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

Catherine L. Berchok[1], Ph.D.
Phillip J. Clapham[1], Ph.D.
Jessica Crance[1], M.S.
Sue E. Moore[2], Ph.D.
Jeff Napp[3], Ph.D.
James Overland[4], Ph.D.
Phyllis Stabeno[4], Ph.D.
Christopher Clark[5], Ph.D.

[1]National Marine Mammal Laboratory
Alaska Fisheries Science Center

[2]National Marine Fisheries Service
Office of Science & Technology

[3]Resource Assessment and Conservation Engineering Division
Alaska Fisheries Science Center

[4]Pacific Marine Environmental Laboratory
Ocean Environment Research Division

7600 Sand Point Way NE
Seattle, WA 98115

[5]Bioacoustics Research Program, Cornell University
159 Sapsucker Woods Road, Ithaca, NY 14850

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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 quarterly report covers the period between April 16th and July 15th 2012.

The major activities during this period consisted of preparation for the Chukchi Sea Acoustics, Oceanography, and Zooplankton (CHAOZ) cruise that will take place from 8 August through 5 September 2012. The cruise will take place on the chartered research vessel the R/V *Aquila*. Analyses are currently ongoing, and some preliminary results are detailed below.

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 PROGRESS

Preparations for the 2012 cruise are well underway. The vessel contract for the 2012 field season was awarded in early June to the R/V *Aquila*, and the fuel contract was awarded this week. All contractor task orders have been awarded, flights and hotel rooms have been booked, and all equipment has been purchased or ordered. Loading will take place on July 26th and 27th at the NOAA Sand Point dock. The three winches (one hydraulic, two electro-hydraulic) have been delivered to the vessel for installation. A total of 17 scientists will be participating in the cruise, although there will never be more than 15 scientists on board at once. Figure 1 shows the Chukchi portion of the CHAOZ cruise, including the oceanographic and zooplankton stations as well as all long-term mooring deployments.

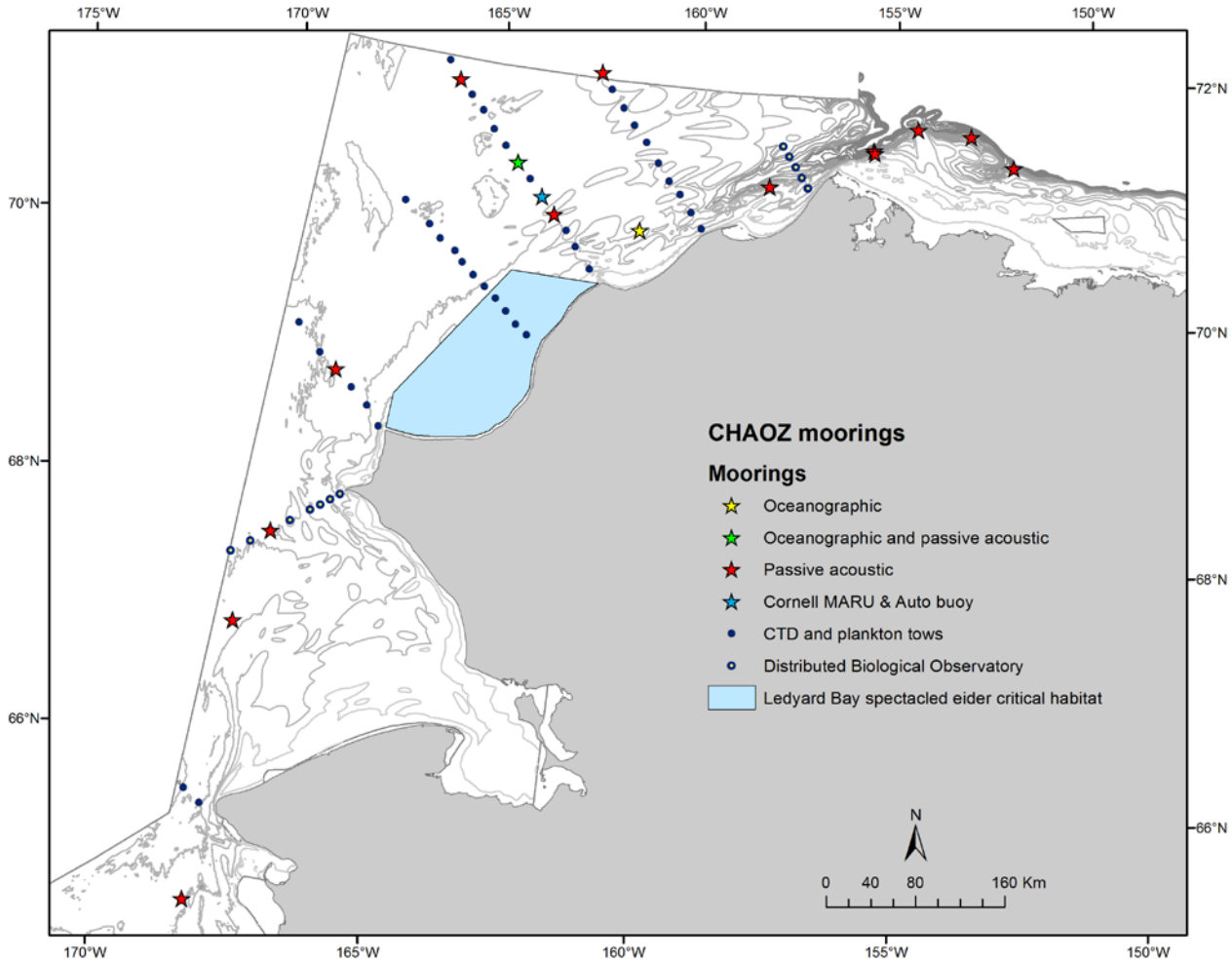


Figure 1. Map of all CHAOZ activities in the Chukchi portion of the cruise.

ACOUSTICS COMPONENT

Preliminary results

NMML Long-term moorings:
The first deployments of the long-term passive acoustic recorders were retrieved in fall 2011 and analyses are still underway. These units recorded on a duty cycle of 95 minutes every 5 hours, at a sampling rate of 16kHz. 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 and fin whale, and bearded seal detections from one mooring within the middle IC6 array are shown in Figure 2. Results showing bowhead whale detections from one mooring within the IC3 array (inshore) are shown in Figure 3. Data analysis of the long-term moorings is still on-going. Modifications to the localization code will be completed in 2012 by Berchok.

Ellen Garland, a new post-doc from the University of Queensland, Australia, has begun analyzing the CHAOZ moorings for the presence of beluga whales. The inshore Icy Cape mooring analysis is almost complete. Once initial presence/absence has been established on all moorings, her analysis will then focus on cataloguing beluga vocalizations, and determining if they have population-specific vocalizations. Kalyn MacIntyre, a graduate student at the University of Washington, is analyzing these recorders along with numerous others to determine bearded seal spatial and temporal presence throughout the entire Bering, Chukchi, and Beaufort Seas.

