COSIM:

Climate Ocean Sea Ice Modeling

Marine Biogeochemistry for CESM

LANL: Elliott, Maltrud, Hunke, Jeffery
LBL: Reagan, Moridis, Collins
LLNL: Cameron-Smith, Bergmann, Bhattacharyya
ORNL: Branstetter, Erickson
ANL: Jacob
IARC: Deal, Jin
Universities and international…

DOE: SciDAC, IMPACTS, Fossil Energy, COSIM core, Cloud-Cryosphere, EPSCOR (IARC)
Other: New Mexico IAS, IARC/JAMSTEC Cooperative, various lab LDRD, international

OUTLINE

HISTORY: Sea-air transfer trace GHGs, aerosol precursors

CH_4 & DMS: Emergent, point to organics and ice

STRUCTURE: Montage and teaser for each of…

- Methane
- Dimethyl Sulfide
- Global O-Chem
- Sea Ice Biogeochemistry

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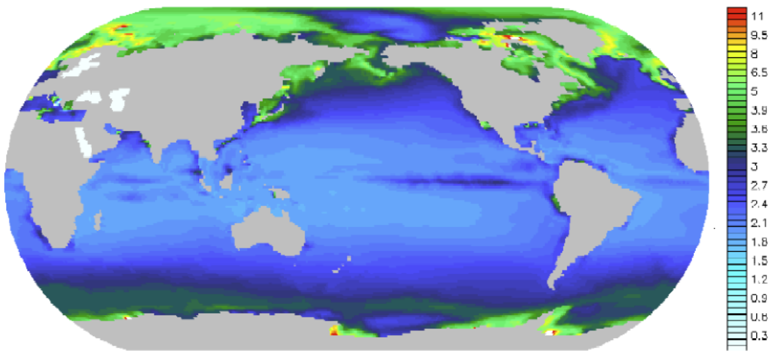
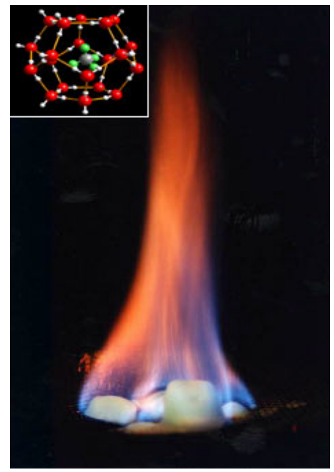
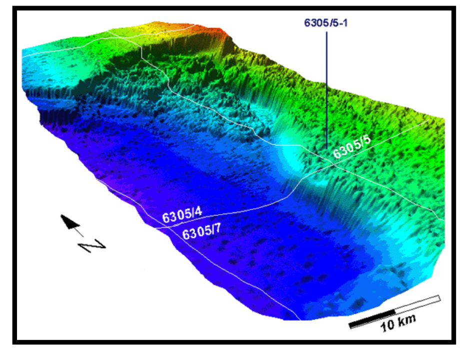
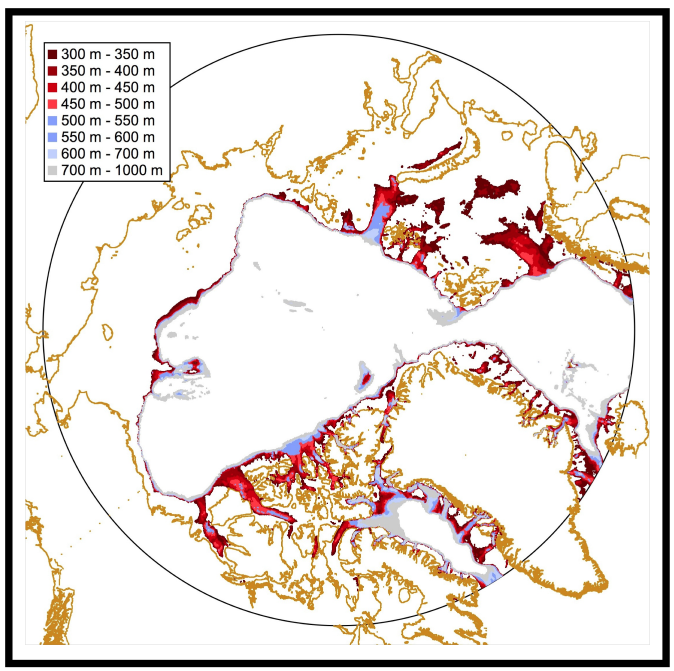
MONTAGE: Methane

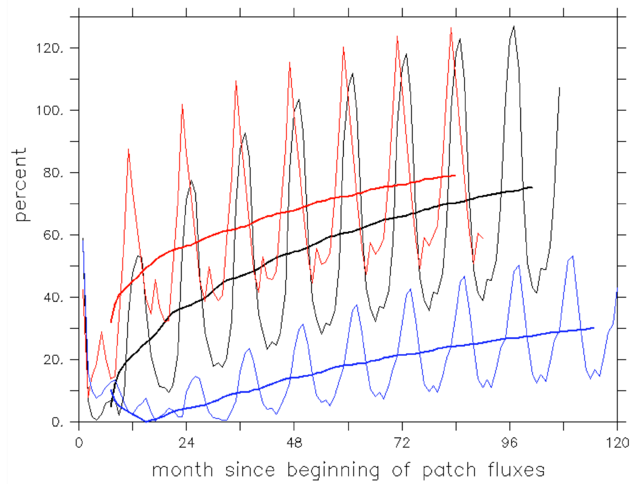
JGR 2011







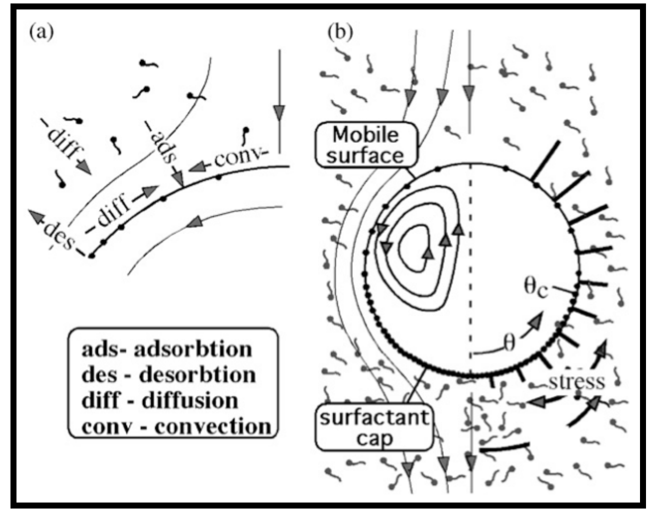


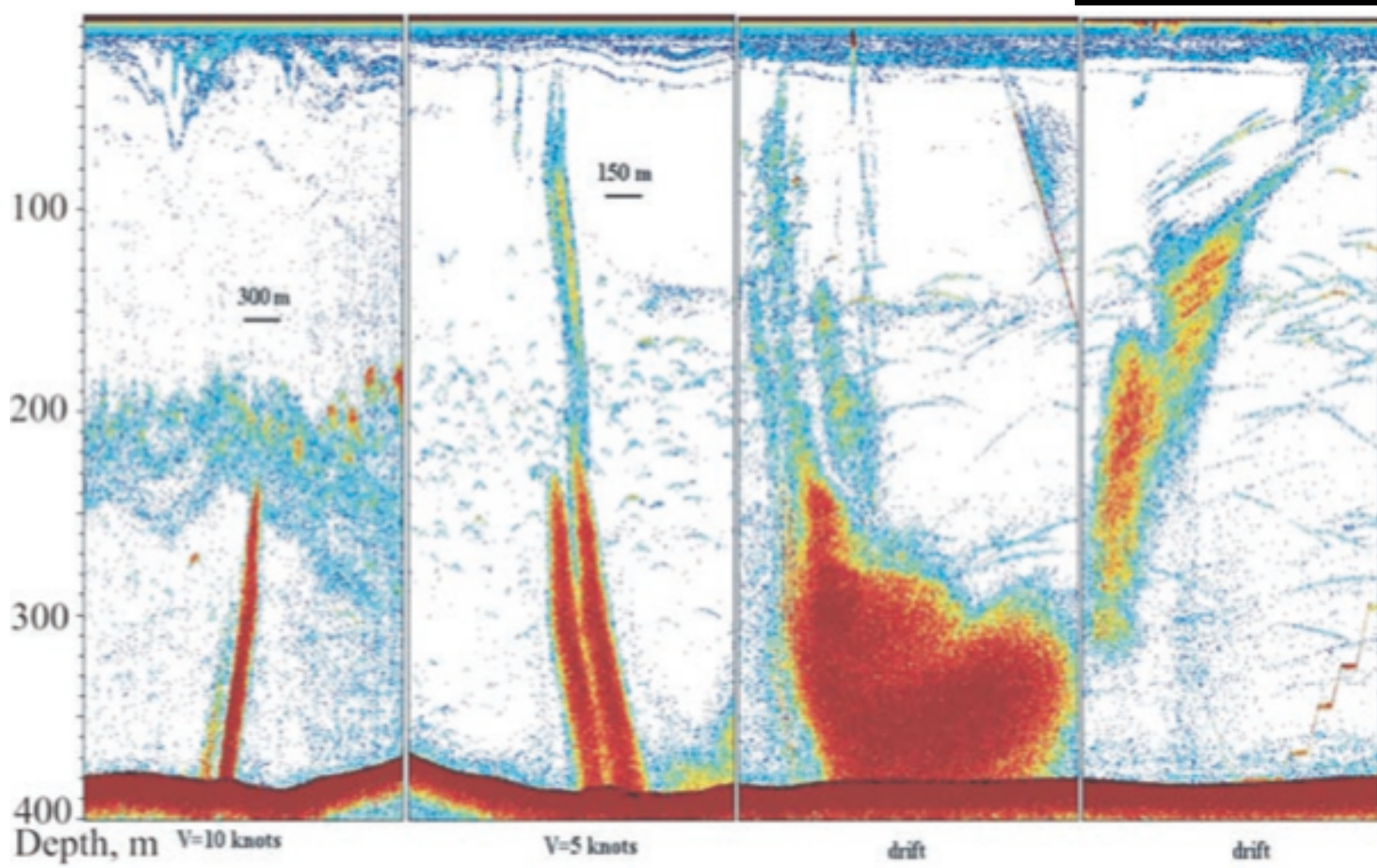


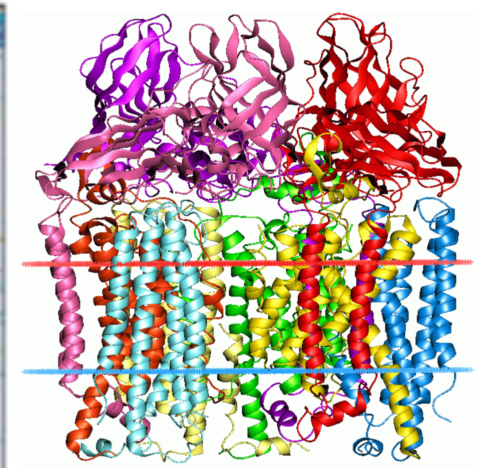
GRL 2010, JGR 2011
JGR & ICGH in press

A Scientific Win-Win*

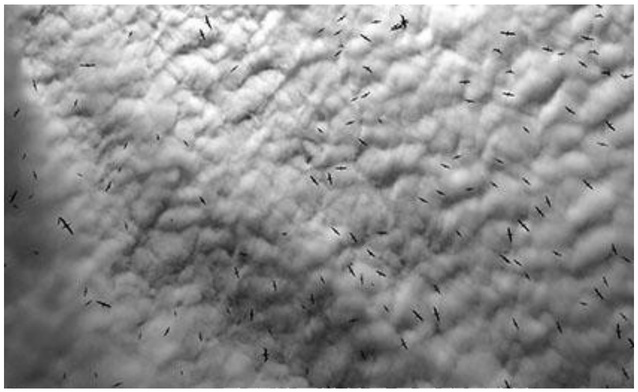
CH_4 in atmosphere: GWP 30
CH_4 in seawater: Reductant

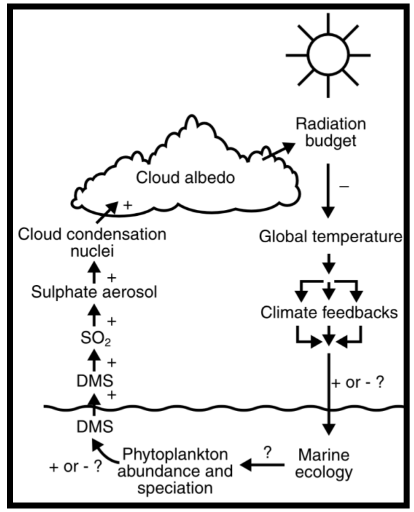


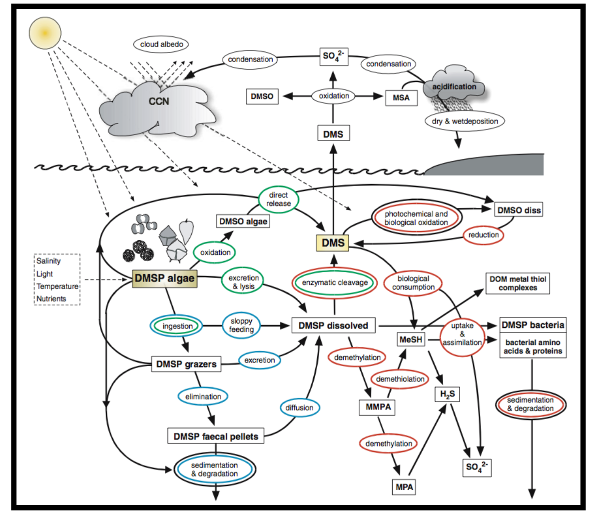




MONTAGE: Dimethyl Sulfide

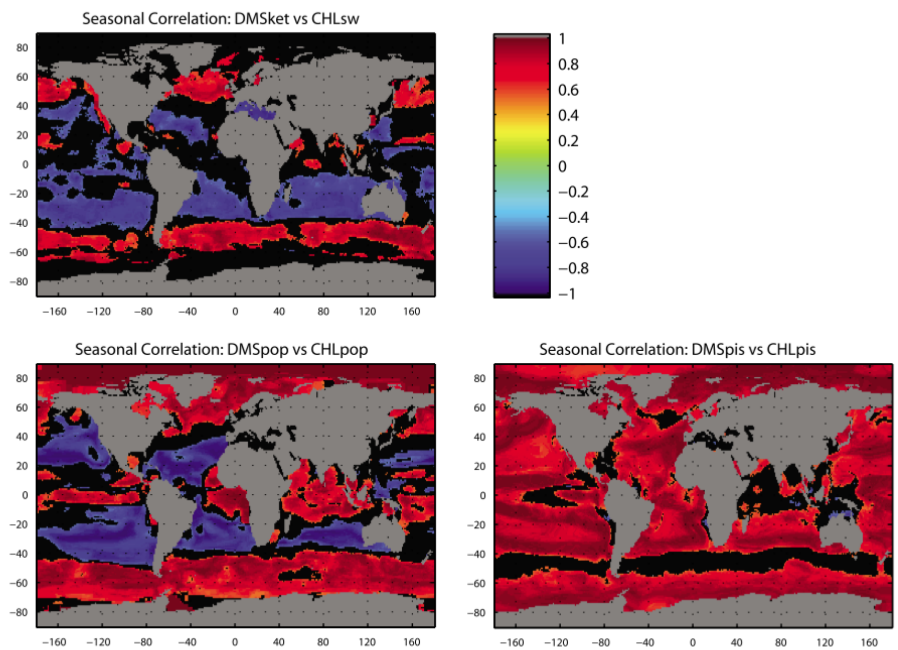






JGR 2009

GBC 2010



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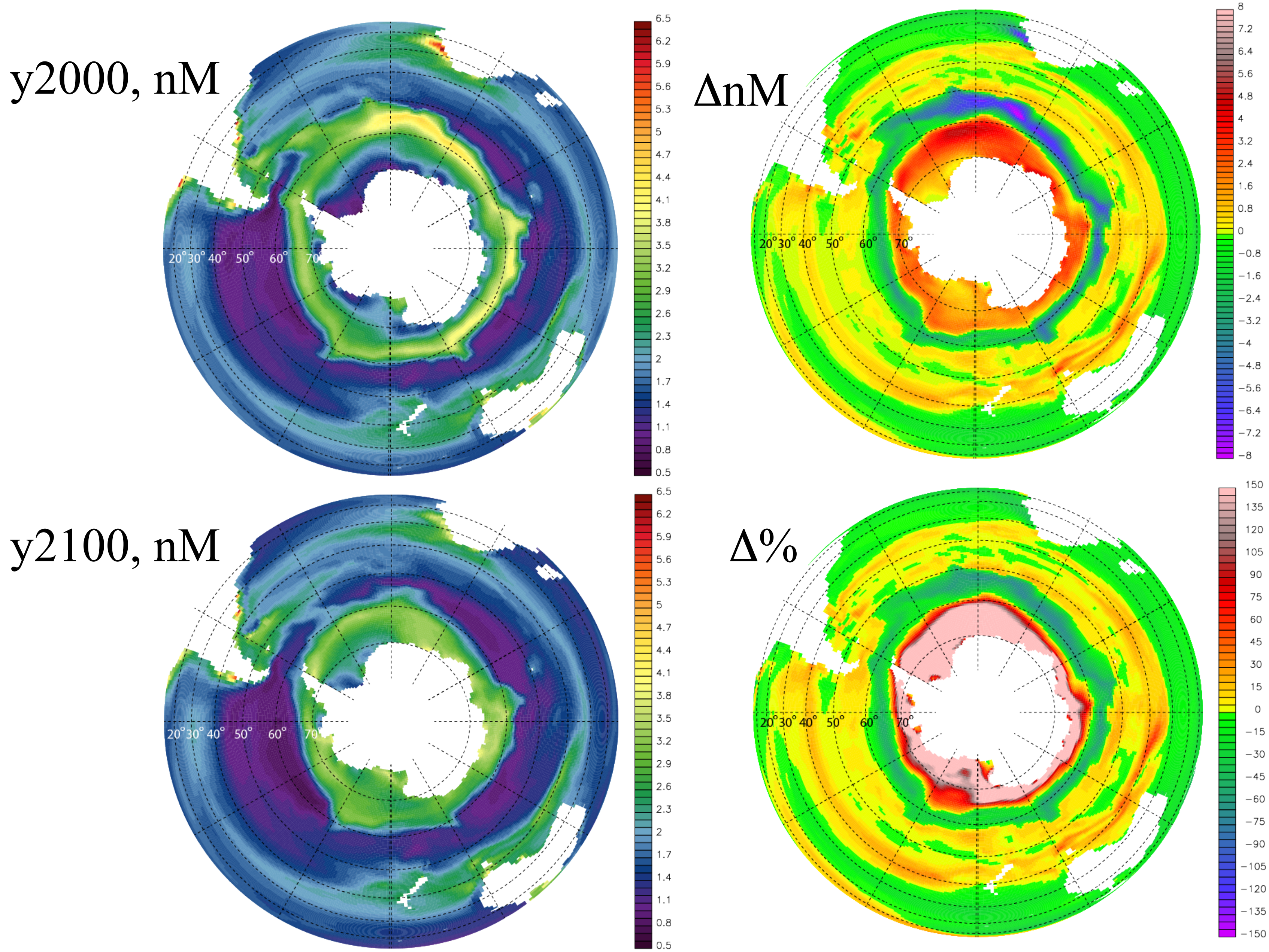
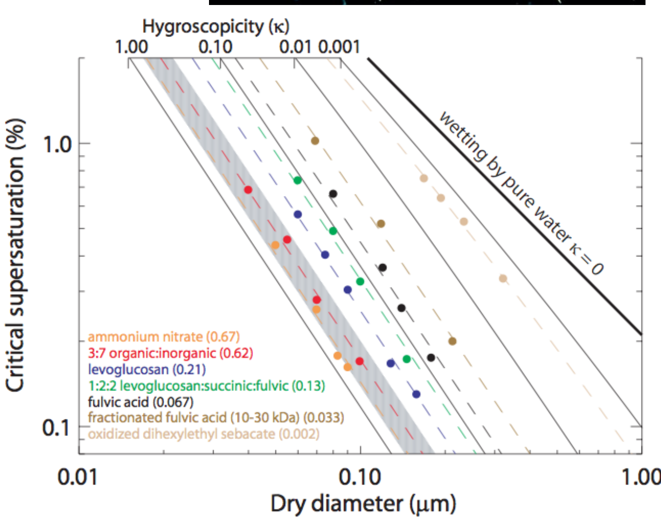
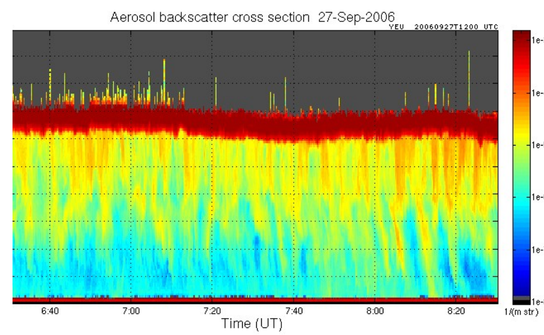
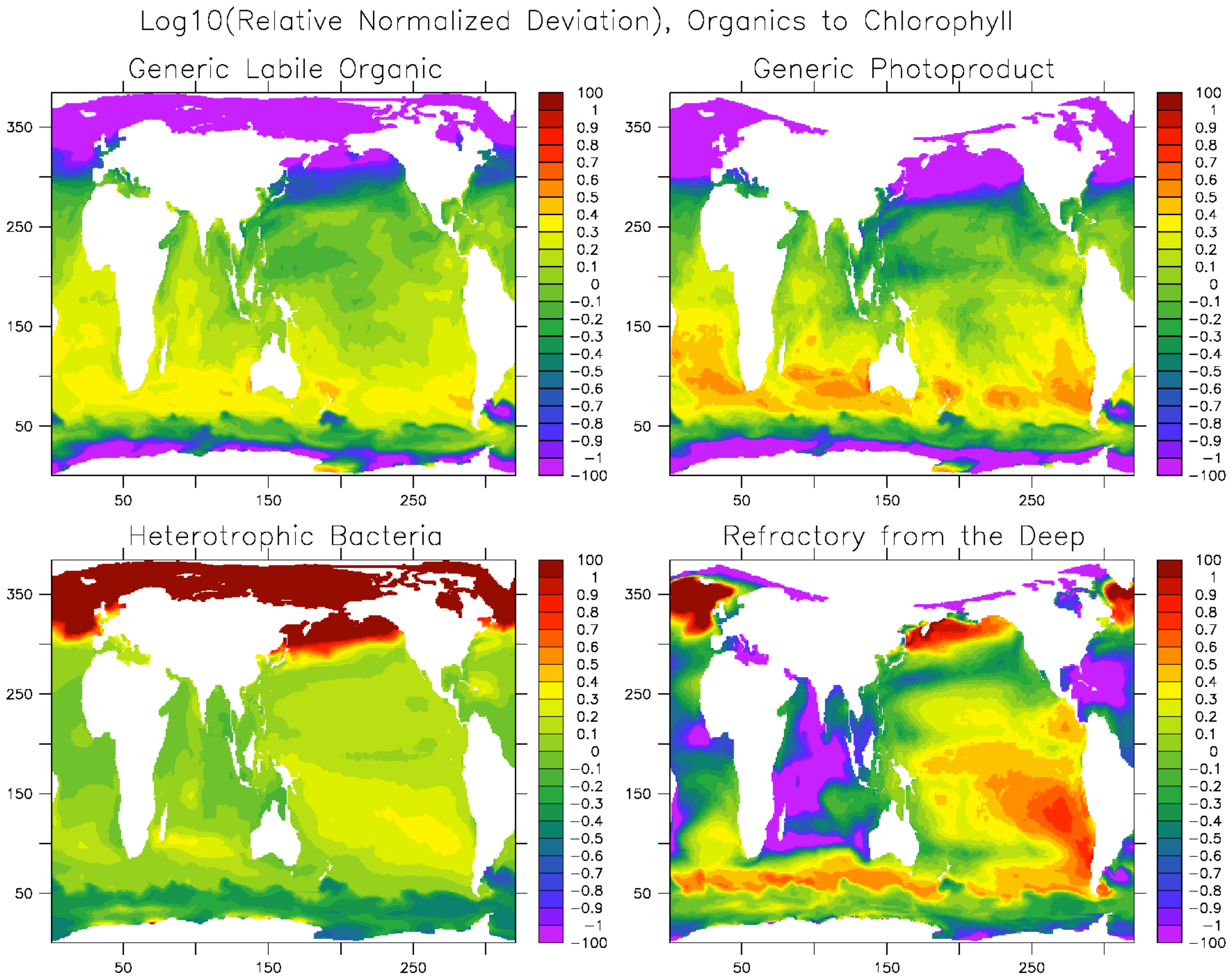
Once and future DMS in CCSM: GRL 2011



