Influence of Sea Ice on Arctic Marine Sulfur Biogeochemistry

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DOE EPSCoR State/National Laboratory Partnership Project:

Influence of Sea Ice on Arctic Marine Sulfur Biogeochemistry in the Community Climate System Model

Research Objectives:

Overall: Improve the treatment of arctic marine biogeochemistry in CCSM. Add sea ice algae and arctic dimethyl sulfide (DMS) production and related biogeochemistry in CICE coupled to POP.

Specifically:

1) Develop a state-of-the-art ice-ocean DMS ecosystem model

2) Assess and predict sea ice influences on DMS dynamics

Clouds and DMS in the Arctic

DMS is an important precursor of cloud condensation nuclei (CCN).

Summertime Arctic Ocean is a strong source of DMS.

In clean marine air the supply of CCN is often limiting.

Arctic stratus-cloud radiation feedback inextricably linked with ice albedo feedback.

Arctic suffers from scant spatial and temporal coverage of DMS measurements.

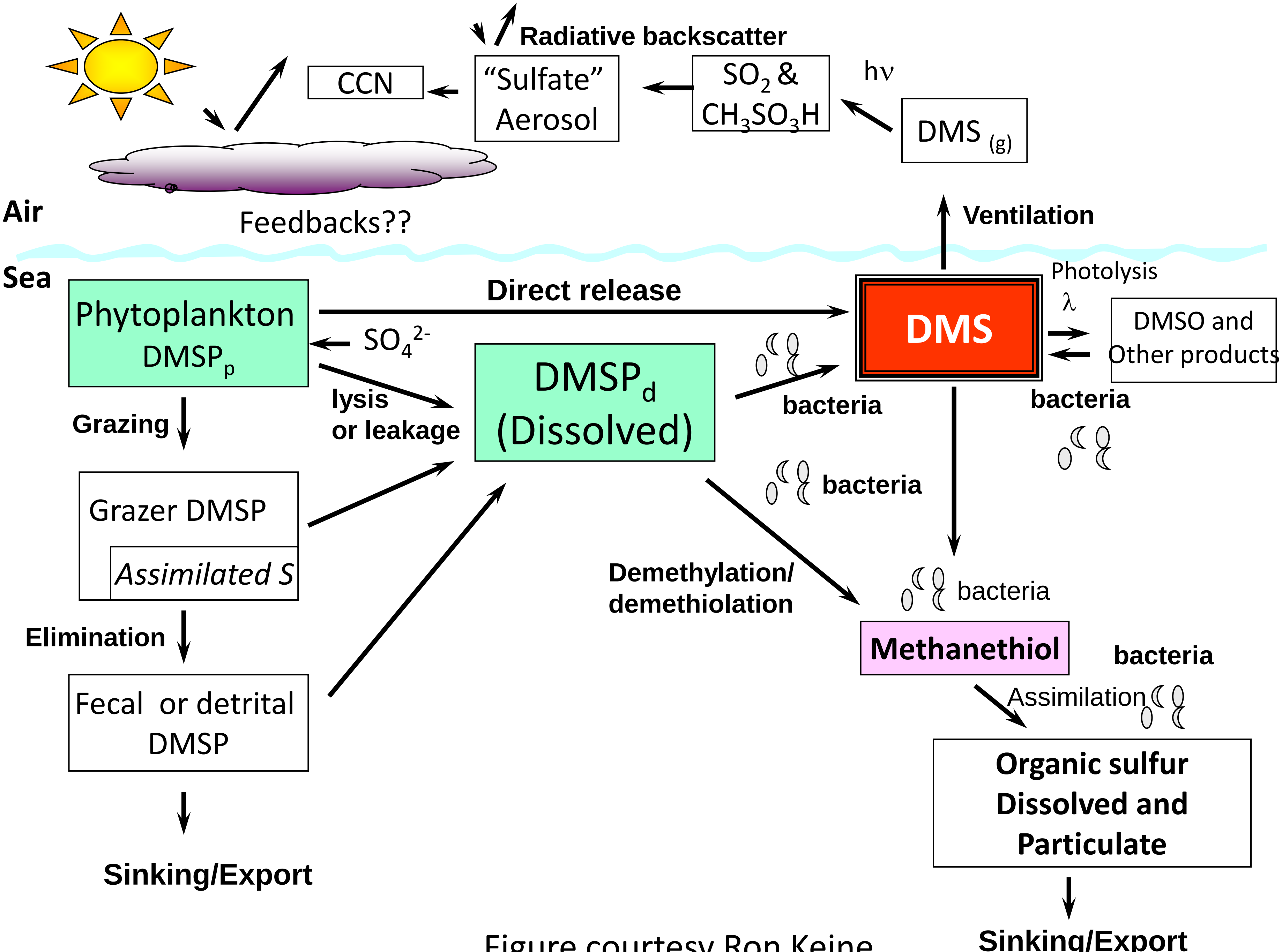
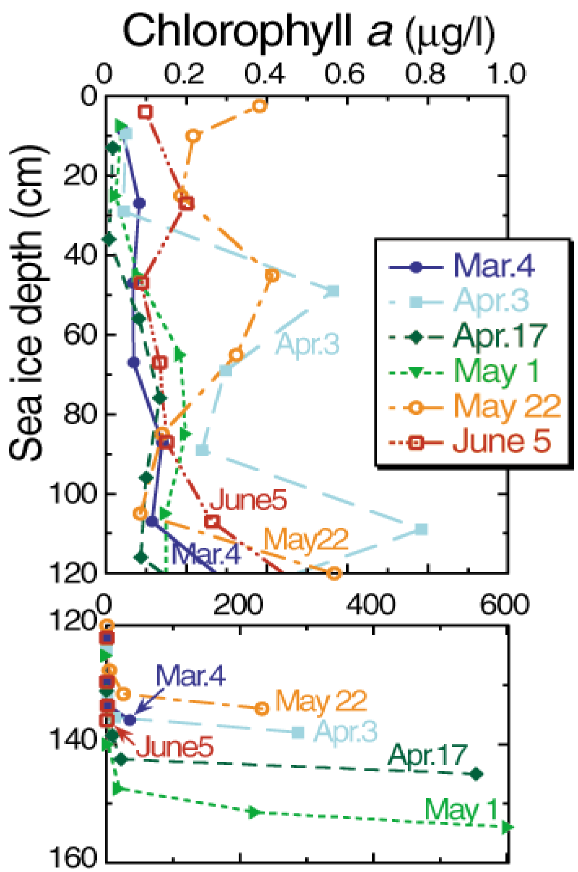
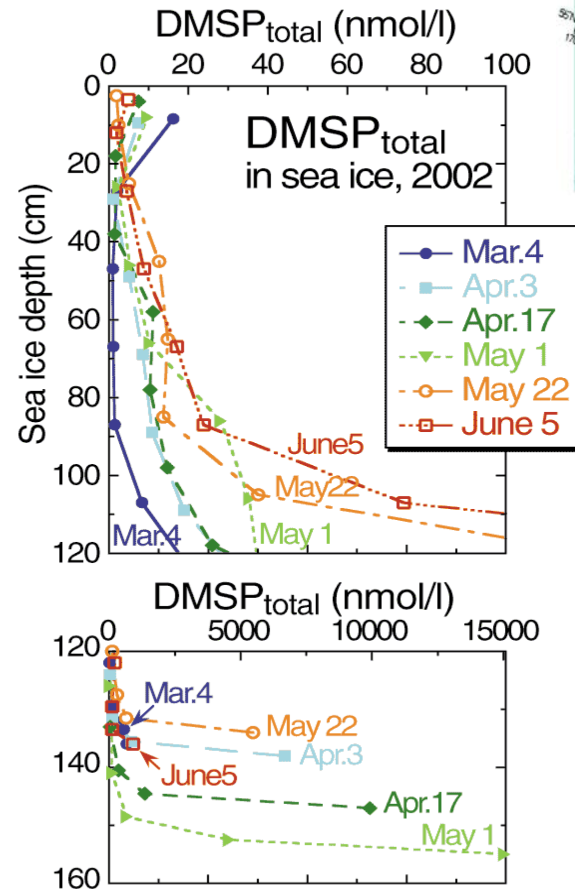


