Carbon and Chlorophyll in the Oceanic Ice Domain

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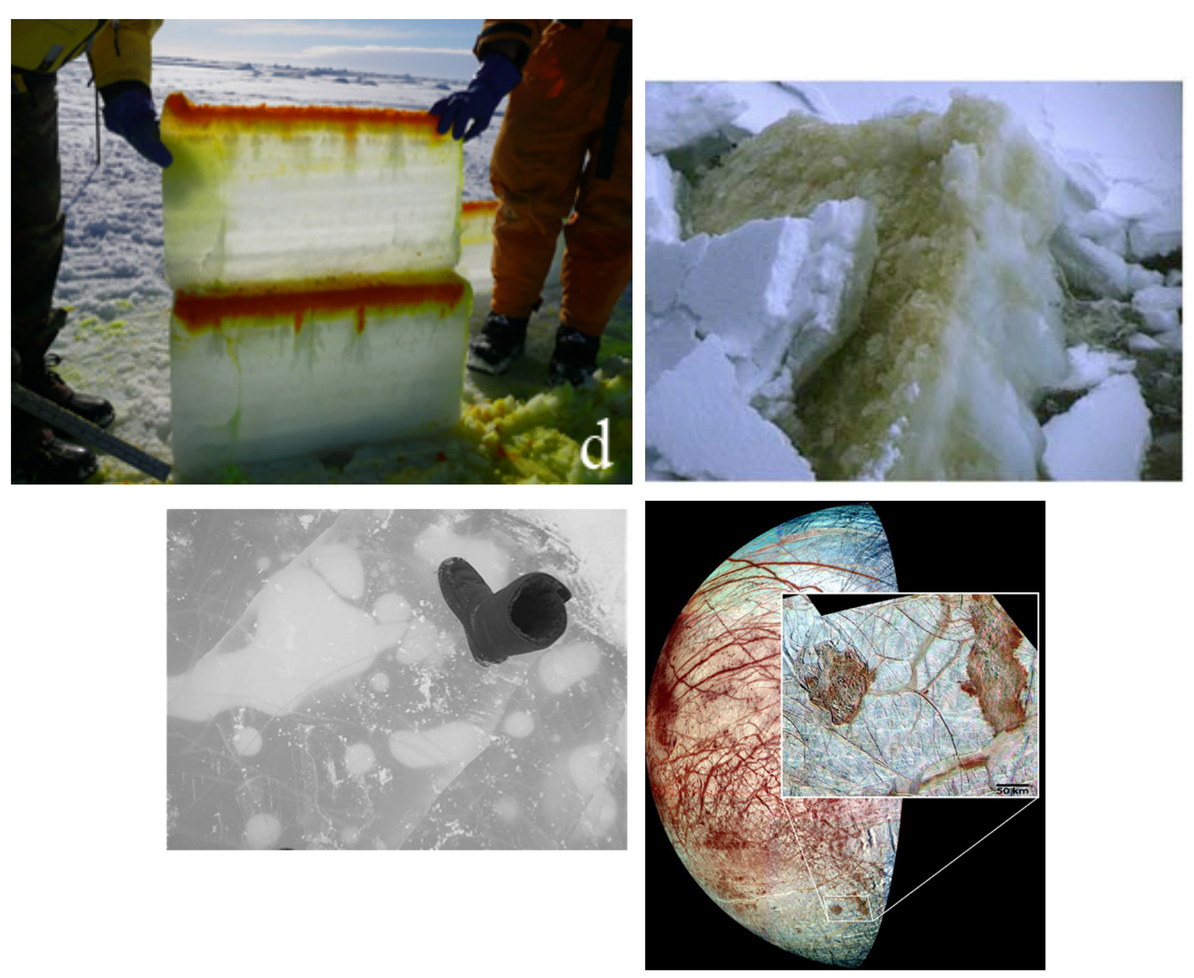
Abstract

Brine channels of the global pack ice system import nutrients from below, provide habitat for primary producers and constitute a reservoir for organic detritus. Our ice biogeochemistry team is currently developing a global three dimensional simulation capability for these processes. Inorganics enter sea ice from the marine mixed layer, driving photosynthesis given light availability. The ensuing pack internal ecosystem generates carbonaceous waste with several critical effects on the polar environment - dissolved organic matter determines brine network permeability in Arctic sea ice, plus trapping and retention of iron in the Antarctic counterpart. In parallel with this work, DOE aerosol modelers are now improving distributions of soot deposition onto the pack. But in many locations, ice algal chlorophyll is likely to compete as an absorber. In a second phase, we will transport black carbon through overlying snow cover and into a common biogeochemical brine transport system. Absorption by the anthropogenic material will be compared with that of the ice algae themselves. We will map areas of soot versus bio-pigment dominance in the sense of single scattering, then couple into a full radiation transfer scheme to attribute the various contributions to polar climate change amplification. Early progress will be described in both these areas. The work prepares us to study more traditional issues such as chlorophyll warming of the pack periphery and carbonate expulsion from the ice bottom.