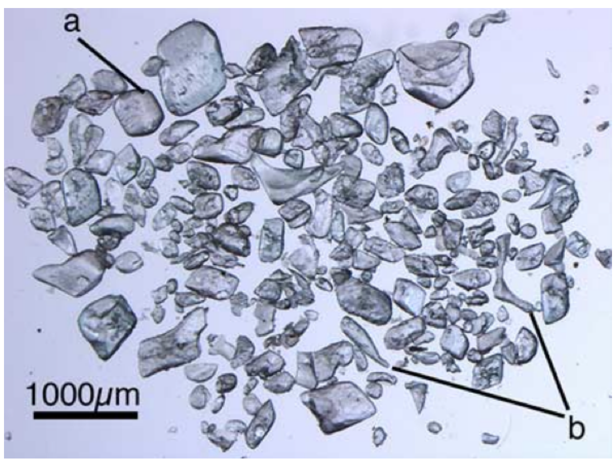
MONTAGE: O-Chem

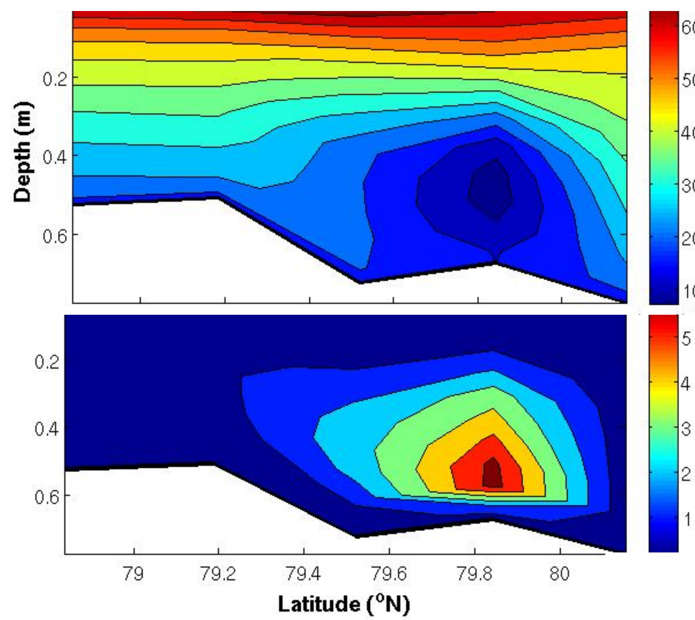





Log10(Relative Normalized Deviation), Organics to Chlorophyll
Generic Labile Organic
Generic Photoproduct
Heterotrophic Bacteria
Refractory from the Deep
350
250
150
50
50
150
250
100
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
−0.9
−1
−100

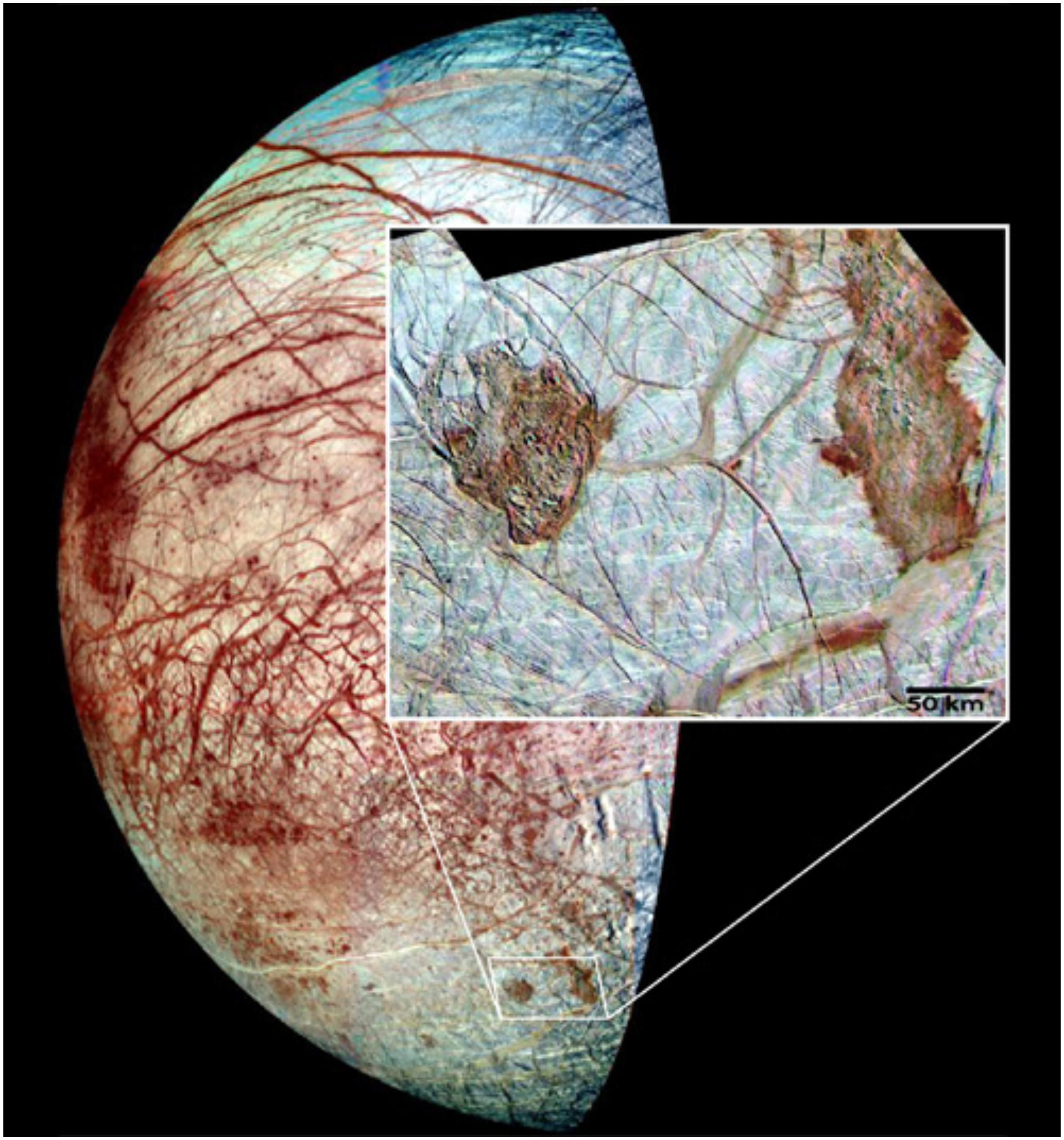
MONTAGE: Ice BGC





JGR 2011 (algorithm)

μM nitrate
mg/m^3 chl



Europa

SUMMARY

HISTORY: Sea-air transfer trace GHGs, aerosol precursors

CH_4 & DMS: Emergent, point to organics and ice

STRUCTURE: Montage and teaser for each of…

- Methane
- Dimethyl Sulfide
- Global O-Chem
- Sea Ice Biogeochemistry

NEXT: Expand effort in CESM

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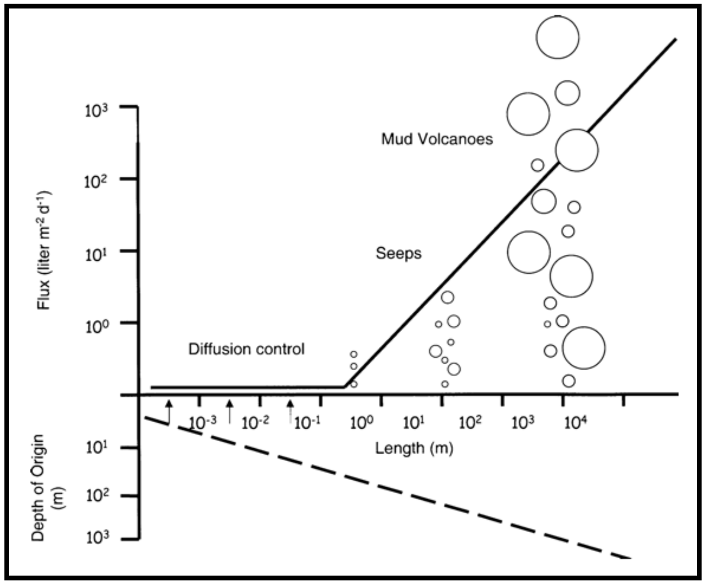
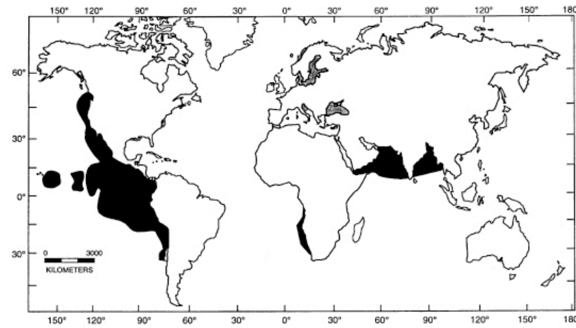
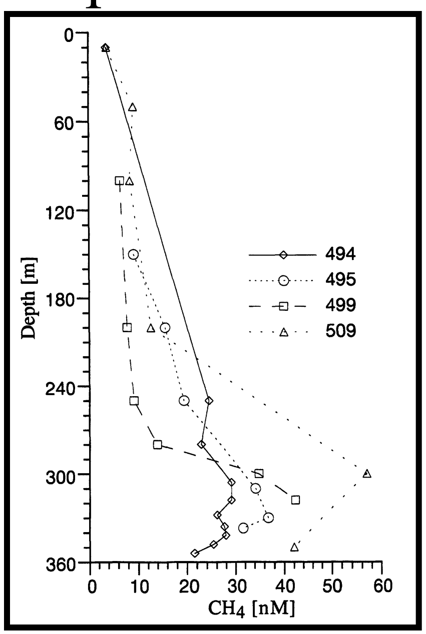
EXTRAS

Average seabed fluid flow and particulate sources



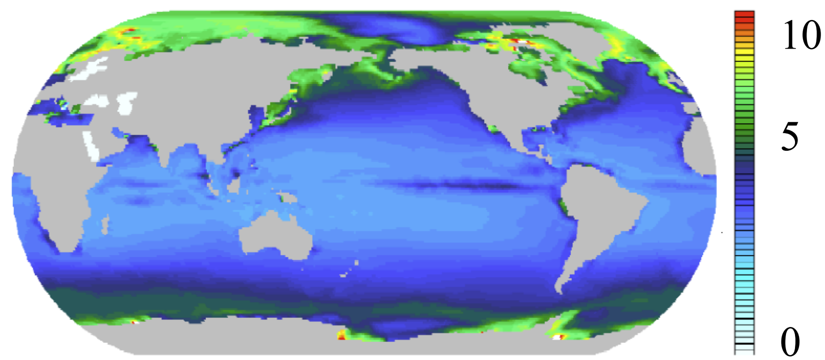


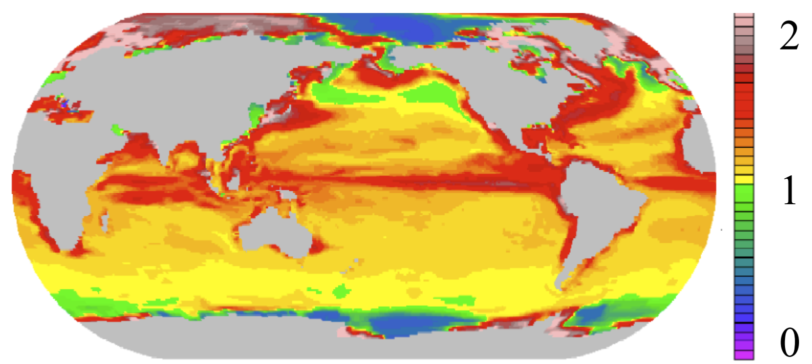
Empirical τ −Less is more



CH_4, nM
Bear Island

Surface concentration (nM), Saturation ratio





Mat Background Run

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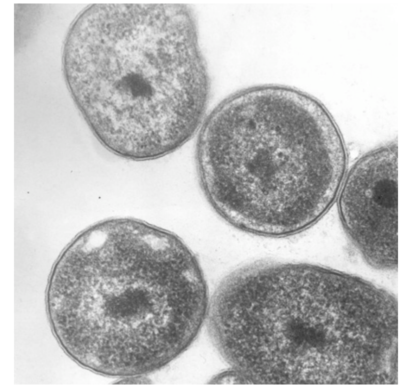
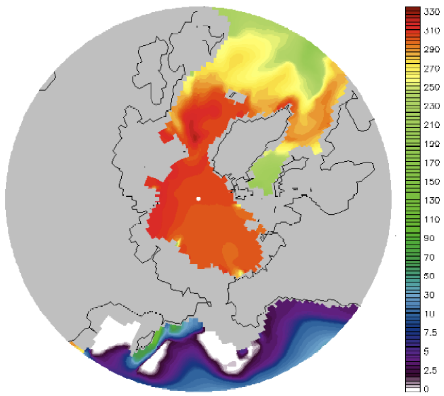
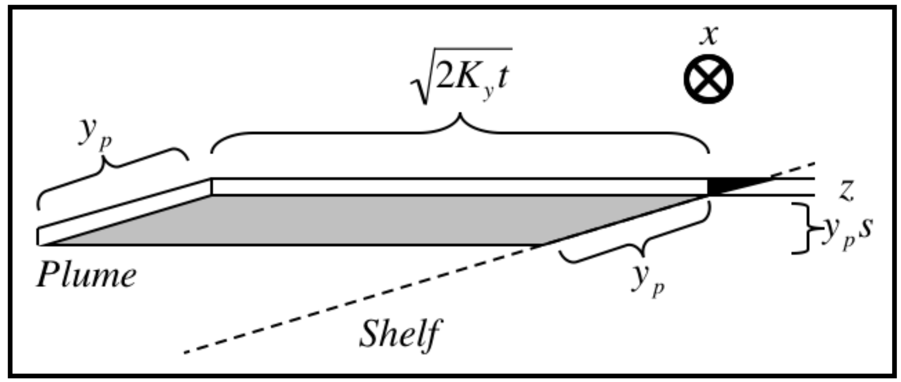
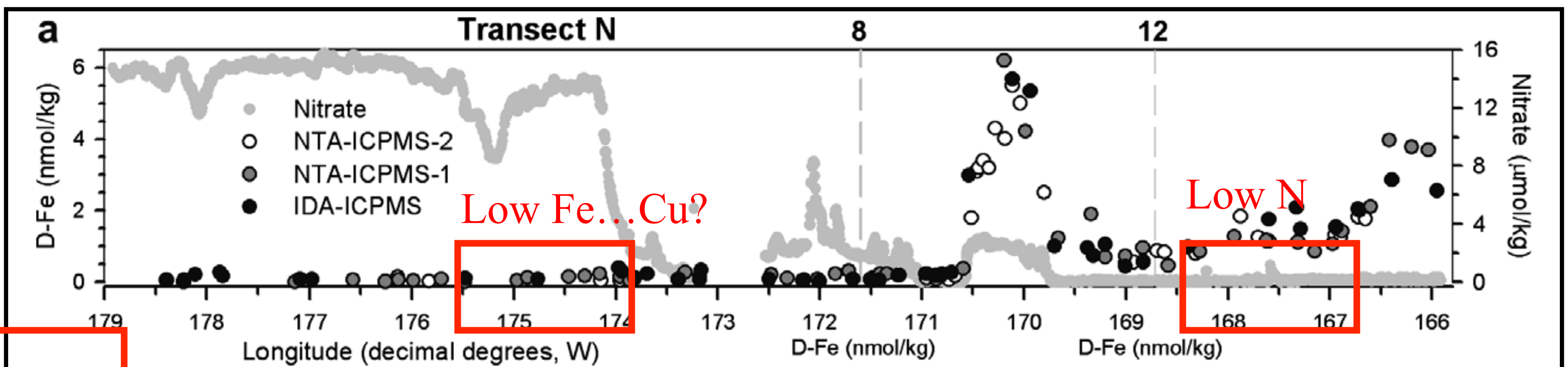
Methanotrophs, Resource Limits



GRL 2010
JGR 2011

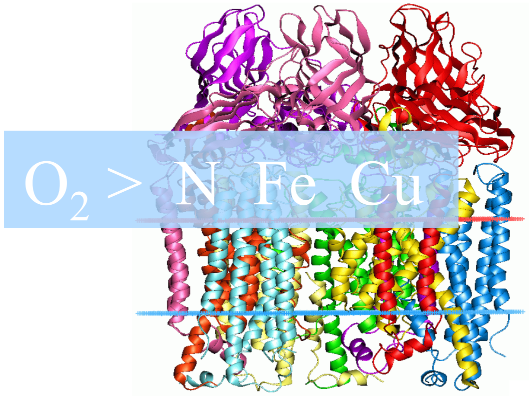






Low O_2, acidification

1^{st} CUT: RESOURCES



METHANOTROPHS, LBL patches

POP: 8 sites, 300 meters, 30 years

RESULTS: Hypoxia, acidification

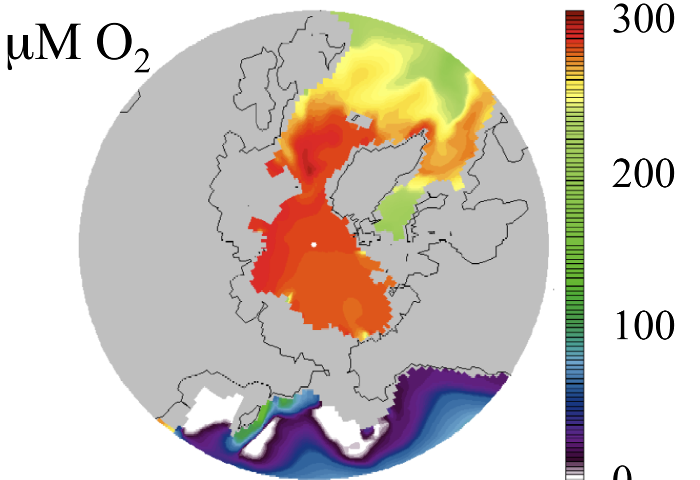
OFFLINE: Gaussians, observations

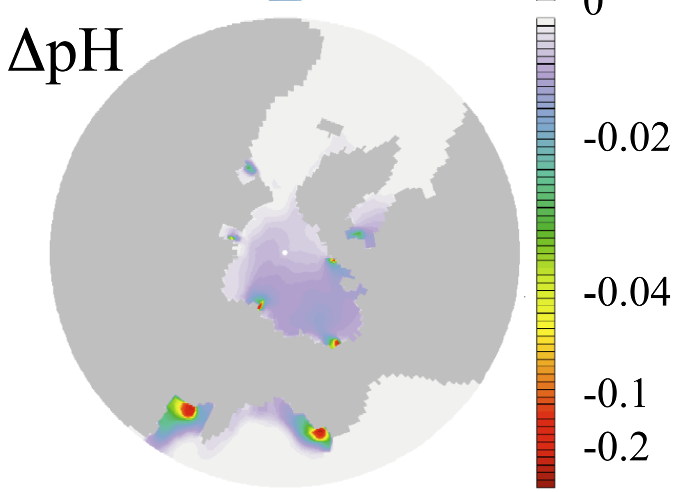
FURTHER: N, Fe, Cu loss

GENERAL:

- Regional depletions
- CH_4 plume expansion

GRL 2010, JGR 2011





CODiM Results

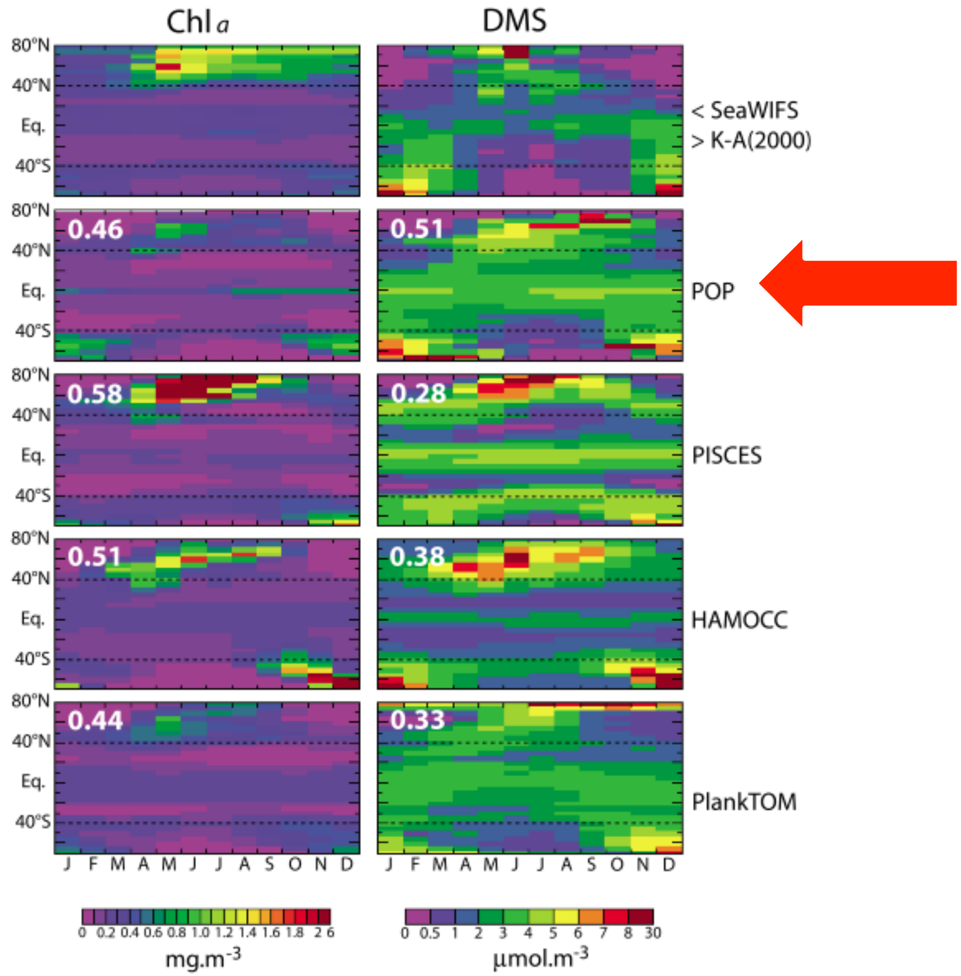


Figure 2. Latitude-time (Hovmøller) plots of (top row) climatologies and (following rows) results from 4 global models for (left column) chlorophyll *a* (Chl *a*) ($mg \cdot m^{-3}$) and (right column) DMS ($\mu mol \cdot m^{-3}$). Data were binned and averaged in 5° latitude × 1 month boxes and are displayed here from 70°S to 80°N on a linear color scale. Models are identified in Table 1. Numbers in the upper left-hand corner of each model plot are the Spearman rank correlations between the variables (Chl *a* or DMS) simulated by the corresponding model and the SeaWiFS or *Kettle and Andreae* [2000] climatologies represented in the top panels.