Figure courtesy Ron Keine.

Ice algal biomass is highest in the bottom 2-3 cm of arctic FYI and MYI (Gradinger et al. 2009), where S compounds accumulate.

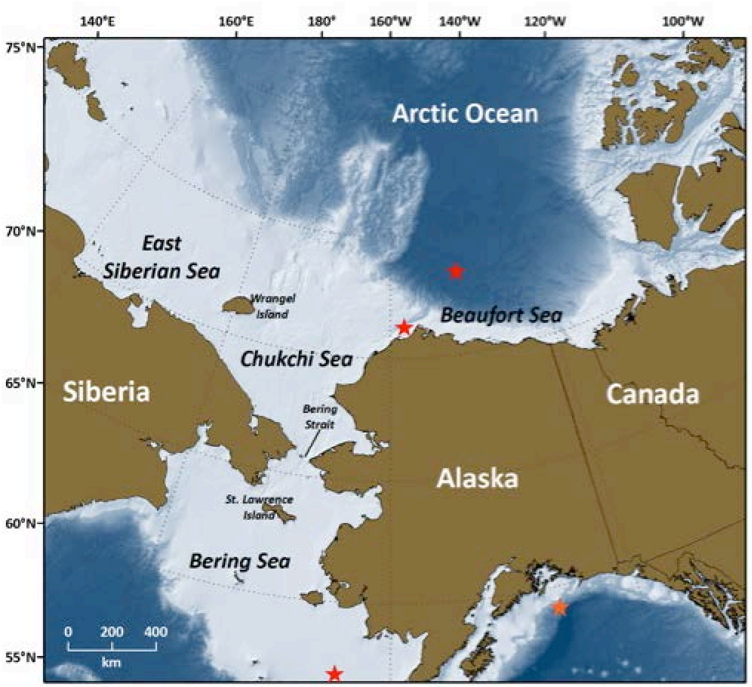


April through May, >90% ice algal biomass (chlorophyll a) observed in bottom of sea ice (3 cm layer) (Shin et al., 2003).



Very high levels of total DMSP up to 15 μM, were observed at Barrow, Alaska (Uzuka et al., 2003).

1-D Physical ice-ocean Ecosystem model (PhEcoM) applied at: land-fast ice zone, multi-year pack ice, and pack ice of SIZ.



Findings from 1-D modeling studies:

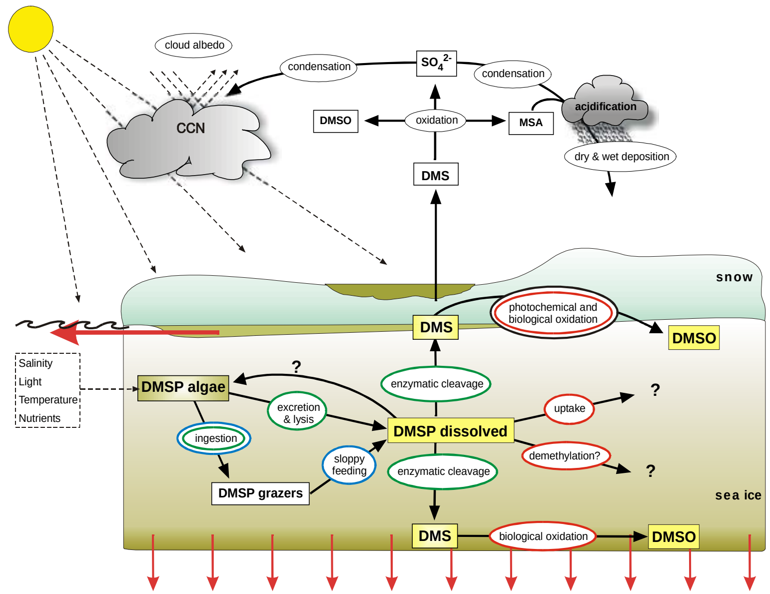
• suggest "seeding" of phytoplankton bloom by ice algae (Jin, Deal, et al., *GRL* 2007)

• shift in lower trophic level production and dominant phytoplankton type in response to climate regime shift (Jin, Deal, et al., *JGR* 2009)

• vertical mixing role in microalgal composition and DMS sea-to-air flux (Jin, Deal, et al., *JGR* 2006; Deal, et al., *JGR* 2001)

• major controls on sea ice algal production (Lee, Jin, et al., *Polar Biol*, 2010; Jin, Deal, et al., *Annals Glaciol*, 2006)

