A Coupled Arctic Ocean-Ice DMS Ecosystem Model

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Talk outline

Introduction
- Motivation
- Objectives
- DMS in Arctic Ocean and Sea Ice

Background on ice-ocean biogeochemistry-ecosystem modeling

DMS modeling
- 1-D vertical ice-ocean DMS model
- Pan-Arctic stand CICE DMS model
- CICE-POP DMS 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.

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.

Complex interactions between the marine food web and the physical environment determine amount of DMS emitted to the atmosphere.

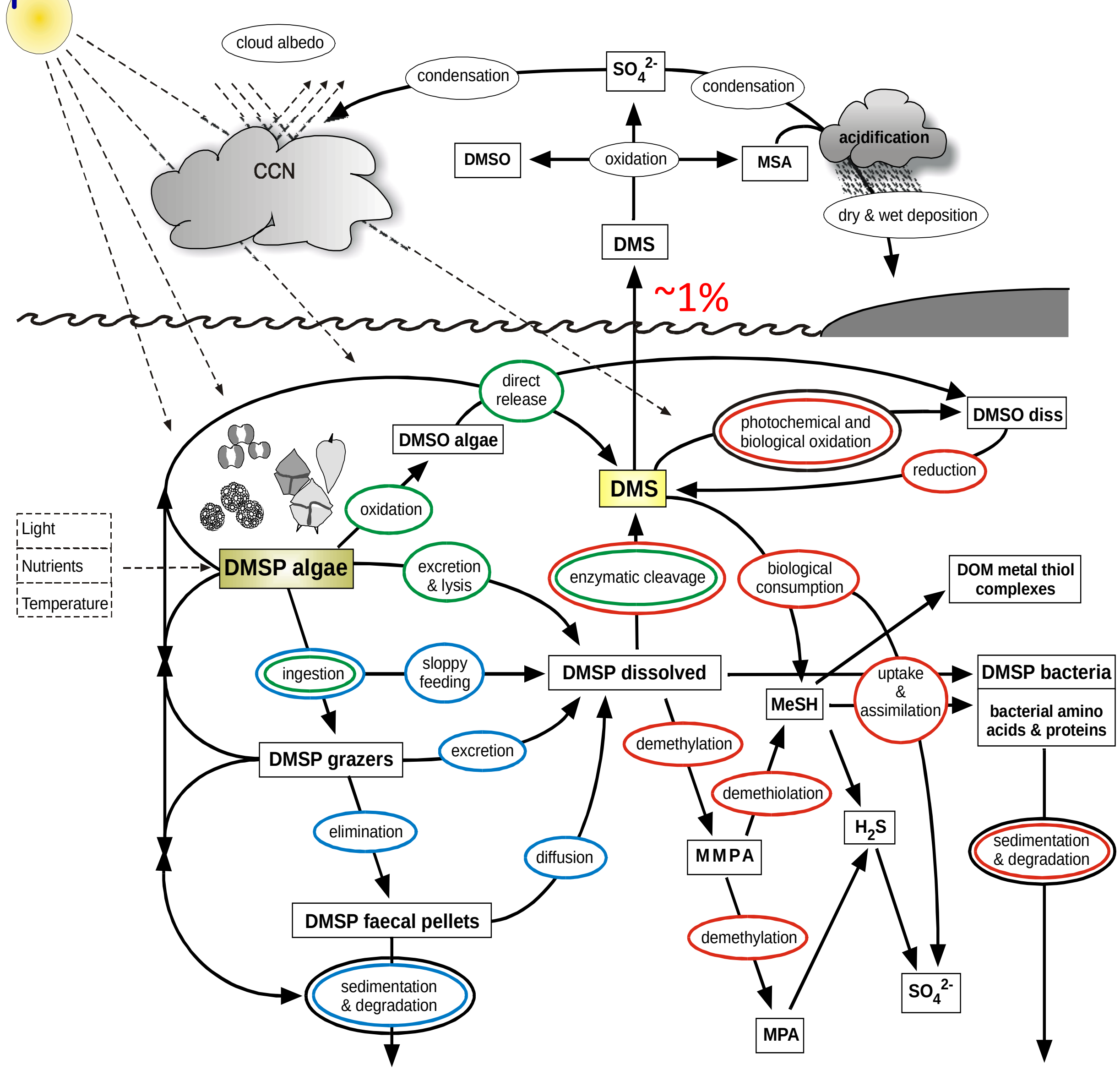
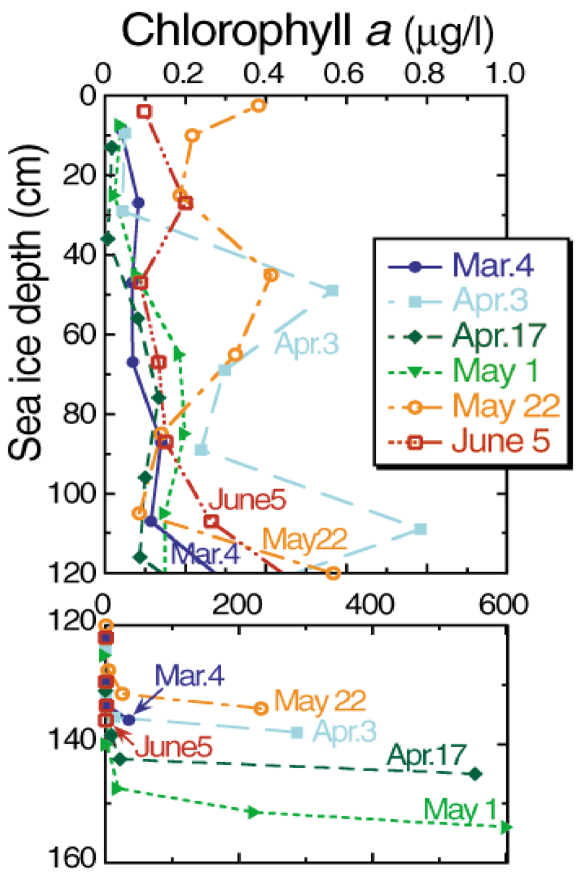
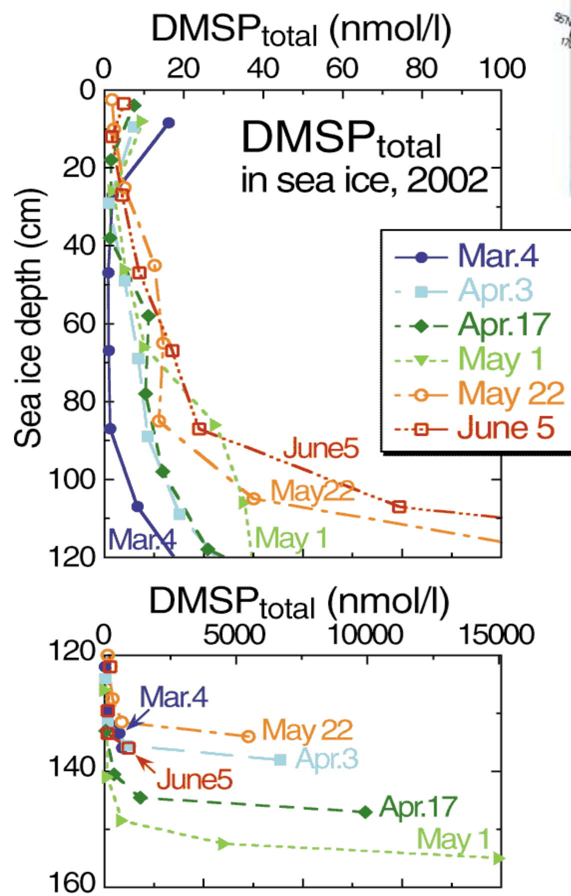


Figure courtesy J. Stefels.