Table 2. Annual average increase in DMS flux going from a present-day climate to a future climate, in 10º latitude bands, for the models in Table 1[a].

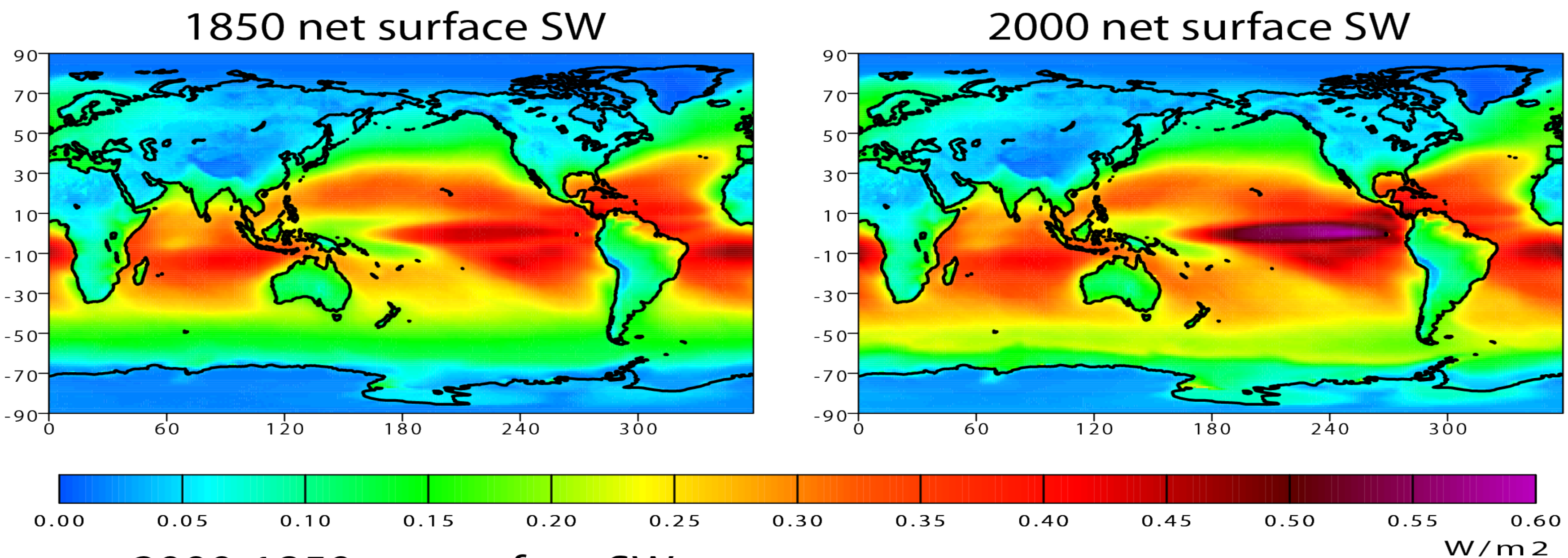
	Reference	**Degrees South Latitude**								**Interpretation**
		80-70	**70-60**	**60-50**	**50-40**	**40-30**	**30-20**	**20-10**	**10-Eq**	
	Gabric et al., 2001,03		+30		+5					Ice cover domiates
	Gabric et al., 2004		+50	+105	+30	+10	+5	+5	+5	ML[b] changes dominate
PNAS 2007	*Vallina et al.*, 2007	-5	0	+5	+5	0	0	+5	+5	ML[b] changes dominate, notes [c]
	Bopp et al., 2003		0	(+10)	+30	+10	(0)	(-10)	-15	See text, notes [d,e,f]
	Kloster et al., 2007	>+30	+10	-20	0	0	-10	-10	-10	See text, notes [d,f]
GRL 2011	This work	+170	+70	-15	+5	0	-10	-10	-10	See text.

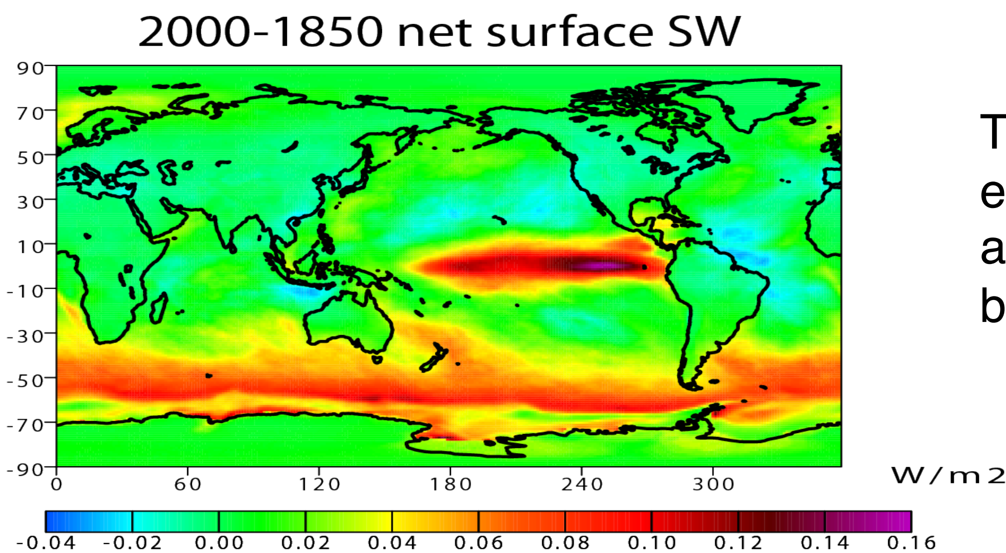
[a]The percentage changes are taken directly from text interpretations in the original work wherever possible, and rounded to the nearest 5%.

[b]ML stands for 'mixed layer'.

Table from Mess

20th Century change in net SW radiation from *direct* DMS sulfate –up to tenths W/m²





The effect of sulfate from DMS is enhanced in tropics because of

a) higher solar radiation,
b) faster oxidation of SO_2 to SO_4.

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C, chlorophyll major phyto-classes

Inorganic Ballast (SiO_2 & $CaCO_3$ with hanging chad)

POM, DOM

ESM have above

ESM need below

..Cysteine, methionine, DMSP, DMS, DMSO

Polysaccharides carboxylated and otherwise

Amino acids, peptides, proteins, derivatives

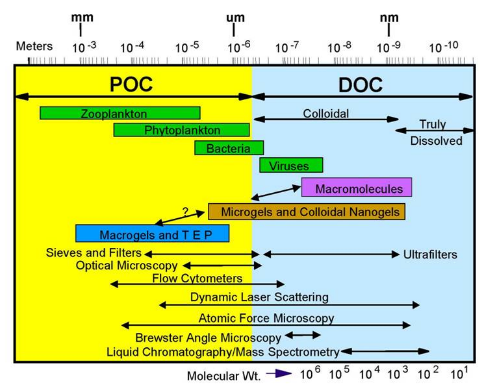
Lipids, peptidoglycan, chitin, lignin

Isoprene and monoterpenes

Volatile organics and halogenates

Bacteria, viruses, bioparticles

JGR, GBC ,GRL



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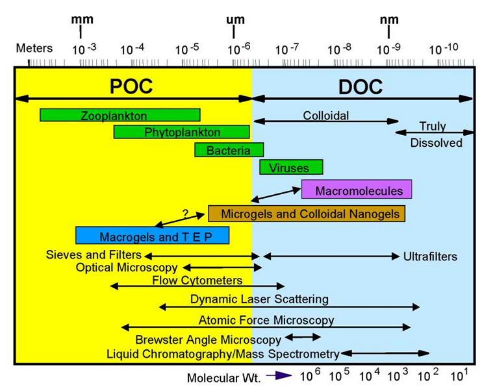
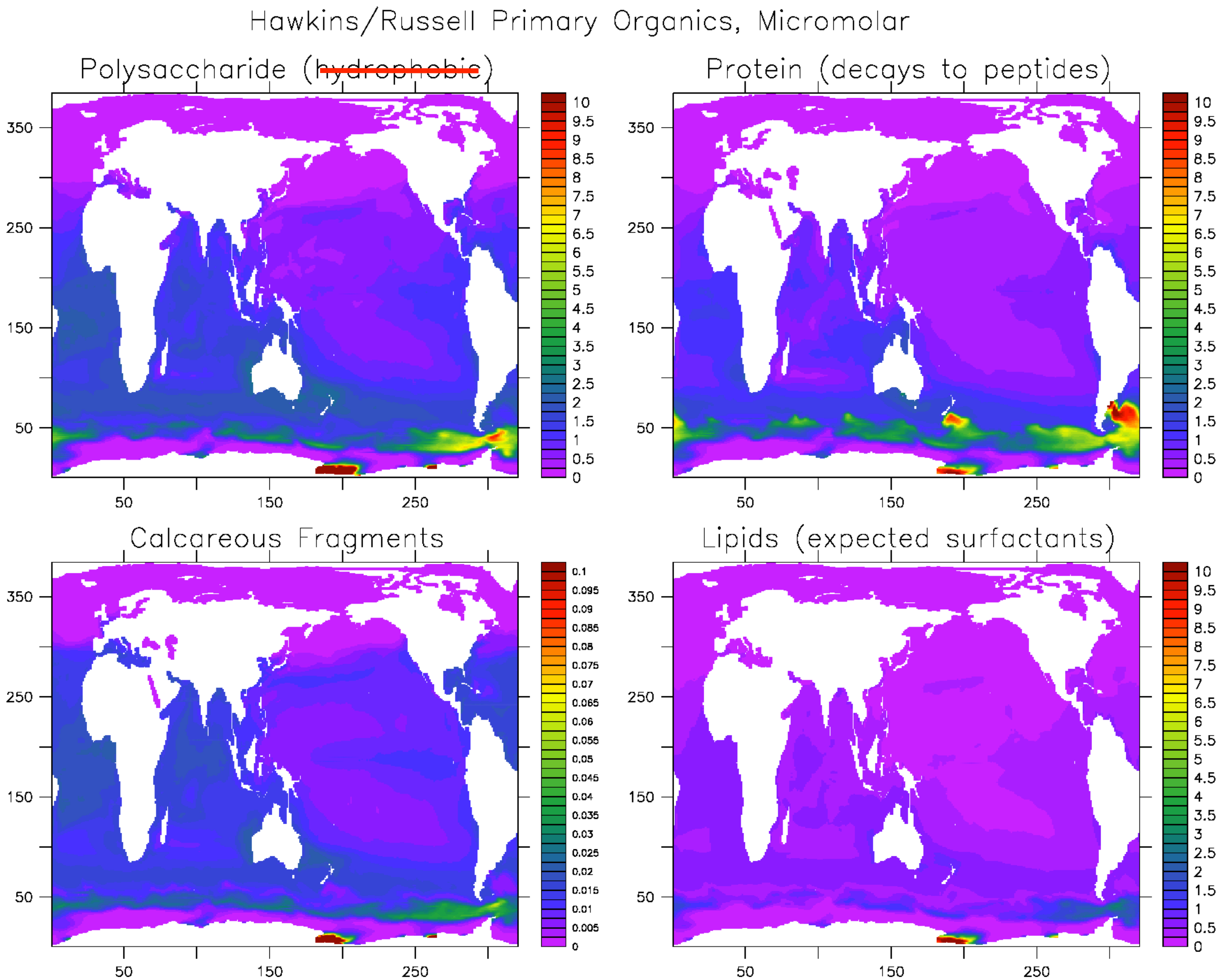
JGR, GBC ,GRL

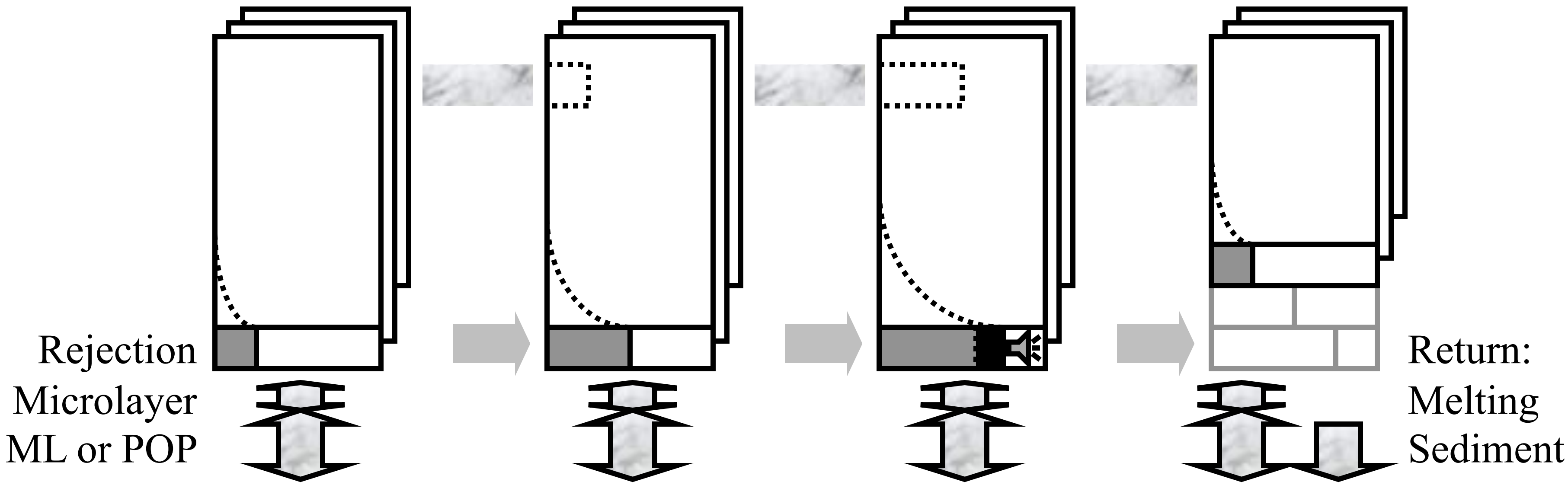



Hawkins/Russell Primary Organics, Micromolar
Polysaccharide (~~hydrophobic~~)
Protein (decays to peptides)
Calcareous Fragments
Lipids (expected surfactants)
350
250
150
50
50
150
250
10 9.5 9 8.5 8 7.5 7 6.5 6 5.5 5 4.5 4 3.5 3 2.5 2 1.5 1 0.5 0
0.1 0.095 0.09 0.085 0.08 0.075 0.07 0.065 0.06 0.055 0.05 0.045 0.04 0.035 0.03 0.025 0.02 0.015 0.01 0.005 0

HawkRuss

CICE Bottom Layer BGC

Ice categories with evolving box SKL, expand outward



General: Nutrient data

Monod L_i
Redfield ratios

Graze 10%
N/S routing

Fractional return
of N, Si, C, S

Jin et al.: Brine flushing

Continuous L
Adjust absorption

Algal flushing

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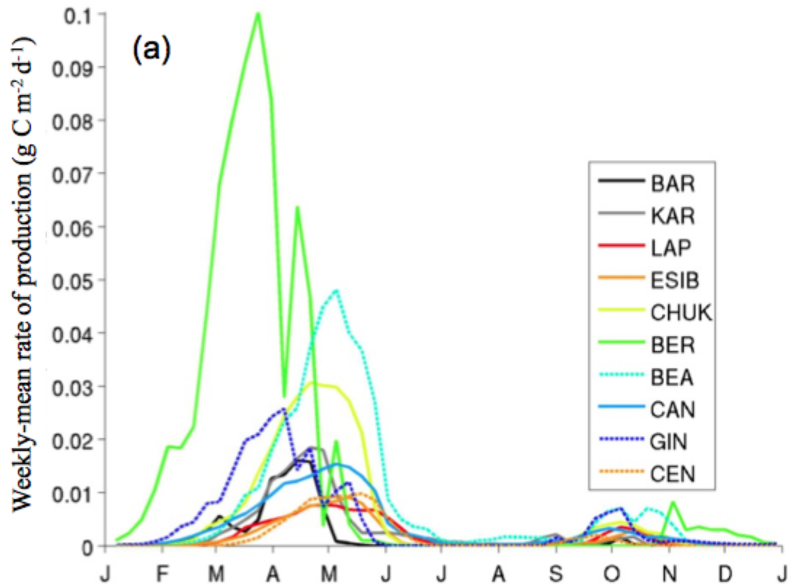
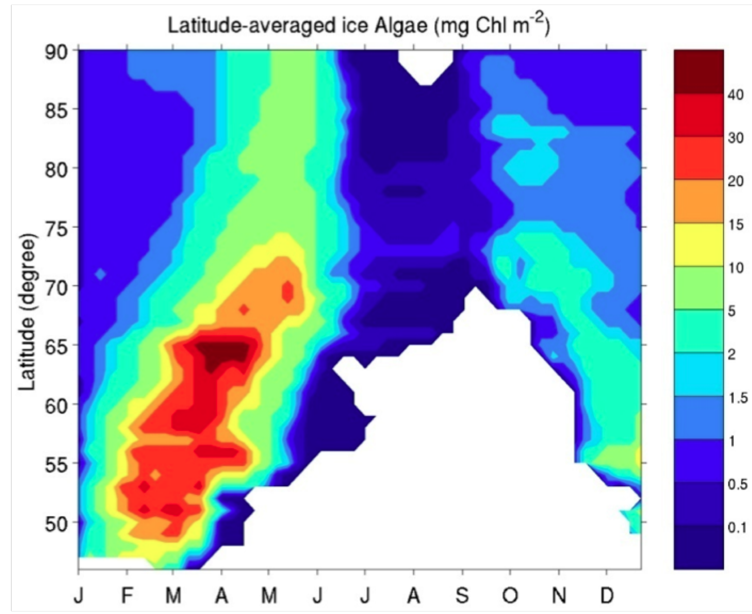
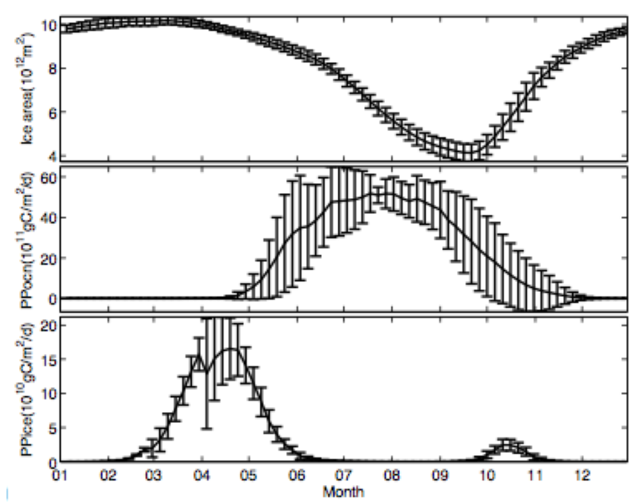
All roads lead first to ecodynamics…

