PASSIVE ACOUSTIC DETECTION AND MONITORING OF ENDANGERED WHALES IN THE ARCTIC (BEAUFORT, CHUKCHI)

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ECOSYSTEM OBSERVATIONS IN THE CHUKCHI SEA: BIOPHYSICAL MOORINGS AND CLIMATE MODELING

QUARTERLY REPORT

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Executive Summary

Through an Inter-Agency agreement (IA) between the National Marine Mammal Laboratory (NMML) and the Bureau of Ocean Energy Management (BOEM), NMML is conducting a dedicated multi-year study to determine the distribution and relative abundance of endangered whales in the Chukchi Sea Planning Area and to relate any variability in those parameters to oceanographic conditions, indices of potential prey density, and anthropogenic activities. This quarterly report covers the period between January 16th and April 15th 2014. The major activities during this period consisted of data analysis and synthesis.

Introduction and objectives

The western Arctic physical climate is rapidly changing. The summer Arctic minimum sea ice extent in September 2012 reached a new record of 3.61 million square kilometers, a further 16% reduction from a record set in 2007 (4.30 million square kilometers). This area was more than 50% less than that of two decades ago. The speed of these changes was unexpected, as the consensus of the climate research community just a few years ago was that such changes would not be seen for another thirty years. As sea temperature, oceanographic currents, and prey availability are altered by climate change, changes in baleen whale species composition, abundance, and distribution are expected (and evidenced already by local knowledge and opportunistic sightings). In addition, the observed northward retreat of the minimum extent of summer sea ice has the potential to create opportunities for the expansion of oil and gas-related exploration and development into previously closed seasons and localities in the Alaskan Arctic. It may also open maritime transportation lanes across the Arctic adding to the ambient noise in the environment. This combination of increasing anthropogenic impacts coupled with the steadily increasing abundance and related seasonal range expansion by the bowhead, gray, humpback, and fin whales, indicates that more complete information on the year-round presence of large whales is needed in the Chukchi Sea planning area. Timing and location of whale migrations may play an important role in assessing where, when, or how exploration or access to petroleum reserves may be conducted to mitigate or minimize the impact on protected species.

This study has four component projects: oceanography, passive acoustics, zooplankton, and climate modeling. Each component project is a technical discipline and is coordinated by a Project Leader with extensive experience in that discipline. Passive acoustic moorings, deployed concurrently with bio-physical moorings will provide previously unattainable year-round assessments of the seasonal occurrence of bowhead, humpback, right, fin, gray, and other whales in this planning area and their response to environmental changes (including oceanographic conditions, climate, indices of potential prey density, and anthropogenic activities). Moorings permit observations during long periods when ice covers the region, especially during the critical spring and early summer periods when spring phytoplankton blooms occur. Such measurements are virtually impossible to obtain from ships, because of the relatively short duration of cruises and severe limitations in the availability of ships able to work in ice-covered seas.

The overall goal of this multi-year IA study is to document the distribution and relative abundance of bowhead, humpback, right, fin, gray, and other whales in areas of potential seismic surveying, drilling, construction, and production activities and relate changes in those variables to oceanographic conditions, indices of potential prey density, and anthropogenic activities.

The specific objectives are:

1. Assess the year-round seasonal occurrence of bowhead, gray, and other whale calls in the Chukchi Sea.
2. Estimate relative abundance of these whales.
3. Obtain two full years of biophysical measurements on the shallow Chukchi shelf utilizing moorings at three sites, and collect hydrographic and lower trophic level data during deployment/recovery of the moorings.
4. Evaluate the extent to which variability in environmental conditions such as sea ice, oceanic currents, water temperature and salinity, and prey abundance influence whale distribution and relative abundance.
5. Run the National Center for Atmospheric Research (NCAR) climate model (Community Earth System Model: CESM1.0) for future projections using the sea ice extents from 2007/2008 as initial conditions.
6. Analyze multiple ensemble members CESM as well as the group of CMIP5 models to assess the future variability of sea ice cover and extended sea ice free seasons during fall for the Chukchi Sea.
7. Evaluate whether changes in seasonal sea ice extent are resulting in a northward shift of Bering Sea cetacean species such as fin, humpback, and North Pacific right whales.
8. Provide long-term estimates of habitat use for large whale species and compare this with predictions about annual ice coverage to establish predictive variables that describe large whale occurrence.