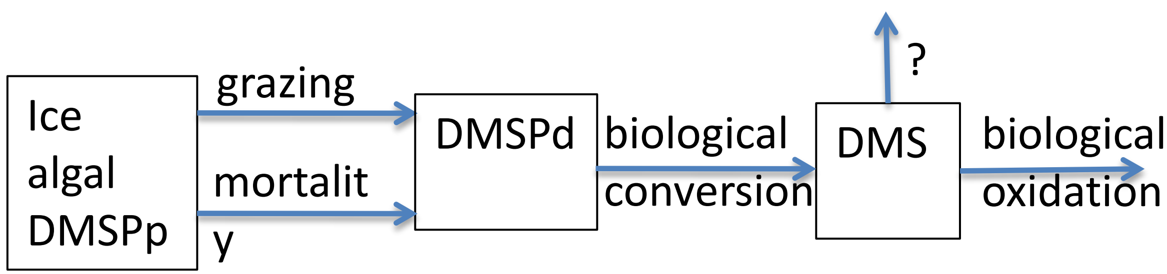
Sea ice DMS model



$$\frac{dAi}{dt} = Ai(G^{Ai} - f_g - Rg^{Ai})$$

$$\frac{dDMSPd_{sk}}{dt} = -\frac{DMSPd_{sk}}{\tau_{skc}} + R^{Ai}_{S:N} \cdot Ai \left(\left[f_{gs} + f_{ex} f_e f_{ga} \right] f_g + R^{Ai}_g \right)$$

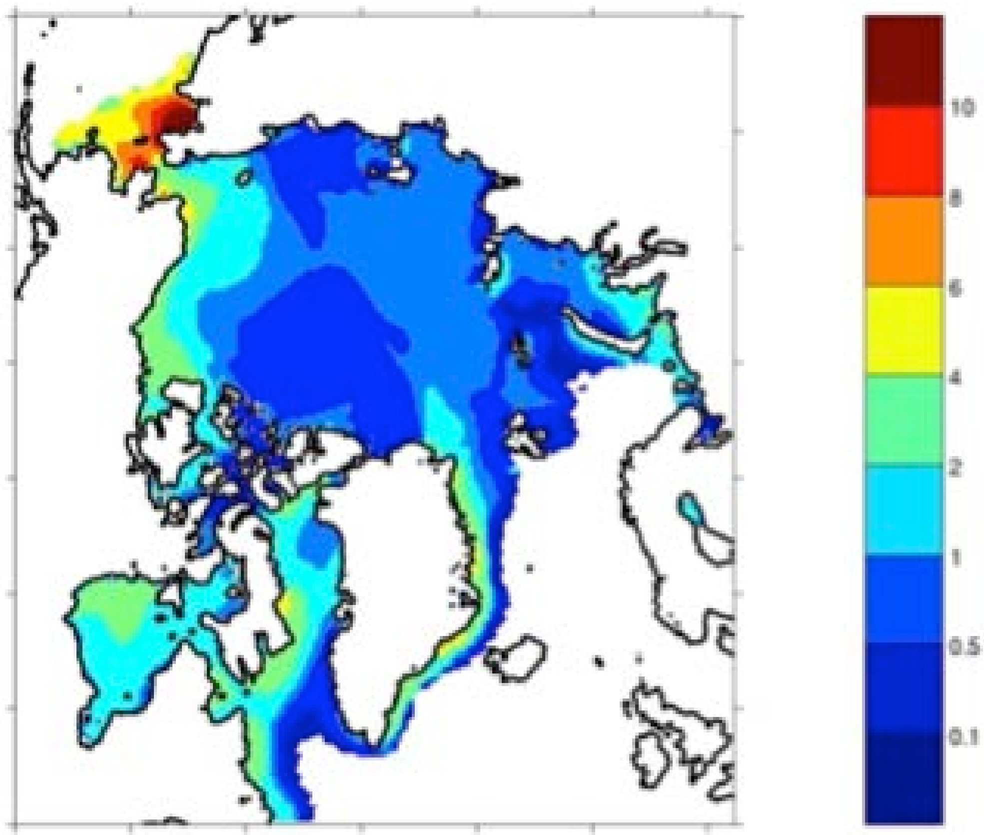
$$\frac{dDMS_{sk}}{dt} = -\frac{DMS_{sk}}{\tau_{sko}} + \frac{Y_{sk}}{\tau_{skc}} DMSPd_{sk}$$



3-D Model Results

Simulated annual primary production within arctic sea ice (for 1992) reproduces observed large-scale patterns and seasonality.

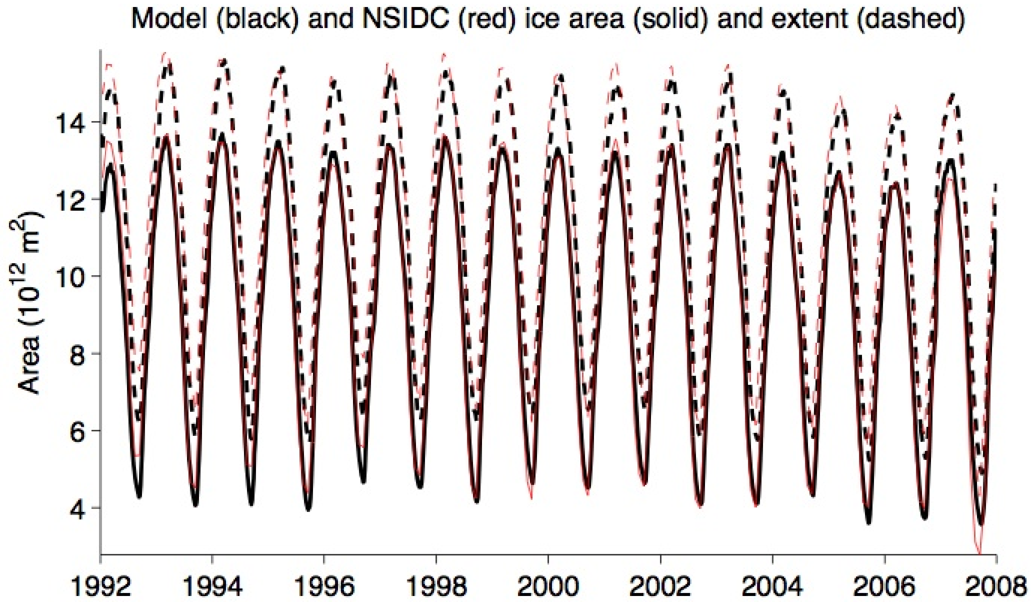
CICE with ice ecosystem (from PhEcoM): (g C m^{-2})