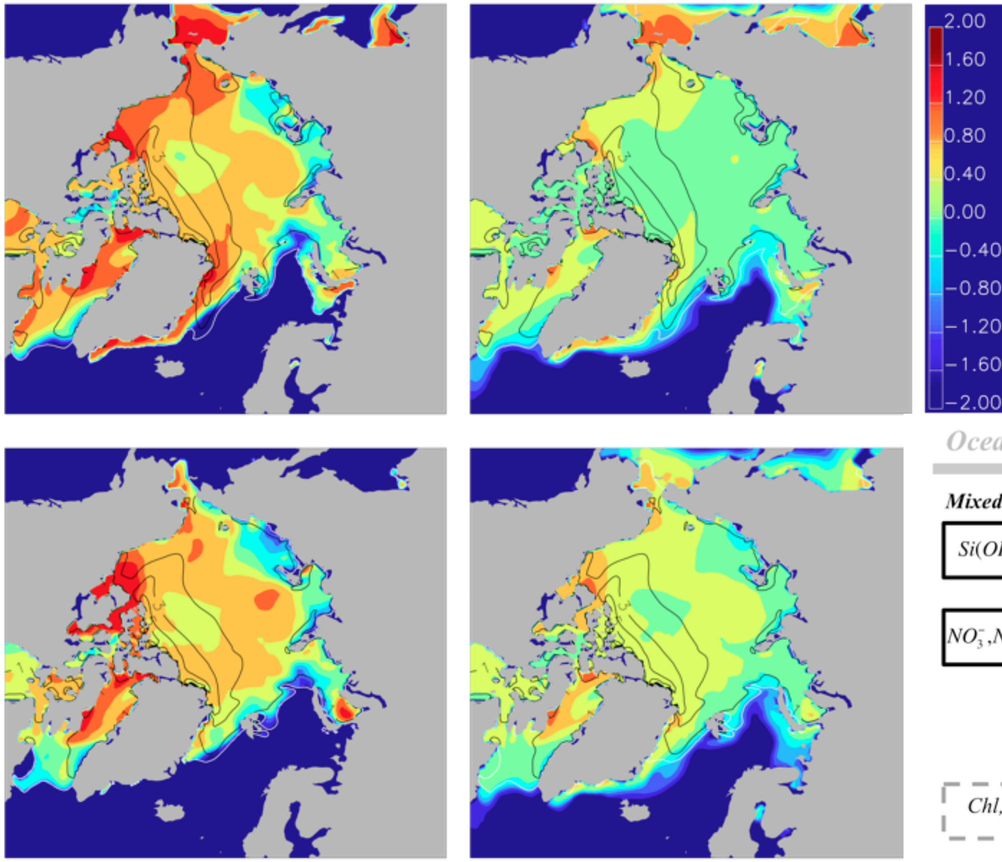






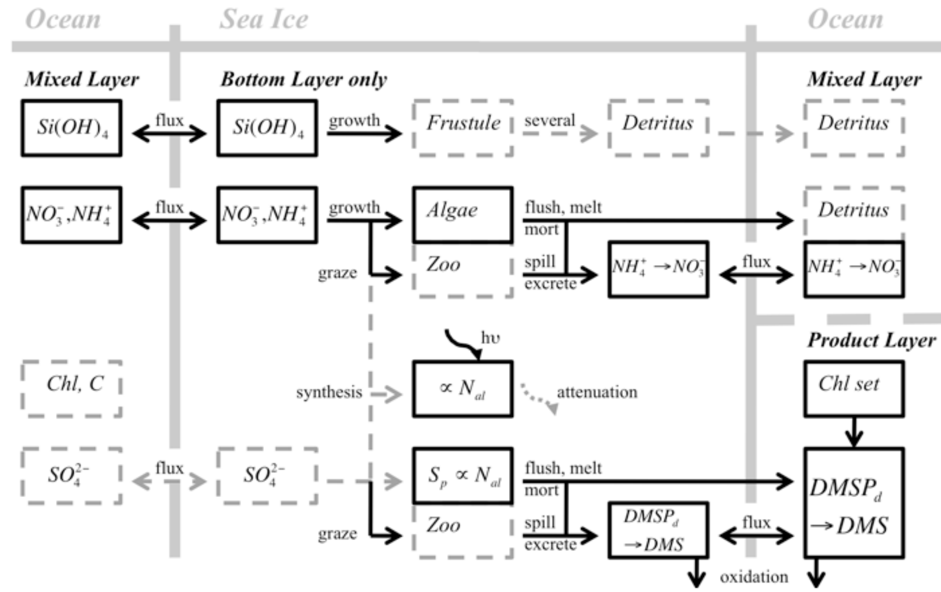
JGR and DSR

IARC collab



$\log_{10}$Chl (l), mg/m^2
May 1992 (upper)
|June 1992 (lower)

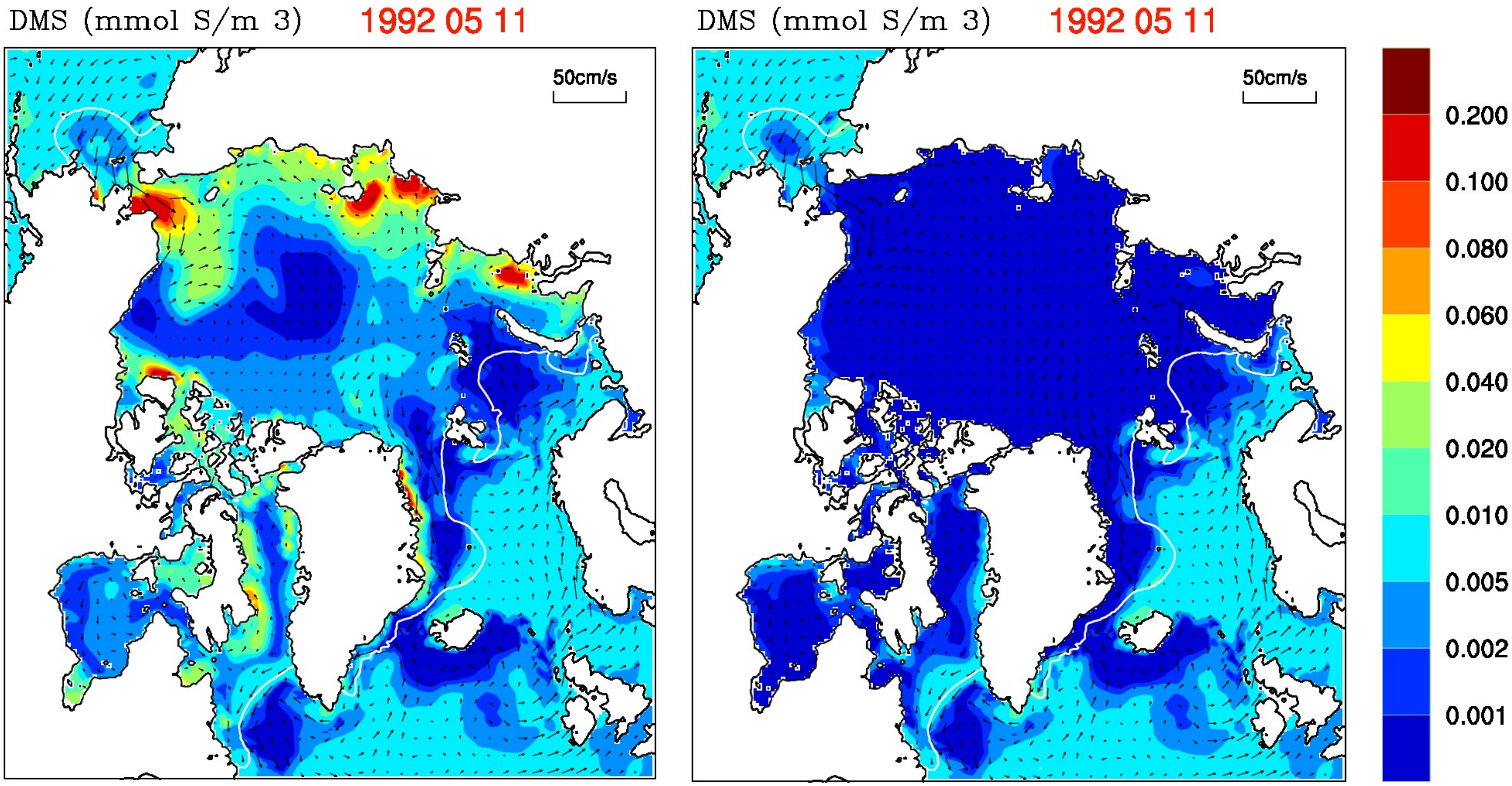
$\log_{10}$DMS (r), nM



Chl in, DMS from bottom:

JGR, in revision

DMS: CICE bgc on-off

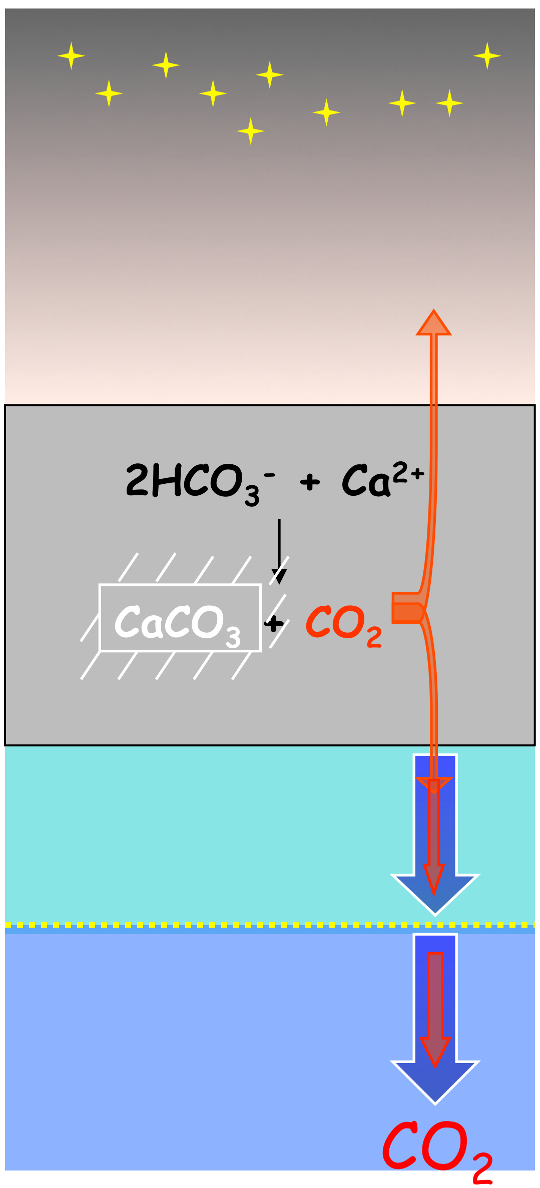


DSR, sulfur in revision JGR

GAS COMPOSITION IN SEA ICE

A potential abiotic $CaCO_3$ Carbon pump

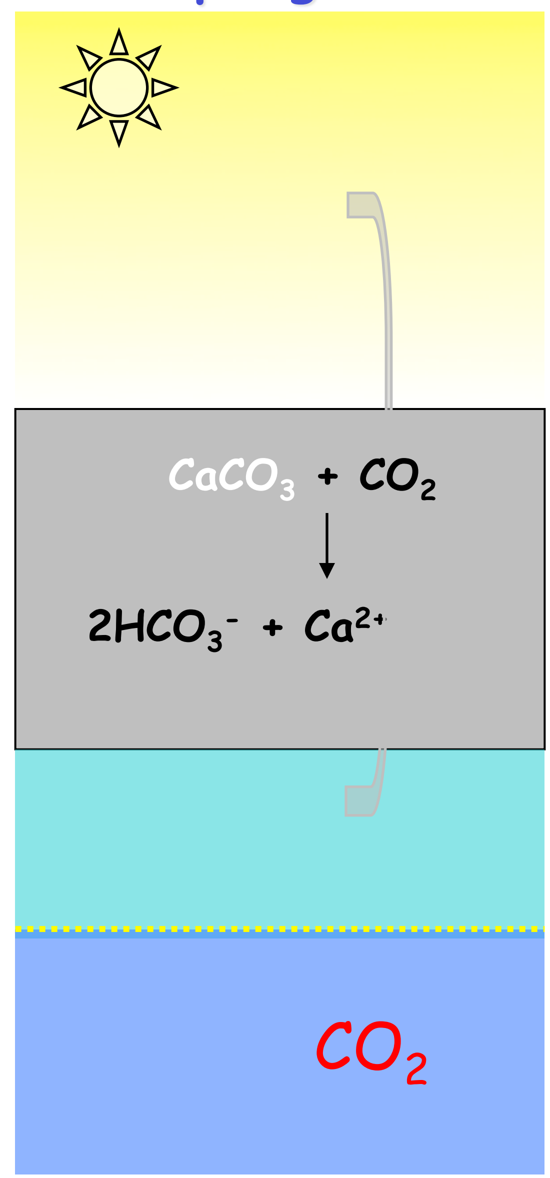
fall/winter



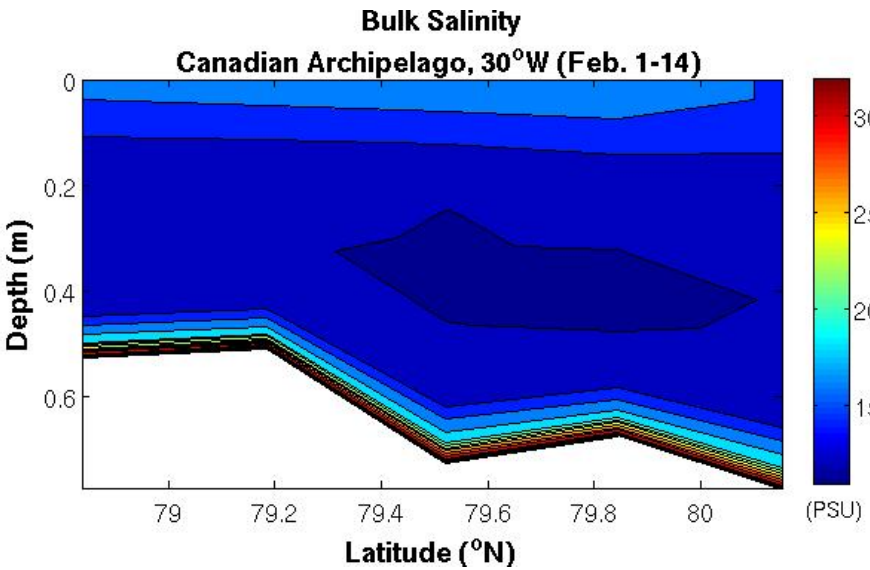
- In spring, $CaCO_3$ trapped within sea ice dissolves. This process consumes CO_2.

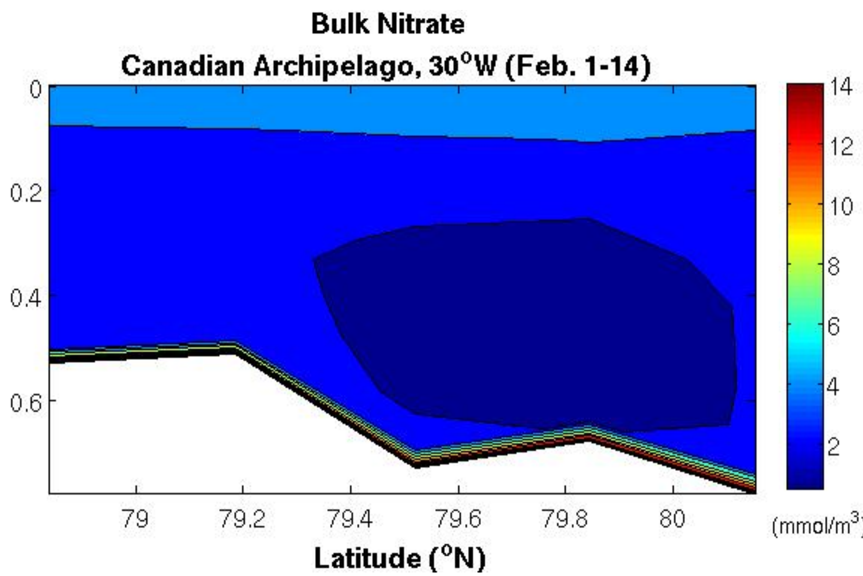
- Budget of winter and spring processes is a net sink of CO_2. It depends on:
- ratio of $CaCO_3$ trapped vs CO_2 expelled (?)
- quantity of CO_2 which pass below the pycnocline during the autumn-winter (?)

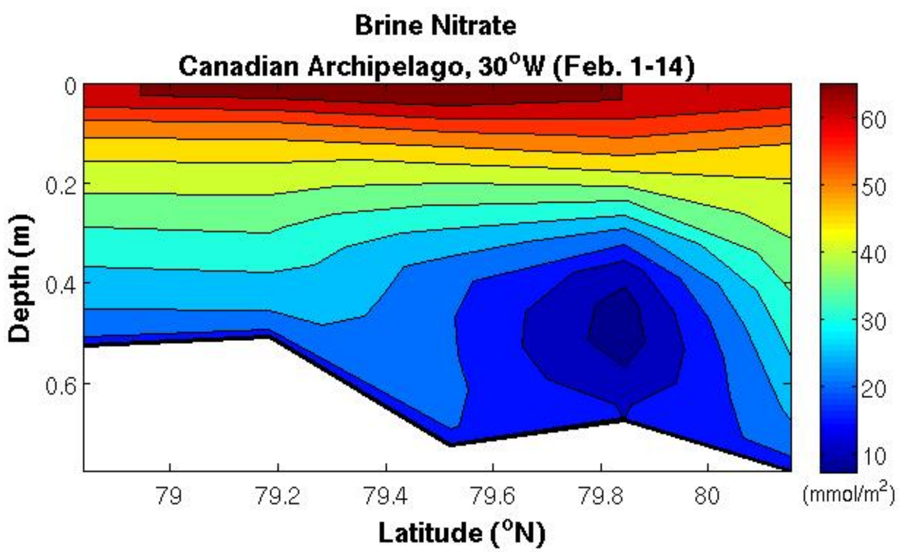
spring

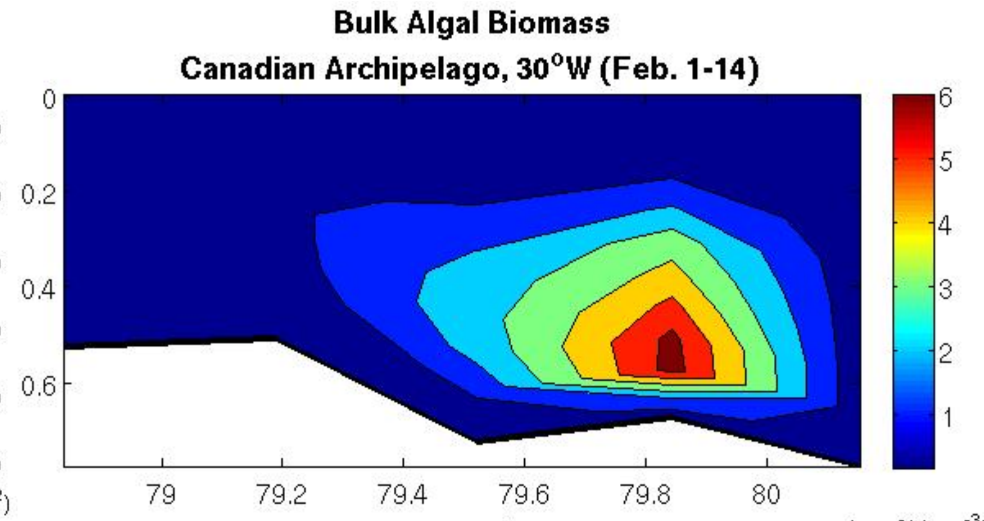


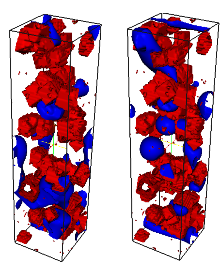
Rysgaard et al., 2007, Delille et al., in prep.











algorithm in press, JGR
(Nicole, don't forget the bubbles)

NJ goes 3D

EXTRA EXTRAS

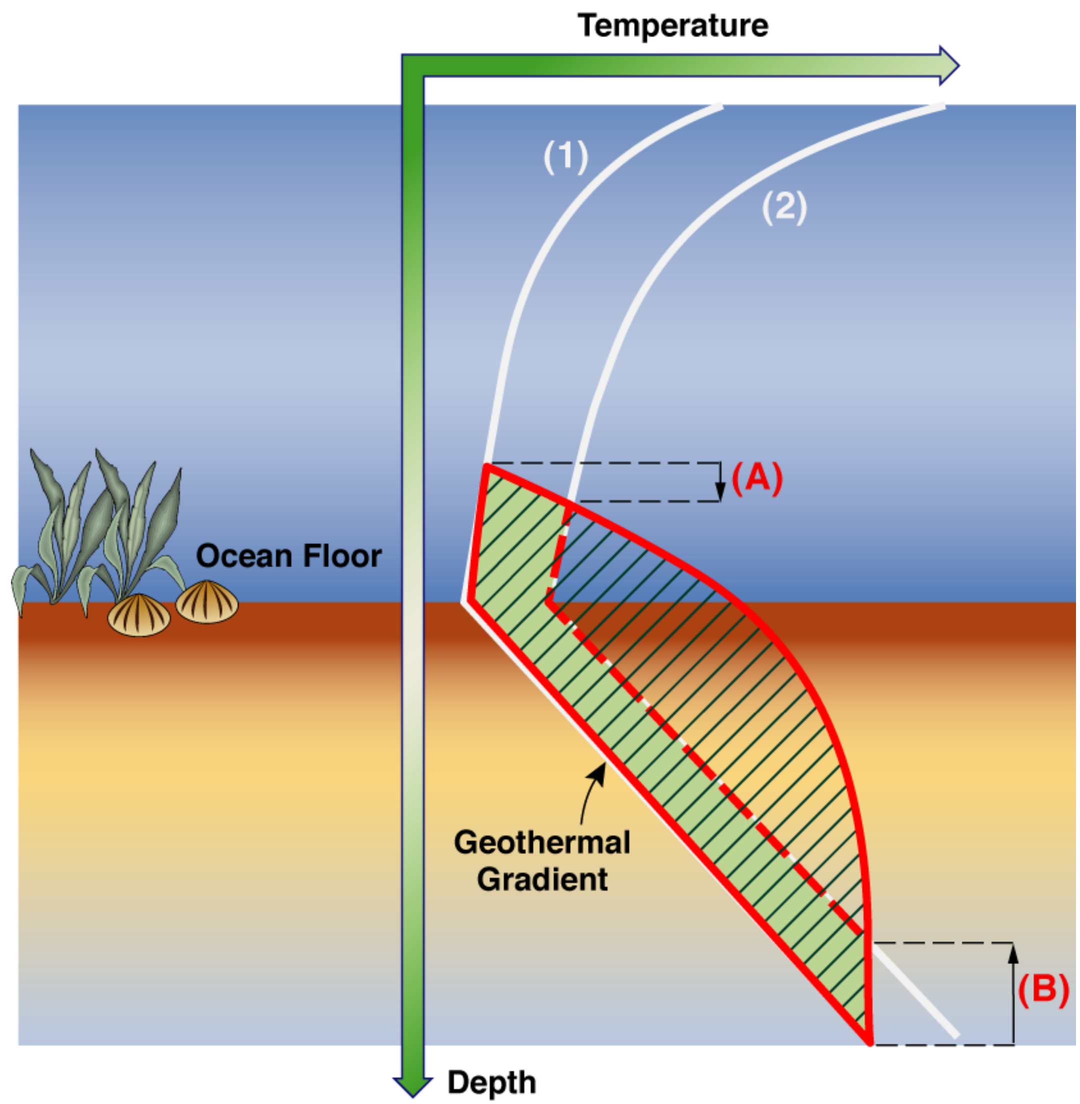
Oceanic Gas Hydrates:Dissociation

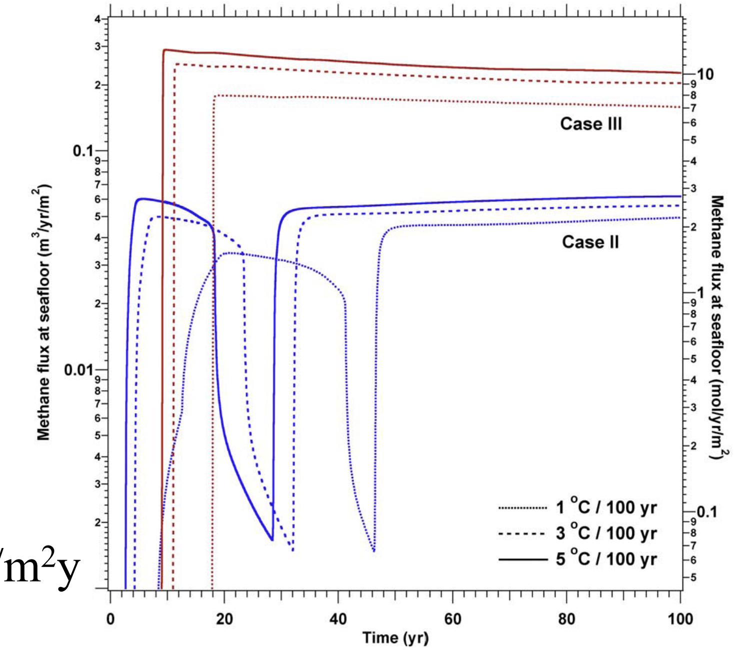
Climate change alters ocean temperature (and geothermal gradient)

