

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

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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.

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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 from August 17 – August 30, 2009 using the *R/V Annika Marie*. Surveying was conducted primarily across three –transects co-located with transects previously established during 2005/2006 NSF sponsored and 2007 NOAA/WHOI/UAF sponsored fieldwork. Results from these three transects, two of which were surveyed twice and one that was surveyed once, are good indicators of the hydrographic and biological/chemical conditions on the shelf and in adjacent Barrow Canyon (Fig. 1). Continuous sampling was conducted on the outward

leg of each transect using a towed vertically profiling Acrobat vehicle equipped with CTD, optical backscatter sensor, and chlorophyll and CDOM fluorometers and using a towed Teledyne/RDI 300 kHz acoustic Doppler current profiler (ADCP). On the inbound leg of each transect, directed sampling using CTD, Niskin bottles, and plankton nets was conducted at locations selected on the basis of hydrographic and biological features (e.g., fronts, chlorophyll maxima) identified in sections described from the outbound leg data. Water for nutrient and chlorophyll a concentrations and for flow cytometry analysis was collected using Niskin bottles. Mesozooplankton were collected using oblique tows with a ring net equipped with 500 μ m mesh nets and a 0.25 m Tucker trawl equipped with 333 μ m and 500 μ m mesh nets. Both net types also were equipped with a time-depth recorder and flow meters to estimate the volume of water filtered. Marine mammal, and to the extent possible, bird locations were enumerated. Altogether 41 stations were conducted during ~57 hours on the water over 5 days.

Two year long oceanographic moorings, equipped with acoustic recorders, which had been deployed in August 2008 were recovered on July 29 and August 2, 2009 by personnel on the *USCGC Healy* (cruise HLY0904) in collaboration with the NOPP project of R. Pickart (see Pickart NOPP report for additional details). To decrease the possibility of ice scouring over winter, the instruments had been deployed in 100 m of water in the Beaufort Sea (Fig. 2). Both moorings were instrumented, bottom to top, with an acoustics recorder to archive marine mammal vocalizations, microcat CT sensor to measure water temperature and salinity, and HOBO ProV2 temperature sensors at 75 m, 50 m, 40 m, 30 m, 25 m, 20 m depths (Fig. 3). The eastern mooring was also instrumented with upward-looking Teledyne/RDI 300 kHz ADCP to aid in monitoring the movement of zooplankton between the slope and shelf. The acoustics recorder was programmed to sample at 8192 Hz on a duty cycle of 9 min/30 min so that a full year's data can be obtained on a 160 Gb hard drive. Upon recovery, it was found that the upper portions of each mooring string were apparently torn away and the Onset/HOBO temperature sensors attached at 50-m, 40-m, 30-m, 25-m, and 20-m depths were lost (Fig. 3). The whale acoustics recorders, microcats, and ADCP were recovered and oceanographic data from these instruments presently are being analyzed. The whale acoustic recorder from the eastern mooring had flooded from the bottom and recorded only 2 weeks of data (the recorder from the western mooring recorded data all year). These data will be substituted by data from a mooring nearby deployed as part of our companion NOAA/MMS project for analysis purposes. The ADCP from the eastern mooring recorded data only until mid-December because of a faulty battery pack cable. The instruments were serviced and the mooring strings reassembled and then redeployed at the same locations. These moorings will be recovered during summer 2010.

A third, short-term, bottom mounted mooring was deployed by the *R/V Annika Marie* at the edge of Barrow Canyon on August 22 and recovered on September 14. This mooring was instrumented with an upward-looking Teledyne/RDI 300 kHz ADCP and a SeaBird microcat CTD to investigate the relationship between the overlying wind field, shelf currents, particularly upwelling currents, and the presence of zooplankton by using ADCP backscatter as a proxy for zooplankton.

Bowhead whale prey analysis is being conducted by C. George on whale stomach contents collected by C. George and local whalers during the IWC sanctioned fall whaling seasons of 2008 and 2009.