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

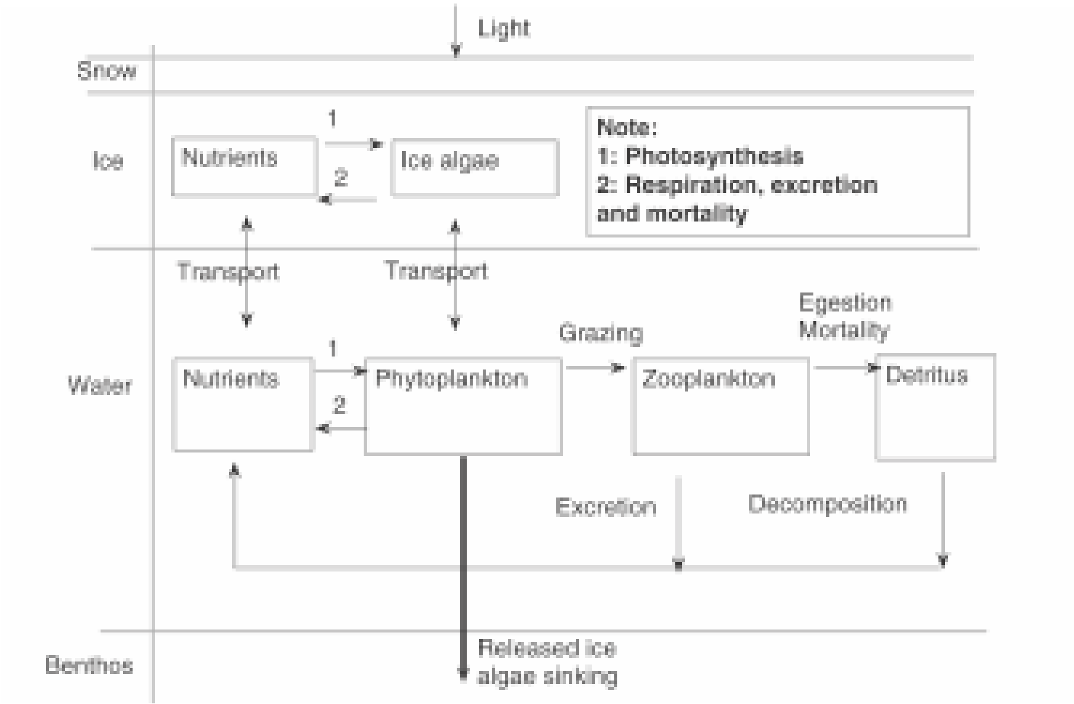


April through May, >90% ice algal biomass (chlorophyll a) observed in bottom of sea ice (3 cm layer) (Shin et al., 2003).



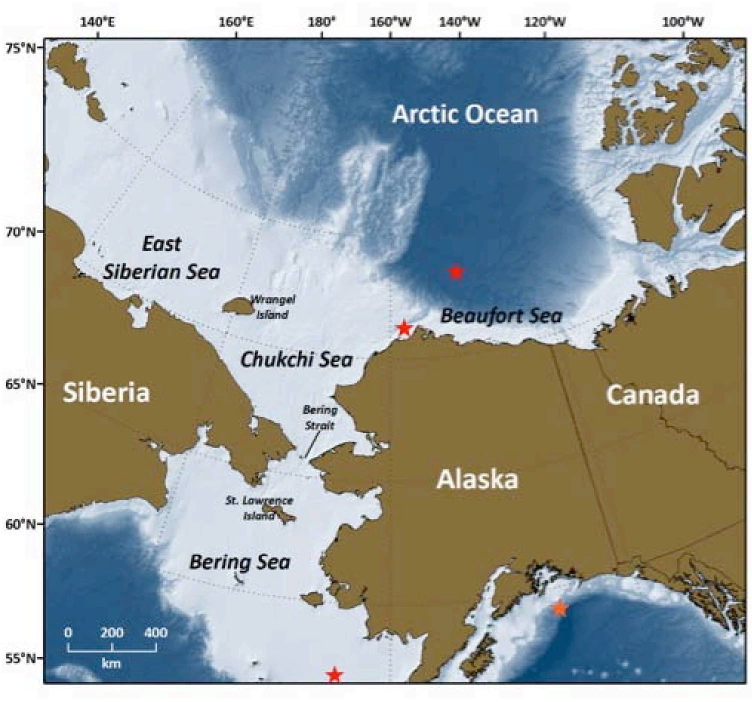
Very high levels of total DMSP up to 15 µM, were observed at Barrow, Alaska (Uzuka et al., 2003).

Ice-ocean biogeochemistry-ecosystem model.



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

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



Findings from 1-D vertical modeling studies:

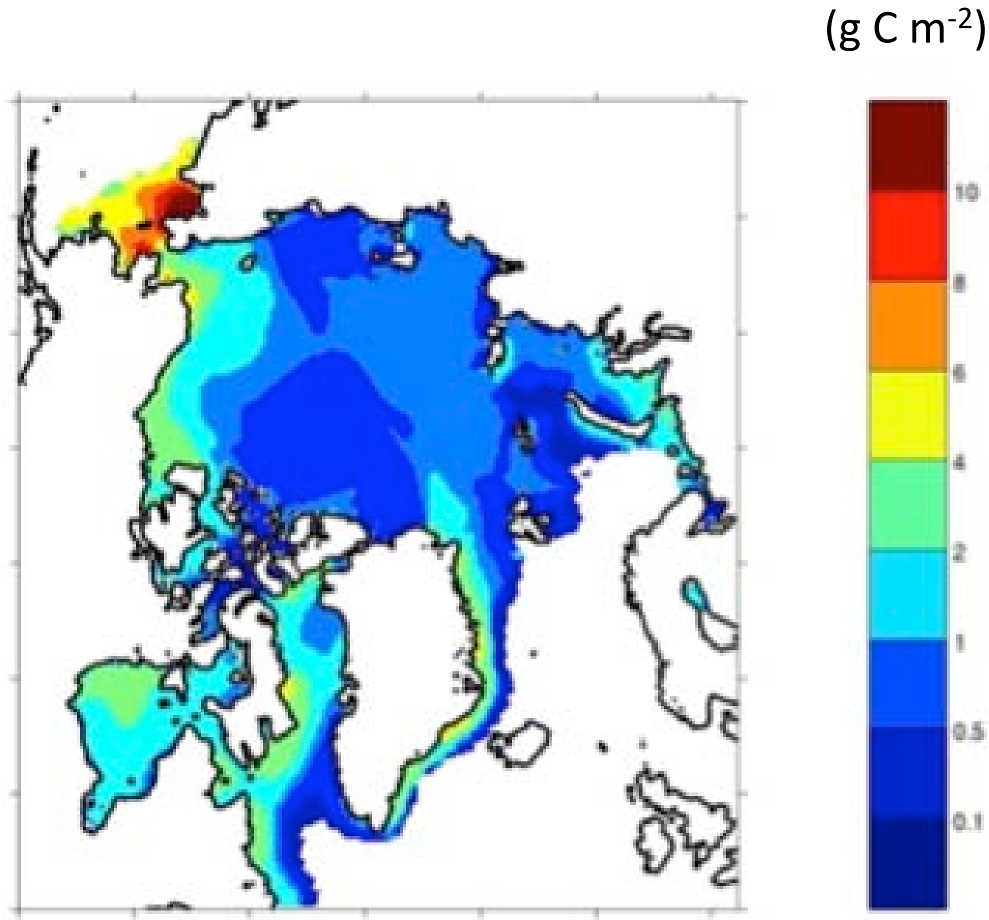
- light and nutrients major controls on ice algal production
(Lee et al. *Polar Biol*, 2010; Jin et al. *Annals Glaciol*, 2006)