Decreases hydrate stability region

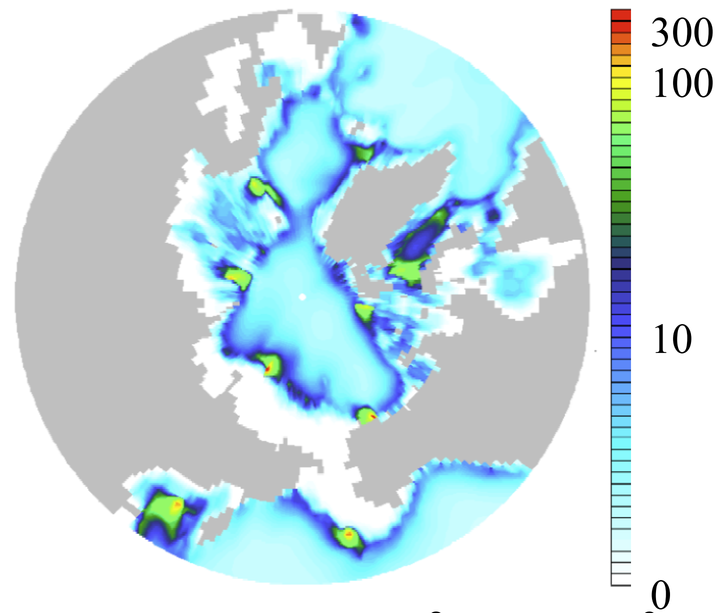
Methane release to ocean by hydrate dissociation

What happens between (1) and (2)?



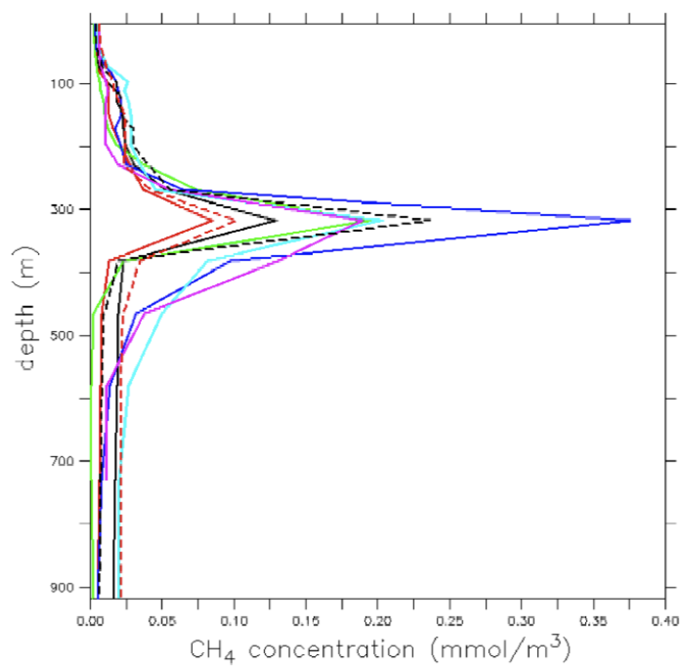


LBL,
mole/m^{2}y

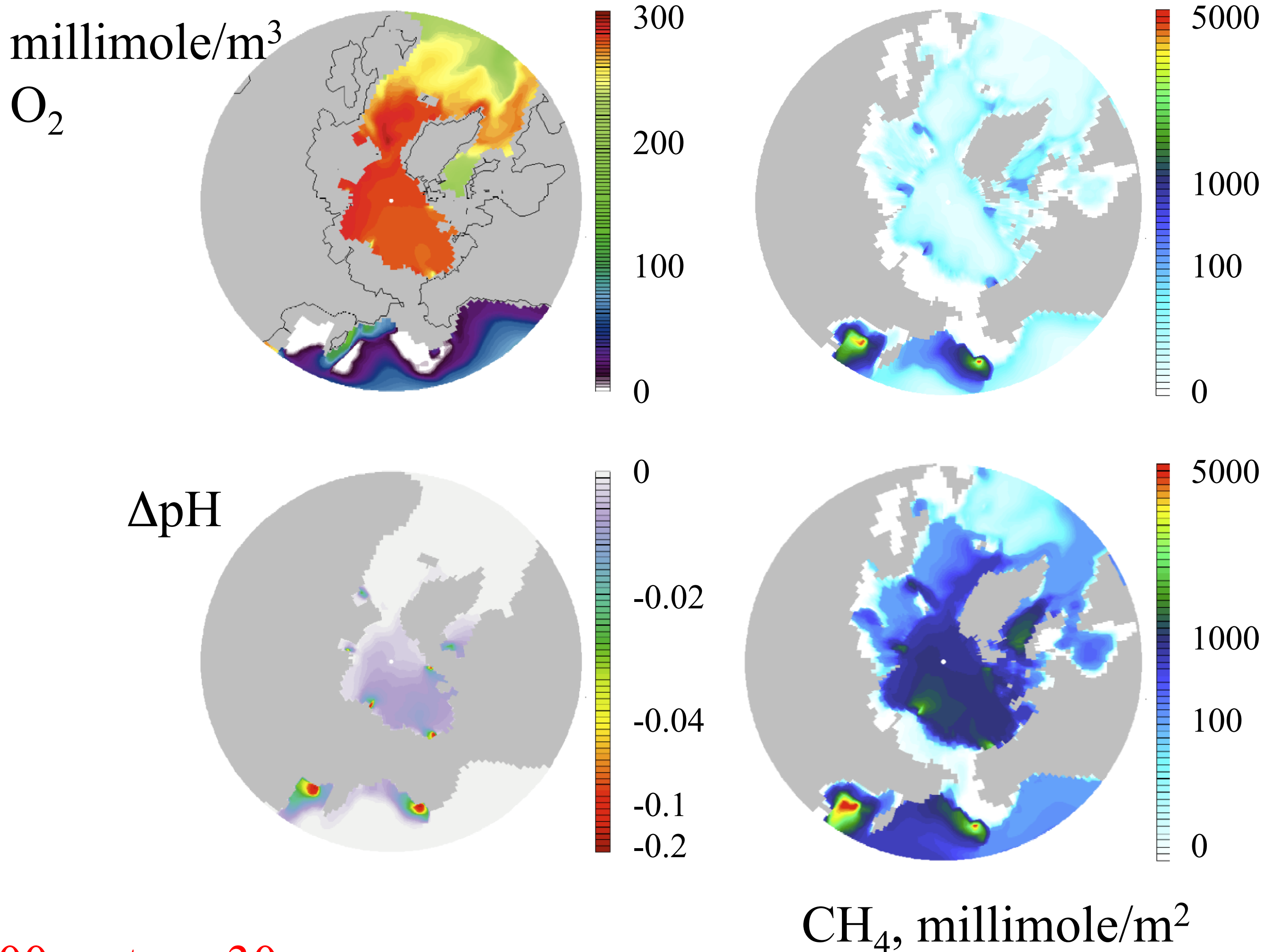


CH_4 (millimole/m^2 and /m^3)

320 meter fluxes
8 one-cell sites
Empirical τ
30 years, coarse POP



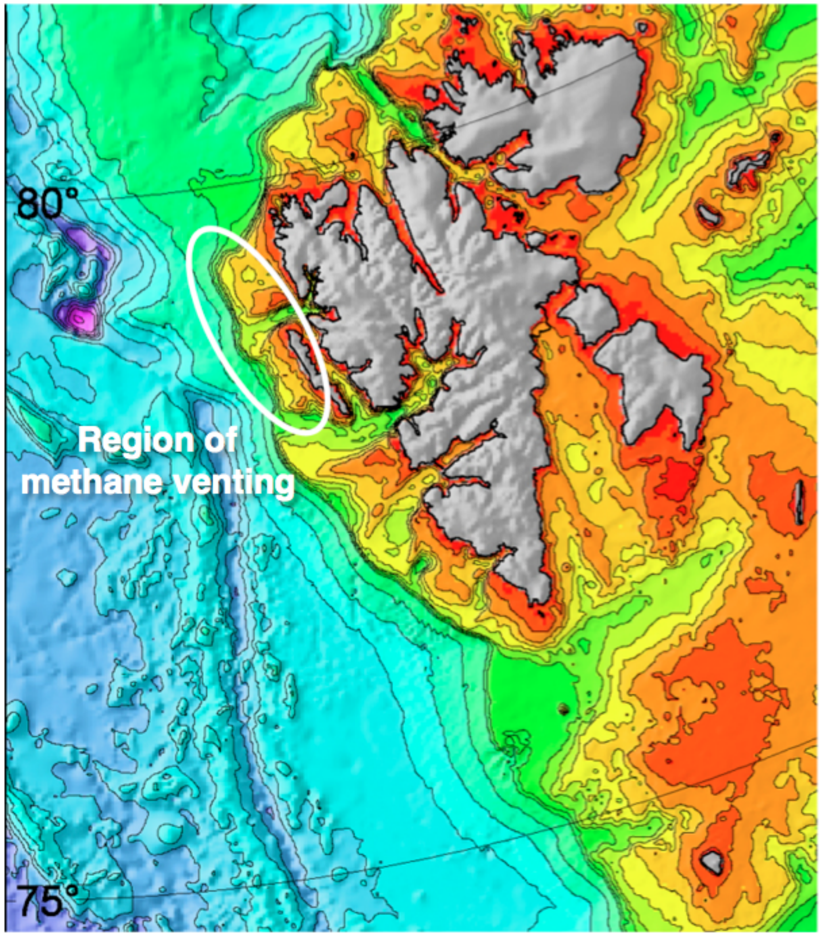
O_2, CO_2 and Plume Expansion



300 meters, 30 years

2-D Hydrate Dissociation Model

from NOAA/IBCAO (http://www.ngdc.noaa.gov/)



[4]Westbrook, G.K., *et al.*, Escape of methane gas from the seabed along the West Spitsbergen continental margin *Geophys. Res. Lett.*, **36**, L15608, doi: 10.1029/2009GL039191, 2009.

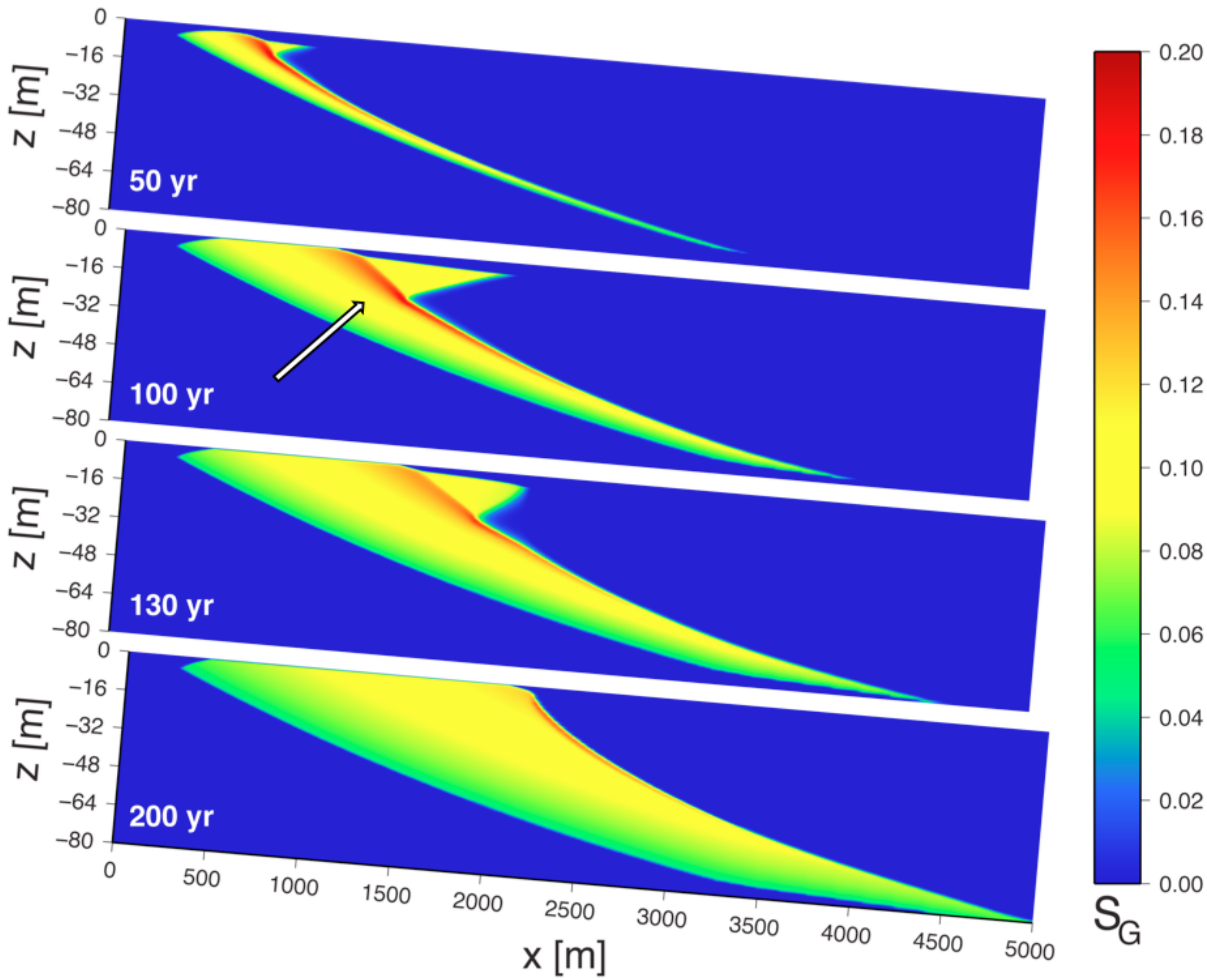
- Methane plumes reported west of Svalbard at the upper limit of a receding GHSZ[4]
- Region affected by recent measured warming

- Could shallow hydrates alone produce such plumes?

- Could similar systems exist elsewhere?
- How much methane could be released on short timescales?
- Do we need to supplement the 1-D column model?

2-D Hydrate Model: Rapid Change

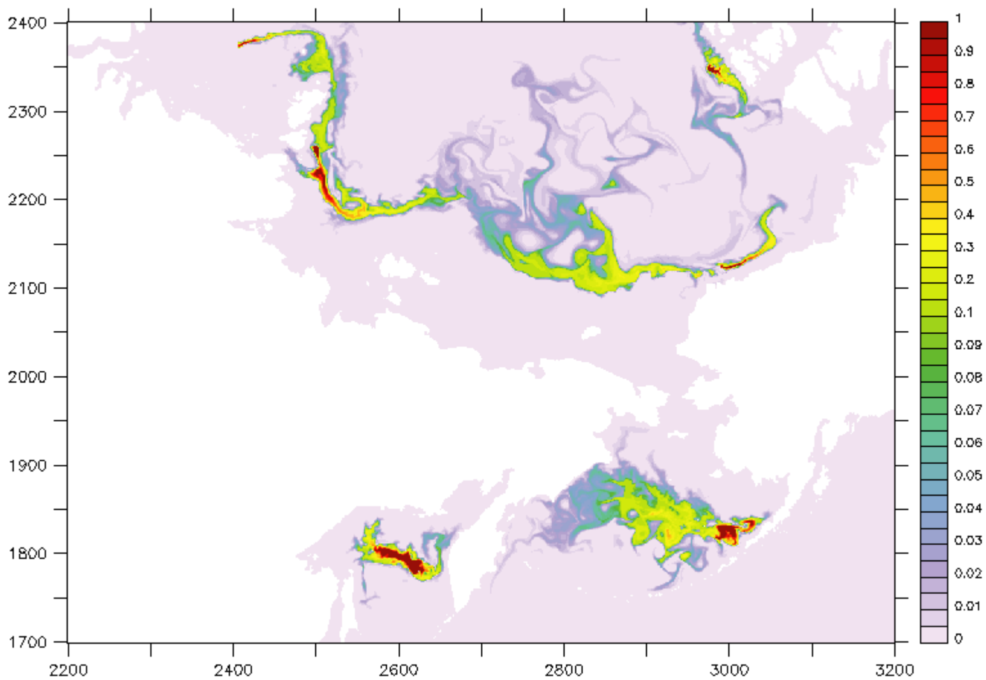
- A linear change of 3°C/ 100 yr imposed for 100 yr, then temperature held constant
- A "plume" of high gas saturation forms at upper limit of dissociating hydrates
- Plume focused by the remaining hydrate layer
- Plume reaches seafloor and moves downslope within the sediments



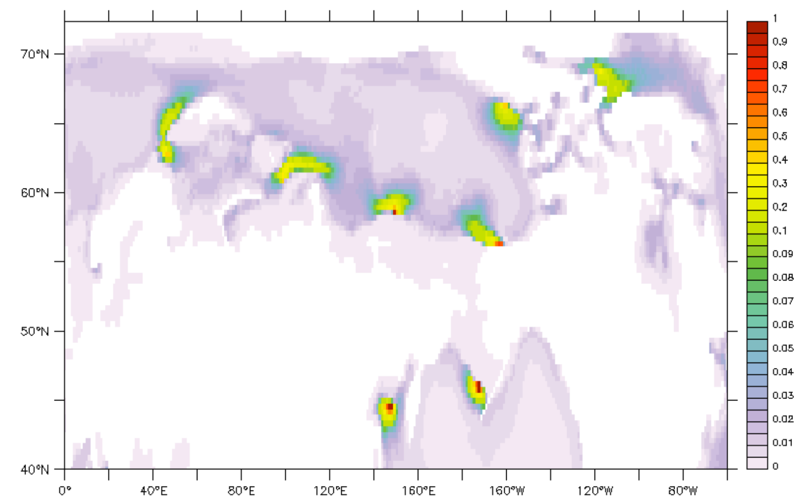
Vertically integrated concentration

(*normalized by maximum*)

