Some consequences of ocean-ice biogeochemical interactions

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This Talk

1. Motivation – HiLAT and ACME projects

2. Status of ice bgc in models: CICE (zbgc-colpkg), MPAS-seaice, ACME-HiLAT

3. Key Processes, Issues and Resolution

4. CASE1 – NICE2015: Key process -- Algal motility

5. CASE2 – GCASE ocean-ice system: Key process -- Iron adsorption

6. Conclusions
Motivation

HiLAT: DMS and organic macromolecules—

a. How do polar marine DMS and organics emissions change in a future climate (~100 yr timescales)?
b. Under scenarios of enhanced Antarctic melt?
c. What is the impact on cloud radiative properties?
d. What is the feedback on climate?
Motivation

**ACME: Carbon, color, and clouds** – Land BGC is the primary focus of ACME.v1. However, ice algal carbon production and marine ecosystem function on global, climate scales is poorly understood*

1. What is the annual carbon production of ice algae?
2. How great is the natural variability in production?
3. What are the predominant sources of this variability?
4. How do ice algal and ocean algal ecosystems impact one another?
5. What is the radiative impact of marine bgc on ice and ocean physics?
Status of Models – CICE (zbgc-colpkg)

- CICE.v5

Stand alone test cases for tuning and process development

1) First year ice
2) 3-5 weeks of data
3) S, T, Chla, dFe, NO$_3^-$, SiO$_4^-$, DOC, some algal speciation

1. ISPOL, Weddell Sea
   (Jeffery and Hunke, JGR, 2015)

2. NICE2015, Nansen Basin
   (Duarte et al, JGR, Submitted)
Status of Models – CICE (zbgc-colpkg)

- **Key Processes**
  1) Gravity drainage, flushing and snow loading
  2) Tracer adsorption at ice/brine interface -- eg. Iron accumulation during ice growth
  3) Heterotrophy of small plankton
  4) **Algal motility** – eg. Retention during melt
Status of Models – MPAS-seaice

- **MPAS-sea ice:**
  Stand alone simulation, 6 months duration, of ice bgc with radiative feedback.

- **ACME:**
  “Smoke test” of ocean/ice/land bgc
Status of Models – ACME-HiLAT

- **ACME-HiLAT**

  Uses cice.v5 zbgc-colpkg + ocean bgc with DMS module (S. Wang).

Testing ocean/ice bgc coupling on decadal timescales for tuning, debugging and process development in coupled system.
Status of Models – ACME-HiLAT

• **Issues and resolution**

1) Unphysical accumulation of humic material in multiyear ice – Added saturation of the ice/brine surface

2) Unphysical buildup of nitrate in the upper ocean – Corrected a flux imbalance in the ice

3) Excessive nutrient buildup in the snow-ice layer – Added “ocean” flooding of surface in regions of ice area fraction < 1
A. N-ICE2015:
Special session: Atmosphere-ice-ocean-ecosystem processes in a thinner Arctic sea ice regime: the Norwegian young sea ICE cruise 2015 (N-ICE2015)

Figure 1. Lance drift between the 18th of April and the 5th of June, from the Nansen Basin, across the Yermak Plateau, to Fram Strait. The part of the path corresponding to the time span of the simulations described in this study for the refrozen lead is shown in red.
Model configuration

- CICE stand alone + zbgc
- Column mode- Rectangular grid 5X5
- Mushy thermo- and halo-dynamics on 15 vertical layers
- zbgc on 15+1 vertical layers

ZBGC tracers

- diatoms, small phytoplankton and Phaeocystis sp.
- 2 DOC (polysaccharids, lipids)
- 1 DON (proteins)
- DMS, DMSPd
- Limitation by SiO3, NO3, NH4, dissolved Fe
Summary of initial results:
- Chla and algal N peaks are earlier than observations.
- Modelled algal accumulation/growth rates are too high.

Simulation 1

Algae peak near maximum ice thickness
Algal N increases too quickly, peaks too early, and abruptly declines with bottom melt.
Algal N increases too quickly, peaks too early, and abruptly declines with bottom melt.

