A modeling study of sea ice and plankton in the Bering and Chukchi Seas during 2007-2008

Jia Wang and Haoguo Hu NOAA Great Lakes Environmental Research Laboratory, 4840 South State Road, Ann Arbor, MI 48108. Email: jia.wang@noaa.gov

Abstract A nutrient (N), phytoplankton (P), zooplankton (Z), and detritus (D) ecosystem model (PhEcoM) coupled to an ice-ocean model (CIOM) was applied to the Bering and Chukchi Seas for 2007-2008 (Wang et al. 2013, JGR). The model reasonably reproduced the seasonal cycles of sea ice, phytoplankton, and zooplankton in the Bering-Chukchi Seas. The spatial variation of the phytoplankton bloom was predominantly controlled by the retreat of sea ice and the increased gradient of the water temperature from the south to the north. The model captured the basic structure of the measured nutrients and chl-*a* along the Bering shelf during July 4-23, 2008, and along the Chukchi shelf during August 5-12, 2007. In summer 2008, the Green Belt bloom was not observed by either the satellite measurements or the model. The model-data comparison and analysis reveal the complexity of the lower trophic dynamics in the Bering and Chukchi Seas. The complexity is due to the nature that the physical and biological components interact at different manners in time and space, even in response to a same climate forcing, over the physically-distinct geographic settings such as in the Bering and North Aleutian Slopes, deep Bering basins, Bering shelf, and Chukchi Sea. Sensitivity studies were conducted to reveal the underlying mechanisms (i.e., the bottom-up effects) of the Bering-Chukchi ecosystem in response to changes in light intensity, nutrient input from open boundaries, and air temperature. It was found that 1) a 10% increase in solar radiation or light intensity for the entire year has a small impact on the intensity and timing of the bloom in the physical-biological system since the light is not a limiting factor in the study region; 2) a 20% increase in nutrients from all the open boundaries results in an overall 7% increase in phytoplankton, with the Slope region being the largest, and the Bering shelf and Chukchi being the smallest; and 3) an increase in air temperature by 2 °C over the entire calculation period can result in an overall increase in phytoplankton by 11%.

Data The temperature and salinity datasets used in this study are monthly mean PHC; Daily atmospheric forcings from NCEP reanalysis.

Models The physical model used is the CIOM (Wang et al. 2002, manual; 2005, JO, 2009, JGR). It is coupled ice dynamic and thermodynamic model (Hibler 1980, MWR) to the Princeton Ocean Model (POM) with two improvements: a) wave mixing effect and b) tidal mixing. Since the tidal current is strong in the Bering shelf sea, and the tidal energy is more than 80% of the total energy (Kind and Schumacher 1981b, JGR). PhEcoM is the Physical-Ecosystem Model developed by Wang et al. (2003, manual) for polar ans subpolar seas.

1） Surface wind-wave mixing parameterization is implemented using formula of Hu and Wang (2010, JGR): $K_W = \frac{2Pk^2}{g}\delta\beta^3 W^3 e^{\frac{gz}{\beta^2 W^2}}$
where $\boldsymbol{K_w}$ is vertical eddy diffusion coefficient cause by wave，$\boldsymbol{k}$ is Karman constant，$\boldsymbol{\delta}$ is typical wave steepness, $\boldsymbol{\beta}$ is wave age，**W** is wind speed，**P** is coefficient related to Richardson number，and **z** is distance from sea surface to somewhere in the sea 。

2） To simulate the tidal current and circulation simultaneously, the conversion from tide surface elevation to tidal current speed at the open boundary: $V_{tide} = \eta\sqrt{\frac{g}{H}}$

where $\boldsymbol{H}$ is depth , $\boldsymbol{\eta}$ is tide surface elevation, $\boldsymbol{\eta = \sum H_i \cos(\omega_i t + g_i)}$，$\boldsymbol{H_i}$、$\boldsymbol{\omega_i}$、$\boldsymbol{g_i}$ is amplitude, frequency and phase lag of tidal component, respectively, $\boldsymbol{t}$ is time. The speed on the open boundary is given by: $V_{total} = V_{tide}$ ***+Inflow/Area***

3) Horizontal resolution 15′×10′, vertical resolution 24σ layer.

