NOPP: Circulation, Cross-Shelf Exchange, Sea Ice, and Marine Mammal Habitats on the Alaska Beaufort Sea Shelf

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LONG-TERM GOALS

Our long-term goals are to understand how the physical oceanography, sea-ice dynamics, and marine mammal utilization of arctic shelves will change in response to a diminishing ice cover. We thus seek to understand better the wind-forced response of the shelf and shelfbreak and the cross-shelf exchange of mass, materials, and momentum. These responses will likely affect the use of arctic shelves by marine mammals. We are applying several recently developed technologies to an arctic shelf in synergistic ways, including passive acoustic recorders, moored profiling CTDs, autonomous underwater vehicles, shore-based current mapping radars, and geophysical processing tools to determine ice displacement and deformation. These bear on another long-term goal which is to demonstrate the applicability of these technologies to other arctic shelves.

OBJECTIVES

Predicting how arctic shelves will adjust to changes in ice conditions requires that we address several critical unknowns pertinent to the present-day functioning of arctic shelves. These unknowns motivate our specific proposal objectives, which are to determine:

1. The annual cycle of shelf circulation and stratification,
2. How circulation and stratification change across the shelf due to variations in sea-ice distribution, river runoff, and winds,
3. The seasonal and synoptic variations in the exchange of mass, momentum, and water properties across the shelf, and
4. How marine mammal occurrence on the shelf and slope varies in response to seasonal and synoptic changes in winds and ice-cover.

APPROACH AND WORK PLAN

To attain these objectives we will conduct in-situ measurements and retrospective analyses of historical data, which, in aggregate, encompass a broad range of space and time scales. The observational components and the investigators primarily responsible for each of these are:

1. a cross-shelf array of moorings and the occupation of CTD sections (Pickart and Weingartner);
2. high resolution hydrographic/velocity surveys from the REMUS, an autonomous underwater vehicle (AUV) (Plueddemann);
3. high-frequency (HF) surface current mapping radars (Weingartner);
4. autonomous acoustic recorders for marine mammal vocalizations (Moore and Stafford); and
5. satellite-derived estimates of sea ice concentration, displacement, deformation, and characteristics of the sea surface (Holt and Kwok).

Field work began in August 2008 and consisted of the deployment of moorings, the occupation of CTD sections, and REMUS surveys. The moorings (including the acoustic recorders) will be in place for a complete annual cycle and will be recovered in August 2009, when additional CTD and REMUS surveys will occur. Winter and spring 2009 activities will focus on satellite data collection and analyses, processing AUV and CTD data sets from summer 2008, preparing for the 2009 field effort work, and retrospective analysis of historical physical oceanographic data from the Alaskan Beaufort

Sea (ABS) shelf. The field program is occurring on the central ABS shelf, offshore of the Colville River, and is centered on the cross-shelf oceanographic mooring array (Figure 1).

WORK COMPLETED

From August 5 – 16, 2008, we successfully deployed 17 moorings (Figure 1), occupied 3 CTD transects, and several AUV transects (Figure 1). The moorings are from three separate programs: two funded under the auspices of NOPP (one being this project and the second the "Episodic Upwelling of Zooplankton within a Bowhead Whale Feeding Area near Barrow, AK" led by Dr. Carin Ashjian of Woods Hole Oceanographic Institution) and a third the ONR-supported Ice Covered Response to Atmospheric Storms (ICORTAS) project led by Dr. Harper Simmons of the University of Alaska.

