Episodic Upwelling of Zooplankton within a Bowhead Whale Feeding Area near Barrow, AK

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Award Number: N00014-08-1-0311

LONG-TERM GOALS

Our long term goals are to understand (1) the biological-physical oceanographic characteristics and mechanisms on the shelf near Barrow, AK that together produce a favorable feeding environment for the bowhead whale there and (2) the potential impact of climate change, particularly the ongoing reduction in sea ice and variability in Pacific Water presence near Barrow, on this feeding environment. This region is a critical feeding area for migrating bowhead whales, particularly during the fall migration (e.g., Lowry et al., 2004). Results from biophysical sampling conducted during August-September 2005- 2008 demonstrated that the oceanography of the shelf is complex, dynamic, and highly variable and that advection is closely coupled to the direction and magnitude of the winds. In addition, oceanographic and atmospheric conditions impact the composition, distribution, and availability of plankton prey for the bowhead whale. Assessment and understanding of interannual and longer-term variability in the physical mechanisms influencing ocean conditions and the resulting distribution and abundance of plankton on the shelf are necessary to predict potential impacts of climate change.

OBJECTIVES

Our overall objectives are to explicitly identify and document the occurrence, frequency, and persistence of wind-driven shelf-slope exchange events at the Barrow Canyon and the Beaufort shelf breaks during the summer and early fall in association with the presence of ice cover, water column stratification, and the presence of bowhead whales and to further document short-term and interannual variability in the ocean system and how this variability is associated with changes in climate and ice.

1. Document exchanges of Pacific Water and plankton/krill (acoustic backscatter as a zooplankton proxy) between Barrow Canyon and the adjacent Beaufort shelf over two full years.
2. Document shelf-slope exchanges between the Beaufort Sea and Beaufort shelf.
3. Determine the seasonal occurrence of bowhead whales in the study area via year-round sampling for marine mammal vocalizations using autonomous recorders.
4. Determine the correlations between exchange events and wind speed and direction, wind duration, ice cover, shelf water column stratification, whale presence or absence, and whale prey selection.
5. Conduct surveys along transects running across Barrow Canyon and across the shelf to ground-truth mooring observations and to continue the two-year time series of observations collected during the larger, NSF funded project to further describe interannual variability and hydrographic and associated biological characteristics on the shelf during early September and to provide critical information for validation of oceanographic modeling of the region.

APPROACH

This project is a partnership between the academic PIs listed above (Ashjian, Campbell, Okkonen, and Stafford), collaborators at Oregon State University (B. Sherr and E. Sherr), a collaborator at NOAA (S. Moore), and a collaborator at the North Slope Borough Department of Wildlife Management (C. George).

The objectives are being addressed through three main field approaches: Boat Based Oceanographic Sampling (Task 1), Year-Long Oceanographic Moorings (Task 2), and Bowhead Whale Prey Analysis (Task 3). Data analysis and presentation of results (Task 4) and Outreach (Task 5) are accomplished simultaneously with the three work approaches.

WORK COMPLETED

Boat-based oceanographic sampling was conducted in 2008 and 2009. This work continues through funding from NOAA/BOEM and the NSF Arctic Observing Network (AON) program; the 2011 field season finished on Sept. 20. The additional sampling will permit us to continue to understand oceanographic variability near Barrow, AK. The NOPP sponsored sampling of 2008 and 2009 is an integral part of that understanding. Analyses of these data are ongoing with the goal of preparation of two manuscripts (one focusing on interannual variability, a second on upwelling of whale prey).

Results of the analysis of interannual variability in biological and physical ocean conditions for 2005-2009 (inclusive of years funded by this project) were presented orally at the 2010 Ocean Sciences Meeting in Portland OR and at the 2011 Alaska Marine Sciences Meeting in Anchorage AK (Ashjian et al., 2010a, 2011).

Two year-long oceanographic moorings were deployed at 100 m of water along the shelf break (Fig. 1) for two years (August 2008 – September 2010), with deployments, annual servicing, and recoveries done during *USCGC Healy* cruises. Instrumentation on both moorings included an acoustics recorder to archive marine mammal vocalizations and microcat CT sensor to measure water temperature and salinity. The hydrophones were on a 30% duty cycle and recorded from 0.1-4.1 kHz from September 2008-September 2010. The western mooring (A1) was also instrumented with upward-looking Teledyne/RDI 300 kHz ADCP at 7-m above the bottom to aid in monitoring the movement of zooplankton between the slope and shelf and to describe current speeds and directions, particularly those associated with shelf-break upwelling events. Both years of marine mammal vocalization data from mooring A1 have been analyzed, only the first year from mooring A2 has been completed and the second is underway.

