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 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 July 16th and October 15th 2013. 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

<u>Preliminary results</u>

Analyses of the long-term passive acoustic recorders are still ongoing. The middle Icy Cape mooring (IC6) from 2011-2012 was re-analyzed to account for original errors in species attribution, and to include airgun results. Results from the re-analysis are shown in Figure 1.

<u>2014 analysis plans</u>

Data analysis of the other two 2011-2012 long-term moorings has begun. We have been running a new version of our Matlab-based SoundChecker program to allow for simultaneous multi-species analysis.

We are well on our way to testing Mark Baumgartner's (WHOI) low-frequency detection and classification system (LFDCS) on our data. Eliza Ives has been put in charge of implementing the system on our data. Unfortunately, her two-week sabbatical to WHOI to learn the system was cancelled due to the government shut-down. The next time Mark is available to host her won't be until after January, so she has been teaching herself the system with email and phone help from Mark. She has familiarized herself with the system and has begun to meet with our team to populate the system with exemplars of the main call types of each species, starting with bowhead and belugas (our best studied species). She will test the system on two of the Icy Cape moorings that have already been analyzed, to see how well the system works.

If successful, this system will not only reduce the amount of effort expended on each recording, it will allow us to obtain results for all species of interest. It will also allow us to fine-tune any auto-detection devices installed on gliders or auto-detection buoys that we may send out into our study areas in the future.

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

<u>Synthesis</u>

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.

