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

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Talk Outline

Introduction

Motivation

Objectives

How important?

Why Arctic?

Observations

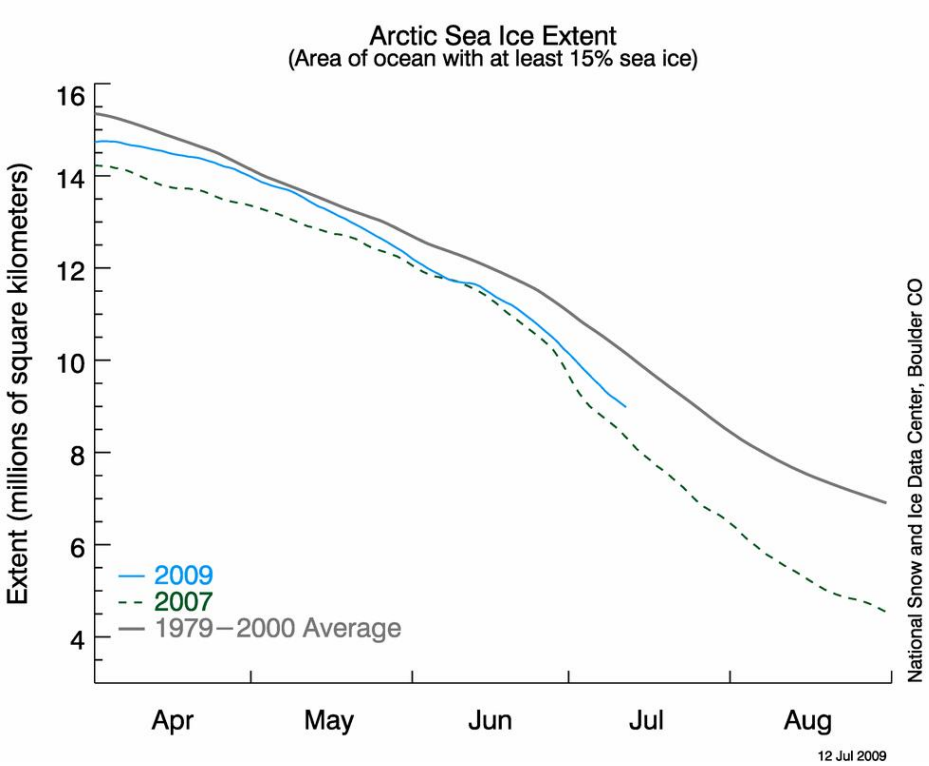
Approach & Models

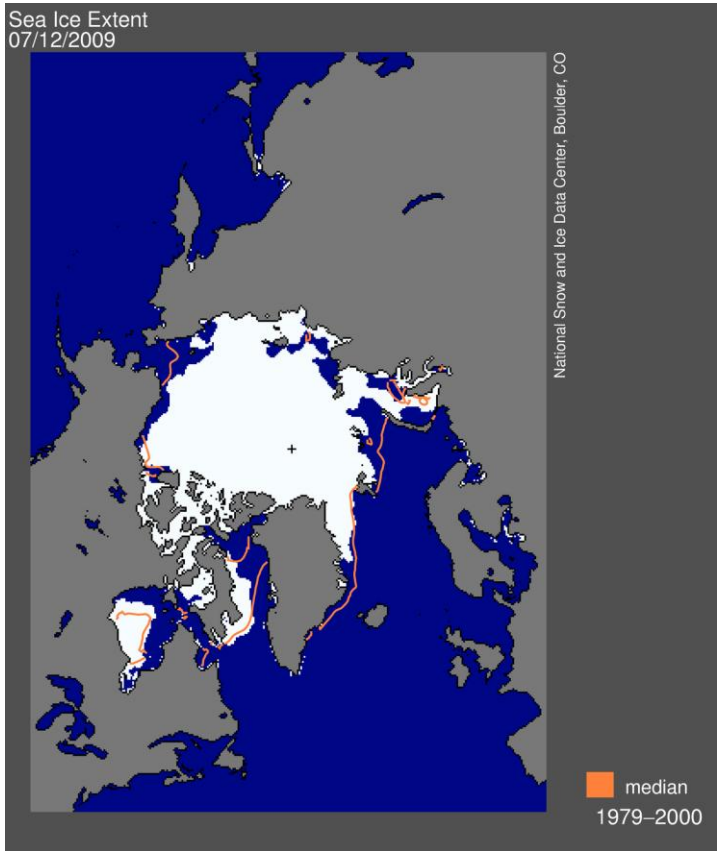
Recent progress

Future work

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

Arctic sea ice has declined dramatically over at least the past thirty years with the most extreme decline see in the summer melt season.





Graph compares 5-day running mean for Arctic sea ice extent.
http://nsidc.org/sotc/sea_ice.html

Ice-covered water of the Arctic Ocean with its marginal ice zone extending toward permanently open water (purple).