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

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

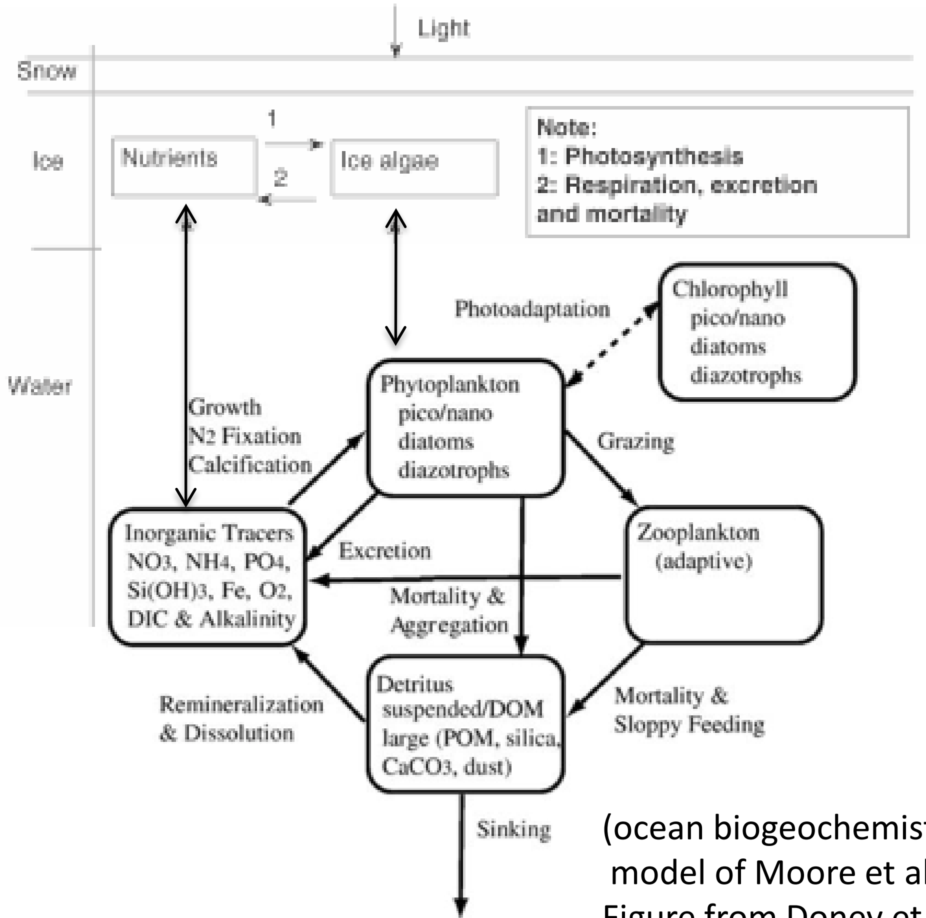
- role of vertical mixing in microalgal composition and DMS sea-to-air flux
(Jin et al. *JGR* 2006; Deal et al., *JGR* 2001)

Simulated annual primary production within arctic sea ice (for 1992) reproduces observed large-scale patterns and seasonality (not shown).



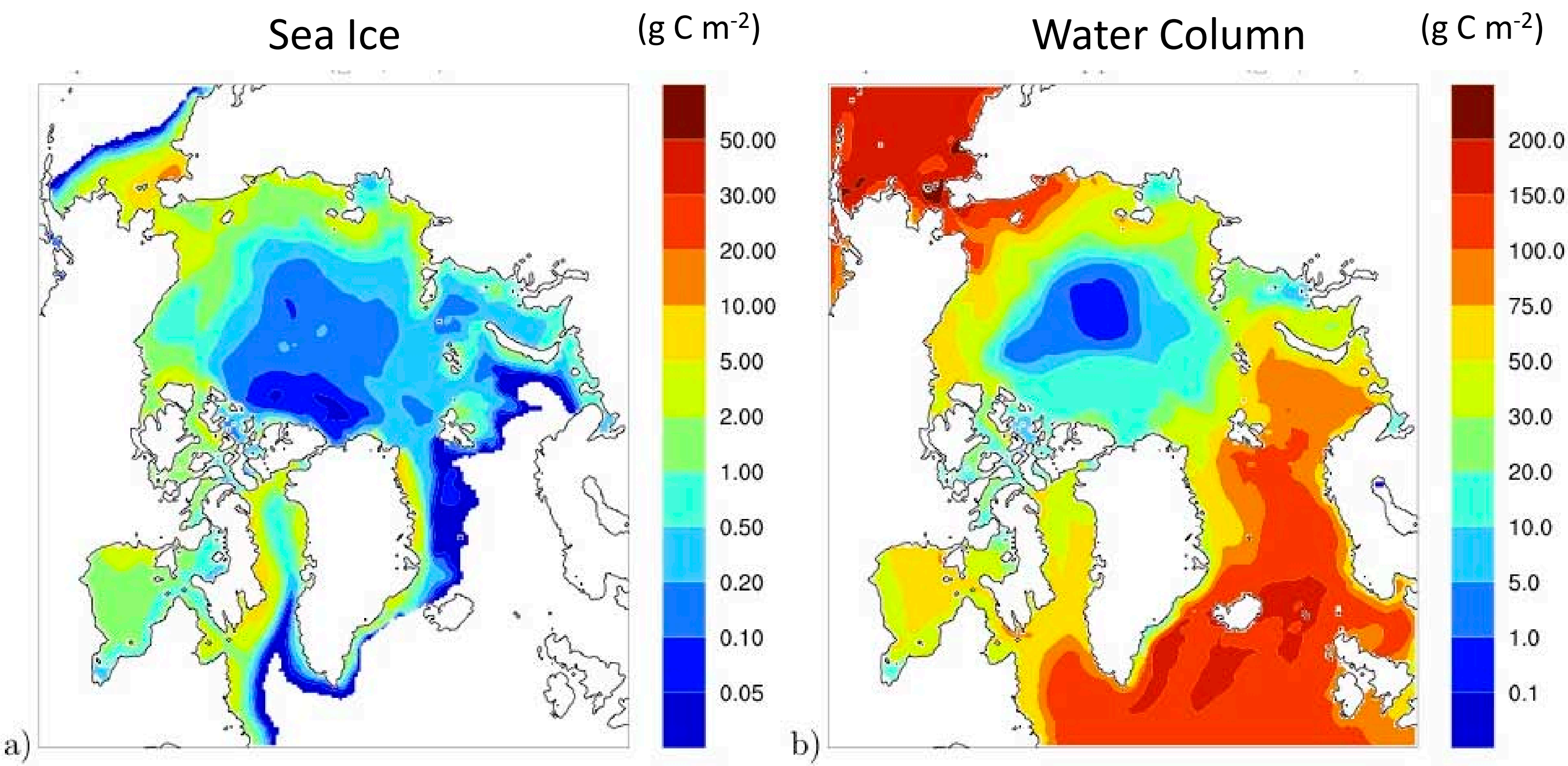
Deal **et al.** (2011) Large-scale modeling of primary production and ice algal biomass within arctic sea ice in 1992. *J Geophys Res-Oceans*.

Ice-ocean biogeochemistry-ecosystem model.



