Arctic Marine Biogeochemistry

LANL: Elliott, Maltrud, Hunke, Jeffery, Rowland
LBL: Reagan, Moridis, Collins
IARC: Deal, Jin
LLNL: Cameron-Smith, Bhattacharyya, Bergmann
PNNL: Liu, Ghan, Easter, Rasch
ORNL: Hoffman, Erickson, Branstetter
OTHER: NPS, universities and international…

DOE: SciDAC, Fossil Energy, EPSCOR (IARC), Cloud-Cryosphere, SFA core, SciDAC redux
Other: New Mexico IAS, IARC/JAMSTEC Cooperative, SOLAS, the Chevron Alliance

OUTLINE

STRUCTURE –From 50^o northward via Pacific Arctic

OKHOTSK –A methane hub

MARGINS –CICE and coupling POP

EAST SIBERIA –More CH_4, brine bgc/transport

CENTRAL –Resource limitations, biogenics to clouds

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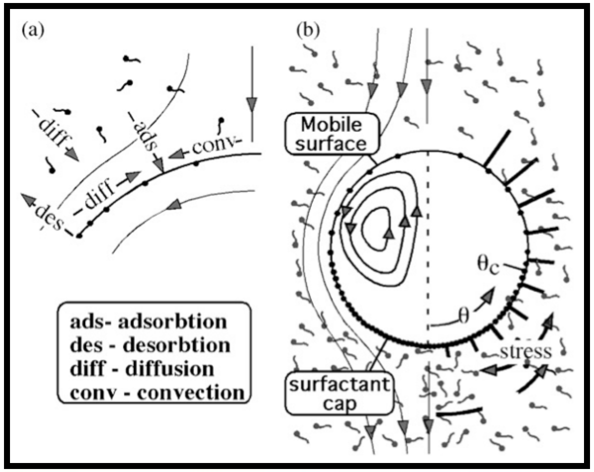
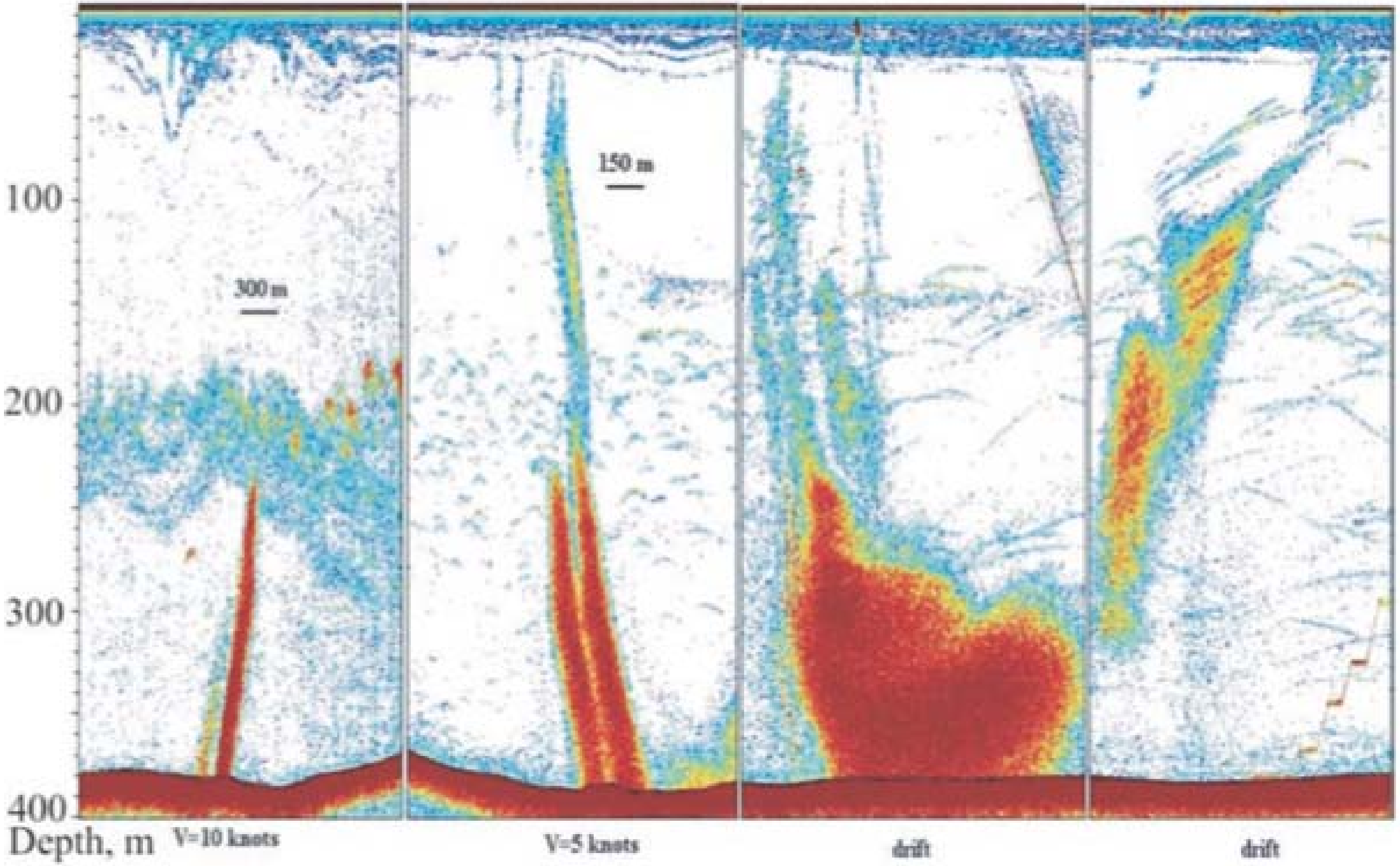
Arctic Plumes

CH$_4$ flare rise:
Determined by surfactants

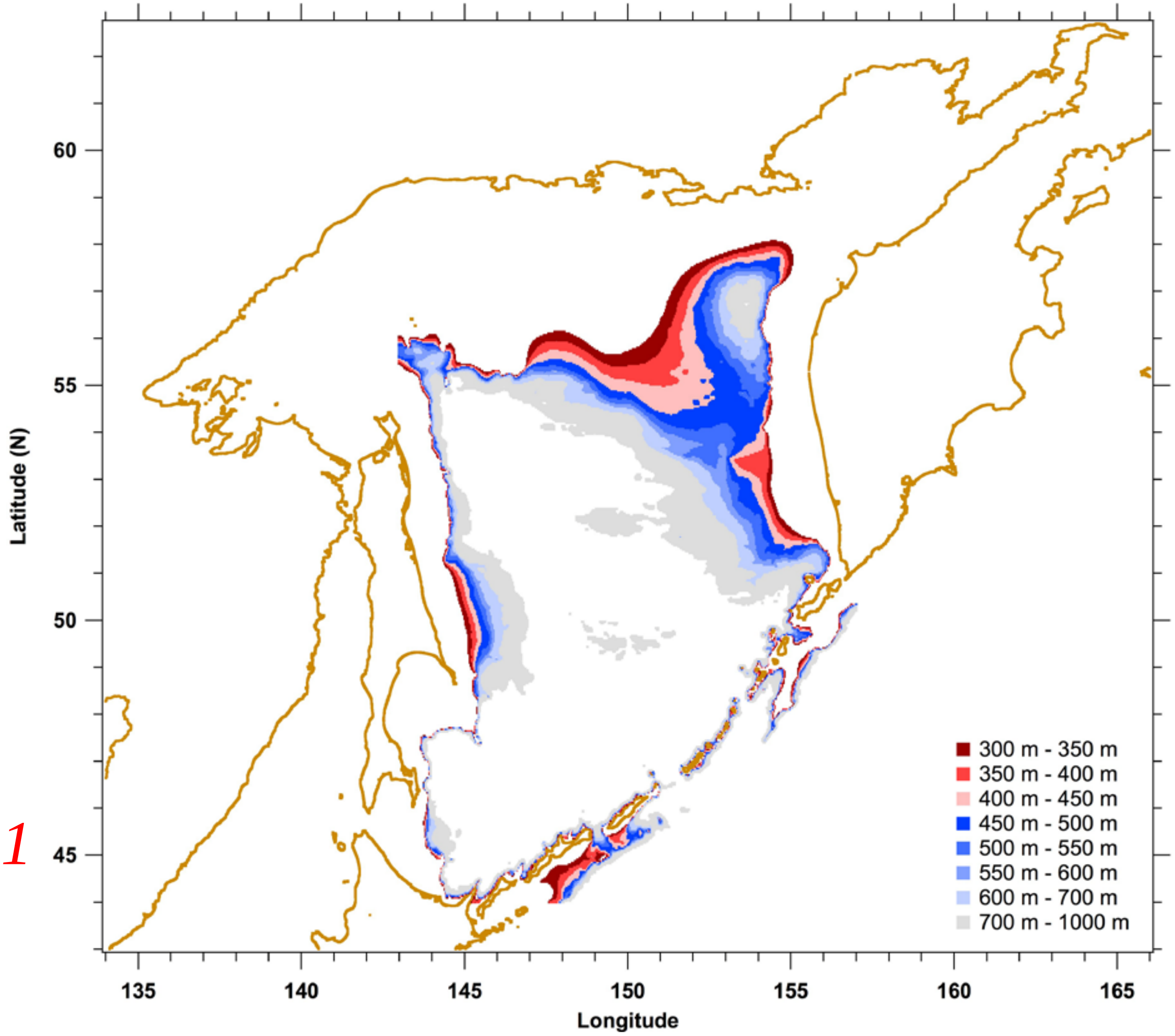




Obzhirov 04
Methane Flares
100-300 meters

Integration: Sea of Okhotsk

Depth contours, coloring suggesting areas of potential destabilization (reds) vs. low-flux areas (blues)



GRL 2010
ICGH 2011
JGR 2011

IARC ice geocycling:

JGR, DSR, AGU monograph

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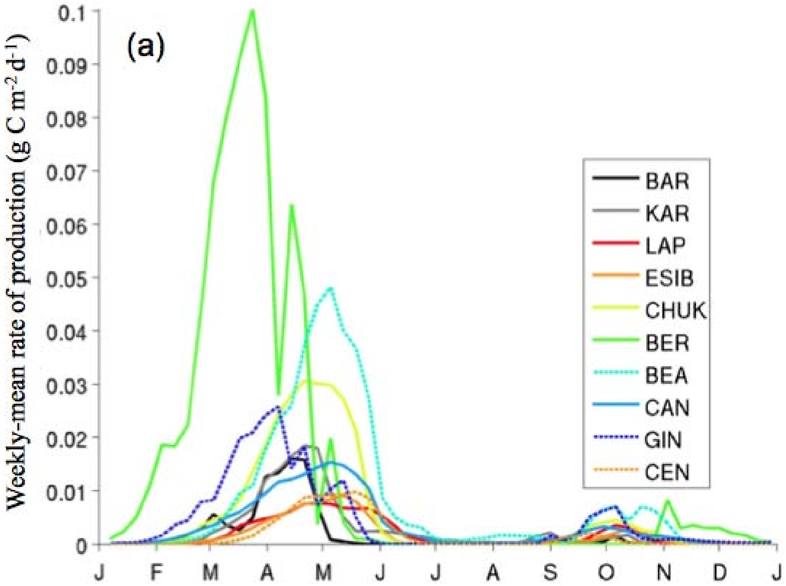
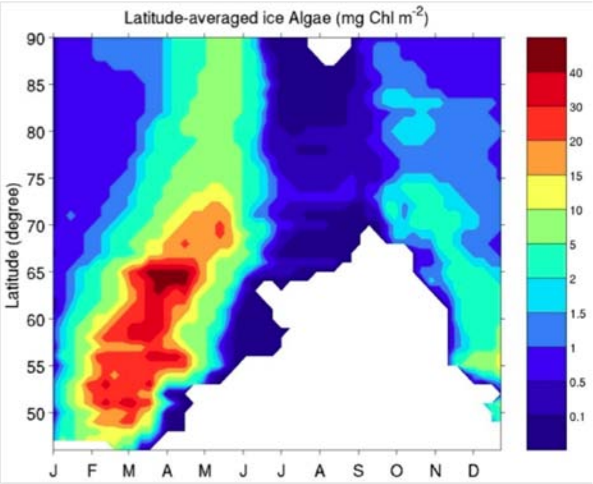
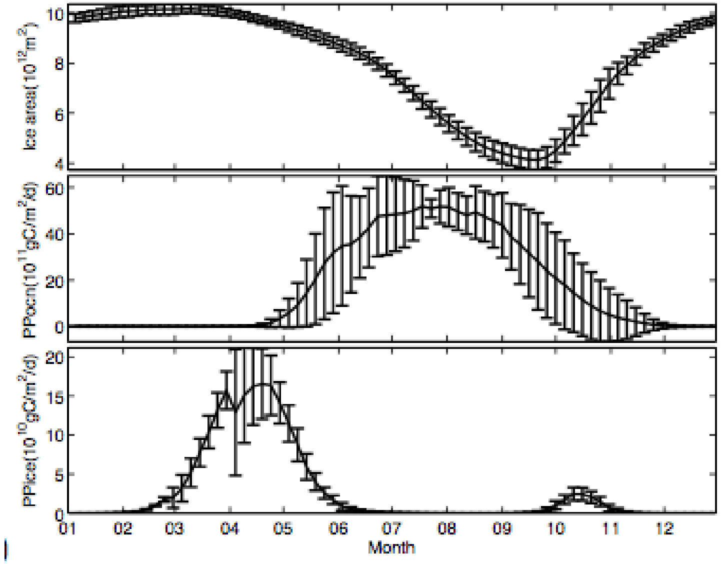
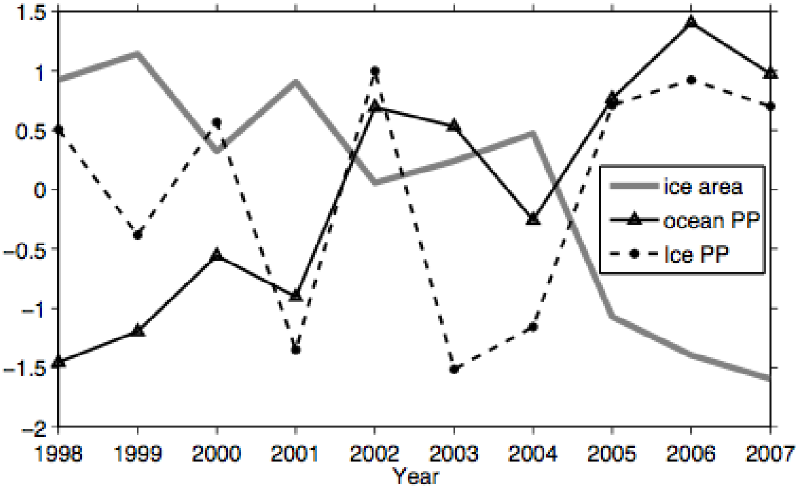
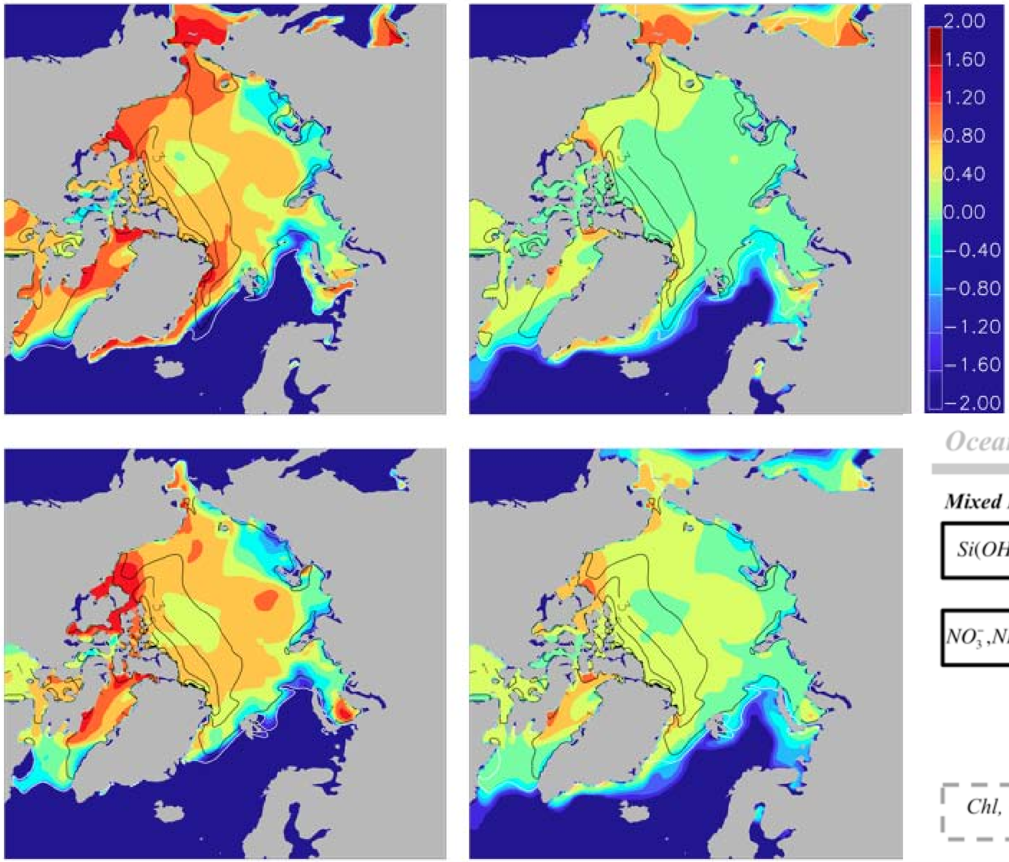