Bowhead whale prey analysis was conducted by C. George on whale stomach contents collected by C. George and local whalers during the IWC sanctioned fall whaling seasons of 2008-2010.

RESULTS

Ocean temperatures measured during the boat based oceanographic sampling in August-September 2011 were similar to those observed during 2005 and 2010 (Fig. 2), with warmest ocean temperatures at ~8°C. Significant year-to-year variability in the temperature-salinity characteristics in the study area has been observed over the seven years (2005-2011) (Fig. 3). Upwelling of water along the shelf-break under strong, sustained east wind, recurrently upwelled whale prey (euphausiids) on the shelf. If upwelling winds are followed by weak or south winds, the strong, northeastward flowing Alaska Coastal Current is moved up against the shelf break, blocking the dominantly westward flowing shelf water, forming elevated concentrations of euphausiids on the shelf (e.g., Ashjian et al., 2010b; Okkonen et al., 2011).

Bowhead (*Balaena mysticetus*) and beluga (*Delphinapterus leuca*) whales are the only Arctic endemic cetaceans that occur regularly in the Beaufort Sea. Each species winters in the Bering Sea and migrates northwards in the spring, returning south in the late autumn. Bearded seals (*Erignathus barbauts*) are a pan-Arctic species found in the Beaufort year-round. Bowhead whales vocalize using both calls and songs. There was distinct seasonal variability in the detection of the different species' calls/songs. Calls/songs from whale species were detected in fall and declined as ice concentration in the mooring vicinity increased (Figs. 4 & 5). In the spring, however, whale calls/songs were detected beginning in April when the region was still covered with ice, and continued throughout the summer. Bowhead whale song was only recorded in the early spring, from April until mid-May and detections of calls and songs progressed from west to east as spring turned to summer. Bearded seals were recorded at relatively low levels in the fall when there was no ice cover over either mooring (Fig. 6). They increased dramatically in late December and early January and were the dominant signal during winter when ice concentration approached 100%. Unlike the cetaceans, bearded seal signals decreased abruptly in spring as sea ice disappeared.

Bowhead whales use acoustic signals to maintain contact with each other, for navigation in dark, ice-covered waters, and, likely as a reproductive display by males in spring (Würsig and Clark 1983). The animals recorded on the two moorings are part of the Bering-Chukchi-Beaufort population that winters in the northern Bering Sea and summers, generally, in the Canadian Beaufort where food is reliably available. During both the northward and southward migration, whales pass through the western Beaufort Sea. The decrease in call detections in fall months at both sites can be attributed to the whales migrating west towards the Chukotka Coast before heading south to the Bering Sea for winter (Quakenbush et al. 2010). In the spring, whales migrate northwards, often in heavy ice, by using a series of flaw leads that form along the western coast of Alaska. The relatively poor resolution of the satellite data used to determine ice concentration (12.5 km) does not reflect the variability and dynamics of spring pack ice movement. Bowhead whale calls were detected on the western-most mooring only a day or two before the eastern mooring and suggest a steady migration to the east in both years.

Beluga whales are quite vocal animals, particularly during socializing and feeding. They are less so during migration. In this study beluga whale calls were detected in bouts that may be indicative of feeding behavior. In late summer-fall of both years, beluga whale calls were more frequently detected when the Alaska Coastal Current (strong current to the NE), containing warmer, fresher Alaska Coastal water, moves over the mooring, potentially forming a strong front between ACC and Arctic basin water further offshore where beluga prey are concentrated (Fig. 7). The beluga whales migrating north from the Bering Sea are thought to be from two separate populations: eastern Chukchi and eastern Beaufort. These two populations are thought to have different migratory timing with the eastern Beaufort animals migrating towards the Bering Sea up to two months earlier than the eastern Chukchi animals (Suydam et al., 2001). It is possible that the bouts of calling we recorded are from the different populations as they migrate past. At present, it is unknown if different populations produce calls that are unique to those populations.

Of the three species discussed here, bearded seals are found year-round in the Beaufort Sea. To date, evidence points to only males producing the trill calls we recorded and these are associated with reproductive displays. Males may defend territories that are in the vicinity of the ice edge with ready access to open water for hunting prey and ice for hauling out and resting. Bearded seals are known to display in the spring which is mating season but the relatively high number of detections in the fall was previously unreported. The fall calls appear to be shorter and somewhat higher frequency than spring calls suggesting that males, potentially juveniles, are "warming up" or practicing for the spring.