(ocean biogeochemistry-ecosystem model of Moore et al. 2004; Figure from Doney et al. 2009)

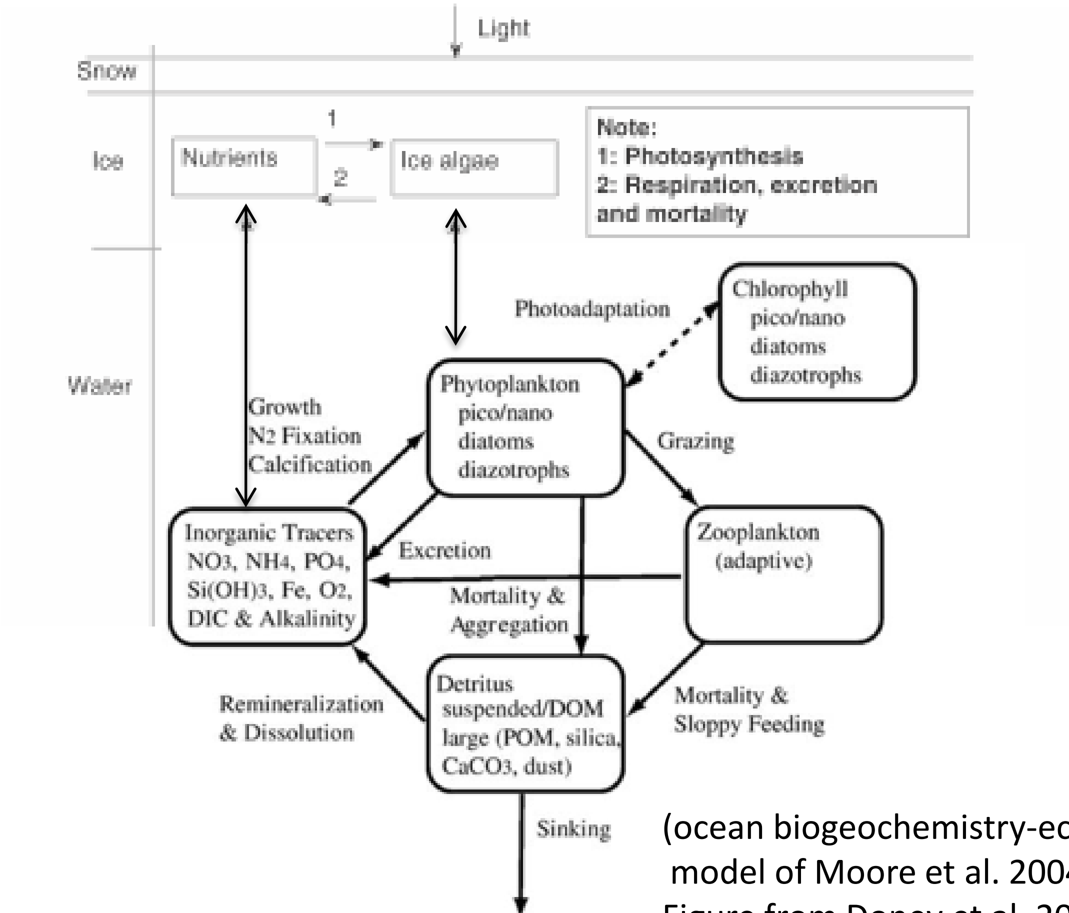
Modeled pan-Arctic annual primary production averaged over 1992-2007.



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

Jin, Deal, Lee, Elliott, Hunke, Maltrud, and Jeffery (2012) 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.*

Ice-ocean biogeochemistry-ecosystem model.



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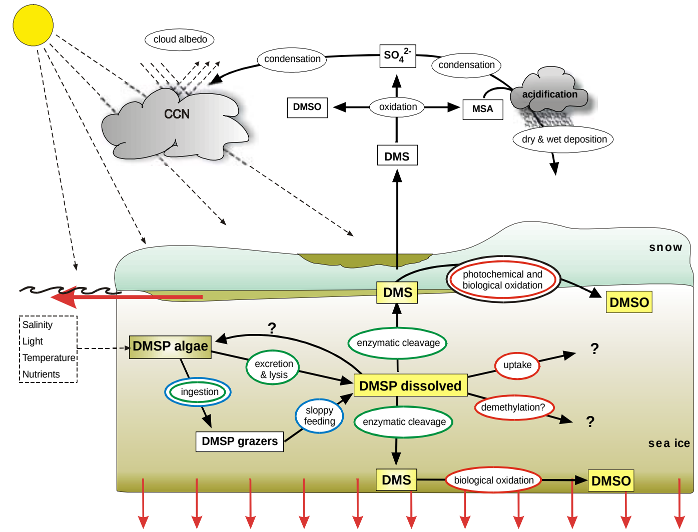
Sea ice DMS model

Sea ice DMS model



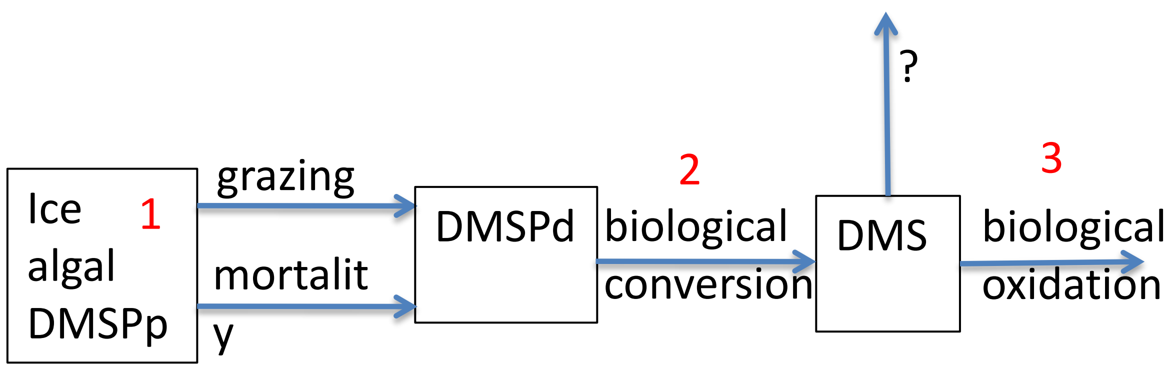
$$\frac{dAi}{dt} = Ai\left(G^{Ai} - f_g - Rg^{Ai}\right)$$

1

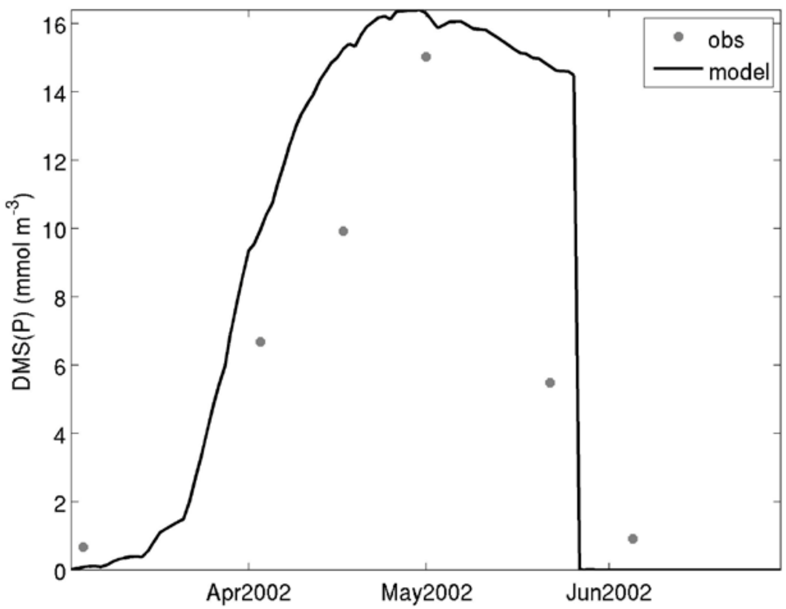
$$\frac{dDMSPd_{sk}}{dt} = -\frac{DMSPd_{sk}}{\tau_{skc}} + R^{Ai}_{S:N} \cdot Ai\left(\left[f_{gs} + f_{ex} f_e f_{ga}\right] f_g + R^{Ai}_g\right)$$

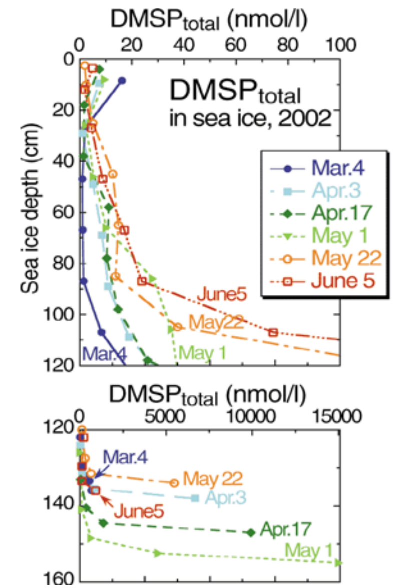
2, 3

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



Model parameter optimization using time-series station observations.