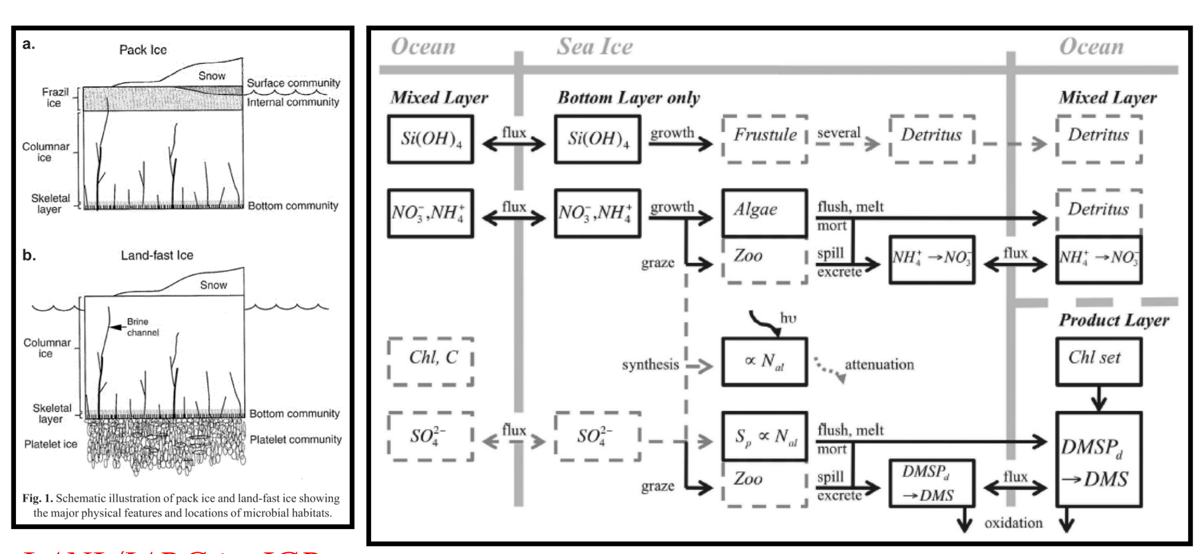
Starter Images: Sea Ice Biogeochemical System

Golden and company –Land ice extracted, inverted and dye-loaded. Ackley and company –Algae exposed between snow and pack, by ice breaker in the Weddell. Shakhova and company –methane bubbles below coastal ice in the Laptev Sea. JPL – Europan ice models provide Debye-Huckel equilibrium parameters.



Initial Ice Algal Simulations: The Bottom Layer

- Habitat definitions from Arrigo series plus some fundamental parameter settings
- Ecodynamic structure also Arrigo but add Jin, Lavoie, expand for regional scales
- LANL/IARC couple N, Si with full C and Chl, also DMS aerosol source