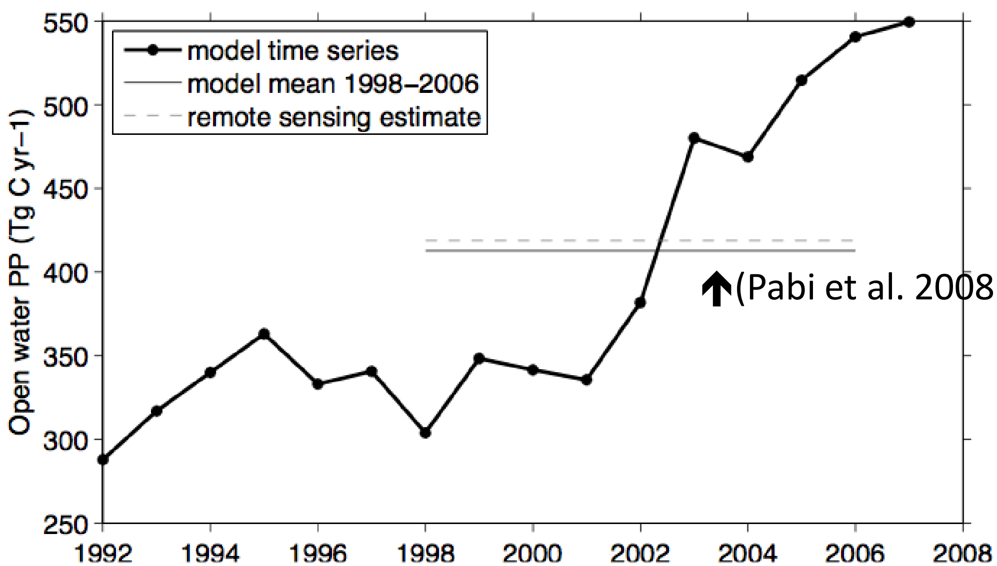
Deal, Jin, Elliott, Hunke, Maltrud, and Jeffery (2011) Large-scale modeling of primary production and ice algal biomass within arctic sea ice in 1992. *J Geophys Res-Oceans*.

Coupled CICE-POP with ice-ocean ecosystem:

The simulated ice area and ice extent match the NSDIC remote sensing data very well.



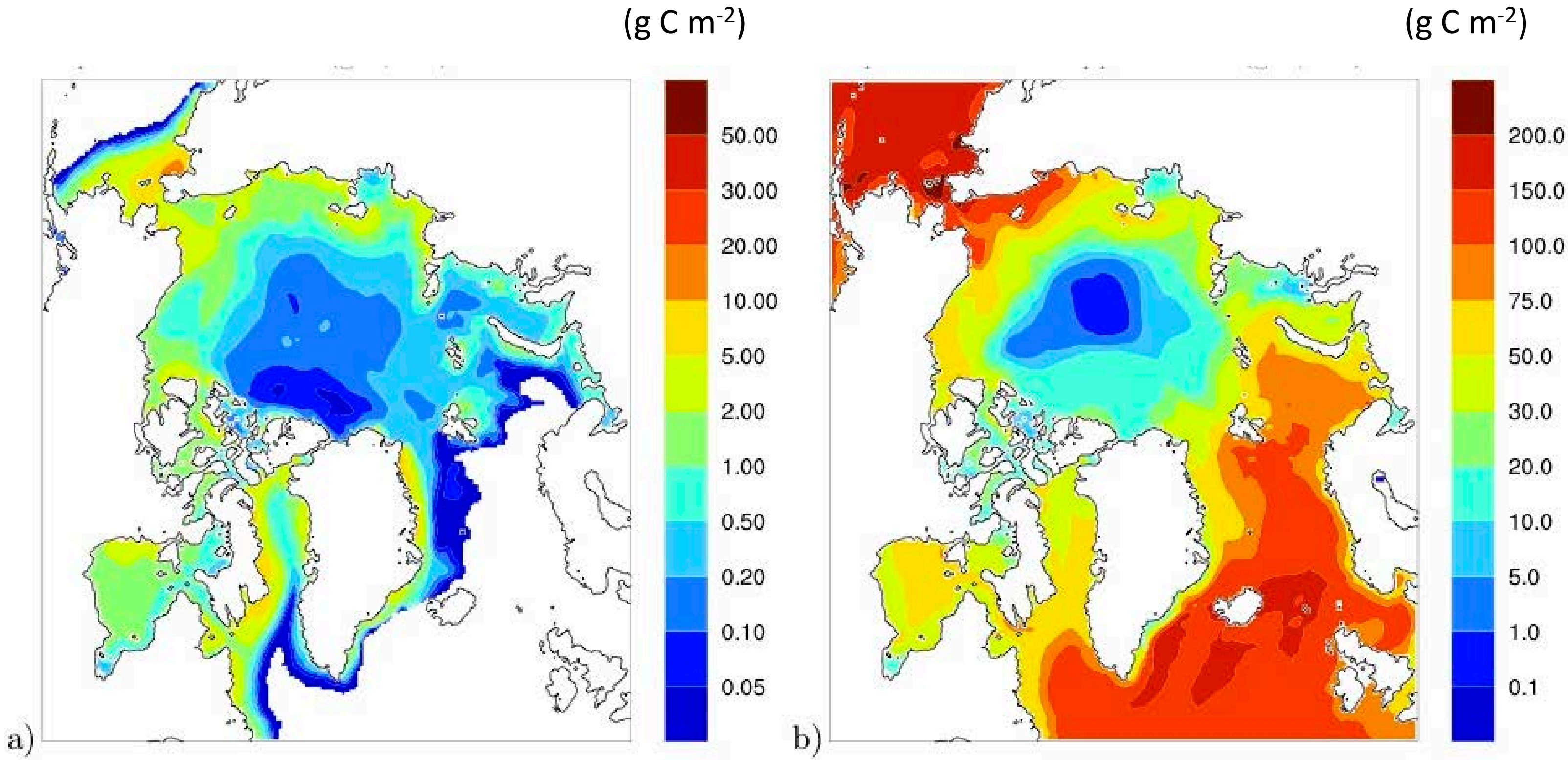
Simulated open water primary production (upper 100m) is close to the average estimated by remote sensing (Pabi et al. 2008).