PASSIVE ACOUSTICS COMPONENT

Preliminary results

Ellen Garland, our NRC postdoctoral fellow, has analyzed four 2010-2011 moorings for beluga vocalizations; one in the western Beaufort Sea, two CHAOZ moorings in the Chukchi Sea (inshore and offshore Icy Cape), and one in the northern Bering Sea (M8, deployed under CHAOZ funds). The aim of this study is to identify peaks in beluga vocal activity over a single year to better understand the migratory movements and fine-scale timing of the eastern Beaufort Sea and eastern Chukchi Sea populations as they undertake their extended migrations in the Alaskan Arctic and Subarctic. After overwintering in the Bering Sea, belugas from the eastern Beaufort Sea and eastern Chukchi Sea populations migrated north through the northeastern Chukchi and western Beaufort Seas in multiple waves which were temporally distinct. These results suggest peaks in vocal activity are able to capture fine-scale temporal movements of populations when temporal or spatial differences between detection peaks are large enough to be identified as independent events. This study agrees with the overall understanding of seasonal beluga movements from satellite tagging studies, and highlights the successful application of passive acoustic monitoring to improve our understanding of the fine-scale migratory timing of populations for management and conservation in a region undergoing rapid change. After conducting the spatio-temporal distribution analysis and presenting those data at the Biennial Conference on Marine Mammals in December and the Alaska Marine Science Symposium in January, she has now begun extracting and measuring individual beluga calls to generate a beluga call repertoire for each population. After the repertoires are built, she will investigate the feasibility of using differences in repertoires (dialects) to identify each population, and thus track the migration and movement patterns of different beluga populations based entirely on passive acoustics.

Crance and Berchok are preparing a manuscript for submission that describes a fin whale acoustic detection using passive acoustic sonobuoys deployed during the 2012 CHAOZ cruise. This detection, which occurred approximately 26 nm off Peard Bay in 62m water depth, represents the farthest northeast detection of a fin whale in the Alaskan Arctic.

2014 analysis plans

Analyses of the long-term passive acoustic recorders are still ongoing, with an additional part-time analyst joining the team to work on the high-frequency species (beluga, minke, and killer whales, bearded and ribbon seals) as well as ice noise. We will continue to process the data manually until the low-frequency detection and classification system (LFDCS by Mark Baumgartner, Woods Hole Oceanographic Institute (WHOI)) is fully online.

Eliza Ives, tasked with implementing the LFDCS on our data, is in the process of conducting iterative testing of the Chukchi bowhead whale call library. She has completed a couple rounds of testing the call library's efficacy against moorings from which she selected the call type exemplars. This process ensures false detection rates and missed detection rates are as low as possible before putting the call library through logistic regression analysis and testing it against novel data sets. Old mooring data are constantly being reformatted from .wav files to NetCDF files, the audio format understood by the LFDCS. This process will continue until all our mooring data are reformatted for use and analysis in the LFDCS. Once she is very confident the bowhead call library will perform well against any of our data sets, she will move onto creating a fin whale call library.

Most effort in 2014 will be spent analyzing the remaining recordings and integrating our results with those from the oceanography and zooplankton components.

Synthesis

Berchok has been working with Napp and Stabeno for the submission of the note to Geophysical Research Letters which is described in the Zooplankton Component section below.

Distributed Biological Observatory (DBO) contributions

The CHAOZ program has agreed to contribute data to the DBO Workspace, supported by AOOS/AXIOM. CHAOZ principal investigators were invited to join the password-protected workspace in December 2013, and are in the process of contributing data and data products (maps and figures) as are other DBO contributors. The development of the Workspace is an activity of the DBO Implementation Team (http://www.arctic.noaa.gov/dbo/about.html#DBO_Implementation_Team) and is in its early stages. The contribution of information from the CHAOZ program is considered foundational to the development of the workspace, especially for the visual and acoustic data provided on marine mammals. To date, short-term passive acoustic monitoring results (sonobuoys) from the 2010-2012 CHAOZ field surveys have been uploaded, as well as a map detailing the location of our currently deployed passive acoustic moorings. Once we get the green light from the DBO coordinators, we will upload our long-term passive acoustic monitoring results (AURAL recorders) from the three Icy Cape moorings (IC3, IC6, and IC11).

OCEANOGRAPHIC COMPONENT

The monthly mean transport at Icy Cape during 2010-2013 was highly variable during winter and fall (Fig. 1). During spring and summer, however, transport was consistently northward and less variable among years. Year-long average transport ranged from 0.25 – 0.45 Sv.

