Modeling the cycling of dimethylated sulfur compounds in the arctic sea ice environment

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Talk outline

Introduction
- Motivation
- Objectives
- Dimethylsulfide (DMS) biogeochemical cycle

Background – Ecosystem modeling

Sea ice DMS model
- 1-D sea ice DMS model
- CICE DMS model

CICE-POP DMS ecosystem model – Arctic focus

Summary

Lead cloud offshore Barrow, Alaska. Photo courtesy Bill Simpson.

Motivation

Global climate models have not effectively considered how responses of arctic marine ecosystems to a warming climate will influence the climate system. A key response of arctic marine ecosystems that may substantially influence energy exchange is a change in DMS emissions, because DMS emissions influence cloud albedo.

DOE EPSCoR State/National Laboratory Partnership Project:

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

Research Objectives

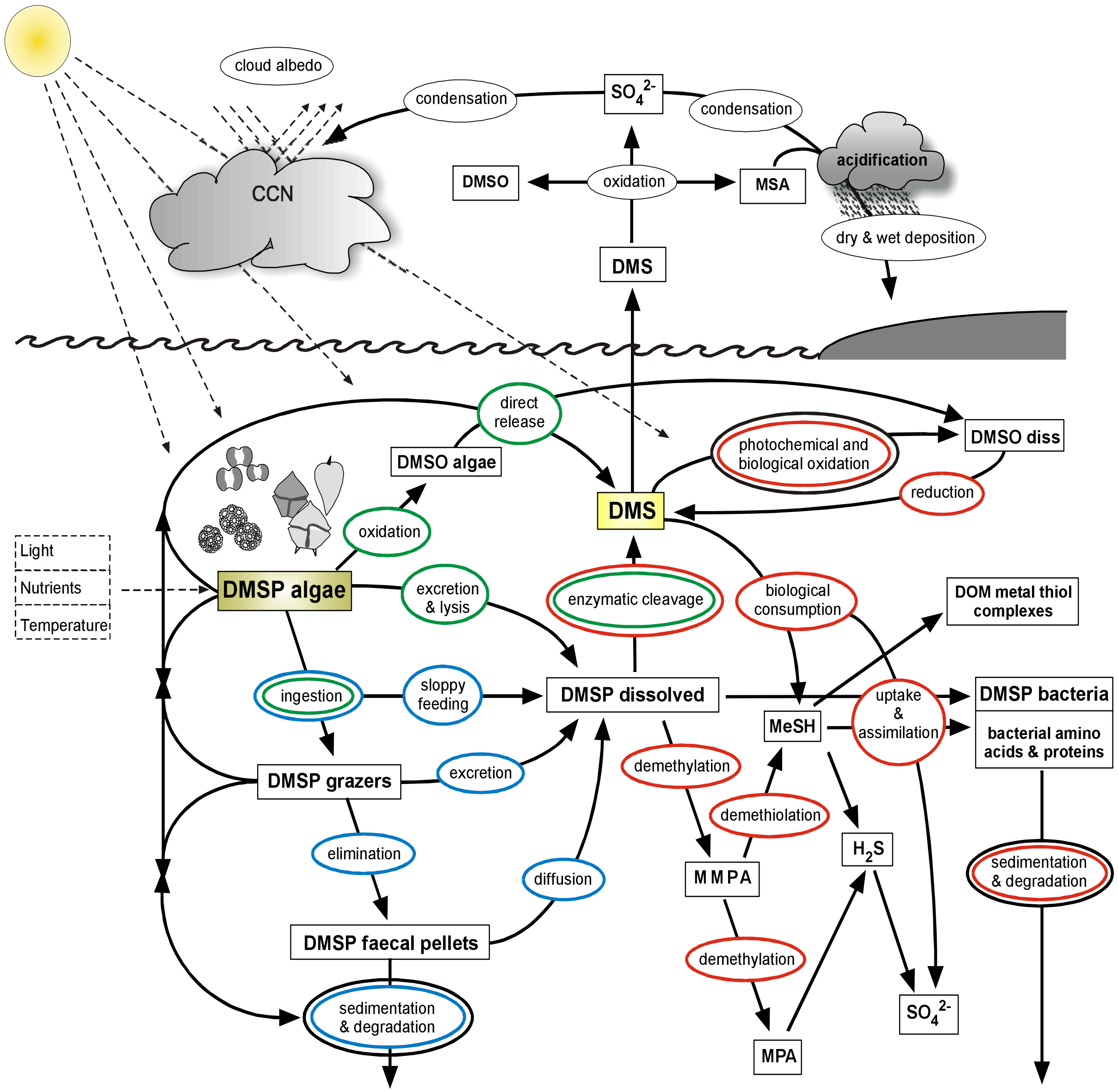
Overall: Improve the treatment of arctic marine biogeochemistry in CCSM. Working closely with COSIM team at LANL, we propose adding sea ice algae and arctic DMS production and related biogeochemistry in CICE coupled to POP.

Specifically:

1) Develop a state-of-the-art ice-ocean DMS model for application in climate models, using observations to constrain the most important parameters.

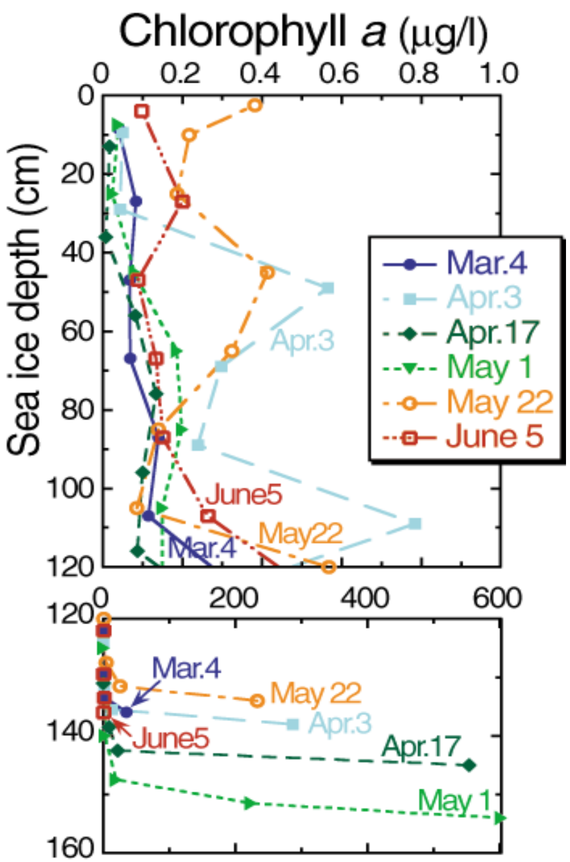
2) Assess how sea ice influences DMS dynamics in the arctic marine environment and predict how it will do so in the future.