RESULTS

Ocean temperatures this year were in the middle range of those observed during the 2005-2009 summer field seasons (Fig. 4). The warmest ocean temperatures encountered in Barrow area waters

this summer were about 7°C. The freshest surface waters ($S \approx 26$) were encountered in Barrow Canyon and were likely derived from distant melting sea ice. Significant year-to-year variability in the temperature-salinity characteristics of the waters sampled in this region has been observed over the past five years (2005-2009) (Fig. 4). The 2005 and 2007 surveys encountered very warm Pacific Water, whereas the 2006, 2008, and 2009 surveys encountered much cooler Pacific Water. The presence of extensive sea ice cover in 2006 is reflected in the prevalence of sea ice meltwater.

Winds were low and variable during the first portion of our 2009 field season, precluding upwelling of water and krill along the Beaufort Shelf (Fig. 5). However, upwelling favorable winds from the E occurred in late-August, early-September from August 30 –early September. High abundances of krill were collected on the shelf following this period of upwelling winds and extending through the field season until mid-September (sampling conducted during our companion NOAA/MMS funded project). Bowhead whales were present and feeding on the shelf throughout this period. Comparison of ADCP backscatter from the towed system and from the short-term mooring deployed on the edge of Barrow Canyon demonstrated that higher acoustic backscatter, and hence plankton (krill), was observed in 2009 than in 2008. Shelf waters were very turbid during September, likely associated with higher than normal precipitation/runoff occurring in late August and early September. We speculate that the high turbidity/severe light attenuation within the water column may have been a contributing factor to large numbers of krill being caught throughout the water column in early September, since visual avoidance of the net by the krill would have been reduced under the lower light conditions. Alternatively, elevated abundances of krill at Barrow may result from increased transport of krill into the region from the Bering Sea to the south, due either to increased water transport or to increased abundances of krill in the source region. We are investigating these possibilities to explain the increased krill abundances.

Current speeds adjacent to Barrow Canyon were generally greater during late summer 2009 than in late summer 2008 (Fig. 6). Comparison of the 2009 current direction record with the 2009 wind record (Fig. 5) reaffirms the wind-current relationship identified in previous years to show that westward-flowing currents are associated with moderate-to-strong winds from the eastern quadrant. The clearest signatures of diel vertical migration in the 2009 plot occur during nighttime hours on 10-14 September after a period of upwelling-favorable winds from the east.

Current speed and direction measurements from the year-round mooring (Fig. 7 top left and middle left panels) indicate that flow over the upper continental slope at the eastern mooring location is predominantly to the east and that these eastward-flowing currents are stronger than westward-flowing currents. The bottom left panel depicting relative acoustic backscatter suggests that fewer krill are being carried past the mooring location during November and December than during the preceding months. The bottom right panel shows a five-day subsample of the backscatter record to illustrate the characteristic acoustic backscatter signature of diel vertical migration of zooplankton (inferred to be krill).

The acoustic recorders documented the presence of bowhead and beluga whales, bearded seals, and walrus (Figs. 8 and 9). Preliminary analysis shows that ambient noise levels at low frequencies were ~10 dB lower in spring than in fall and there were seemingly fewer “loud” events (shown by the 95% curve) in spring (Fig. 10). Ambient anomaly spectra show tremendous intra-annual variability (Fig. 11), with highest ambient noise levels at lower frequencies in late fall and early winter and with relatively low values during late winter and spring when the instrument was ice-covered.

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 a larger, ongoing NOAA (MMS) 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 cruise 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.

REFERENCES

Lowry, LF, Sheffield G, George JC. 2004. Bowhead whale feeding in the Alaskan Beaufort Sea, based on stomach contents analyses. *J. Cet. Res. Man.* 6(3): 215–223.