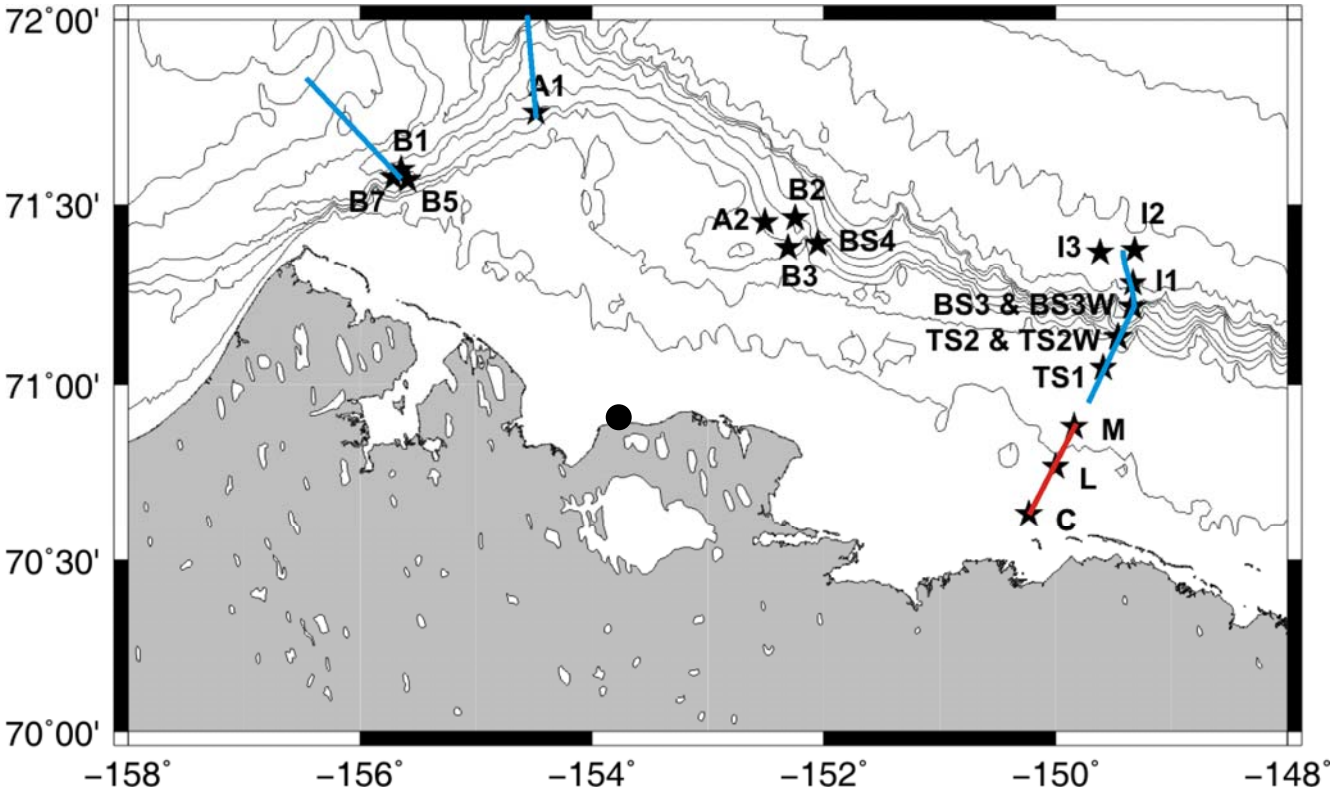

Figure 1. Location of current meter and/or passive acoustic (marine mammal) recorders moorings deployed in August 2008 from the USCG icebreaker *Healy* and the *R/V Annika Marie*. The red line shows one of the AUV transects on the inner shelf and the blue lines are CTD transects. The black circle shows the approximate study location of Dr. Cameron Wobus's NOPP project addressing coastal erosion.

Moorings C, L, and M were deployed on the 13, 20, and 28 m isobaths on the inner-shelf from the *R/V Annika Marie*. These moorings have an ADCP and a temperature-conductivity-pressure recorder with all instruments within 1 m of the seabed to avoid damage from deep ice keels.

Moorings TS1 and TS2 are on the 35 and 45 m isobaths, and moorings BS3 and BS4 are deployed near the shelfbreak. Each of these contains an Arctic Winch, which profiles from the bottom or 50 m depth (whichever is deeper) to the surface once a day. Moorings BS3 and BS4 also include moored profilers to capture the vertical T/S structure between the bottom and 50 m depth. The ICORTAS array is deployed on the 1265, 1865, and 1665 m isobaths. In aggregate, the cross-shelf and slope array will

provide an unprecedented data set for examining arctic shelf processes from the nearshore (land fast ice zone) to the deep slope (pack ice). Mooring BS4 was deployed at the shelfbreak along 152°W, west of the main mooring line. This site was previously occupied by Pickart's moorings from 2002 – 2005. Mooring BS4 adds to that time series and provides a temporal context for interpreting the results from our NOPP array. The cross-shelf array is completed by whale recorders (moorings TS2W and BS3W), to enable interpretation of marine mammal recordings in conjunction with the physical oceanographic data.