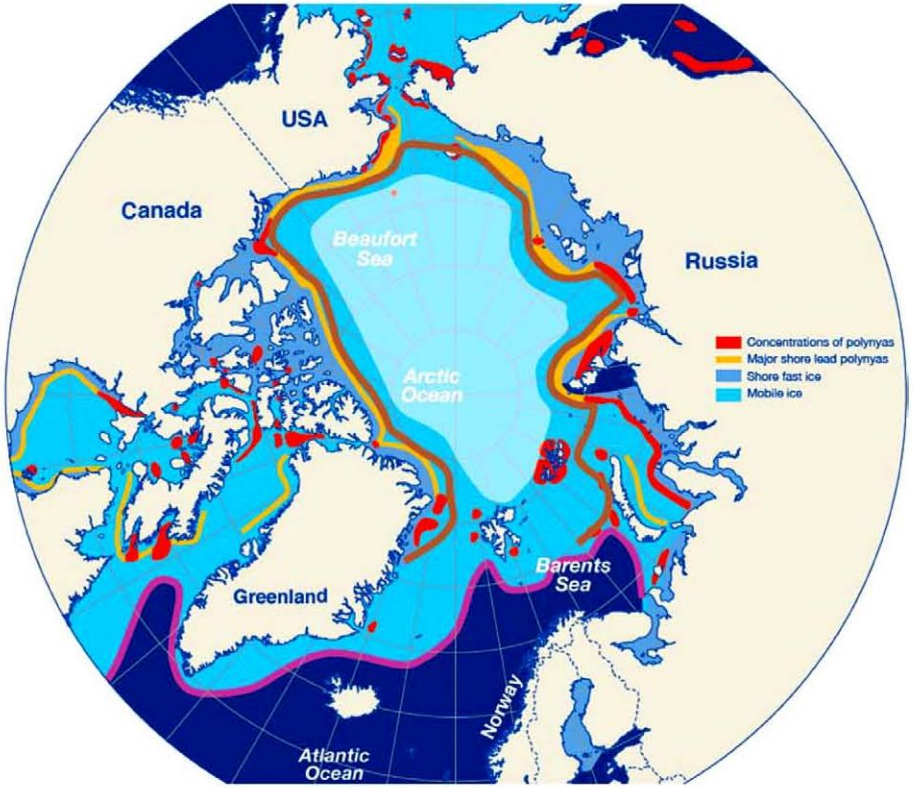


Figure from Carmack and Wassman, 2006.

Arctic seas hold a multitude of unique life forms. Major nutrient elements cycle through the ice, water column, and benthic ecosystems.

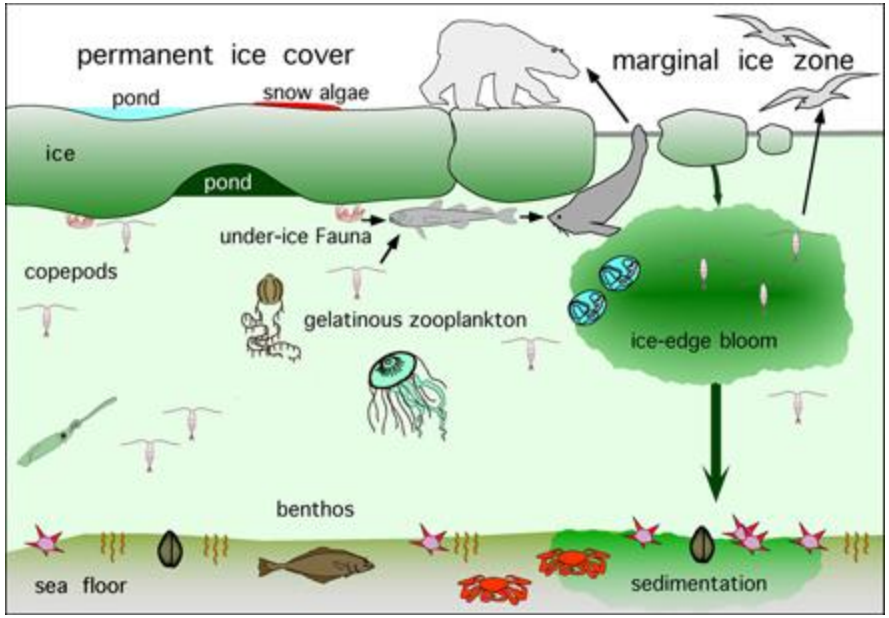


Figure from website for Arctic Ocean Diversity - lead for the **Arctic Ocean diversity** cluster within the **International Polar Year**.