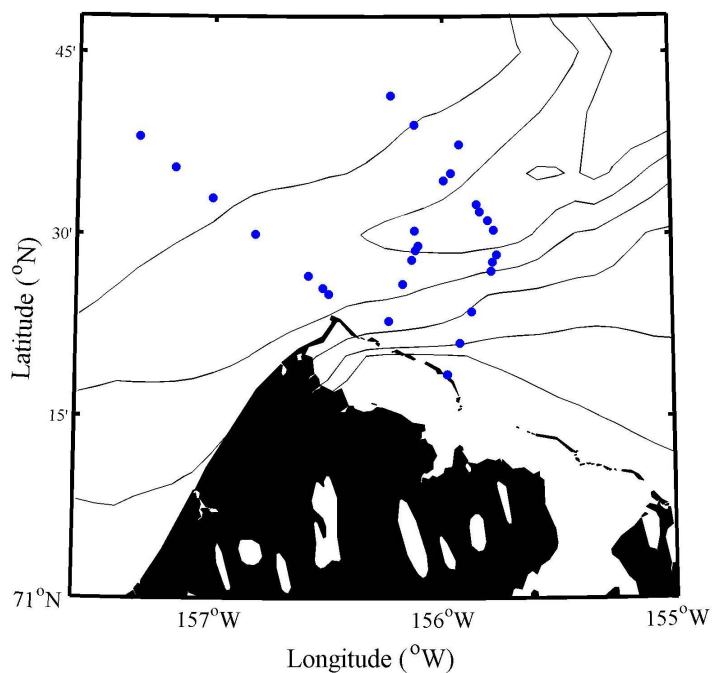


Figure 1. Station locations (blue symbols) and transect lines along which continuous data were collected using the Acrobat and the ADCP.

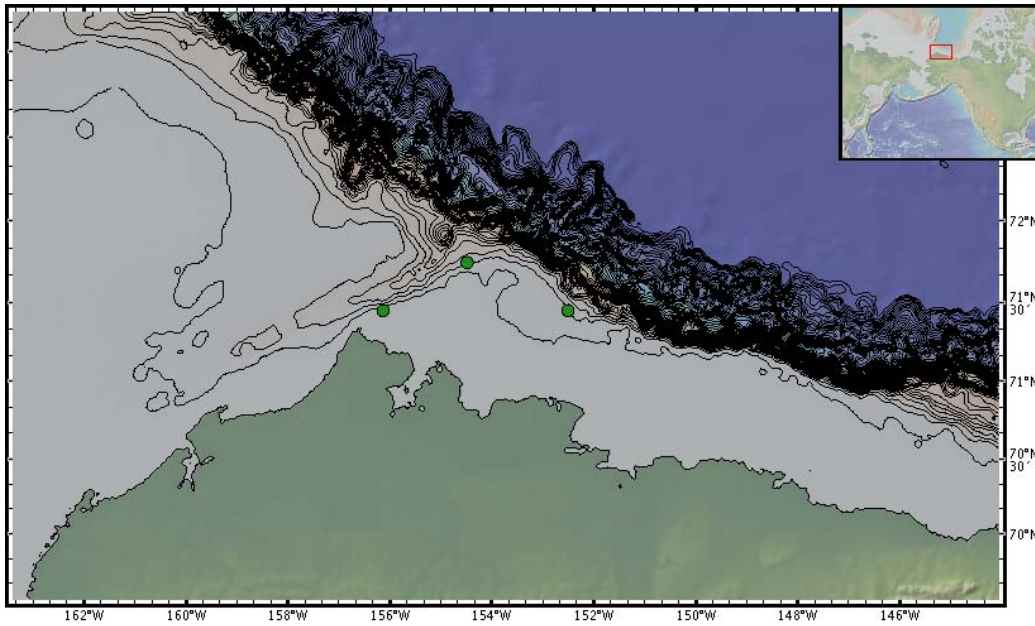


Figure 2. Locations (green circles) of moorings deployed along the Beaufort Shelf break during the Healy cruise (easternmost two moorings) and at the edge of Barrow Canyon by the R/V Annika Marie (westernmost mooring).