The other moorings in Figure 1 are part of Ashjian's program and consist of marine mammal recorders (B1, B2, B3, B5, and B7) and marine mammal recorders in combination with current meters (A1 and A2). The complete mooring array provides good along-stream/shelf coverage of the circulation, water properties, and marine mammal calls over a distance of 200 km and cross-shelf coverage over a distance of 100 km. In addition, the two sets of marine mammal recorder triads (B1, B7, B5 and B2, B3, and A2) allow estimates of source levels of whale calls and an index of the number of animals calling at any one time.

The planned HF radar installation had to be cancelled for this summer because a large drill rig was placed near one of the planned radar sites in July. This obstruction, along with planned oil field construction activities, risked damage to our installation and/or a time-varying RF environment that we could not control or measure. There was not enough time to find another site and acquire the requisite permits for site use by the time we were informed of this development. We are instead planning to deploy an HF radar installation in Barrow, Alaska, in summer 2009.

RESULTS

Figure 2 shows temperature and salinity distributions across the shelf composited from the AUV data and *Healy* CTD stations. The section is synoptic, since both operations were conducted on the same day. The gap between the sections is due to AUV battery problems that limited its offshore range. The section was occupied several days after strong westerly (downwelling-favorable) winds abated and during the buildup of moderate (5 – 10 m/s) easterly (upwelling-favorable) winds. During most of the summer, weak upwelling-favorable winds blow along this shelf, and summer 2008 appears to have been typical in this regard. There are numerous interesting features in the cross-section. Two bands of very warm water (>4^{o}C) exist in the upper 10 m, one inshore and one near the shelfbreak. Nearshore waters are likely riverine in origin and appear to be embedded in alongshore flow with substantial vertical shear. Warm offshore waters are of uncertain origin. They may be part of the shelfbreak jet that includes the eastward extension of the Alaska Coastal Current, which is advecting warm water throughout the upper 40 m. Alternatively, some of this warm water may be associated with Mackenzie River plume waters that have spread eastward through the summer (as evident in satellite imagery from July 2008; not shown). Over the shelfbreak, at about 35 m depth and between CTD stations 36 and 38, there is a ~10 km wide tongue of relatively warm (0 – 1°C) water that may represent a spawning eddy. Also of interest is the presence of a bottom-trapped "cold pool" on the mid-shelf. This pool likely originated from offshore and was transferred onto the inner shelf during a prior upwelling event. Such shelf-basin exchange processes are central to the goals of this NOPP project.

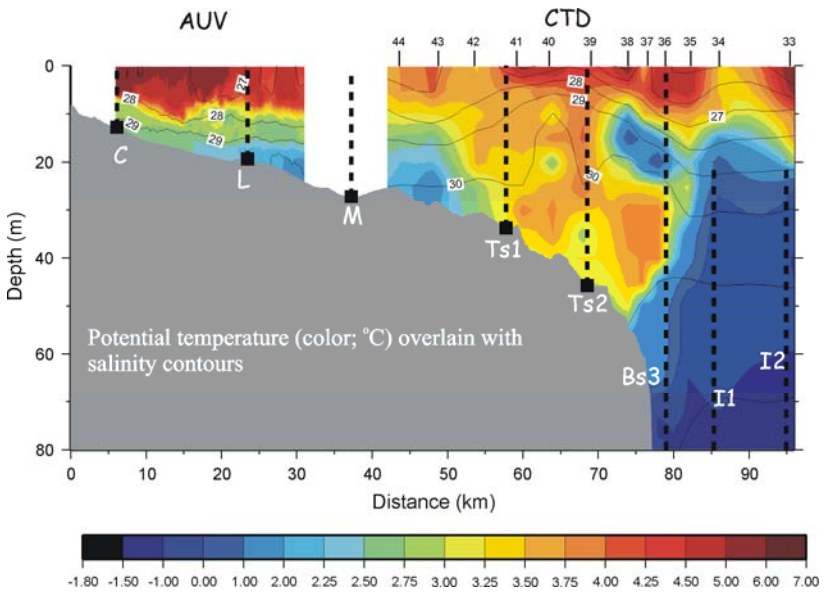

Figure 2. Cross-shelf distribution of potential temperature (color) and salinity (contours) along the mooring line. Mooring positions are indicated by the vertical dashed lines.