DMS Biogeochemical Cycle – Figure courtesy J. Stefels

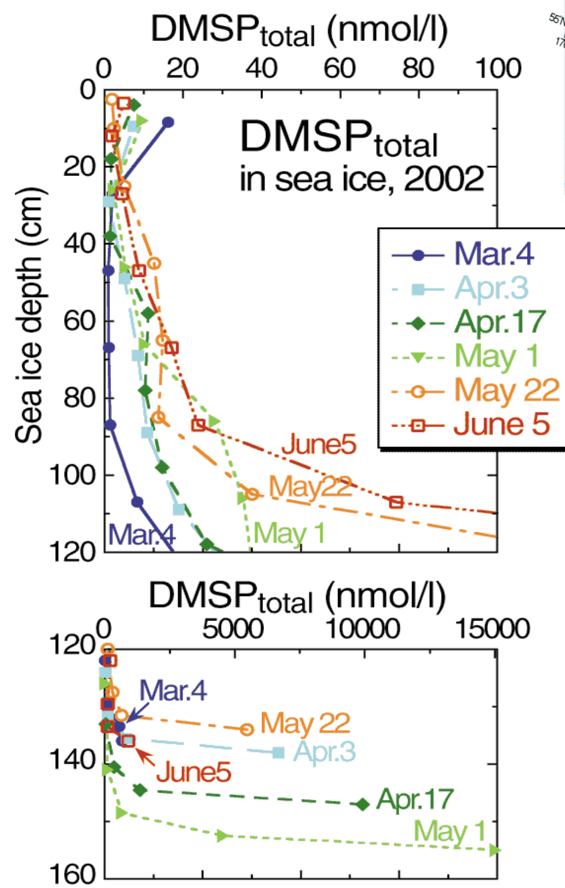


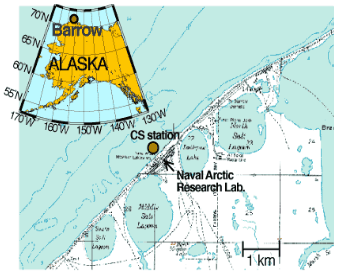
The DMS model is only as good as the ecosystem model to which it is coupled.

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



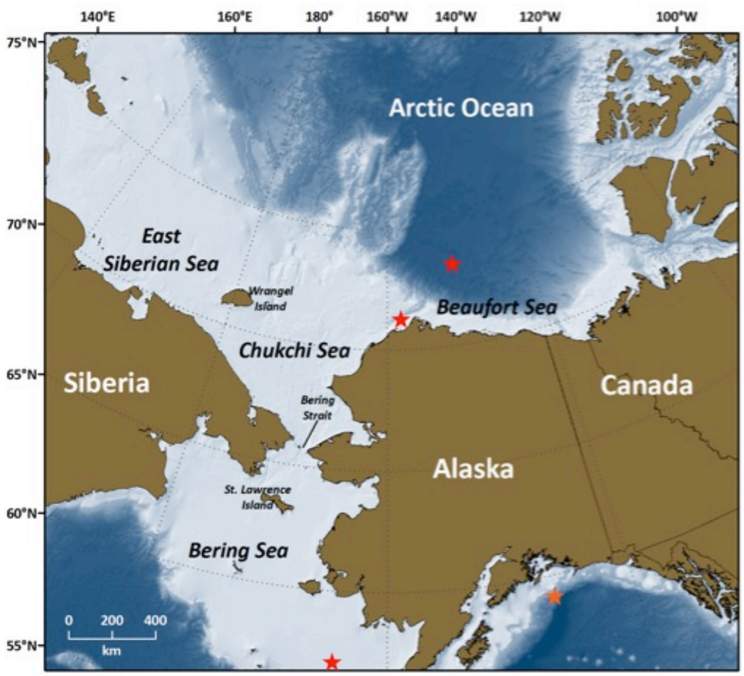
April through May, >90% ice algal biomass (chlorophyll a) observed in bottom of sea ice (3 cm layer) (Shin et al., 2003).





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:

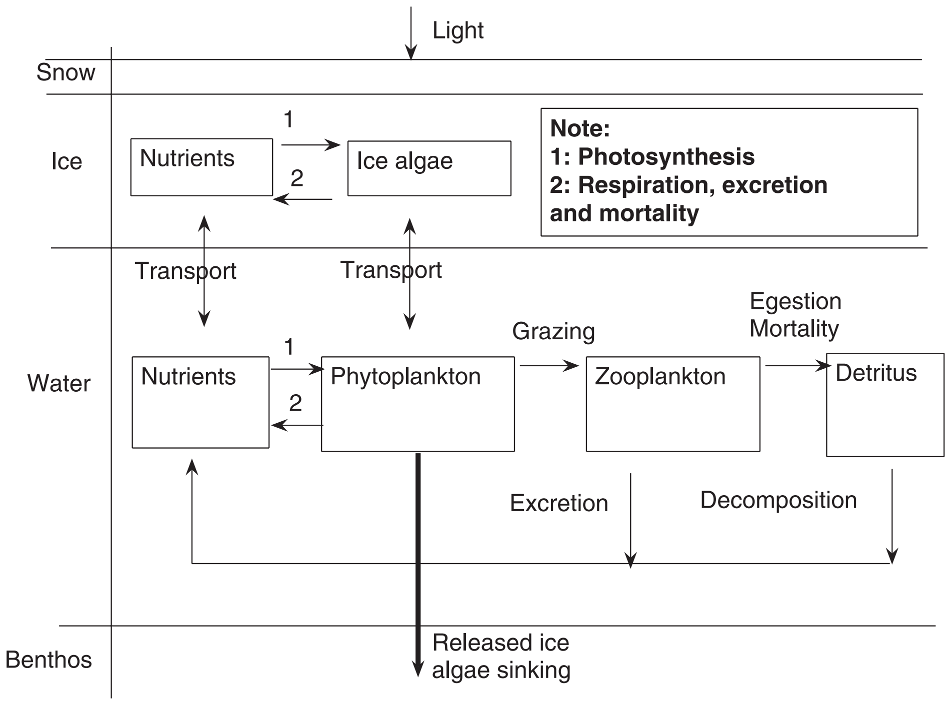
- major controls on sea ice algal production
(Lee, Jin et al. *Polar Biol*, 2010; Jin, Deal et al. *Annals Glaciol*, 2006)

- 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)

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

Physical pelagic ecosystem model (PhEcoM) with ice ecosystem.



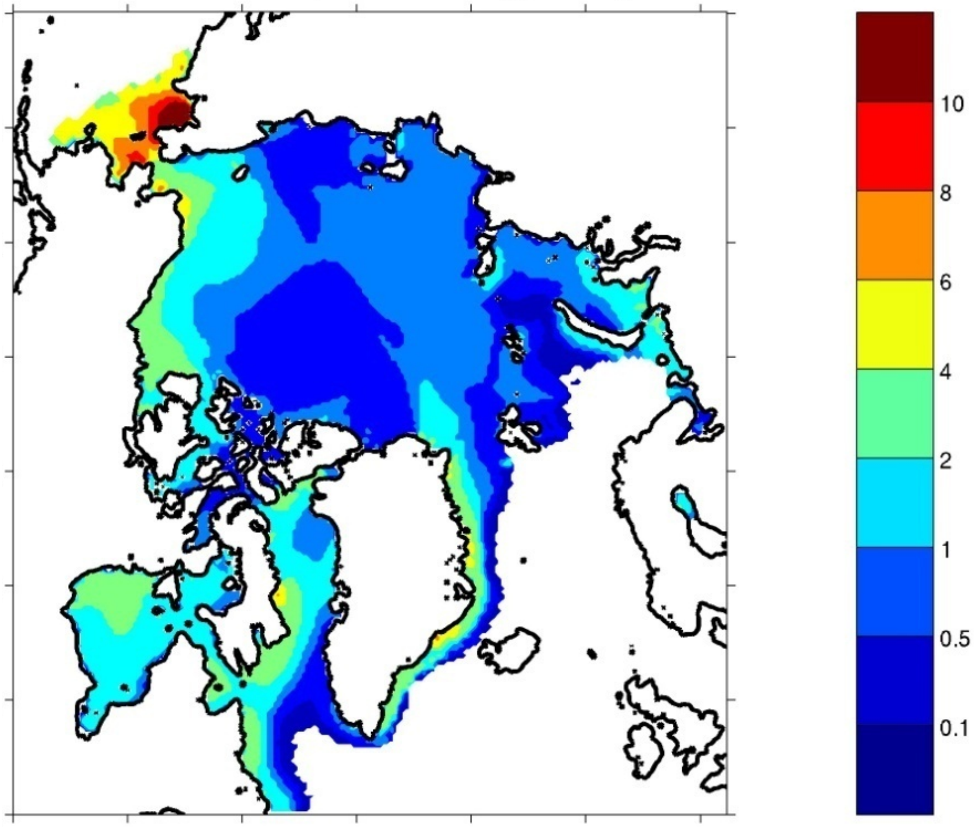
(Jin et al., Annals of Glaciol. 2006)