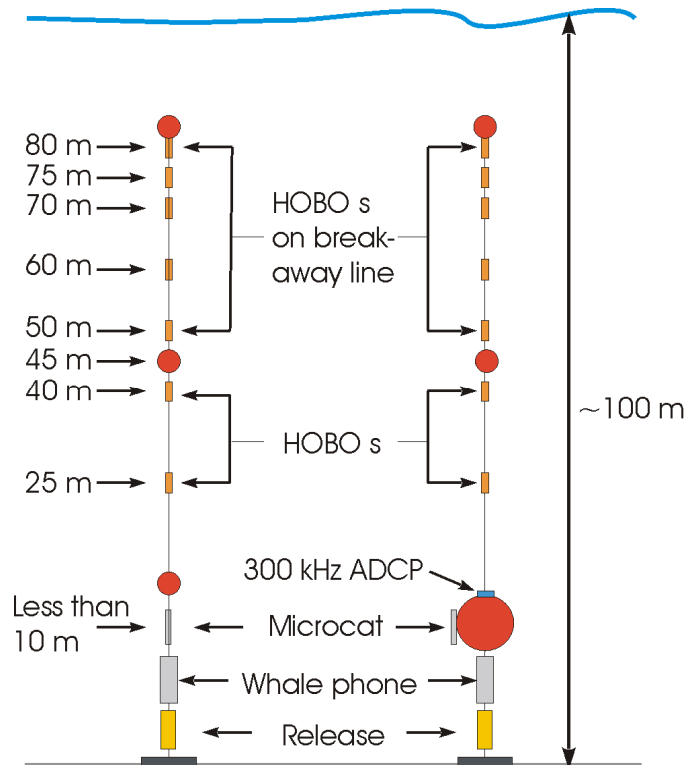


Figure 3. Cartoon of long-term moorings deployed in the Beaufort Sea. The HOBOs are thermistors that record water temperature.

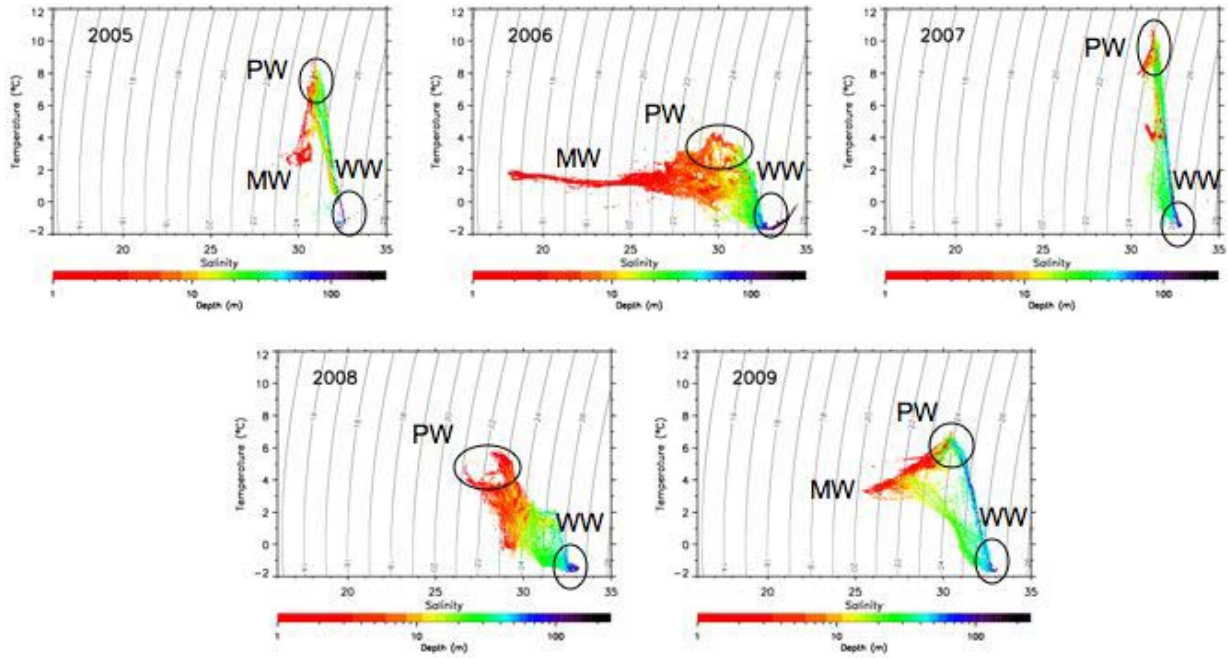


Figure 4. T-S plots of each year's aggregate (Acrobat and individual cast) CTD data. Representative water masses are Pacific Water (PW), Winter Water (WW), and Meltwater (MW). Curved lines are isopycnals (constant sigma-t). Water depth of each point indicated by color.