IMPACT AND APPLICATIONS

National Security

Reduced ice cover has implications for National Security and Homeland Defense, including increased marine development and exploration, new shipping routes, and increased prominence of the USCG in the Arctic. This research will provide information useful for navigation, search and rescue, and minimizing potential hazards due to marine industrial development.

Economic Development

This project has indirect economic development influences on the offshore Alaskan oil industry and adjacent communities. This is reflected in the increased interest by industry in offshore exploration and development in offshore waters in northern Alaska. Our data will contribute to environmental and engineering designs. The economic importance of this effort is recognized by Shell Oil Inc., which has provided $184,000 additional funding to the project. We have alerted numerous industry and governmental entities about this project, and, in response, we have been informed of additional marine mammal recordings being made throughout the Beaufort and Chukchi seas. Ongoing discussions suggest that Drs. Moore and Stafford will be able synthesize many of these data sets to develop a more comprehensive understanding of marine mammal usage of these shelves. Figure 3 shows the distribution of recorders whose data are likely to be synthesized as a consequence of these collaborative efforts.

Quality of Life

This project represents the most systematic effort undertaken to understand the oceanography of the ABS and its year-round use by marine mammals. Physical measurements provide a basis for understanding the marine ecosystem and how best to address potential environmental changes. Marine mammals are of primary importance to the subsistence communities along the Beaufort Sea coast.

Improved knowledge of marine mammal use of the shelf habitat will enhance management of these species by local communities and resource agencies.

Science Education and Communication

We anticipate several scientific papers will stem from this research. We will also prepare reports useful in developing oil spill response plans for the State of Alaska (see for example the report in http://www.ims.uaf.edu/beaufort/index3.html). We are starting work on project website similar to those developed for previous projects in which the PIs have been engaged. In addition we are participating in two meetings this fall where we will present aspects of the project. Both meetings include participants from industry, local community and municipal organizations, and state and federal government regulators. The first is the 11th Information Transfer Meeting sponsored by MMS and held in conjunction with the United States and Canada Northern Oil and Gas Research Forum. The second is the "Experts Workshop on Assessing & Reducing Environmental Risks in Offshore Oil & Gas Development" that will be held in Barrow in mid-November.

TRANSITIONS There are none at this time**.**

RELATED PROJECTS

This NOPP project will provide data for the evaluation of numerical models, headed by W. Maslowski of the Naval Post-graduate School, that seek to predict the response of the Alaskan coastal system to an ice-diminished Arctic. We have and will continue to collaborate via data sharing and logistics with Dr. Ashjian's project in the western Beaufort Sea. We will also share our oceanographic data with Dr. Cameron Wobus of the University of Colorado's Cooperative Institute for Research in Environmental Sciences. Dr. Wobus's NOPP project is looking at shoreline erosion in the western Beaufort Sea, and he has expressed interest in using our nearshore current measurements from the open water season in his project. His study site is indicated by the black circle in Figure 1.

As noted above, this NOPP project is establishing collaborations that will likely lead to a more comprehensive understanding of marine mammal utilization of these shelves. Dr. Weingartner is also a Co-PI on an MMS-funded project to assess marine fish distribution and abundances in the Alaskan Beaufort Sea. That project, led by Dr. Libby Logerwell of NOAA-NMFS's Alaska Fisheries Science Center's Status of Stocks and Multispecies Assessment (SSMA) Program, will provide estimates of abundance, species composition, and biological information of marine fish and invertebrates, oceanographic properties, and information on the macro- and micro- zooplankton communities. This survey was also conducted in mid-August 2008 and coincided with the shipboard efforts undertaken in this NOPP project. Figure 4 shows the location of CTD stations occupied during the fish survey. These data, along with the NOPP hydrographic data, have resulted in nearly synoptic hydrographic coverage of the western half of the Beaufort Sea shelf.