Nutrient flux between sea ice and the ocean is based on observations of Wakatsuchi and Ono (1983) that brine flux volume has a high correlation with ice growth rate.

When the ice bottom melts, nutrients and algae within ice are released to the ocean.

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})

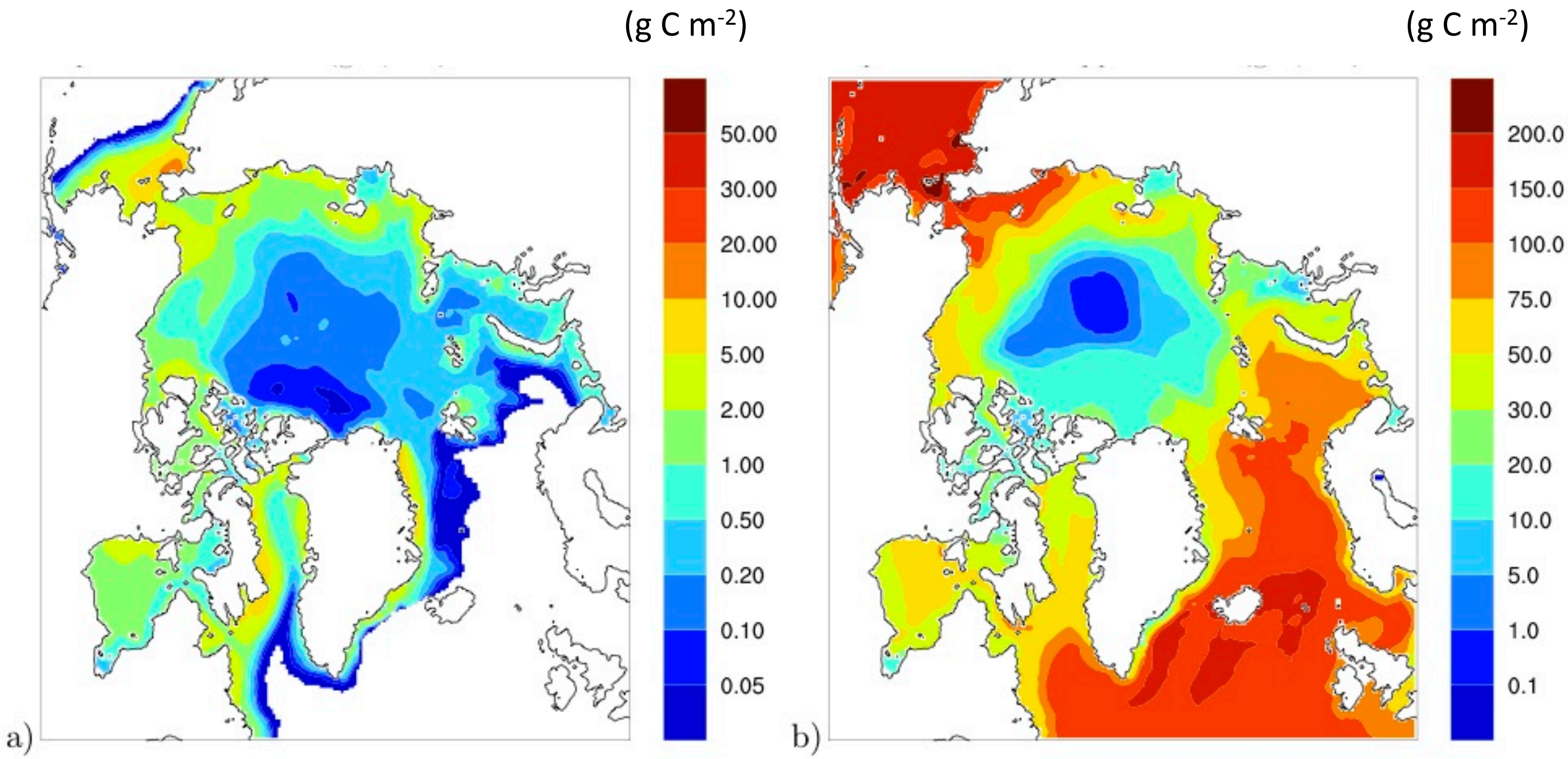


Deal, Jin, Elliott, Hunke, Maltrud, and Jeffery (2011) Large-scale modeling of primary production and ice algal biomass within arctic sea ice in 1992. *J Geophys Res-Oceans*.

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

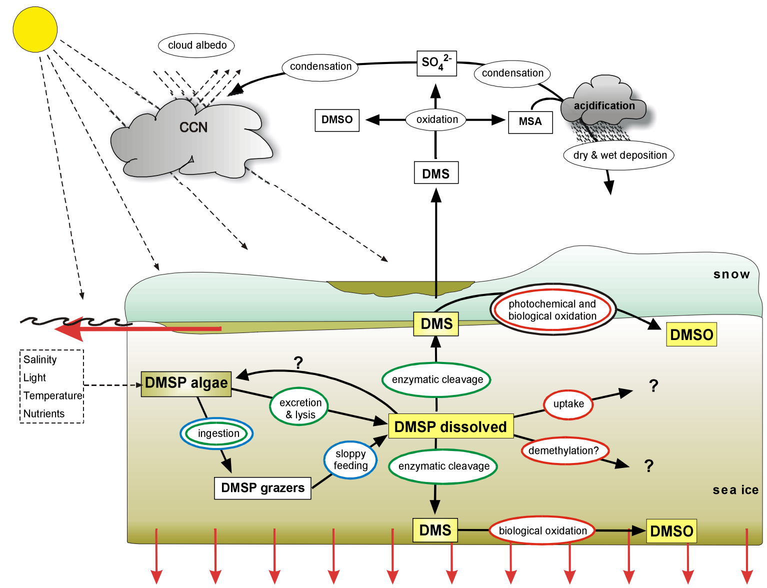
55-145 g C m^{-2} yr^{-1} observed Chukchi shelf 2002-2004 (Lee et al. 2007)

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



Jin, Deal, Lee, Elliott, Hunke, Maltrud, and 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.*