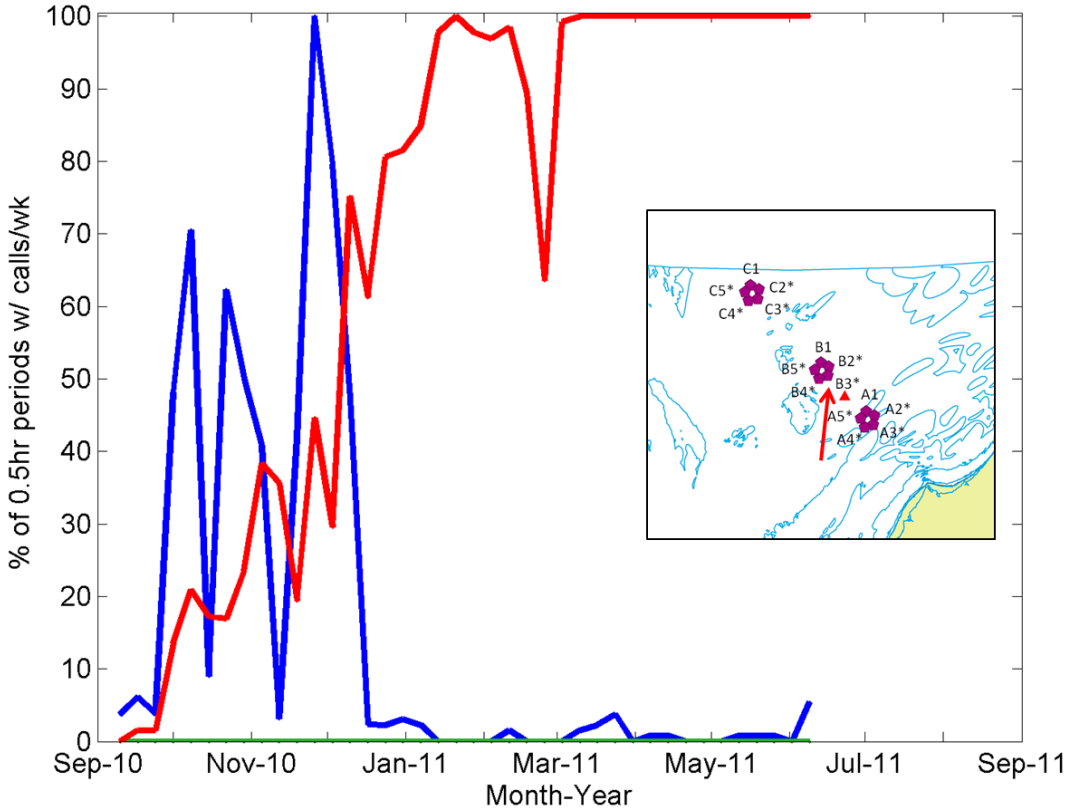


Figure 2. Seasonal acoustic detections of bowhead whales (blue), fin whales (green), and bearded seals (red) at mooring B3 within the IC6 array (indicated by arrow in inset map) off Icy Cape, AK (Sept. 10, 2010 – June 21, 2011).

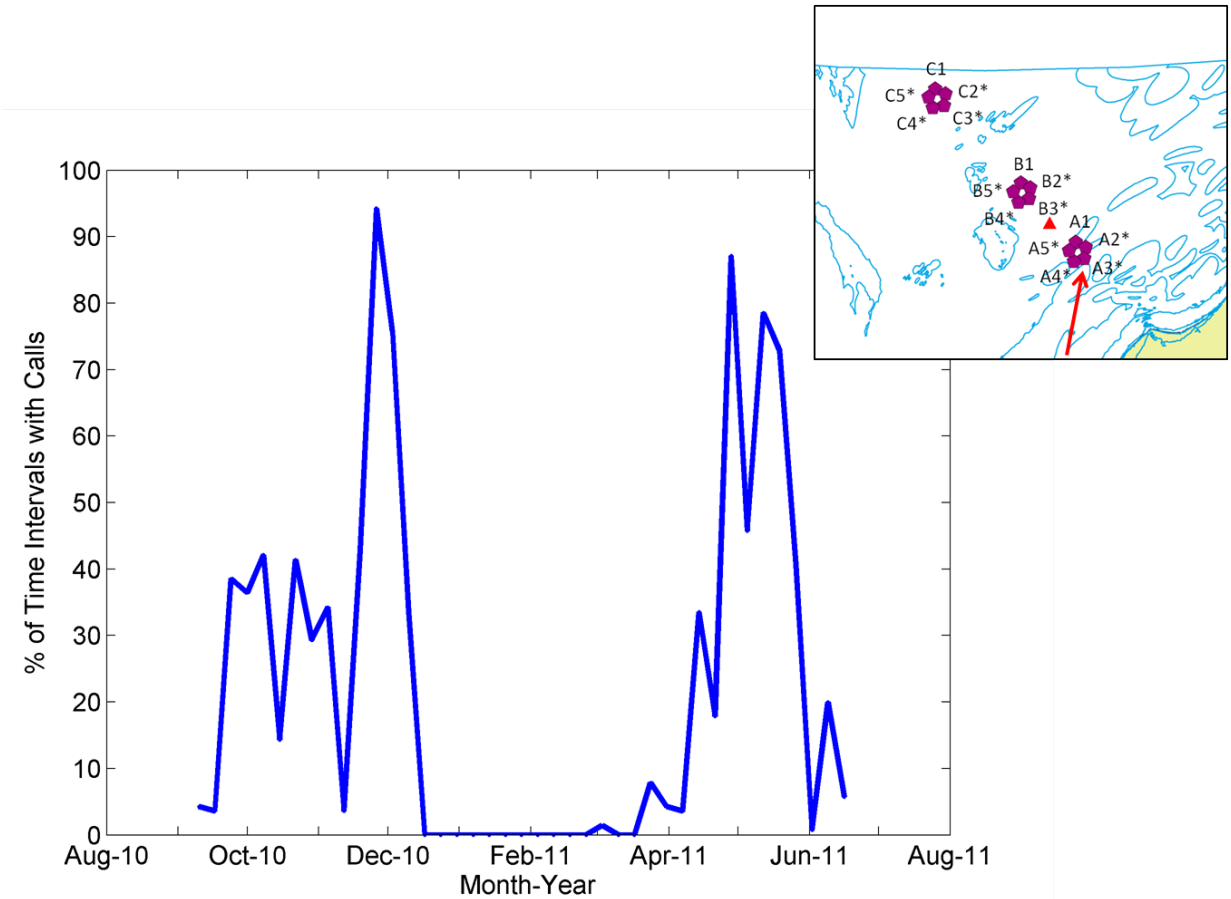


Figure 3. Seasonal acoustic detections of bowhead whales at mooring site A3 within the inshore IC3 array (indicated by arrow in inset map) off Icy Cape, AK (Sept. 10, 2010 – June 27, 2011).