Modeled pan-Arctic annual primary production averaged over 1992-2007 in a) sea ice, and b) ocean upper 100m.

55-145 g C m^{-2} yr^{-1} observed Chukchi shelf 2002-2004 (Lee et al. 2007)

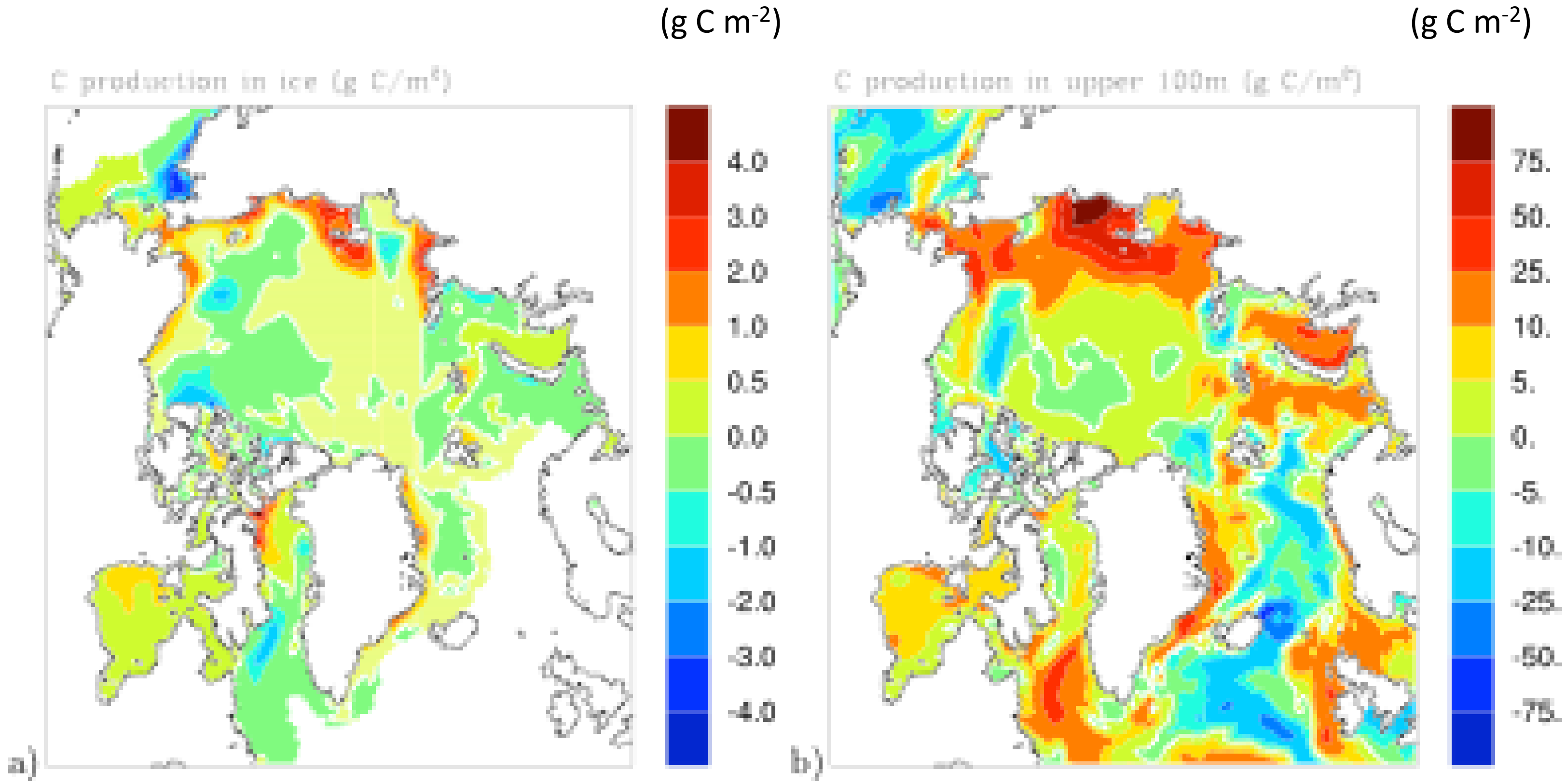
Coupled CICE-POP with ice-ocean ecosystem (ocean ecosystem; Moore et al. 2004):



Jin, M., C. Deal, S. Lee, S. Elliott, E. Hunke, M. Maltrud and N. Jeffery (2011) Investigation of Arctic sea ice and ocean primary production for the period 1992 to 2007 using a 3-D global ice-ocean ecosystem model *, Deep Sea Res Part-II.*

Modeled pan-Arctic annual primary production difference (i.e., mean low ice years minus mean high ice years) in a) sea ice, and b) ocean upper 100m.

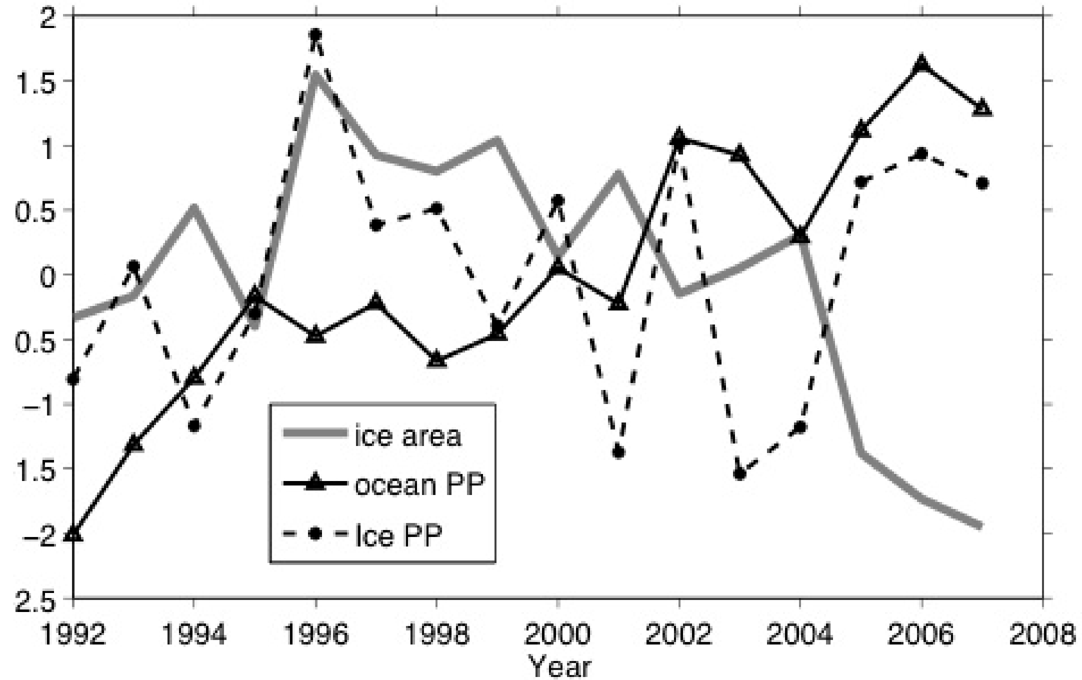
Coupled CICE-POP with ice-ocean ecosystem:



Jin, M., C. Deal, S. Lee, S. Elliott, E. Hunke, M. Maltrud and N. Jeffery (2011) Deep Sea Res Part-II.

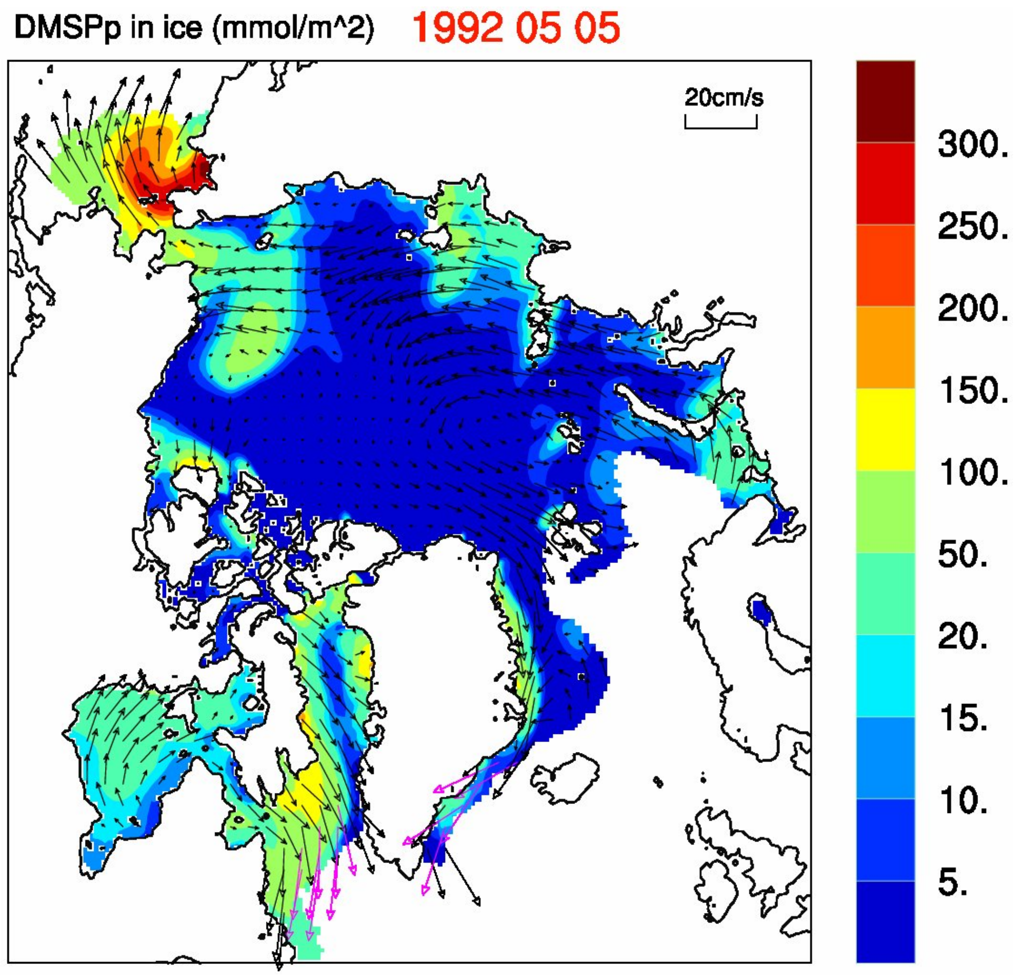
The normalized time series of simulated sea ice primary production within the Arctic Circle shows a lack of correlation with ice area.

Coupled CICE-POP with ice-ocean ecosystem:



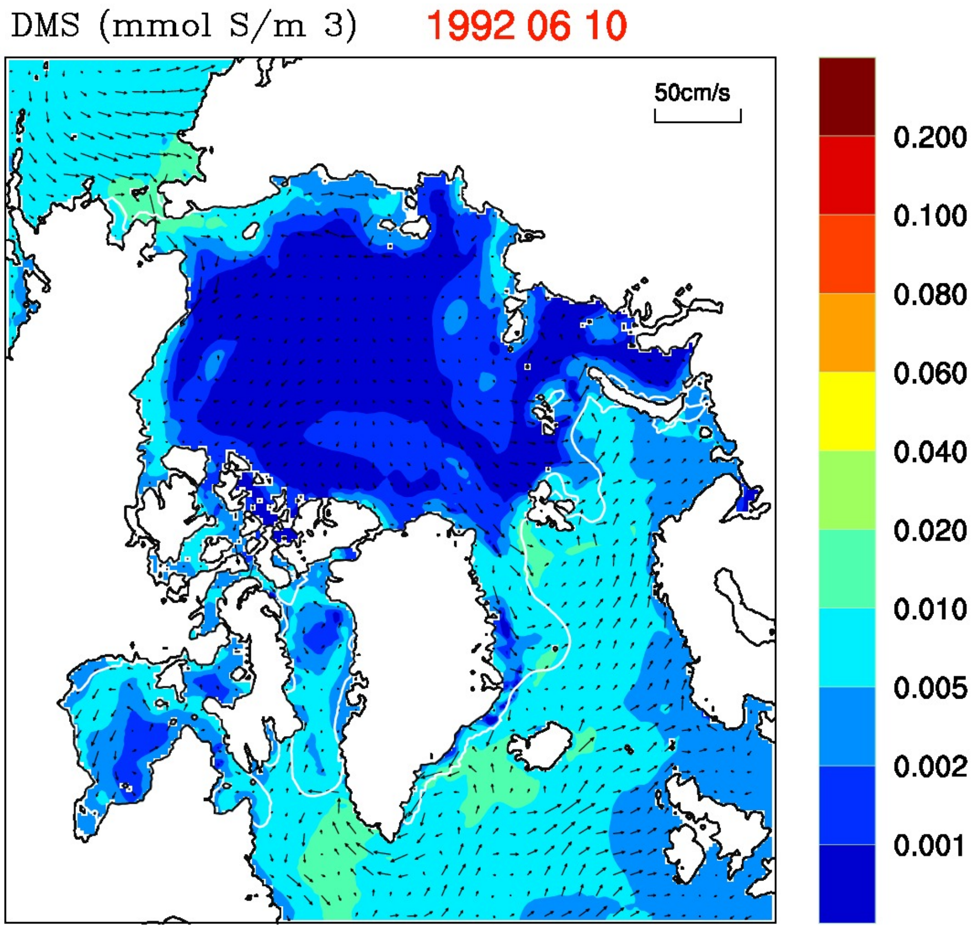
Jin, M., C. Deal, S. Lee, S. Elliott, E. Hunke, M. Maltrud and N. Jeffer, (21011) Deep Sea Res Part-II.