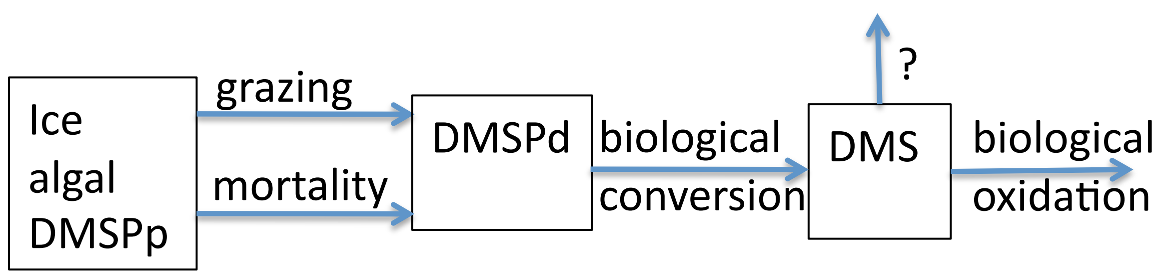
Sea ice DMS model



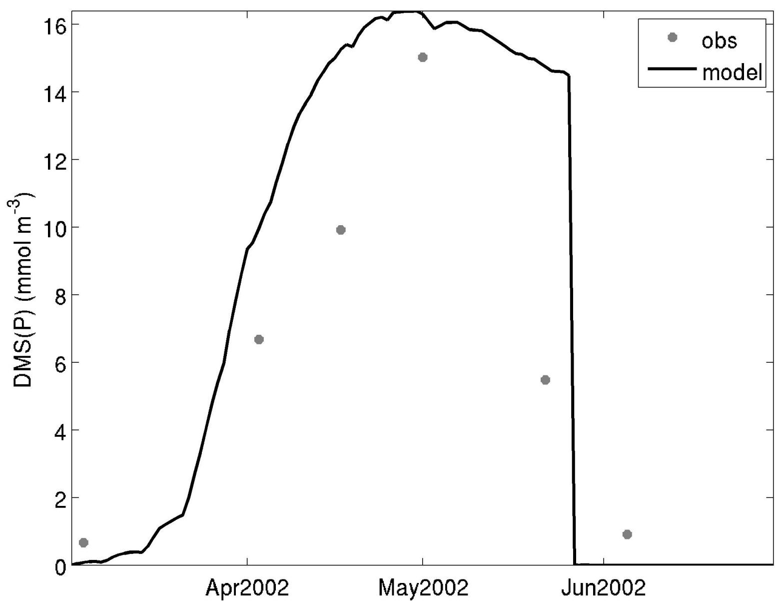
$$\frac{dAi}{dt} = Ai(G^{Ai} - f_g - Rg^{Ai})$$

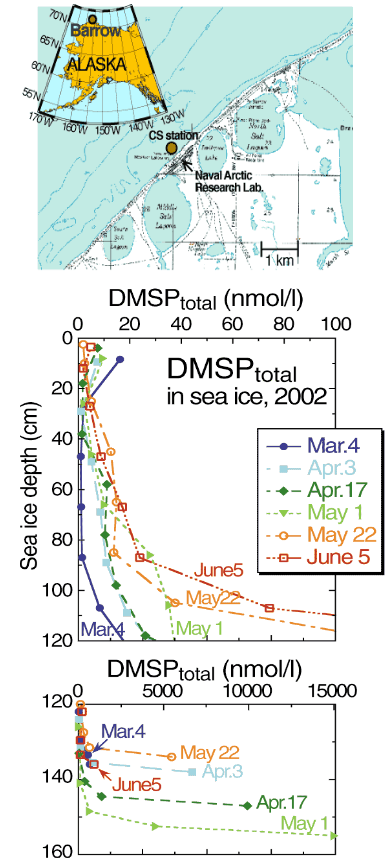
$$\frac{dDMSPd_{sk}}{dt} = -\frac{DMSPd_{sk}}{\tau_{skc}} + R^{Ai}_{S:N} \cdot Ai \left(\left[f_{gs} + f_{ex} f_e f_{ga} \right] f_g + R_g^{Ai} \right)$$

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



1-D ice DMS model results



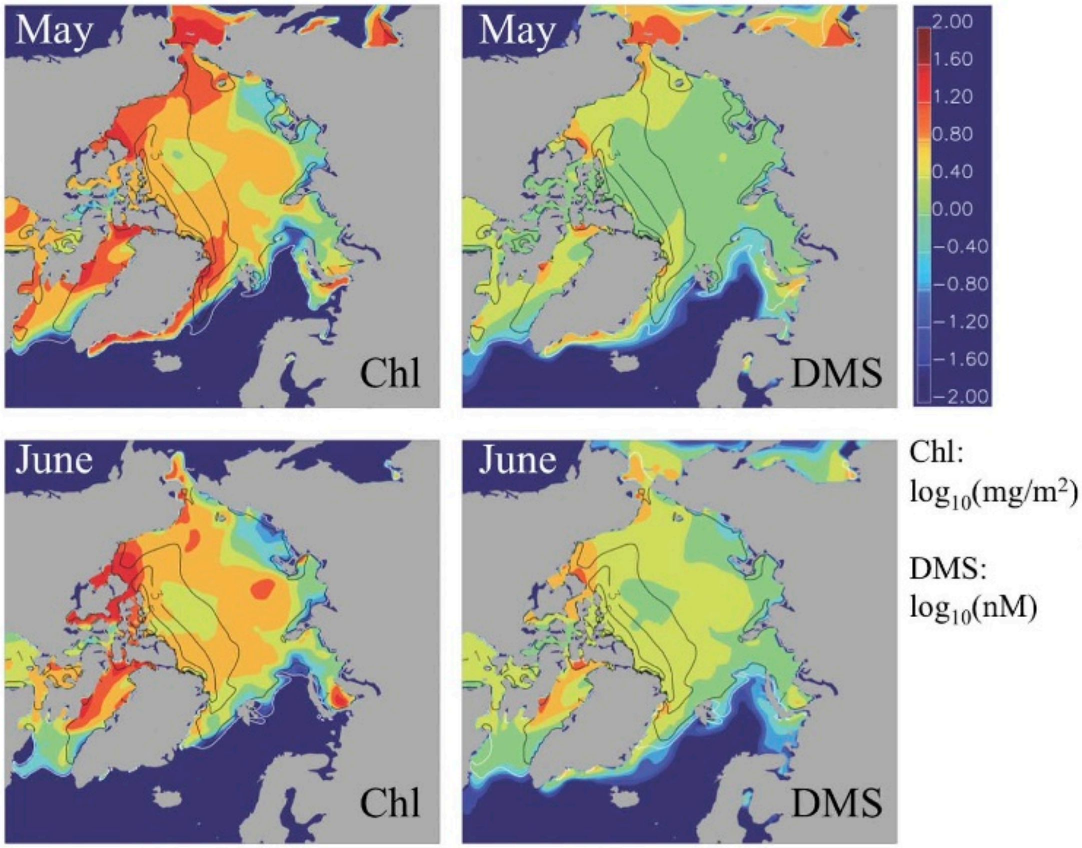


Ice algal S:N = 0.05

DMSPd to DMS yield = 0.5

DMS turnover time = 86400 s (1 day)

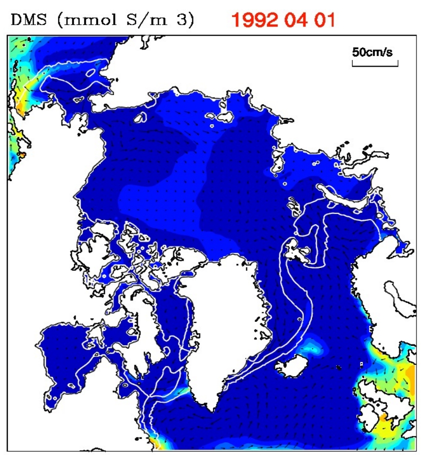
CICE DMS ecosystem model



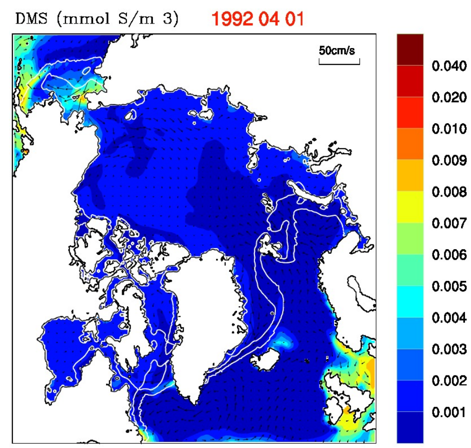
S. Elliott, C. J. Deal, G. Humphries, E. Hunke, M. Jin, J. Stefels, and M. Levasseur, *J. Geophys. Res.-Biogeosciences*, (in press).

