Simulation of Phytoplankton Distribution and Variation in the Bering-Chukchi Sea using a 3-D Physical-Biological Model

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Abstract

A three dimensional physical-biological model has been used to simulate seasonal phytoplankton variations in the Bering and Chukchi Sea with a focus on understanding the physical and biogeochemical mechanisms involved in the formation of the Bering Sea Green Belt (GB) and the Subsurface Chlorophyll Maxima (SCM). Model results suggest that the horizontal distribution of the GB is controlled by a combination of light, temperature, and nutrients. Model results indicated that the SCM, which frequently exists just below the thermocline, is due to rich nutrients and seldom light limited. The seasonal onset of phytoplankton blooms is controlled by different factors at different locations in the Bering Sea. In the off-shelf central region of the Bering Sea, phytoplankton blooms were regulated by available light. On the Bering Sea shelf, sea ice through its influence on light and temperature played a key role in the formation of blooms, whereas in the Chukchi Sea, bloom formation was largely controlled by ambient seawater temperatures. A numerical experiment conducted as part of this study revealed that plankton-sinking is important for simulating the vertical distribution of phytoplankton and the seasonal formation of the SCM. An additional numerical experiment helped reveal that sea ice algae account for 14.3~36.9% of total phytoplankton product during the melting season, and it cannot be ignored when evaluating primary productivity in the Arctic Ocean.

Model

Physical-Biological Model (Hu et al. 2004, 2010, 2011, Wang et al. 2009, 2013).

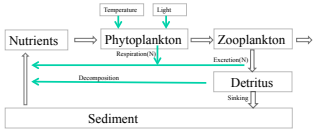
$$\left(\frac{d}{dt}-\nabla^2+W_P\frac{\partial}{\partial z}\right)\cdot P=(growth_P-respiration_P-mortality_P)\cdot P-grazing\cdot Z$$

$$\left(\frac{d}{dt}+W_Z\frac{\partial}{\partial z}\right)\cdot Z=(growth_Z-excretion_Z-mortality_Z)\cdot P$$

$$\left(\frac{d}{dt}-\nabla^2+W_N\frac{\partial}{\partial z}\right)\cdot N=(-growth_P+respiration_P)\cdot P+excretion\cdot Z+remi\cdot D$$

$$\left(\frac{d}{dt}-\nabla^2+W_D\frac{\partial}{\partial z}\right)\cdot N=(-growth_P+respiration_P)\cdot P+excretion\cdot Z+remi\cdot D$$

where $\frac{d}{dt}=\frac{\partial}{\partial t}+\vec{V}\cdot\nabla$, $\nabla=i\frac{\partial}{\partial x}+j\frac{\partial}{\partial y}+k\frac{\partial}{\partial z}$



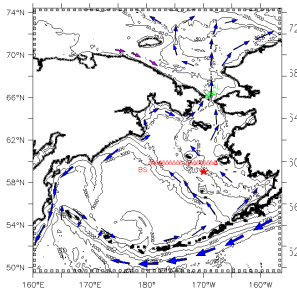


Fig 1. Model domain and open boundaries, contour lines denote water depths. Cruise transect AL is shown in green and transect BS in red triangles. The red star denotes the Subsurface Chlorophyll Maxima site Currents are shown in blue arrows, and the seasonal North Siberian Current is shown in purple arrows.

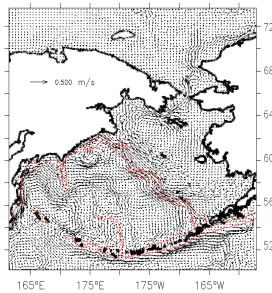


Fig 2. Model domain and modeled surface circulations in March

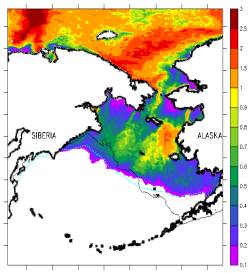


Fig 3. Modeled sea ice thickness in March

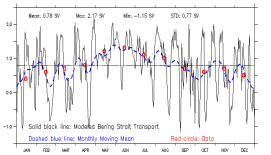


Fig 4. Bering Strait transport: modeled (black-solid line) and measured (red-dotted)

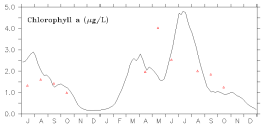


Fig 5. Seasonal surface Chlorophyll _a variation, model result in line and satellite data in triangles