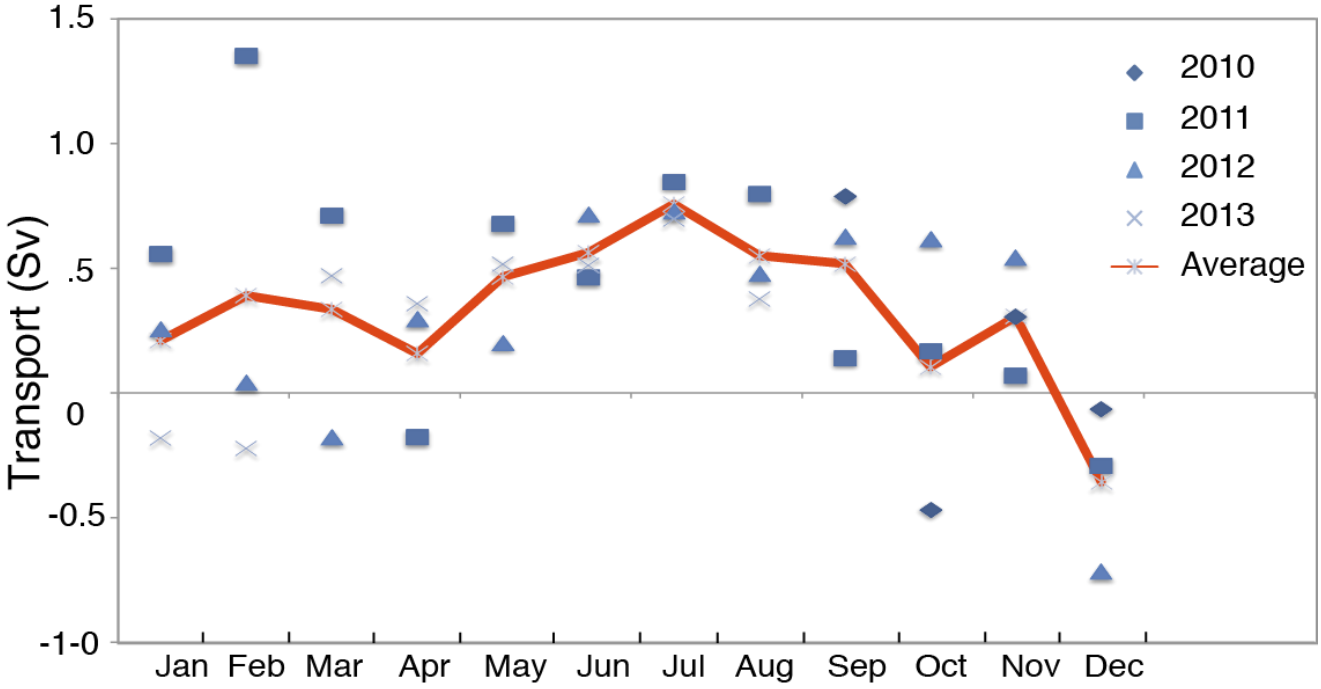

Figure 1. Mean transport per month for four years during 2010 – 2013 at Icy Cape, Alaska. Means combine the CHAOZ (2010 – 2012) and CHAOZ-X (2012 – 2013) data.

Ice cover and ice thickness data from the C2 (middle IC6) mooring displayed a clear signal of the Arctic sea ice mega-fracture event during February 2013 (Fig. 2; for background on this event see: http://nsidc.org/arcticseaicenews/2013/03/a-fractured-maximum/). During the first two years of deployment (CHAOZ) percent ice cover was consistently near 100% during November – May (Fig. 3). Average ice thickness increased steadily throughout the cold season, with keels > 24 m. During 2012-2013 (CHAOZ-X), however, percent ice cover dropped below 80% on several occasions during winter and spring. Daily ice draft in this year was lower and did not have the positive trend of seasonally increasing depth observed in the previous two years.