IMPACT/APPLICATIONS

Our work will provide a greater understanding of the physical and biological factors that produce a favorable feeding environment for the bowhead whale on the shelf near Barrow. This will permit educated decisions regarding development of industry, tourism, and commerce in this region by regulators and policy makers. The work also will provide greater insight into the potential impact of climate change on the Arctic ecosystem. In addition, the continued documentation of interannual variability of the ocean conditions is of both local (importance to shelf ecosystem) and broader importance since the region near Barrow is a critical juxtaposition of the Chukchi Sea and Beaufort Seas and is where much of the Pacific Water flowing through the Chukchi Sea from Bering Strait enters the Beaufort Sea, either through Barrow Canyon or from more western locations in the Chukchi Sea. The Pacific Water supplies heat, nutrients, and organic material including plankton (especially the krill that are the preferred prey of the bowhead whale near Barrow) to the Chukchi Sea and ultimately the Arctic Ocean.

RELATED PROJECTS

This ongoing project is a follow on to a previous National Science Foundation funded project examining "Oceanography, Bowhead Whale Distribution, Climate Variability, and Iñupiat Subsistence Whaling", with PIs including Ashjian, Campbell, George, Moore, Okkonen, Sherr, and Sherr for which fieldwork was conducted in 2005 and 2006. Many of the hypotheses being explored in this project resulted from data collected during the NSF project. The ongoing project also is a companion to two ongoing projects of ours: a NSF-funded Arctic Observing Network project to document interannual variability in ocean conditions near Barrow and a NOAA/BOEM project "Bowhead Whale Feeding in the Western Beaufort Sea" for which the PIs deployed short-term, shallow oceanographic and year-long marine mammal acoustic recording moorings and conducted additional oceanographic fieldwork during the summer of 2008 and 2009. Additional components of this larger project include aerial surveys of marine mammals/bowhead whales, long-term satellite tagging and short-term suction cup tagging of whales to determine migration paths and feeding behavior, and visual observations of whale behavior and locations from small boats. Together these projects provide a greater understanding of the oceanographic conditions off of Barrow as well as providing opportunities to sample over longer time periods in that region in order to better describe the impact of the strength and magnitude of the wind on upwelling along the Beaufort Shelf and the importance of this mechanism to providing prey on the shelf for the bowhead whale. The ongoing project also complements two other NOPP projects "Circulation, Cross-shelf Exchange, Sea Ice, and Marine Mammal Habitats on the Alaskan Beaufort Sea Shelf" led by R. Pickart and including Stafford and Moore as PIs and "A Comprehensive Modeling Approach Towards Understanding and Prediction of the Alaskan Coastal System Response to Changes in an Ice-diminished Arctic" led by W. Maslowski with J. Cassano and J.J. Walsh as co-PIs. The former project focuses on physical oceanography, upwelling, and bowhead whale distribution in a region further to the east of Barrow using a combination of year-long oceanographic and whale acoustic recorder moorings and field observations. Not only does the work of the Pickart NOPP project together with this project extend the spatial range of observations, field logistics were conducted in collaboration. For example, the Healy cruises that deployed moorings for this project also deployed the moorings for the Pickart NOPP in a very fruitful collaboration between the two projects. Several CTD casts were conducted near the Pickart NOPP moorings during the transit of the 2008 *R/V Annika Marie* from Barrow to Prudhoe Bay. The latter project applies state-of-the-art regional modeling of sea ice, ocean, atmosphere and ecosystem to provide a system approach to advance the knowledge and predictive capability of the diverse impacts of changing sea ice cover on the bio-physical marine environment of coastal Alaska. Hydrography acquired during surveys conducted from the *R/V Annika* Marie has been forwarded to Maslowski for comparison with model output.