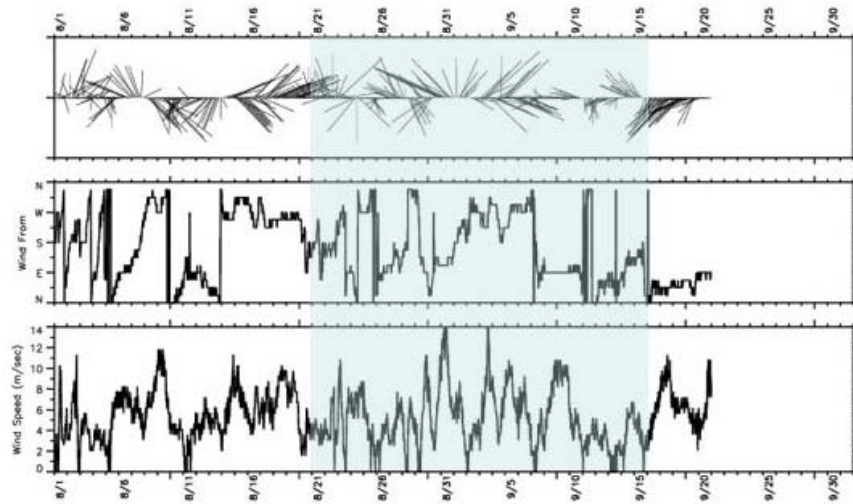


Figure 5. Preliminary data. Winds at Barrow in 2009, showing vectors (top), direction (middle), and speed (bottom). The period when the short term mooring was deployed, August 22 – September 14, is shaded blue.