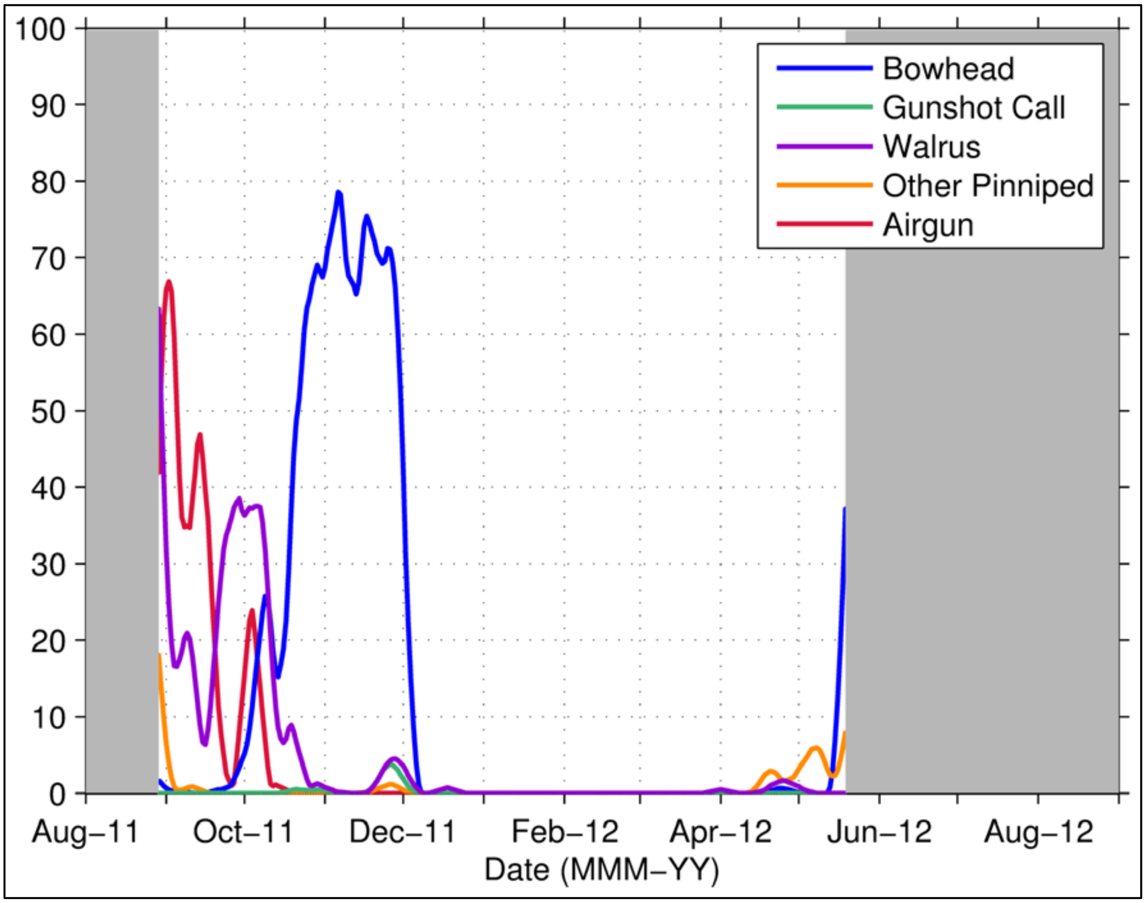

Figure 1. Corrected seasonal acoustic detections of bowhead whales, walrus, other pinniped, gunshot calls and airguns on one of the recorders in the middle mooring cluster off Icy Cape, AK (August 29, 2011 – May 19, 2012). Results are presented as a 7 day moving average of the number of 4 minute time intervals per day with calls detected.

OCEANOGRAPHIC COMPONENT

Synthesis of results is ongoing, and there are no new results or updates at this time.

ZOOPLANKTON COMPONENT

<u>Zooplankton Acoustics</u>

Analysis of ADCP and TAPS data continues. We have been examining zooplankton net data from the 2012 cruise to determine which scattering models are most appropriate to apply to TAPS data from the mooring. During 2012 thecate pteropods (small shelled pelagic molluscs) were prevalent in the study area. Target strengths for 1 mm pteropod can be > 7 db higher than that of a 5 mm copepod in the Rayleigh part of the scattering curve. Thus we are experimenting with multi-scattering model solutions to the inverse problem.

Preserved Zooplankton Samples

Data sheets for preserved zooplankton samples from the August 2012 cruise were returned from Poland during the last quarter; however the computer data entry program was not finished until this quarter. Data were entered by Poland at the end of the quarter. We are presently engaged in checking the data entry accomplished last quarter for errors. Each and every handwritten form is being compared to what was entered into the computer in Poland.

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. The PI's met several times last quarter to look at data and prepare the manuscript. 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. The multi-model inverse solution will be tested after the addition of a model for a hard elastic scatterer (pteropods). We hope to complete a draft of the synthesis note describing unique events during the CHAOZ field years.

OCEAN NOISE AND REAL-TIME PASSIVE ACOUSTIC MONITORING

We have developed a methodology for evaluating the performance of the automated bowhead (BWHD) detector used on the NOAA-AK-NW Autobuoy (AB), deployed from 29 August, through 09 November, 2012. While the manual analysis of the Chukchi AB dataset has not yet been performed, we have tested against verified data collected for a different Beaufort Sea deployment in 2008, within which a number of bowhead (BWHD) calls have been manually identified.

Since BWHD 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 compute *a posteriori* the Precision and Recall at various intermediate thresholds, yielding various curves as shown in Figure 2.

As a point of reference, the detector was run with a simple "classifier" score, the maximum SNR achieved during a detected acoustic event (blue contour_ampl line). Not surprisingly, Precision does not change significantly as the score is increased, since a higher score simply corresponds to a louder event.

The specific AB detector settings are represented by the red "contour_hmm" line. We can estimate from this line that we could have improved the threshold such that, while detecting about 30% of the calls that were present, about 80% of reported calls would be true calls. In the interest of simplicity, the HMM (Hidden Markov Model) used on the deployed 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 the set of vector-quantized state sequences, where we used the k-means algorithm to estimate state centroids. This is shown in the light blue "contour_hmm_vq" curve. It can be seen that if we were to use the vector-quantized feature set, we could reduce the number of false positive reported events by 50%.

In addition, we ran the detector with a lower threshold to produce a greater number of candidates. The performance of the lower threshold detector/classifier is shown by the two lines labeled "contour_ampl_th2" (green) and "contour_th2_hmm_vq" (pink).

