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

ANNUAL 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 of the distribution and relative abundance of endangered whales in the Chukchi Sea Planning Area and relate variation in those parameters to oceanographic conditions, indices of potential prey density, and anthropogenic activities. This annual report covers the period between February 2011 and January 2012.

The major activities during this period consisted of the preparation for and execution of the Chukchi Sea Acoustics, Oceanography, and Zooplankton (CHAOZ) cruise from 12 August through 11 September 2011. The cruise took place on the chartered fishing vessel F/V *Mystery Bay*. A total of fifteen scientists and observers participated on the CHAOZ cruise.

Since the completion of the cruise, all data have been stored, organized, and analyses begun (where possible), and the preliminary results are detailed below. In addition, the contract with Cornell University's Bioacoustics Research Program (BRP) was awarded this fall and ocean noise modeling analyses have begun. Work has begun on the modeling component of the project, which aims to predict the impact of climate change on the sea-ice characteristics and physical variables in the Chukchi Sea.

Introduction and objectives

The western Arctic physical climate is rapidly changing. The summer minimum sea ice extent in 2007 and 2008 covered an area which was 37% 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 Climate System Model: CCSM) for future projections using the sea ice extents from 2007/2008 as initial conditions.
6. Analyze multiple ensemble members from the NCAR model and other IPCC 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.

Cruise activities and summary

The 2011 CHAOZ cruise took place from 12 August through 11 September aboard the F/V *Mystery Bay*. Fifteen scientists participated in the survey. A total of 60 CTD and plankton tow stations were completed, 34 long-term oceanographic and acoustic moorings were deployed, 3 ARGOS drifters were deployed, over 1,400 miles were visually surveyed, and 246 sonobuoys were deployed (Figure 1). Please see the attached 2011 CHAOZ cruise report for a full summary of activities and accomplishments made during the cruise.

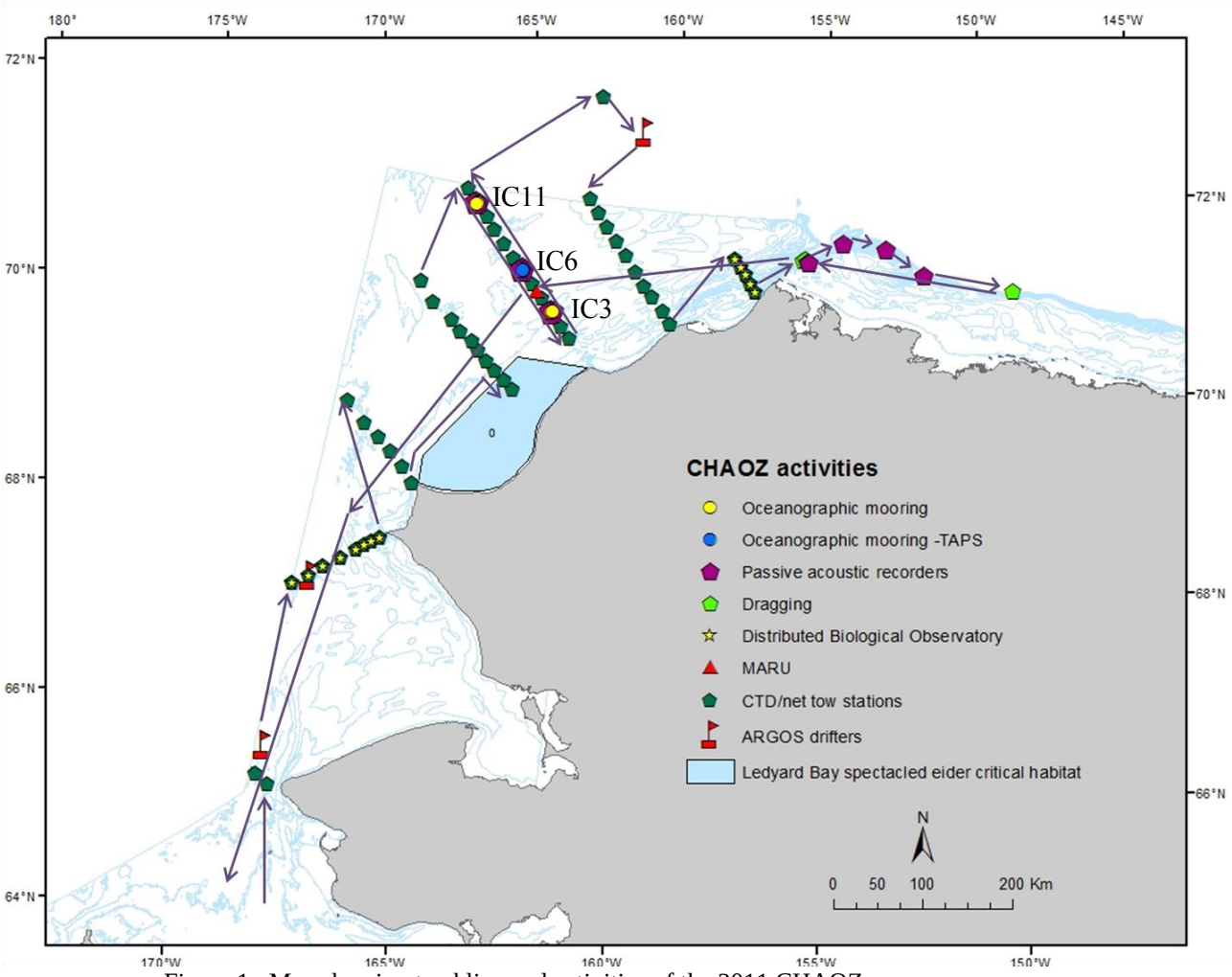

Figure 1. Map showing trackline and activities of the 2011 CHAOZ survey.