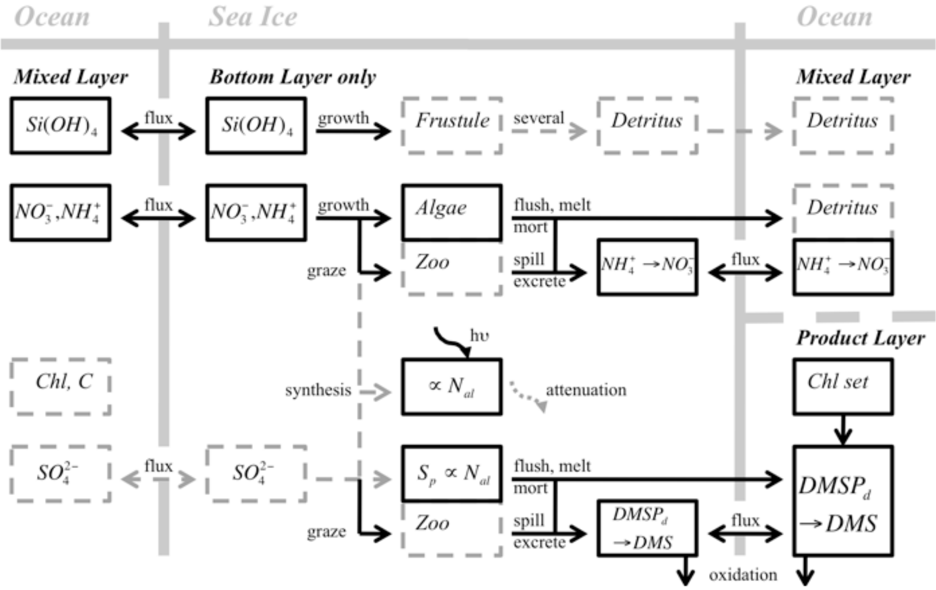




b)



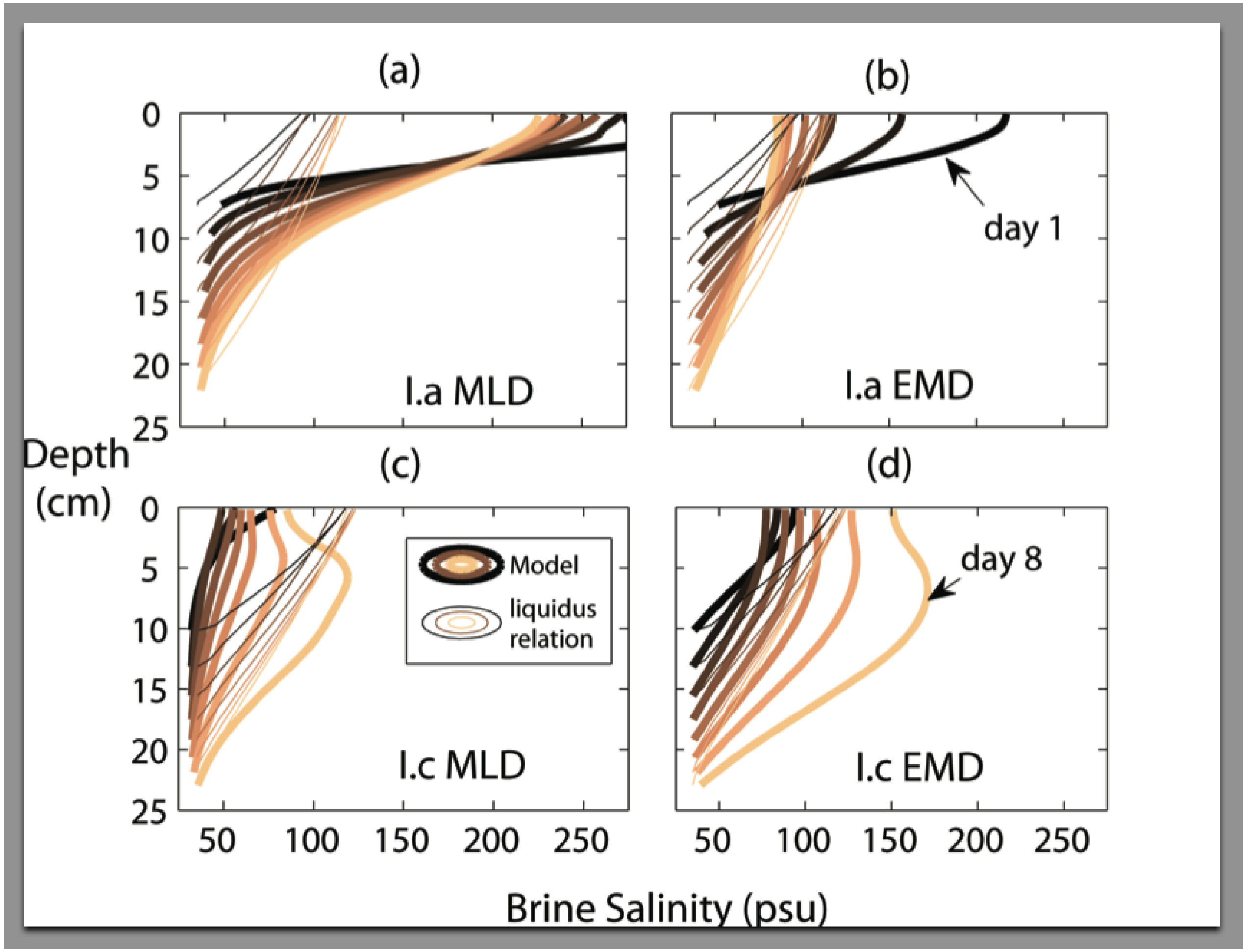
$\log_{10}$Chl (l), mg/m^2 $\log_{10}$DMS (r), nM
May 1992 (upper)
|June 1992 (lower)



Chl in, DMS *from* bottom:

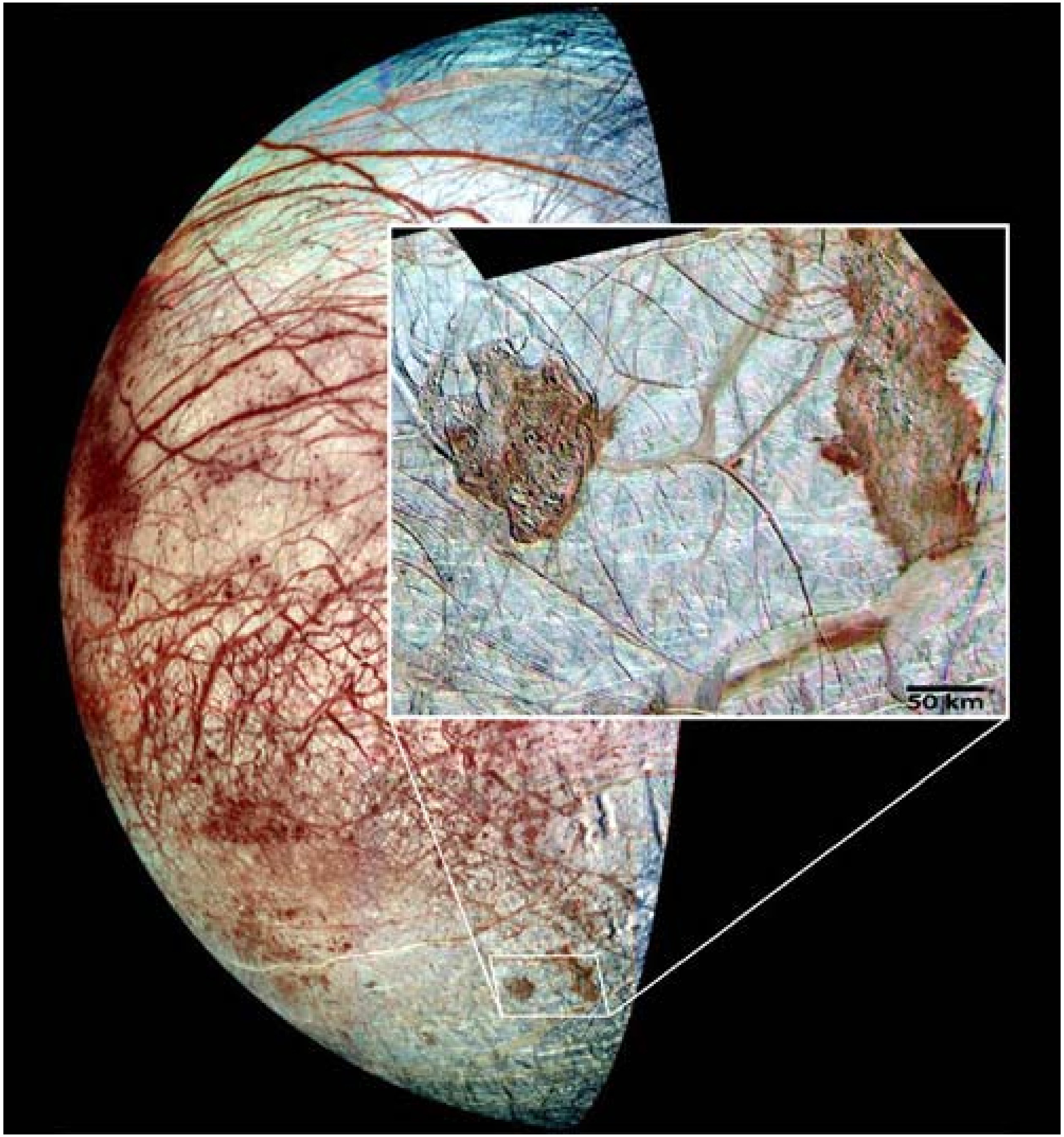
JGR 2009, GBC 2010, Oceanography 2011, JGR 2012

Through sea ice and CICE…

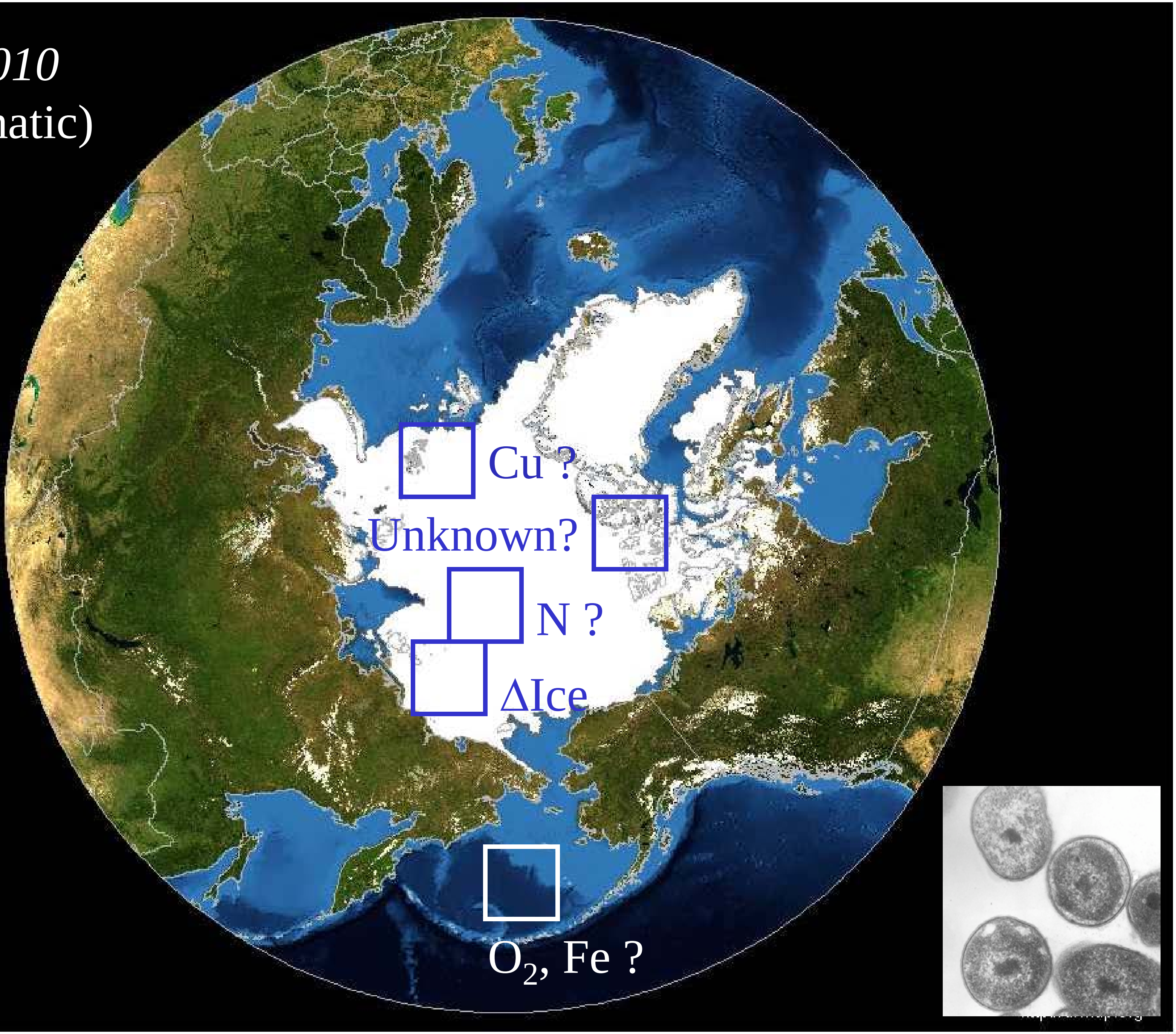


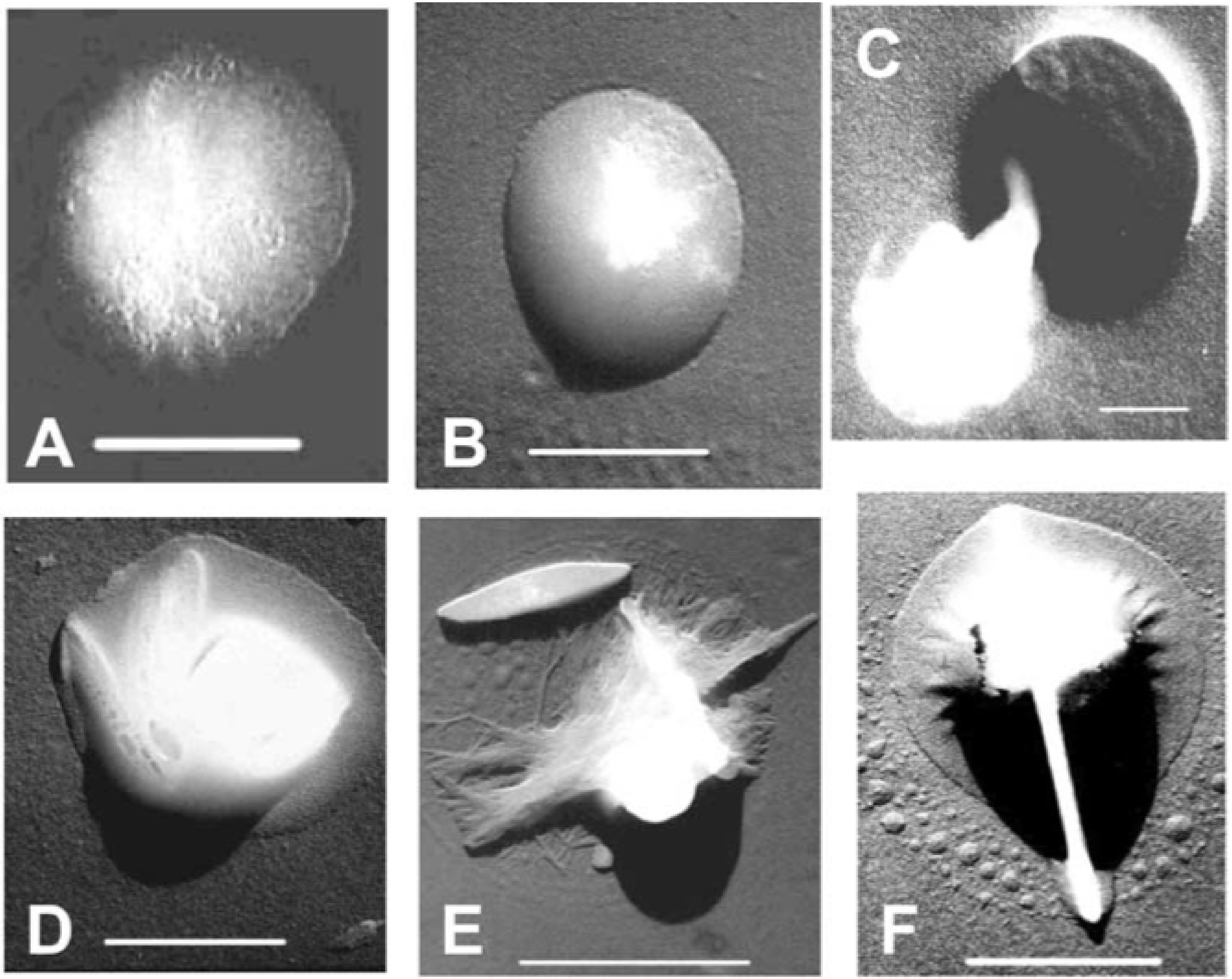
JGR 2011, SOLAS 2011

Marion, 2002



GRL 2010
(Schematic)