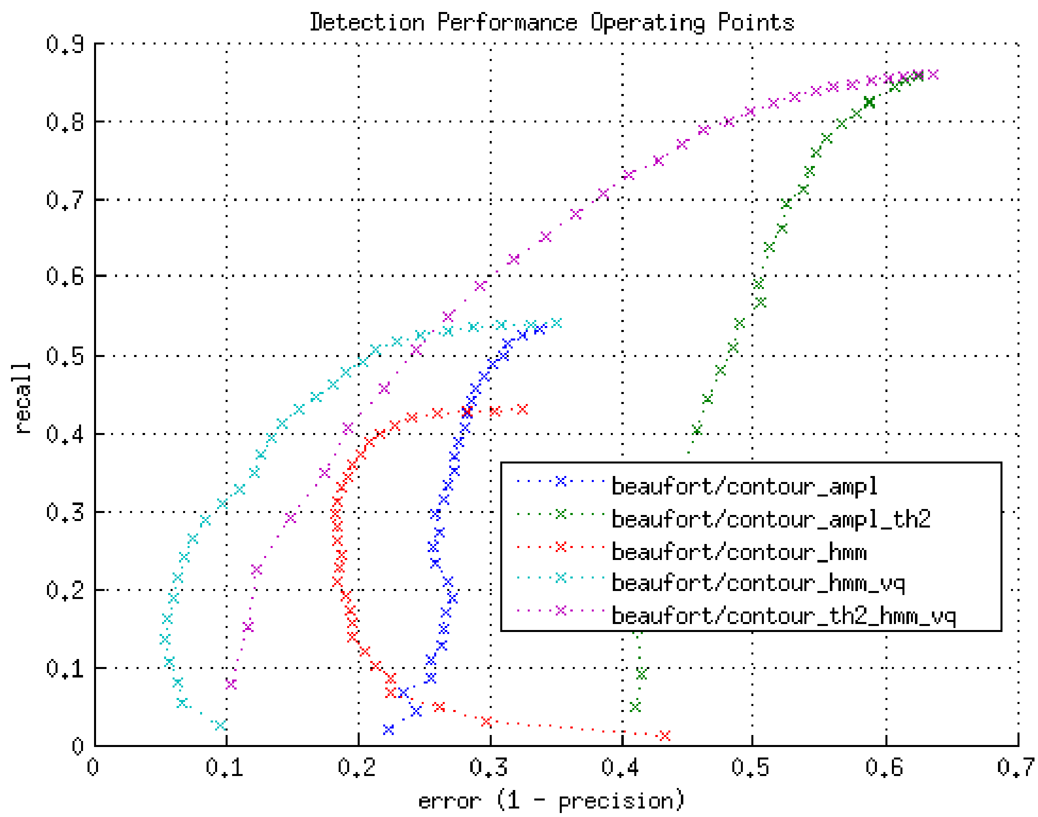

Figure 2. Detector performance curves as a function of different threshold settings.

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 shown in Figure 3, the performance was only slightly degraded between the training and test sets, indicating that we are 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 09-01-2012 and 11-01-2012), 351 were approved by BRP reviewers as being of biological origin (Figure 4). This yields a precision of about 46%. While this is a significantly lower value of precision that 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" BWHD calls corresponding to the Chukchi 2012 deployment.

The literature on HMMs (Rabiner, 1989)[1] makes it clear that the performance could be improved further by using continuous Gaussian mixture modeled state probability densities. The biggest improvements would likely come from adding additional model classes for different types of BWHD call, but this would take a significant amount of manual analysis and class grouping.