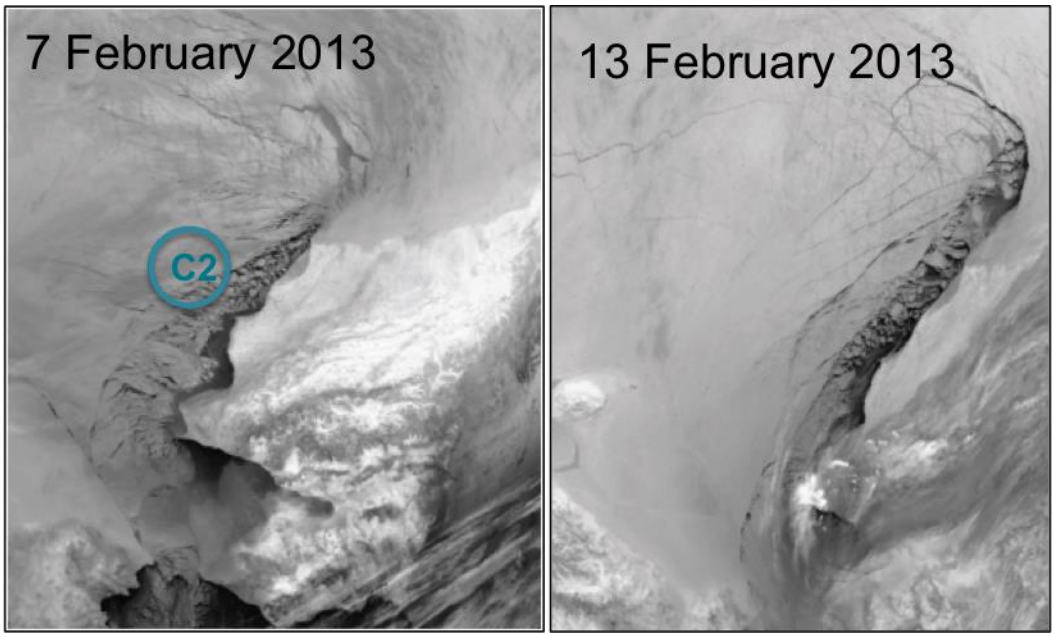

Figure 2. Satellite images of extensive sea-ice fracturing during February 2013 with the location of the C2 mooring shown in blue.

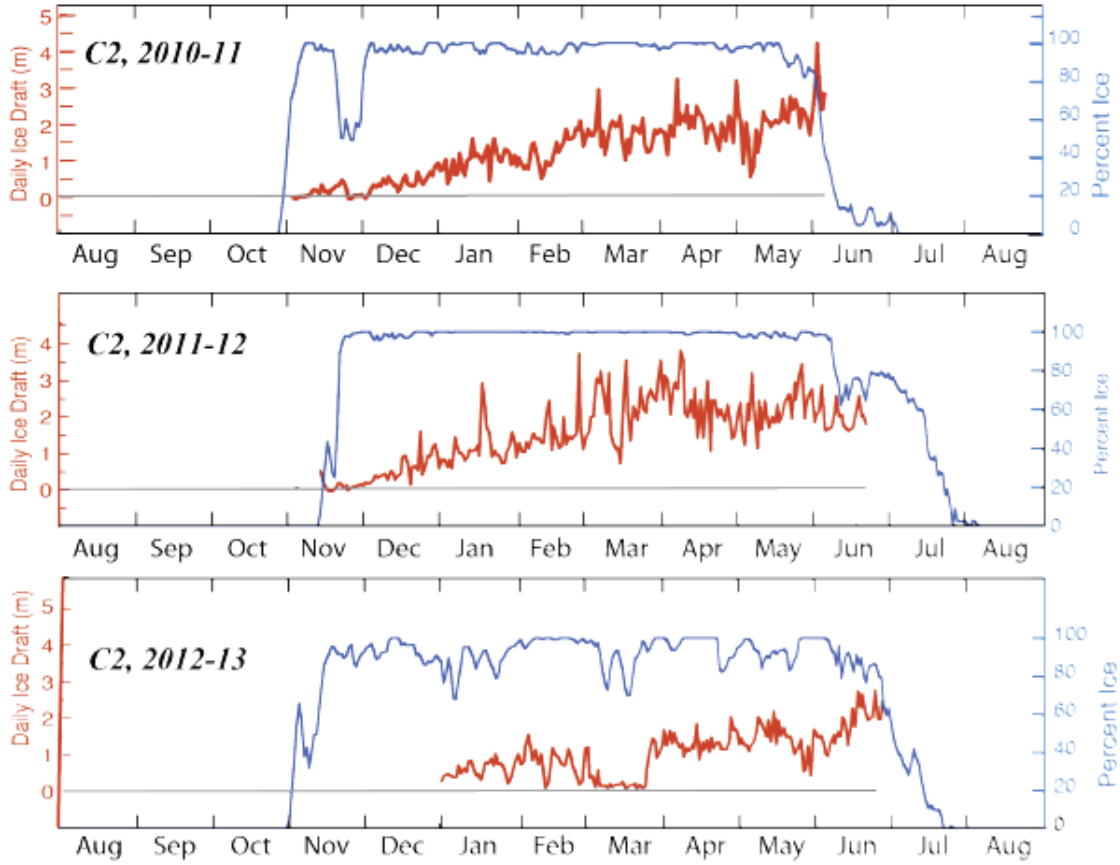

Figure 3. Percent ice cover from satellite data and ice depth data from the C2 mooring during CHAOZ and CHAOZ-X.