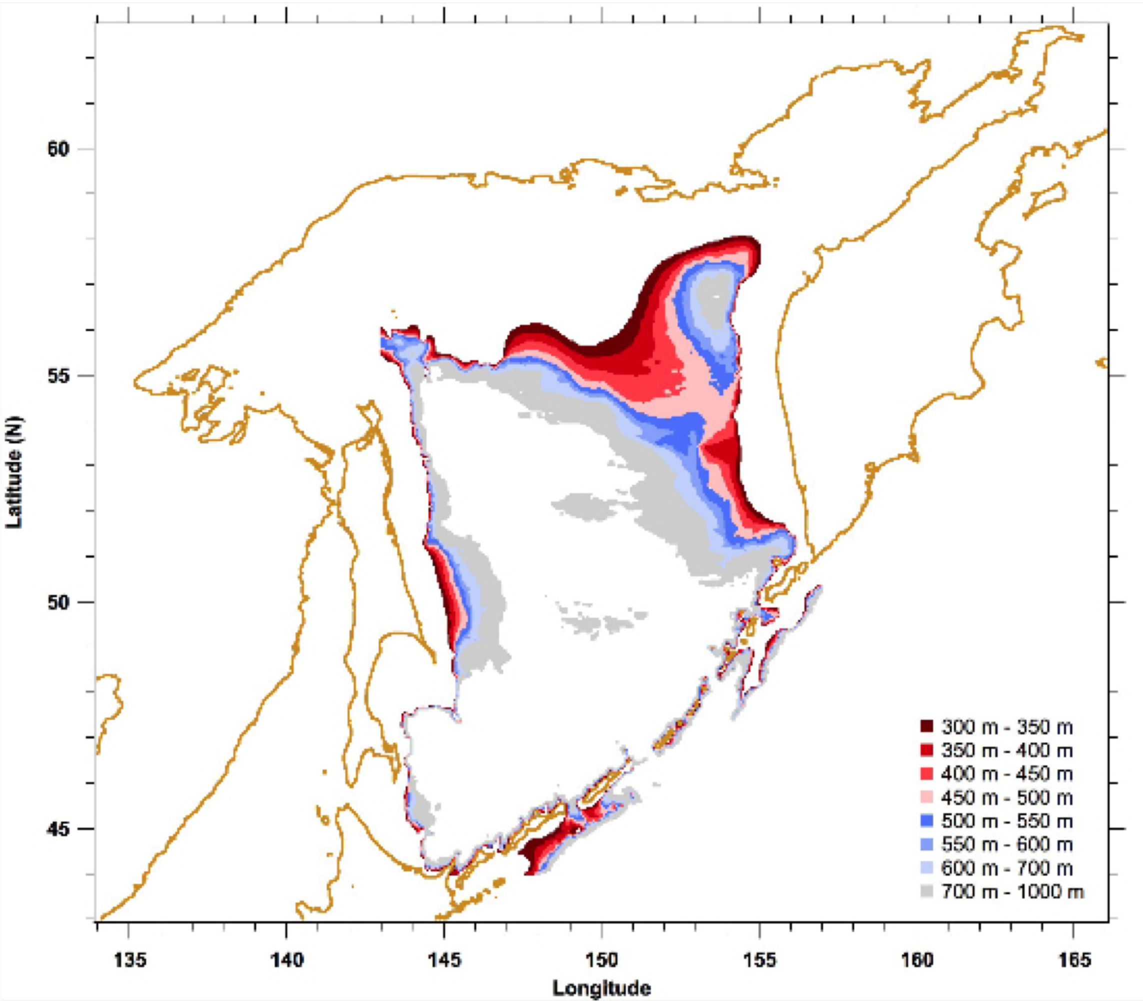
1/10º after 6 months



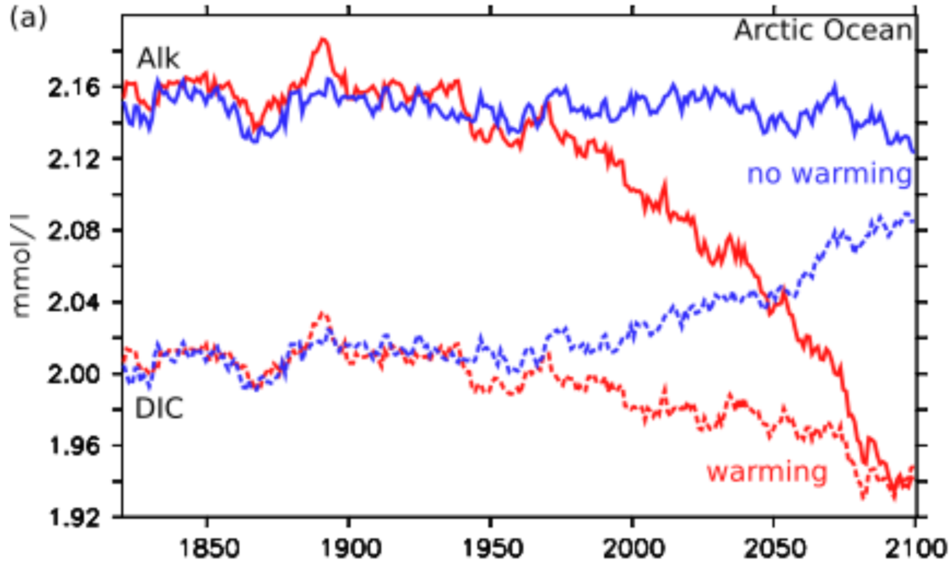
1º after 12 months



(The Okhotsk is going to light up like a candle, dudes



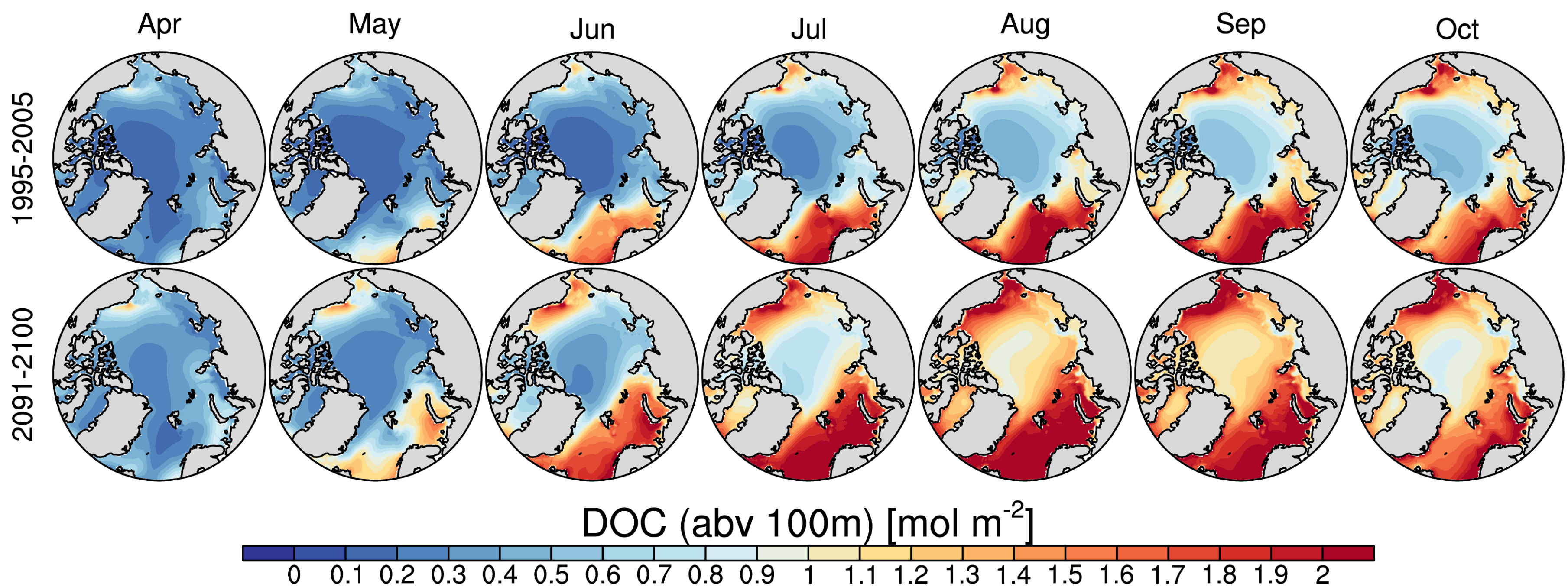
Reagan 2011
Sea of Okhotsk Methane Budget



Arctic pH, C storage

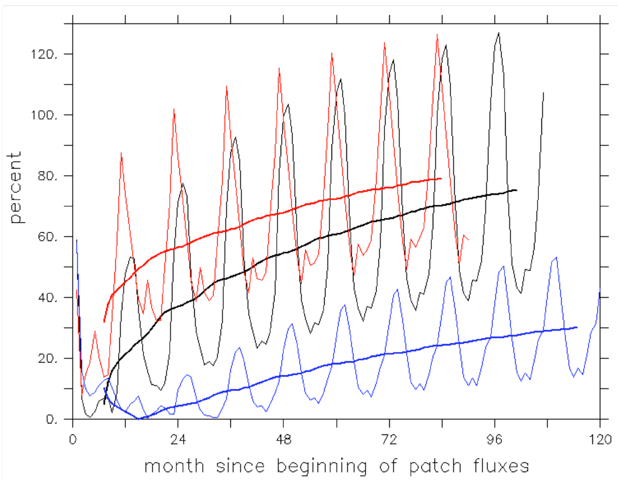
C anions balance Alkalinity

Convert to DOC, POC

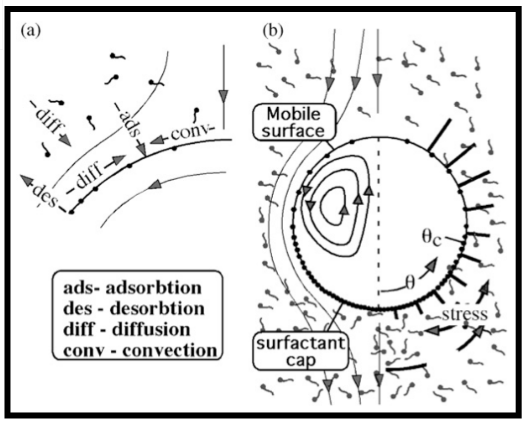


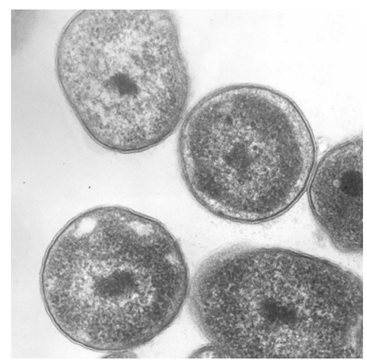
Bubbles, Matrices, CH_4 Futures

Enter mixed layer from:
50 meters
150 meters
300 meters



Percent CH_4, Atlantic Layer to Arctic Mixed Layer (conservative K_v)						
		Bubble Rise (vertical from destabilization at 350)				
		0 m	100 m	300 m (floor up)	300 m (Δ100)	>300 m
Circuit	**Biology**					
1,000 km	on	0	0	**0**	**0**	**100**
	off	0	0	**10**	**20**	**100**
10,000 km	on	0	0	**0**	**0**	**100**
	off	0	0	**20**	**40**	**100**
>10,000 km	on	0	0	**0**	**0**	**100**
(GIN mix)	off	100	100	**100**	**100**	**100**





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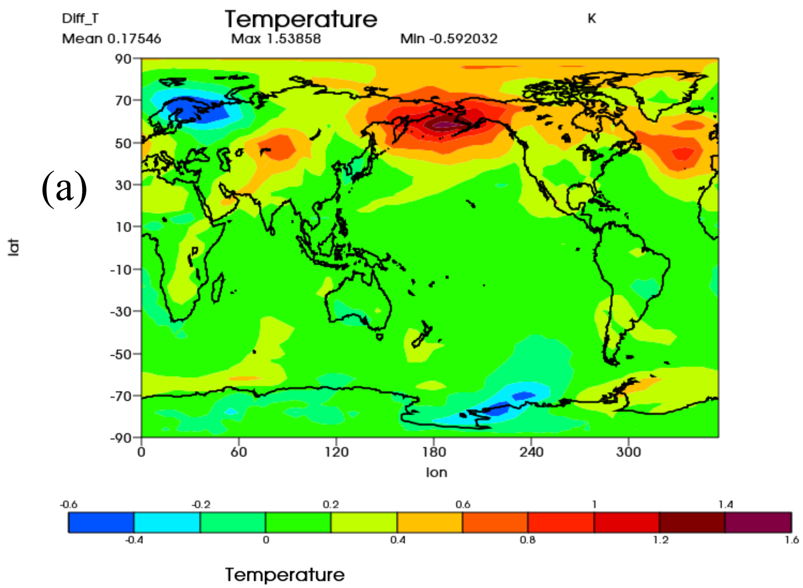
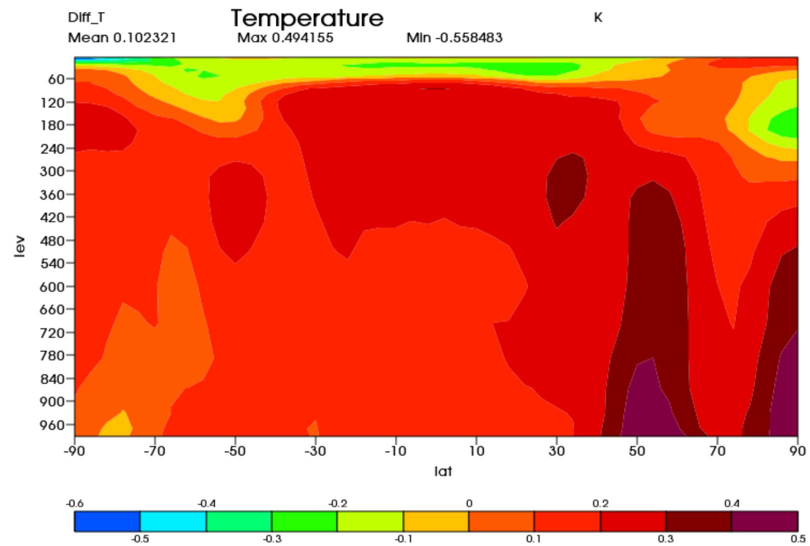
Notable Increase in temperature not spatially uniform

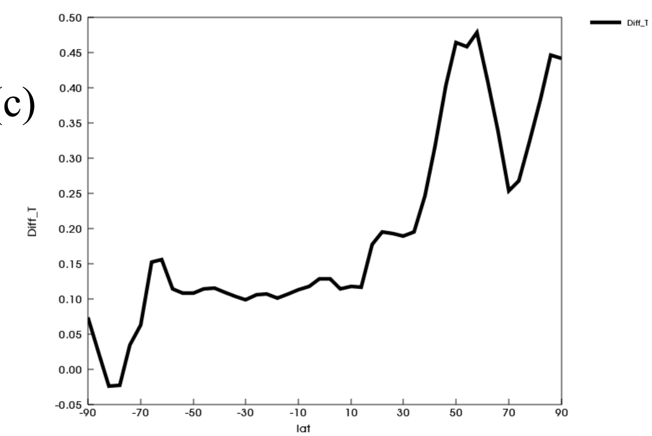
(a)



(b)



(c)



(a) Raw Difference in surface air temperature relative to control
(b) Raw Difference in Temperature averaged over longitudes
(c) Zonal Mean of Raw Difference in Surface Air Temperature

East Siberia falling through Cracks

Shakhova et al. document tens of nM at sea surface
Likely source is degrading submarine permafrost
Not covered in *any* CCSM working group

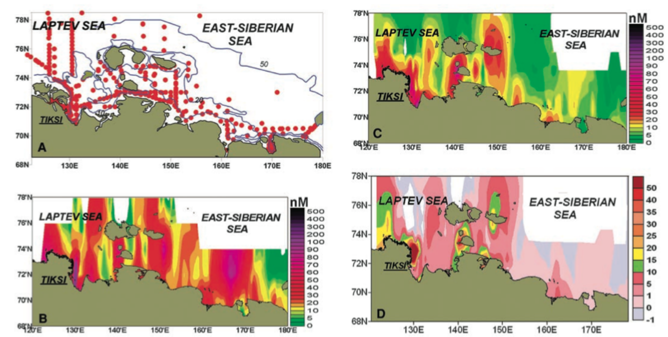


Fig. 1. Summertime observations of dissolved CH_4 in the ESAS (*21*). (**A**) Positions of oceanographic stations in the eastern Laptev Sea and East Siberian Sea; bathymetry lines for 10, 20, and 50 m depth are shown in blue. (**B**) Dissolved CH_4 in bottom water. (**C**) Dissolved CH_4 in surface water. (**D**) Fluxes of CH_4 venting to the atmosphere over the ESAS.

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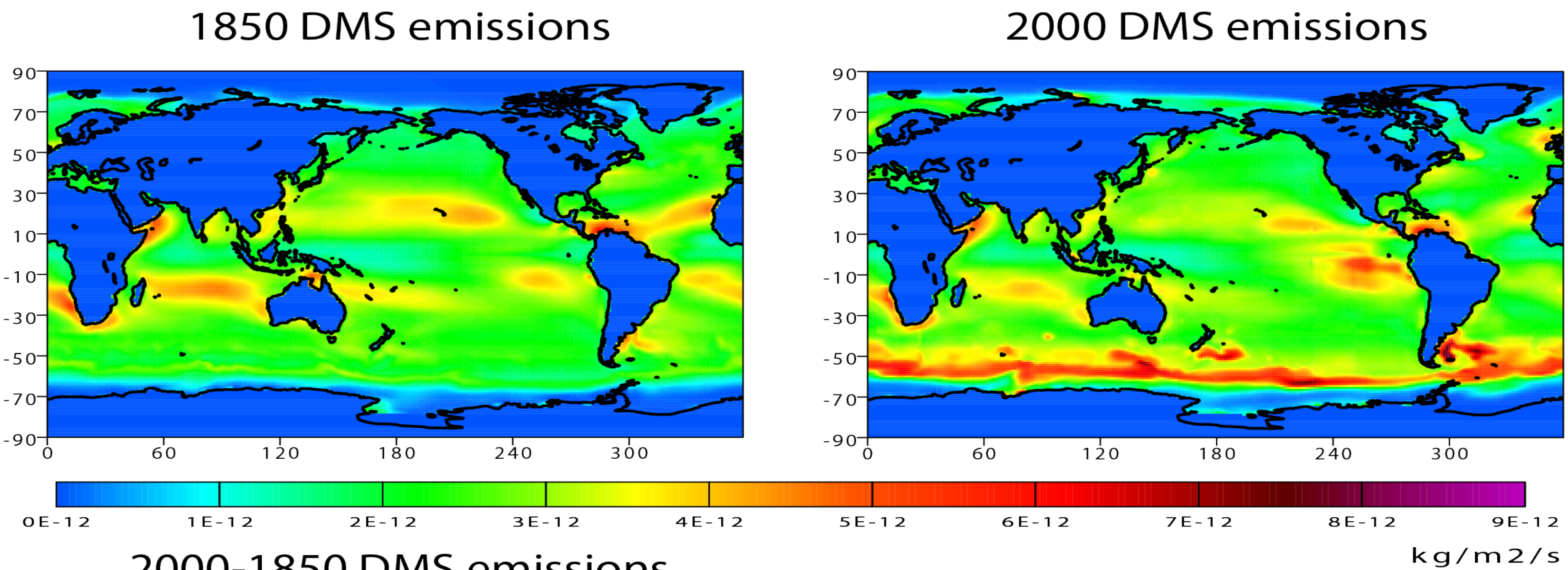
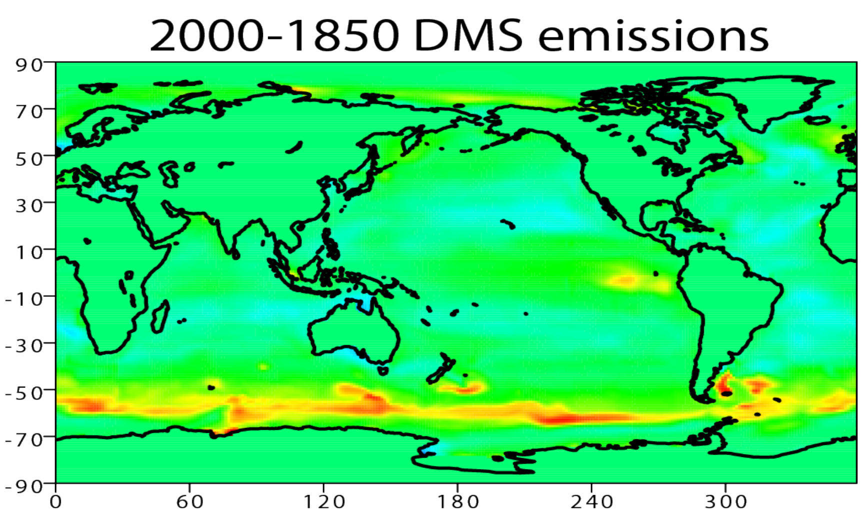
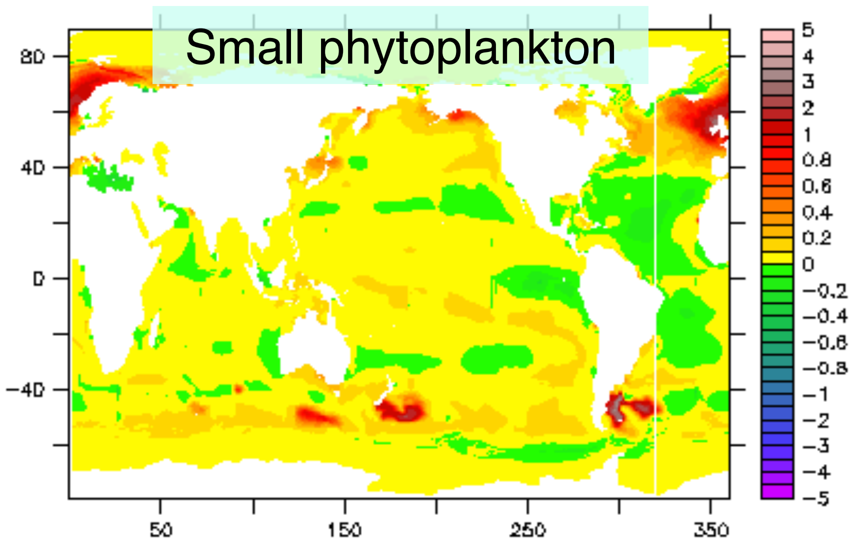
DMS flux changes dramatically from 1850 to 2000, especially in Southern ocean

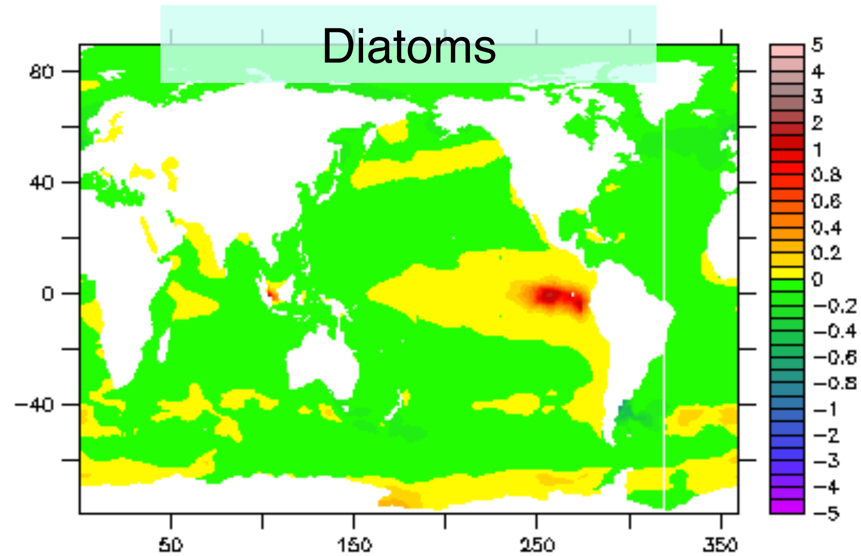


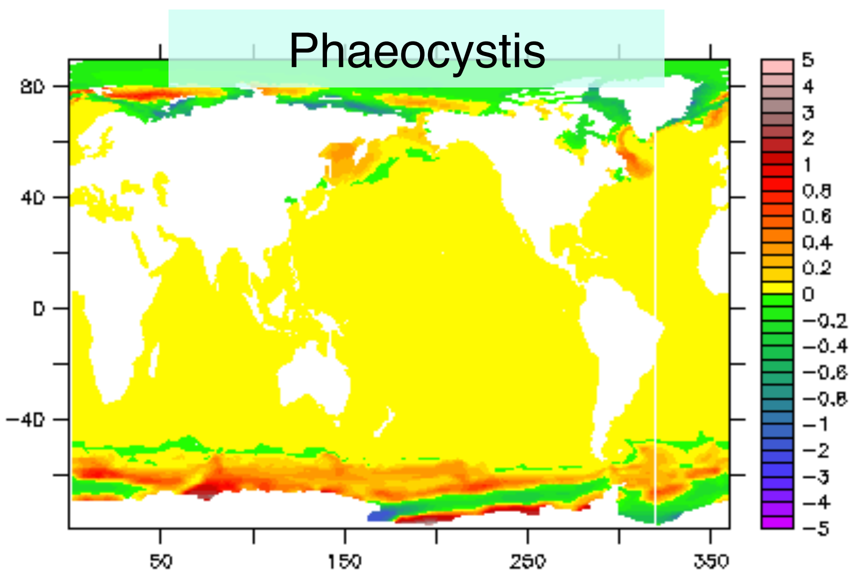


Globally averaged increase in DMS emission is 10%

Changes in DMS are strongly affected by changes in ecosystem structure.



