STUDY TITLE: Beaufort and Chukchi Seas Mesoscale Meteorology Modeling Study

REPORT TITLE: Beaufort and Chukchi Seas Mesoscale Meteorology Modeling Study, Final Report

CONTRACT NUMBER: M06PC00018

SPONSORING OCS REGION: Alaska

APPLICABLE PLANNING AREAS: Chukchi Sea and Beaufort Sea

FISCAL YEARS OF PROJECT FUNDING: 2007–2013

COMPLETION DATE OF REPORT: July 2013

COSTS BY FY: FY2007: $71,094; FY2008: $243,198; FY2009: $220,766; FY2010: $153,279; FY2011: $267,300; FY2012: $472,686; FY2013: $320,412

CUMULATIVE PROJECT COST: $1,748,735

PROJECT MANAGER: Xiangdong Zhang

AFFILIATION: International Arctic Research Center, University of Alaska Fairbanks

ADDRESS: 930 Koyukuk Dr., P.O. Box 757340, Fairbanks, AK 99775-7340

PRINCIPAL INVESTIGATORS*: Xiangdong Zhang, Jing Zhang, Jeremy Krieger, and Martha Shulski

KEY WORDS: Chukchi Sea; Beaufort Sea; Weather Research and Forecasting (WRF) Model; data assimilation; reanalysis; wind field

BACKGROUND:

The Chukchi–Beaufort Seas have experienced significant environmental changes over recent decades, as evidenced by the fastest rate of decline and maximum interannual variance of sea ice cover of anywhere in the Arctic Ocean. At the same time, surface wind speed and surface air and water temperatures have also increased. In addition to these changes in the natural environment, the potential for expanded offshore oil drilling also exists in the area. With oil extraction comes the threat of oil spills, which can have serious environmental consequences, leading to increasing attention from the government, scientific community, and general public. Oil spills may impact not only the immediate area, but also remote regions due to transport via ocean currents and drifting sea ice. It is therefore of critical importance to be able to accurately predict and assess the dispersal and movement of oil spills, and to evaluate the potential environmental impacts should a spill occur. Doing so requires a good understanding and an accurate, high-resolution representation of the surface wind field, a crucial parameter for driving ocean circulation and assessing and predicting oil spill transport. Therefore, a mesoscale meteorological modeling study over the Chukchi–Beaufort Seas region has been conducted under support from the U.S. Department of the Interior, Bureau of Ocean Energy Management.

OBJECTIVES:

The primary objective of this study was to develop a high-resolution regional atmospheric reanalysis data set, which provides the best estimate of surface wind and other meteorological parameters over the Chukchi–Beaufort Seas and Arctic Slope (Figure 1). In particular, the project comprised the following specific objectives: (1) acquiring and quality controlling surface-based and satellite-retrieved observations from all available sources; (2) conducting a field program to collect additional surface observations in a selected key and data-sparse area; (3) optimizing model configurations and physical parameterizations with improved treatment of the unique Arctic environment; (4) customizing a data assimilation system for the best estimation of model errors and efficient observational assimilation; (5) constructing a high-resolution regional reanalysis for the study area through the use of the optimized modeling system and quality-controlled observational data; (6) evaluating the resulting reanalysis product against observational data and the latest generation of global reanalysis datasets; (7) analyzing the reanalysis data in order to describe the climatology, variability, changes in, and extremes of the surface wind field; and (8) disseminating the reanalysis data and scientific results to the broader community through conferences, workshops, and publications.

DESCRIPTION:

Surface wind is primarily determined by the interaction of synoptic and mesoscale weather systems with prominent underlying geographic features. In the Chukchi–Beaufort Seas region, including the Arctic Slope, the Beaufort High and Aleutian Low are the two dominant synoptic-scale weather systems that most heavily influence surface winds. When the intensity and location of these systems change, the surface winds over the study area vary in response. The geography in the region is characterized by seasonally ice-covered ocean, along with the Brooks Range in northern Alaska and the Chukotka Mountains in eastern Siberia. In addition to the influence of topography, the presence of little-to-no sunlight during the winter months can cause the surface to become extremely cold, resulting in frequent temperature inversions throughout the area. Each of these local geographic features interacts with the weather systems, generating complex mesoscale or finer-scale atmospheric circulations that correspondingly influence the surface winds in the region.

