Modeling Sea Ice-Ocean-Ecosystem Responses to Climate Changes in the Bering-Chukchi-Beaufort Seas with Data Assimilation of RUSALCA Measurements

Primary Investigator: Jia Wang - NOAA GLERL

Co-Investigators: Leo Oey - Princeton University, Tel Ezer - Old Dominion University, K. Mizobata - Tokyo University of Marine Science and Technology, Haoguo Hu - CILER, University of Michigan

Overview

This project will use the combination of an IARC high-resolution (4-km) Coupled Ice-Ocean Model (CIOM, Wang et al. 2002, 2004, 2005) and Princeton’s Regional Ocean Forecast (and Hindcast) System’s (PROFS) data-assimilation methodologies to improve our understanding of ocean and sea ice circulation in the Bering-Chukchi-Beaufort (BCB) seas, driven by ocean tides, Alaska Stream (AS) and Alaska Coastal Current (ACC) inflow/outflow, freshwater discharge, and synoptic wind stress. We propose to implement the data assimilation approach based on PROFS to cover the Bering Sea, Chukchi Sea, and part of the Beaufort Sea. That will allow assimilations of existing and on-going hydrographic data and moorings across the Bering Strait in addition to those data in the Chukchi Sea and Bering Sea. Importantly, PROFS’ Lagrangian assimilation scheme will also assimilate the Argo data. Particularly the developed PROFS approach will allow the CIOM to assimilate hydrographic data measured during the period (2007-2012) when the Russian-American Long-term Census of the Arctic’s (RUSALCA) moorings will be deployed near the Bering Strait. A high-resolution coupled atmosphere-ice-ocean global climate model (from Japan) will provide the BCs to both CIOM and PROFS. Then, a series of sensitivity simulations with CIOM combined with PROFS will be conducted to examine: 1) AS inflow 2) Response to a change in position of the Aleutian Low, 3) Both positive and negative phases of AO (Arctic Oscillation) and PDO (Pacific Decadal Oscillation) to identify the similarity and difference of the ice-ocean response to AO and PDO, and 4) Response to Arctic Dipole Anomaly (DA) to investigate the DA’s impact on SST, sea ice concentration (retreat) in the Alaska Arctic water due to the enhanced Bering Inflow. In return, the modeling results will be discussed with those PIs with RUSALCA field observation projects and an optimal sampling strategy will be designed to improve coverage.

A 3-D, 9-compartment, Physical-Ecosystem Model (PhEcoM), coupled to CIOM, will be used to study the ice-ocean-ecosystem dynamics in the same region. The data from RUSALCA nutrient and plankton moorings will be used for conducting independent data analysis to also validate this model, and for assimilation by PROFS. This model will be used to test our proposed hypotheses: 1) North-south connection/advection of nutrients and planktons, 2) West-east seesaw of plankton blooms due to a change of location of the Aleutian Low, and 3) On-shelf nutrient supply by mesoscale eddies for sustainable “Green Belt” booms. Therefore, this proposed study using PhEcoM-CIOM-PROFS will have a broad impact on 1) the ice-ocean-ecosystem dynamics that explains the high primary productivity region, along the Green Belt (i.e., along the Bering Slope), seasonal blooms and the interannual variability in the BCB seas,
and 2) ice edge variability due to climate changes and the impacts on primary and secondary productivity.

**Proposed Work**

We will:

1. Implement the pan Bering-Chukchi-Beaufort seas Coupled Ice-Ocean Model (CIOM) and
2. Princeton’s Regional Ocean Forecast System (PROFS)

![Figure 1: CIOM-simulated general circulation (upper panel) and throughflow (lower) transports of Aleutian passes: Inflow of the strait/pass mainly from the right side and outflow from the left side of Amukta and Buldir Pass, Amchitka, Near and Kamchalka Strait. Flow through Unimak Pass is completely northward.](image-url)
Figure 2: CIOM-simulated vertical temperature (°C) structure in summer (July, see Transect A in Figure 1, which is the same as that in Kinder and Schumacher 1981a): (a) Case 1: circulation only is simulated; isotherm at the surface layer is straight and flat; the depth of mixed layer is about 5 m, and the thermocline is weak. (b) Case 2: the circulation and tides are simulated simultaneously; the bottom water is mixed to be homogenous and isotherm is lifted up. Vertical temperature has a dome-shaped structure, whereas the upper mixed layer is still shallow. (c) Case 3: when wave-mixing is considered, the circulation and tidal current are simulated simultaneously; the upper mixed layer with a sharp-gradient thermocline layer between 10-30 m is well reproduced. (d) Observation (after Kinder and Schumacher, 1981a).
Figure 3: CIOM-simulated vertical heat diffusion coefficient $\log (K_h)$ (m s$^{-1}$) along the same section as temperature in July. (a) Case 1: circulation only. (b) Case 2: the circulation and tides are simulated simultaneously; the mixing is strong in the bottom layer. (c) Case 3, when wave-mixing is considered, the circulation and tidal current are simulated simultaneously; mixing becomes strong in both the upper and the bottom mixed layers.
Measurements vs. Model Simulations