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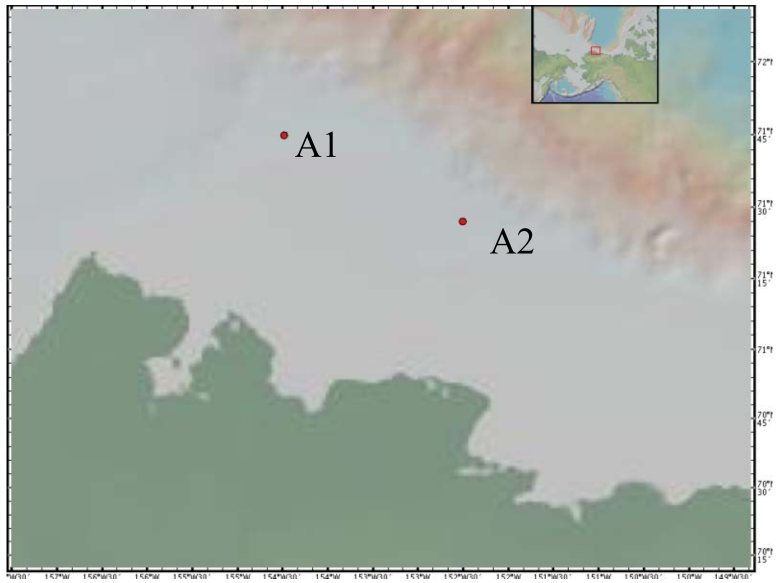

Figure 1. Locations (red circles) of moorings along the Beaufort Shelf break recovered during the 2010 Healy cruise.

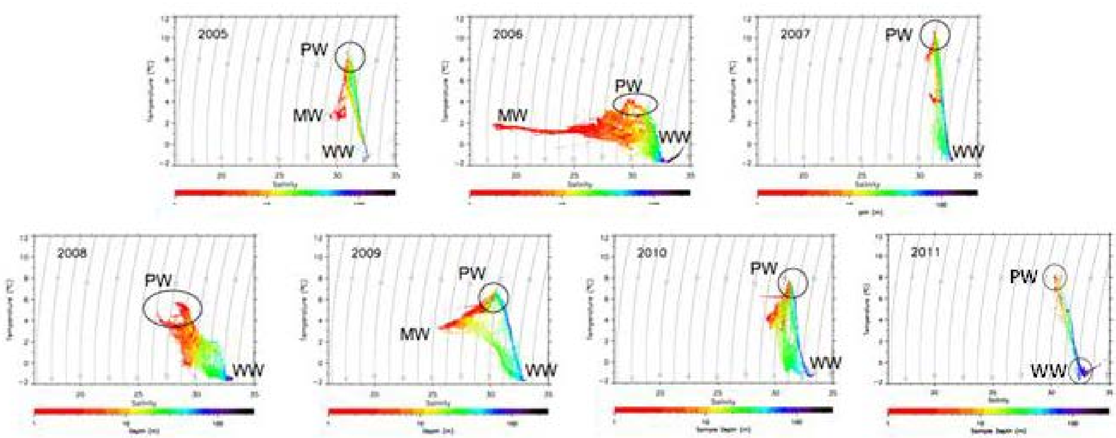

Figure 2. Temperature-salinity plots of each year's CTD data. Representative water masses are Pacific Water (PW), Winter Water (WW), and sea ice Melt Water (MW). Curved lines are isopycnals (constant sigma-t). Color indicates water depth at each data location. Highest Pacific Water temperature (~12 °C) was observed in 2007; lowest Pacific Water temperature (~4°C) was observed in 2006, with the greatest amount of sea ice Melt Water also seen in that year.