Algae can actively move within the ice to resist melt.
Adsorbed Diatoms maintain their relative position in the ice during growth, but **not melt**.

Adsorbed Diatoms maintain their relative position in the ice during growth and melt for **melt rates < maximum algal velocity**.
ACME-HiLAT
CORE II BGC coupled

G-INTERANNUAL, gx1 (1° ocean/ice grid)
Ocean and Ice BGC active: 1 way and 2 way bgc coupling

Couple:
3 Algal groups – Diatoms, small plankton, Phaeocystis sp.
3 dissolved organics pools – lipids, saccharids and proteins/amino acids
3 macronutrients – nitrate, ammonium, silicate
1 micronutrient – iron
DMS and DMSPd
humics
Fully Coupled BGC (000) vs. One-Way Coupling (001)

000. Fully coupled BGC -- Ocean concentrations to Ice, Ice fluxes to Ocean
Continues from previous run until year 49

001. One-Way Coupling – Ocean concentrations to Ice only.
Branch from year 40 of 000 until year 53
Fully Coupled BGC (000) vs. One-Way Coupling (001): Arctic

Ice (integrated)

Arctic: Total Algal

Integrated over Latitudes > 50°

Ocean (upper 10 m)

Arctic: Total Algal
Arctic Ice Algal Chla (mg/m^2) Monthly Avg (Years 12-25)

Ocean peak 110 mg/m^2
Fully Coupled BGC (000) vs. One-Way Coupling (001): Arctic

Ice diatom “seeding” of the upper ocean

110 mg/m²
Fully Coupled BGC (000) vs. One-Way Coupling (001): Antarctic

Consistent 50-100% increase in ocean chla
Fully Coupled BGC (000) vs. One-Way Coupling (001): Antarctic

Iron “seeding” of the upper ocean.

But how much is physical?
TEST 1
Weak Iron accumulation
2X ocean value
~0.1% change in Ocean chla

TEST 2
Strong Iron Accumulation
10X ocean value
~50-100% increase In upper ocean chla

What do observations suggest?

No change in ice chla
Strong Iron Accumulation
10X ocean value

Ocean iron values ~1 nM

*Obs of ice dFe up to 40 X ocean value*
Conclusions

1. Diatom motility is important for reproducing the timing and retention of algal chlorophyll in sea ice.

2. Other key parameters: a) algal velocity (algal_vel), b) max algal growth rate, c) heterotrophic grazing pressure

3. In Arctic, ice diatom seeding is one way ice algal production impacts upper ocean chla. Impact is $O(10^{-1})$

4. In Southern Ocean, iron seeding is likely the dominant impact of ice biogeochemistry on upper ocean chla. Impact is $O(1)$
Figure 3. Refrozen lead results. a) Observed (closed circles) and predicted (lines) ice thicknesses. Ice thickness results were obtained assuming different values for the under-ice mixed layer depth (h_{mix}) and the minimum current velocity forcing (0.005 ms$^{-1}$). In the case of h_{mix} = 10 m*, results were obtained using the velocity values shown in Figure 2d. Salinity results are shown only for the simulation “h_{mix} = 10 m”. Results from all the remaining simulations are very similar (not shown), except for those obtained with h_{mix} = MLD due to the late ice formation (refer text).
Diatom Motility

What determines the vertical motion of Ice tracers?

a) Brine motion (gravity drainage + flushing)
b) Loss/gain of sea ice (melt, growth, snow ice formation)
c) Adsorption/desorption at ice crystal surface
d) Active motility

Observational evidence indicates
- Salinity/nitrate/silicate – move with brine and loss/gain of ice (a + b)
- Small algae*/ammonium/iron/humics/DOC -- also adsorb/desorb (a, b + c)
- Diatoms – also actively move (a, b, c + d) ~ 1 cm/day
Southern Ocean Ice Algal Chla (mg/m^2) Monthly Avg (Years 12-25)