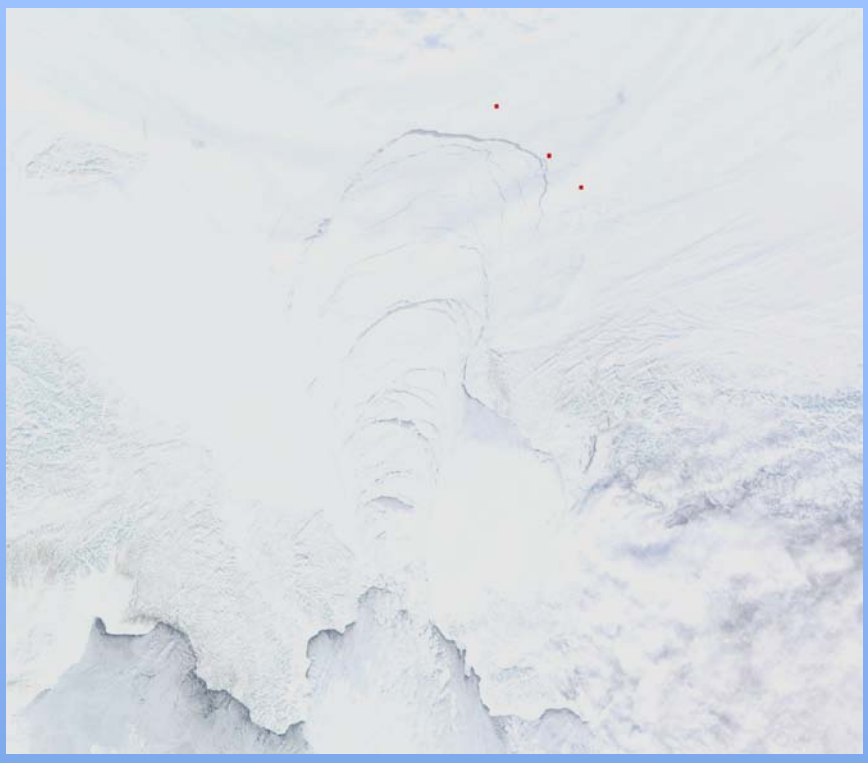
2012 preparations and analysis plans

Because future projects will guarantee ship time in the same area, we are redeploying our recorders. All Beaufort mooring locations will remain the same, as well as the Bering Sea mooring locations, to maintain a consistency in the long-term data set. The three arrays of five recorders off Icy Cape will be replaced with one recorder per location. Additional moorings will be deployed offshore of Wainwright, in Peard Bay, Cape Lisburne, Point Hope, Kotzebue Sound, and the south Bering Strait (Figure 1). Because changes in the Duracell battery cell capacity resulted in a shortened life span of the recorders in 2010 and a shortened duty cycle in 2011, we have switched to battery packs that use Panasonic batteries. Hopefully this will increase the cell capacity and allow the AURALs to run on the original duty cycle for a full year.

OCEANOGRAPHIC COMPONENT

Preliminary results

Analysis of satellite images of ice extent was completed for the winter and spring 2012. An impressive ice arch formed north of Bering Strait in late February 2012 (Figure 4) and the impact of collapse of the arch extended to the moorings within two weeks. Transport of ice floes through Bering Strait is evident in Figures 4 and 5.



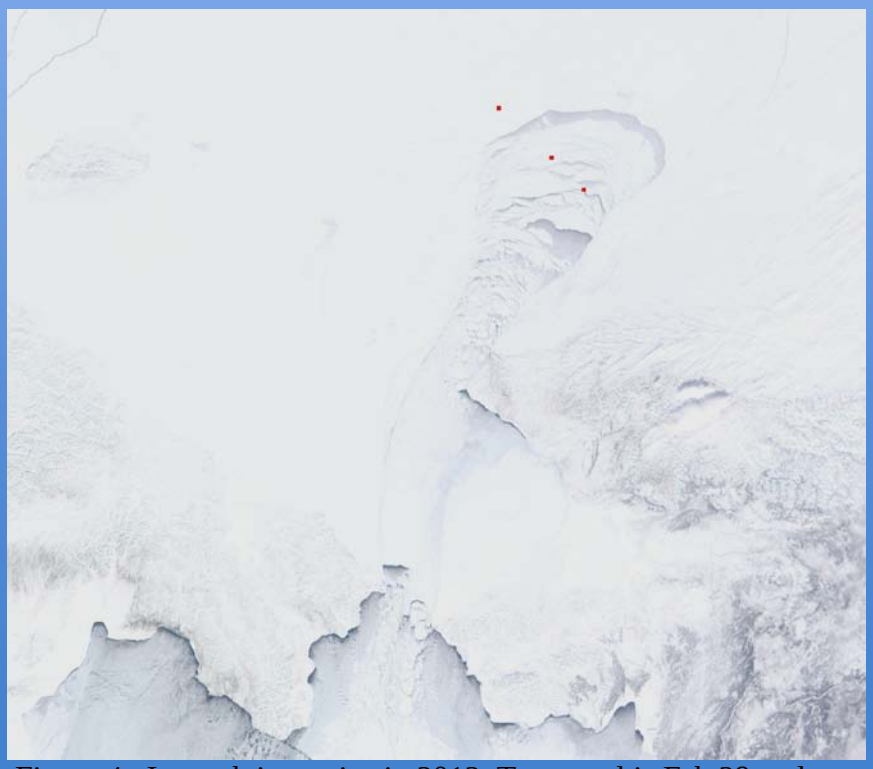


Figure 4. Ice arch in sea ice in 2012. Top panel is Feb 29 and bottom panel is March 19. The red dots are the mooring locations off Icy Cape.

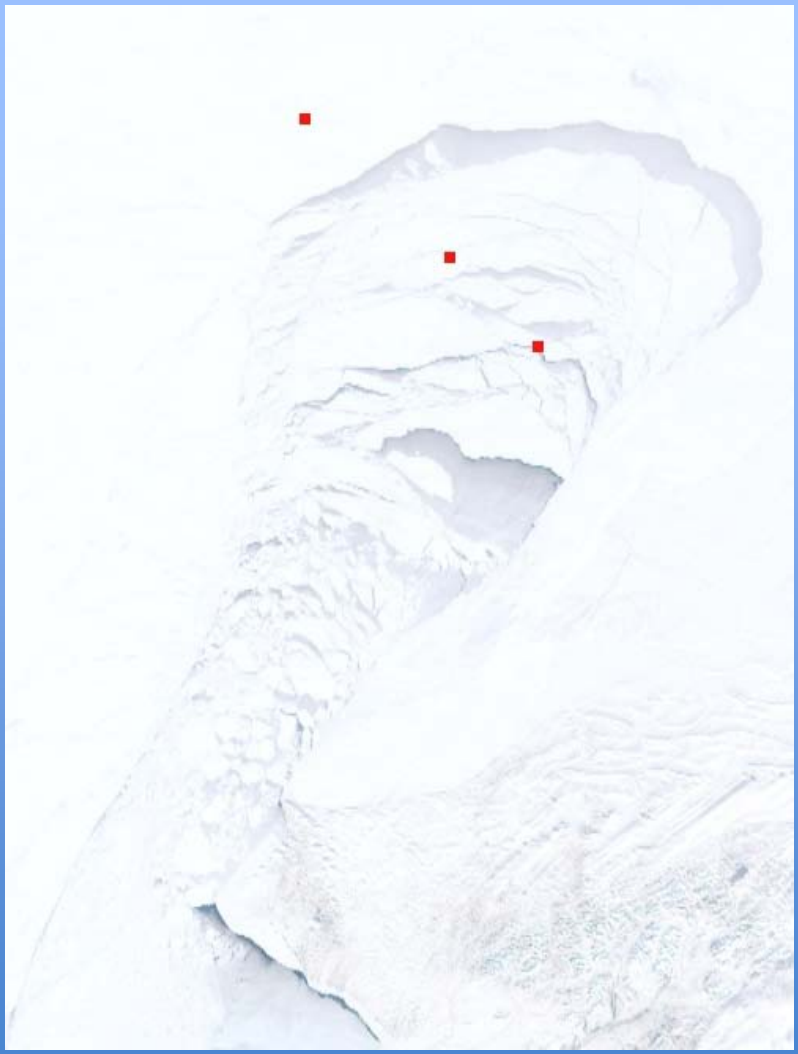


Figure 5. An enlargement of the bottom panel of Figure 4 showing the flow of ice through Bering Strait. The red dots are the mooring locations off Icy Cape.