ACOUSTICS COMPONENT

Preliminary results

NMML Long-term moorings:
The first deployments of the long-term passive acoustic recorders were retrieved this year and data analysis has begun. These units recorded on a duty cycle of 95 minutes every 5 hours, at a sampling rate of 16kHz. Table 1 lists the 15 passive acoustic moorings, and the actual time period when they were recording data. The reason that no unit recorded for the full year span was because of a design change in the Duracell batteries that were used in the recorders, giving us a much reduced outcome. The units redeployed in 2011 were set to a duty cycle, so that those units should record for the full year. Preliminary analyses of the 2010-2011 units consist of one recorder from each array being analyzed for presence of bowhead, gray, fin, and beluga whales, and bearded seals. Results showing bowhead whale, fin whale, and bearded seal detections from one recorder within the IC6 array are shown in Figure 2. Once these preliminary analyses are finished, the remaining recorders will be analyzed. Modifications to existing array localization code will be completed in 2012 by Berchok.

Table 1. Recording period, position, and depth of all long-term passive acoustic recorders deployed off Icy Cape, AK. The 'A' moorings were deployed at IC3, 'B' moorings at IC6, and 'C' moorings at IC11.

Mooring	Record Start	Record End	Latitude	Longitude	Depth (m)
CZ10_AU_A01	9/10/2010	7/8/2011	70.9071500	-163.2394000	42.5
CZ10_AU_A02	9/10/2010	7/7/2011	70.8717167	-163.0441667	44.3
CZ10_AU_A03	9/10/2010	6/27/2011	70.7983833	-163.0811167	43.4
CZ10_AU_A04	9/10/2010	6/10/2011	70.7826000	-163.2872500	44.3
CZ10_AU_A05	9/10/2010	6/8/2011	70.8536000	-163.3698500	42.5
CZ10_AU_B01	9/10/2010	6/7/2011	71.2527500	-164.2770167	42.5
CZ10_AU_B02	9/10/2010	6/11/2011	71.2357333	-164.1898000	42.5
CZ10_AU_B03	9/10/2010	6/21/2011	71.2020333	-164.1922333	42.5
CZ10_AU_B04	9/10/2010	6/25/2011	71.1961500	-164.2969833	43.4
CZ10_AU_B05	9/10/2010	6/5/2011	71.2285833	-164.3444333	43.4
CZ10_AU_C01	9/10/2010	5/28/2011	71.8534000	-165.9958000	44.3
CZ10_AU_C02	9/10/2010	6/8/2011	71.8339500	-165.9033000	44.3
CZ10_AU_C03	9/10/2010	5/23/2011	71.8024167	-165.9220333	44.3
CZ10_AU_C04	9/10/2010	6/3/2011	71.7982167	-166.0302000	44.3
CZ10_AU_C05	9/10/2010	5/23/2011	71.8287333	-166.0707667	44.3

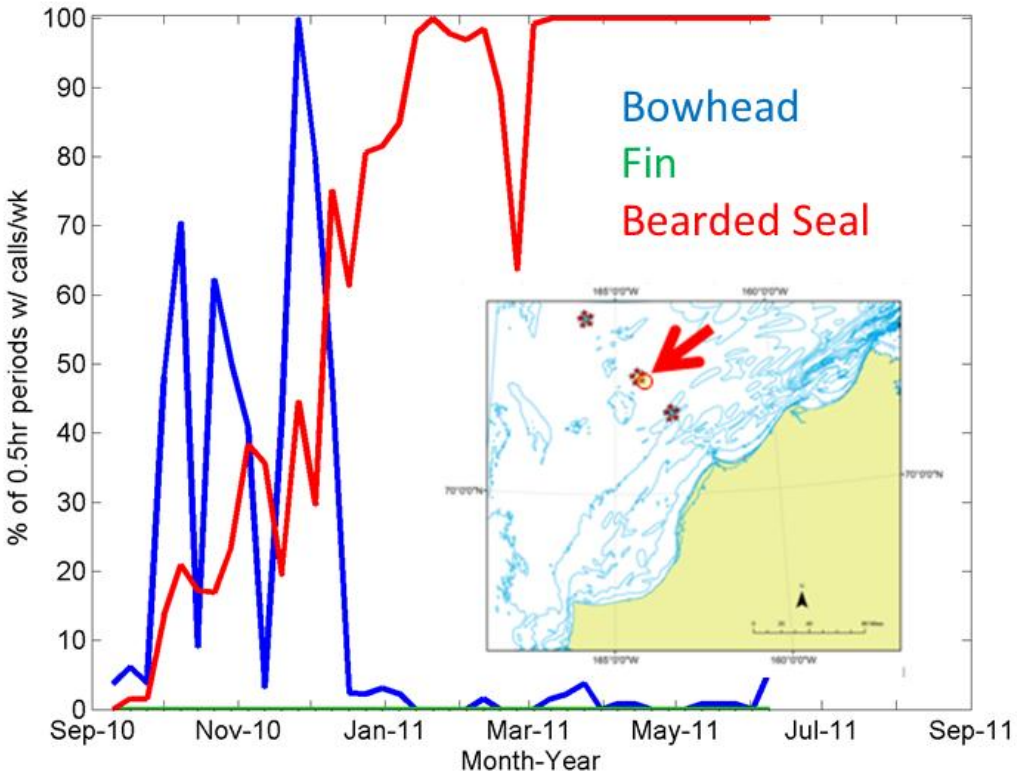

Figure 2. Seasonal acoustic detections of bowhead whales (blue), fin whales (green), and bearded seals (red) on recorder CZ10_AU_B03 at mooring IC6 (indicated by arrow in inset map) off Icy Cape, AK (September 10, 2010 – June 21, 2011).