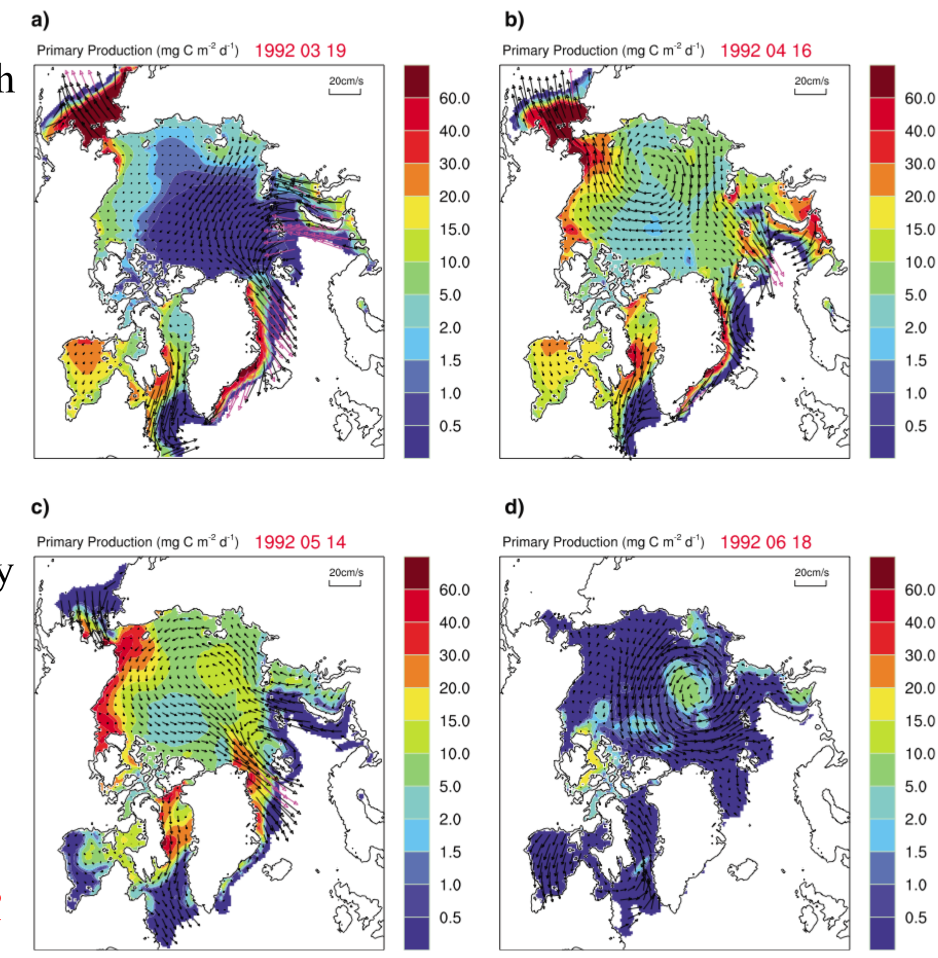
LANL/IARC in JGR

Photosynthesis: Pan-Arctic Primary Production

- First major application of bottom layer biogeochemistry in the CICE component
- First pan-Arctic ice algal primary production calculations in entire community
- Large scale budgets match nondynamic estimates such as Legendre et al. 1992

March

April



May

June

IARC, LANL in JGR

Full coupling: Nutrients and Carbon, Ocean to Ice

- N, Si, C flow from mixed layer into the bottom layer and back, along with organisms
- Photosynthesis, trophic levels and detritus tracked in both media simultaneously
- Here a ten year time series with statistics and trends, full maps available on request