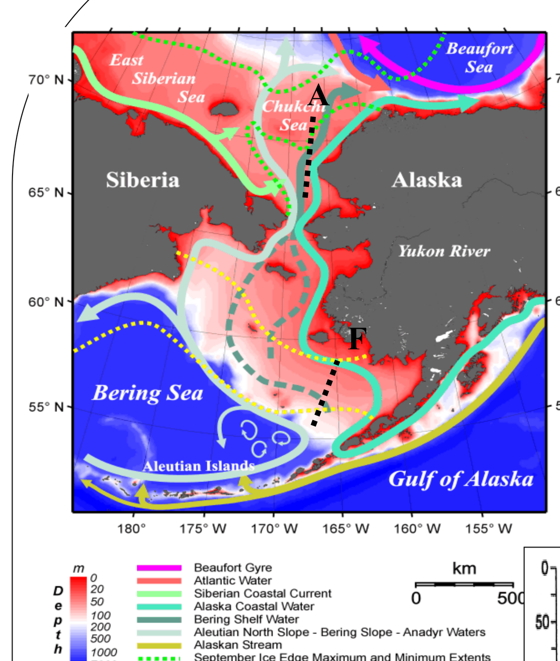
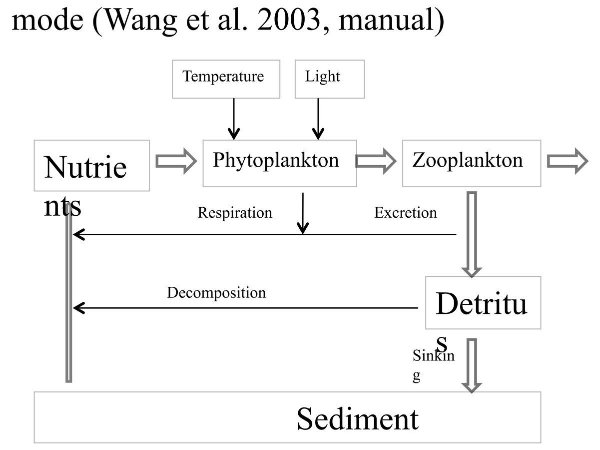


Figure 1. Topography and bathymetry of the Bering and Chukchi Seas, and the western/ Pacific Arctic region. The schematic circulation systems are marked by colored arrows. Water depths are in meters. (courtesy of T. Weingartner, University of Alaska Fairbanks). The model domain is from 50-74N and 160E-173W. Transects A and F are denoted by the dashed lines.

Figure 2. Schematic flow chart of the ecosystem mode (Wang et al. 2003, manual)



Modeled Circulation Pattern

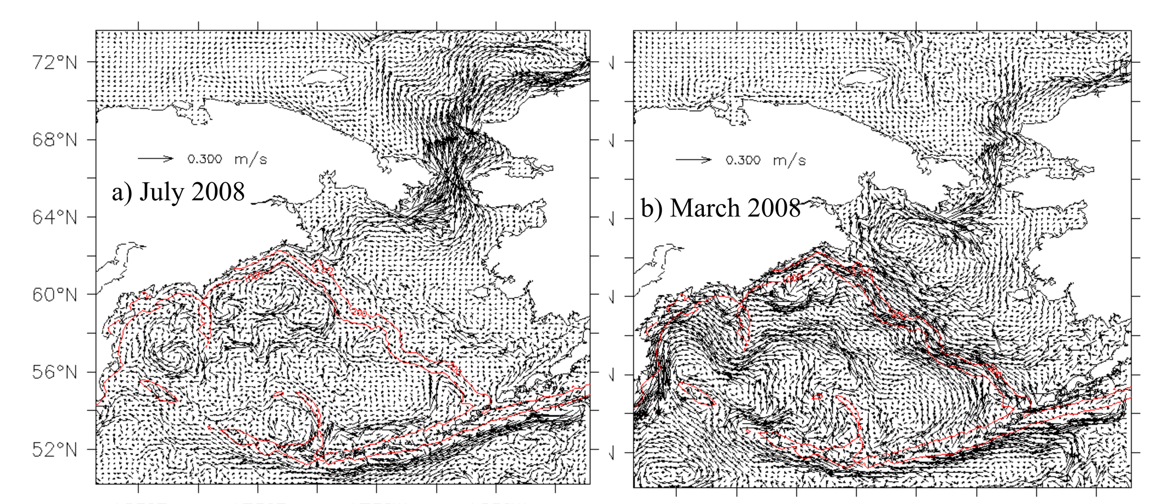


Figure 3. Modeled upper 20-m average ocean circulation in July (a) and March (b) 2008.