At the C2 mooring, chlorophyll from the spring bloom was evident on the bottom in June and July of all three years during CHAOZ (2010 - 2012) and CHAOZ-X (2012 – 2013). During the beginning of the bloom, PAR was reduced to zero even when ice cover fell below 20% (Fig. 4). This suggests that blooms can be dense enough to prevent light from reaching the bottom.

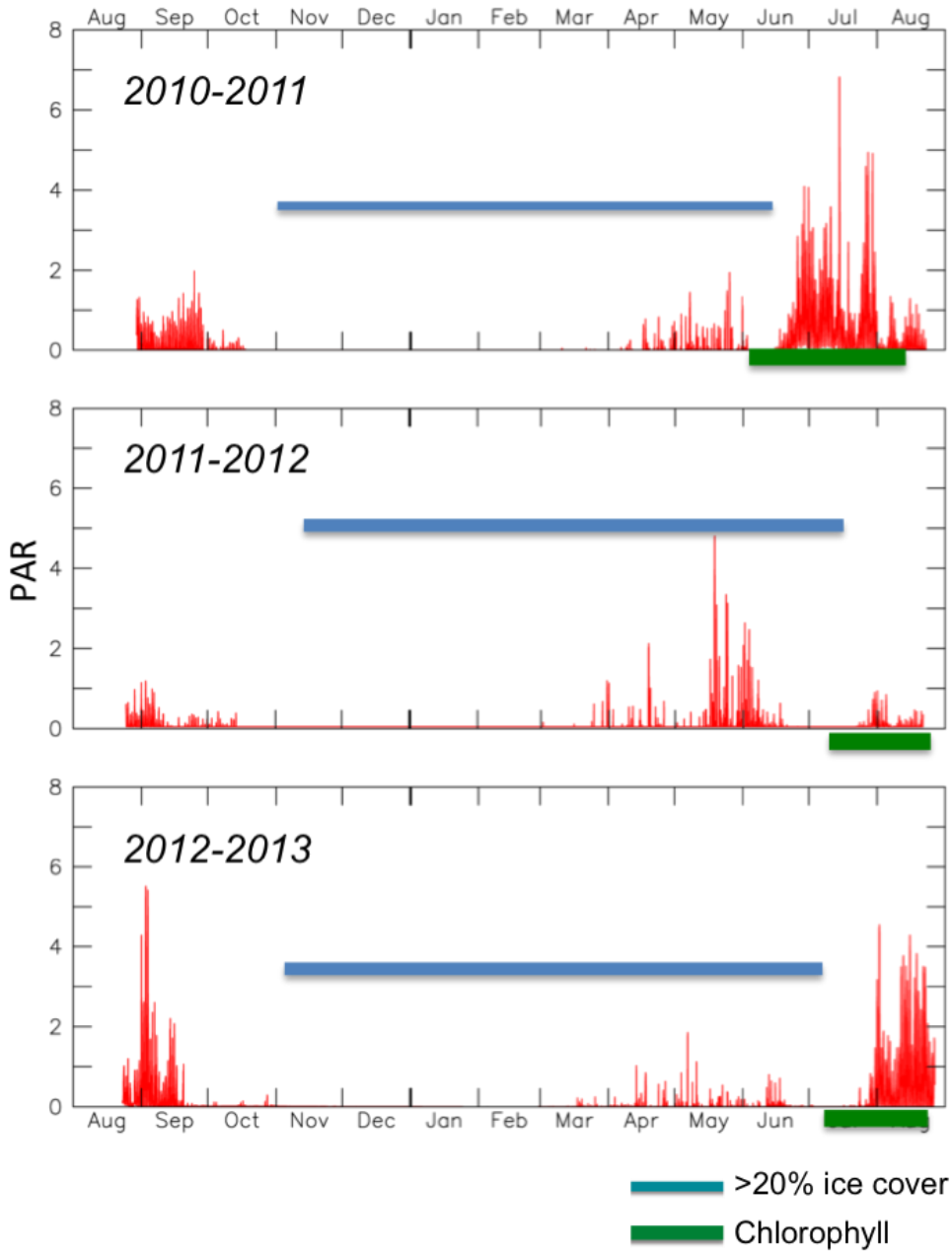

Figure 4. Bottom PAR (Photosynthetically Active Radiation) values in red, observed at C2 during three years of the CHAOZ (2010 – 2012) and CHAOZ-X (2012 – 2013) studies. Blue bars show ice cover greater than 20% and green bars show bottom chlorophyll fluorescence.

