere, land, and ocean surface conditions. Coupling these observations with synchronized observations of the seafloor, water column, and water surface (frozen or not) would make comprehensive monitoring of the northern Alaskan environment a reality. This would be a conceptual leap beyond the "investigator who brings an instrument" model, and make it possible to observe correlations between processes independent of any discipline. This integrative observational capability would substantially enhance, and could be the centerpiece of, the Barrow Global Climate Change Research Facility.

There are few locations where ocean processes (weather, ice, biology) are so intimately connected to the local human communities as in the Arctic. Whaling and other subsistence activities are part of the physical and spiritual sustenance of the local Iñupiat population. Already, through rapid beach erosion and changes in the distribution of plant and animal species, the effects of change are evident across northern Alaska. A seafloor cabled observatory would give the world a window on this critical part of the Arctic Ocean and the tools to integrate observations of the water column, the seafloor, and the underside of the ice with the thousands of years of empirical knowledge possessed by the native peoples of northern Alaska.

The Science and Education Objectives for a Seafloor Cabled Observatory on the Beaufort Shelf, Alaska Workshop was held in Barrow, Alaska, 7–8 February 2005.

Acknowledgments

We gratefully acknowledge contributions from all workshop participants, in particular the keynote speakers. Carin Ashjian and Margo Edwards provided helpful reviews. Financial support was provided by the NSF Office of Polar Programs through Collaborative Grants OPP-439107 to the University of Alaska Fairbanks, OPP-0438100 to Lamont-Doherty Earth Observatory, and OPP-0438102 to Woods Hole Oceanographic Institution.

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