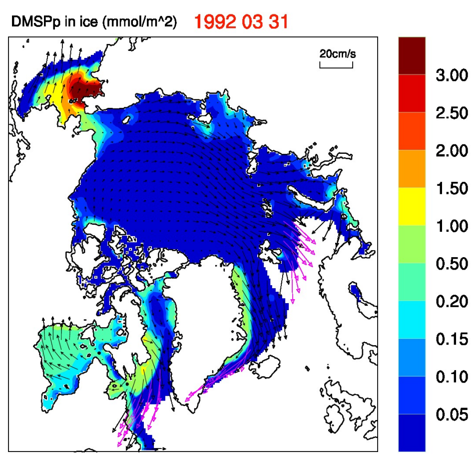
CICE-POP DMS ecosystem model

Without ice BGC

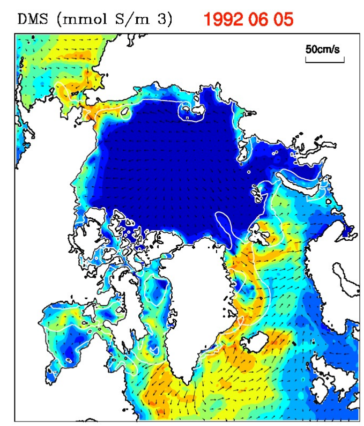


With ice BGC

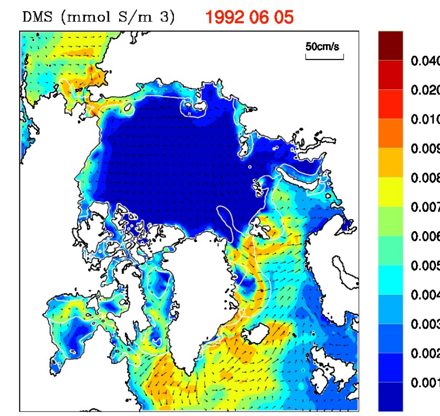


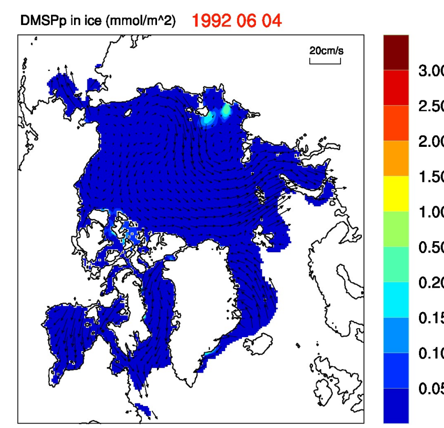


Without ice BGC



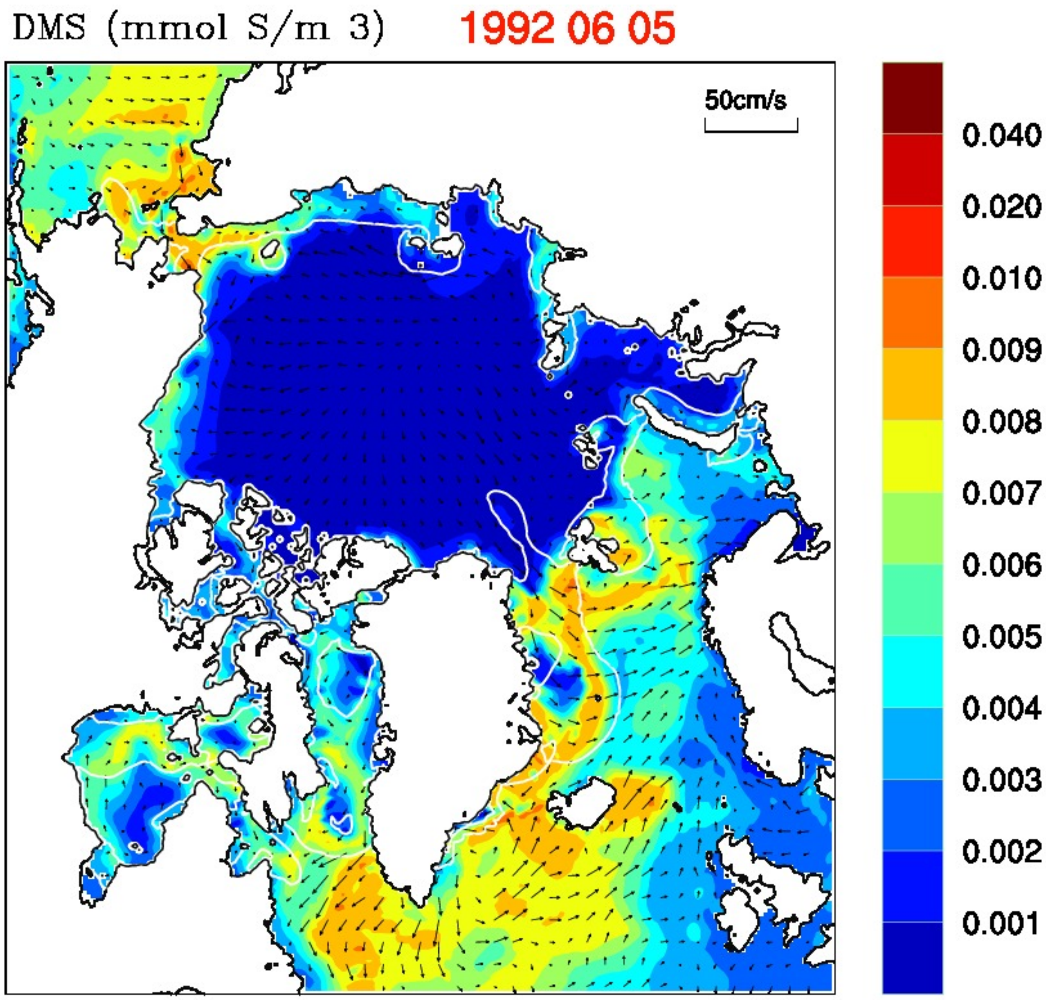
With ice BGC





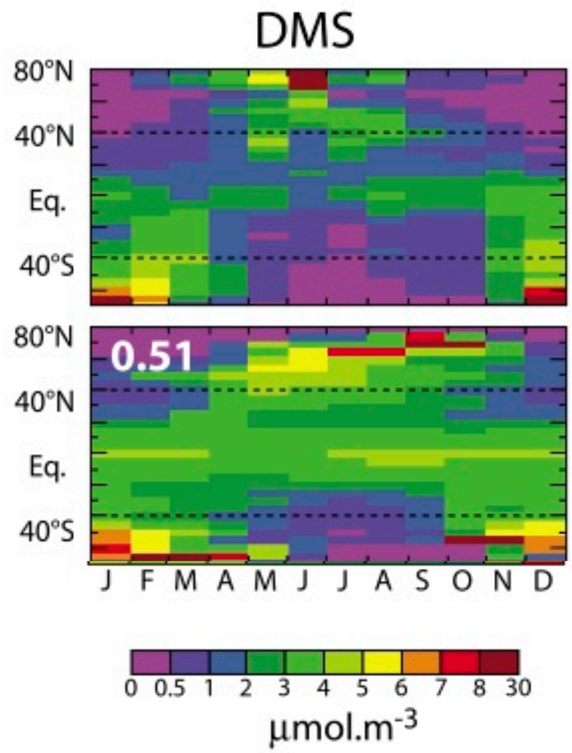