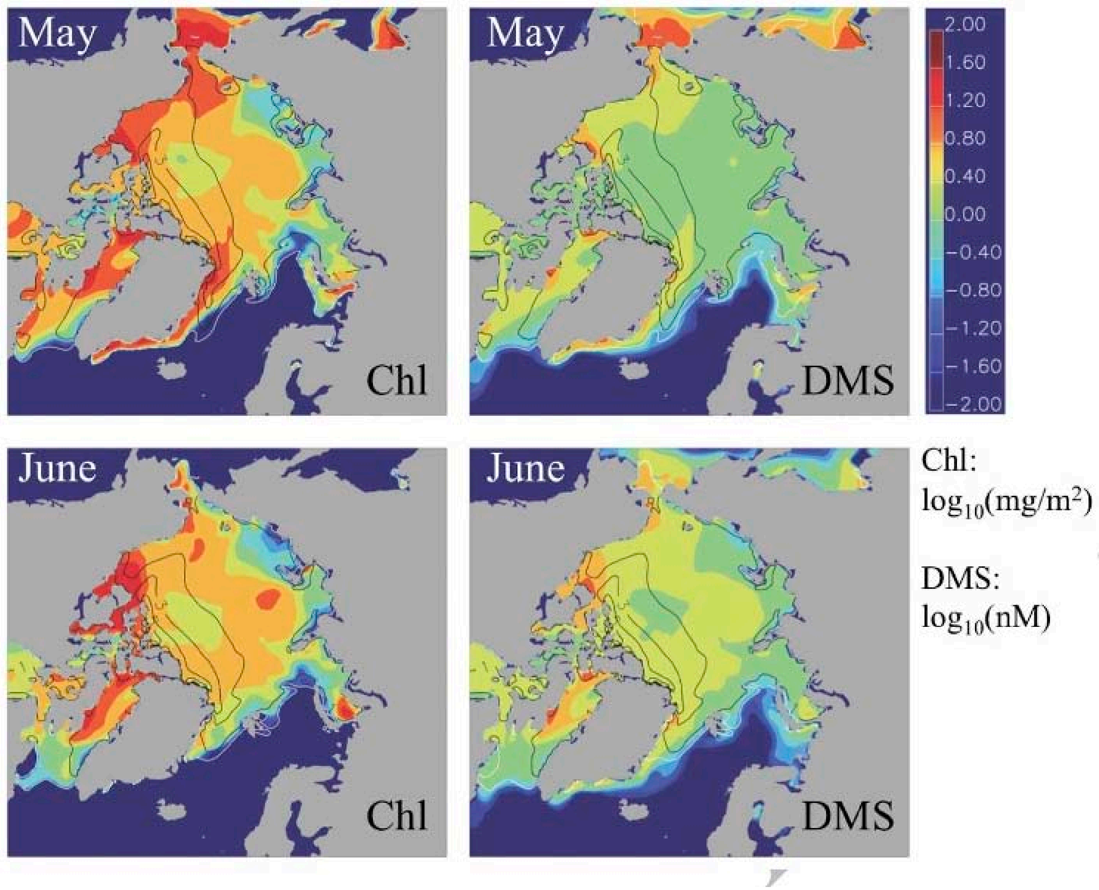


Ice algal S:N = 0.05

DMSPd to DMS yield = 0.5

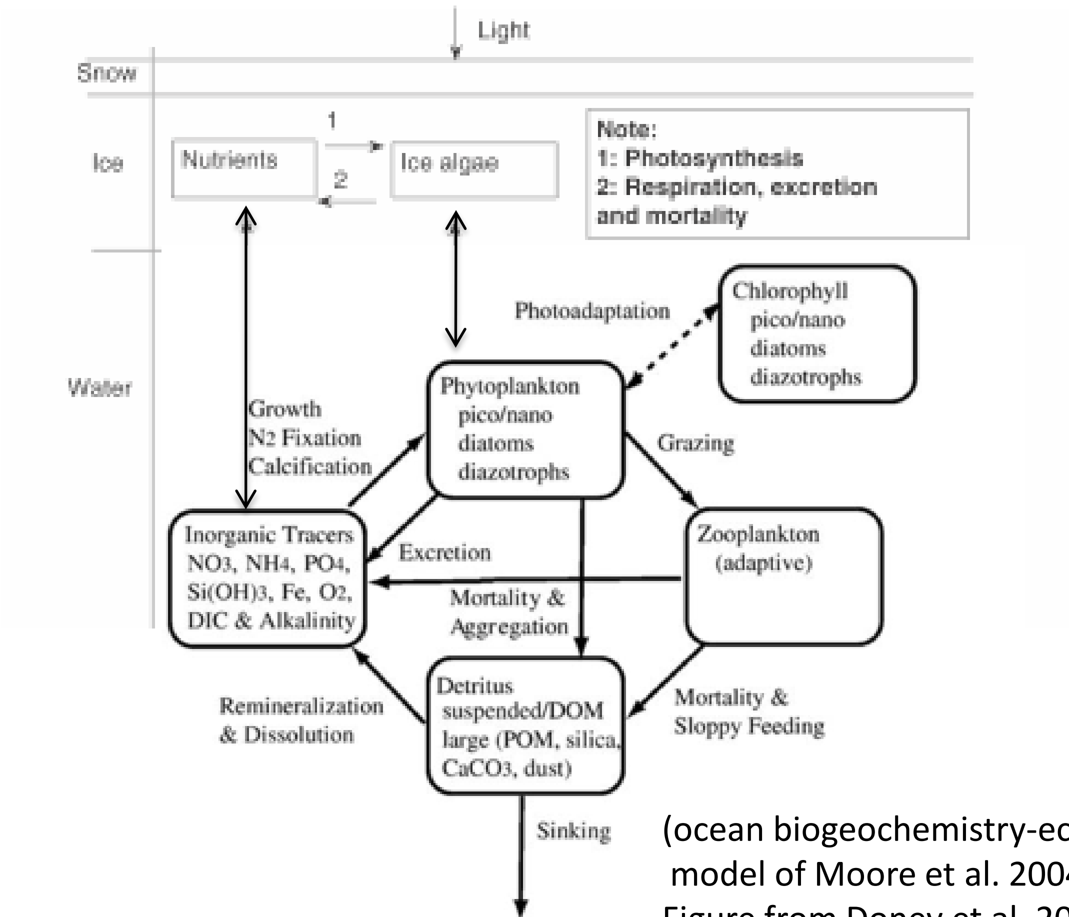
DMS turnover time = 86400 s (1 day)

Stand alone CICE DMS ecosystem model



Elliott et al. (2012) Pan-Arctic simulation of coupled nutrient-sulfur cycling due to sea ice biology: Preliminary Results, *J. Geophys. Res.-Biogeosciences*.