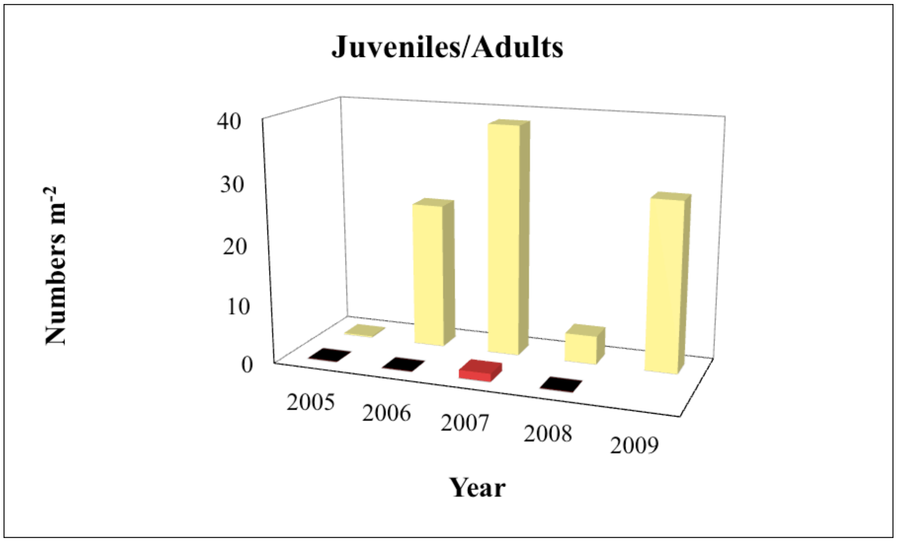

Figure 3. Abundance of bowhead whale prey (juvenile and adult euphausiids) on the shelf near Barrow following an upwelling/concentrating event (yellow) and before such an event or after the relaxation of the concentrating mechanism (red). Not all conditions were sampled in all years. Elevated concentrations of whale prey were observed on the shelf after upwelling east winds were followed by low or south winds.

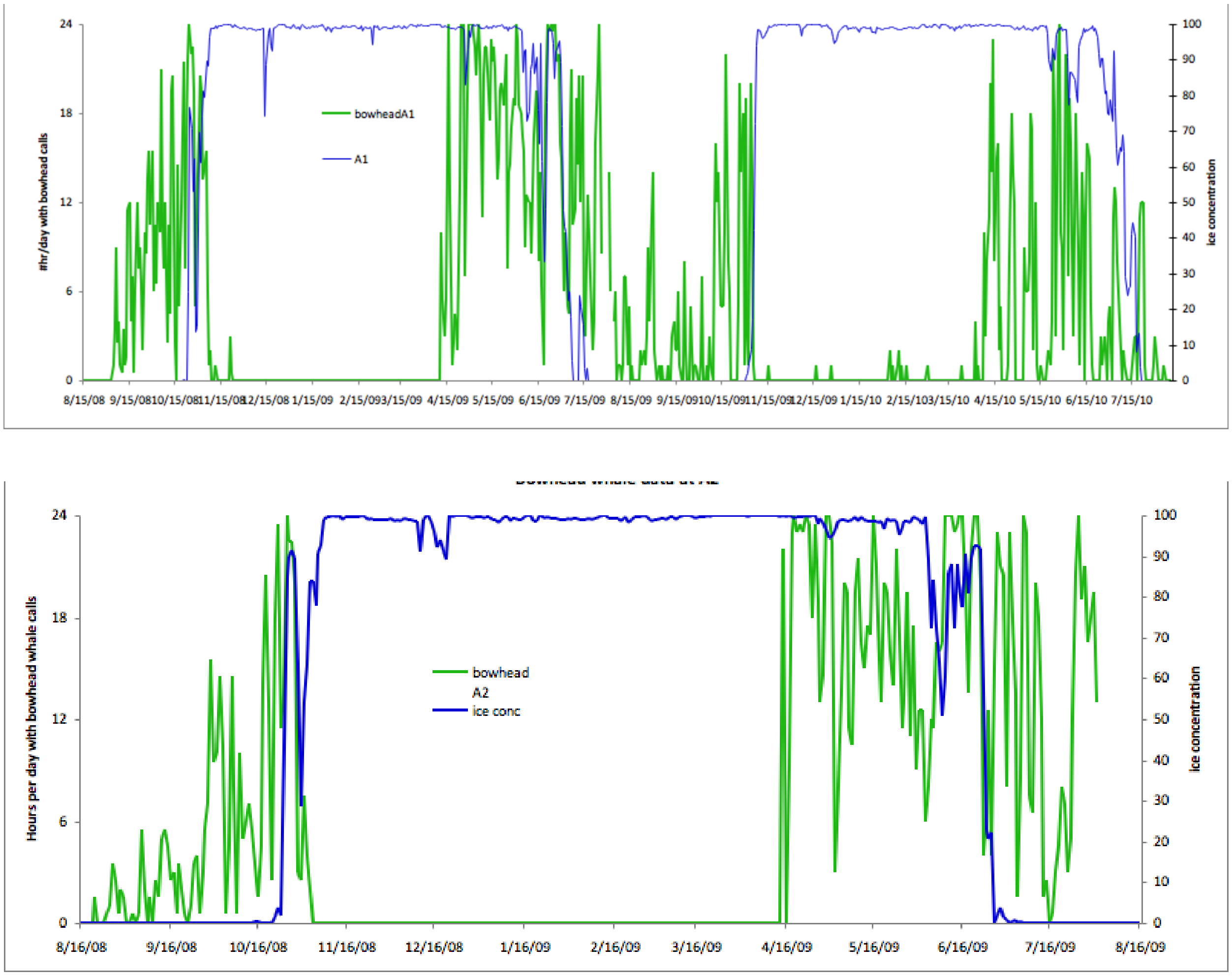

Figure 4. Number of hours per day with bowhead whale call or song detections (green line) and ice concentration (blue line) within 30 km of mooring sites. Upper panel: Mooring site A1, 2008-2010. Lower panel: Mooring site A2, 2008-2009. Bowhead whale call/song detections decreased in fall as ice cover increased but increased in both springs while ice cover was still extensive.