Simulated surface DMS concentrations, in general, agree with observations: ~1-3 nM under-ice, higher in MIZ, highest near ice edge.

CICE-POP DMS ecosystem



Simulations display seasonality of sea surface DMS.

LE CLAINCHE ET AL.: CODiM—COMPARISON OF OCEAN DMS MODELS

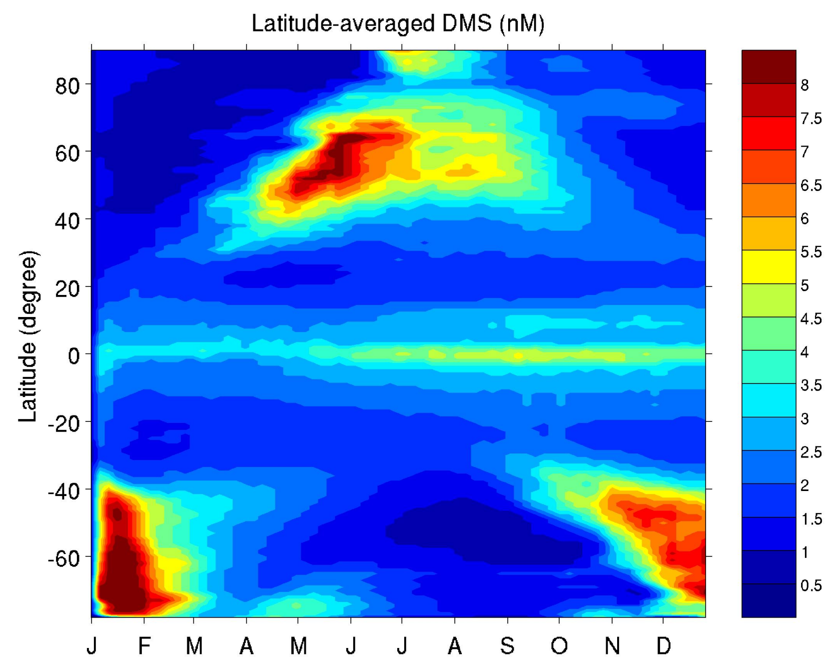


Kettle and Andreae (2000) DMS climatology

POP

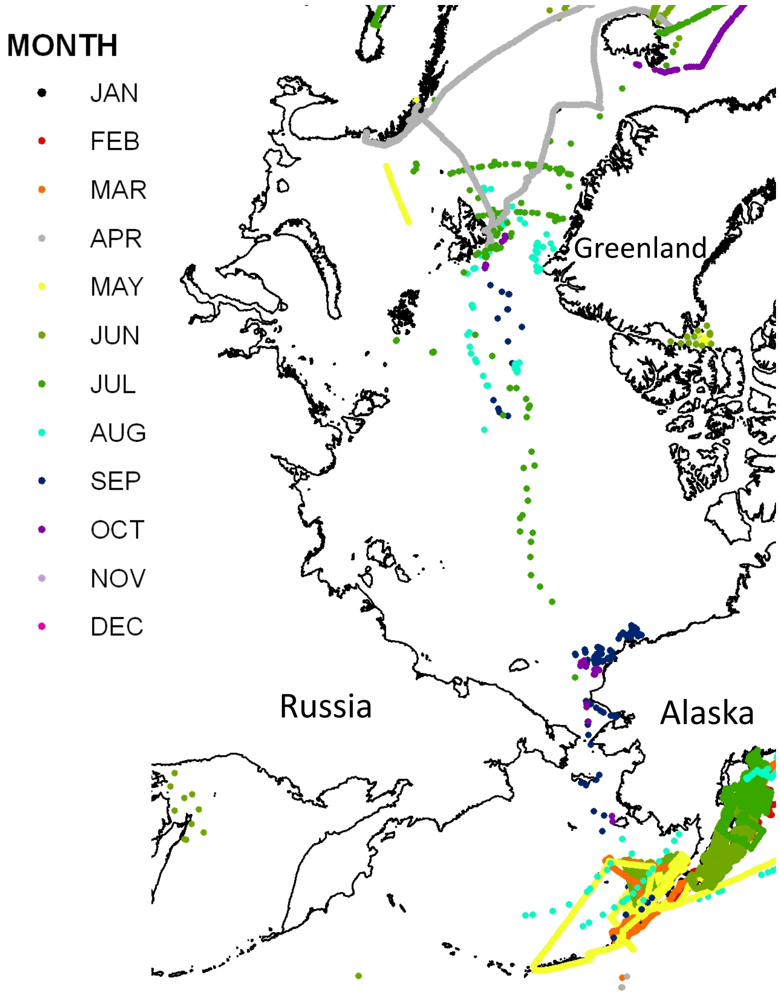
(Le Clainche, et al., Deal, Elliott, Jin, et al. *GBC*, 2010)