Shipboard measurements:
Temperature, salinity, nutrients, PAR, oxygen and chlorophyll fluorescence will be collected on each of the hydrographic lines (Figure 1). The nutrients and chlorophyll samples will be collected and frozen in a -80°C freezer and analyzed at PMEL and AFSC (respectively) in the fall. Oxygen samples will be collected and analyzed at sea. Salinity samples for calibration of the CTD will be collected and processed at PMEL. We will contribute our data to the Distributed Biological Observatory (DBO).

Satellite-tracked drifters:
A dozen satellite-tracked drifters (drogued at 30 m) will be deployed in July and August 2012. We are using ships of opportunity to deploy 6 of the drifters before our cruise and the remaining 6 will be deployed during our cruise.

Satellite Remote Sensing:
Satellite images 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. The large ice floe in Figure 7 had at least one deep keel as shown in the time series Figure 6.

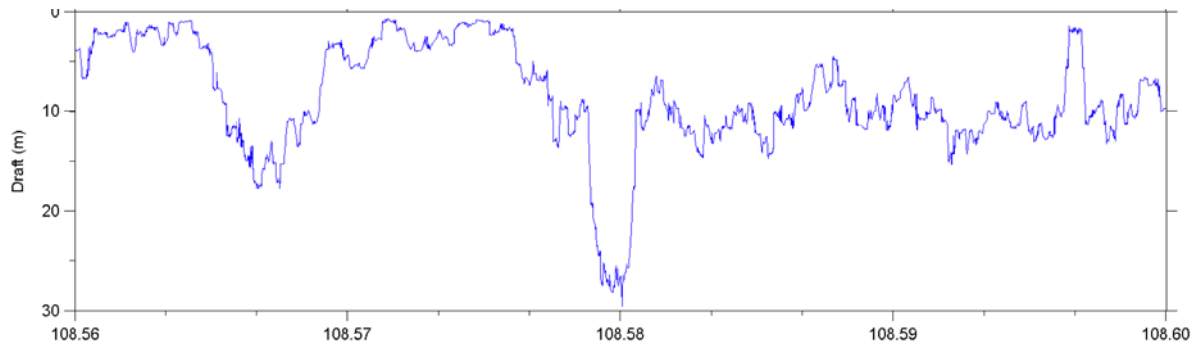


Figure 6. Time series of ice thickness at IC3 on April 18, 2011 at 13:30 – 14:30.

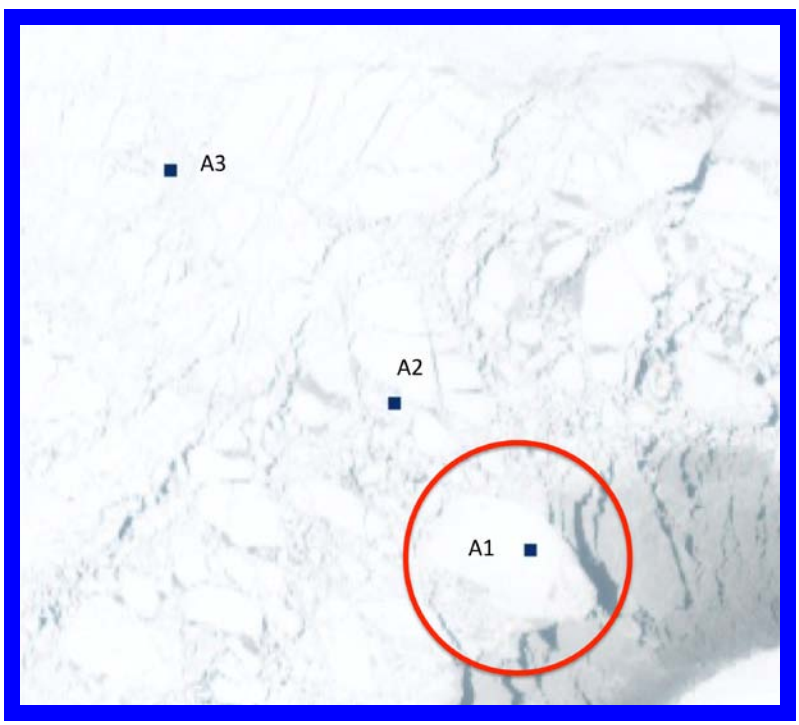


Figure 7. At the time of time series shown in Figure 6, the large ice floe near IC3 (red circle) was at the site. A1 = IC3, A2 = IC6, A3 = IC11

2012 preparations and analysis plans

We are preparing for the summer cruise in 2012. All equipment has been calibrated and prepared for deployment, and personnel for the upcoming cruise have been notified. Because future projects will guarantee ship time in the same area, we are re-deploying our biophysical moorings at two sites. All equipment has been prepped and is ready for loading at the end of July. We plan to deploy moorings at IC6 and at an additional site closer to Wainwright in 2012. The configuration of equipment used in 2011 was very successful and will be replicated in 2012.

ZOOPLANKTON COMPONENT

Preliminary results

TAPS Data Processing:
We continued our work with the instrument designer to correctly process and interpret the data we are collecting. This year we hope to capture live euphausiids to make measurements of their acoustic density at sea using a velocimeter. We continue to discuss and work on the appropriate scattering models for the inverse solutions. We are investigating a new model for Bering Sea euphausiids developed by Ressler *et al*. in a collaboration between the Alaska Fisheries Science Center and the SUNY Stony Brook Acoustic Laboratory for Ecological Studies (Joe Warren). We are also working to process and interpret in parallel TAPS and ADCP data from the eastern Bering Sea that show a strong season pattern to the vertical migration by plankton.

2012 preparations and analysis plans

Instrument Design and Construction:
We successfully built and calibrated two new TAPS6-NG instruments during the quarter. In the process of testing them in Lake Washington and Puget Sound we discovered some firmware issues (e.g. missing code for electronic or background noise measurements) that are being corrected by our contractor (Charles Greenlaw). The new code will arrive early in the 3rd Quarter and be tested in Lake Washington before the instruments are loaded on the R/V *Aquila* in late July. We have also begun to work with another firm to engineer a new TAPS6-NG controller board. Once designed and built, the new boards should draw much less power when the instrument is not taking measurements enabling us to sample more frequency for the same size battery packs. The new design will also expand our data storage capacity and enable us to save the raw data allowing us more options with the data processing.