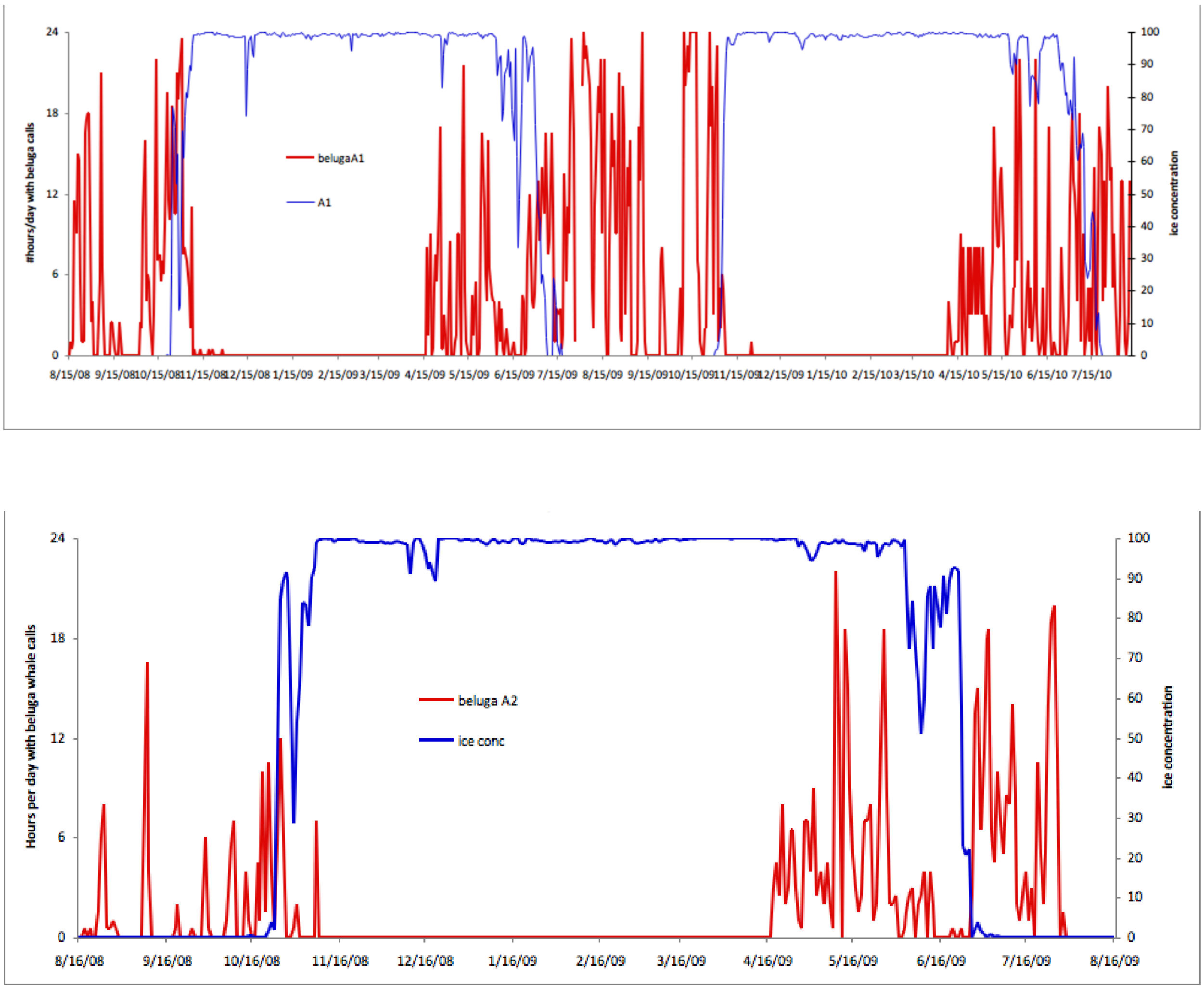

Figure 5. Number of hours per day with beluga whale call detections (red line) and ice concentration (blue line) within 30 km of mooring sites. Upper panel: Mooring site A1, 2008-2010. Lower panel: Mooring site A2, 2008-2009. Beluga whale call detections decreased in fall as ice cover increased but increased in both springs while ice cover was still extensive.