As the first step toward realistically capturing these weather systems and the interactive processes that govern the surface wind field, an observational database was developed through the collection and quality control (QC) of meteorological data from 262 stations in the Beaufort and Chukchi Sea regions of the Arctic. These stations include land-based observations as well as offshore data from buoys, ships, exploration well sites, and an ice camp. Observed variables include: surface air temperature (°C), dew point temperature (°C), relative humidity (%), wind speed (m s^{-1}), wind direction (degrees), station pressure (hPa), sea level pressure (hPa), altimeter (in Hg), shortwave radiation (W m^{-2}), longwave radiation (W m^{-2}), 1-hr accumulated precipitation (mm), 6-hr precipitation (mm), 24-hr precipitation (mm), and snow depth (cm). A unified data QC technique was applied in creating the database. Selected satellite remote-sensing data sets were also collected. To enhance the observational representation over the data-sparse coastal ocean, a meteorological buoy was successfully deployed in the highly sea-ice-dynamic Beaufort Sea.

At the same time, a physically optimized, Arctic-processes-enhanced Weather Forecasting and Research (WRF) model and WRF-based data assimilation system were also developed. The WRF model includes a large number of physical parameterizations developed for various applications, primarily in the tropics and mid-latitudes, that may not perform well for an Arctic environment, especially for simulating complex air-sea-ice interactions and the seasonally varying land-sea thermal contrast and topographic effects involved. In particular, prior to this project neither the WRF model nor its associated data assimilation system had yet been well utilized over the Chukchi–Beaufort Seas and Arctic Slope area. There existed an imperative to evaluate the capability and performance of the WRF model and its data assimilation scheme, and to define the model configuration best capable of representing the atmospheric state in this region. This optimization was accomplished through a thorough evaluation of model physical parameterization schemes for the study area, including a careful selection of various in situ observation types and satellite retrievals for assimilation, and a further improvement of model physical parameterizations that require specific considerations for the unique Arctic environment.

Finally, the WRF model and its data assimilation system were applied to the study area to generate the 31-year Chukchi–Beaufort High-Resolution Atmospheric Reanalysis (CBHAR) at a grid spacing of 10 km and a one-hour interval. Based on the results of CBHAR, a comprehensive evaluation of surface wind and temperature, as well as a climatological analysis of the surface wind field over the Chukchi–Beaufort Seas and Arctic Slope were carried out. The results of the evaluation suggest that CBHAR provides a clearly improved representation of surface winds over the study area compared to the latest generation of global reanalysis products. The climate analysis not only reveals regional-scale variability and changes in the surface winds, but also characterizes the prominent local dynamically and thermodynamically forced mesoscale wind processes.

SIGNIFICANT CONCLUSIONS:

The most significant conclusion is that the CBHAR data developed for this project provide a significantly improved estimate of surface wind over the study area (Figure 1). By using CBHAR data, along with the newly created observational database and the latest generation of global reanalysis data sets, this project has also delivered the following specific scientific conclusions:

1. Monthly mean and extreme (as measured by the 95^{th} percentile) surface wind speeds over the ocean have increased markedly since 1979, with the largest increase in October, while wind speeds over most land areas have decreased.
2. Climatology of and long-term changes in the mean and extreme surface winds exhibit an obvious seasonal cycle and a variable spatial distribution, with stronger winds occurring in autumn and along the Alaskan coast.
3. Changes in wind speed are negatively correlated with changes in sea ice cover and sea surface temperature, suggesting that retreating sea ice and a warmed ocean favor the occurrence of stronger winds.
4. More strong storms occur in winter than in summer in the climatological seasonal cycle. The frequency of intense winter storms entering the Chukchi–Beaufort Seas region has increased since 1979, playing a significant role in contributing to the occurrence of strong surface winds.
5. Northeasterly wind dominates the Chukchi–Beaufort Seas region and exhibits a clear seasonal cycle, strengthening from September through May and weakening from June to August.
6. Diurnally varying sea and mountain breezes are pronounced in the summer, reaching their peak intensity in the late afternoon. Combined sea and mountain breezes along the eastern Brooks Range and Chukotka Mountains serve to intensify the onshore surface winds, the impact of which can reach out to 50–100 km offshore.
7. A strong cold-air damming process occurs on the north slope of the Chukotka Mountains in winter, producing mesoscale northwesterly winds. Radiative-cooling-induced downslope wind is the primary driver of the wintertime surface wind field in the eastern Brooks Range.