Preserved Samples:
Ms. Nissa Ferm completed the QA/QC on the 2010 zooplankton samples processed in Poland and the data have been uploaded into our database.

Cruise Preparation and Other Activities:
A large part of our effort over the last quarter was to prepare for the upcoming cruise. We prepped our plankton winch and delivered it to the R/V *Aquila* for securing to the deck. Some equipment, such as a deck table for processing samples has been built; new batteries for the TAPS6-NG were ordered. We have been working on the 2012 sampling plan, gathering equipment, and discussing how to coordinate with the cruise and with the many other cruises occurring in the Chukchi during August and September of 2012. Note that we have made two changes to this year's sampling plans for the zooplankton. A second TAPS6-NG will be deployed between the Icy Cape and Wainwright lines and we will add an inshore station on the Icy Cape and Point Lay both lines at the expense of the last station on each line. This is to ensure that we are sampling any Alaska Coastal Water or Barrow Canyon Water that is near the coast.

OCEAN NOISE AND REAL-TIME PASSIVE ACOUSTIC MONITORING

Auto-Detection Buoy System (AB)
We were able to successfully integrate the modified AB electronics with WHOI's ruggedized buoy at Woods Hole, and continue to perform some testing of the unit and spare units. An additional lid for the spare electronics is being machined, the goal being to have a drop-in spare ready for integration in Seattle.

AB Firmware:
A custom firmware image was created for the upcoming deployment, and is being tested on the bench.

Noise Measurements:
We were successful in capturing data on 21 June 2012 at the Navy Underwater Warfare Center's (NUWC) Sonar Test Facility on Seneca Lake, which is one lake over from Cayuga Lake. Data were captured through the hydrophone and a replica of the signal path that will be deployed in the Chukchi Sea, so that we might calibrate the output of the noise measures we will receive from the AB, *in situ*. Progress was also made toward the visualization interface, the database backend and the signal processing firmware for computing and reporting power spectra.

We're looking forward to integration testing in Seattle during the week of 23rd July.

Figure 8. Picture of AB system ready for calibration testing at the NUWC Sonar Test Facility on Seneca Lake, NY on 21 June 2012.

We are in the process of comparing results for computing power spectral density (PSD) based on the algorithm implemented in the AB firmware for the summer 2012 deployment and our LTSpect software tool operating in the lab at Cornell. For this effort we are using data recorded by the MARU deployed for approximately 12 months in the Chukchi Sea in 2010-2011. The objective is to make sure that the AB output and the spectral analysis of the MARU dataset agree. The next steps are to lock in the AB spectral analysis code and to process the entire 2010-2011 dataset with our LTSpect software tool to create daily and long-term spectrograms.

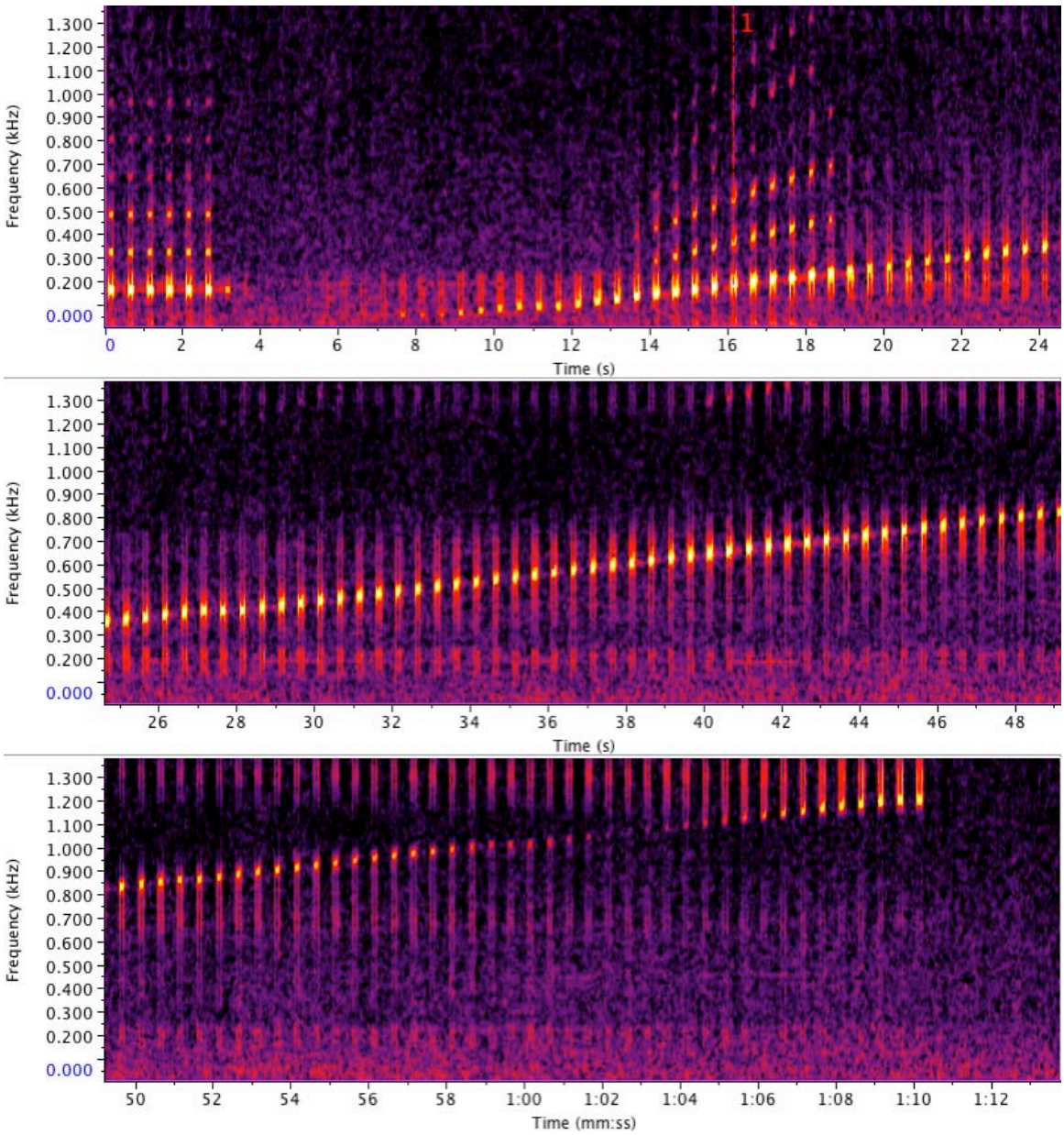


Figure 9. Spectrogram image showing the sequence of received calibrated signals as recorded on the AB system at the NUWC Sonar Test Facility on Seneca Lake, NY on 21 June 2012.

After several steps, we established contact with Jeff Hawkins (at NRL) who provided an FTP site to download wind data from the Beaufort/Chukchi region: 25-km swath, grid data are available as well as the 12.5-km slice composites. We are still trying to understand the format of the data (.nc) and how to manipulate it. Jeff recently connected us to several people at JPL who manage these datasets, to get their advice.

Finally, we contacted Todd Sformo (North Slope Borough) asking for local shipping information, but we have not yet heard back from Todd on this request.