Leck, 2002

SUMMARY

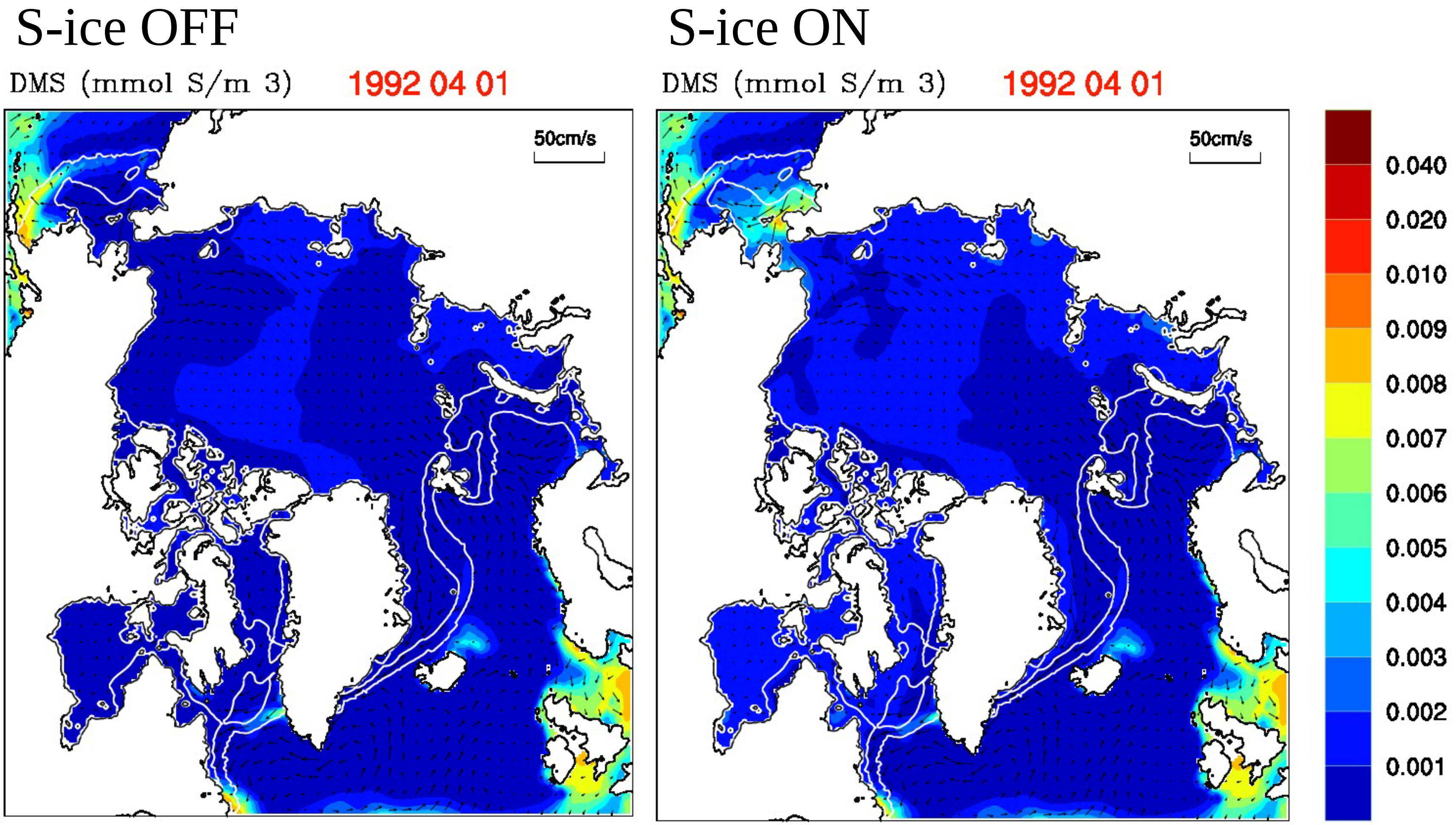
STRUCTURE –From 50^{o} northward via Pacific Arctic

OKHOTSK –A methane hub

MARGINS –CICE and coupling POP

EAST SIBERIA –More CH_4, brine bgc/transport

CENTRAL –Resource limitations, biogenics to clouds

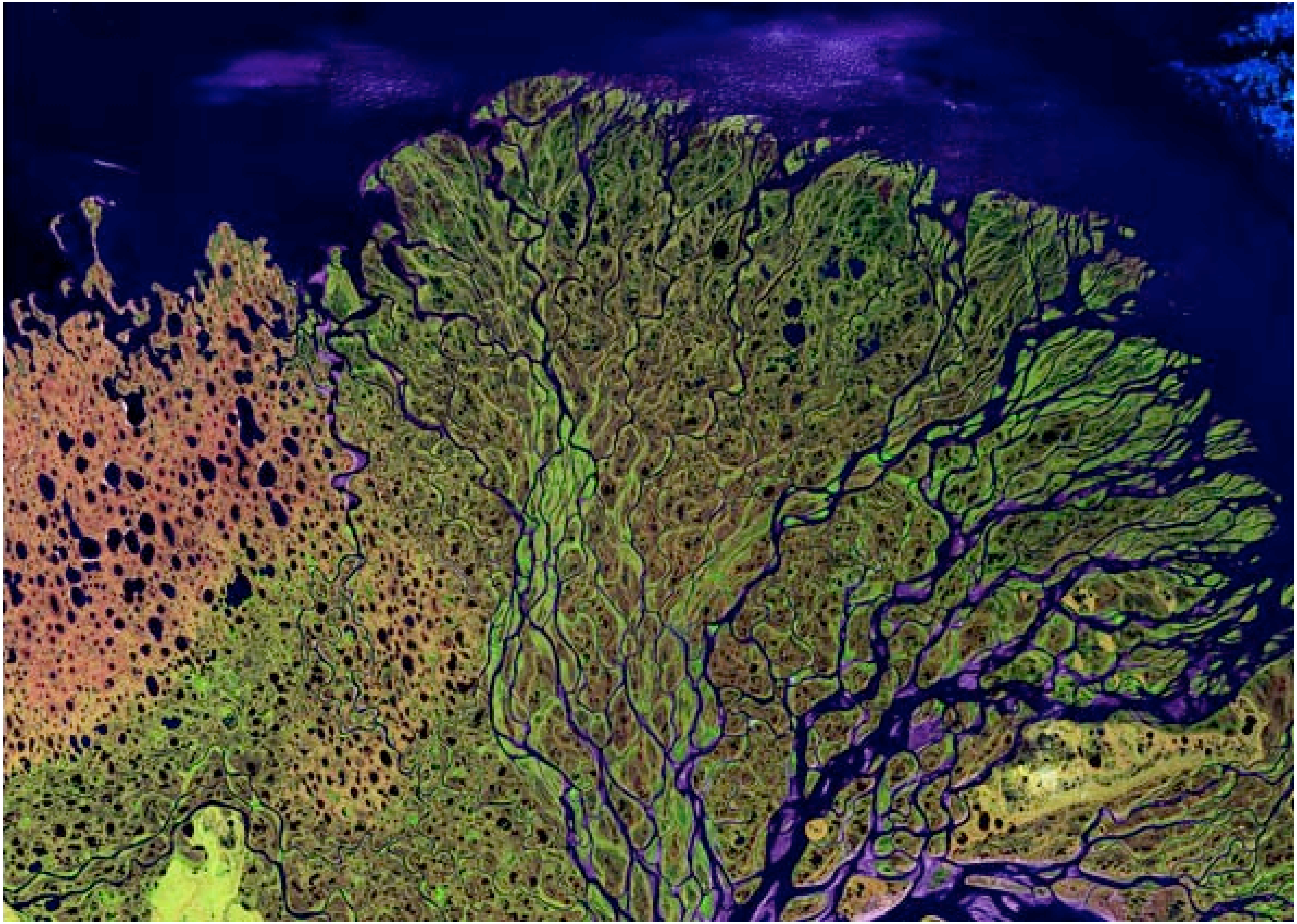


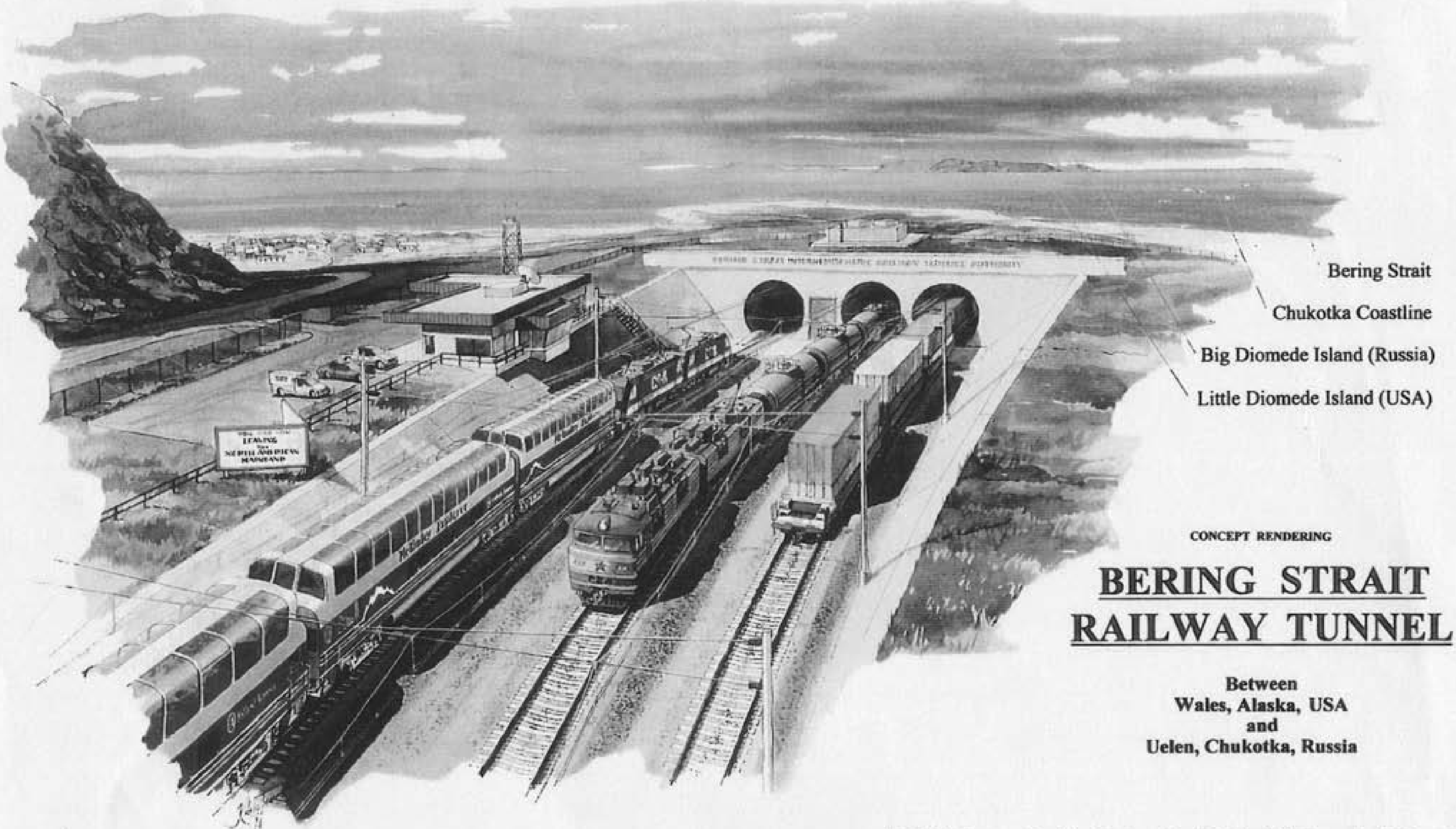
S-ice OFF

S-ice ON

In Prep

IARC Coupled Sulfur Cycle:
Subdued effects in POP/CICE
Points to algal loss vs. retention?