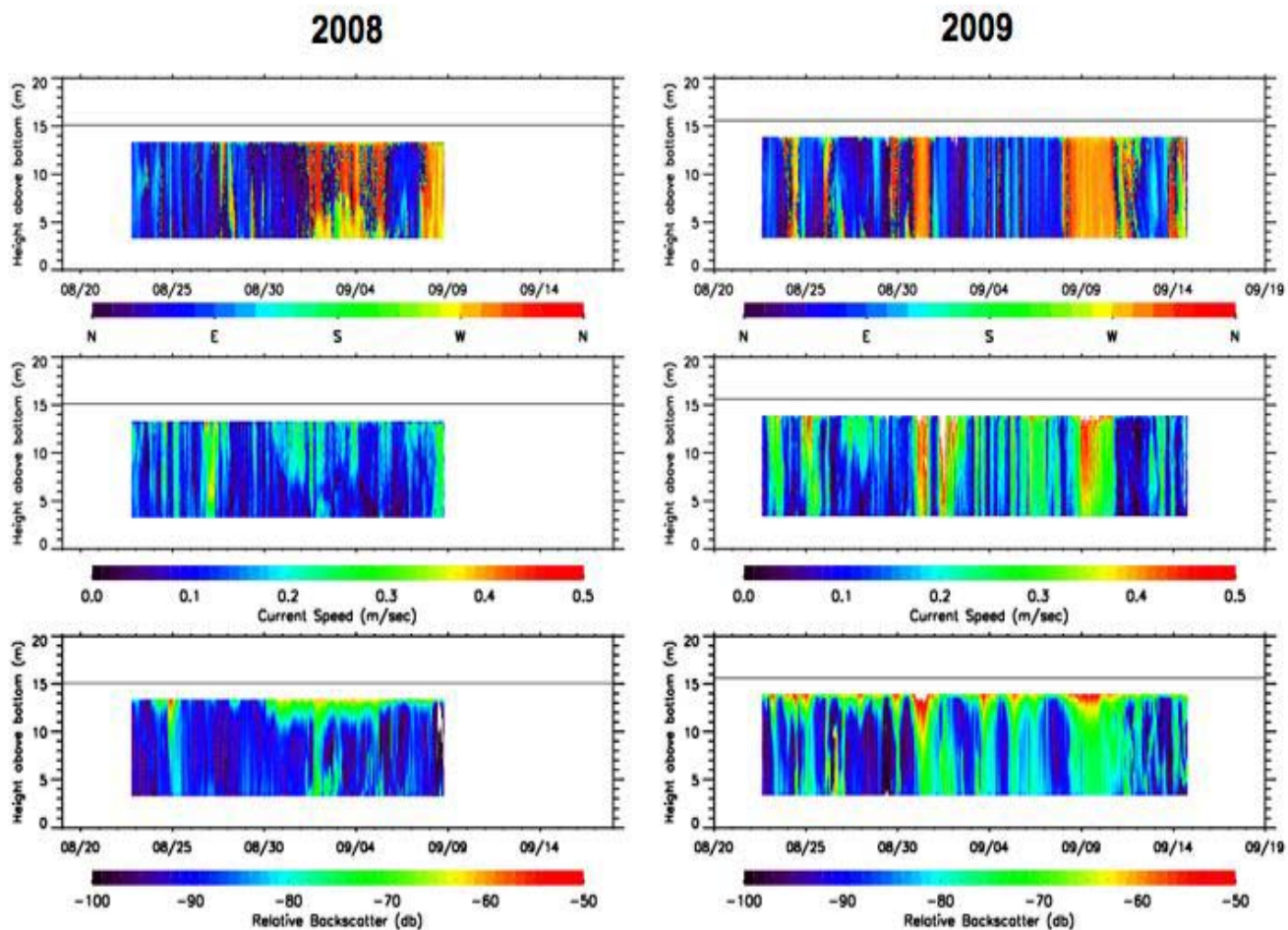


Figure 6. Preliminary data. Comparison of current direction (top), current speed (middle), and relative acoustic backscatter (bottom) from the short-term mooring at Barrow Canyon for 2008 (left) and 2009 (right).

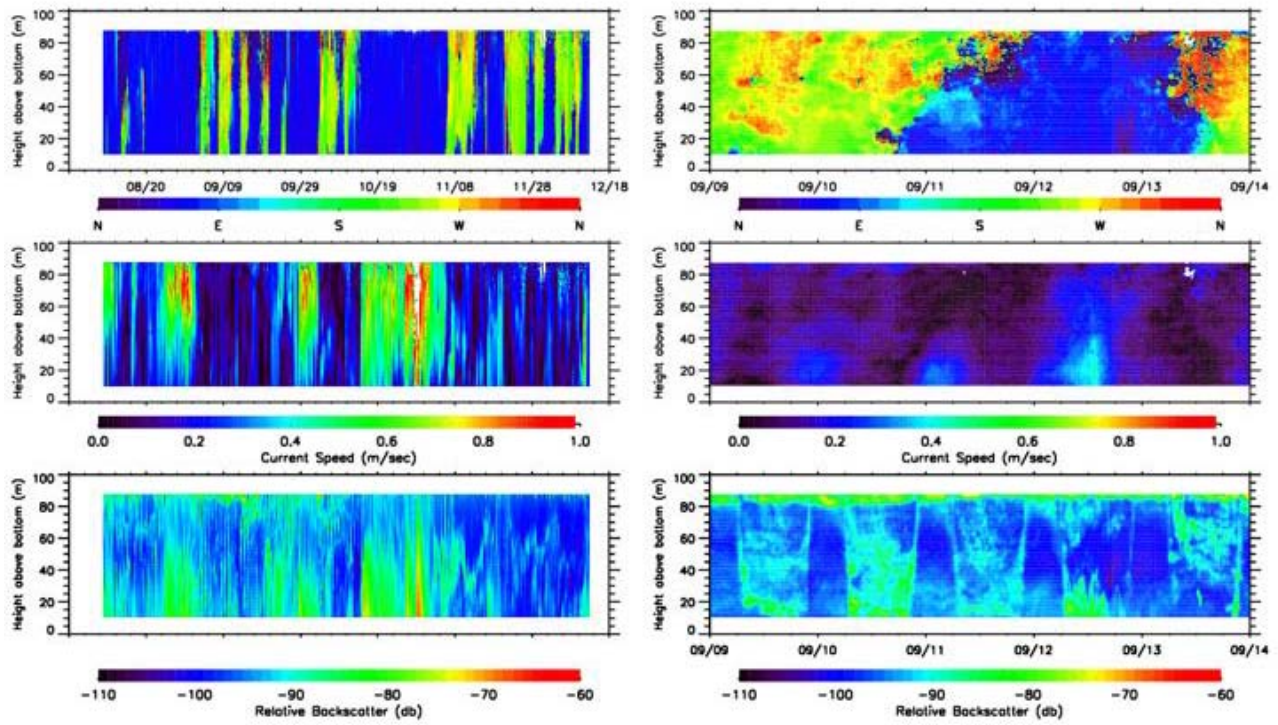


Figure 7. Preliminary data. Current direction (top), current speed (middle), and relative acoustic backscatter (bottom) from the ADCP deployed on the year-long mooring at $\sim 71.75^{\circ}\text{N}$, 154.48°W in ~ 100 m of water. Because of a faulty cable, the ADCP recorded data only until mid-December. The entire record is shown on the left; a five day subsample from September during which the relative acoustic backscatter depicts apparent diel vertical migration of zooplankton is seen on the right.