Sonobuoys:
A total of 246 sonobuoys were deployed during the cruise. A preliminary analysis of species detected was conducted and the results are shown in Figure 3. The most commonly detected species in the Chukchi Sea were gray whales (*Eschrichtius robustus*) and walrus (*Odobenus rosmarus*). The most common species in the Bering Sea were fin whales (*Balaenoptera physalus*), humpback whales (*Megaptera novaeangliae*), and right whales (*Eubalaena japonica*). Refer to the cruise report for a more detailed description.

2012 preparations and analysis plans

The vessel contract for the 2012 field season was submitted in November 2011, and several discussions/meetings have taken place with the contracting agent. We are hoping for a late April award date. Preparations for the 2012 cruise are already underway. Equipment purchase orders and contractor task orders are being drafted and will be submitted shortly.

Data analysis of the recovered long-term moorings has begun. When possible, localizations of calling whales will be run to produce a finer scale analysis of whale distribution within the Chukchi and Bering Seas.

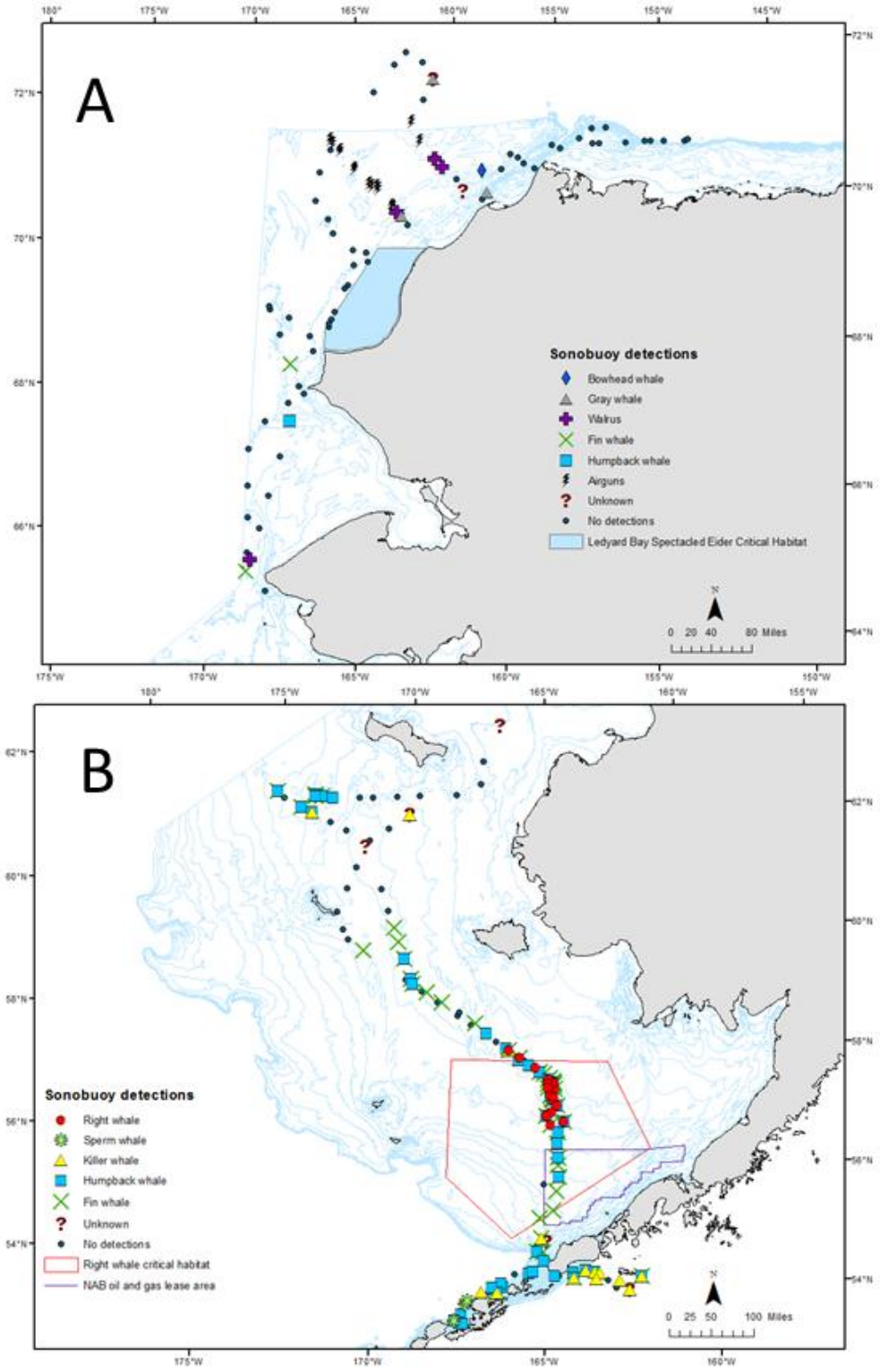

Figure 3. 2011 sonobuoy deployment and acoustic detections in the A). Chukchi Sea (18 Aug – 03 Sep); and B). Bering Sea (12 Aug – 18 Aug & 03 Sep – 11 Sep).