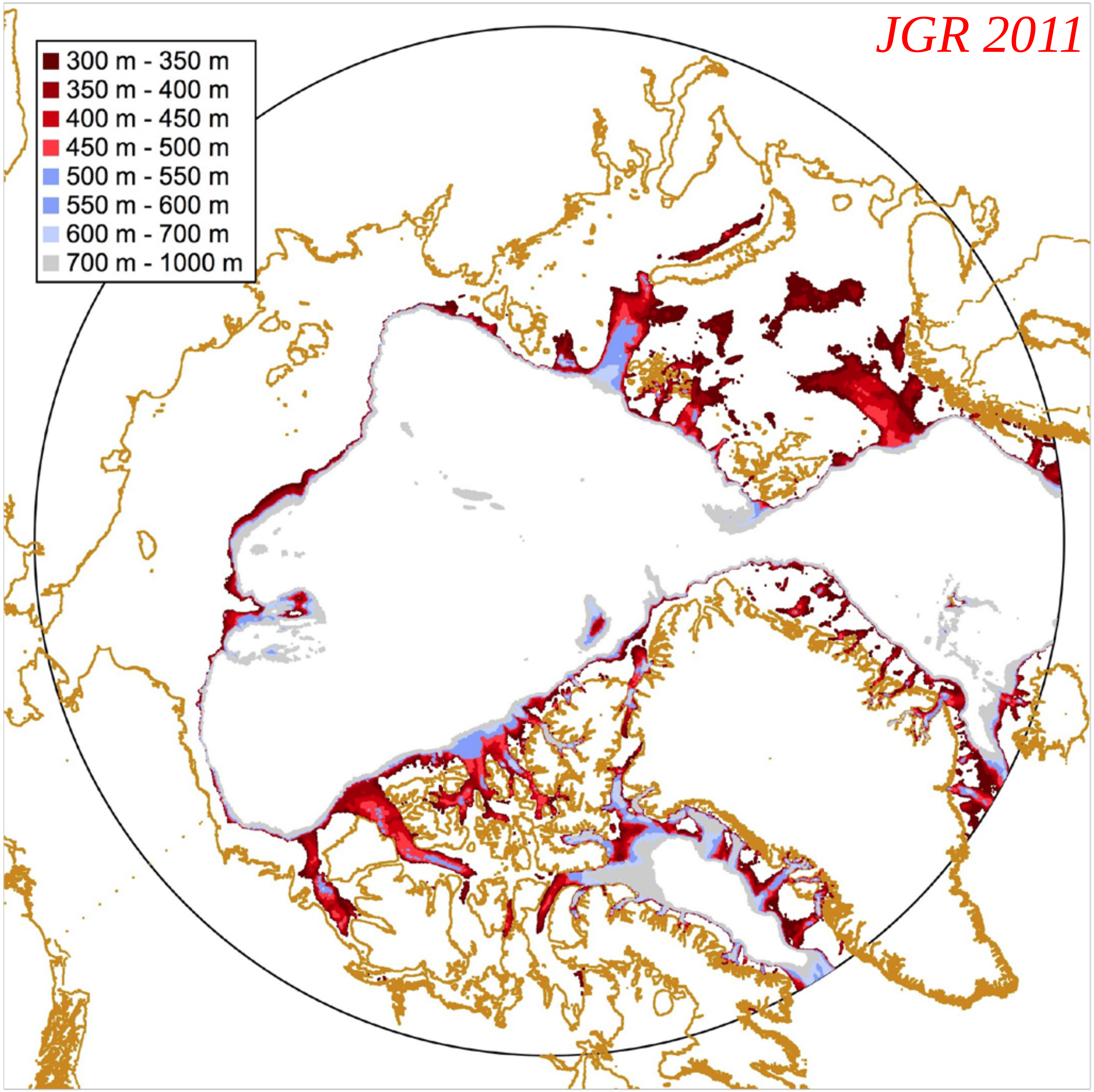
CONCEPT RENDERING

BERING STRAIT RAILWAY TUNNEL

Between
Wales, Alaska, USA
and
Uelen, Chukotka, Russia

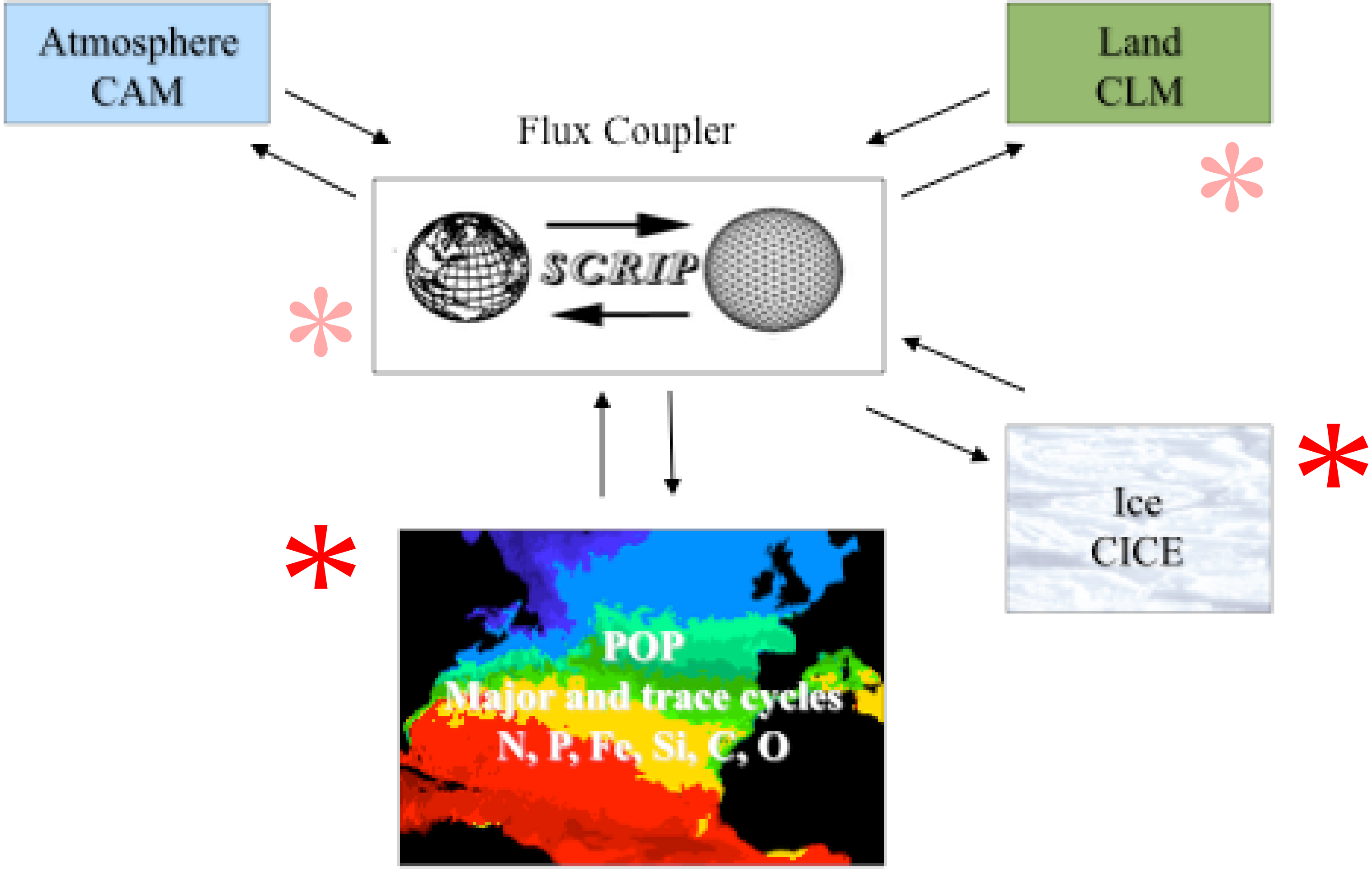
Commissioned by Cooper Consulting Co. for Alaska Governor Frank Murkowski

EXTRAS


300 m - 350 m
350 m - 400 m
400 m - 450 m
450 m - 500 m
500 m - 550 m
550 m - 600 m
600 m - 700 m
700 m - 1000 m

JGR 2011

Ocean-Ice in NSF/DOE CESM



Atmosphere
CAM

Land
CLM *

Flux Coupler

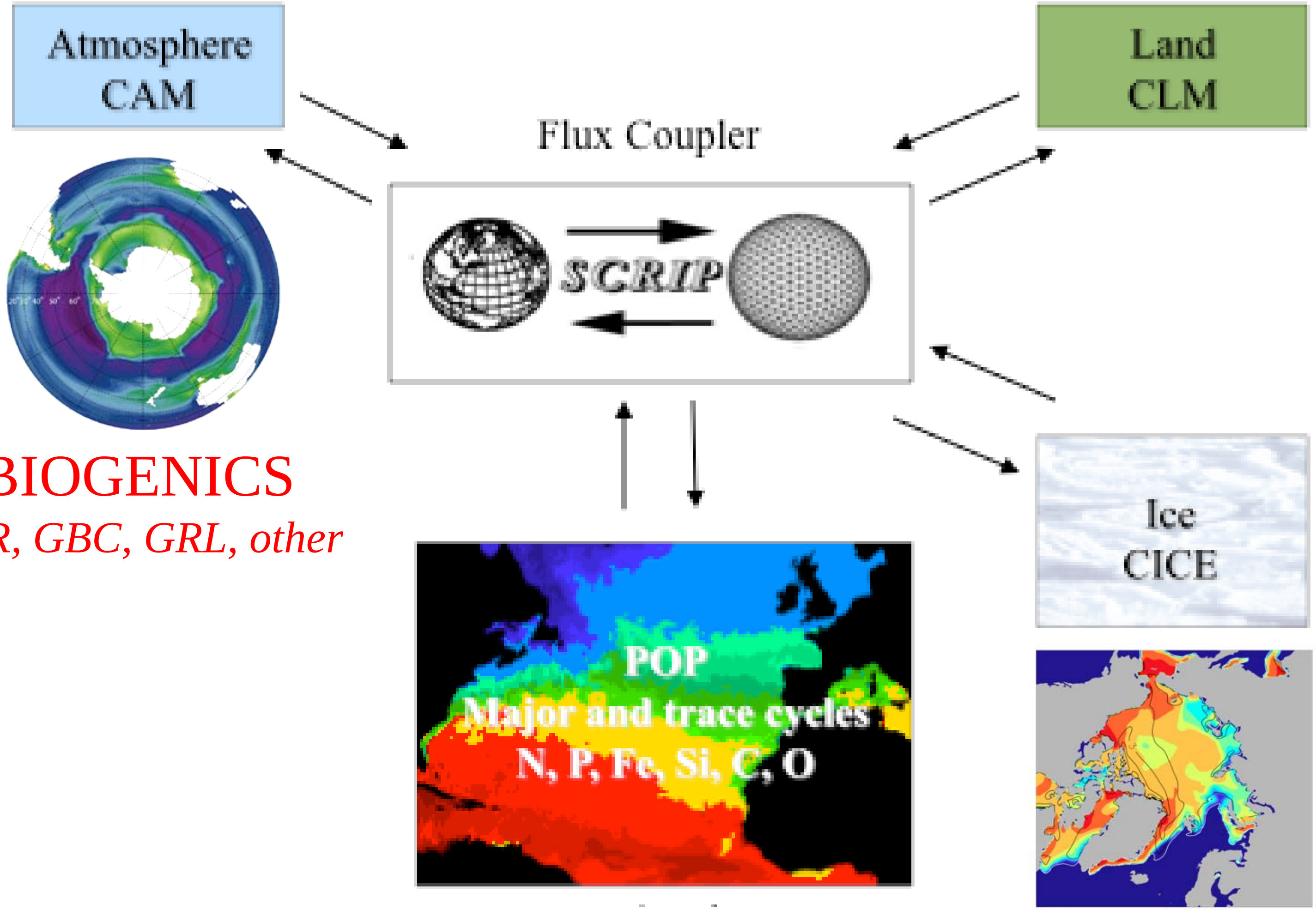
SCRIP *

Ice
CICE *

POP *
Major and trace cycles
N, P, Fe, Si, C, O

*LANL

Systems Modeling means BGC



Atmosphere
CAM

Land
CLM

Flux Coupler

SCRIP

POP
Major and trace cycles
N, P, Fe, Si, C, O

Ice
CICE

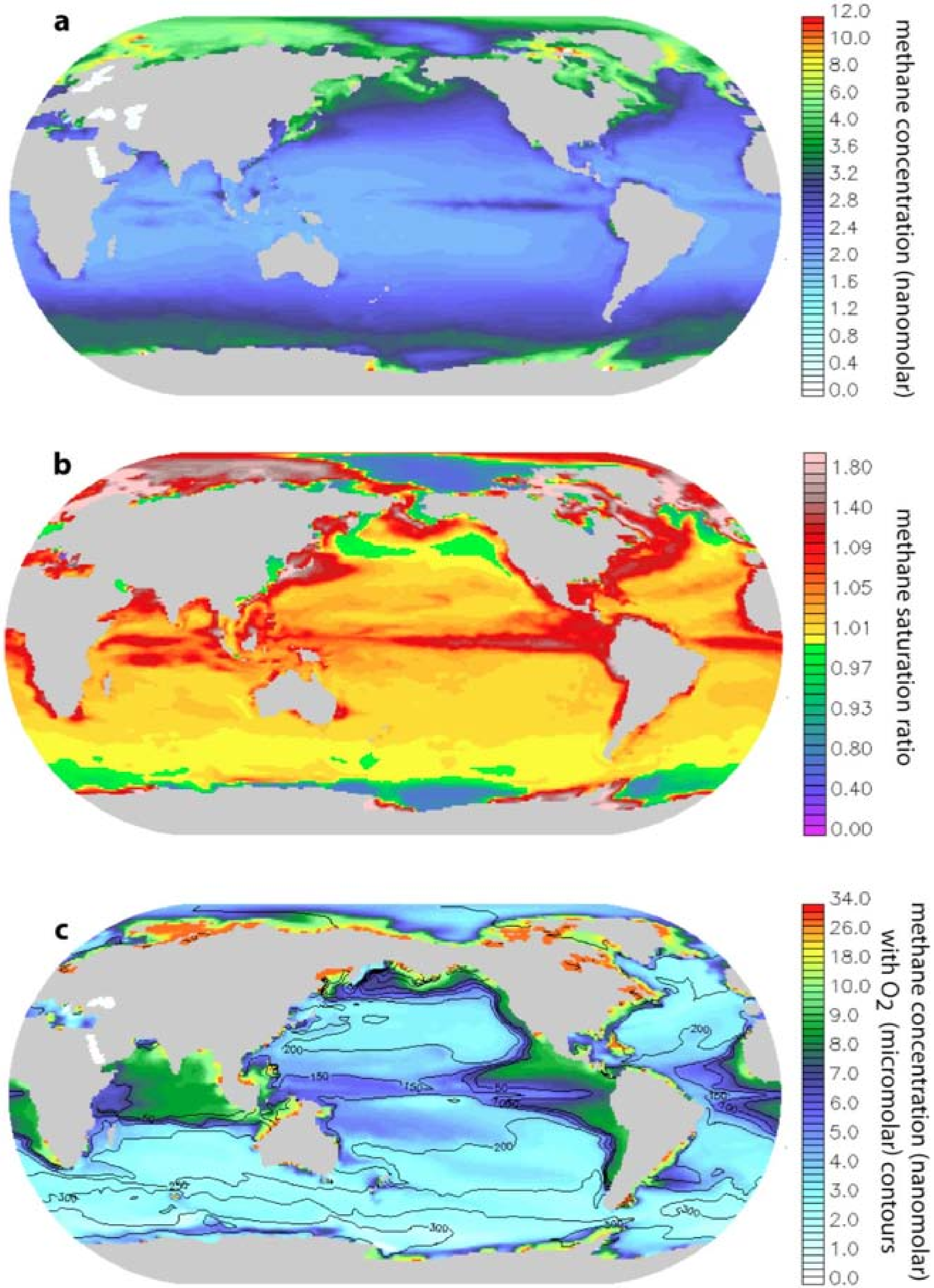
BIOGENICS

JGR, GBC, GRL, other

ICE GEOCYCLING

JGR, DSR, SOLAS, other

JGR 2011



Global Cycle

CH_4 sources:
Upward seabed flow
Sinking particles

CH_4 sinks:
Empirical log linear

a) Surface (nM),
b) Saturation ratio,
c) 150 meters (nM)

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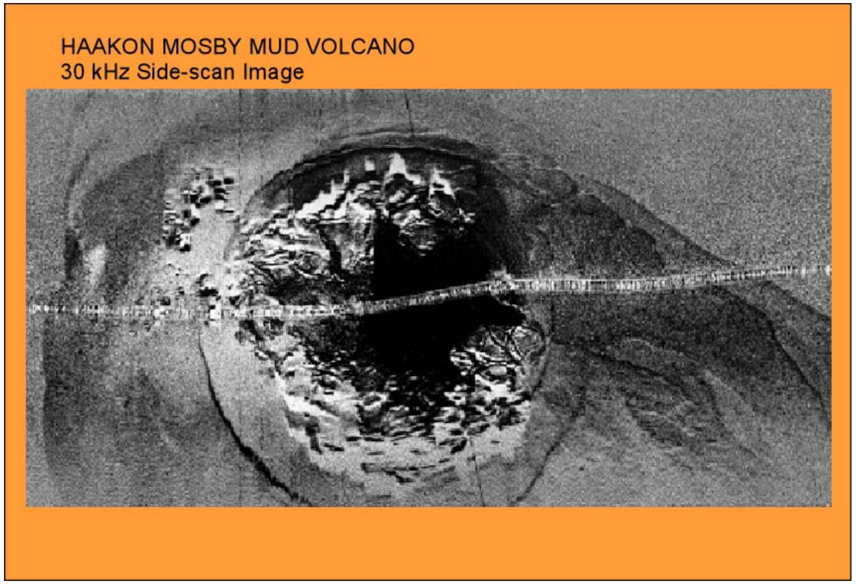
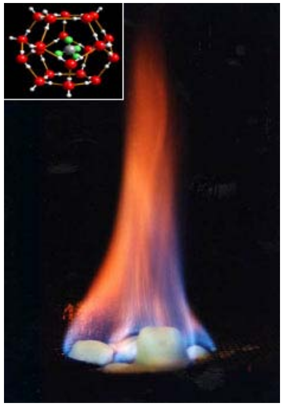
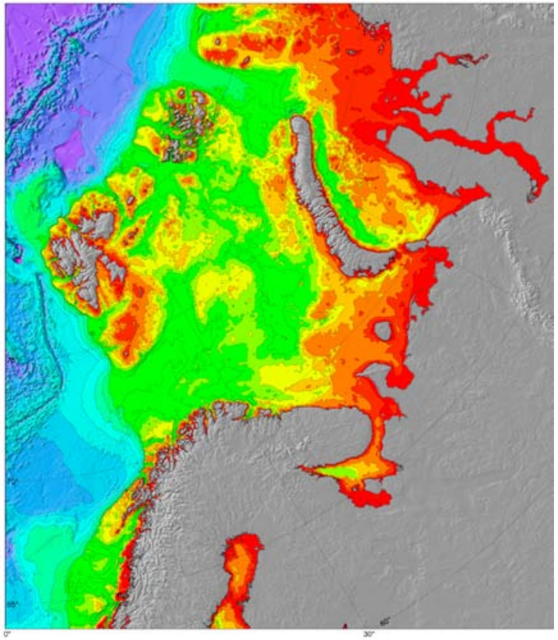
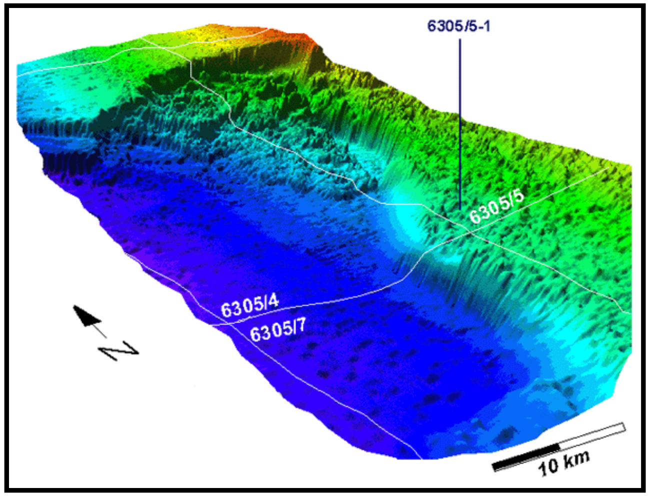
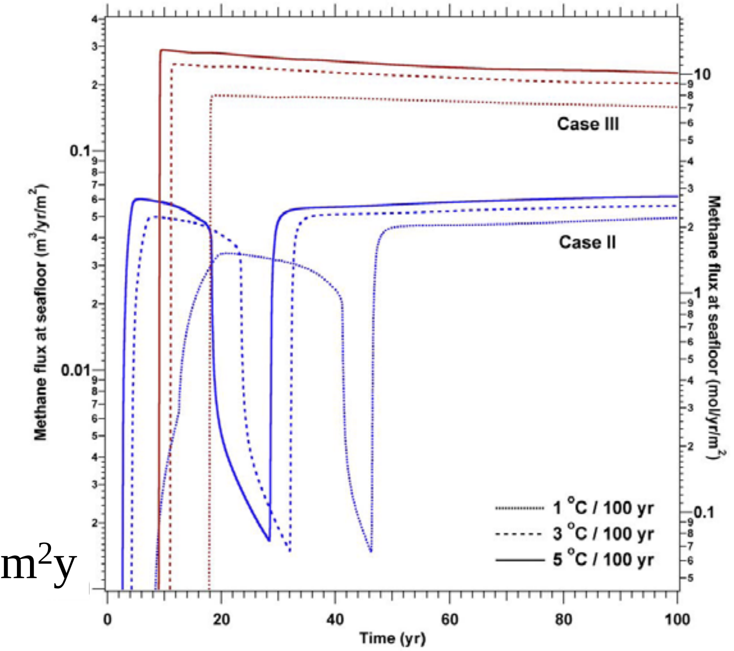