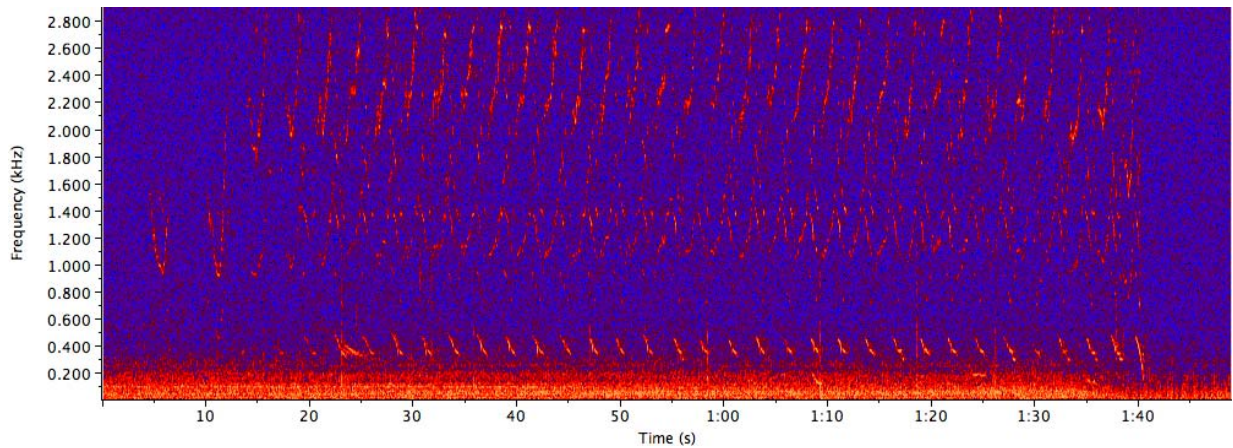


Figure 8. Example of a single spring 2009 bowhead whale song.

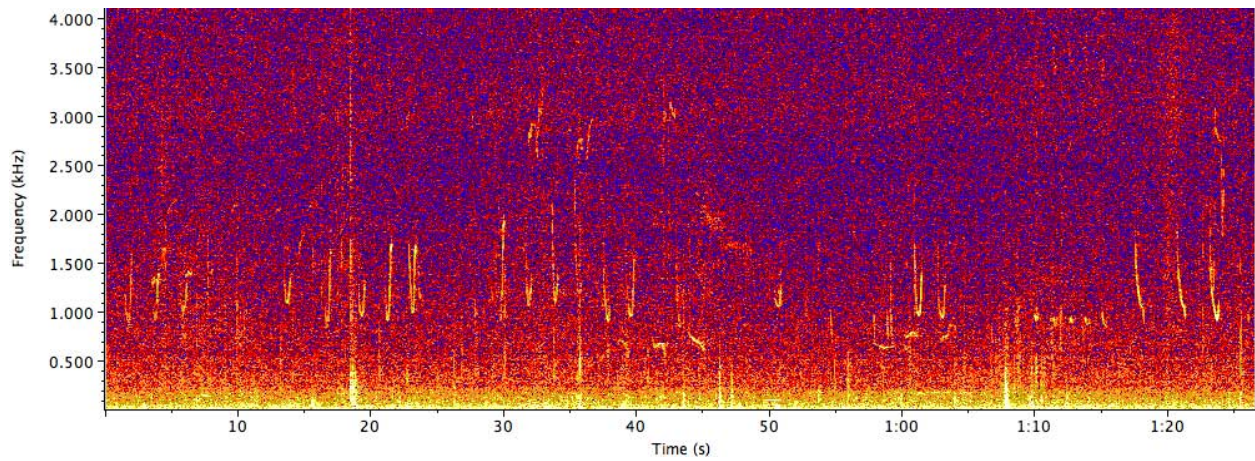


Figure 9. Beluga whale calls from May 2009.