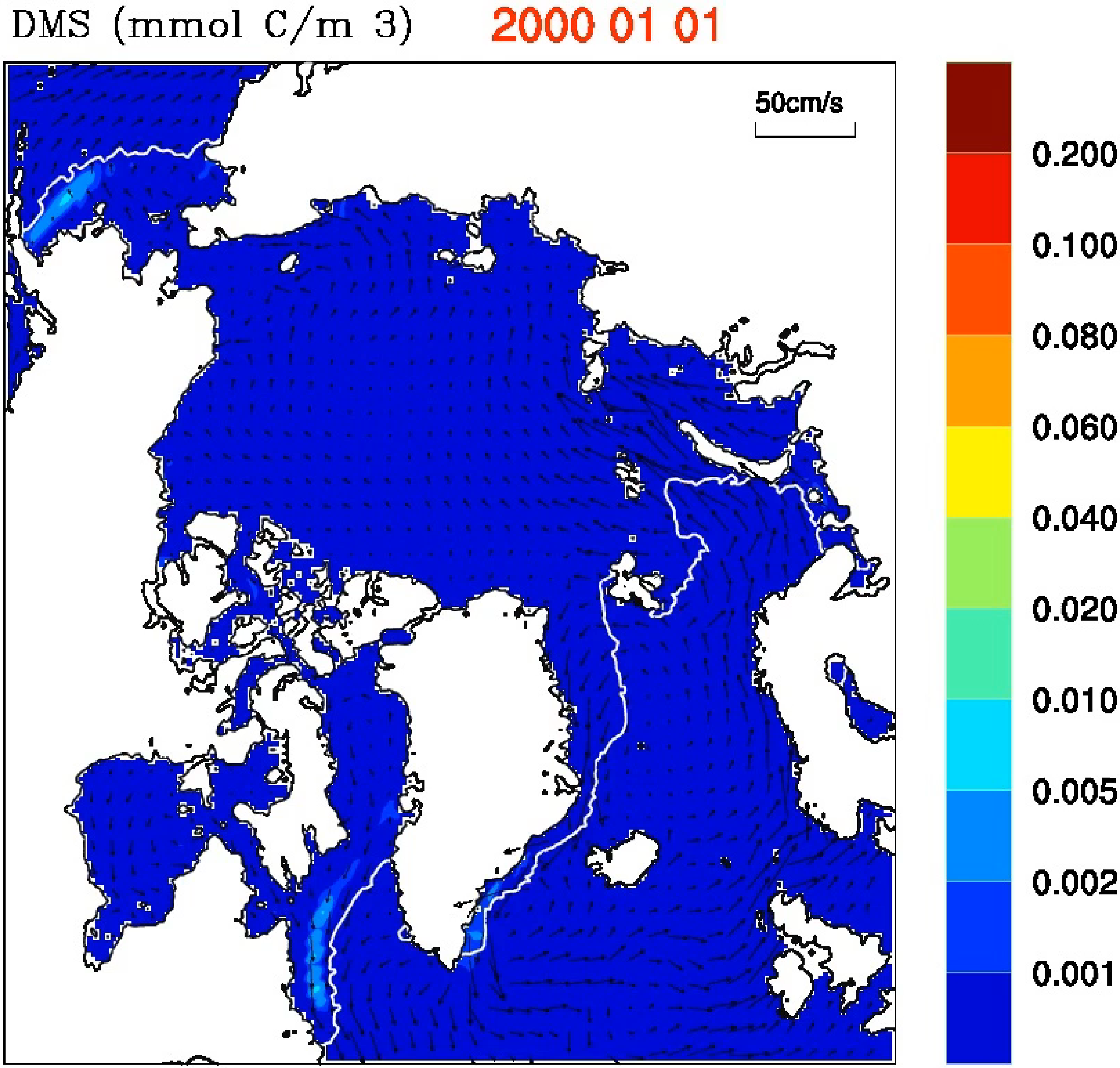
Ice-ocean biogeochemistry-ecosystem model.



(ocean biogeochemistry-ecosystem model of Moore et al. 2004; Figure from Doney et al. 2009)

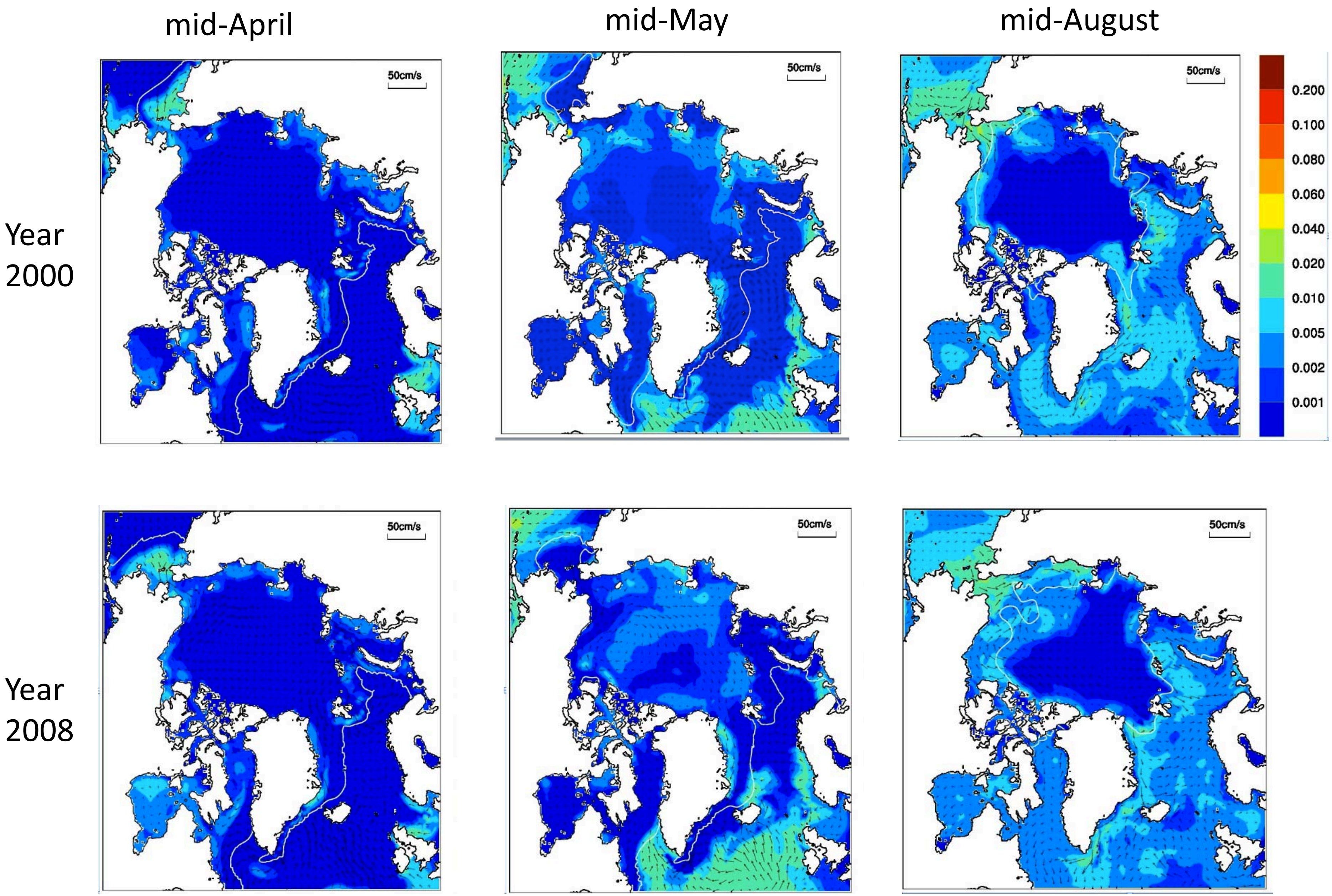
→ Sea ice DMS model

→ Ocean DMS model (Elliott et al., 2009)



DMS (mmol C/m 3)
2000 01 01
50cm/s
0.200
0.100
0.080
0.060
0.040
0.020
0.010
0.005
0.002
0.001

Surface seawater DMS (μM) results from ice-ocean DMS ecosystem model:

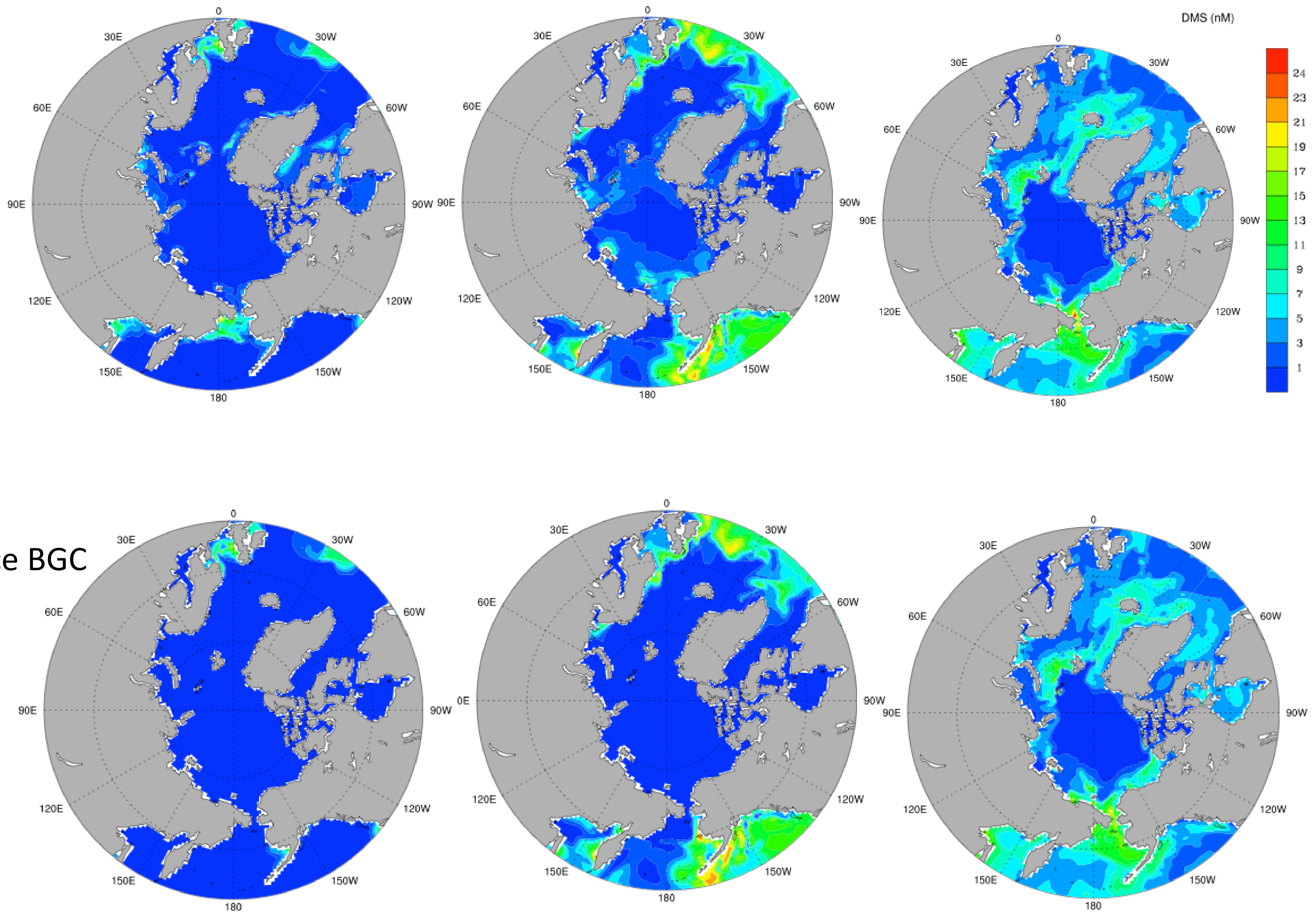


Surface seawater DMS (nM) results from ice-ocean DMS ecosystem model:

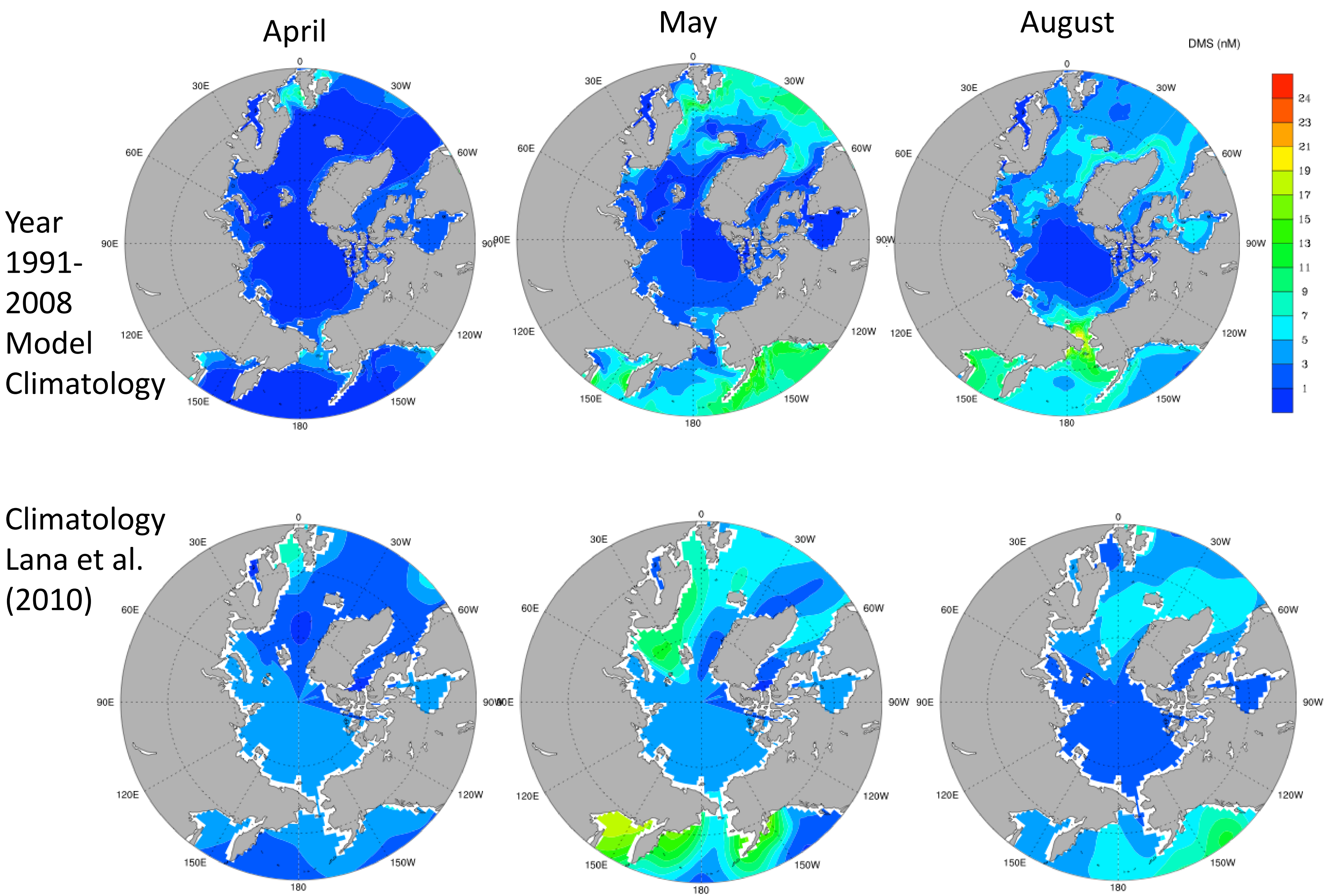
mid-April | mid-May | mid-August

Year 2000

Year 2000 No Ice BGC

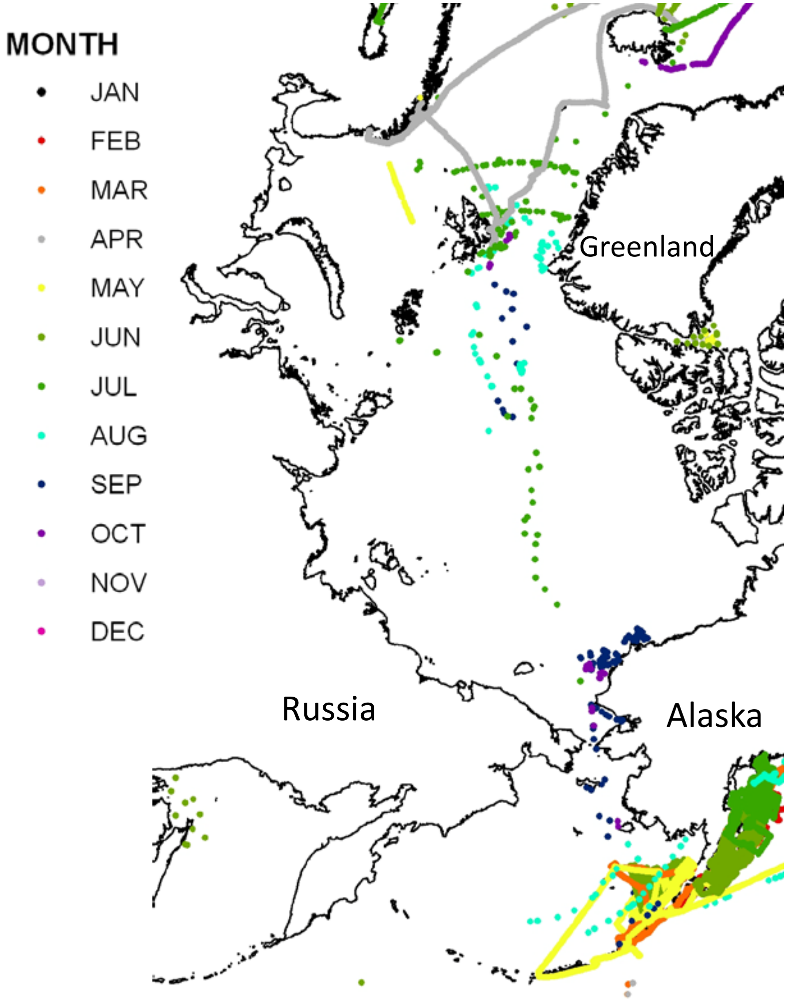


Surface seawater DMS (nM) climatologies from model and based on observations:

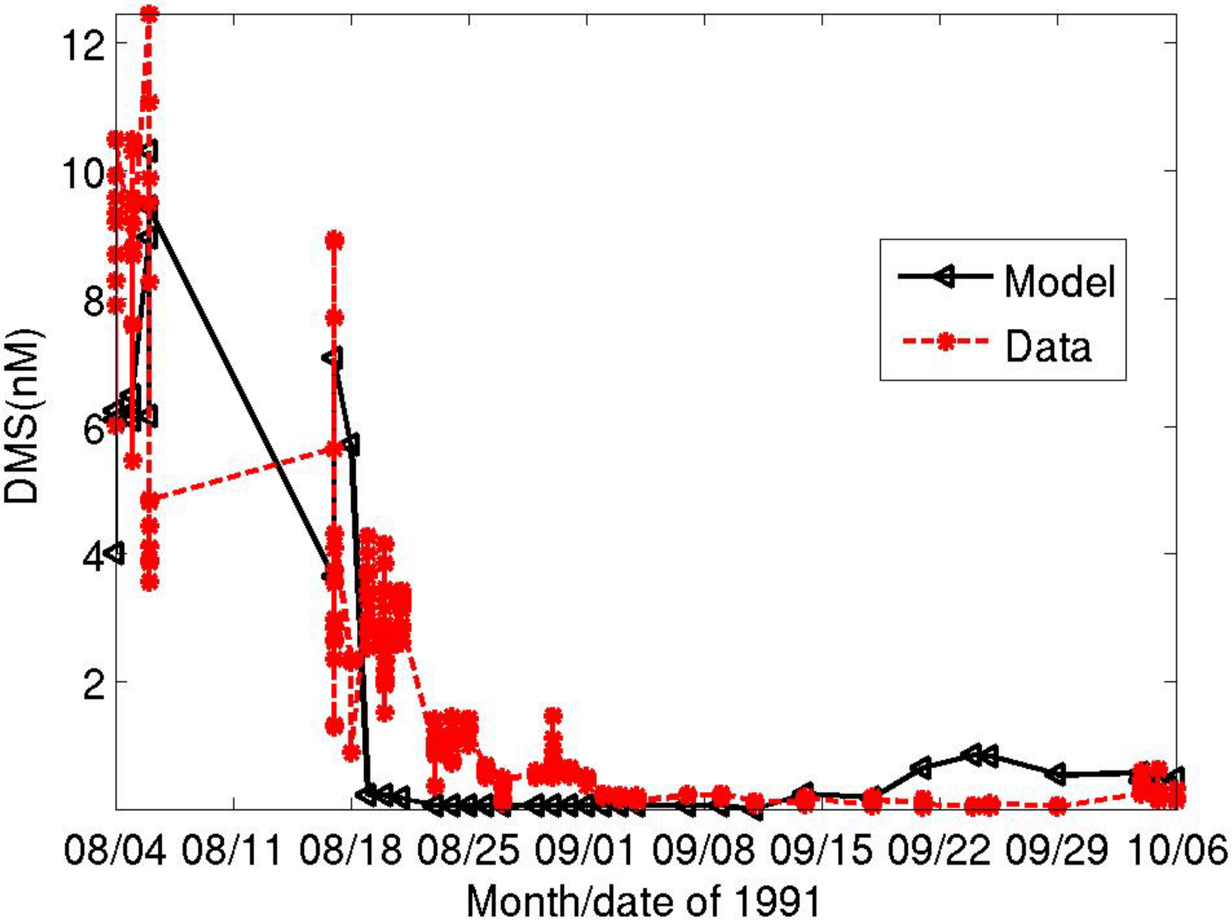


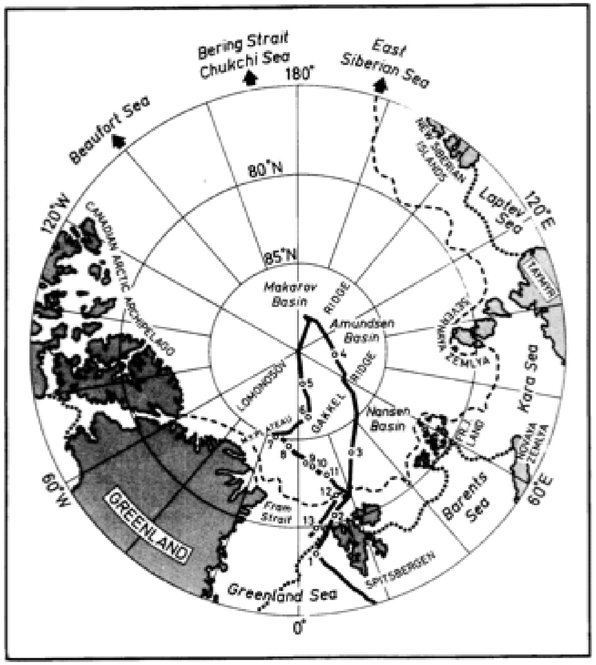
Distribution of seawater DMS concentration data from NOAA PMEL DMS database.

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



Surface seawater DMS (nM) results from ice-ocean DMS model vs. observations of Leck & Persson (1996):





Map of study area (from Leck & Persson 1996)

Take Home Messages

- Coupled Arctic ice-ocean biogeochemistry ecosystem model:

  CICE-POP DMS ecosystem model with Arctic focus

- Model results suggest ice algae significant source of seawater DMS in April and May

- Work in progress – preliminary, model validation and metrics

Year
2000
mid-April