http://www.arcodiv.org/

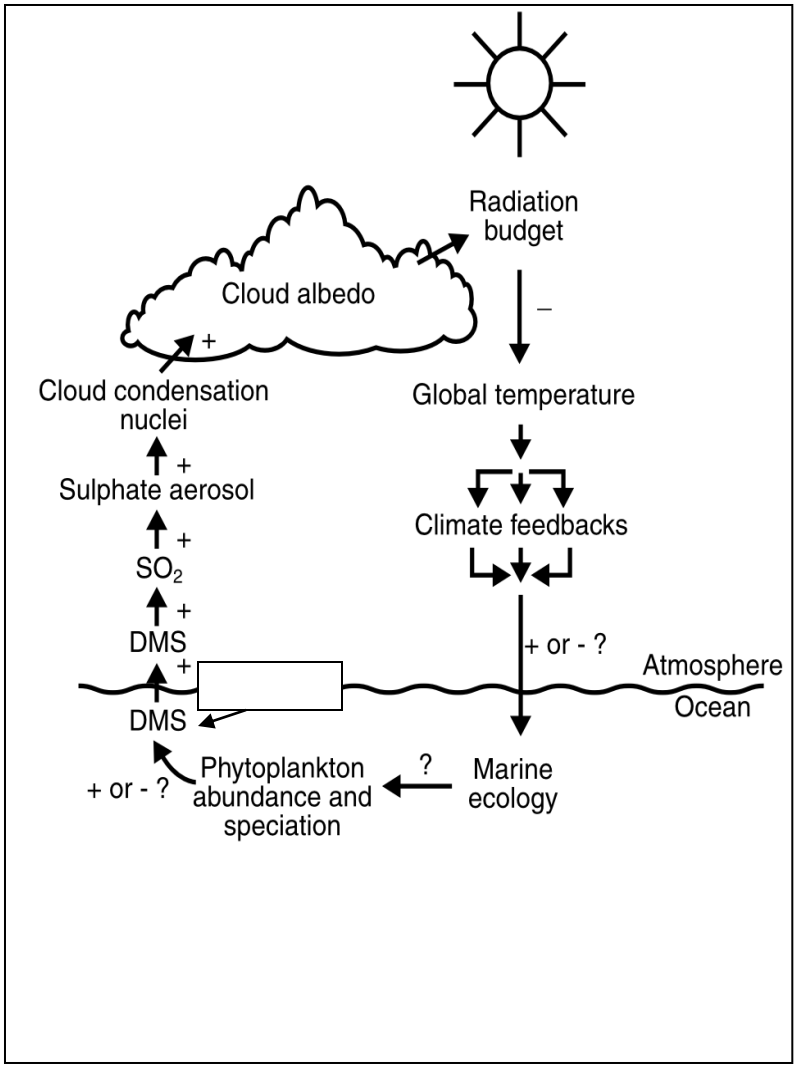
<u>Ice algal contribution to primary production:</u>

Permanently ice-covered Arctic Ocean:
> 50% (Gosselin et al. 1997)

Surrounding seas:
4 - 26% (Legendre et al. 1992)

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 dimethyl sulfide (DMS) emissions, because DMS emissions influence cloud albedo.



Mechanism by which marine algae may influence cloud albedo through production of DMS. Figure from Surface Ocean Lower Atmosphere Study Science Plan.

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 POP coupled to CICE.

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

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

- 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

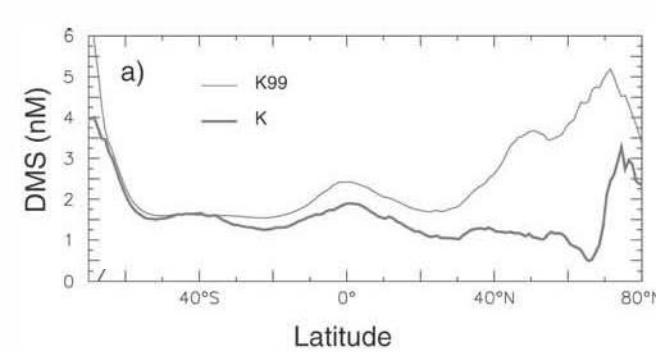
Why study DMS impact on climate in the Arctic?

Feedbacks that involve clouds are particularly relevant to the Arctic because clouds influence the physical processes most important to the warming of the Arctic and the melting of sea ice.

Clouds remain one of the largest uncertainties in climate modeling.

Cloud properties such as albedo, extent, and duration are determined in large part by cloud condensation nuclei (CCN).

Source of CCN over the summertime Arctic is nucleated particles of marine biogenic origin that grow to CCN size with the aid of aerosol precursor gases, predominantly DMS.



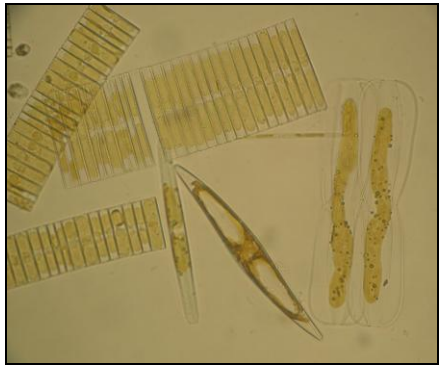
Kettle et al. (1999) DMS climatology updated by Belviso et al. (2004).

Late-spring low stratus offshore Barrow, Alaska.