OCEANOGRAPHIC COMPONENT

Preliminary results

Long-term moorings:
We successfully recovered all oceanographic mooring which were deployed in August 2010. Only one instrument failed completely (an ISUS nitrate meter), all other instruments collected data for most of the deployment time. Processing has been completed for instruments measuring currents (both ADCP and point current meters), PAR, oxygen, nitrate, chlorophyll fluorescence, temperature and salinity.

The instruments measuring ice thickness require more complex processing. One instrument (IC6-A2) has been processed at the preliminary stage; only the final temperature correction for speed of sound still needs to be done. The ice-thickness data from the two remaining instruments will be completed within the next 4 months. The maximum keel depth at this location was >24 m and was observed in early June (Figure 4). From the current meters a calculation for transport has been completed (Figure 5), revealing that mean transport is 0.4×10^6 m^3 s^{-1}, approximately half the transport which flows through the Bering Strait. These data and results were presented at the Alaska Marine Science Symposium (AMSS) in January 2012.

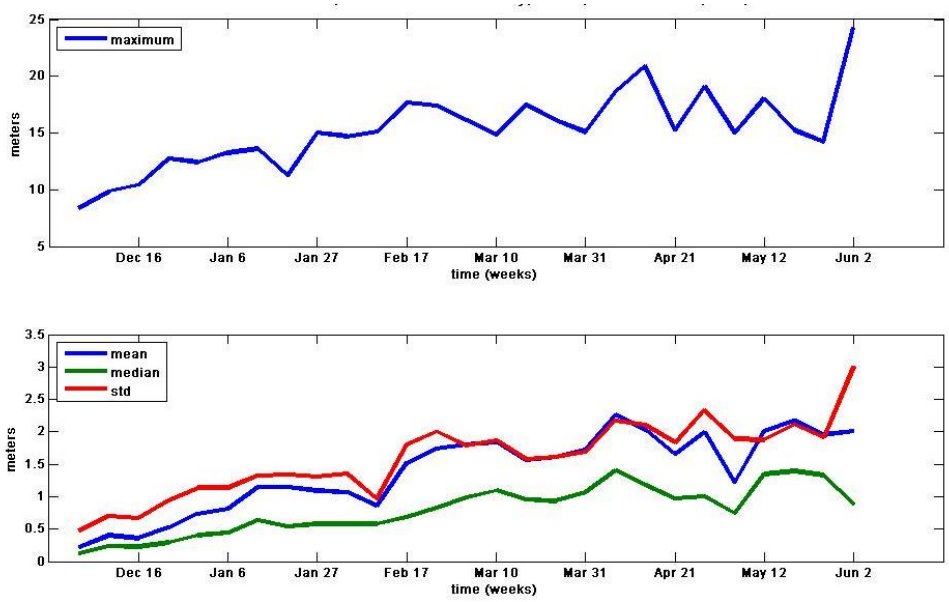

Figure 4. Data from the instrument measuring ice thickness. The top panel is the magnitude of the deepest keep observed during a one week period and the bottom panel is mean, median and standard deviation during each one week period.

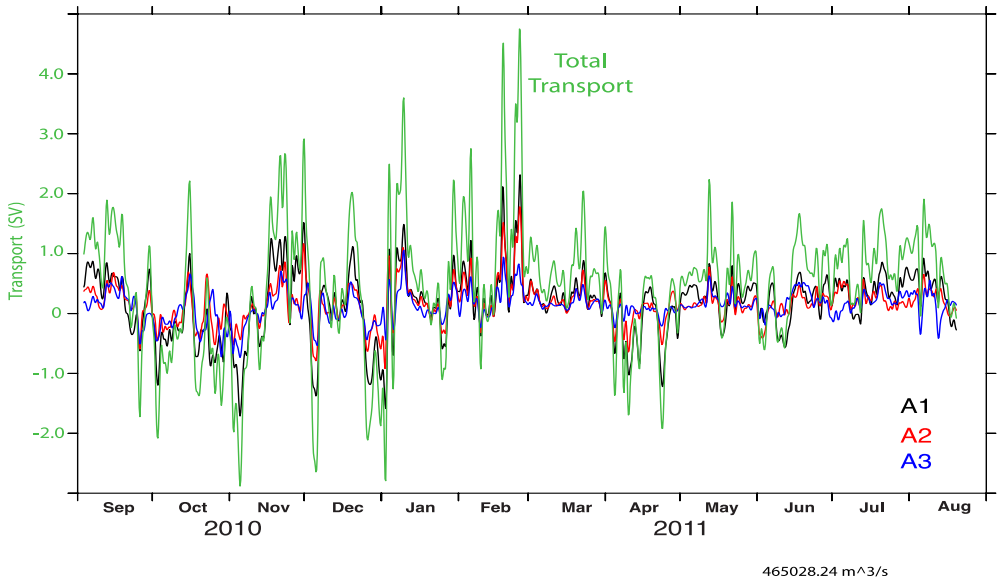

Figure 5. The transport (toward the northeast) at each of the three mooring sites and the total transport (green). The average transport is 0.4 Sv. All measurements are Sverdrups (10^6 m^3 s^{-1}). A1 at IC3, A2 at IC6, and A3 at IC11.

Eight moorings were deployed in August 2011 at the three mooring sites (IC3 and IC11 have two moorings each and IC6 has four moorings). An additional mooring was deployed at IC6 from the USCG Healy in November (see discussion below in the Zooplankton Component).