HAAKON MOSBY MUD VOLCANO
30 kHz Side-scan Image

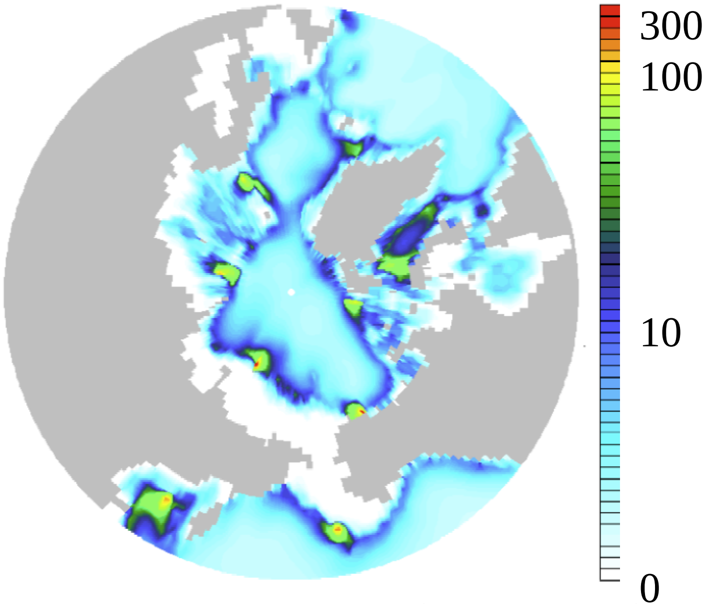






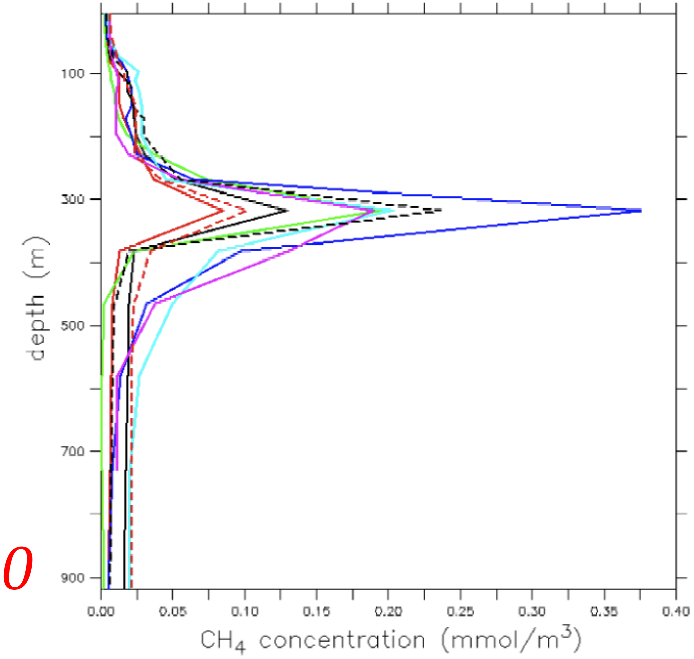


LBL,
mole/m^{2}y



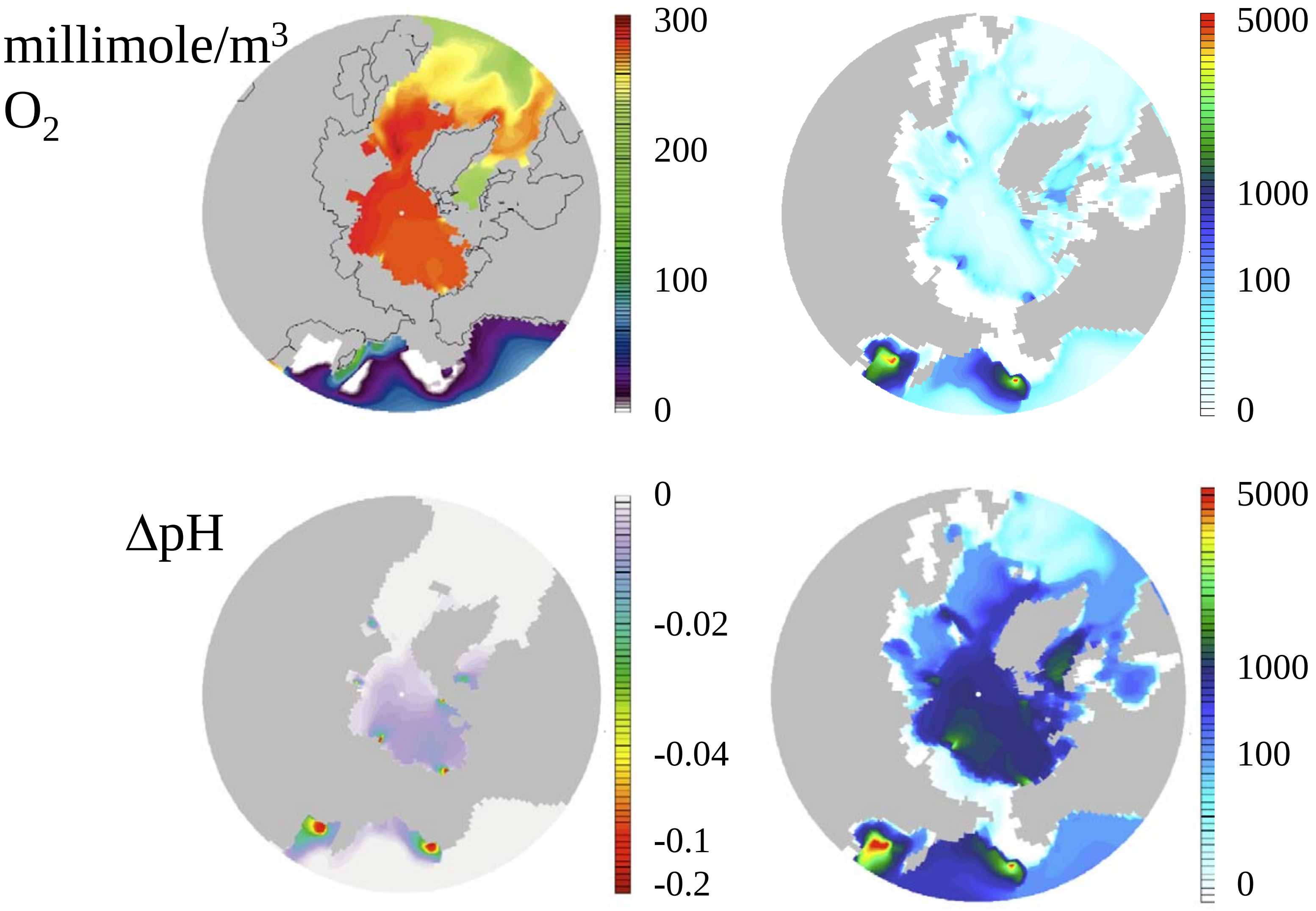
CH$_4$ (millimole/m^2 and /m^3)

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



JGR 2010

O_2, CO_2 and Plume Expansion

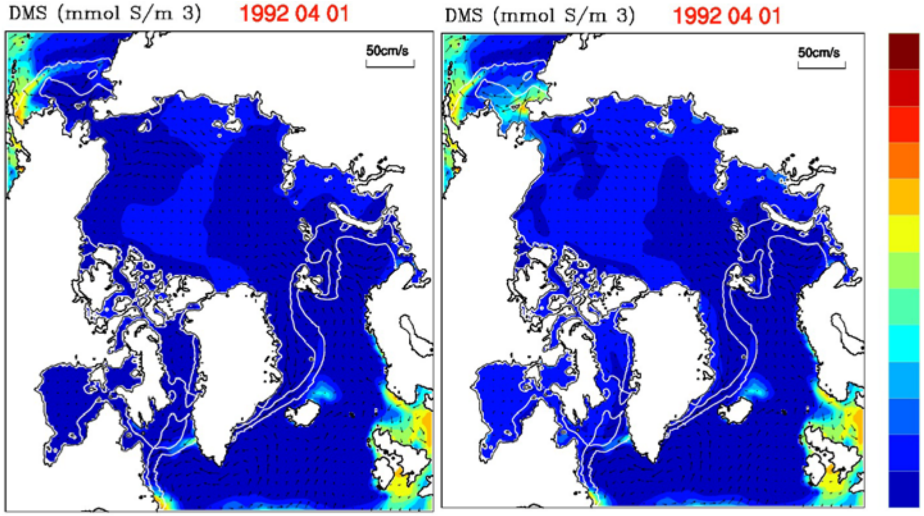


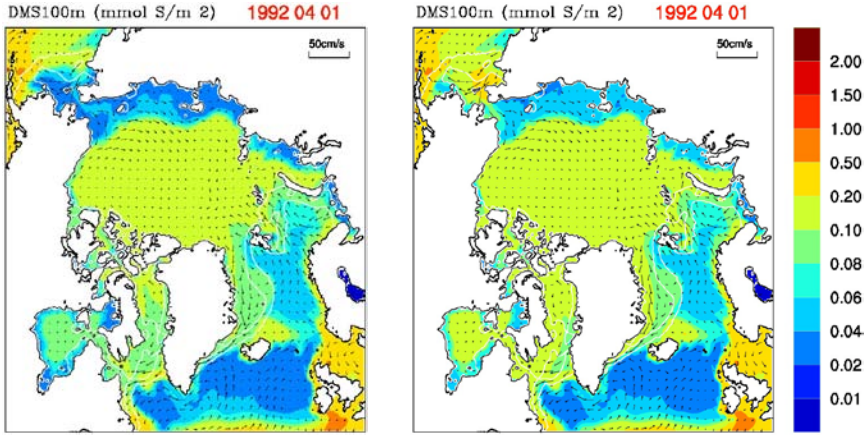
CH_4, millimole/m^2

300 meters, 30 years

JGR 2011

CD sends these today, DMS left ice algal source off, right on (bluer images on left side of page are concentration, right yellow are column)
This is coupled open water and ice biogeochemistry, pretty rare
Real DMS increases in surface waters as early as April
Nanomolar large areas, Bering extreme at close to ten nanomolar
But nanomolar scale activity many locations
Less pronounced than in my stand alone CICE simulations and we are now sorting out the potential reasons
One is that POP is not capturing the then freshened bottom layer below and left over from the pack as it melts
The other is that we are using different release parameterizations for the algae from the ice, quicker in the coupled version
In stand alone I took a hard look at bottom layer chl data beyond the Pacific Arctic and decided I had to include some extension
See Lavoie et al. 2005 for a closely related approach and some references… if growth and melting are slow the algae can maintain position
L05 section 3.2.3 is good on this and I encourage Clara to ask MBJ to test in the coupled model





MBJ (caption)

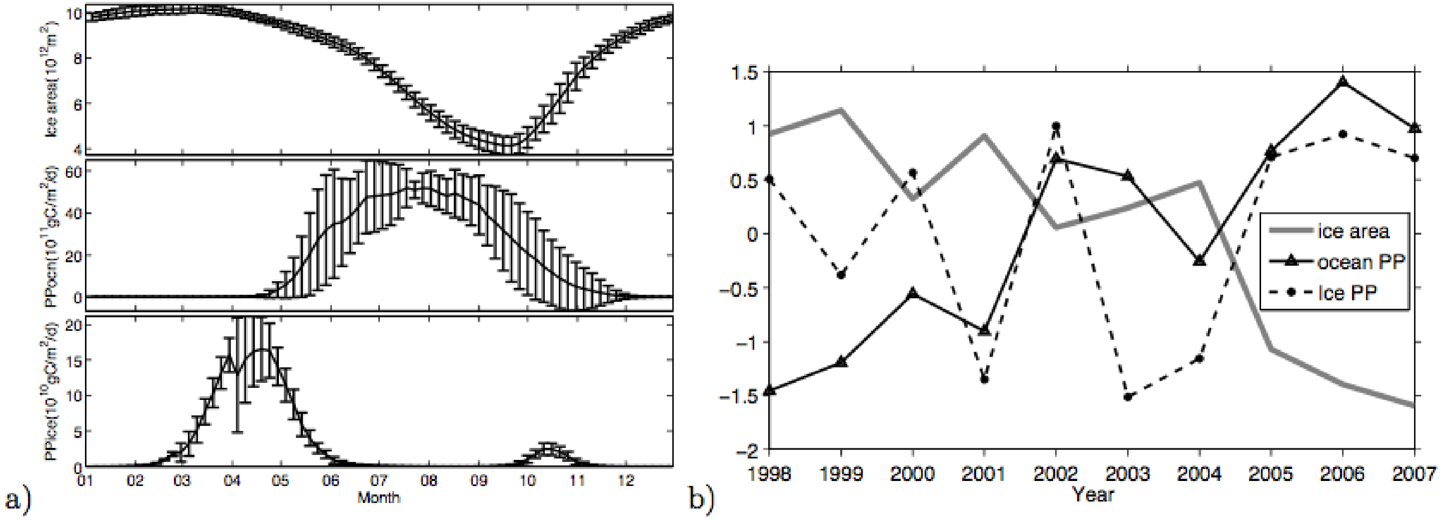


Figure 3: Time series of modeled sea ice area, upper ocean 100m integrated primary production and sea ice algal prodution within the Arctic Circle: a) mean seasonal cycle of 1998-2007 and standard deviation, b) normalized annual production. The normalization was done by minus the mean and divided by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