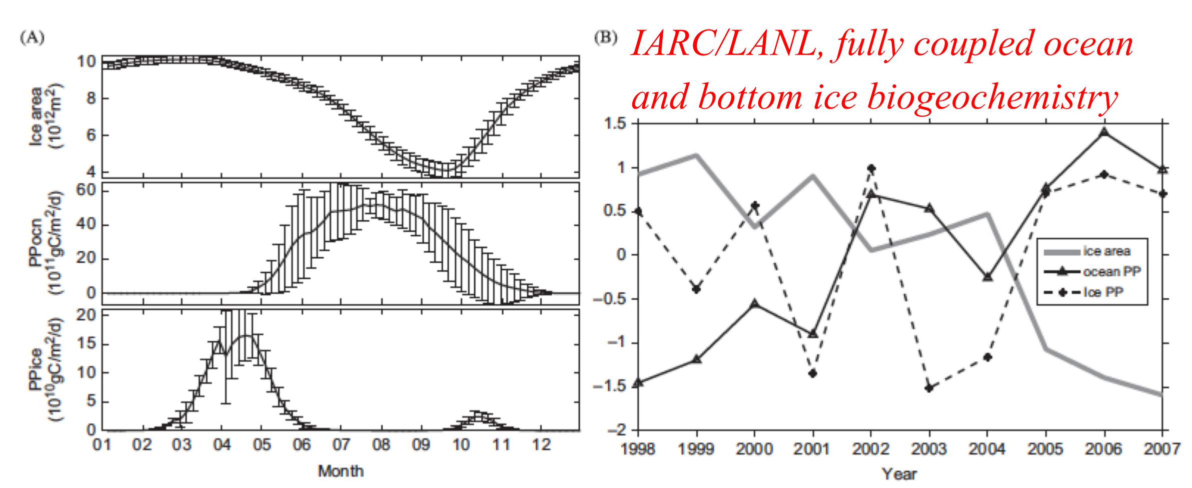
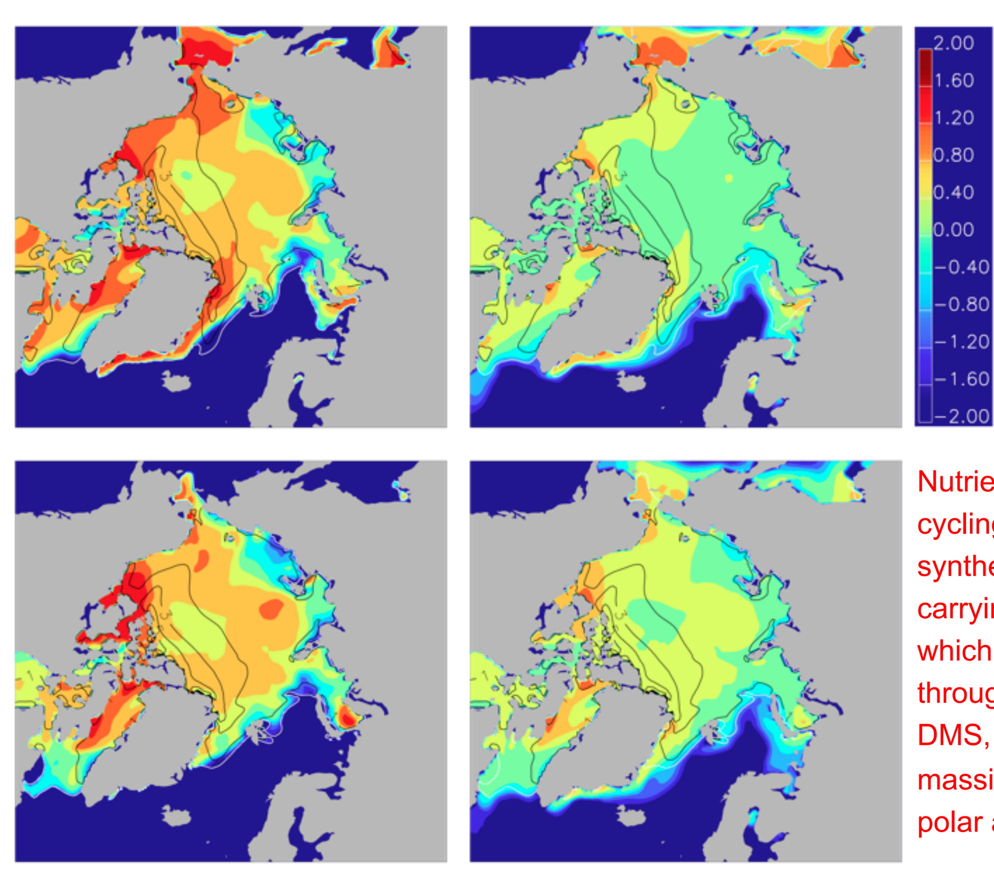


Fig. 3. Time series of modeled sea ice area, upper ocean 100 m integrated primary production and sea ice algal production within the Arctic Circle: (A) mean seasonal cycle of 1998–2007 and standard deviation and (B) normalized annual production. The normalization was done by minus the mean and divided by the standard deviation of the time series.