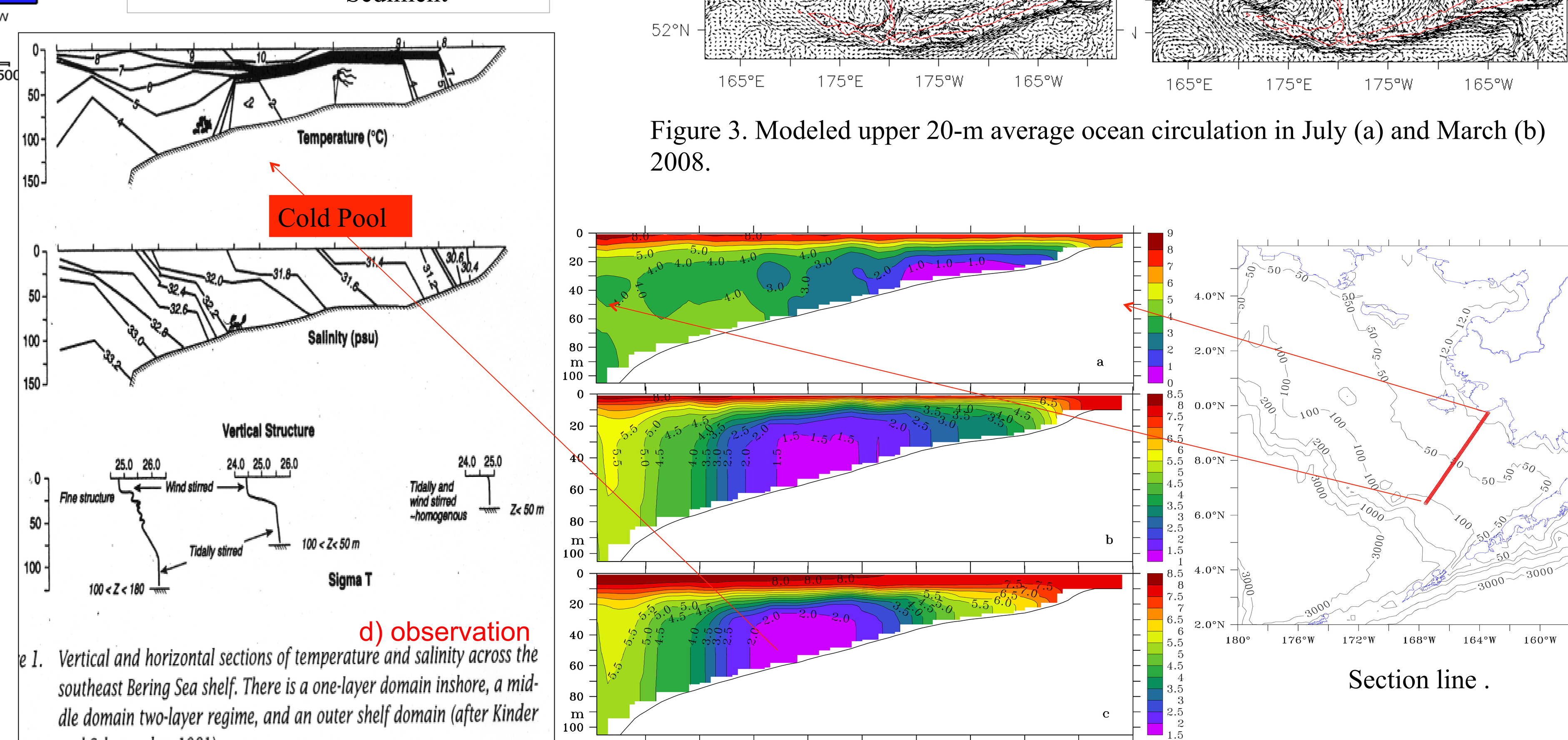


Figure 4. Model result of temperature, all show the cold water mass in summer (July) (Hu and Wang 2010, JGR): a) Model result with circulation only; b) Simulate circulation and tidal current simultaneously; and c) With circulation, tide and wave mixing . d) Observation