**Figure 4:** The comparison (T, S, and Sigma-T) between the in situ measurements in July 2000 by T/S Oshoro-maru (left column) and the Bering-CIOM simulated climatology (right column).
Two distinct surface ocean circulation:

Winter wind

Summer wind

Figure 5: The Bering-CIOM simulated surface current field on the Bering shelves in January (a) and July (b). Note that the two distinct surface current patterns are due to both the surface wind forcing and Pacific-Arctic pressure head.
Figure 6: The Bering-CIOM simulated July 10-m ocean temperature (a) and salinity (b), showing upwelling exists along the Siberian coast in summer. Note that the Anadyr Current advects warmer and saltier water, while the Alaska Coastal Water advects colder and fresher water northward.

Scientific Rationale

The northern North Pacific Ocean, including the Bering Sea and the Gulf of Alaska, is among the most productive marine ecosystems in the world, as evidenced by large populations of marine and freshwater salmon, fish, birds, and mammals. This productivity is critical not only to the US economy, since fish and shellfish from these regions constitute about 52% of the US fisheries harvest, but also to the economy of surrounding countries.

The Bering Sea (Fig. 7, left) is a complex semi-enclosed basin with shallow shelves, shelf breaks, and deep basins. The ocean circulation pattern is complicated (Fig. 7, right). The Alaskan Stream (AS) flows along the Aleutian Peninsula (with two branches) into the Bering Slope Current (BSC) and the Alaskan Coastal Water (ACW). The BSC splits into two coastal
currents: the Anadyr Current (AC), which joins the ACW and flows into the Chukchi Sea through the Bering Strait, and the southwestern coastal current, which joins the Kamchatka Current (KC). Numerous possible mesoscale eddy generation sites exist within the AS and BSC, due to the interaction between baroclinic instability and the continental slope (Wang and Ikeda, 1997; Mizobata et al., 2002). The basic circulation pattern is fairly well known, based on available observational evidence (Kinder and Coachman, 1978). The interaction or exchange between shelves and deep basins is a physical phenomenon that significantly influences primary and secondary productivity (Mizobata et al. 2002; Mizobata and Saitoh, 2004).

Ecosystem dynamics related to physical forcing have been summarized by ISHTAR (Inner Shelf Transfer and cycling in the Bering-Chukchi Seas) (Coachman and Handell, 1993). A detailed review of the Bering Sea “Green Belt” has also been conducted by Springer et al. (1996). The Bering Sea shelf-edge processes and ecosystem productivity are the key focus in the area. The high productivity near the shelf break (i.e. along the AS and BSC) is qualitatively described. There are some hypotheses linking high productivity to climate change, upwelling, downwelling, nutrient pumping due to internal tides, etc. However, these hypotheses need to be tested by sophisticated ice-ocean-biogeochemical models, which has been validated by observations (Deal et al. 2006; Jin et al. 2006a, b; Hu and Wang 2006).

A biological-physical model was also developed, based on Nihoul’s ocean model, by Shuert and Walsh (1993). The model has the same domain as Nihoul’s model, but is confined to the northern Bering Sea and southern Chukchi Sea shelves. Since only the summer case was simulated no ice component was included. The shelf break processes and the exchange between the deep basin and continental slope were also ignored as were other important processes, such as upwelling and mesoscale eddies along the BSC. The full seasonal cycle of the ecosystem has not yet been simulated. Eslinger and Iverson (2001) applied a 1-D coupled ocean-ecosystem model using mixed-layer dynamics to the Bering Sea shelf. Eslinger et al. (2001) applied a similar model to Prince William Sound, Alaska. Subsequently, Wang and Jin (2002) and Jin et al. (2003) applied a more robust 3-D physical-biological model to Prince William Sound, which included four compartments.