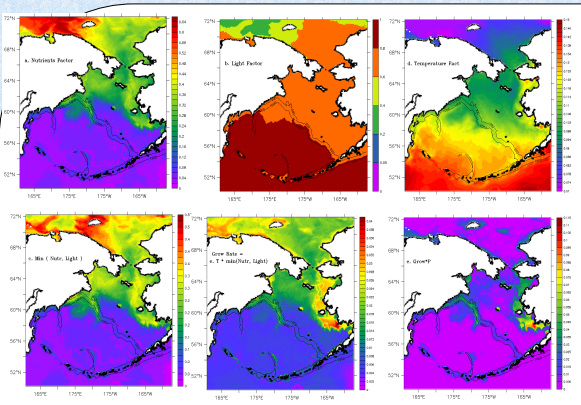


Fig 6. Factors (averaged from May to Sept.) that contribute to Chl-a horizontal distributions (a) nutrients factor $f_n = \min(\frac{N}{N+k_N}, \frac{P}{P+k_P}, \frac{Si}{Si+k_{Si}})$, (b) light factor $f_L = e^{-\gamma_1 I}(1-e^{-\gamma_2 I})$, (c) the minimum of light and nutrients factor, (d) the temperature factor $f_T = m_p e^{-\mu_p T}$, (e) the total integrated growth factor $grow = f_T \cdot f_{nL}$, *and* (f) the increased quantity (per hour) is $\Delta P = f_T \cdot f_{nL} \cdot P$

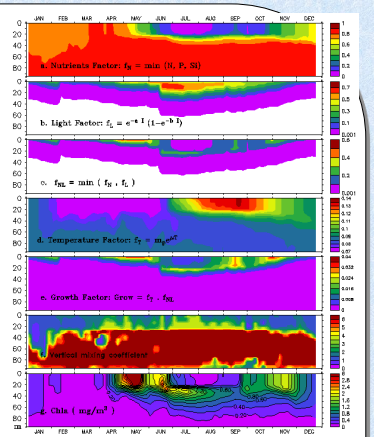


Fig 8. Factors that control summer SCM. (a) nutrient factor $f_n = \min(\frac{N}{N+k_N}, \frac{P}{P+k_P}, \frac{Si}{Si+k_{Si}})$, (b) light factor $f_L = e^{-\gamma_1 I}(1-e^{-\gamma_2 I})$, (c) the minimum of light and nutrients factor, (d) the temperature factor $f_T = m_p e^{-\mu_p T}$, (e) the total integrated grow factor $grow = f_T \cdot f_{nL}$, (f) the vertical mixing coefficient – log (K_v), and (g) modeled Chl-a variation in 2010.

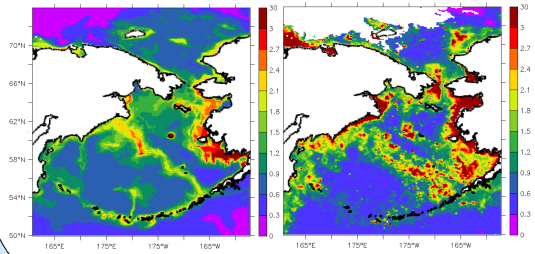


Fig 7. (a) Observed average surface Chl-a (May-Seder of year is not included because of sea ice cover and a lack of SeaWiFS data). (b) Simulated average surface Chl-a (May-Sept. 2009, SeaWiFS.

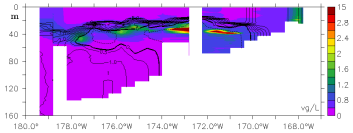


Fig 9. Measured Chl-a (μg/L, color filled) and temperature (°C, contour lines) from Aug. 2008 cruise in BS, see Figure 1 for location.

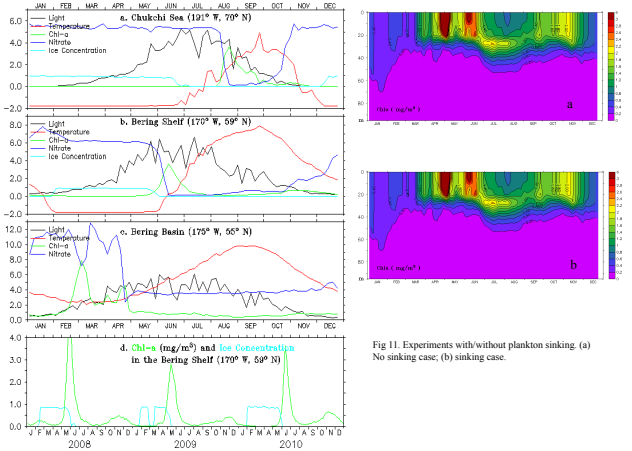


Figure 10. Spatial difference of bloom timing, light in black, temperature in red, Chl-a in green, nitrate in blue, and sea ice concentration in light blue. (a) In Chukchi Sea (191 °W, 70 °N), (b) in Bering Shelf (170 °W, 59 °N), (c) in Bering Basin (175 °W, 55 °N), and (d) Chl-a and sea ice concentration in Bering Shelf (170 °W, 59 °N, see Figure 1 star for location) of multiple

Fig 11. Experiments with/without plankton sinking. (a) No sinking case; (b) sinking case.

Fig 12. Experiments with/without sea ice algae ((a) and (b) at 175 °W, 61 °N, depth 100 m). (a) Sea ice algae, sea ice thickness, and phytoplankton (Chl-a) in the surface water (b) Sea ice algae, sea ice thickness, and nitrate in the surface water.(c) Integrated (water mass × Chl a concentration) Chlorophyll a in the Bering Shelf and the Chukchi Shelf.

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