Shipboard measurements:
Data were collected at all planned hydrographic sites during the August 2011 cruise. Temperature, salinity, nutrients, PAR, oxygen and chlorophyll fluorescence from the hydrographic lines have all been processed and are available for use. The Alaska Coastal Current water is clearly evident in each of the southern transects. We have contributed our data to the DBO.

Satellite-tracked drifters:
Three satellite tracked drifters (drogued at 25 m) were deployed during the August cruise. These drifters were provided by FOCI/PMEL. Two were deployed near Bering Strait and travelled generally north/northwestward toward Harold Canyon. The third was deployed near Hannah Shoal and travelled first eastward along the slope and then westward in deeper water. All were caught in the advancing ice in November and December.

Satellite Remote Sensing:
Images from satellites have been processed and made available for chlorophyll. In addition, ice concentrations from the National Ice Center have been used to complement both the trajectories of satellite-tracked drifters and to help in the analysis of the mooring data.

2012 preparations and analysis plans

Cruise Preparation:
We have begun preparation for the summer cruise in 2012. This includes sending equipment away for calibrations. Personnel for the upcoming cruise have been notified. We plan to deploy moorings at IC6 in 2012. The configuration of equipment used in 2011 was very successful and we plan to replicate it in 2012.

ZOOPLANKTON COMPONENT

Preliminary results

Additional Deployments: After recovering the instruments during the August cruise we learned that our TAPS-8 instrument had filled its memory before the end of the deployment. The two instruments deployed this year were another TAPS-8 and a brand new TAPS-6NG. Although the TAPS-6NG has more memory and should be able to collect data until the end of the deployment, we made the decision to attempt a third deployment so that there were 2 instruments that could sample until next September. Therefore we contacted Dr. Carin Ashjian to ask if she could deploy our second TAPS-8 from the USCG Healey. She agreed and the instrument was successfully deployed in November at site IC6 with the other instruments after it received a post-cruise calibration. This TAPS-8 was set to sample less frequently to ensure there would be enough memory to last until next September.

TAPS Data Processing: We have been working with the instrument designer to correctly process and interpret the data collected last year from the TAPS-8 at site IC6. Discussion has centered around the correct background noise to subtract from the data and which statistics to use to determine when the data fulfill the volume backscatter assumptions. It appears that the noise correction for the instrument is different for the near field (small volume) versus the far field (large volume) data. Preliminary plots of volume backscatter corrected for noise have been produced and will be displayed on the poster presented at the January 2012 AMSS meeting. We continue to discuss and work on the appropriate scattering models for the inverse solutions. Some of the scientific literature suggests that micro-scale turbulence in the water column is a non-biological source of sound scattering that must be accounted for in the models.

TAPS-6 data collected during the August 2011 cruise have been processed and will be presented on our poster at the AMSS meeting. Two types of data were collected – a diel series at the mooring site IC6 (Figure 6, A-C) and vertical casts at each of the hydrographic stations. The vertical casts have been prepared as 2-dimensional slices for each transect conducted (Figure 7, A-D).

2012 preparations and analysis plans

Instrument Design and Construction: We worked to obtain parts (transducers, boards, electrical components) to build two more instruments. Assembly and testing will begin next quarter.

Preserved Samples: Preserved zooplankton samples from the August 2011 cruise were sent to Poland for processing and arrived mid-December. Data files and paper forms from the August/September 2010 zooplankton samples were returned from Poland and will undergo QA/QC procedures during the next quarter before being uploaded into our database. The information about the zooplankton community will be used to help choose the appropriate scattering models for the TAPS-8 and TAPS-6 data analyses. Frozen chlorophyll samples from the August 2011 cruise were processed. The data must undergo QA/QC procedures before being uploaded into our database. The EcoFOCI Program is currently in the process of building a new database that will better integrate biological and physical data. This effort is being funded by NOAA.

Other Activities: We have begun planning activities for the 2012 field season and have had multiple discussions with other researchers on how to coordinate CHAOZ activities with other programs such as ArcWEST. Napp also accepted an invitation from the Synthesis of Arctic Research (SOAR) Steering Committee to participate in the synthesis workshop that will be held in March.