Dimethylsulfoniopropionate (DMSP) is produced by marine algae that use it as an osmolyte ***and*** for other functions.

It is a natural precursor of dimethylsulfide (**DMS**)

DMSP **comprises** up to 20% of the total cellular carbon for *Phaeocystis* sp. (Matrai et al. 1995)



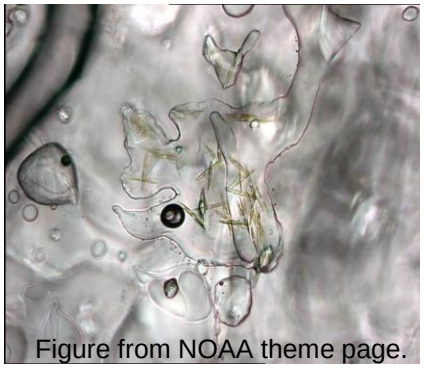
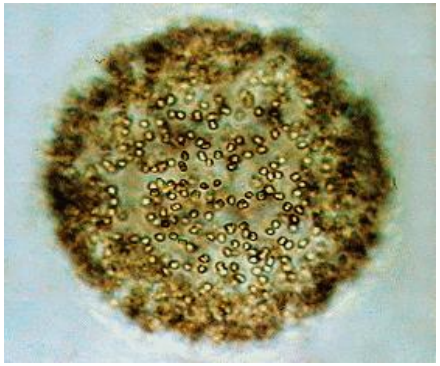
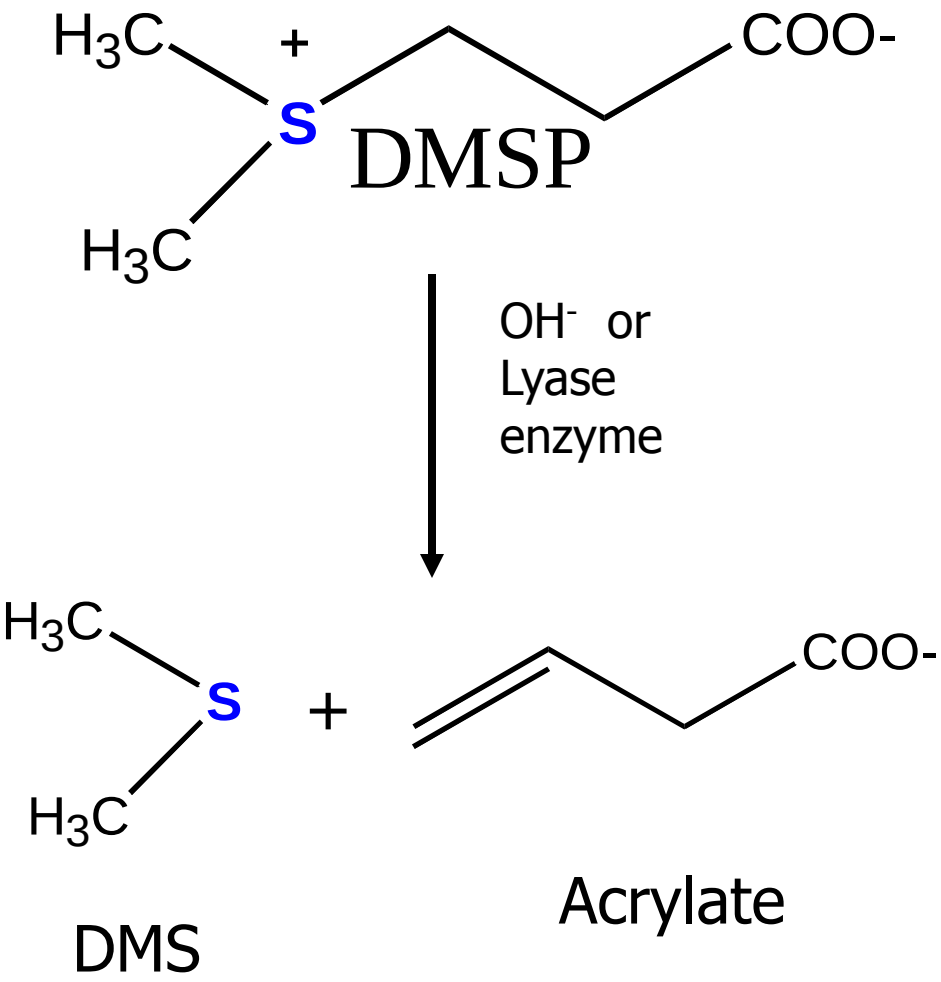
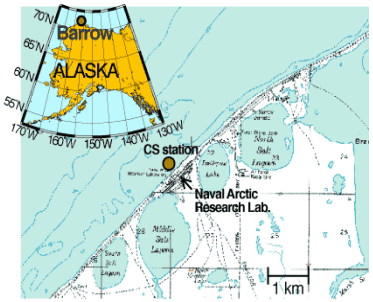