Application: DMS Production in Arctic Ice

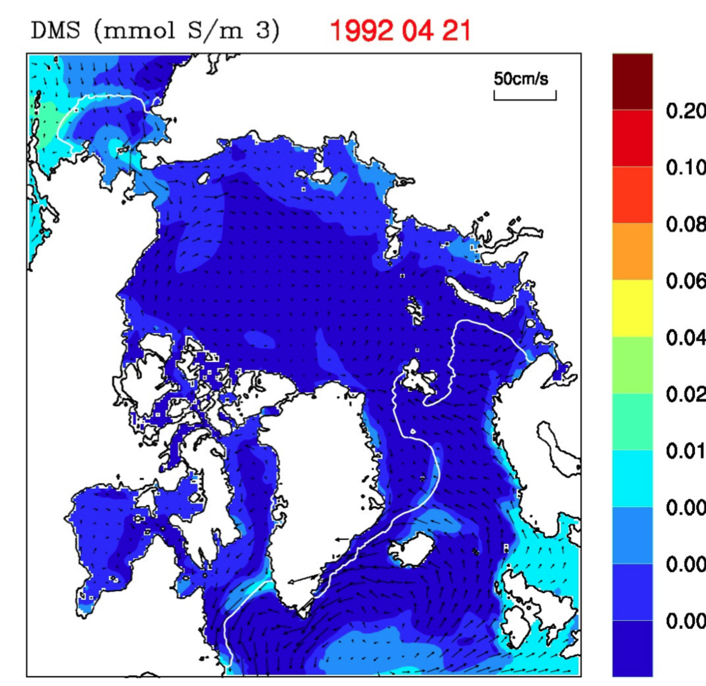


LANL IARC JGR

Nutrient and carbon cycling together drive synthesis of sulfur carrying amino acids, which then metabolize through DMSP to DMS, supporting massive leakage into polar aerosol system.

Coupled DMS Production as Well

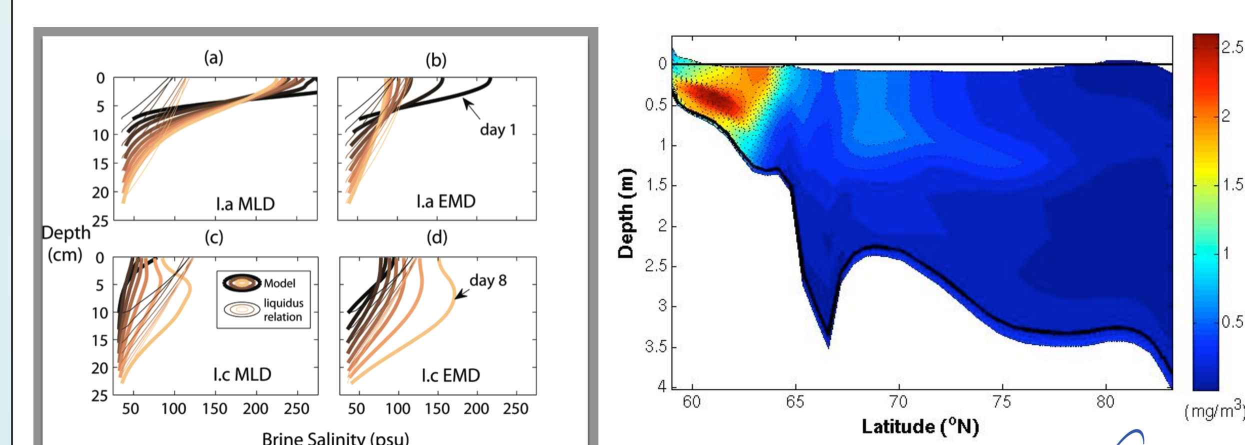
- Early IARC attempts to track ice DMS after release into open water were successful
- Measurements reproduced where available –mainly Bering, Chukchi, Archipelagic
- As yet unpublished but obtain results from the authors on request, as time series.



Parallel Ocean Program to CICE coupling, for all the trace elemental cycles including sulfur. Ice edge marked in white. DMS peaks tend to form just behind the melt and roll inward toward the pole, as the season progresses. Values exceed ten nano-molar in key locations. This is another example collaboration involving Fairbanks IARC and the Los Alamos COSIM team.

Three Dimensional Ice Algae Coming Soon

- LANL has developed dynamic tracer transport through the CICE brine system
- Mixing length theory with variable permeability/porosity in the channel network
- Already handling nutrients, carbon and chlorophyll but tracer vector can extend
- Global (bipolar) approach to the ice algae and their ecodynamics coming very soon
- Will entail the light absorbing pigments as usual but also…
- Emphasis to be place on dissolved organic carbon –the detrital side of the equation
- Plans for calculation of organic effects on pore structure through colloids, gels
- The detritus also contains strongly iron-binding ligands and they are surface active
- We will analyze their affects in the Southern Ocean pack and ice domain