CICE-POP DMS ecosystem



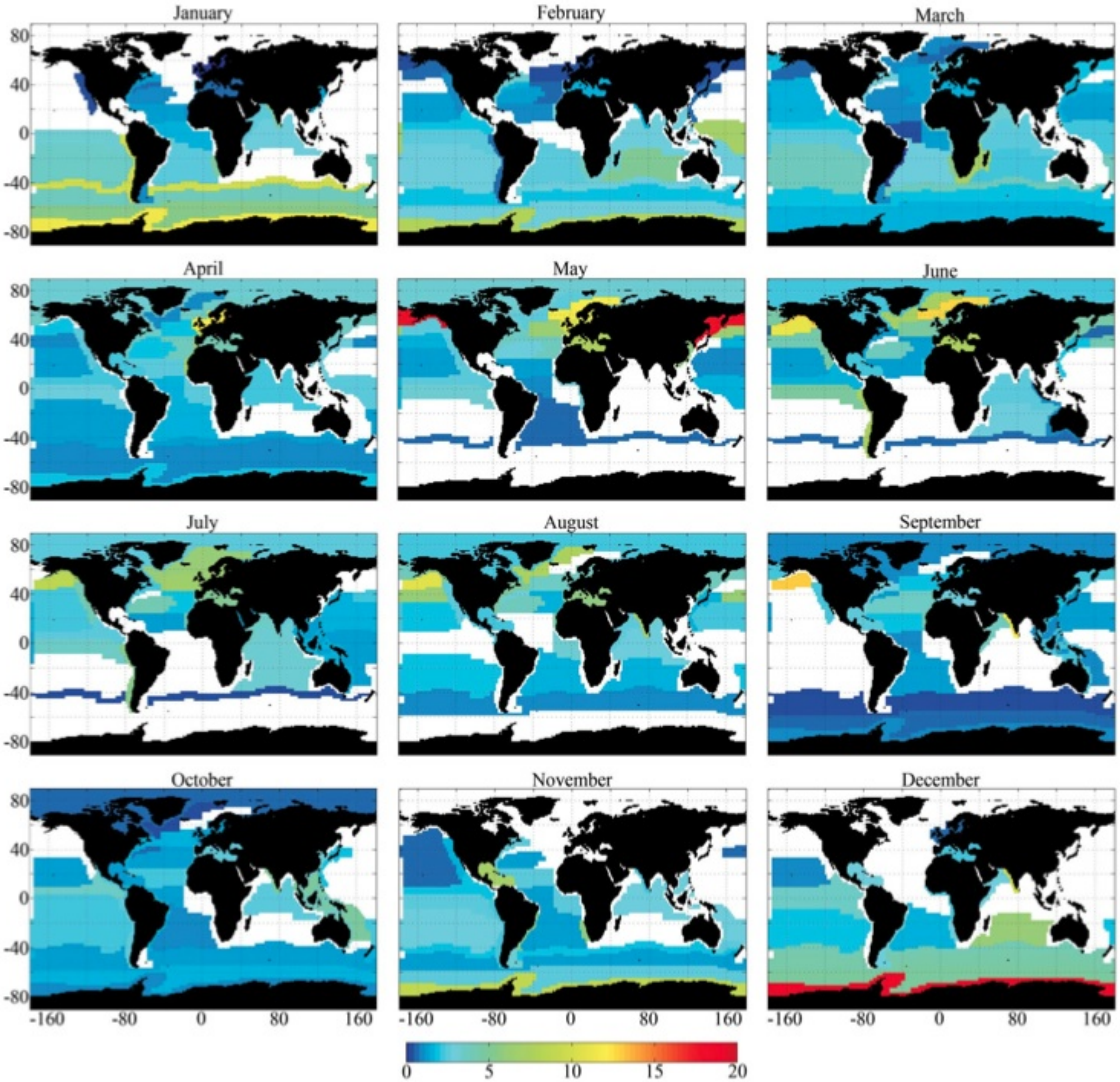
Distribution of seawater DMS concentration data from NOAA PMEL DMS database.

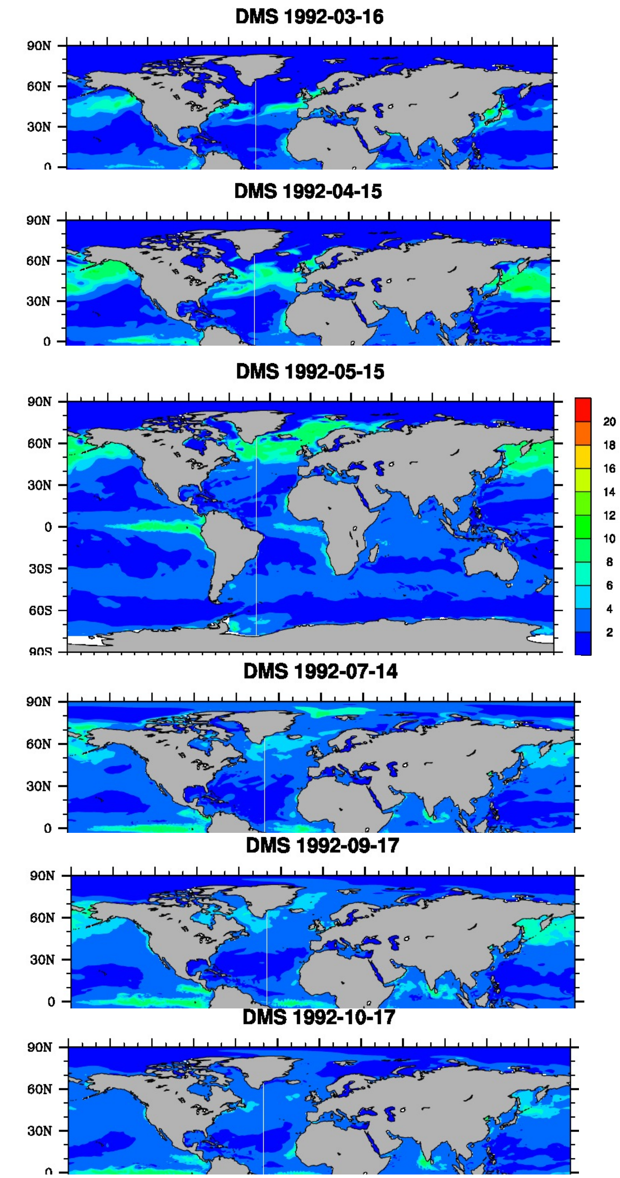
http://saga.pmel.noaa.gov/dms/



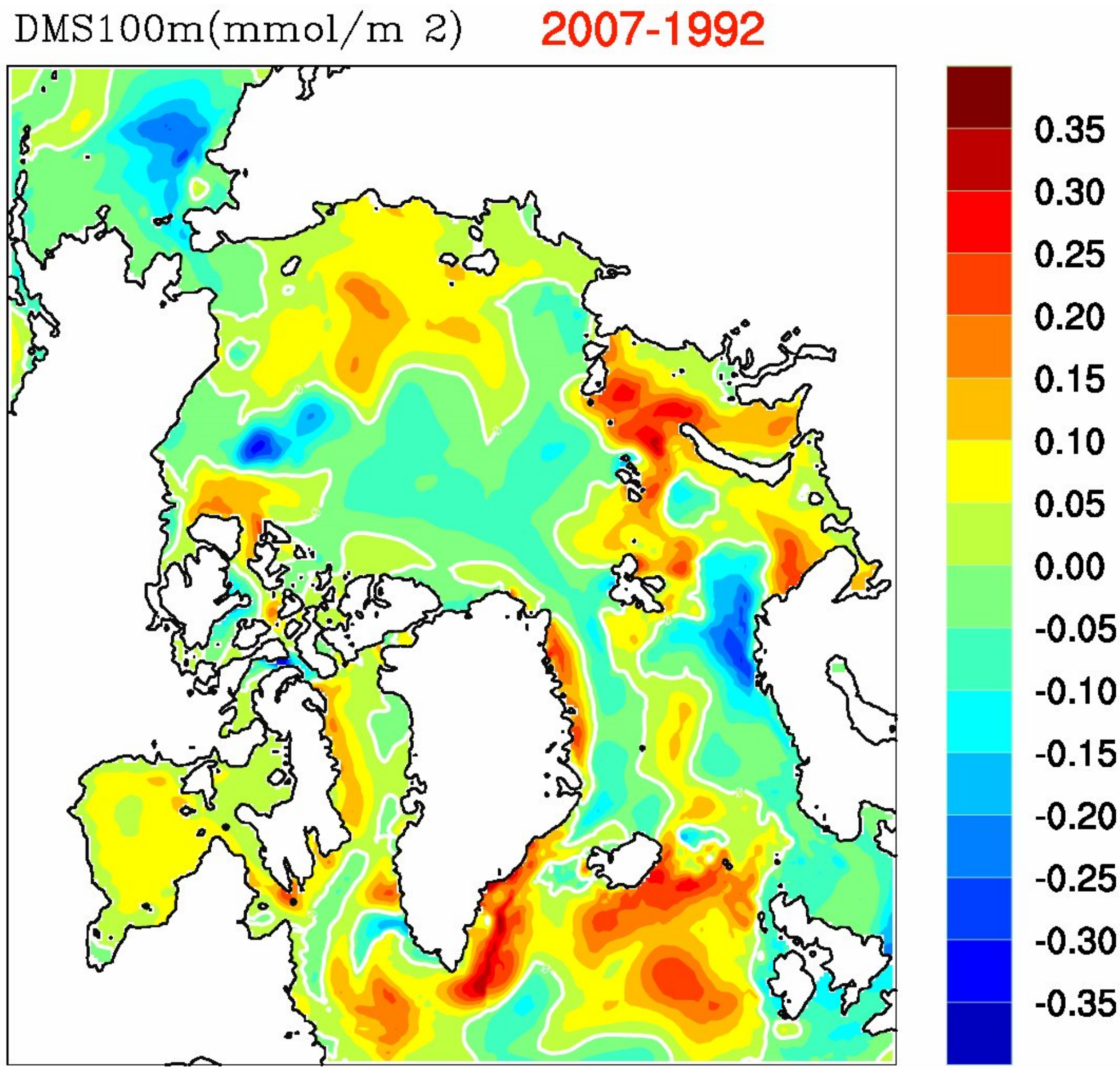
CICE-POP DMS ecosystem model (preliminary)