Extensive oceanographic and fisheries observations have been conducted in the past several decades. Hydrographic measurements include typical CTD stations and transects, current meter moorings (Cokelet and Stabeno, 1997; Onishi and Ohtani, 1999), towed/mounted ADCP (Acoustic Doppler Current Profiler) transects (Cokelet et al., 1996), and satellite tracked buoys. The major dynamic features in the Bering Sea are very rich: tide/wind-dominated shelves, deep basin circulation and eddies (Cokelet et al., 1996), frontal instability between the deep basin and the Bering shelf (Kinder and Coachman, 1978), and mesoscale eddies pinched off from the BSC (Kinder et al., 1980; Mizobata et al. 2002). However, the regional observational studies mentioned above lack a systematic, quantitative understanding of the connection between those physical processes and primary productivity. Thus, an eddy-resolving ocean model is essential for better understanding of the ocean general circulation from tidal to synoptic to climate time scales in the Bering Sea (Mizobata et al. 2006a,b).
Sea ice in the Bering Sea is first year ice, with ice thickness being typically 0.5-2.0m (Niebauer, 1980). Seasonal variation is the dominant phenomenon (Wang and Ikeda, 2001), though interannual and decadal variability is significant due to the teleconnection of the Aleutian Low to the tropical Southern Oscillation (SO, Wallace and Gutzler, 1981; Minobe, 1999), the so-called PNA (Pacific-North America) pattern. The NPO (North Pacific Oscillation; Minobe, 1999), which may be coupled to the AO (Thompson and Wallace, 1998; Wang and Ikeda, 2000, 2001), is also an important predictor in the region. Thus, the synoptic cyclone frequency, pathway, and intensity, and the resulting precipitation (that is equivalent to river/glacier freshwater runoff of the following year) all depend on these climate patterns.

In the Bering Sea, sea-ice cover is an important predictor of regional climate (Niebauer, 1980; Wang and Ikeda, 2001). Sea-ice extent also determines ocean circulation patterns and thermal structure because: 1) wind stress drag is different in magnitude over water surface than over ice surface; 2) the albedo over ice vs. water differs; thus, prediction of the sea-ice extent (i.e., edge) is crucial to predicting the ocean mixed layer, ocean circulation, upwelling, and thus, to predicting primary and secondary productivity (Springer et al., 1996); and 3) spring ice-melt freshwater increases stratification in the upper layer which may enhance phytoplankton blooms. In addition, climate change, through its effect on the timing of ice melting, will determine the timing of phytoplankton and zooplankton blooms. As a result, sea-ice conditions and the ecosystem in the Bering Sea will be driven mainly by atmospheric forcing, from tidal, synoptic, and seasonal, to interannual and decadal time scales (top-down processes).

Marine bio-production in the Bering Sea is based primarily on microscopic unicellular algae (phytoplankton) in the water column and micro-algae associated with ice. Diatoms and flagellates are the most common algae groups in the Bering Sea. They predominantly multiply by binary fission. The limiting factors on their growth are solar radiation (especially Photosynthetically Available Radiation, or PAR), SST, and nutrient supply. In the Arctic the growth season begins with a bloom that feeds on the winter nutrients and is triggered by the seasonal increase in light and stabilization of the upper water layers. The growth season ends when the critical depth for algae growth is reduced to < 20 m and/or when formation of sea ice begins. Spring bloom in the permanently ice-free water (open water bloom) peaks in late May – early June. Productivity occurs in the coastal fast ice prior to the summer melt with a strong production peak in spring. In areas with first-year ice, the growth season begins with an ice-edge bloom that forms a 20-100 km wide belt off the ice edge. Ice edge phytoplankton blooms are common features, as well as under-ice blooms and “blooming plates” that can cover large areas.

Based on our previous modeling experiences and observations in Prince William Sound, Alaska (Eslinger et al., 2001) and the Bering Sea (Wang et al., 2003; Deal et al. 2006; Jin et al 2006a,b; Hu and Wang 2008), it is inadequate to use an ocean-ecosystem only model to examine the ecosystem dynamics in the Bering Sea. This is in part because sea ice dynamics and thermodynamics control the ocean temperature and water column stratification, which are very important factors controlling the phytoplankton blooms.
Governmental/Societal Relevance

Knowledge of the sea ice dynamics and thermodynamics in the Bering and Chukchi seas are important not only to wintertime navigation, recreation safety, and rescue efforts, but also to prediction of ecosystems, and fisheries studies, and environmental preconditioning for phytoplankton and zooplankton blooms.

Relevance to Ecosystem Forecasting

Incorporation of the ecosystem model into the CIOM is one of the next goals of the physical modeling effort at GLERL. The results of this project will aid this effort by providing knowledge of the important processes in both the Arctic and subpolar seas, including the Great Lakes circulation and ecosystems.

Products

Papers (published and accepted)


Papers (submitted)


Ikeda, M. and J. Wang. Arctic dipole mode responsible for the recent ice cover anomaly in the Pacific sector (submitted to GRL)


Mizobata, K., K. Shimada, R. Woodgate, S. Saitoh and J. Wang, Estimation of heat flux through the eastern Bering Strait (submitted to J. Oceanography)


**Presentations (2008 Invited)**


**Presentations (2008)**


**Presentations (2007 Invited)**


Presentations (2007)

Modeling sea ice-ocean-oil spill system (SIOMS) for the nearshore Beaufort and Chukchi Seas, IAGLR, College City, PennState, May 2007.

Posters


Wang, J., 2008. Ice-ocean-ecosystem modeling in the Bering, Chukchi, and Beaufort seas, NOAA Climate Observation Division 6th Annual System Review, September 3-5, Silver Spring, D.C.

References