Modeled seasonal sea ice variations

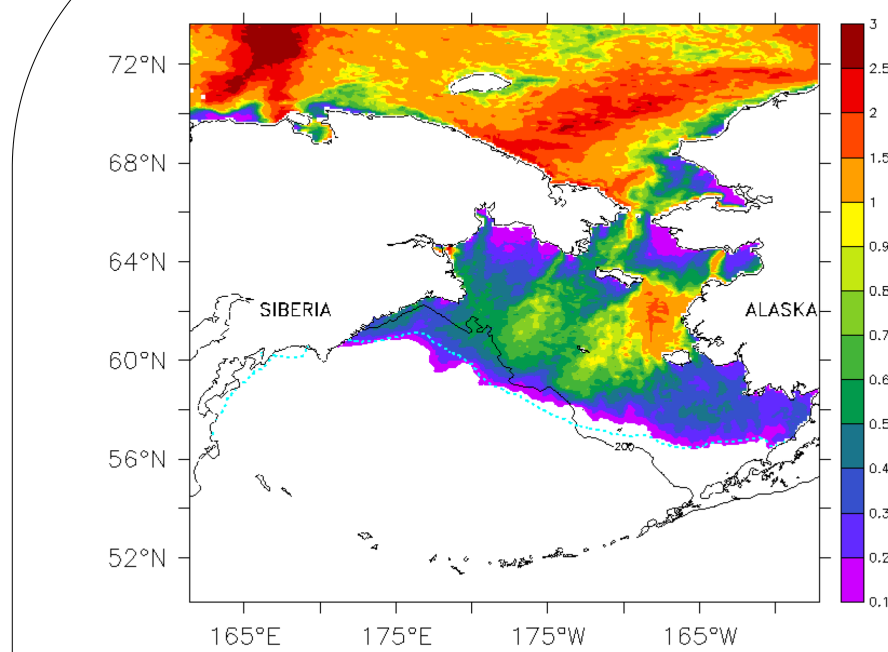


Figure 5. Model-simulated March sea ice Modeled sea ice thickness (in meters) and satellite-measured sea ice edge (green dashed line) in March 2008. The 200 m isobaths is noted as a solid black line.

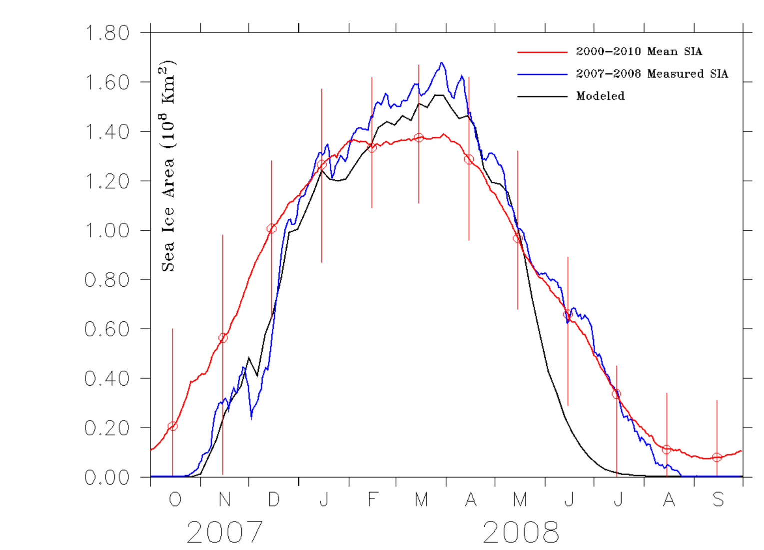


Figure 6. Model-simulated sea ice area (black line) and satellite-measured sea ice area (blue) over the entire Bering and Chukchi Seas for 2007-2008. The red line denotes the 11-year average area and the red vertical bars denote the maximum and minimum ice areas during 2000-2011.