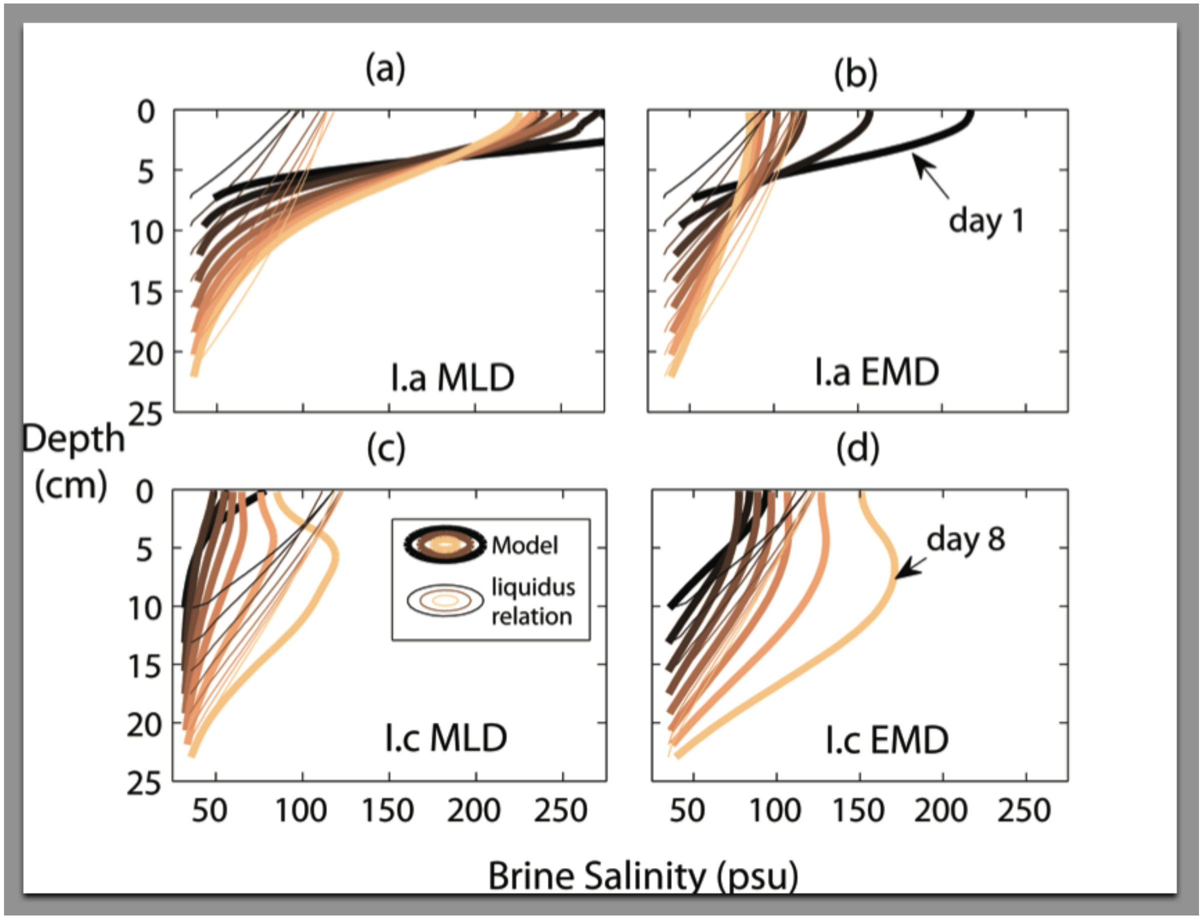


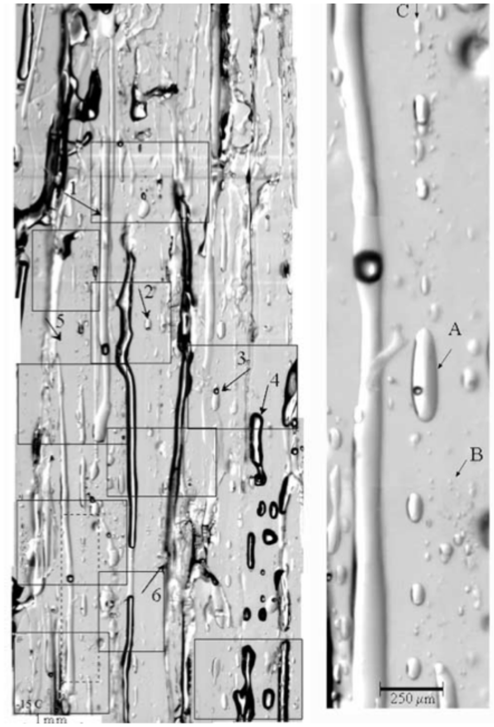


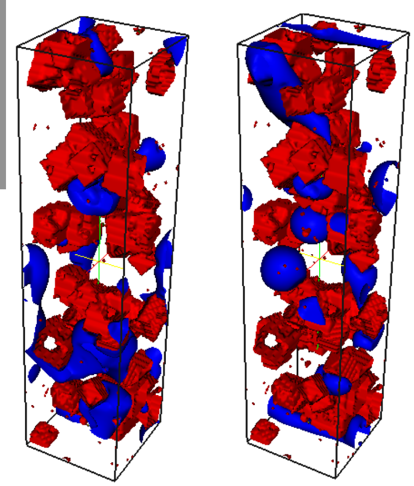
Change in DMS concentration (in sea-water) contributed by different phytoplankton types.

Units are normalized DMS concentrations, and are comparable across panels.

Through CICE

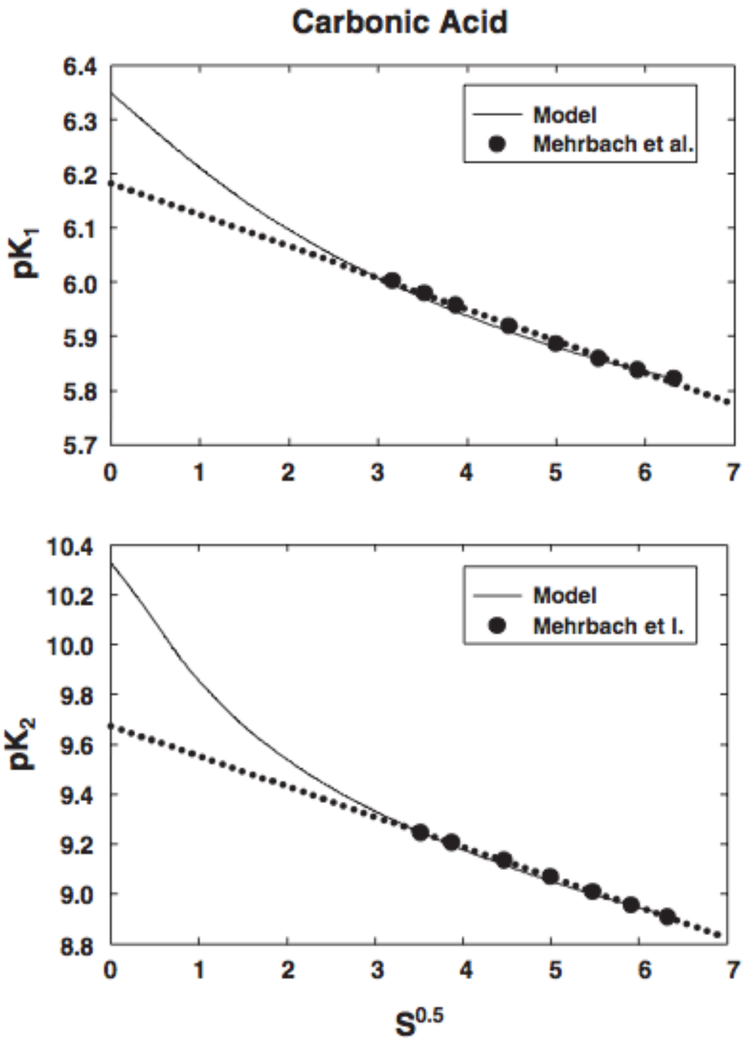


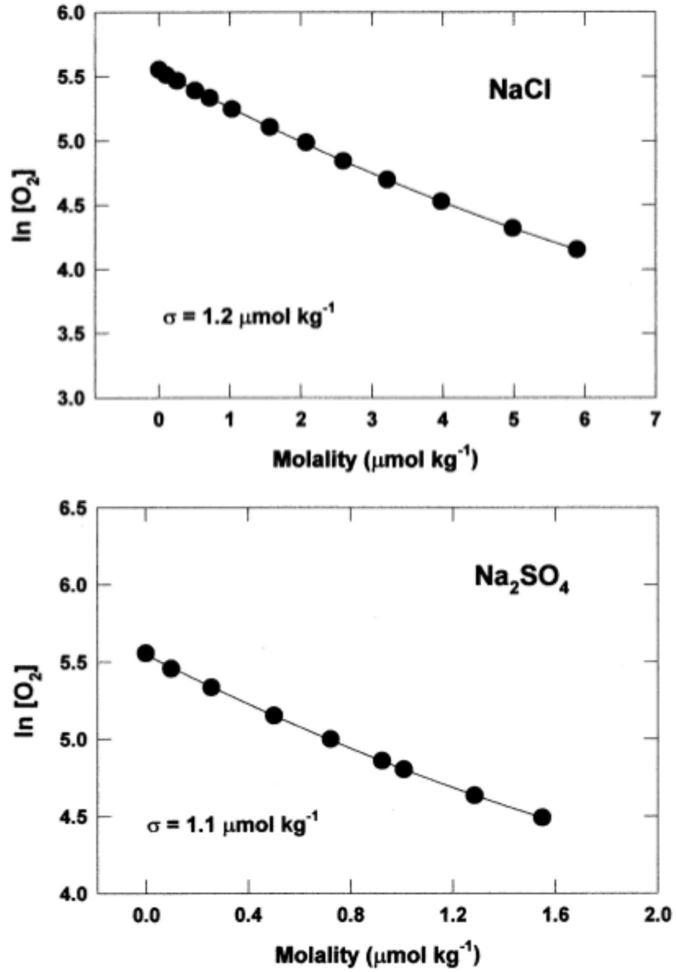




JGR in press

Extreme Thermochemistry

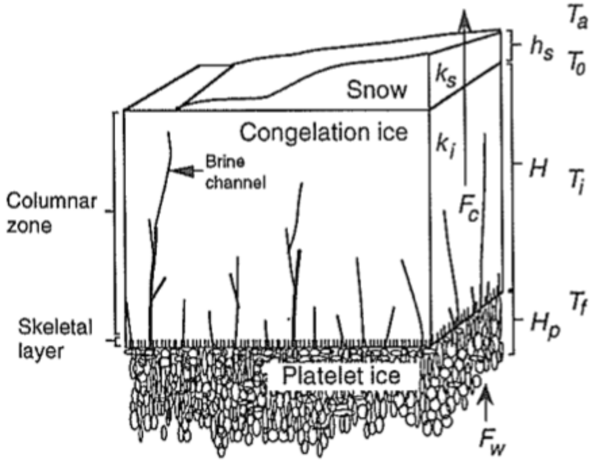


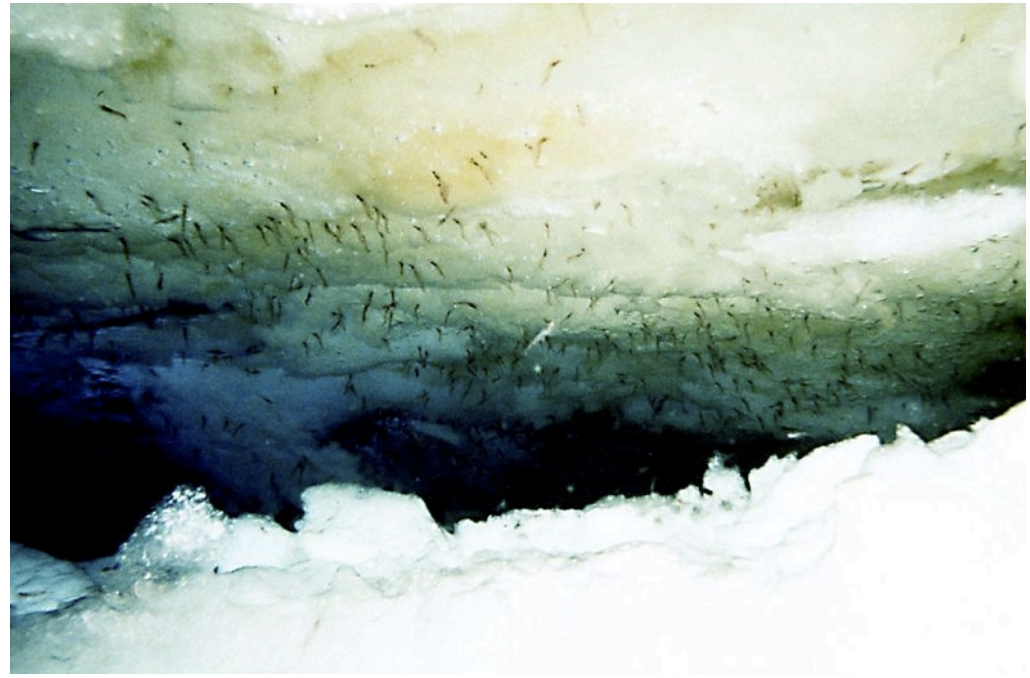


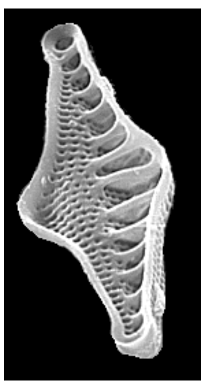
$$
\begin{aligned}
\ln\gamma_N = {} & 2\Sigma_n\lambda_{Nn}m_n \\
& + 2\Sigma_c\lambda_{Nc}m_c + 2\Sigma_a\lambda_{Na}m_a + 3\Sigma_n\mu_{Nnn}m_n \\
& + 6\Sigma_n\Sigma n'm_n m_{n'}\mu_{Nnn'} + 6\Sigma_n m_N\mu_{NNn} \\
& + 6\Sigma_n\Sigma_c m_n m_c\mu_{Nnc} + 6\Sigma_n\Sigma_a m_n m_a\mu_{Nna} \\
& + 6\Sigma_c\Sigma_a m_c m_{ca}\zeta_{Nca} + \Sigma\Sigma_{c<c'}m_c m_{c'}\eta_{Ncc'} \\
& + \Sigma\Sigma_{a<a'}m_a m_{a'}\eta_{Naa'}
\end{aligned}
$$

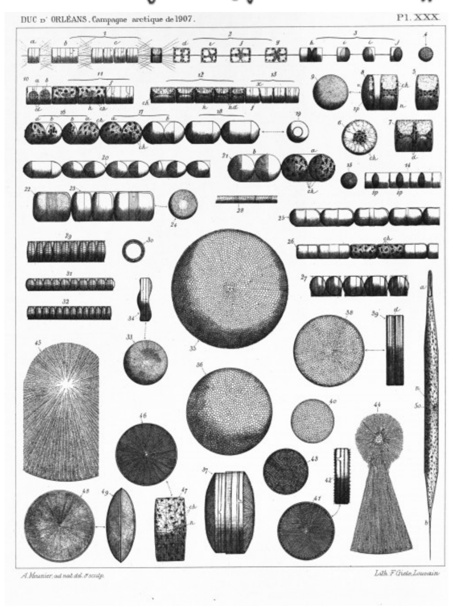
Millero et al., several ? No, CRREL as usual
Pitzer equations -just Debye-Huckel on steroids

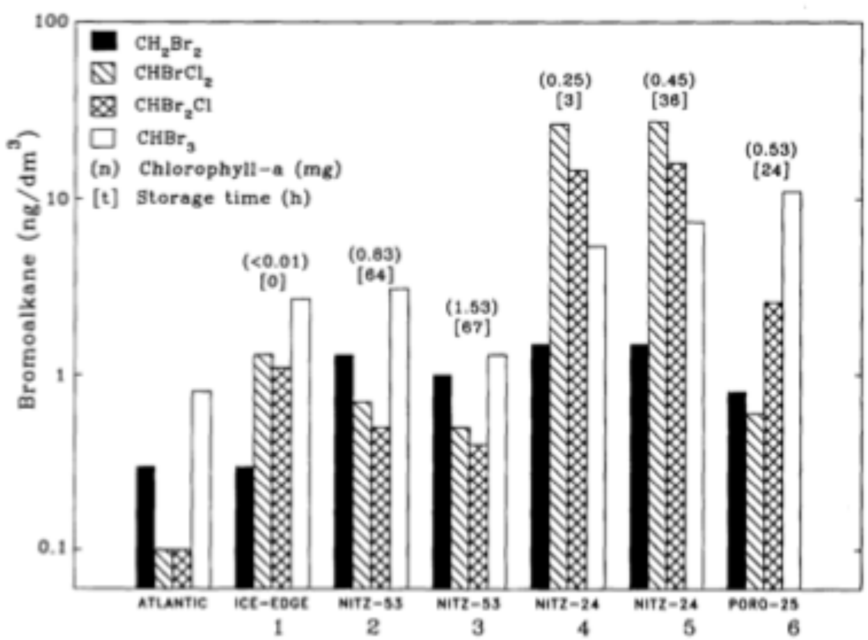
A Halogen Tale



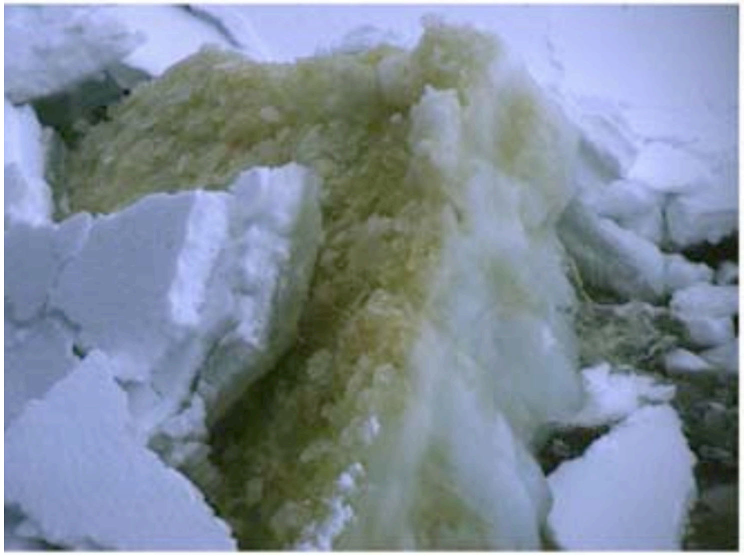


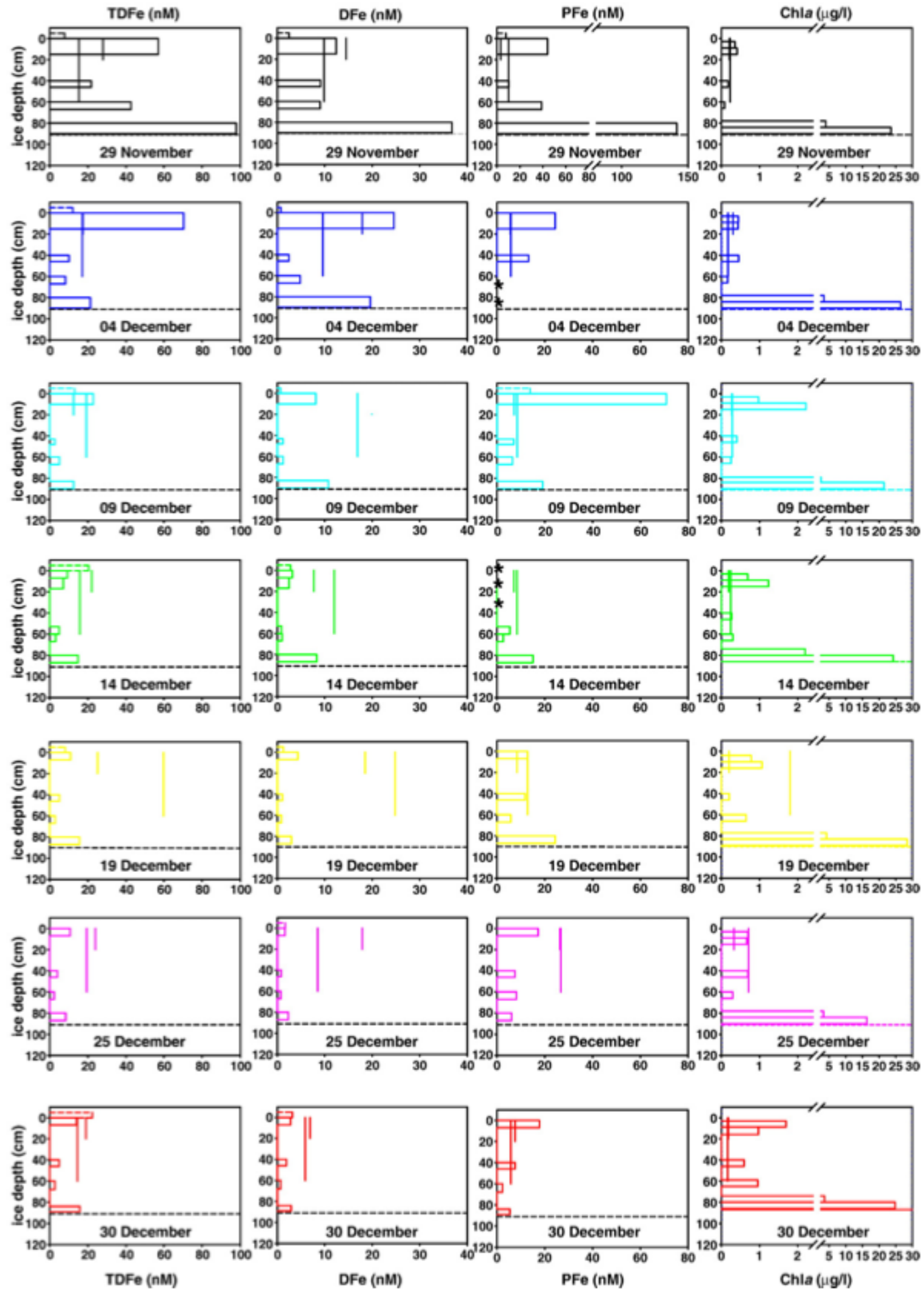






(Southern Ocean Alert)