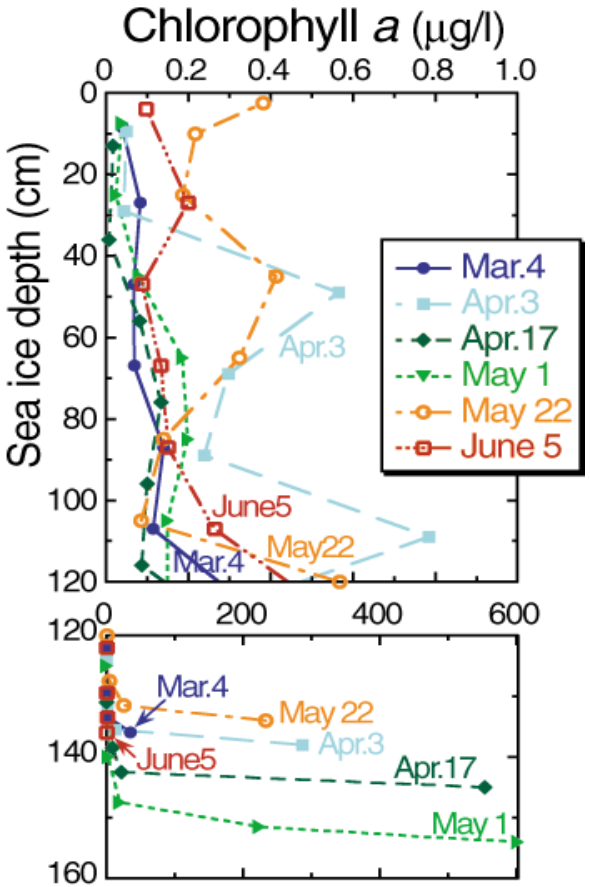
Figure from NOAA theme page.



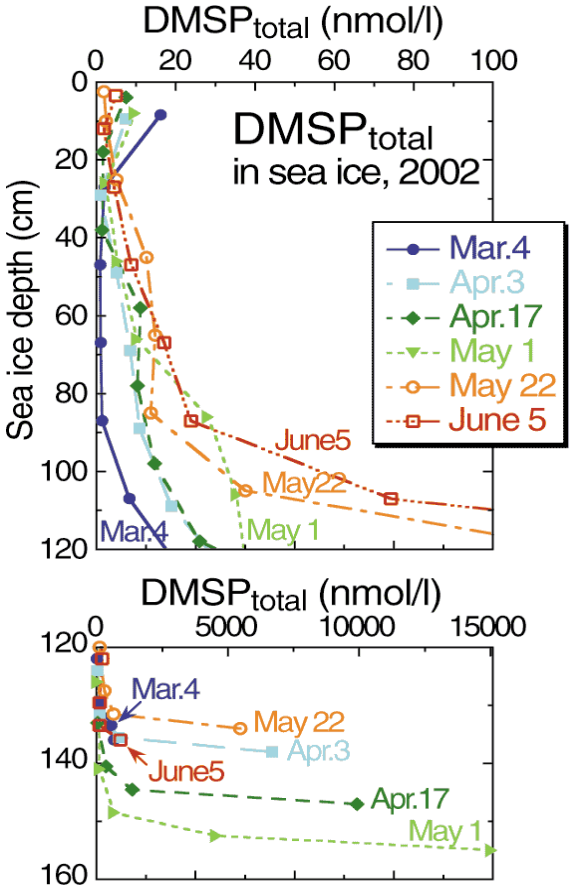


Sulfur compounds accumulate near the bottom of the ice core where ice algal biomass in highest.





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).

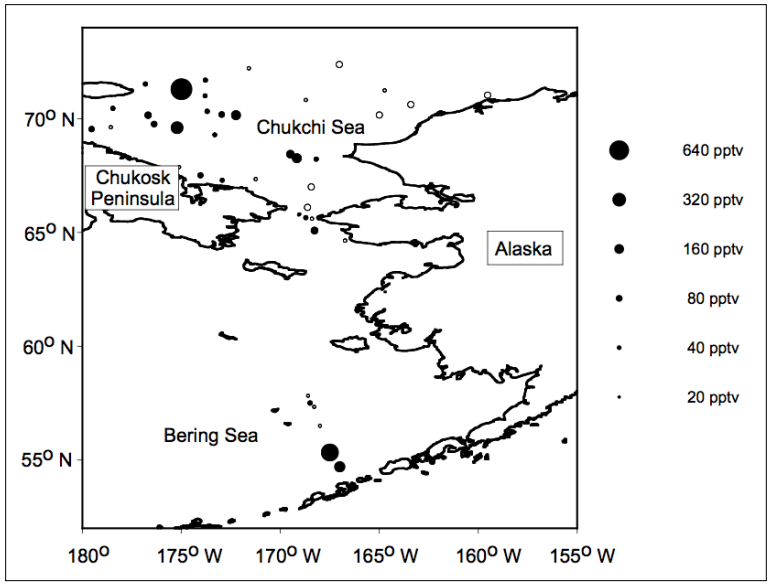
Arctic DMS and DMSP observations show strong sea ice influence.