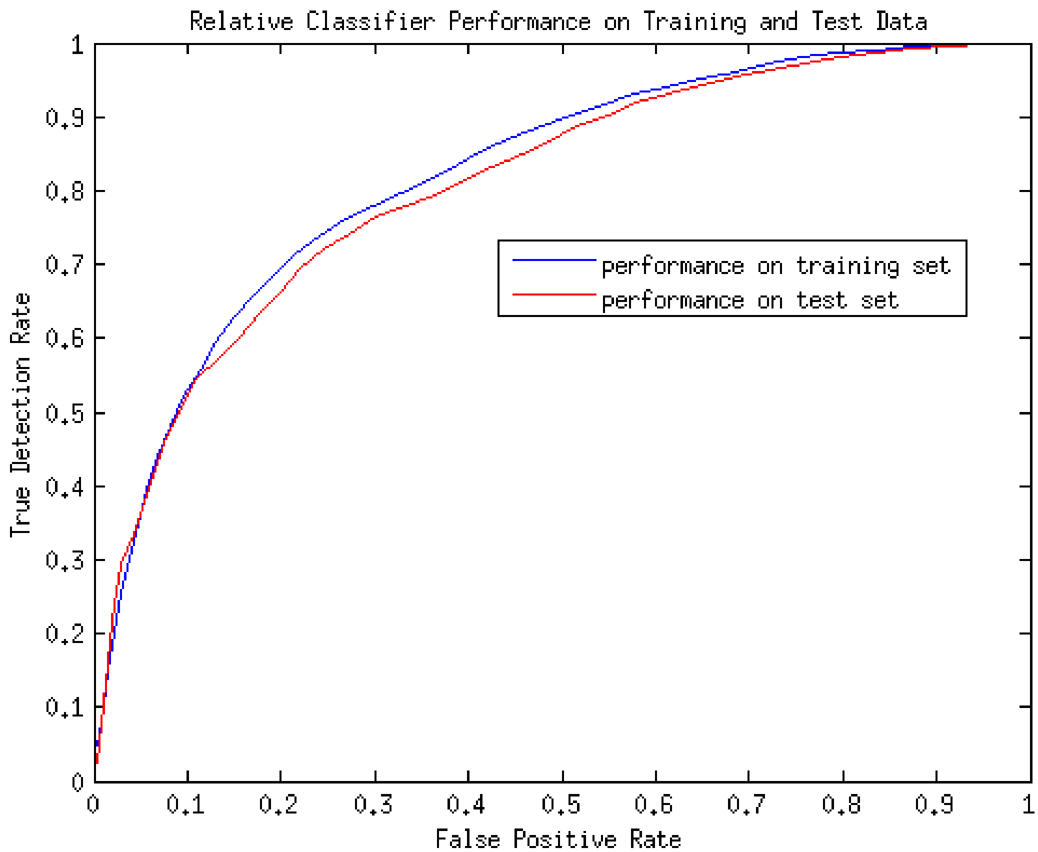

Figure 3. Relative classifier performance of training and test datasets.

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

The following decisions were reached:

- In order to complete the objective of reporting occurrences of acoustically active marine species in near-real-time, the performance of the AB system must be evaluated. SLT has agreed that the Chukchi data collected by the AB must be manually reviewed for comparison against the output of the AB detector. We are estimating the cost/benefit of manually analyzing the entire 3-month dataset *versus* an appropriate sub-sampling protocol. In case of the latter, different ambient noise/SNR conditions will be considered. This work is also

[1] Rabiner, L. (1989). "A Tutorial on Hidden Markov Models and Selected Applications in Speech Recognition" IEEE Proc., Vol. 77, No. 2, p. 257-286.

critically important leading into the goals of CHAOZ-X, as the extension project includes new AB deployments in the Chukchi.

- With the late-September arrival of the third consecutive, year-long CHAOZ MARU dataset (2012-2013) at BRP, SLT approval was granted for performing the same analyses already performed on the previous two datasets (2010-2012). The analyses include: Noise Analysis and seismic/BWHD manual analysis in 12-hr bins. This newly-arrived dataset was also concurrent with the AB deployment in the summer of 2012, so a comparison between the two recording systems will be explored.