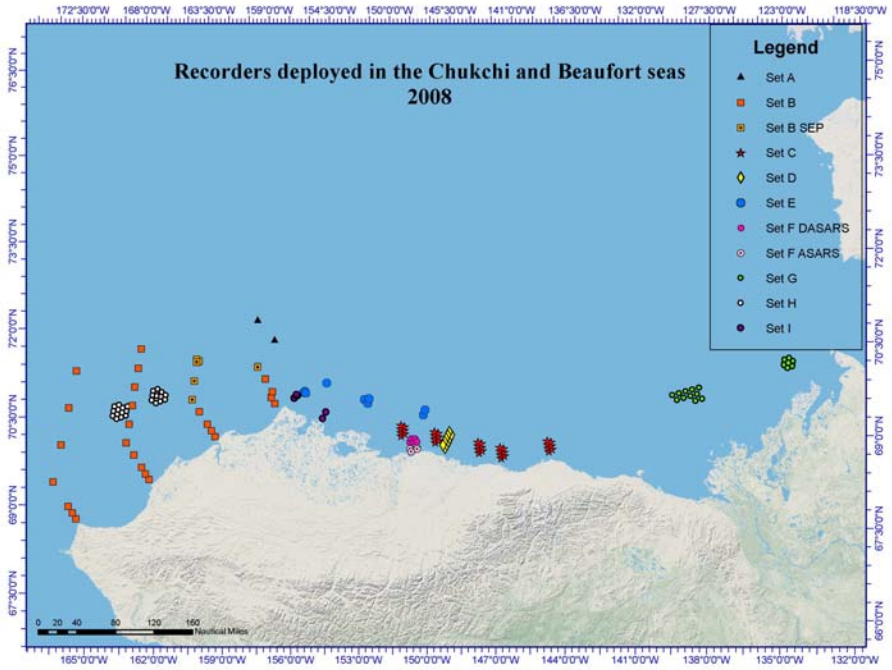

Figure 3. Distribution of marine mammal recorders in the Chukchi and Beaufort seas including those associated with the NOPP, the oil industry, and government agencies.

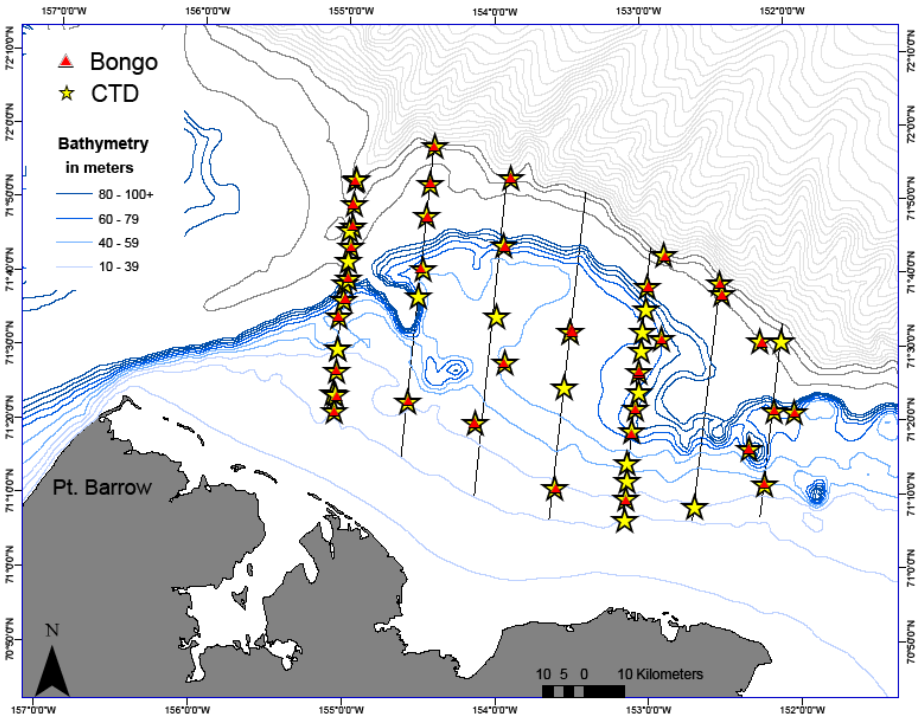

Figure 4. Location of August 2008 CTD and Bongo stations during the MMS supported fish survey in the western Beaufort Sea.