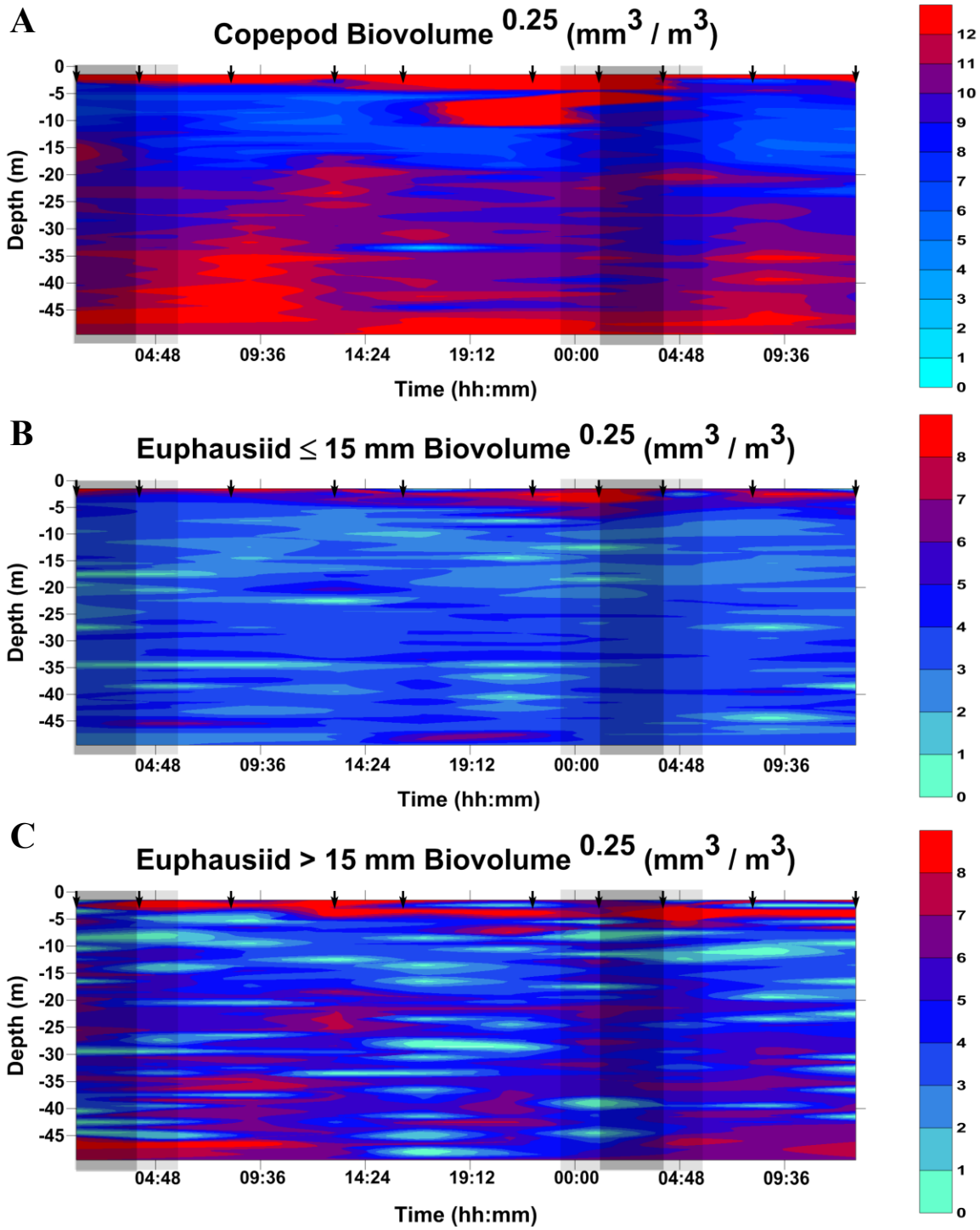

Figure 6. Acoustic estimates of zooplankton biovolume at the mooring site IC6. Arrows at the top of each panel indicate time of sampling and shaded areas indicates twilight and dark periods, respectively. Acoustic measurements were made with a TAPS-6 mounted on a Tucker sled. Casts were accomplished every couple of hours to determine whether or not Diel Vertical Migration (DVM) was occurring during our cruise. The TAPS-6 data have been processed using inverse methods to simultaneously determine the biovolume of sound scatterers using two different scattering models: the truncated fluid sphere model (approximates copepod-like scatterers, A) and the Distorted Wave Bjorn Approximation model (approximates elongate scatterers such as euphausiids, B & C).