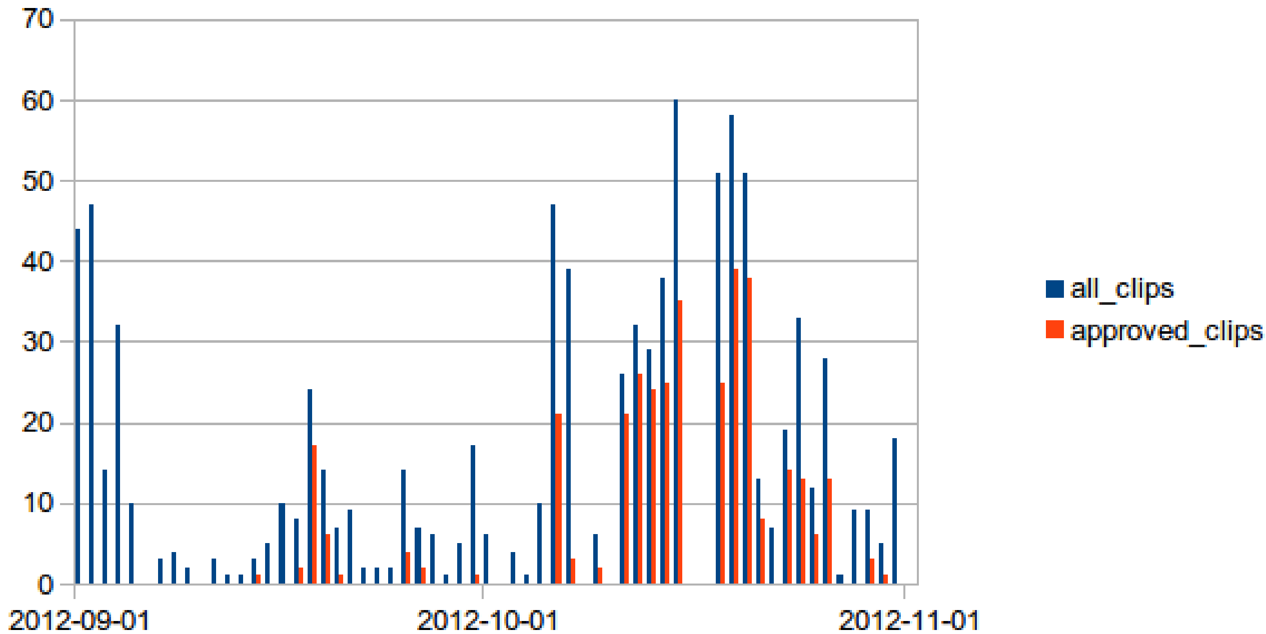

Figure 4. Distribution of clips reported by the AB detector (blue) and clips attributed to biological origin from manual review (red) over the entire Chukchi deployment.

CLIMATE MODELING COMPONENT

We have downloaded more than 3 TB of data from CMIP5 model simulations. The model simulated sea ice condition over the Arctic wide was assessed by Wang and Overland. The findings were published in 2012. Recently the two authors updated their 2012 study after more models have completed their simulations, with another paper published in Geophysical Research Letters, 2013, and another three manuscripts under review. Among 36 models they evaluated, twelve of them simulated the sea ice extent in reasonable agreement with observations. We further analyzed these 12 models' performance over the Chukchi and Beaufort Seas. Model projections of sea ice conditions over these two sub-Arctic seas were summarized in a manuscript submitted to Progress in Oceanography. The key finding from this study was that these 12 models simulated reasonable sea ice cover in their historical simulations (1981-2000) when compared with observations.

As shown in Figure 5, the average from these 12 models (left panel on 2nd row) shows a similar pattern when compared with observations (top panel) in the current decade averaged over 1996-2005. There is less spatial variability in the model means as the observation (top panel) is only one single realization. The number of months with ice cover at each grid point becomes less and less as time progresses. In the upcoming decades, the models project longer seasons of open water in these two regions. By 2030 the southern Chukchi Sea will have 5-6 months of open water (or 6-7 months of ice cover) compared with only 0-1 months of open water season in the northern Chukchi Sea (up to 80°N). By mid-century, around 2050s, even at the northern Chukchi Sea there will be one to two months of open water (bottom left panel) based on these models under RCP8.5 emissions scenario. Near the end of 21st century, the southern Chukchi Sea will be almost completely ice free year around, and the northern Chukchi Sea will have only 3 month of ice coverage. The caveat is that these projections are subject to the emissions scenario uncertainty, which we need to keep in mind. At the same latitude, the Beaufort Sea will have a shorter duration of open water season compared with the Chukchi Sea.

We also carried out our own CESM1.0 model runs using NCAR super computers. The outputs from our CESM1.0 models runs which were initialized with low sea ice coverage under RCP6.0 emissions scenario, were compared with the original CCSM4 runs, as well as the observations taken along the Icy Cape in the Chukchi Sea. We found large internal variability among these models runs. The comparison with observed variables (currents, temperature, salinity, and sea ice thickness) along the Chukchi Sea Icy Cape mooring sites (IC3, IC6, and IC11) show rather encouraging results. A manuscript based on the same model runs was submitted to the Deep-Sea Research Part II recently with an emphasis on the Eastern Bering Sea.