Updated DMS climatology (Lana et al. 2011)



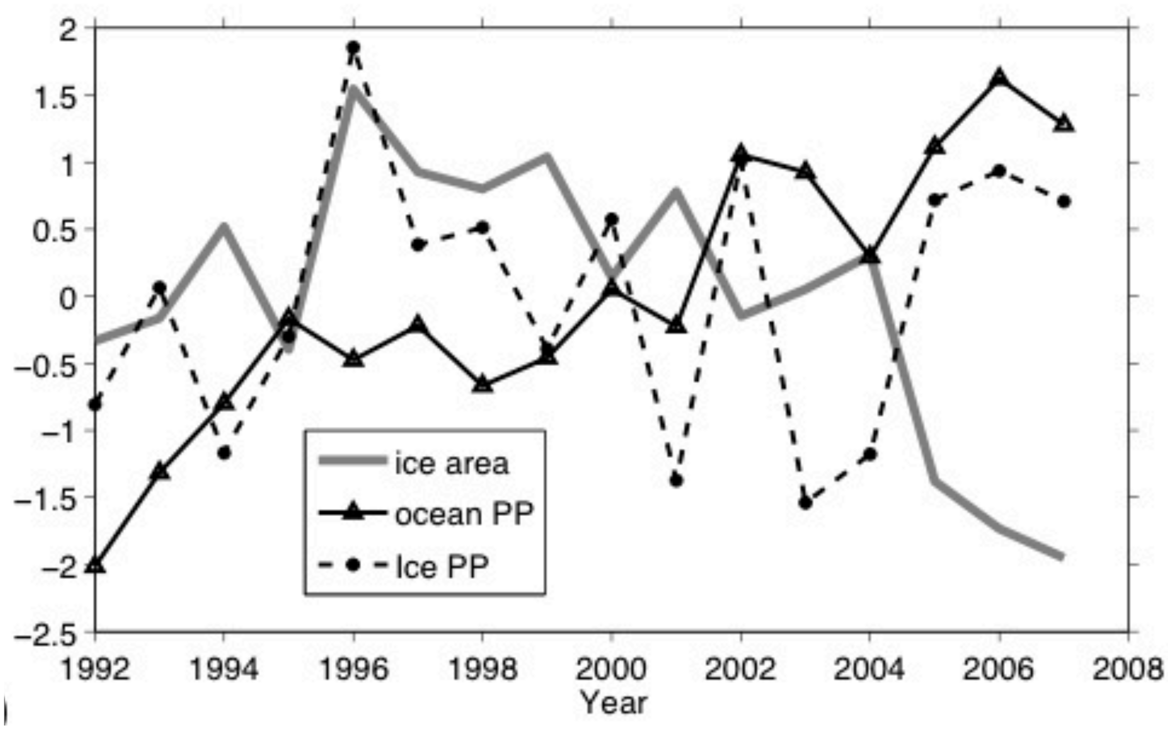


Preliminary model results indicate northward shift in seawater DMS concentrations due to recent sea ice decline.



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 results:



Jin et al. Deep Sea Res. II (2011)

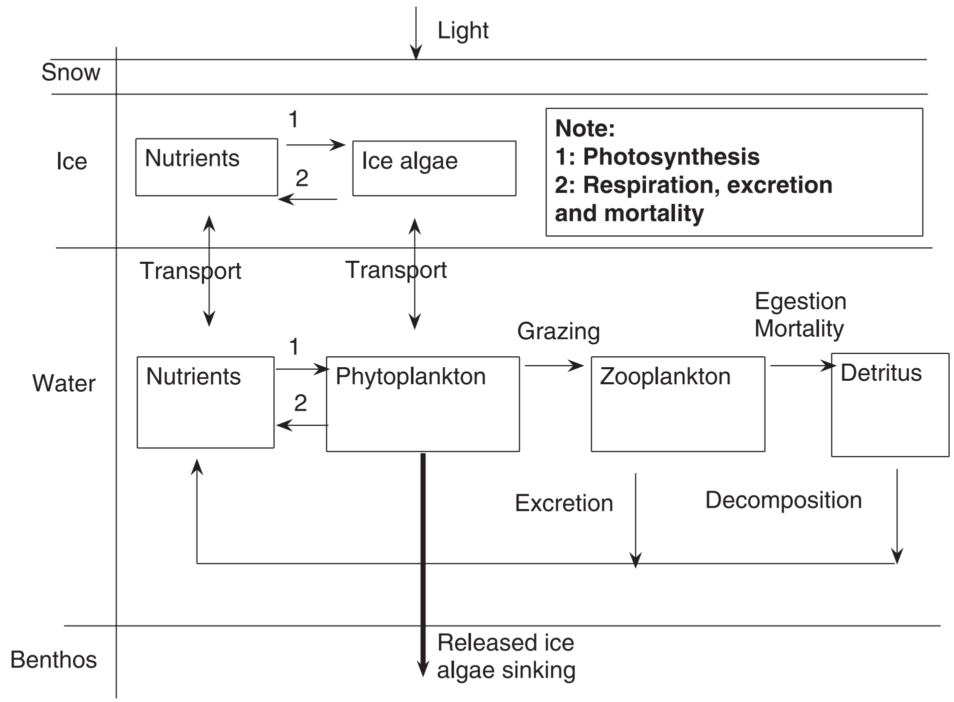
Summary

The model qualitatively captures the observed regional and seasonal trends in ice and ocean primary production, and surface seawater DMS concentrations.

Model results suggest melting of Arctic sea ice produces elevated seawater DMS due to release of sea ice DMS and DMSP.

Thank you for your time and attention!

Physical pelagic ecosystem model (PhEcoM) with ice ecosystem.



(Jin et al., Annals of Glaciol. 2006)

Nutrient flux between sea ice and the ocean is based on observations of Wakatsuchi and Ono (1983) that brine flux volume has a high correlation with ice growth rate.

When the ice bottom melts, nutrients and algae within ice are released to the ocean.

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)