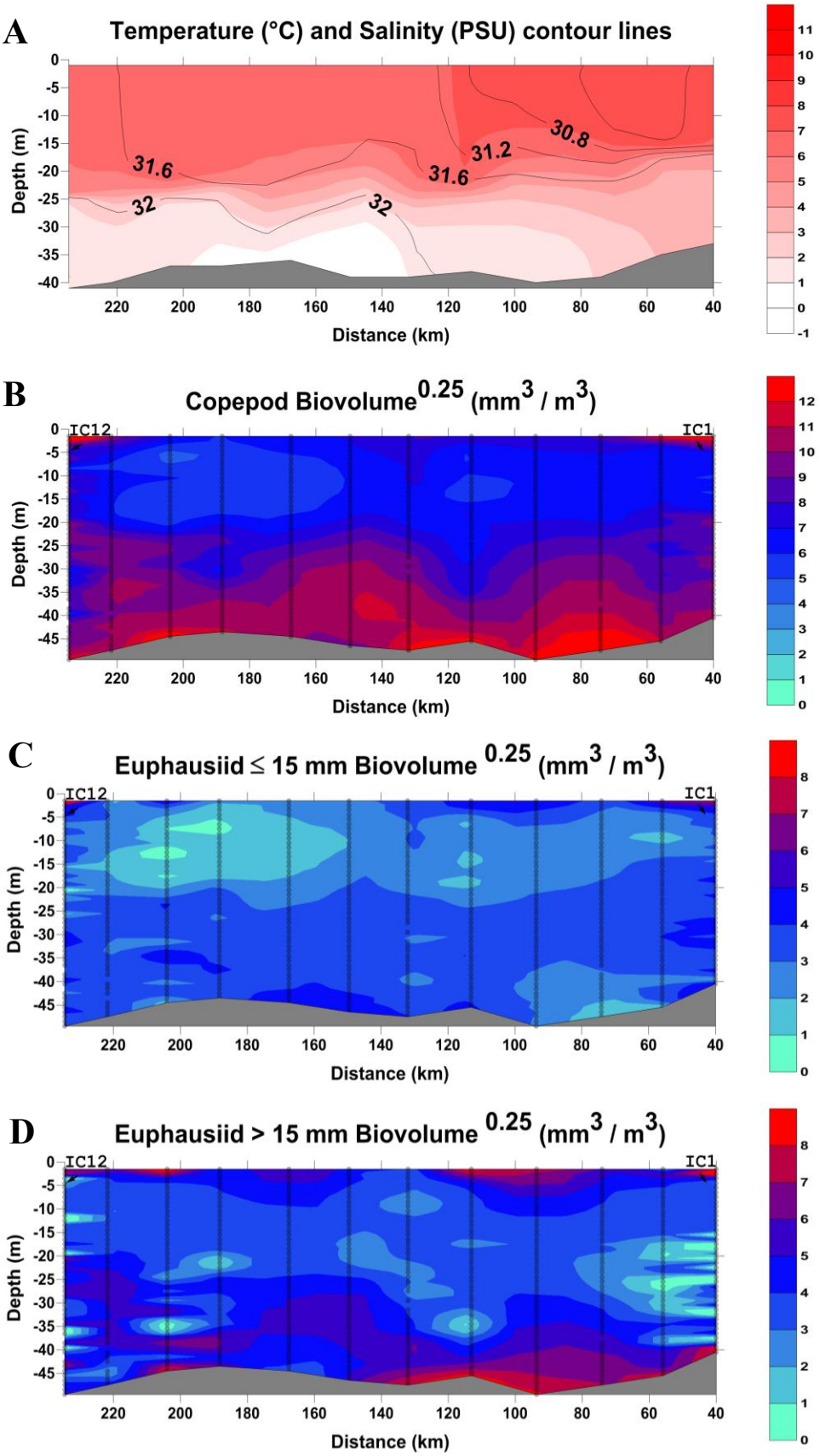

Figure 7. Acoustic estimates of hydrography and zooplankton biovolume measurements across the Icy Cape transect line. A) Temperature and salinity measurements made with an SBE 911*plus*. Acoustic measurements were made with a TAPS-6 mounted on a Tucker sled and processed in exactly the same way as in Figure 6. B) Copepod-like scatterers, C) Small euphausiid-like scatterers, and D) Large euphausiid-like scatterers. Vertical black line across the panels indicate where the measurements were taken along the transect.

OCEAN NOISE AND REAL-TIME PASSIVE ACOUSTIC MONITORING

The Bioacoustics Research Program at the Cornell Laboratory of Ornithology (BRP) is providing scientific and technical expertise in marine acoustics and bioacoustics; analysis and interpretation of existing and new acoustic data; and the deployment, maintenance and operation of auto-detection buoys.

The project's long-term goals for the Chukchi Sea acoustic ecosystem are to:

1. Report occurrences of acoustically active marine species and ocean noise metrics in near-real-time,
2. Quantify the ocean noise "budget",
3. Quantify the contributions of anthropogenic sounds to the ocean noise budget, and
4. Assess the influence of anthropogenic sounds on the acoustic habitats of marine species.

These goals are accomplished through an acoustic monitoring & mitigation component and an analysis component. The acoustic monitoring & mitigation component includes a near-real-time acoustic system (hereafter referred to as the auto-buoy, or AB) and a marine autonomous recording unit, hereafter referred to as a MARU. The acoustic analysis component consists of a) processing data collected via the AB and MARU systems and b) further developing mechanisms for quantifying noise budgets and masking metrics, with specific application to the Chukchi Sea acoustic ecosystem.

Accomplishments for the 2011 period were:

Acoustic Ecology: We continued to work on conceptual and empirical data factors that are part of a model for quantifying and evaluating the cumulative effects of human-made sounds on the acoustic ecology of the Arctic marine environment. We began collecting preliminary sound feature measurements during seismic airgun surveys conducted on the Arctic Ocean shelf at known distances from acoustic recorders. We also began engineering a software system for automating the overall acoustic ecology analysis algorithm.

WHOI Mooring: Towards the end of the year we were able to finally establish a subcontract with WHOI, and have recently started the necessary discussions about summer 2012 deployment locations, field logistics, etc. We also began discussions on the design of the ice-hardened auto-buoy surface expression. Roughly, the current plan is to integrate our new, smaller "CAN3" system electronics (Figures 8 and 9) into the surface buoy along with the Iridium and GPS antennas, all covered by an acrylic, RF-transparent dome. The idea is to minimize the mast profile and eliminate myriad weatherproof cables that typically connect the electronics package to the antennae and power systems. We expect further design effort and a healthy amount of integration testing with WHOI in the upcoming months.

AB Firmware/Testing: Further effort was applied towards developing and testing the detection engine capable of running multiple, simultaneous detectors. In addition, progress was made in developing a Bowhead detector, based on the existing Northern Right Whale (NRW) detector, ISRAT, and what we learned at recent conferences. Data annotation & display interfaces are being developed to allow annotation of detection events from multiple detectors.

Smaller, Modular Electronics Package: We continue to develop the new "CAN3" system, which contains features necessary for this project. We've entered a prototype phase and have fielded a set of test electronics in hopes of discovering defects. This new system includes a modular analog board (see Figure 10) with filters that should enable our monitoring of lower-frequency signals, because the earlier, NRW-tailored version included high-pass filtering which would be inappropriate for detecting fin whales. This system will also enable us to record to persistent data storage, in addition to reporting data in real time. Given the highly remote nature of the pending summer 2012 Chukchi Sea deployment, we've also begun evaluating options for out-of-band systems management (i.e. -- independent watchdogs, fail-safes, and methods for resetting the system should there be an issue) as a form of extra technical "insurance."