We observed an intrusion of Barrow Canyon water and organisms onto the Chukchi Shelf at the C1 (inshore IC3) mooring during late December 2010 – early January 2011 (Fig. 5). Our measurements showed up-canyon flow, increased salinity and temperature, decreased oxygen, dramatic reduction in ice cover, and increased zooplankton backscatter (from ADCP). The increase in backscatter may also be a result of increased turbidity of open water. Upwelling events in Barrow Canyon appear to have far-reaching influence on the surrounding shelf.

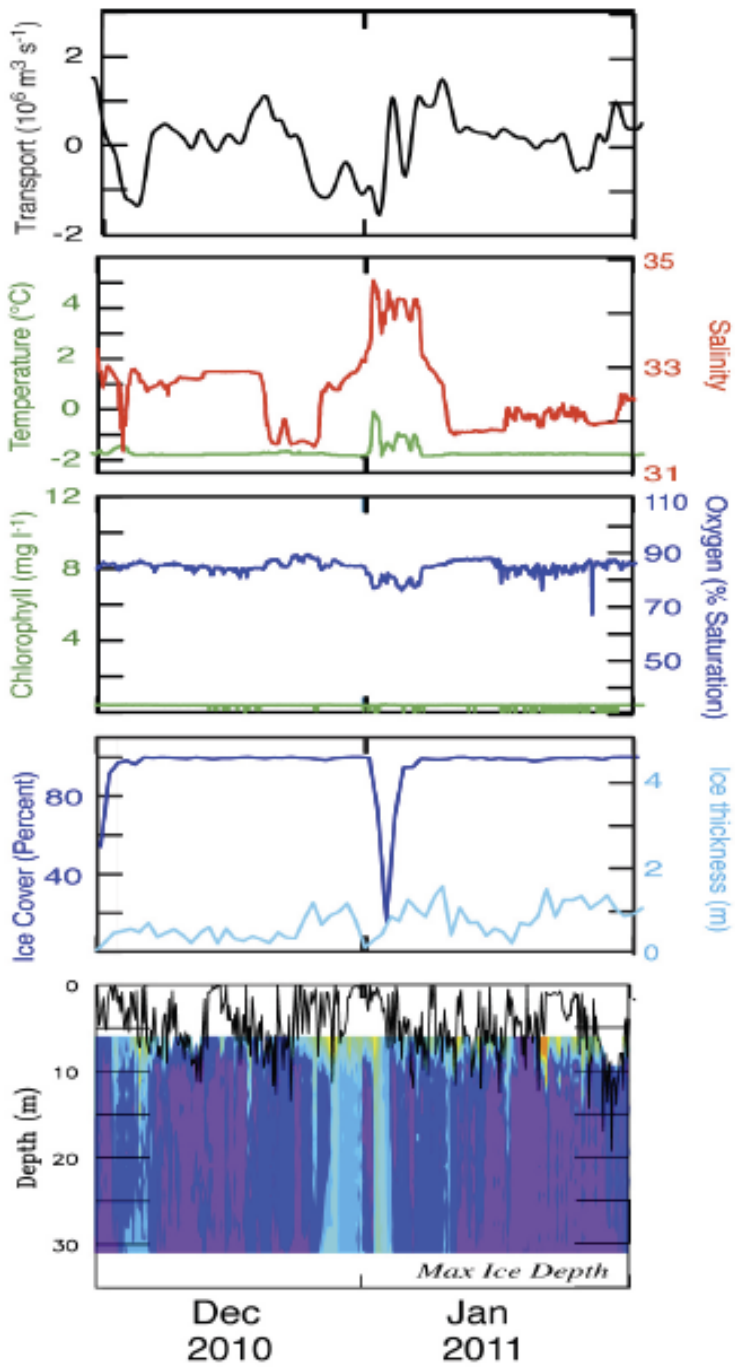

Figure 5. Measurements from the C1 biophysical mooring of transport, temperature, salinity, oxygen, chlorophyll (fluorescence), ice cover and thickness, maximum ice depth, currents, and zooplankton bio-volume (backscatter).