CLIMATE MODELING COMPONENT

We have successfully carried three runs, each consisted 30 years of simulation using CESM1.0 configuration as summarized in the last report, and shown in Figure 10. Initial analysis of the model outputs showed promising results: the simulated surface current pattern and the averaged temperature and salinity over the Chukchi Sea agree with the observations obtained from the CHAOZ biophysical moorings. We also found that neither sea ice extent nor the ice thickness in Chukchi Sea is sensitive to the initial conditions. A poster was presented at the 2012 CESM Annual Workshop, which was held at Breckenridge, CO, 18-21 June, 2012. Dr. Muyin Wang and Wei Cheng participated in the workshop, and gave the presentation.

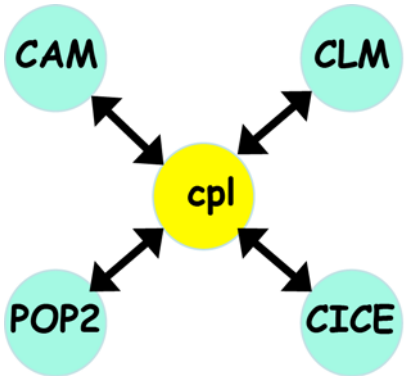


Figure 10. The configuration of the CESM1 used in current simulations. Blue circles represent model components, yellow circle represents the coupler.

The September sea ice extent declines at a different rate under all three emissions scenarios (Rcp4.5, Rcp6.0, and Rcp8.5) in the CCSM4 simulations. We have chosen to run the CESM model using the initial condition as of September 2023, since this is the earliest time when the sea ice over the Arctic reached the lowest value, a number close to the observed sea ice extent in recent years.

Taking this as current sea ice condition (year 2011), we then integrate CESM1 model for 30 years under Rcp6.0 emission scenario starting from Sept. 6th, 1st, and 11th, 2011, respectively. These runs are then compared with the original CCSM4 runs to see if they would be significantly different from the original ones. Our hypothesis is that once the sea ice coverage is low, the positive ice-albedo feedback would keep the ice low, and may speed up the declining trend. Model simulated ocean and ice conditions (currents, temperature, salinity and sea ice thickness) at the mooring sites are also compared with observations (the CHAOZ moorings IC3, IC6, and IC11; Figure 11).

An initial analysis of model outputs shows promising results. The model simulated ocean currents (Fig. 12) captured the main features of the surface currents in the region. A generally northward flow crossing the Bering Strait into Chukchi Sea is seen in Figure 12, which is consistent with previous observations and studies. The northward flow entering the Chukchi Sea diverges as it moves further north: one branch moves toward the Beaufort Sea, and the other moves toward to Siberia Sea.

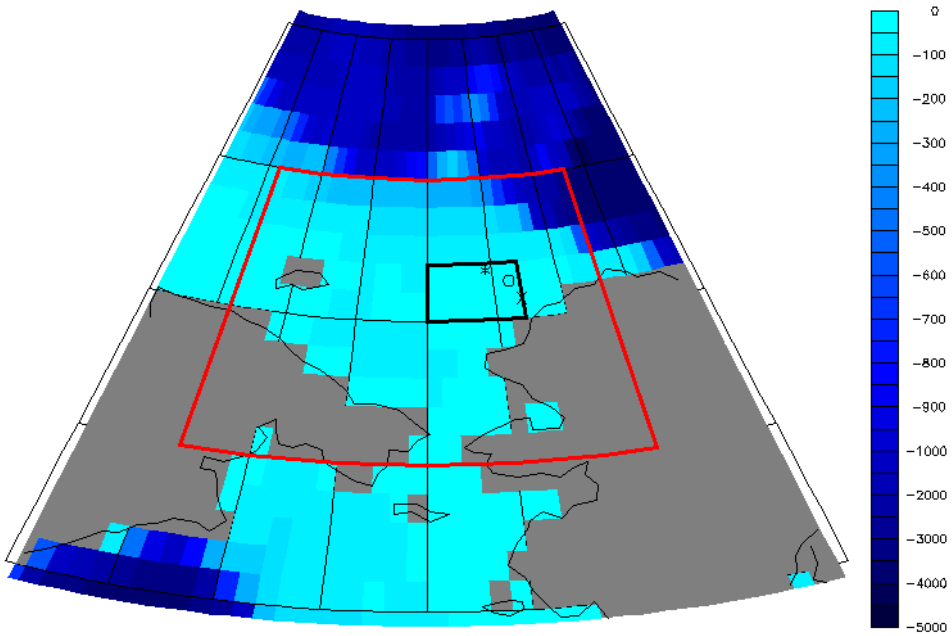


Figure 11. The bathymetry around the Chukchi Sea. Red box outlines the approximate boundary of Chukchi Sea, and the small black box outlines the domain where mean ice thickness is calculated when model results are compared with CHAOZ moorings. The markers inside small black box indicates the location of the moorings for IC3 (x), IC6 (o), and IC11 (*).

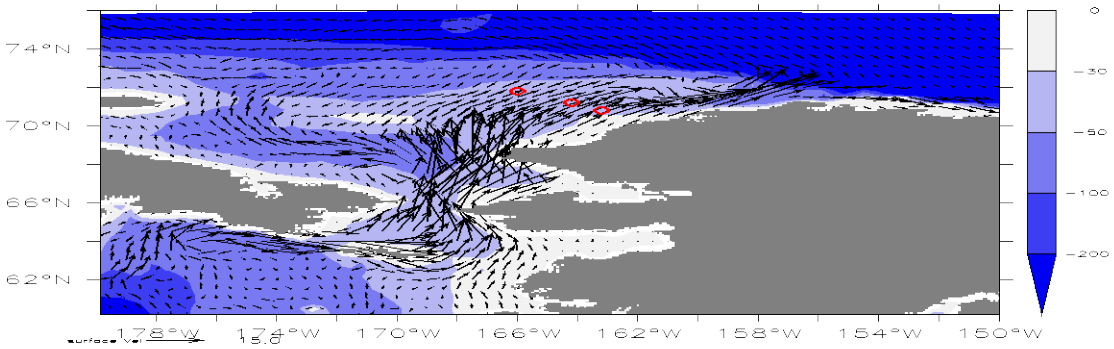


Figure 12. Annual mean surface ocean currents averaged over 30 years as simulated by CESM Model in one run. Color shows the bathymetry, and the red circles indicate the location of CHAOZ moorings.

The direction and magnitude of ocean current at 30m depth simulated by the model also show agreement with observations (Figure 13). Both model-simulated results and observation from the moorings show that the ocean current at 30m depth is stronger at mooring IC11 (offshore) than at IC3 (inshore). The inter-annual variability is obvious from model simulations (only 10 years are shown), and in general, the magnitudes as well as the directions of the currents are captured well by the model simulations. This is shown in Figure 13, as the red stick (observation) is within the envelop of the black sticks (model run).

