



Abstract

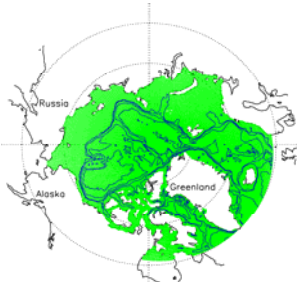
We have developed a coupled 3D pan-arctic **Biology/Ice/Ocean Modeling and Assimilation System (BIOMAS)** to investigate the impact of declining arctic sea ice on the marine planktonic ecosystem over 1988–2007. The BIOMAS results are generally in good agreement with satellite observations of ice extent, chlorophyll a, and primary productivity (PP) and submarine observations of ice thickness. Both satellite observations and BIOMAS results show a downward trend in summer sea ice extent during 1988–2007. The reduction in ice extent results in an increase in the photosynthetically active radiation (PAR) at the ocean surface and in the PP in the upper 100 m over open water areas of the Arctic Ocean. The simulated arctic sea ice thickness decreases steadily during 1988–2007, leading to an increase in the simulated PAR and PP in sea ice-covered areas. The increases in the simulated PAR and PP mainly occur in the seasonally and permanently ice-covered Arctic Ocean. Because of the PP increase, the simulated biomass of phytoplankton and zooplankton has increased.

Introduction

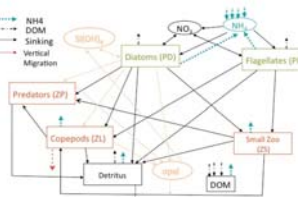
Significant decline in arctic sea ice has been observed in recent years. The summer melt season is lengthening because of earlier melt and later freeze onsets (Belchansky, et al., 2004). The result is unprecedented summer melt-back of the sea ice pack (e.g., Stroeve et al., 2008). The summer melt-back was particularly dramatic during summer 2007, when arctic sea ice extent plunged to the lowest level since satellite observations began in the 1970s. Changes in sea ice affect the arctic marine ecosystem. Pabi et al. (2008) and Arrigo et al. (2008) have found a generally increasing trend in pan-Arctic marine PP over 1998–2007 based on satellite observations over mainly open water areas. Here we use BIOMAS to investigate the arctic planktonic ecosystem response to changes in sea ice in both open water and sea ice-covered areas.

Description of BIOMAS

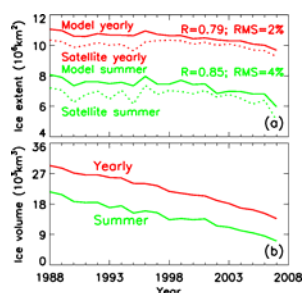
- POP ocean model (Smith et al., 1992)
- Dynamic thermodynamic sea-ice model (Zhang and Hibler, 1997)
- 11-component planktonic ecosystem model
- BIOMAS forced by NCEP/NCAR Reanalysis data.



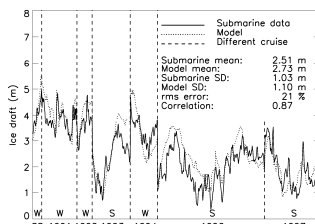
Grid configuration and bathymetry of the coupled 3D pan-arctic Biology/Ice/Ocean Modeling and Assimilation System (BIOMAS); bathymetry contours of 400, 800, 2200, and 3600 m are plotted. The BIOMAS grid is based on a generalized curvilinear coordinate system.



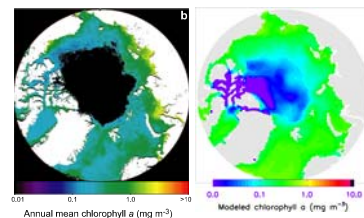
Schematic of the BIOMAS ecosystem model developed based on Kishi et al. (2007). This arctic ecosystem model has two phytoplankton components (diatoms; flagellates), three zooplankton components (microzooplankton; copepods; predator zooplankton), dissolved organic nitrogen, detrital particulate organic nitrogen, particulate organic silica, nitrate, ammonium, and silicate.