Modeled surface chl-a in the Bering Sea

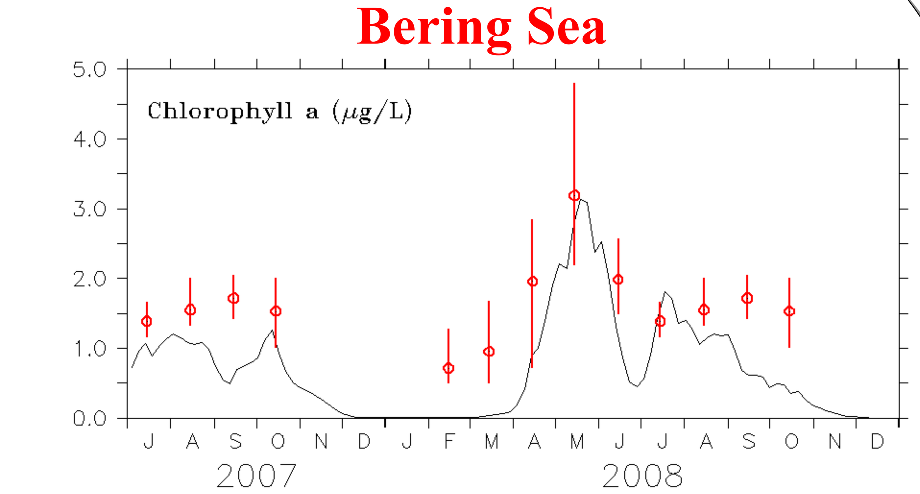


Figure 8. Model-domain averaged chl-a, as simulated by the PhEcoM (solid/black line) and measured by SeaWiFs (red circles). The vertical bars denote the monthly maxima and minima derived from the 2000-2010 data.

Spatial distribution of Chl-a:

Modeled **Satellite** **BEST-field survey**

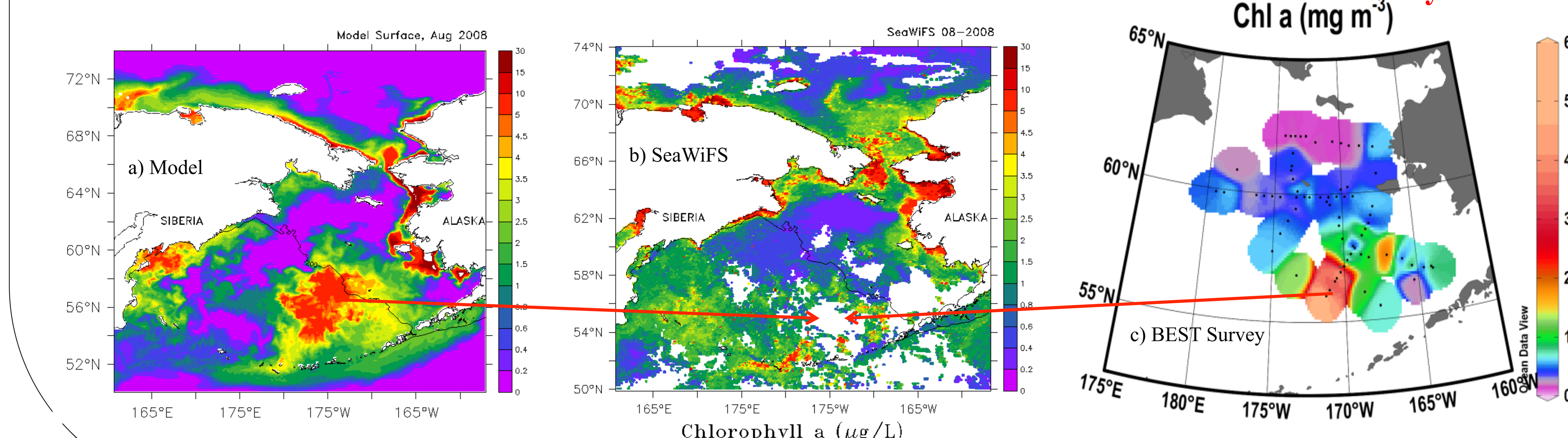


Figure 7. Model-simlated (a) and SeaWiFS estimated (b) satellite-measured , and c) BEST-measured surface chlorophyll a in August 2008.