Simulated DMSPp concentrations in sea ice agree with very limited observations.

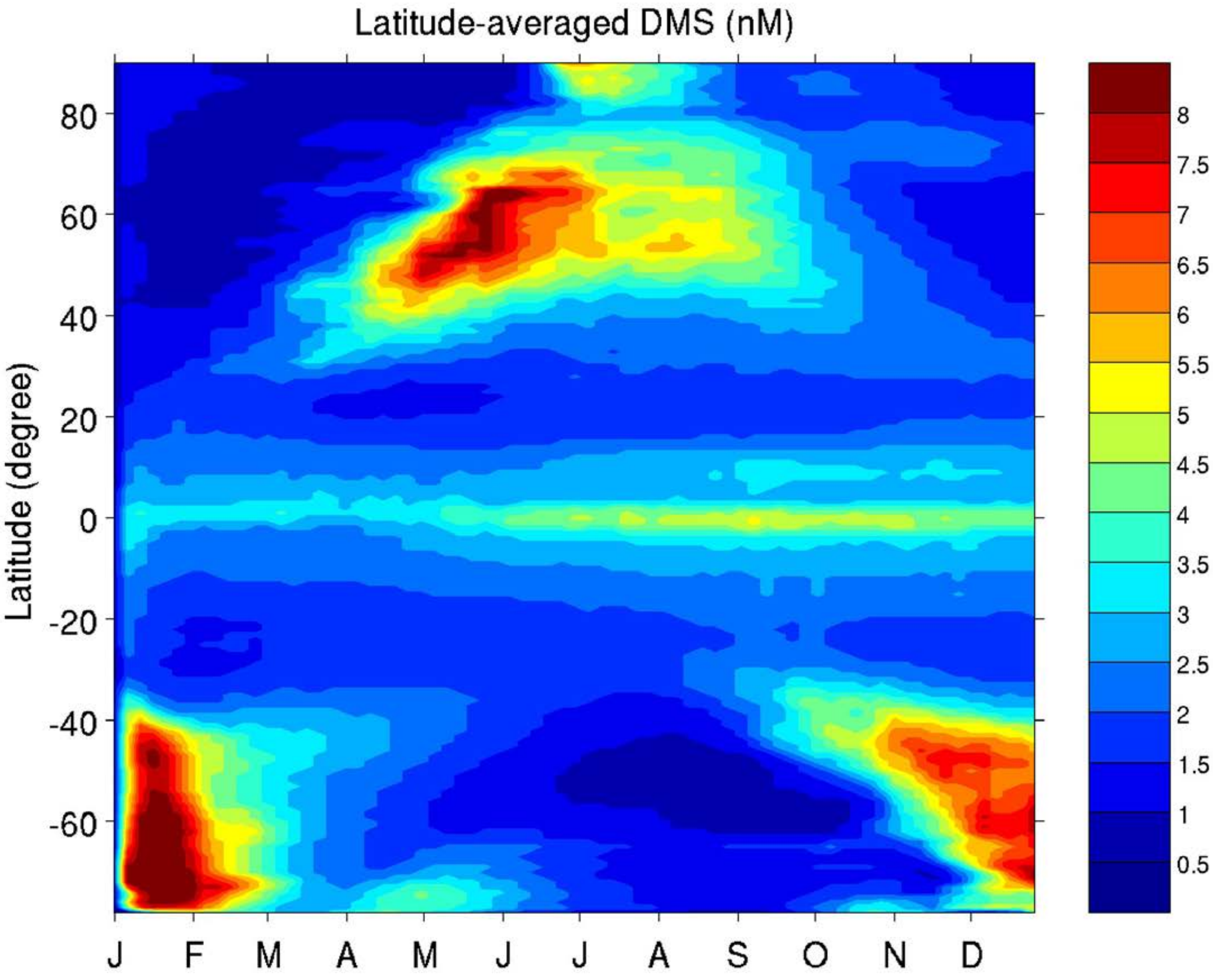


Simulated surface DMS concentrations, in general, agree with observations: ~1-3 nM under-ice, higher in MIZ, highest near ice edge.