ZOOPLANKTON COMPONENT

Zooplankton Acoustics

Analysis of ADCP and TAPS data continues. We have been examining zooplankton net data from the 2011 cruise to determine which scattering models are most appropriate to apply to TAPS-6 data. Overall, we have found a significant correlation between copepod net abundance and TAPS-6 abundance. Both moored instruments deployed in 2012 were recovered and recorded data until the spring of 2013. We have finished correcting those data for noise and surface reverberation. The ADCP deployed in 2012-2013 have been processed and converted from echo intensity units to volume backscatter to look at temporal patterns in zooplankton backscatter. During the next period we intend to apply wavelet analysis to the ADCP data to identify dominate modes of temporal variability.

Preserved Zooplankton Samples

Data for 2010 and 2011 are complete, but data entry and QA/QC is lagging behind for the 2012 data. Data sheets for samples from the August 2012 cruise were delivered on time by the Polish Plankton Sorting and Identification Center. However we are in the middle of a zooplankton protocol and database migration project and the software tools were not ready when the data were delivered. We have finished checking the data entry by Poland for errors (every handwritten form was compared to what was entered into the computer in Poland). The data are now currently being corrected within an intermediate database prior to being uploaded to our main database. These delays were encountered because we needed to upgrade our databases from Access to Oracle. The database migration has taken much longer to accomplish than originally estimated.

Synthesis

Napp is taking the lead on a note for submission to Geophysical Research Letters synthesizing some of the initial results from the CHAOZ project. The note will attempt to identify and describe several "events" where we have physical, plankton, and marine mammal observations. We are still waiting for final figures to be prepared.

2014 analysis plans

We will continue to focus our analyses of TAPS, ADCP, and zooplankton net data. We must finish the QA/QC procedures before the data are ready for use. We are currently working on an in-house calibration setup so that we can more accurately correct for the extreme temperatures (<2 °C) at depth in the Arctic. The final processing of the 2012 TAPS-6 and the 2012-2013 TAPS-6NG data will begin in the next few weeks, after the post cruise calibration.

OCEAN NOISE AND REAL-TIME PASSIVE ACOUSTIC MONITORING

We have further developed a data analytic system for automatic computation of ocean ambient and ocean background noise levels with the motivation of quantifying the contributions from natural biotic (e.g. marine mammals) and abiotic sources (e.g. ice and wind) and anthropogenic sources (e.g. ships, seismic airgun arrays, aircraft). We refer to the topic of this research component as ocean acoustic ecology.

We have further developed a methodology for evaluating the performance of the automated bowhead whale detector used on the first NOAA-AK-NW Autobuoy (AB), deployed from 29 August through 09 November 2012. While the manual analysis of the Chukchi AB dataset is not yet complete, we have

tested it against verified data collected for a different Beaufort Sea deployment in 2008, within which a number of bowhead calls have been manually identified.

Since bowhead detections are rare relative to the null hypothesis, we chose to use Precision/Recall curves to measure performance, because they are not subject to the issues of uneven class size that can be a problem when using Receiver Operating Characteristic (ROC) curves. The general procedure started by running the detector/classifier with a low threshold, yielding a large number of candidate detections, most of which would be false. We then computed *a posteriori* the Precision and Recall at various intermediate thresholds. Not surprisingly, precision does not change significantly as the score increases, since a higher score simply corresponds to a louder call event. All told, we estimate that we can improve the threshold so as to detect about 30% of the potential calls, 80% of which would be classified as true calls.

In the interest of simplicity, the Hidden Markov Model (HMM) operating in the 2012 AB prototype detector used a reduced feature set. In order to estimate the potential performance of the entire feature space we also trained an HMM on a set of vector-quantized state sequences, where we used the k-means algorithm to estimate state centroids. We found that if we used the vector-quantized feature set, the number of false positive events would be reduced by 50%. The vector-quantized HMMs were trained using hold-out cross-validation, where each model was trained on 80% of the data and tested on the remaining 20%. As a result, the performance was only slightly degraded between the training and test sets, indicating that we were most likely not over-fitting the models.