Ackley et al. 2008
gap layer GRL
vs.
Lannuzel et al. 2008
Fe retained in sea ice…
By EPS substances

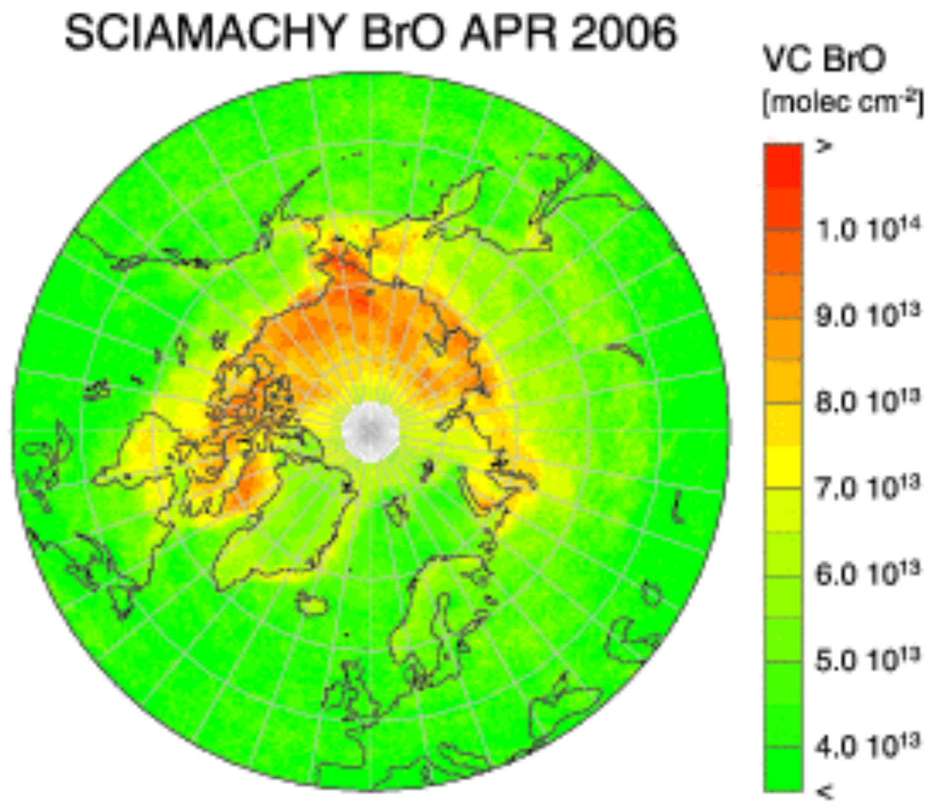
(Southern Ocean Alert)

Lannuzel 08

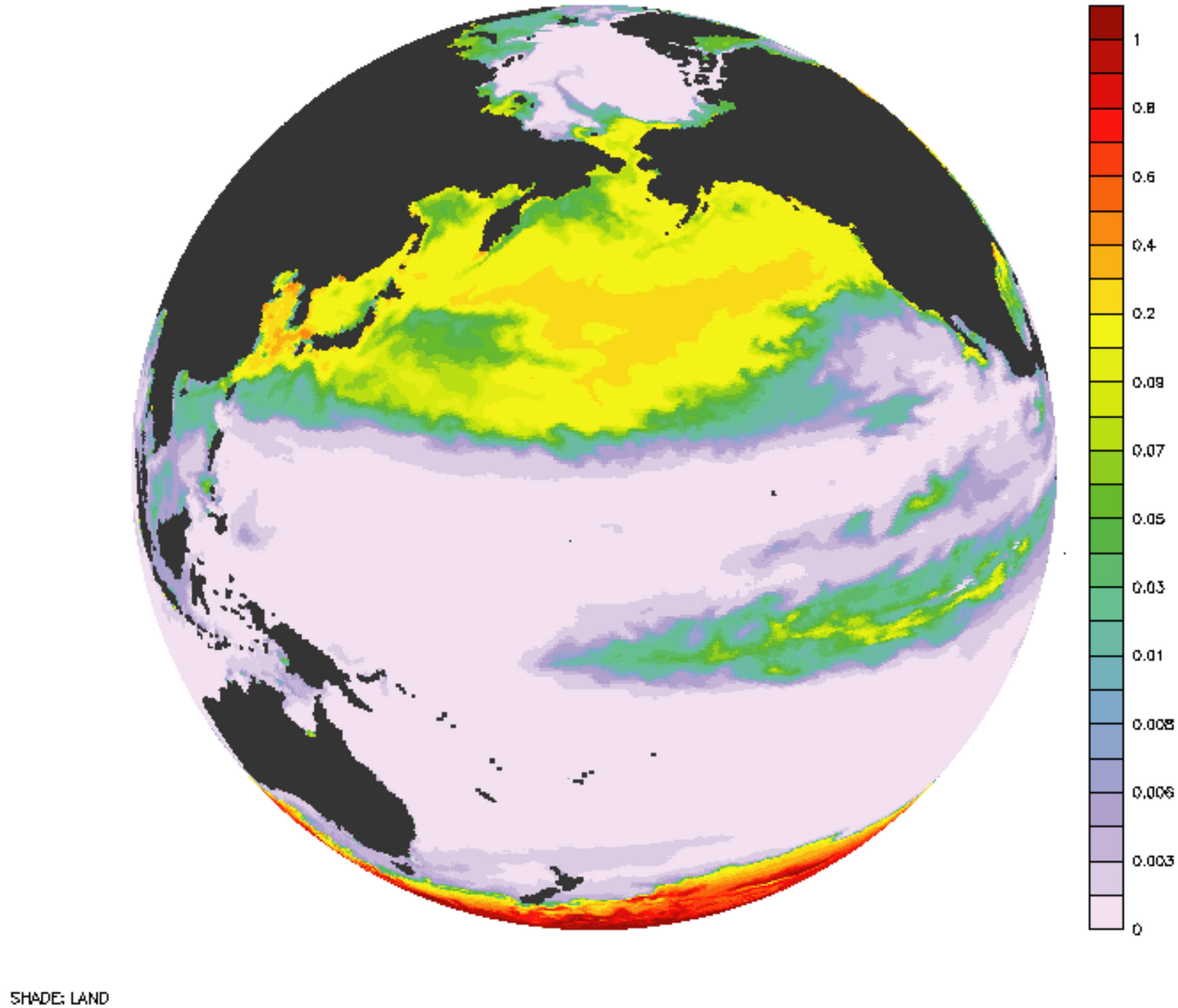
EXTRA EXTRA EXTRAS

Methane

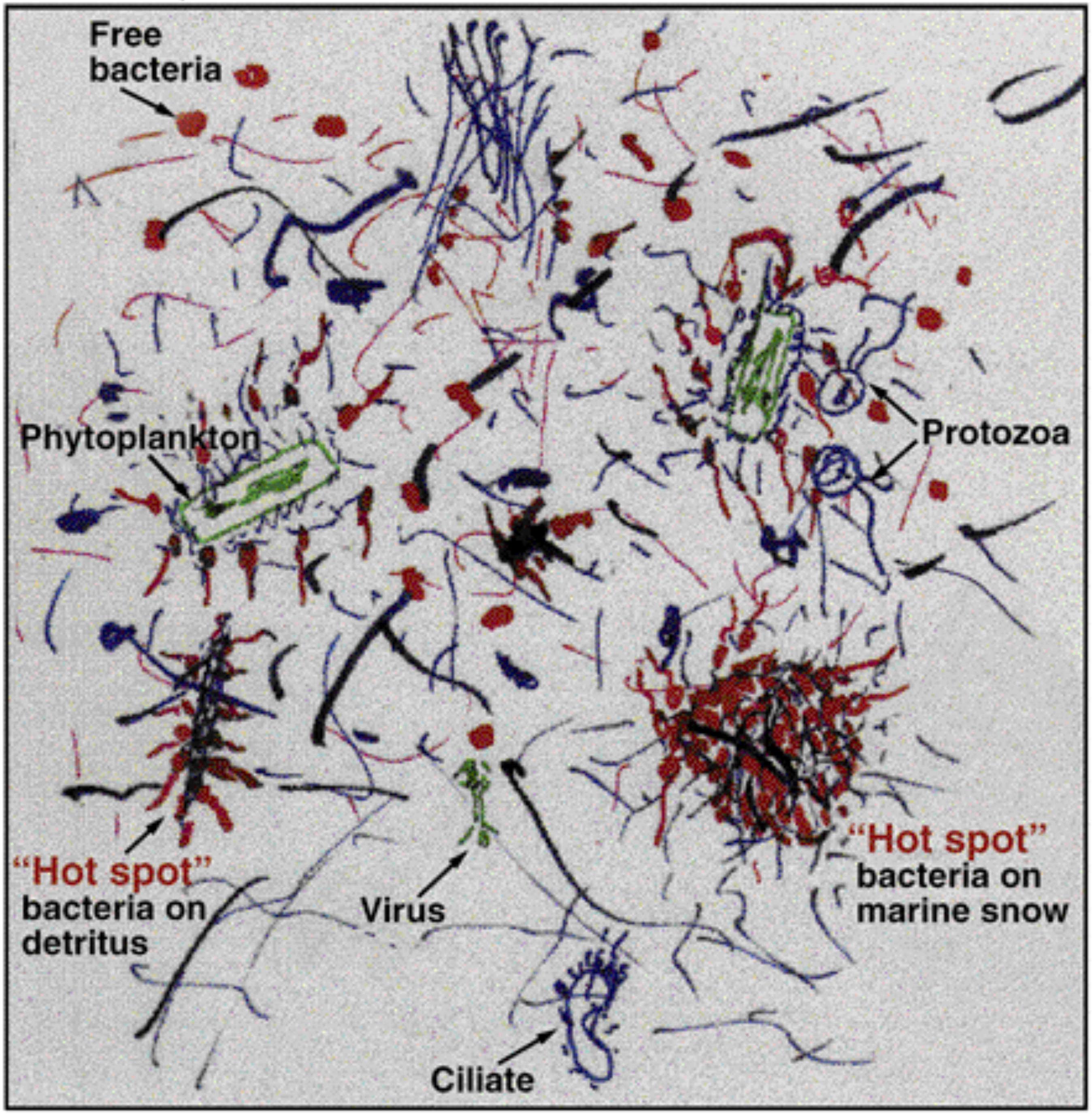
~~Bromine~~ Explosion



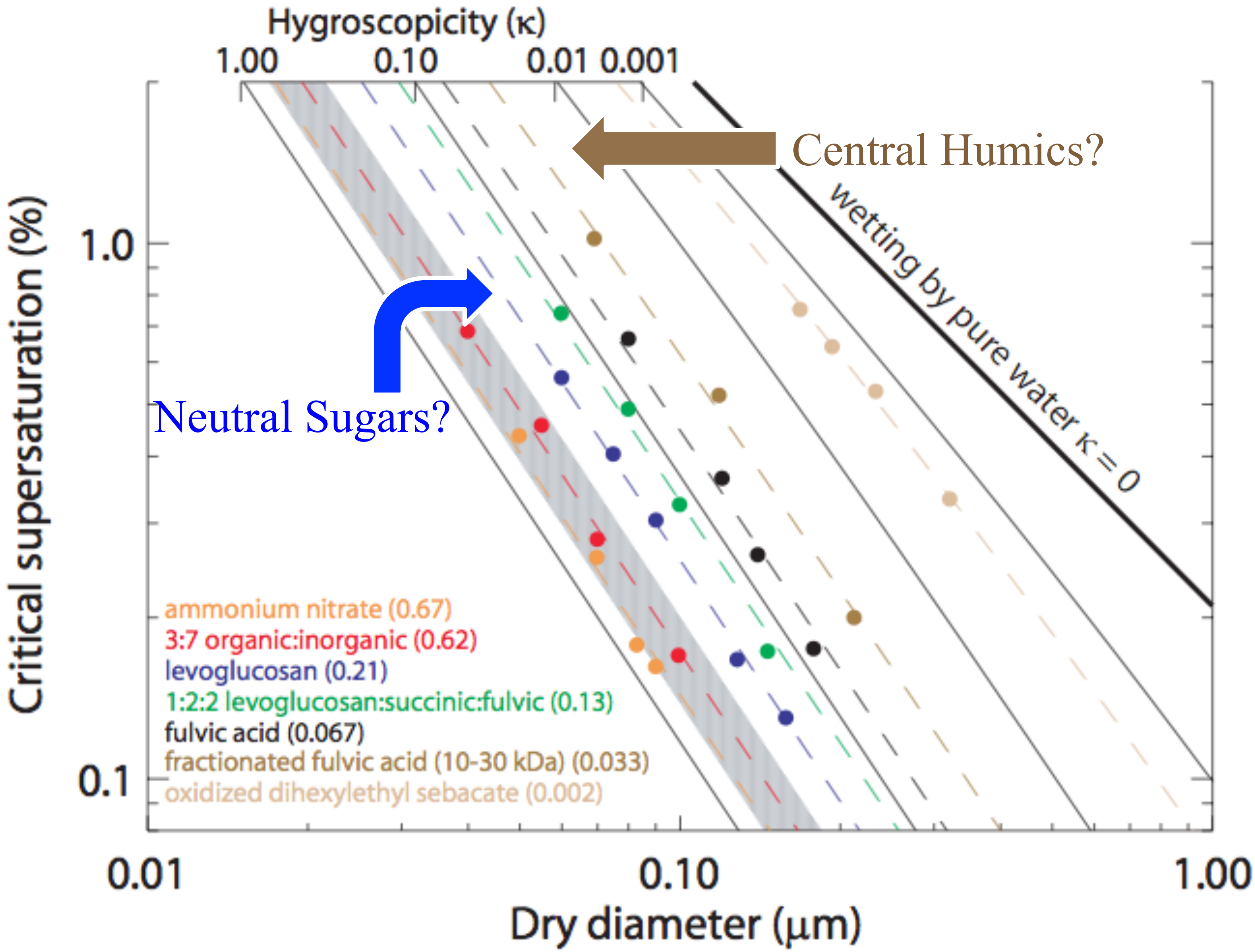
Pacific Ammonium Distribution



February 1996


Free bacteria
Phytoplankton
Protozoa
"Hot spot" bacteria on detritus
Virus
"Hot spot" bacteria on marine snow
Ciliate

Miro



PK meet the chem of the ocean

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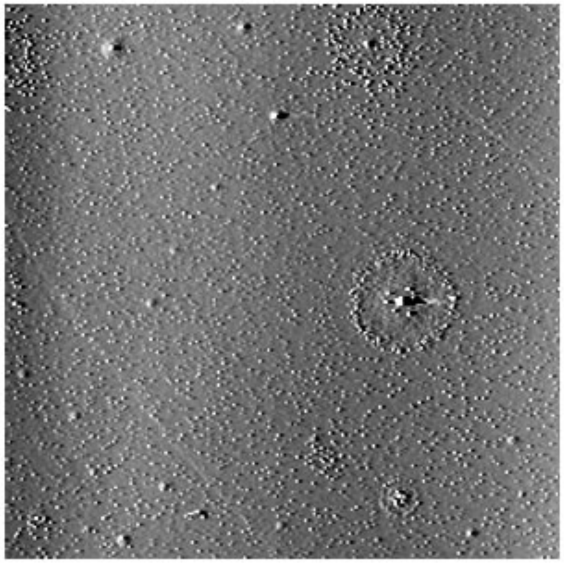
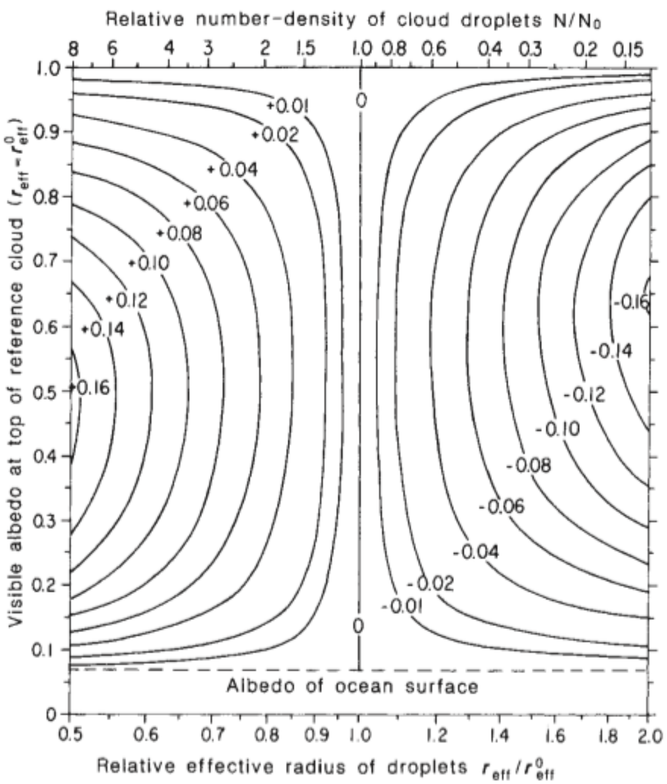
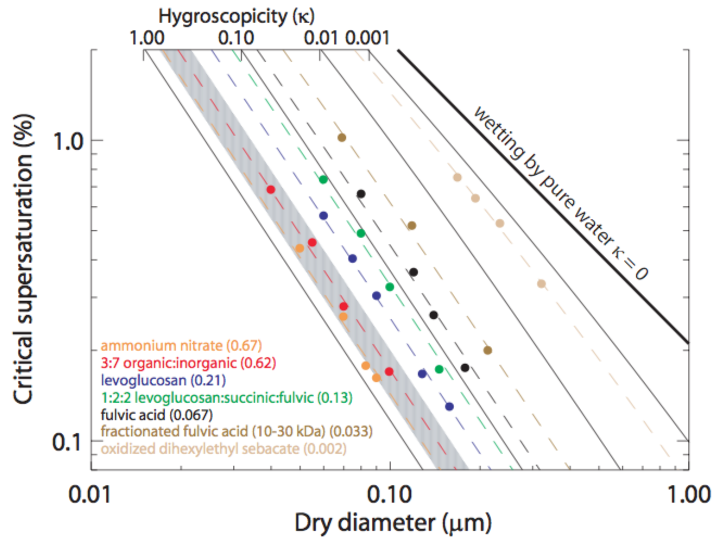






Map:

Organic chemistry onto

Aerosol hygroscopicity onto

Cloud brightness onto

Global climate

GENERAL

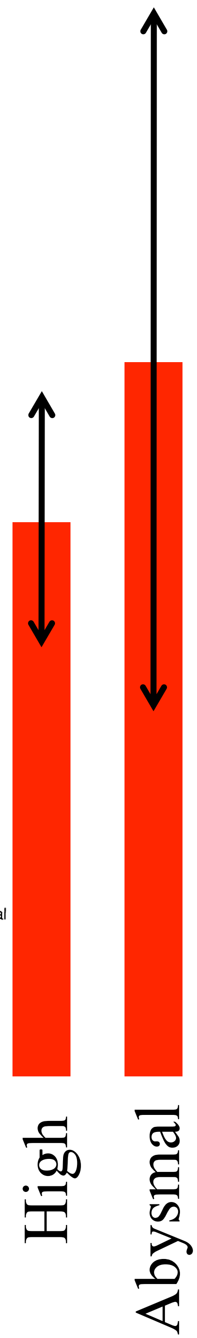
Purgatory

The High Latitude Biosphere Responds

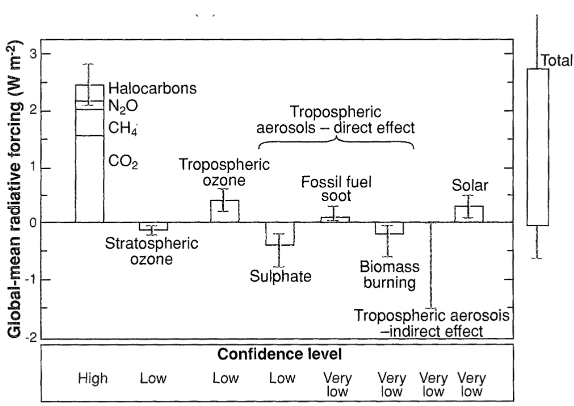
(+3° C)

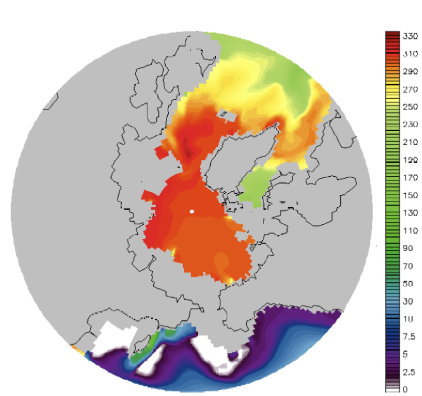
$CO_2+H_2O_{l,c}$

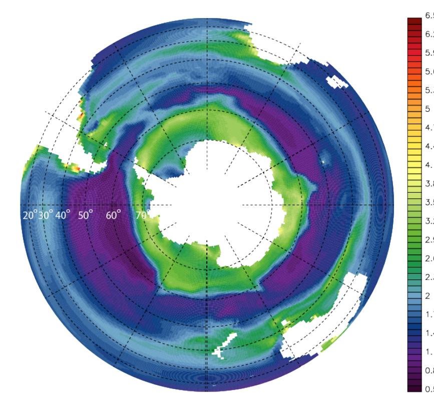
A cozy +1.7°



So shouldn't we dig into these issues a bit?







The envelope please…

By these criteria, rank order for high latitude cycles:

CO_2, O_2

- -Ice chlorophyll (surface darkening)
- -DMS
- -Organics tweak sea-air transfer All
- -CH_4
- -Organics tweak aerosol
- -Seeding tweaks sea-air transfer
- -Open, brine, skeletal C cycles CO_2
- -Aerosol/ice iron cycle
- -Ice nitrogen ($NH_3/_4^+$, N_2O)
- -O_2 and radical photochemistry

Note: Order 10^2 characters –IPCC does same job in 10^6

(Follow the Methane