Comparison in Transect A

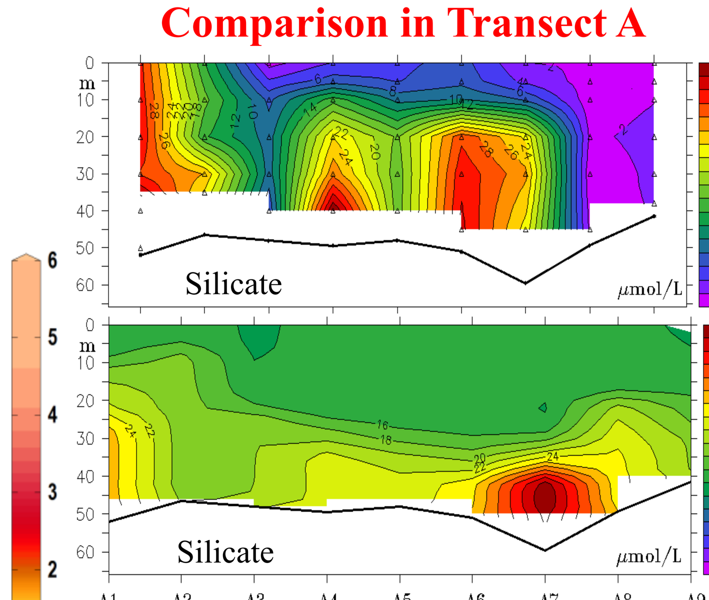


Figure 9. Shipboard-measured (upper panel) and modeled (lower) nutrients silicate (Si) along Transect A in the Chukchi Sea (see Fig. 1 for location) during the August 5-12, 2007 cruise by T/V Oshoro-maru.

Comparison in Transect F

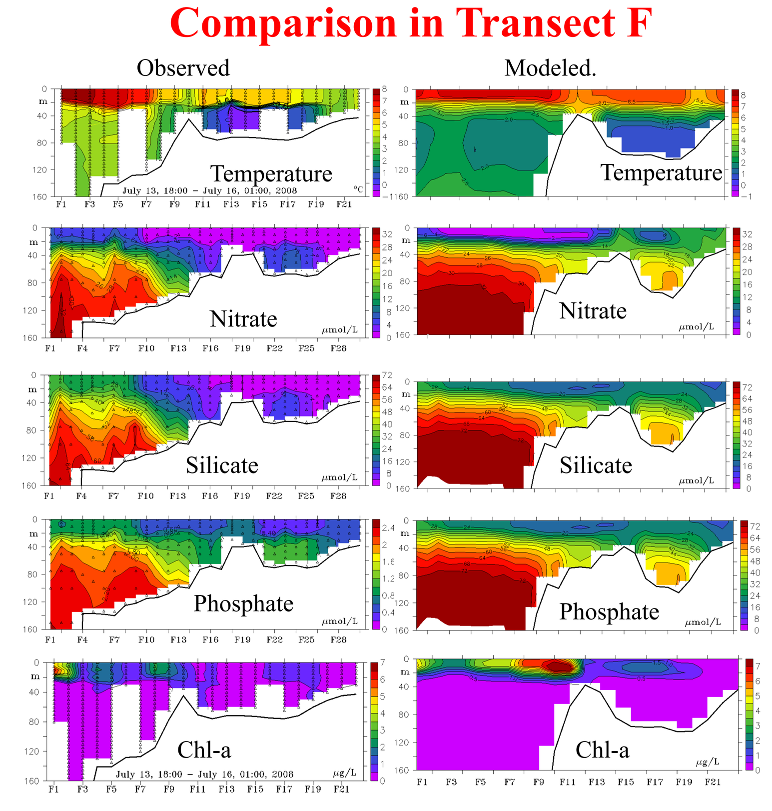


Figure 10. Shipboard-measured (left column) and modeled (right) nutrients (Nitrate, Silicate, Phosphate) and chl-a along Transect F in the Bering Sea (see Fig. 1 for location) during the July 4-23, 2008 Healy cruise.

Simulated seasonal cycle

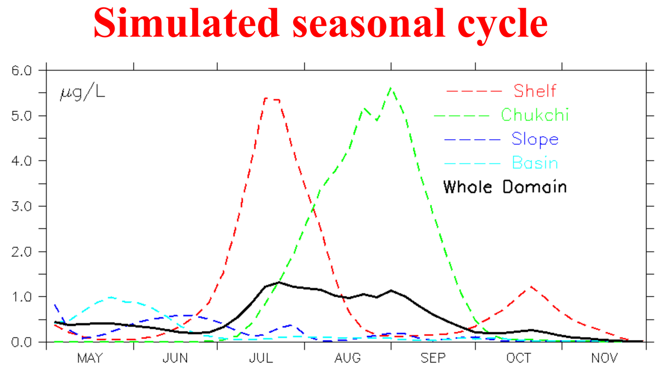


Figure 11. Simulated seasonal variation of phytoplankton (Chl a) for the subregions and the whole domain.