Sea ice algae may be responsible for significant portion of the annual DMS emission from the Arctic Ocean, especially along ice margin and during/after ice break-up (Levasseur et al. 1994)

Spatially, the strongest, most consistent predictor of high DMSP concentration was the ice edge (Matrai et al. 2007).

Atmospheric DMS mixing ratios display highest values (~600 pptv) at ice-edge locations (Sharma et al. 1999; Deal unpublished data).

Highest surface seawater DMS concentrations in open water along the ice edge in the beginning of August, while lowest under heavy pack ice in September (Leck and Persson 1996)



Distribution of atmospheric DMS mixing ratios at sampling stations in the Bering and Chukchi seas, September 6 through October 4, 1995. Hollow dots indicate non-detectable levels of DMS sized to indicate the detection limit for each sample.

Project Approach

- Model development and testing across a range of scales to effectively bridge small scale processes and the GCM.

- Foundation of modeling will be the combination of three ecosystem models:

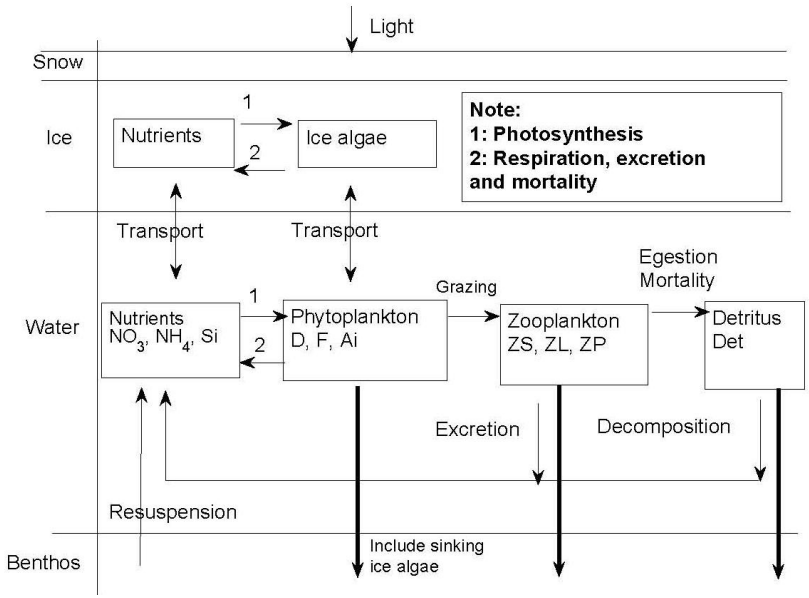
  IARC's 1-D ice-ocean (Jin et al. 2006)

  and high latitude DMS (Jodwalis (Deal) et al. 2000) models,

  LANL's global ocean DMS model (Chu and Elliott, 2007).

- Initial phase followed by global-scale simulations to understand and diagnose the control of sea-ice-related processes on the variability of DMS dynamics.

Compartments and processes included in the IARC ice ecosystem-ocean ecosystem and DMS numerical models.

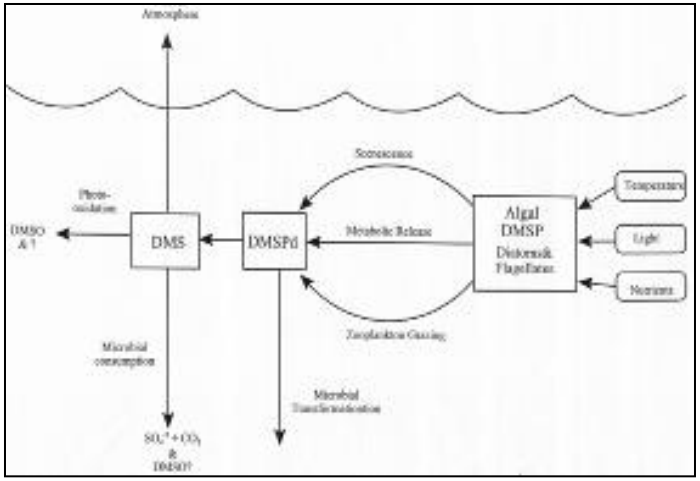


IARC ice-ocean ecosystem model applied:

Land-fast ice in Chukchi Sea (Jin et al. 2006)