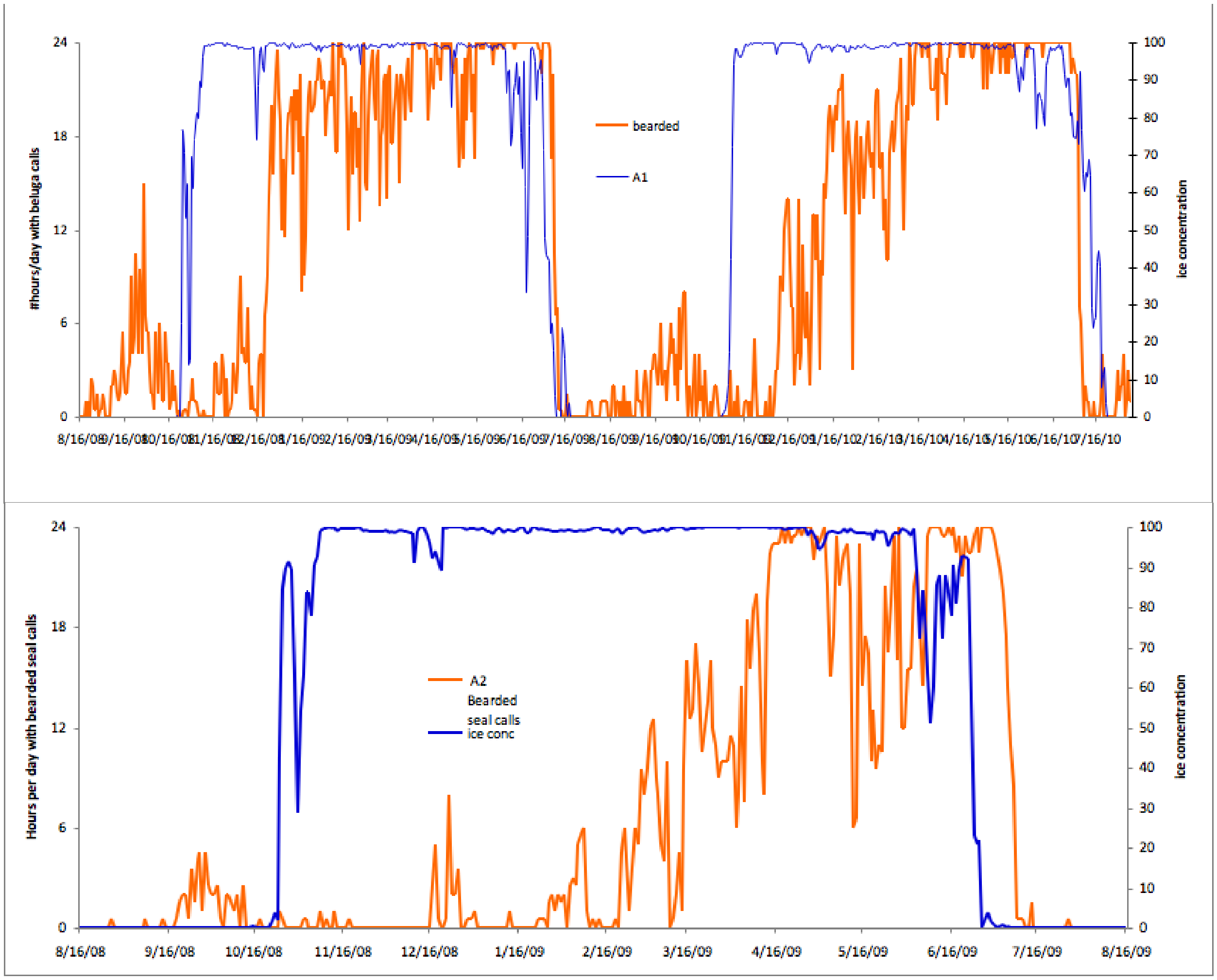

Figure 6. Number of hours per day with bearded seal call detections (orange line) and ice concentration (blue line) within 30 km of mooring sites. Upper panel: Mooring site A1, 2008-2010. Lower panel: Mooring site A2, 2008-2009. Detection of bearded seal calls was strongly associated with ice cover, increasing dramatically in late December and early January and being the dominant signal when ice cover approached 100%. Bearded seal calls decreased abruptly with reduction in sea ice.