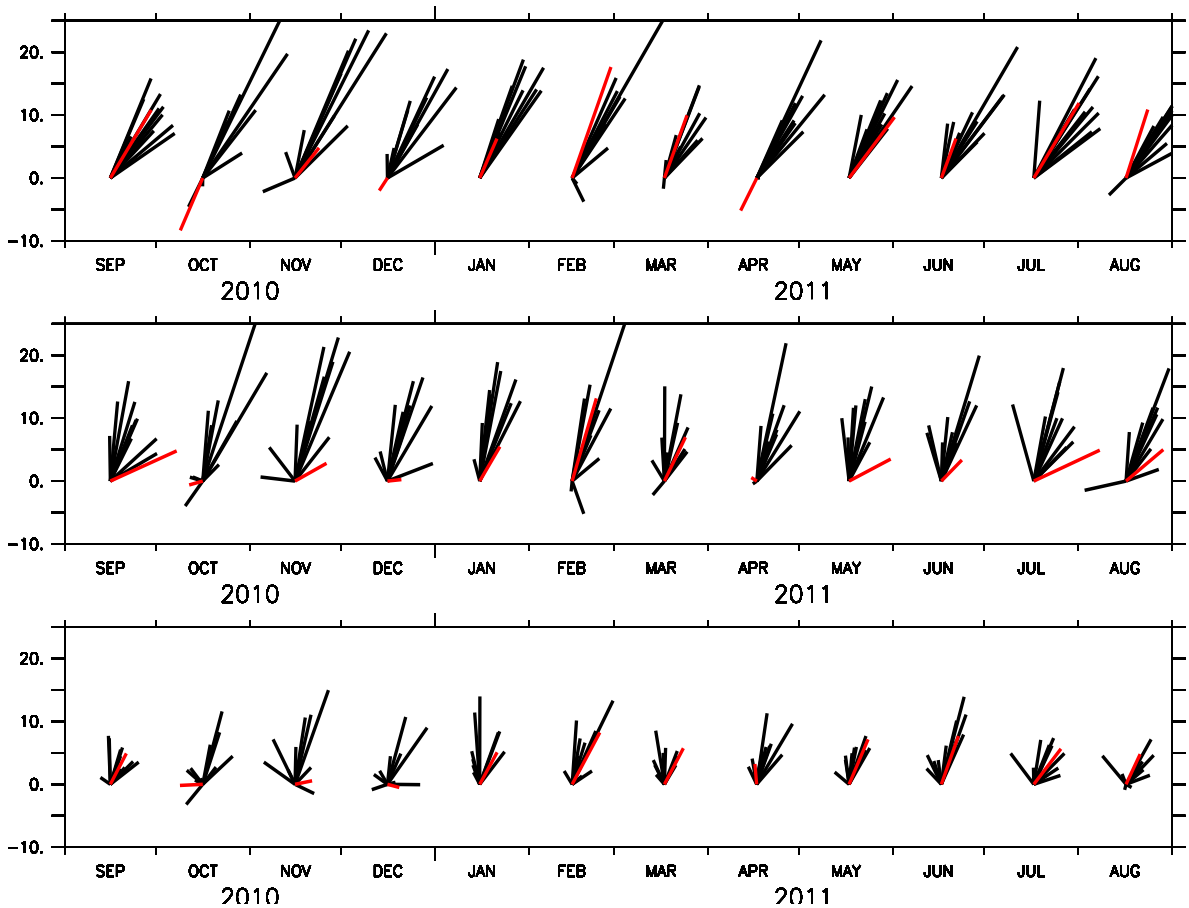


Figure 13. Stick plot of the magnitude (length of the bar) and direction of ocean current at 30m depth from moorings (red) and model simulation (black, 1st decade). Top panel = IC3 (inshore), middle panel = IC6, bottom panel = IC11 (offshore).

As for ocean temperature, the CESM is able to simulate the seasonal cycle in agreement with observations (left panels in Figure 14). During ice-free months (June to November), however, model simulated ocean temperatures at 40m depth generally are higher than those observed by moorings. Also, the ice appeared later (the month when the ocean temperature is below zero) at sites IC3 and IC6 in the model. There are twin peaks in the monthly mean salinity at moorings IC6 and IC11 (right panels in Figure 14), one in the fall (November) and one in Spring (May). Yet model simulations only show a single peak around May. One possible reason is that flows from Barrow canyon may not be captured well by this model due to its coarse resolution. Further analysis is needed. Generally the CESM underestimated the salinity in the region, especially during ice-free months.

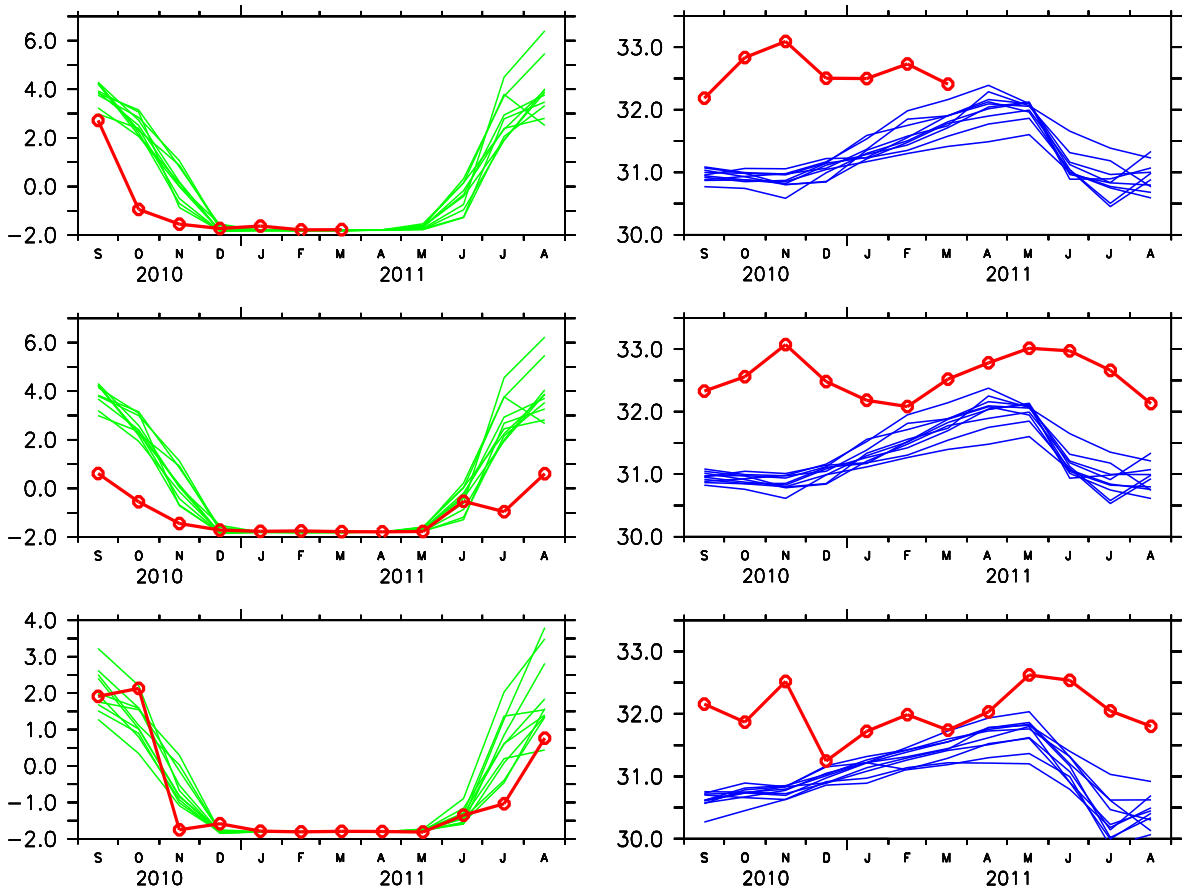


Figure 14. Ocean temperature (left panels) and salinity (right panels) at 40m depth from observation (red) and CESM (green/blue). The first decade run is presented here. Top panels = IC3, middle panels = IC6, bottom panels = IC11.