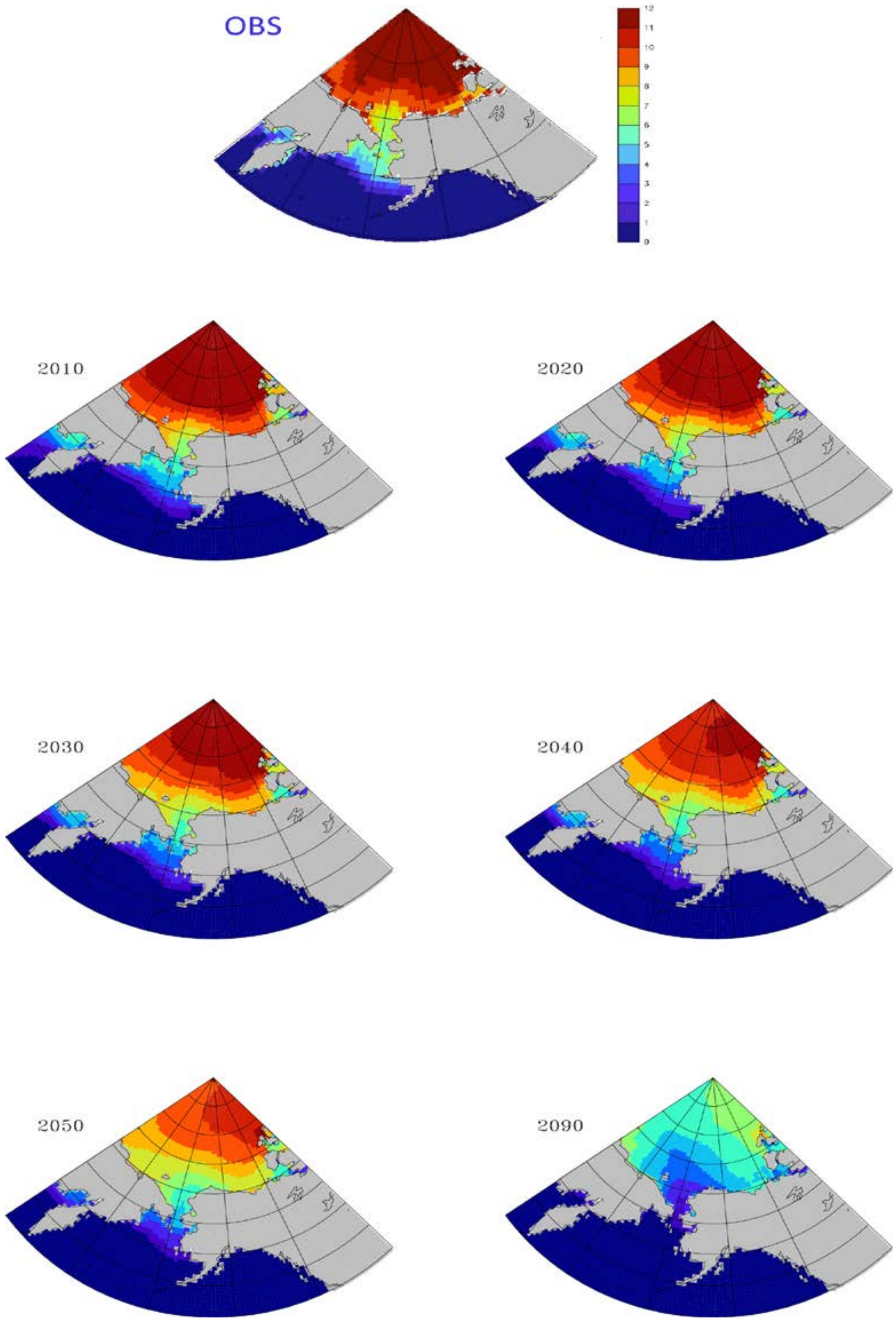

Figure 5. Number of months with ice cover at each grid point based on observations (top panel) and model simulations (bottom 3 rows). The year labeled in each panel indicates the center of the decade in which the decadal mean was calculated. Results are based on 12 CMIP5 models, under the RCP8.5 emissions scenario.

Significant meetings held or other contacts made

9 July & 10 September: Moore includes discussion of CHAOZ contribution to Distributed Biological Observatory (DBO) sampling, during DBO Implementation Team teleconferences.

27 July - 16 August: on BOEM-funded Hanna Shoal cruise, Moore discusses CHAOZ contribution to the DBO sampling with H. Crowley (BOEM); also passes on locations of gray whale aggregation seen in the southern Chukchi Sea to ARCWEST PIs.

September 2013: Overland participated the workshop "Linkages between Arctic Sea Ice Loss and Mid-Latitude Weather Patterns" in College Park, Maryland.

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. Submitted to Deep Sea Research, 2013.

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.* In review.

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

Overland J. E. and M . Wang. 2013 Regional Mechanisms for Arctic/Mid-Latitude Weather Linkages, Tellus (submitted).

Overland, J. E., M. Wang, and J. Walsh. 2013. Mitigation of Arctic Climate Change, Earth's Future (accepted).

Wang, M. and J. E. Overland, 2013, Projected Future Duration of the Sea-Ice-Free Season in the Alaskan Arctic, Progress in Oceanography, (submitted)