Figure 8. Comparison of older electronics can (yellow) and newer can (white).

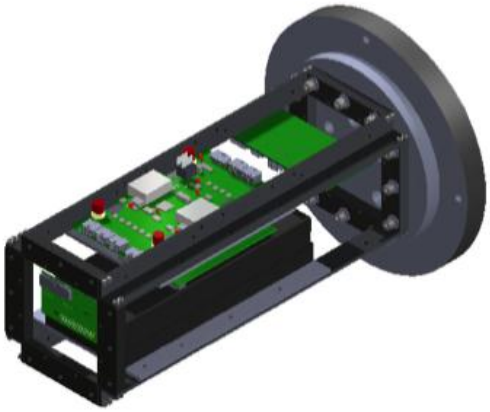

Figure 9. Drawing of electronics insert for new can system.

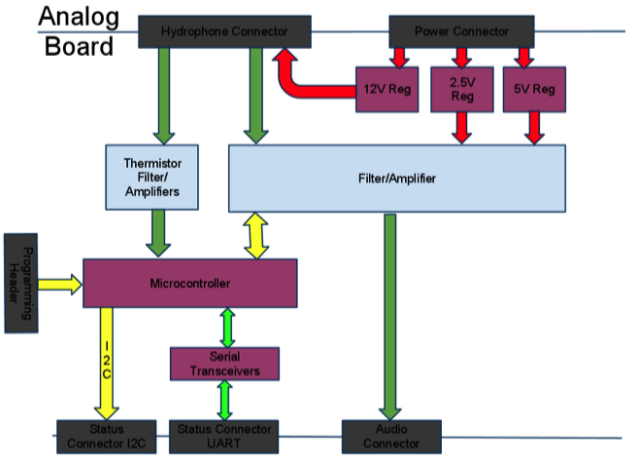

Figure 10. Modular design for new electronics board.

CLIMATE MODELING COMPONENT

Preliminary Results (Jan 1 –Dec 31, 2011)

- A manuscript about future climate projections by IPCC AR4 models over the Bering the Chukchi Seas has been accepted by DSRII in December, 2011. (Wang et al., 2011).
- We have been working with NCAR on their newest version of climate models (CESM1, which replaces the CCSM3 and CCSM4). Users accounts at NCAR's super computer have been set up for both Muyin Wang and Wei Cheng, who will be conducting model runs.
- We have applied computational resources at NCAR super computer, with approval of 90GAUs in total so far. This would allow us to carry at least three 40-year simulations runs in the coupled mode.
- An initial test run at NCAR super computer with 5-day of integration has been carried out. Overland, Stabeno, Wang and Cheng have met several times (June, 10, 2011, Aug. 25, 2011, Dec. 5, 2011, and Jan 9, 2012) together to discuss the set up of the climate model runs. Plan has been made, and we are ready to carry out our first simulations in the near future.
- M. Wang has been downloading the CMIP5 model outputs. She has collected sea ice simulations from 23 climate models. Analysis is under way.
- M. Wang and J. Overland gave a presentation at the WCRP Open science meeting in October, 2011, entitled "A first look at the sea ice simulations from CMIP5". This conference covers all aspects of understanding and predicting climate variability and change, and it delivers a comprehensive assessment of climate research from a diverse research communities. The grand challenges facing the climate research community have been identified.

Significant meetings held or other contacts made

15-17 November 2011: Sue Moore presented marine mammal and seabird sighting data from the 2010 & 2011 CHAOZ cruises, as examples of 'higher-trophic' species contributions to the Distributed Biological Observatory (http://www.arctic.noaa.gov/dbo/), at the DBO Workshop and Pacific Arctic Group (PAG) meeting in Sidney, BC Canada.

5 January 2012: Berchok, Crance, Floering, and Stabeno meet to discuss upcoming cruise logistics.

Presentations

Crance, J.L., C.L. Berchok, B. Rone, A. Kennedy, E. Küsel, L. Morse, J. Thompson, and P.J. Clapham. 2012. "Short-term trends in the summer distribution of cetaceans in the Chukchi Sea". 19th Biennial Conference on the Biology of Marine Mammals, Nov 28 – Dec 2, 2011. Tampa Bay, FL.

Crance, J.L., C.L. Berchok, B. Rone, A. Kennedy, E. Küsel, L. Morse, J. Thompson, and P.J. Clapham. 2012. "Visual and acoustic survey results during the 2010 CHAOZ cruise". Alaska Marine Science Symposium, 16-20 January 2012. Anchorage, AK.

Moore, S., K. Kuletz, and J. Murphy. 2011. "Fish, seabird, and marine mammal observations during the 2010-2011 Pilot DBO." Distributed Biological Observatory (DBO) workshop and Pacific Arctic Group (PAG) meeting, 15-16 November 2011. Sidney, BC.

Napp, J.M., A.H. Spear, and P.J. Stabeno, 2012. "Acoustic detection of zooplankton in the Chukchi Sea". Alaska Marine Science Symposium, 16-20 January 2012. Anchorage, AK.

Stabeno, P., C. Berchok, S. Moore, C. Mordy, J. Napp, and S. Salo. 2012. “Chukchi Acoustics, Oceanography, and Zooplankton (CHAOZ): Observations on the Chukchi Sea”. Alaska Marine Science Symposium, 16-20 January 2012. Anchorage, AK.

Wang, M., J.E. Overland, P. Stabeno. 2011. “Future climate of the Bering and Chukchi Seas projected by global climate models”. Deep Sea Research II. Accepted.