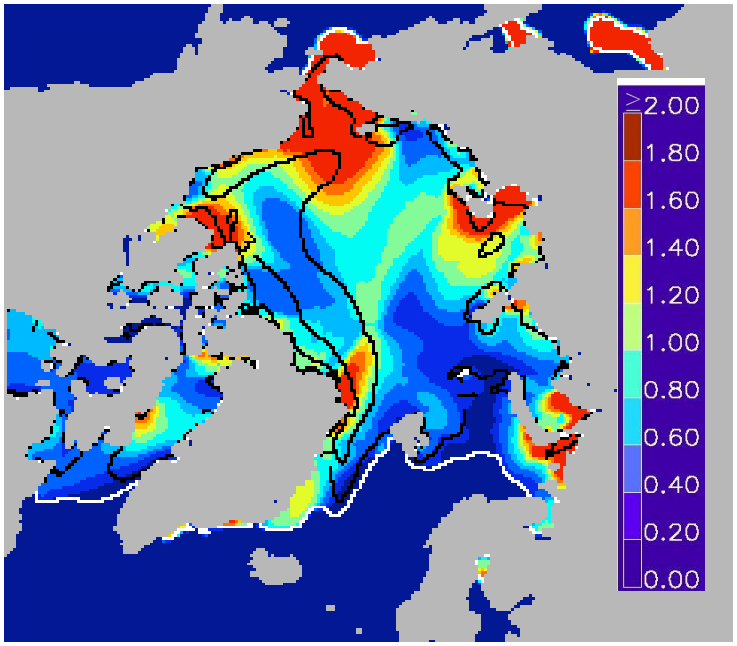
Fluctuating ice zone of Bering Sea (Jin et al. 2007, 2009, Deal et al. 2009)

Multi-year pack ice Canadian Basin (Lee et al. submitted)



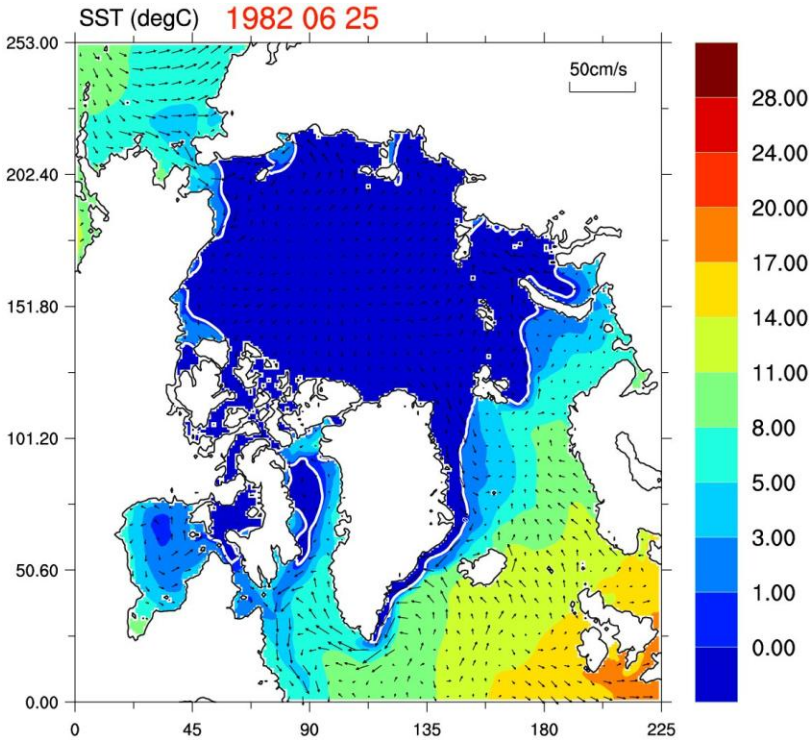
DMS submodel is being updated based on more recent findings (e.g. Deal et al. 2005; Stefels et al. 2007).

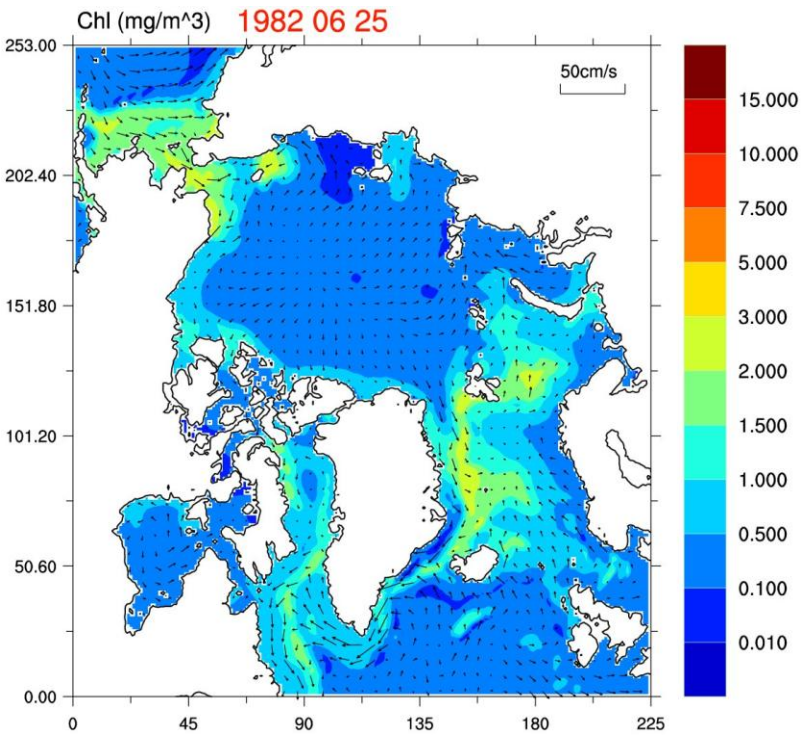
We coupled the IARC ice ecosystem model to the Los Alamos sea ice model, CICE, to generate dynamic simulations of ice algal biomass.