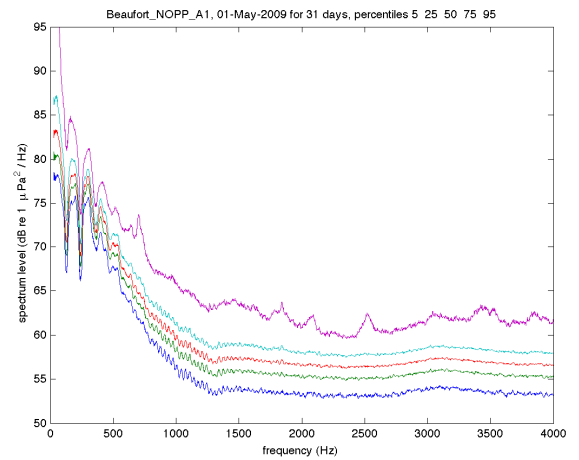
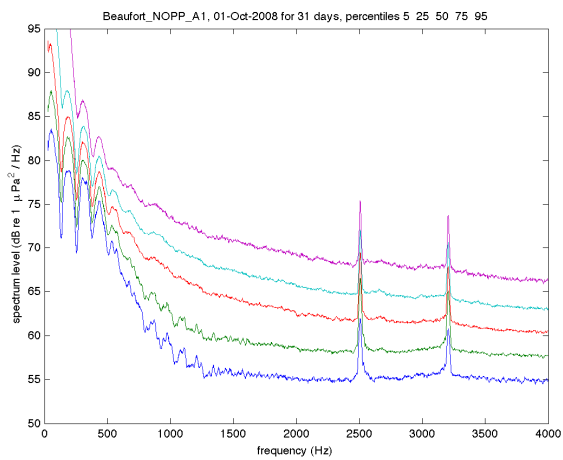


Figure 10. Absolute noise levels at 5%, 25%, 50%, 75% and 95% levels of noise from October 2008 (left) and from May 2009 (right).

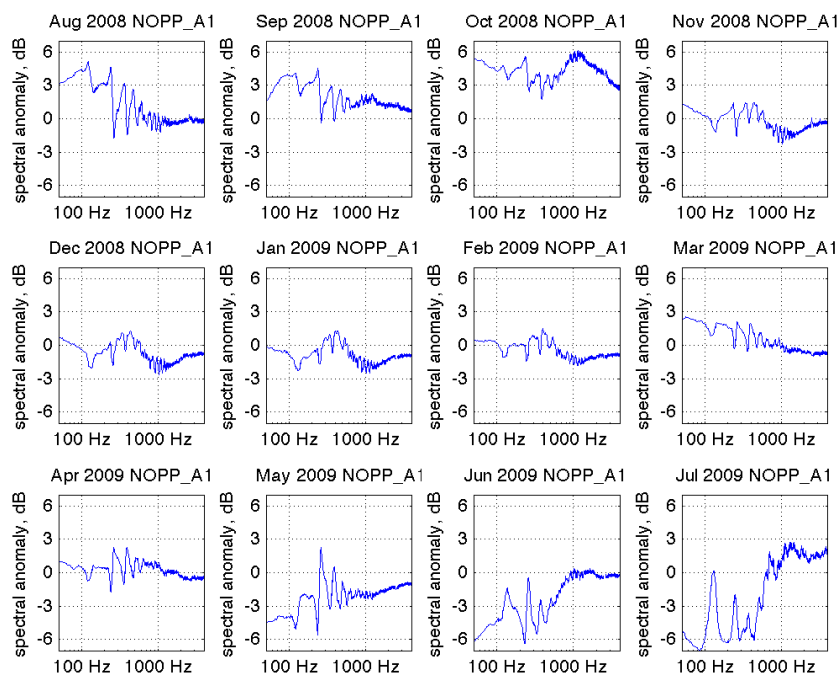


Figure 11. Spectral anomalies (monthly spectra minus mean annual spectra) by month for westernmost year-long mooring.