Leck, 2002

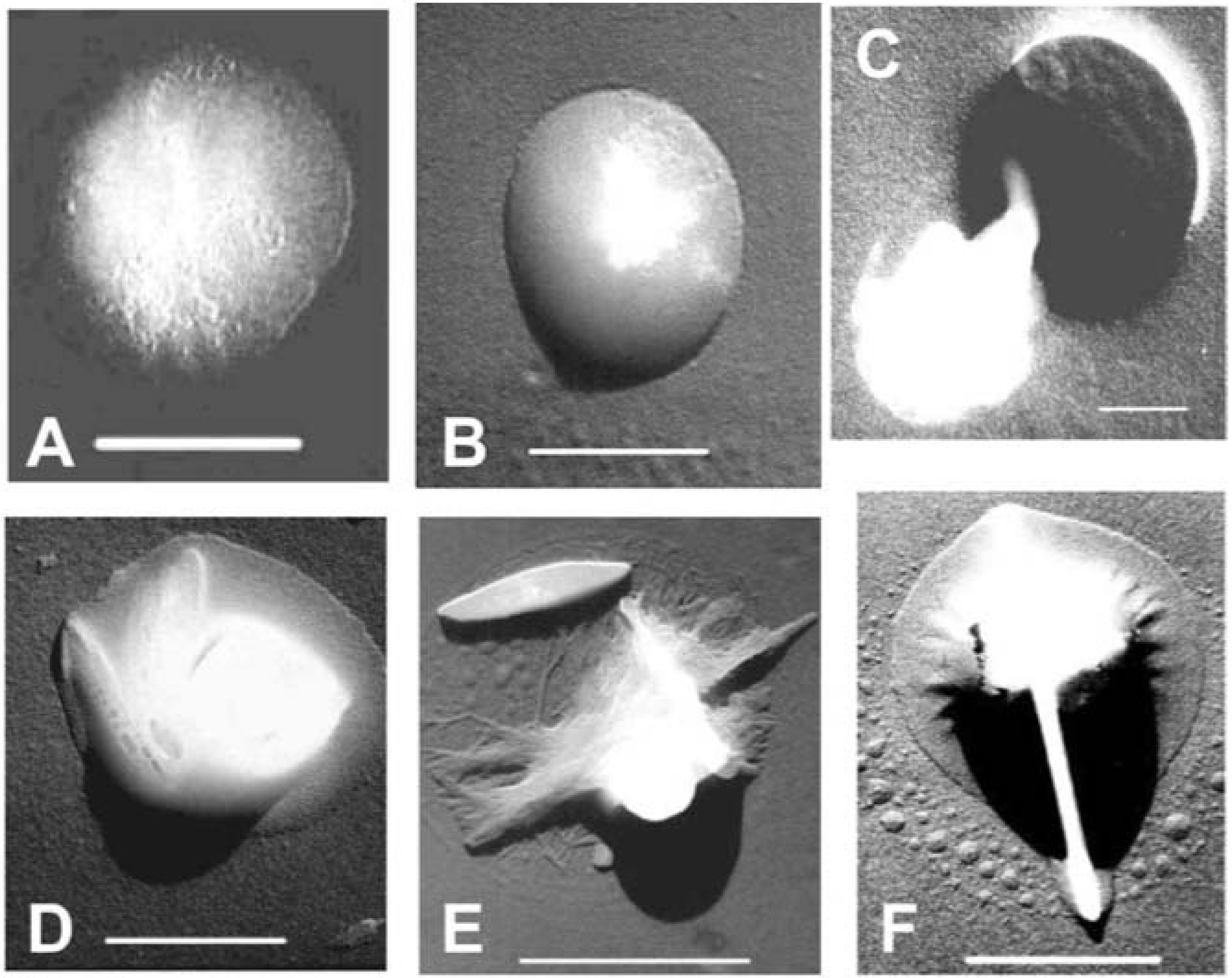
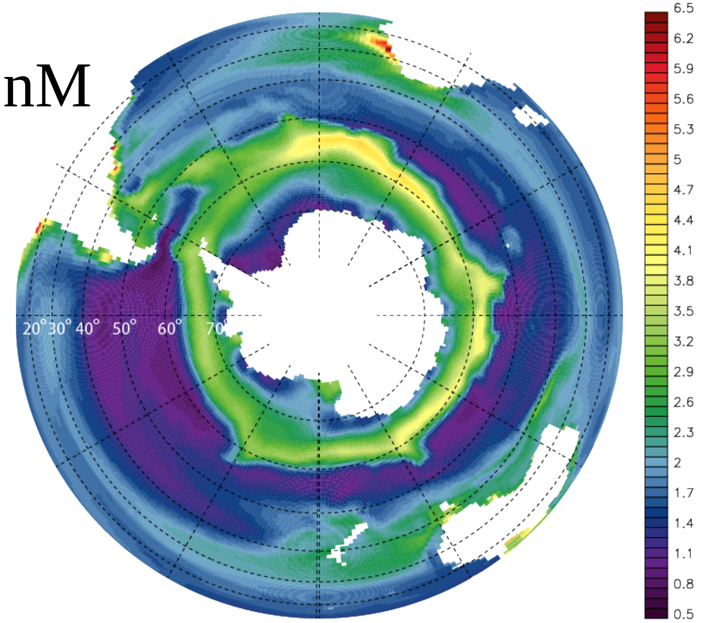


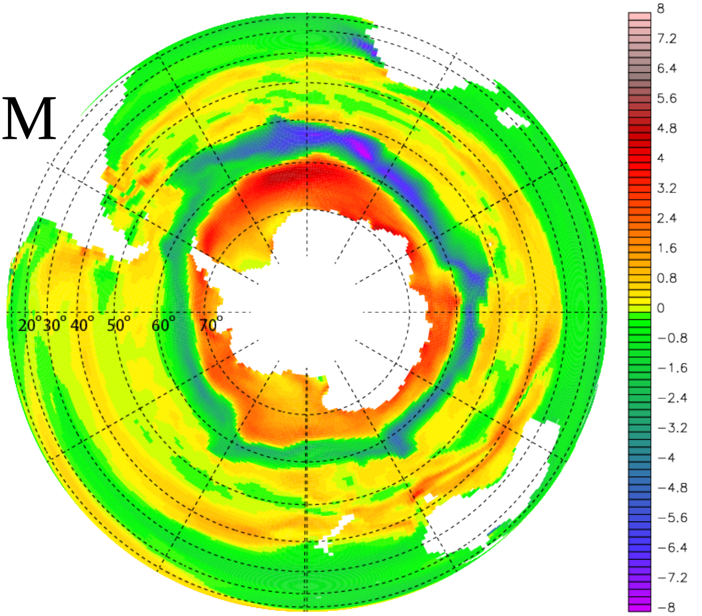
Figure 6. Transmission electron microphotographs of (a–c) film drop particles and (d–f) jet drops. Film drop particles (Figures 6a–6c) were liquid when collected and spread on the surface showing surfactant properties. The liquid had evaporated from the particle in Figure 6a, but not from the particle in Figure 6b. In Figure 6c, the particle had been subjected to decane vapor, and its organic content revealed by the stream of liquid from its interior. The jet drop particles (Figures 6d–6f) are typical sea-salt particles together with an organic content. In Figure 6f, the particle had been longer in the atmosphere and had acquired a coating of sulfuric acid. The rod through its center is thought to be a bacterium. Scale bars are 200 nm for Figures 6a–6c, 1 μm for Figures 6d–6e, and 500 nm for Figure 6f.

Once and future DMS in CC&ESM: GRL 2011

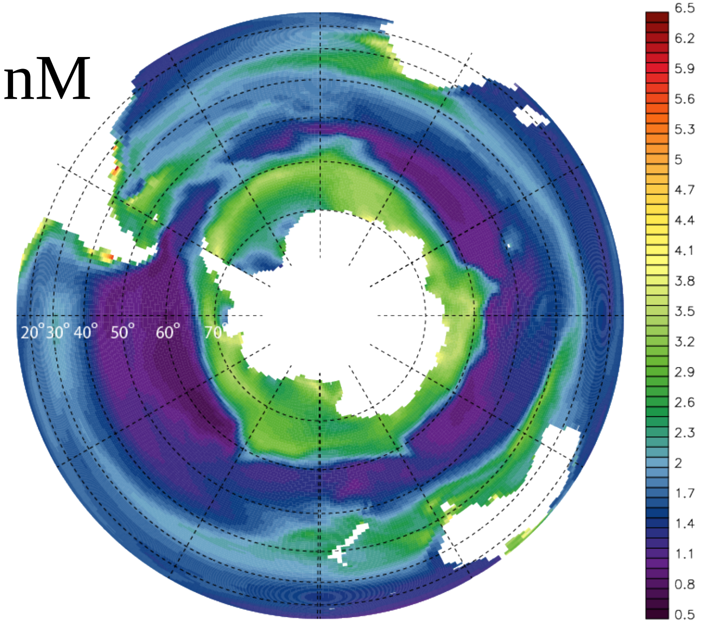
y2000, nM



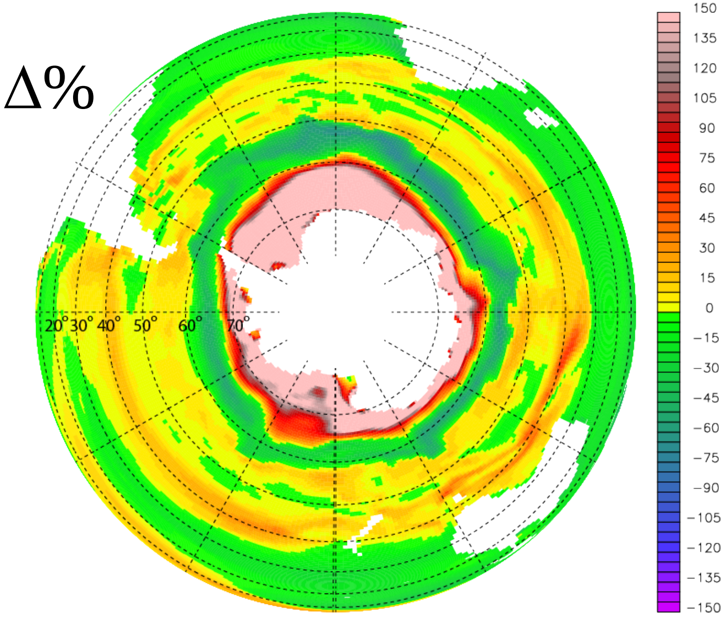
ΔnM



y2100, nM



Δ%



Gases in Ice

^
and around

LANL: S. Elliott, E. Hunke, N. Jeffery, M. Maltrud
IARC: C. Deal, M. Jin
LBL: M. Reagan, G. Moridis
LLNL: P. Cameron Smith, D. Bergmann
Others: B. Loose, J. Stefels, M. Levasseur

U.S. DOE SciDAC for Earth System Modeling,
Plus Gas Hydrates and IMPACTS methane cycling

OUTLINE: Gases of the Ice Domain

OPENING MONTAGE –volatiles on parade

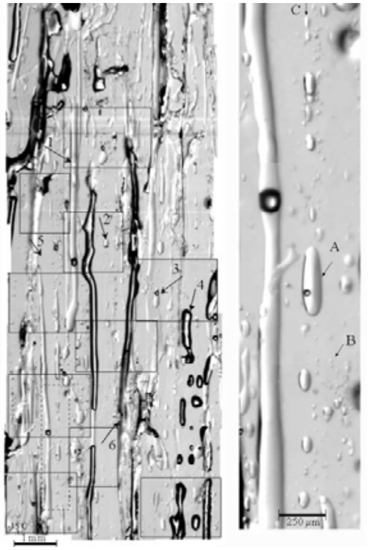
ECOLOGY first but MINERALOGY close behind

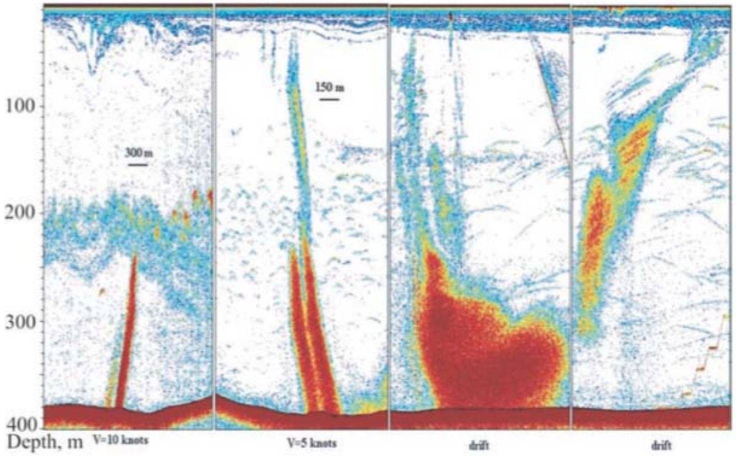
Extreme THERMO and C BUDGETS coming fast

ORGANOSULFUR in ice and surroundings

METHANE BUBBLES below and to the pack

OTHER compounds, issues

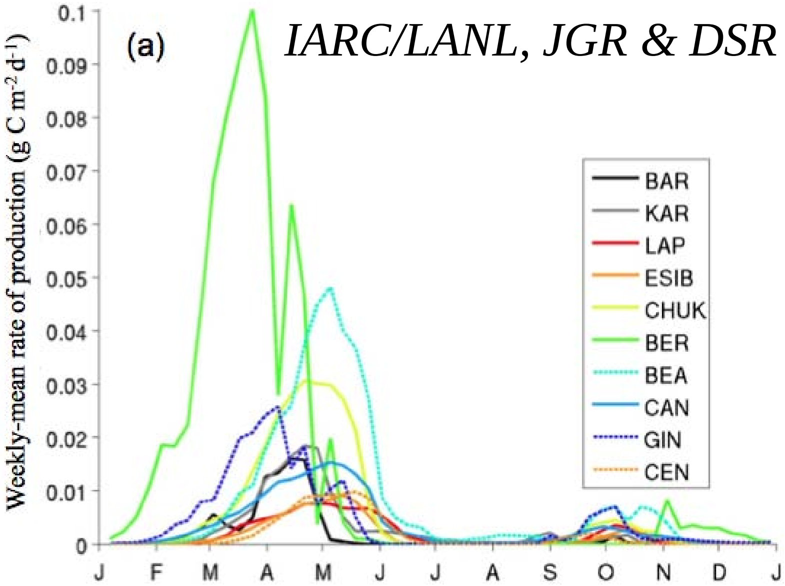




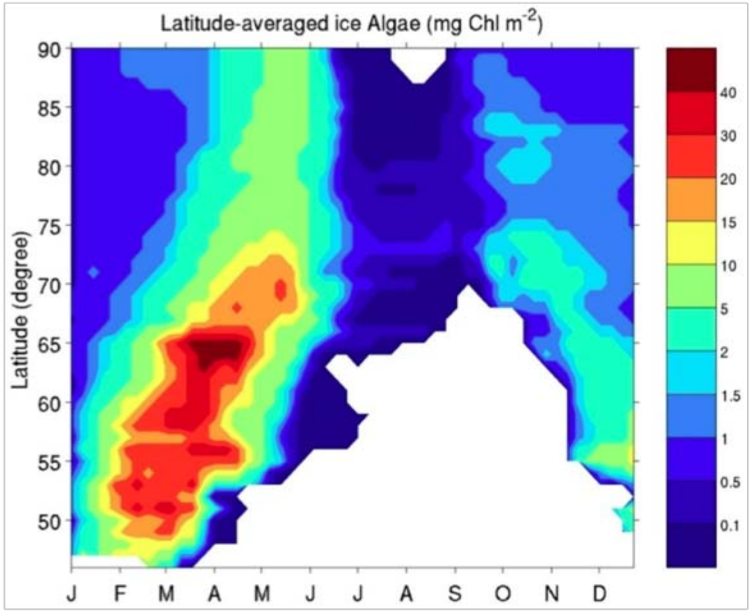
CO_2, DMS, O_2, CH_4

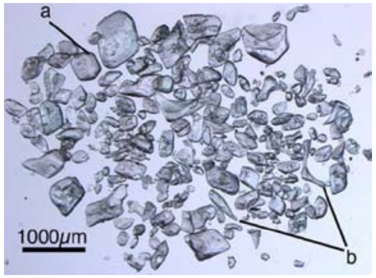
Loose et al. 2011
Deboer et al. 2011
Light et al. 2002
Obzhirov et al. 2004
Shakhova et al. 2009

All roads lead to ecodynamics, but…



IARC/LANL, JGR & DSR





N, Si, Fe drive:

$\boxed{nCO_2} + nH_2O = (CH_2O)n + \boxed{nO_2} + \Delta alkalinity$

$Ca_2^+ + CO_3^{2-} = ikaite + \Delta alkalinity$

$H_2O.CO_2 = H^+ + HCO_3^-$

$HCO_3^- = H^+ + CO_3^{2-}$

Vertical and ice-air transfer

All hypersaline: Pitzer eqs.