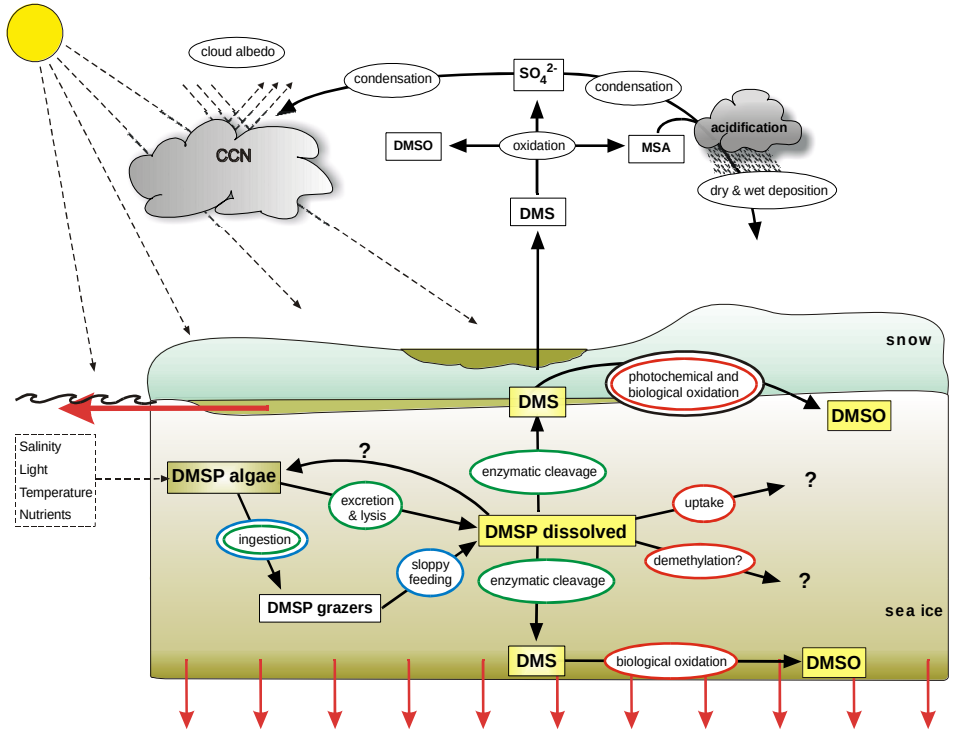
Polar map of base ten logarithm mean ice bottom layer Chl a concentration (mg Chl a m^{-2}) for mid-May. The white line is the 15% ice edge contour and the black lines are ice thickness contours of 1, 2, 3 and 4 m, working inward from the ice edge.

This latest version of CICE now coupled to the Parallel Ocean Program (POP), includes interactions between sea ice ecosystem and ocean.

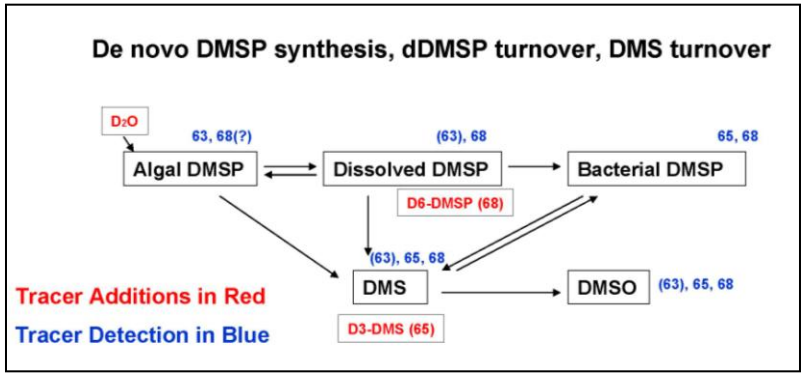




We are improving upon our early version ice ecosystem DMS model through collaborations using time series and laboratory studies of DMS(P) processes in sea ice.



Conceptual model of the S-cycle in sea ice – figure courtesy J. Stefels.



Rates for DMS loss and production processes were measured using stable isotope method – J. Stefels.

Future Work

Now that we have…

an early version ice DMS model coupled to the IARC ice ecosystem model implemented in CICE,

and CICE coupled to POP and running at UAF,

activities for the next year will focus on refinements to the DMS ice-ocean ecosystem model.

Once the model is reasonably simulating DMS dynamics, we will insert it into the CICE-POP framework and conduct global simulations.

Thanks to DOE EPSCoR

(and IARC/JAMSTEC for 10% match.)