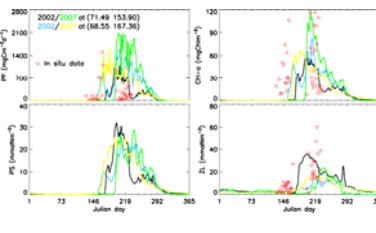
Simulated and satellite observed yearly and summer (July–September) mean arctic sea ice extent (a) and simulated yearly and summer mean total sea ice volume (b) in the Arctic Ocean. Model-data correlation (R) and root-mean-square (RMS) error are indicated in (a).



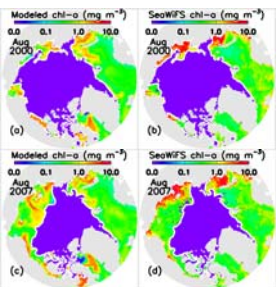
Model simulated and submarine observed sea ice draft along the tracks of submarine cruises 1988–1997. The submarine ice draft data are described in Rothrock et al. (2003). SD: standard deviation; W: winter cruise; S: summer cruise.



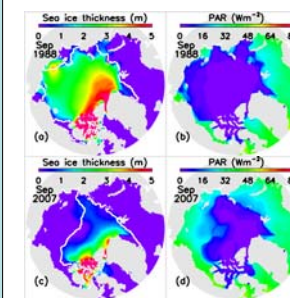
Satellite observed (left) and BIOMAS simulated (right) 1998–2006 mean surface chlorophyll a. The left panel is from Pabi et al. (2008) using SeaWiFS data mainly over open water areas. BIOMAS provides results for both open water and ice-covered areas.



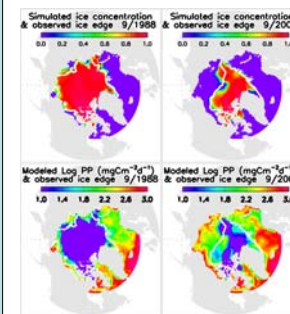
Daily variations of BIOMAS simulated PP, chlorophyll a, flagellates (PS), and copepods (ZL) for 2002 and 2007 in the Chukchi and Beaufort seas. The red circles show in-situ data collected during the Shelf-Basin Interactions program (Campbell et al., 2009; <http://www.eol.ucar.edu/projects/sbi/>).



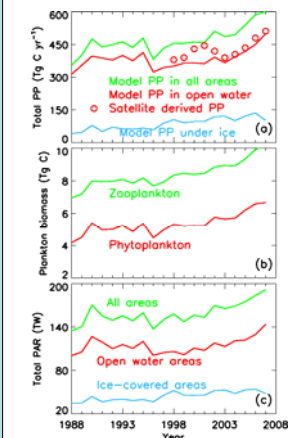
BIOMAS simulated and SeaWiFS-observed composite surface chlorophyll a for August 2000 and 2007. The white line represents satellite observed ice edge defined as 0.15 ice concentration. SeaWiFS chlorophyll a values are unreliable under ice, so, for a comparison, no values (satellite or modeled) are plotted there. As sea ice melts back, production in the open water areas of the Chukchi and Beaufort seas increases in both the model and the observations.



BIOMAS simulated sea ice thickness and photosynthetically active radiation (PAR) at the ocean surface. The results indicate that as sea ice declines in recent years, PAR increases.



BIOMAS simulated sea ice concentration and primary productivity (PP) integrated over the upper 100 m for September 1988 and 2007. The results indicate that as sea ice declines in recent years, PP increases.



(a) Satellite derived annual arctic marine PP using SeaWiFS surface chlorophyll a mainly in open water areas and BIOMAS simulated annual PP in open water, ice-covered, and all (open water plus ice-covered) areas of the Arctic Ocean; (b) modeled annual mean biomass of phytoplankton and zooplankton in the upper 100 m of the Arctic Ocean; and (c) modeled annual mean total PAR in open water, ice-covered, and all areas. Satellite derived PP are from Pabi et al. (2008) and Arrigo et al. (2008).

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