The mean ice thickness is calculated over the small box shown in Figure 11, which is a better representation of the ice condition when comparing with observations. Sea ice thickness is measured by the 3 moorings from December 2010 to May 2011. The monthly averaged mean and median values are compared with model simulations. Figure 15 shows the comparison for the six months when observations are available.

Results clearly show that model-simulated ice thickness is within the range of observations. There is inter-annual variability in the monthly mean ice thickness with the greatest variability occurring in the months of April and May. The mean ice thickness has maximum value of 1.5m in May, and minimum value of 0.02 m in October. In October, most of the Chukchi is near ice free. This can be seen from the ice extent analysis (figure is not shown); during October, the average ice extent is less than 30% of the area in the big box outlined in Figure 11. What we found is that the ice will be around the Chukchi Sea in the next 30 years in winter (December - May) according to the model projections, with near100% coverage over the big box. But the ice will retreat early in spring (June), and form late in the fall (November). We see a declining trend in the sea ice extent over the Chukchi Sea, but the trend is small. One important feature is that at any given year, the long term trend is overwritten by the large inter-annual variability.

We will continue our analysis of the model runs; not only the runs we generated (3 members), but also the runs produced by NCAR CCSM4 model (4 runs). This will help us to better understand the climate changes in the Chukchi Sea, and also to provide projections of the key climate variables in the region.

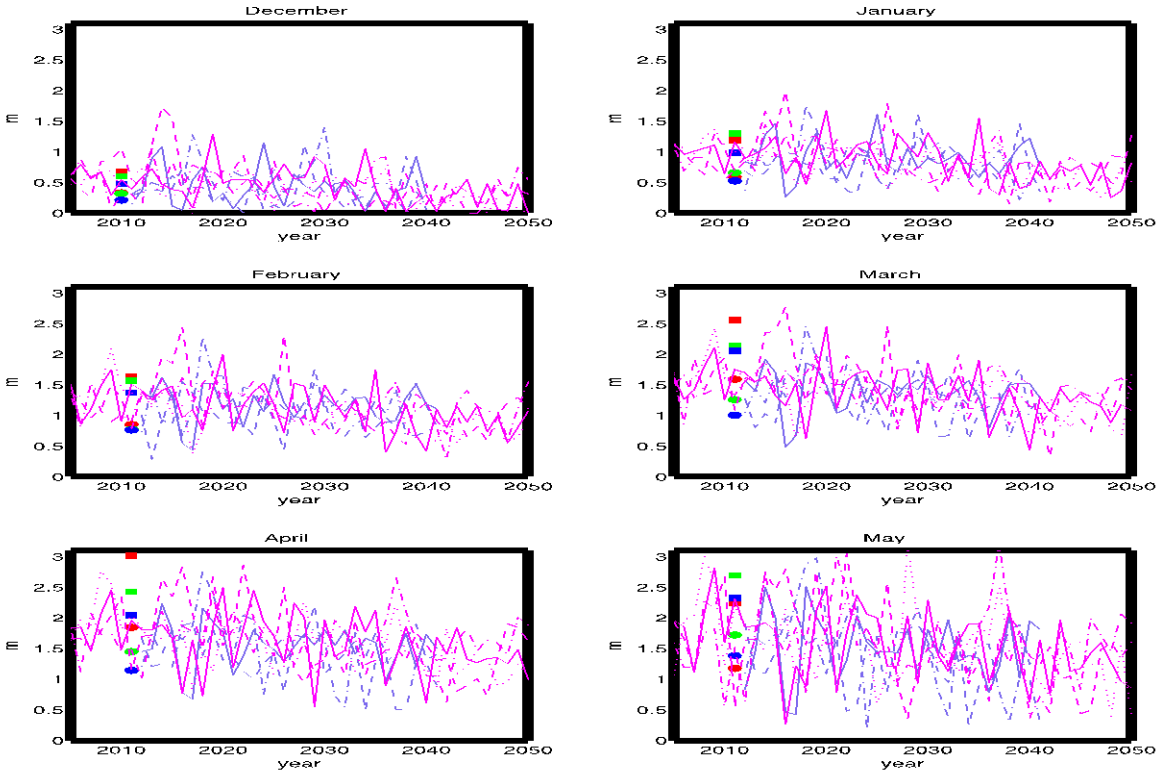


Figure 15. Monthly mean ice thickness averaged over small box outlined in Figure 11 for winter months when ice exists. Colored circles/squares are the median/mean values from mooring IC3 (red), IC6 (green) and IC11 (blue). Each colored line is one ensemble run from CESM (magenta) and CCSM4 (blue). Units are in m.

Significant meetings held or other contacts made

9-13 April: Napp, Ben Bloss, David Strauss, and Adam Spear hosted Charles Greenlaw of Oceantronics. TAPS6-NG Unit B was calibrated at the HTI calibration barge and discussions on data processed were held. After Mr. Greenlaw's visit, Bloss, Strausz, and Napp calibrated TAPS6-NG Unit C on their own.

2-4 May: Crance and Stephanie Grassia travel to Cornell University (Ithaca, NY) to meet with Chris Clark and members of the Bioacoustics Research Program (BRP).

7 May: Berchok and Crance hosted a meeting with the sonobuoy suppliers Theresa Yost, Jeff Leonhard, and Todd Mequet (Seattle, WA).

18 May: Berchok and Crance met with Lilian Davies du Rocher regarding the charter vessel loading at the NOAA Sand Point dock.

22-24 May: Moore participated in NOAA CetSound Workshop @ Washington DC; CHAOZ acoustic data highlighted as source for cetacean seasonal occurrence records, as CetMap software develops (http://cetsound.noaa.gov/index.html).

4 June 2012: Berchok, Crance, Napp, and Stabeno met with Kale Garcia, the owner/captain of the R/V *Aquila* to discuss cruise logistics, loading, deck layout and organization, etc.

11-22 June: Moore participated in the IWC Scientific Committee meeting; CHAOZ work re. bowhead whale seasonal movements & acoustic environment included in discussion of two sub-committees.

18-21 June: Wang and Wei Chang participated in and presented at the 2012 Community Earth System Model (CESM) annual workshop in Breckenridge, CO.

28 June: Crance attended the R/V *Aquila* vessel inspection by the US Coast Guard.

Presentations and Publications

Stabeno, P.J. and J. Napp. 2012. Observations in the Chukchi Sea. Oral presentation for Pacific Marine Environmental Laboratory (PMEL) seminar series, April 10, 2012.

Wang, M., W. Cheng, J.E. Overland, and P. Stabeno. 2012. Chukchi Sea climate variability seen from CESM. Poster presentation for Community Earth System Model (CESM) annual workshop. Breckenridge, CO, June 18-21, 2012.