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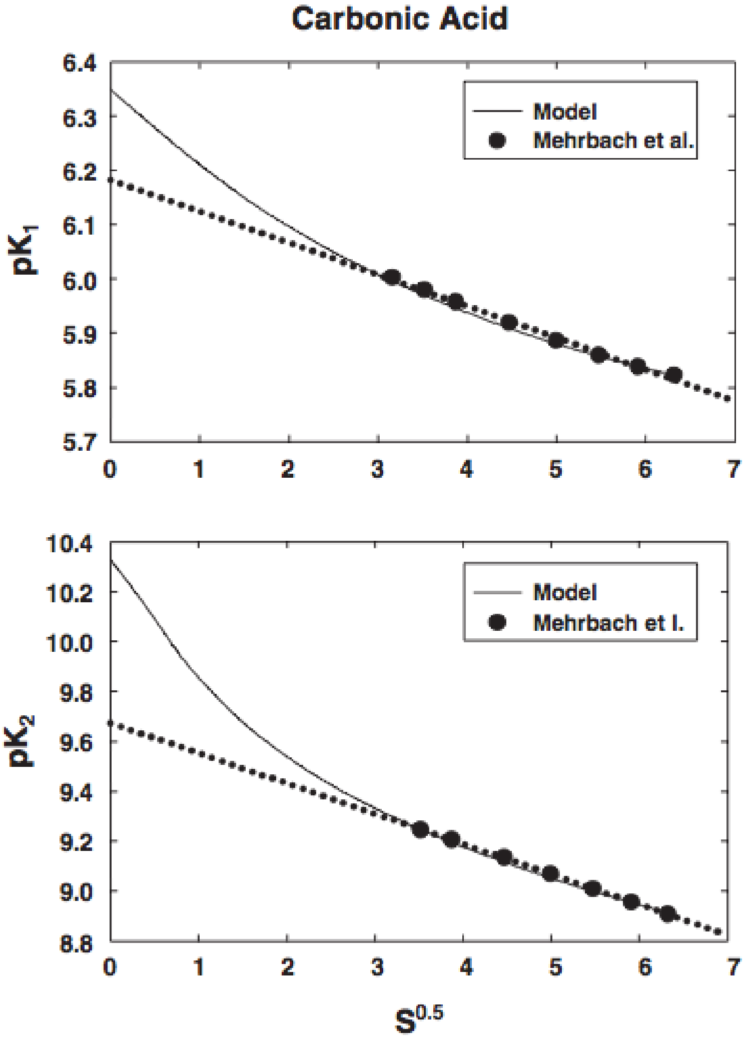
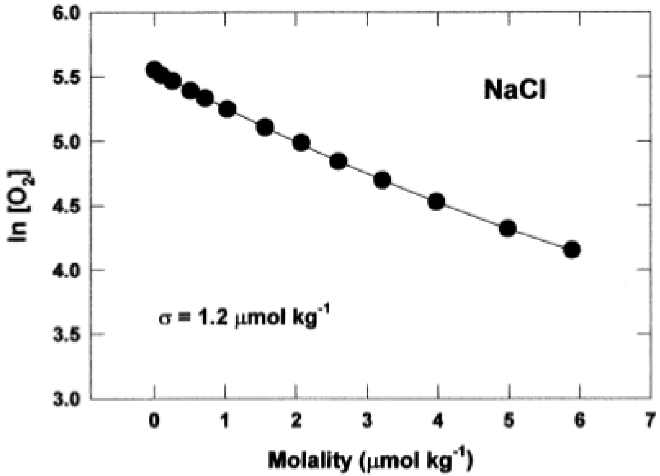
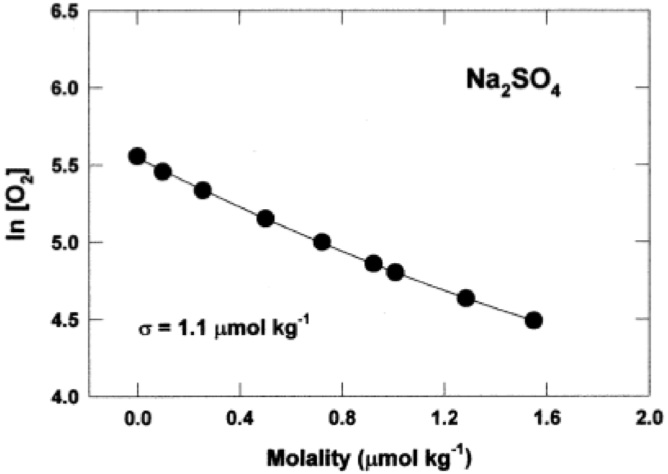
Extreme Thermochemistry







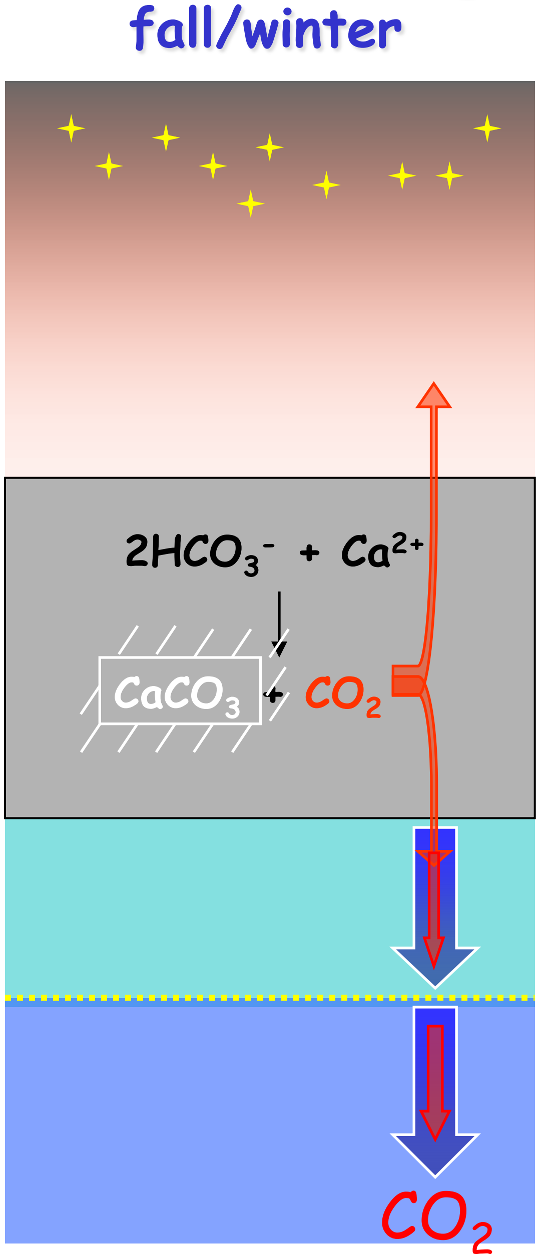
$$
\begin{aligned}
\ln\gamma_N = {} & 2\Sigma_n\lambda_{Nn}m_n \\
& + 2\Sigma_c\lambda_{Nc}m_c + 2\Sigma_a\lambda_{Na}m_a + 3\Sigma_n\mu_{Nnn}m_n \\
& + 6\Sigma_n\Sigma n'm_n m_{n'}\mu_{Nnn'} + 6\Sigma_n m_N\mu_{NNn} \\
& + 6\Sigma_n\Sigma_c m_n m_c\mu_{Nnc} + 6\Sigma_n\Sigma_a m_n m_a\mu_{Nna} \\
&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

Millero et al., several ? No, CRREL as usual

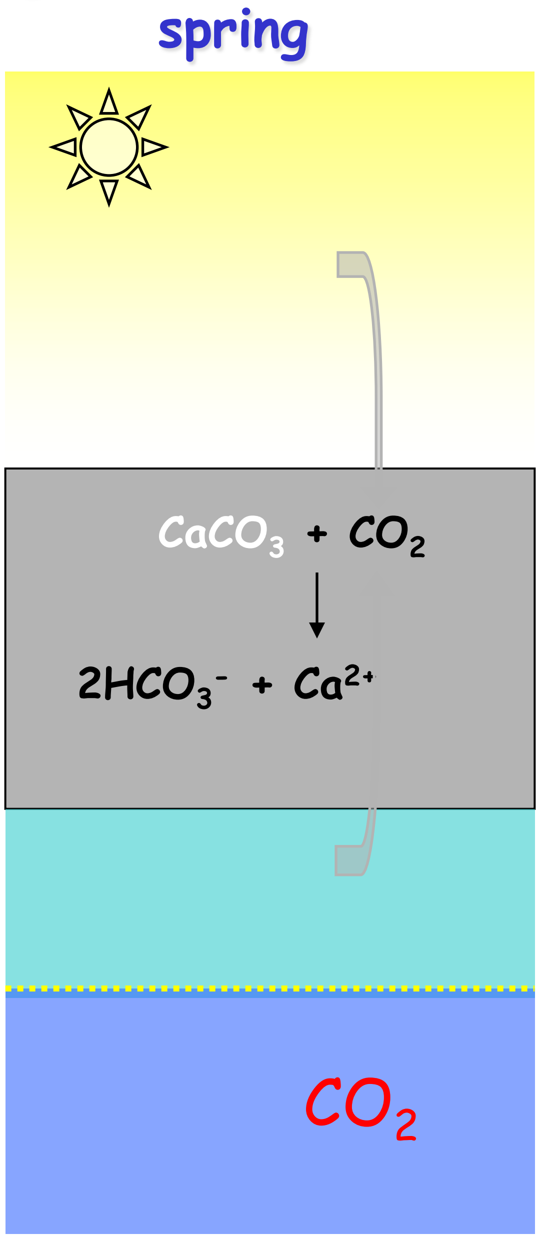
Pitzer equations -just Debye-Huckel on steroids

GAS COMPOSITION IN SEA ICE

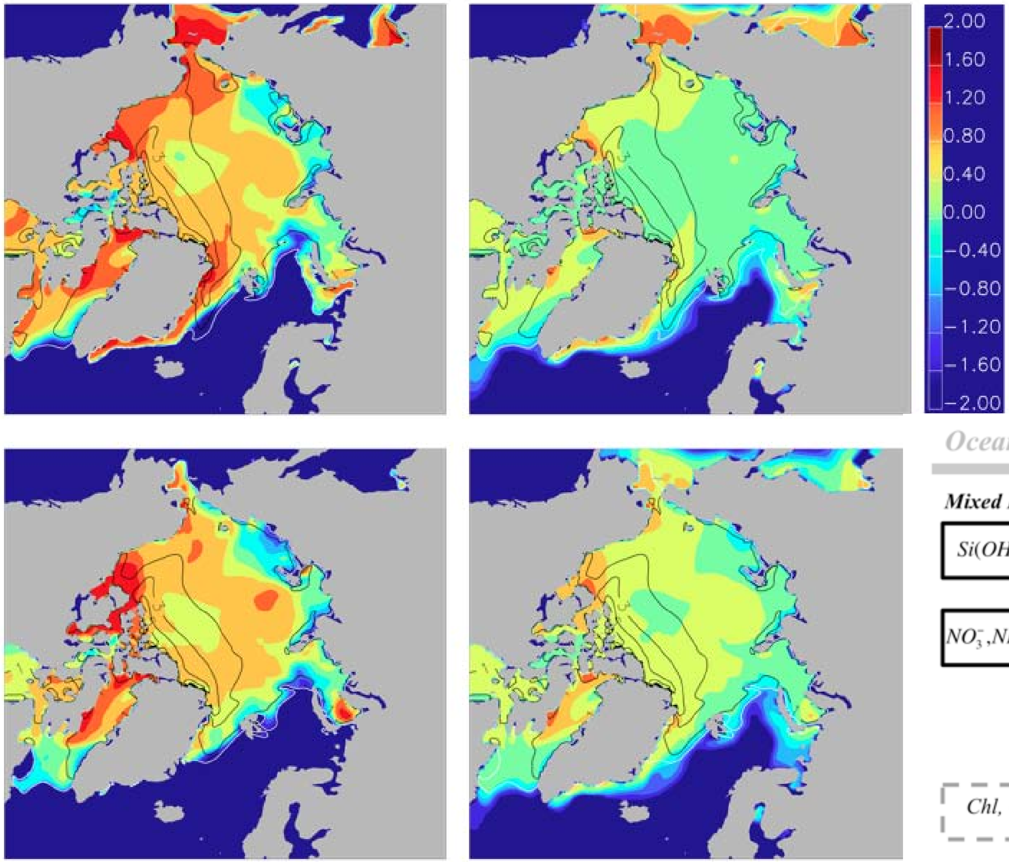
A potential abiotic $CaCO_3$ Carbon pump



- 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 (?)



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



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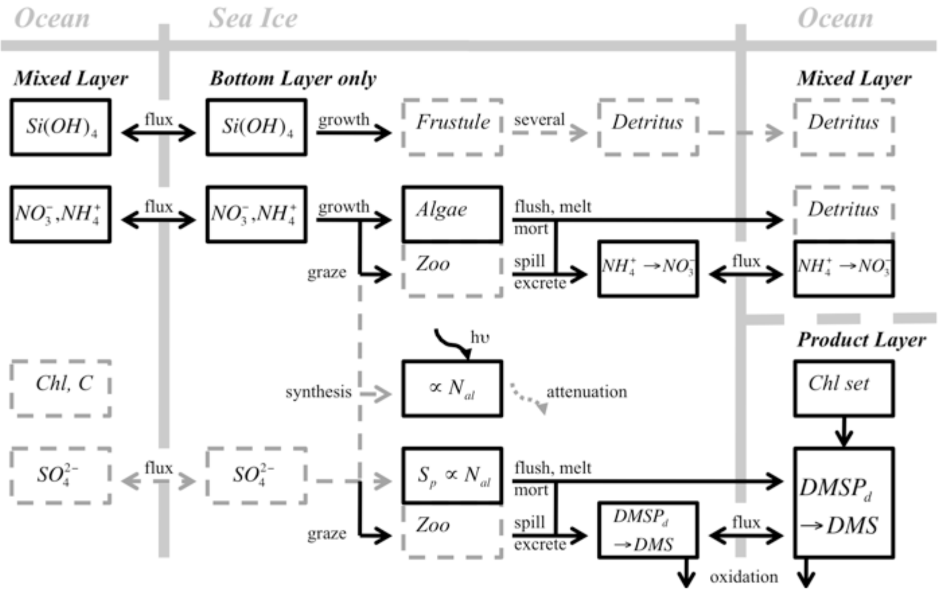


Ocean | Sea Ice | Ocean

Mixed Layer | ***Bottom Layer only*** | ***Mixed Layer***

$Si(OH)_4$ flux $Si(OH)_4$ growth *Frustule* several *Detritus* *Detritus*

NO_3^-, NH_4^+ flux NO_3^-, NH_4^+ growth *Algae* flush, melt mort *Detritus*

graze *Zoo* spill excrete $NH_4^+ \rightarrow NO_3^-$ flux $NH_4^+ \rightarrow NO_3^-$

Product Layer

hυ

Chl, C synthesis $\propto N_{al}$ attenuation *Chl set*

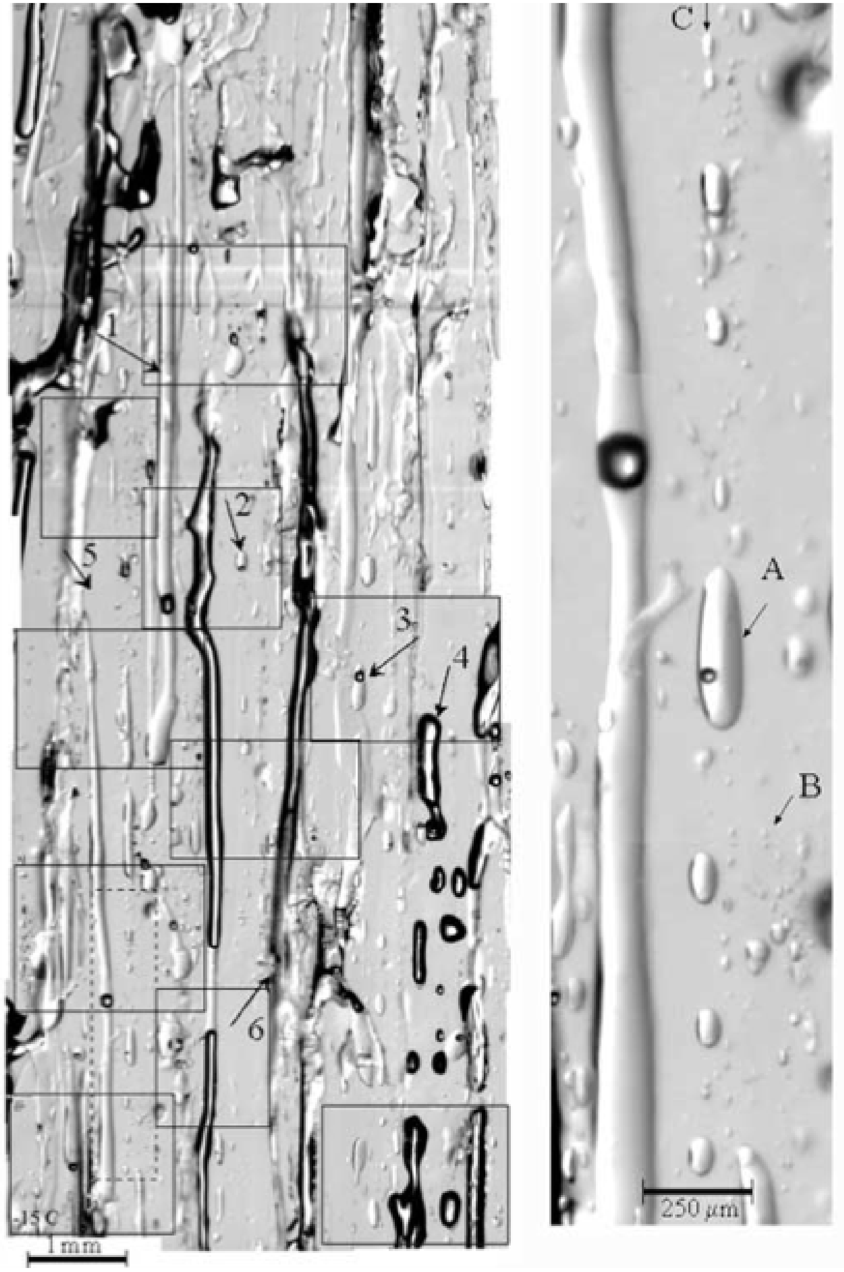
SO_4^{2-} flux SO_4^{2-} $S_p \propto N_{al}$ flush, melt mort $DMSP_d \rightarrow DMS$

graze *Zoo* spill excrete $DMSP_d \rightarrow DMS$ flux

oxidation

DMS via CICE: beneath, residual

Major Elements



O_2, photo-radical chemistry

-Biological stress

Nitrogen redox:

-Nitrification, N_2O

(Which incidentally…

(Points to rest of N system…

(Reduced gases too, NH_3/NH_4+)

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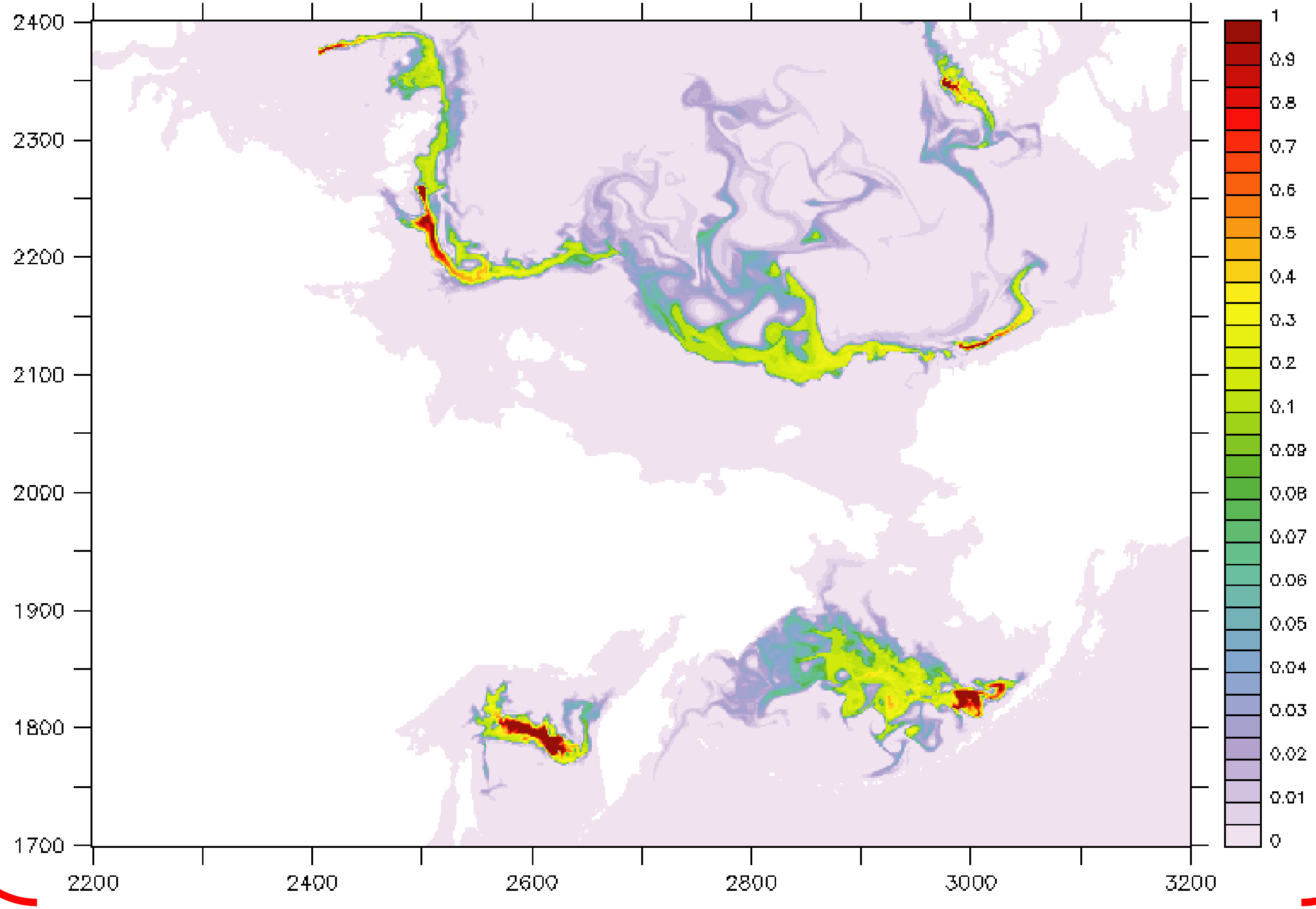
NATIONAL LABORATORY

Bubble rise for DOE Impacts and Gas Hydrates



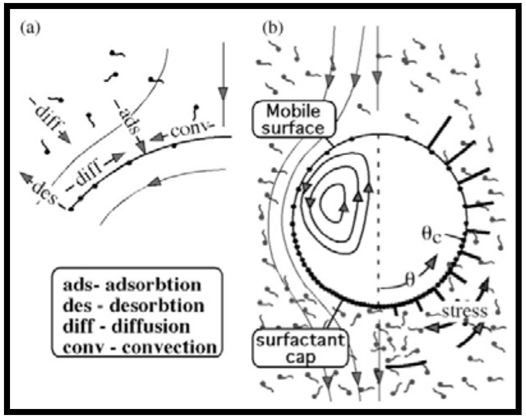
{Swap in latest runs, methane trapped below ice…}

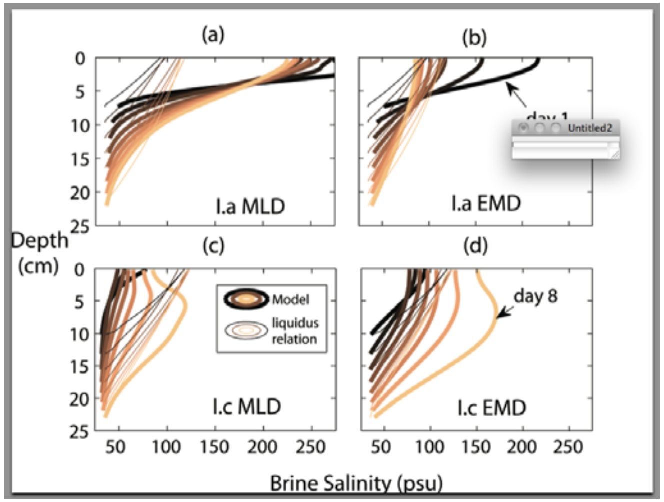
Bubbles and Futures

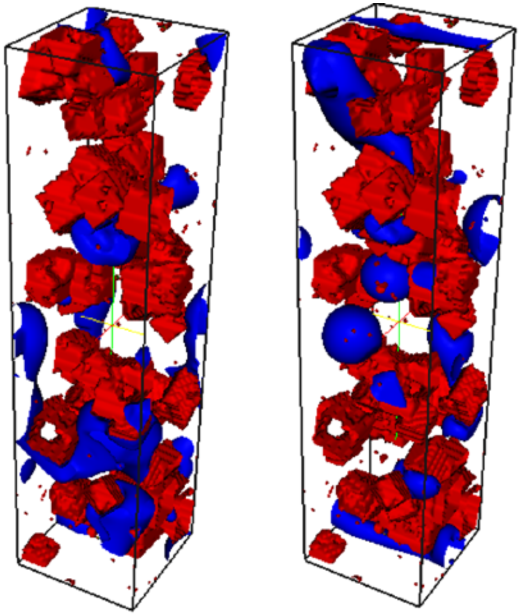
Percent CH_4, Atlantic Layer to Arctic Mixed Layer

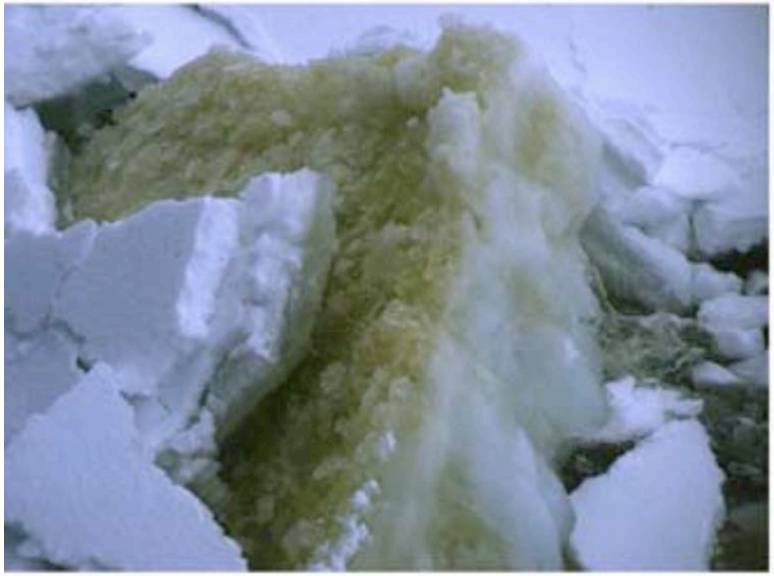
(conservative K_v)

		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	JF 0	0	**0**	**0**	**100**
	off	0	0	**10**	**20**	**100**
10,000 km	on	0	0	**0**	**0**	**100**
	off	0	0	AJ **20**	**40**	**100**
>10,000 km	on	0	0	**0**	**0**	**100**
(GIN mix)	off	100	100	**100**	**100**	**100**



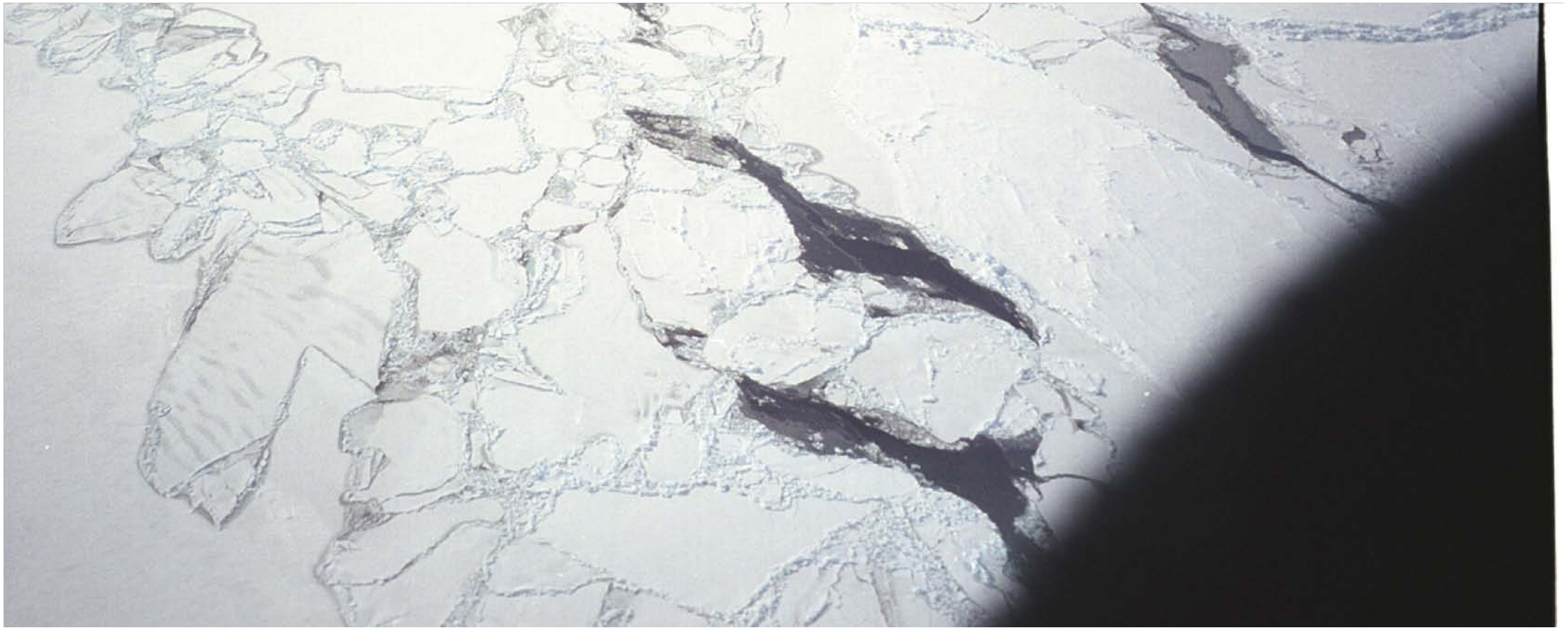


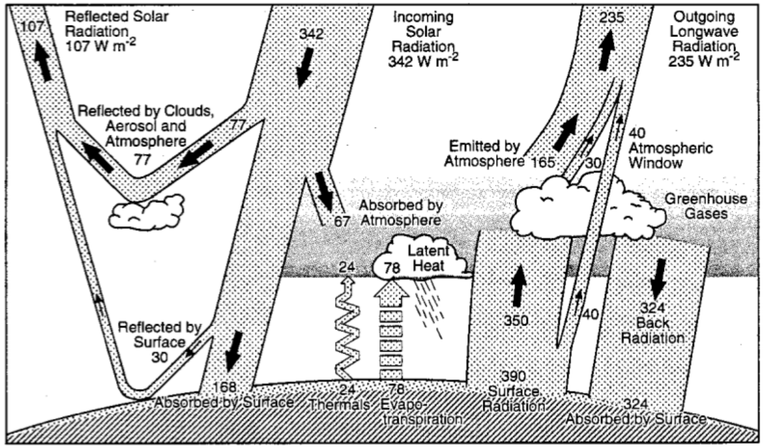




…and (ever) more

Organic surface chemistry
Transfer from leads
Halogenates, I_2




107
Reflected Solar Radiation 107 W m-2
342
Incoming Solar Radiation 342 W m-2
235
Outgoing Longwave Radiation 235 W m-2
Reflected by Clouds, Aerosol and Atmosphere 77
77
Emitted by Atmosphere 165
30
40 Atmospheric Window
Absorbed by Atmosphere 67
Greenhouse Gases
Latent Heat 78
24
350
40
324 Back Radiation
Reflected by Surface 30
168 Absorbed by Surface
24 Thermals
78 Evapo-transpiration
390 Surface Radiation
324 Absorbed by Surface


Slinky
Slinky

The envelope please…

By these criteria, rank order for high latitude cycles:

- -Ice chlorophyll (surface darkening)
- -DMS
- -Organics tweak sea-air transfer
- -CH_4
- -Organics tweak aerosol
- -Seeding tweaks sea-air transfer
- -Open, brine, skeletal C cycles
- -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

The envelope please…

By these criteria, rank order for high latitude cycles:

CO_2, O_2

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-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
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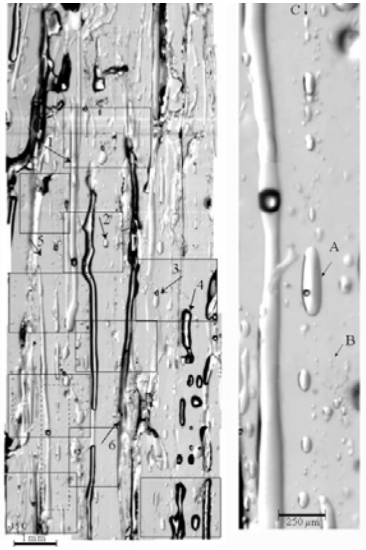

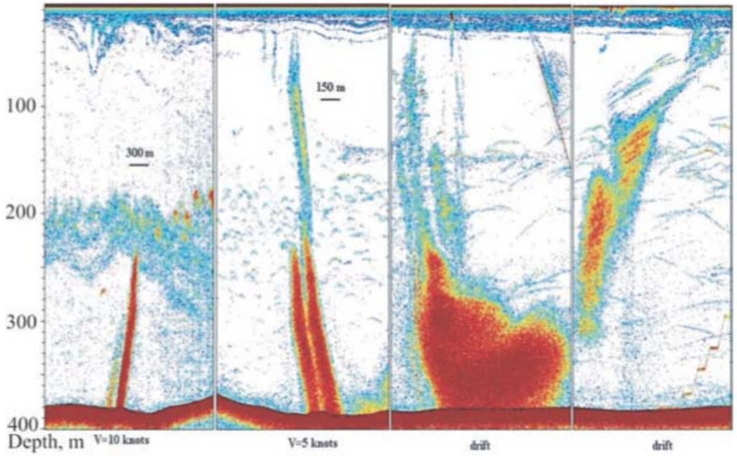

CO_2, DMS, O_2, CH_4

Loose et al. 2011
Deboer et al. 2011
Light et al. 2002
Obzhirov et al. 2004
Shakhova et al. 2009