Of the total number of audio clips (N=762) detected and transmitted via satellite by the AB over the duration of the deployment (between 01 September and 01 November 2012), 351 clips were noted as being of biological origin by BRP reviewers with expertise in bowhead sound recognition. This yielded a precision of about 46%. While this is a significantly lower value of precision than we have seen when testing the performance of the detector against the Beaufort Sea training data, it is not unexpected, since the training and test data sets may not be equivalent. This emphasizes the importance of obtaining a manually revised dataset of "truthed" bowhead calls corresponding to the Chukchi Sea 2012 deployment.

Organizationally, during the first quarter (January-April) of this year several meetings were held at BRP between the NOAA-NW/CHAOZ team (Chris Clark and Matt Robbins) and BRP's Senior Leadership Team (SLT: Aaron Rice, Stan Deforest, Deborah Cipolla-Dennis, Harold Cheyne). These meetings had the goal of developing an action plan for completing the CHAOZ objectives over the next months and setting the stage for transitioning into the goals of CHAOZ-X in 2014.

CLIMATE MODELING COMPONENT

All efforts in this quarter were focused on analyses and synthesis, in preparation for the final report. There is nothing new to report at this time.

Significant meetings held or other contacts made

20 January: Berchok meets with Heather Crowley to discuss timeline and deliverables for the draft final CHAOZ report.

22 January: Berchok hosts workshop entitled "What the Phonation: Arctic Sounds" at the Alaska Marine Science Symposium. In attendance: Catherine Berchok, Jessica Crance, Stephanie Grassia, Ellen Garland, and Manolo Castellote (NOAA/AFSC/NMML); Chris Clark (Cornell BRP); Julien Delarue and Xavier Mouy (JASCO); Susanna Blackwell (Greeneridge Sciences); Carol Fairfield (BOEM); Sheyna Wisdom (Fairweather Science, LLC); Kalyn MacIntyre (Univ. of Washington); Dana Wright (Univ. of Alaska Fairbanks); Daisuke Mizuguchi (Kyoto University); Laura Morse (Shell); Jennifer Gatzke (NOAA/NEFSC); Craig George (North Slope Borough).

12 February: Berchok and Crance meet with Napp, Stabeno, Wang, Clark (with Aaron Rice, conference call), Amy Kennedy, Julie Mocklin, and Adam Spear to discuss the CHAOZ final report timeline and deliverables.

Presentations and Publications

Cheng, W., E. Curchitser, C. Ladd, and P. Stabeno. Ice-Ocean Interactions in the Eastern Bering Sea: NCAR CESM Simulations and Comparison with Observations. Deep Sea Research, in review.

Clark, C. W., C.L. Berchok, S. Blackwell, J. Citta, D. Hannay, J. Jones, L. Quakenbush, and K.M. Stafford. A year in the acoustic world of Western Arctic bowhead whales. In prep.

Crance, J.L. and C.L. Berchok. Stereotyped gunshot call patterns produced by the North Pacific right whale, *Eubalaena japonica.* Marine Mammal Science, in review.

Crance, J.L. and C.L. Berchok. Farthest northeast acoustic detection of a fin whale (*Balaenoptera physalus*) in the Alaskan Chukchi Sea. Arctic, in prep.

Garland, E.G., C.L. Berchok, and M. Castellote. 2014. Spatio-temporal movement patterns of Alaskan beluga whale (*Delphinapterus leucas*) populations based on vocal peaks from passive acoustic monitoring. Poster presentation at the Alaska Marine Science Symposium, January 20-24, 2014. Anchorage, AK.

Garland, E.G., C.L. Berchok, and M. Castellote. Spatio-temporal movement patterns of two Alaskan beluga whale (*Delphinapterus leucas*) populations based on acoustic detections. Marine Ecology Press Series, in prep.

Overland, J. E., M. Wang, J. Walsh, and J.C. Stroeve. 2014. Future Arctic climate changes: Adaptation and mitigation timescales. Published online, Earth's Future. doi: 10.1002/2013EF000162.

Stabeno, P.J., N.B. Kachel, C. Ladd, and J.M. Napp. The CHAOZ project: Influence of climate variability on the northeastern Chukchi ecosystem. Oral presentation at the American Geophysical Union Ocean Sciences Meeting, February 26, 2014. Honolulu, HI.

Wang, M. and J. E. Overland. 2014. Projected future duration of the sea-ice-free season in the Alaskan Arctic. Poster presentation at the Alaska Marine Science Symposium, January 20-24, 2014. Anchorage, AK.

Wang, M. and J. E. Overland. Projected future duration of the sea-ice-free season in the Alaskan Arctic. Progress in Oceanography, accepted pending revisions.