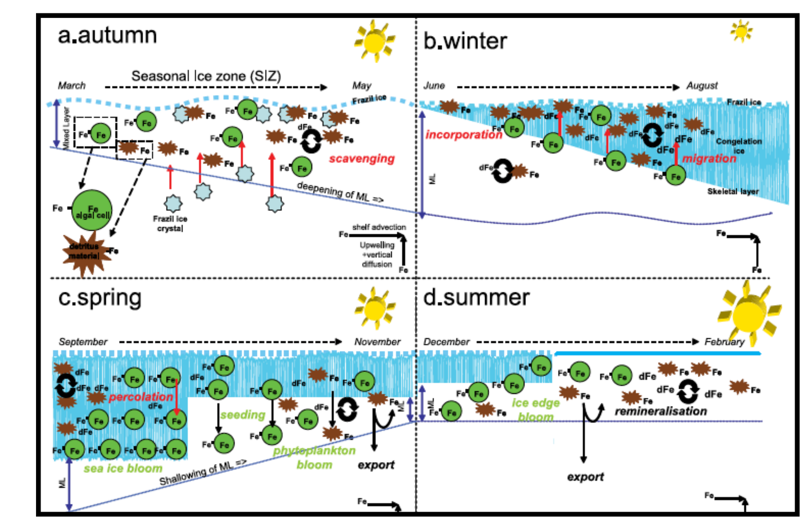
Left: Tests and validation of LANL mixing length theory-based brine transport. Major laboratory studies were matched. Right: Early tests of nutrient inflow driving chlorophyll buildup inside of Arctic CICE. Section shown runs from Bering to the pole. Soon chlorophyll distributions inside pack will be connected interactively to radiation transfer.

Soot and Chlorophyll absorption

- PNNL has recently improved CAM soot transport, deposition onto Arctic sea ice
- LANL has capability to transport soot downward through snow and ice into brine
- Note the above calculations of 3D chlorophyll distributions can be simultaneous
- Under LANL IGPP support, we will map key areas of soot and pigment absorption
- Use Delta Eddington scheme to evaluate competition, polar change amplification

Current Plans: Organics Within the Ice

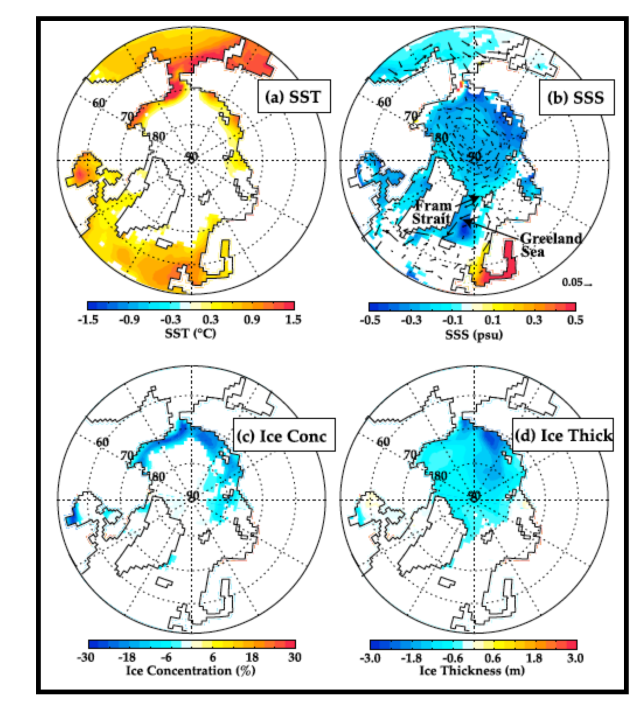
- We will simulate the chemical speciation of DOC as detritus within brine channels
- Based on current macromolecular aerosol sources: surfactants, chelators
- Gel like substances tend to plug pores in brine channels and alter internal transport
- We will evaluate effects on the structure and distribution of the large-scale pack
- A strongly overlapping set of compounds is involved in trapping iron within the ice
- Hence LANL can also determine the stability and bio(non)availability during melt



Right: Lannuzel and company in Hobart have shown that organics trapped within the pack ice matrix are crucial to the witholding of iron from famously nutrient impoverished Southern Ocean waters. We hope to make simulation of trace metal interactions a high priority.

Feedbacks: The Ultimate Goal

- Inorganic ice carbon will experience rapid transport to the thermocline in brine slugs
- Iron regeneration in open water controls drawdown after the melt in Southern spring
- Chlorophyll generated internally amplifies ice losses if habitats are at upper levels
- Soot will compete and must be transported into the pack for radiation computations
- All the above require coupled ocean ice biogeochemistry for full analysis



European marine systems modelers have shown that open water chlorophyll of the ice domain couples into the heat budget of the upper ocean to give amplification of pack removal. Here Lengaigne et al. 2009 map differences in temperature, salinity and most importantly ice coverage and thickness effects, for coupled chlorophyll absorption. Results are shown for the month of September. Our eventual plan is to perform similar simulations but with the inclusion of coupled ice-internal pigments and soot deposition from the CAM component atmosphere

Relevant Recent Publications

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