STUDY RESULTS:

This study represents the first time that such a comprehensive and systematic high-resolution atmospheric modeling study has been conducted over the Chukchi–Beaufort Seas and Arctic Slope region. The major resultant project outcome—the Chukchi–Beaufort High-Resolution Atmospheric Reanalysis (CBHAR)—is the first three-dimensional, thermodynamically and dynamically constrained gridded data set available over the study area with such a high resolution (10 km in space and 1 hour in time) for the period 1979–2009. These features make it possible to be used to investigate not only regional circulation and weather patterns, but also local thermodynamically and dynamically forced finer-scale processes for this remote, climatically harsh area. The major accomplishments of this project are highlighted here:

1. Developing CBHAR data at resolutions of 10 km in space and 1 hour in time, representing a noticeably improved estimate of the regional atmospheric state compared with observations and the new generation of global reanalysis data sets;
2. Establishing a physically optimized, Arctic-processes-enhanced Weather Forecasting and Research (WRF) Model and WRF-based data assimilation system over the Chukchi–Beaufort Seas and Arctic Slope;

3. Compiling an integrative, quality-controlled observational database from all available data sources, including surface-based meteorological stations, ships, and buoys, as well as satellite remote sensing data, for use in the data assimilation system and other applications;
4. Deploying a meteorological buoy over the highly sea-ice-dynamic Beaufort Sea and successfully acquiring offshore observations of surface wind and other fundamental meteorological and ocean-surface parameters;
5. Using CBHAR to analyze the surface climate over the study area from the synoptic to the mesoscale, including an analysis of the region's climatology, variability, changes, and extreme events, and describing new scientific findings;
6. Strengthening national and international collaborations among BOEM, UAF, WHOI, the industry sector including the Shell and ConocoPhillips oil companies, and JAMSTEC; and
7. Training three Ph.D. students and one master's student in mesoscale meteorological modeling, data assimilation studies, and observational data processing and analysis, to participate among the next generation of Arctic scientists.

STUDY PRODUCTS:

1. The Chukchi–Beaufort High-Resolution Atmospheric Reanalysis (CBHAR), having a 10-km grid spacing and 1-hour interval, available over the period 1979–2009;
2. A physically optimized mesoscale WRF model and data assimilation system for the Chukchi–Beaufort Seas and Arctic Slope region;
3. A quality-controlled observational database, including data from 262 stations in the Beaufort and Chukchi Sea region over the period 1979–2009;
4. A climatological analysis of both CBHAR and the observational database, focusing on a characterization of the region's surface wind field regime.

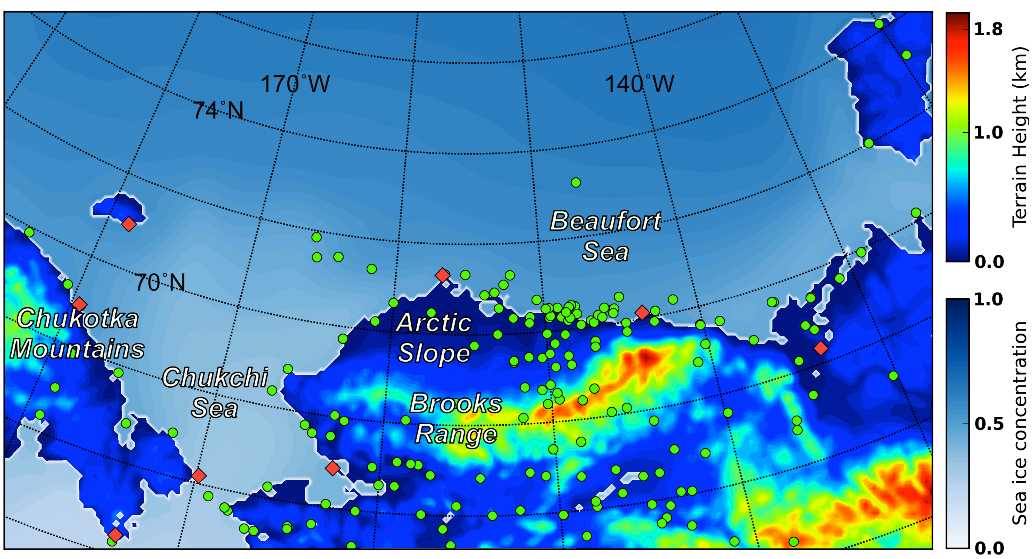

Figure 1. The study region. Color shading over land indicates terrain height, and over the ocean indicates average sea ice concentration. Green dots show the locations of in situ surface observations and red diamonds show the locations of radiosonde observations collected and used for data assimilation in this study.

* P.I.'s affiliation may be different than that listed for Project Manager(s).