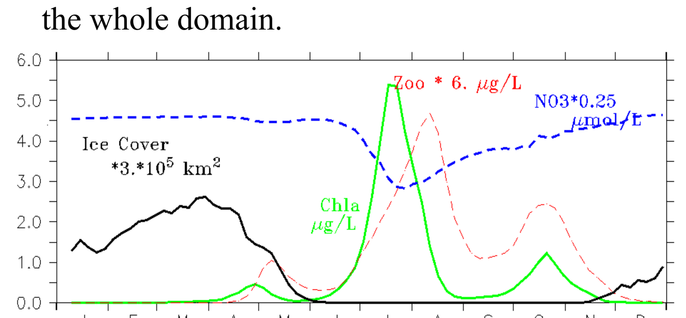


Figure 12. Modeled seasonal variations of sea ice cover (black line), nitrate (blue dashed), chlorophyll a (green), and zooplankton (red dashed) over the Bering Shelf . The units and factors are given.

Sensitivity experiments:

1) **10% increase in solar radiation,**
2) **20% increase in nutrients from open boundaries, and**
3) **2C increase in surface air temperature**

Table 1. Subdomain- and time- (May-November) average chl-a comparison between the sensitivity experiments and the control run (second column) for 1) an increase of solar radiation by 10% (third column), 2) an increase of nutrients from open boundaries (OB) by 20% (fourth column), and 3) an increase of air temperature by 2 °C (fifth column). Numbers in parentheses are the relative increase rate and numbers in column 3-5 are the differences between the sensitivity runs and the control run.

chl-a (μg/L)	Standard Run	Solar radiation increased by 10%	OB nutrients increased by 20%	Air Temperature increased by 2 °C
Basin	0.204	0.003 (1.47%)	0.050 (24.5%)	-0.035 (-17.15%)
Slope	0.186	0.008 (4.30%)	0.096 (51.6%)	0.041 (22.04%)
Shelf	0.987	0.005 (0.51%)	0.051 (5.10%)	0.135 (13.66%)
Chukchi	1.160	0.002 (0.17%)	0.016 (1.30%)	0.220 (18.97%)
Whole	0.507	0.004 (0.78%)	0.035 (6.90%)	0.054 (10.65%)

Table 2. Bering shelf domain- and time (May-November) average comparison between the sensitivity experiments and the control run (second column) for 1) an increase of solar radiation by 10% (third column), 2) an increase of nutrients from open boundaries (OB) by 20% (fourth column), and 3) an increase of air temperature by 2 °C (fifth column). Numbers in parentheses are the relative increase rate and numbers in column 3-5 are the differences between the sensitivity runs and the control run.

Variables	Standard Run	Solar radiation increased by 10%	OB Nutrients increased by 20%	Air Temperature increased by 2 °C
Ice Cover (km^2)	2.20×10^5	-2.97×10^3 (-1.35%)		-2.32×10^4 (-10.56%)
chl-a (μg/L)	0.987	0.005 (0.51%)	0.051(5.10%)	0.135 (13.66%)
Zoopl. (μg/L)	0.272	-0.012 (-4.42%)	0.016(5.89%)	0.055 (20.08%)
NO3 (μmol/L)	15.71	0.194 (1.23%)	1.612(10.3%)	5.053 (32.16%)

Conclusions

1) Seasonal cycle of sea ice, ocean circulation, and temperature in the Bering and Chukchi Seas are reasonably reproduced. Although 2007 and 2008 were record low ice years in the Arctic summer, the Bering Sea ice experienced a normal ice year, with the ice edge being close to the climatology. The simulated volume transport via the Bering Strait compared reasonably well to the observations. The seasonal cycle of the Bering and Chukchi Seas lower trophic level ecosystem was reasonably simulated using the simple NPZD ecosystem model.
2) Sea ice retreat (i.e., the increase of water temperature) controls the timing of the plankton blooms from the south to the north: deep basin, Bering Slope to the Bering shelf, and then to the Chukchi Sea. The bloom on the Bering shelf was stronger than on the Bering Slope and in the deep basin in the summer of 2008. No anomalous bloom along the Green Belt (Bering Slope) was found in either the in situ and satellite measurements or in the modeling results. The Chukchi Sea bloom occurred in late August to early September, accompanying the sea ice retreat or the increase of temperature.
3) Along the Chukchi shelf section A during August 5-12, 2007, nutrient-rich water was located on the bottom, and maximum chl-*a* was located at the subsurface, as captured by the model in general. However, the model underestimated the magnitude of the blooms.
4) Across the Bering Slope (i.e., along transect F) during July 4-23, 2008, nutrient-rich water was observed in the subsurface, which reflects nutrient upwelling to the surface. Across the Bering Slope, a thin layer of chlorophyll was situated on the surface, as also simulated by the model.