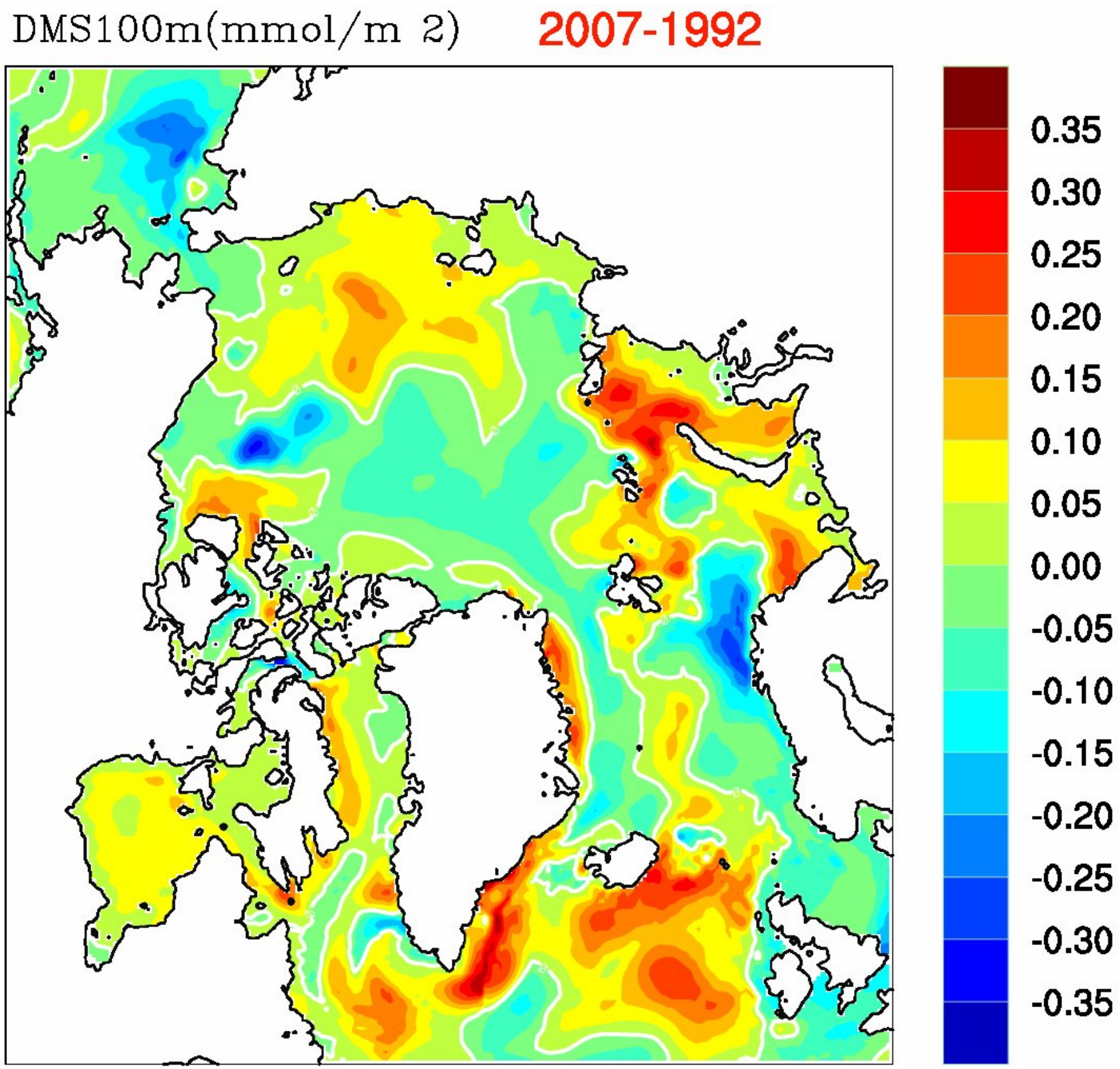
Coupled CICE-POP with ice-ocean ecosystem (ocean ecosystem, Moore et al. 2004; ocean DMS, Chu and Elliott, 2003):



Simulations display seasonality of sea surface DMS.



Preliminary model results indicate northward shift in seawater DMS concentrations due to recent sea ice decline.



Summary of activities

Focus on marine organic C (i.e., primary production) and DMS cycle.

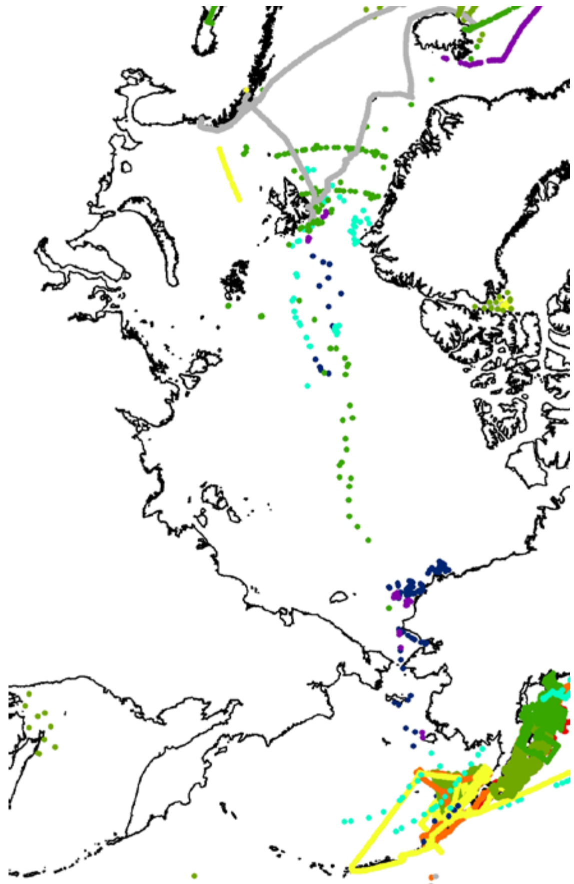
1-D DMS ice-ocean ecosystem modeling (i.e., ice ecosystem-ocean ecosystem with ice DMS module and ocean DMS module)

Stand-alone CICE with DMS ice ecosystem modeling

Coupled CICE-POP DMS ice-ocean ecosystem modeling

Ongoing evaluation and improvements of DMS model.

Thank you for your time and attention!



What is the impact of DMS on climate?

- **Recent climate models** (Gunson et al. 2006):
  - 50% reduction of ocean DMS emission:
    radiative forcing: +3 W/m^2
    air temperature: +1.6 °C
  - doubling of ocean DMS emission:
    radiative forcing: -2 W/m^2
    air temperature: -0.9 °C

- **Model projections** (Gabric et al. 2004) impact of warming on the global zonal DMS flux (70 N- 70 S) indicates greatest perturbations to be at high latitudes

- Use of a **climate model to force ocean DMS model** in Barents Sea (Gabric et al. 2005):
  - By the time of equivalent CO_2 tripling (2080)
    zonal annual DMS flux increase: >80%
    zonal radiative forcing: -7.4 W/m^2
    summer (June-September)