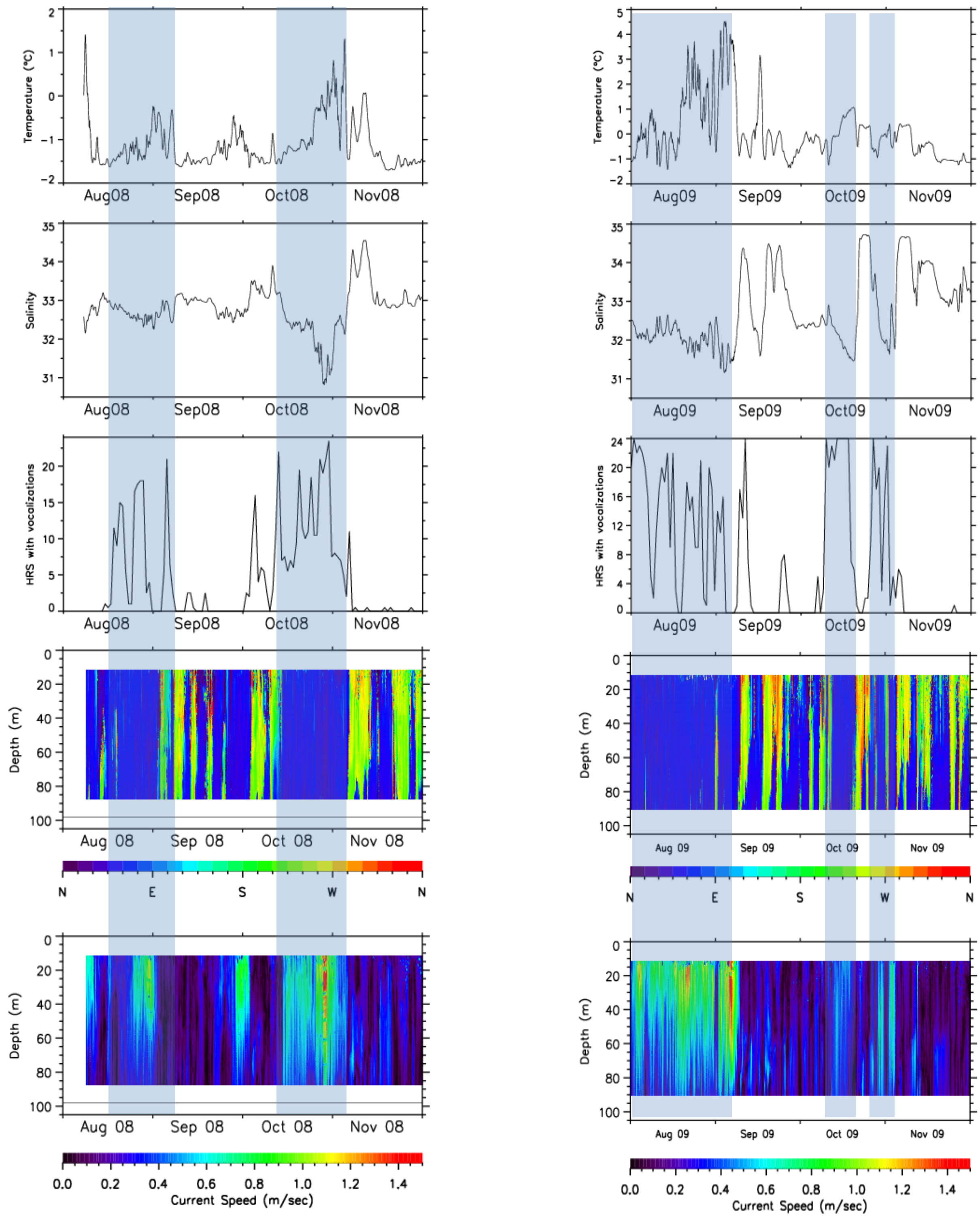

Figure 7. Associations between near-bottom (88 m) water temperature and salinity (upper two panels), occurrence of beluga whale vocalizations (middle panel) and water column velocity (speed and direction) at the A1 mooring during late summer-early fall of 2008 (left) and 2009 (right). Beluga calls were more frequent when the Alaska Coastal Current (high, northeastward velocity) containing Alaska Coastal Water (warmer, fresher) was present over the mooring (noted by blue shading).