



Gases in Sea Ice

and around

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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 and Sea Ice

OPENING MONTAGE –volatiles on parade

ECOLOGY first but MINERALOGY close behind

Extreme THERMO and C BUDGETS coming fast

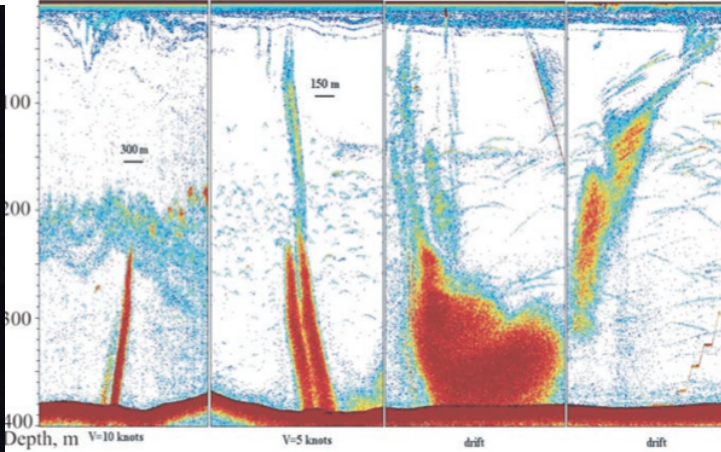
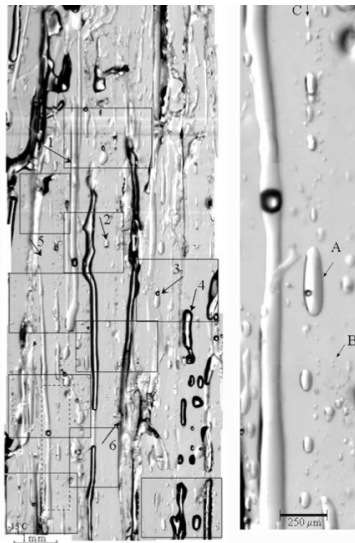
ORGANOSULFUR in ice and surroundings

METHANE BUBBLES below, to, through pack

OTHER compounds including halogens

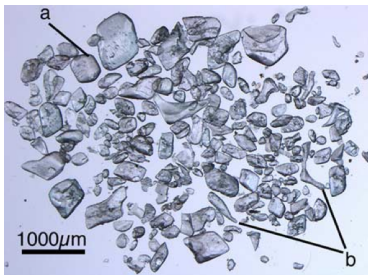
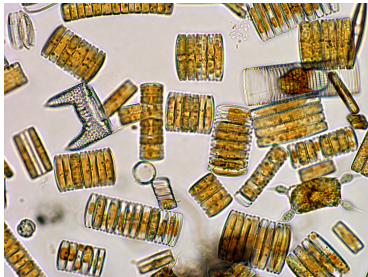
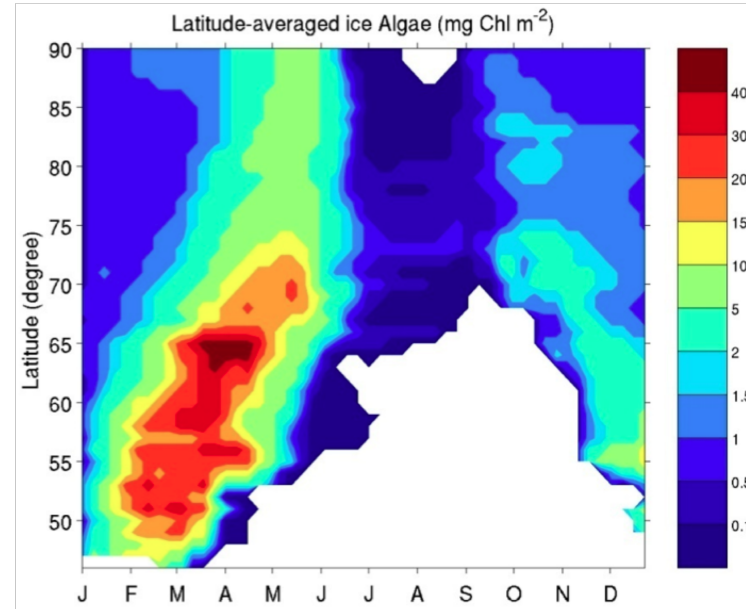
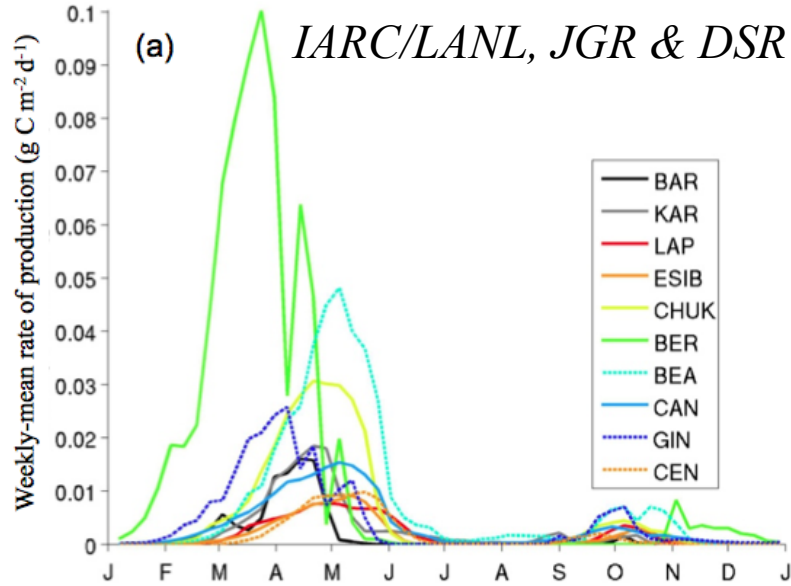


CO₂, DMS, O₂, CH₄...

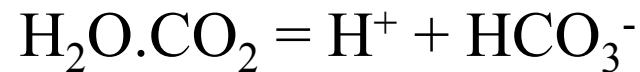
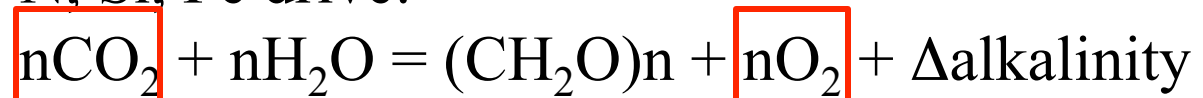


Loose et al. 2011
Deboer et al. 2011
Light et al. 2002
Obzhurov et al. 2004
Shakhova et al. 2009

All roads lead to ecodynamics, but...



N, Si, Fe drive:

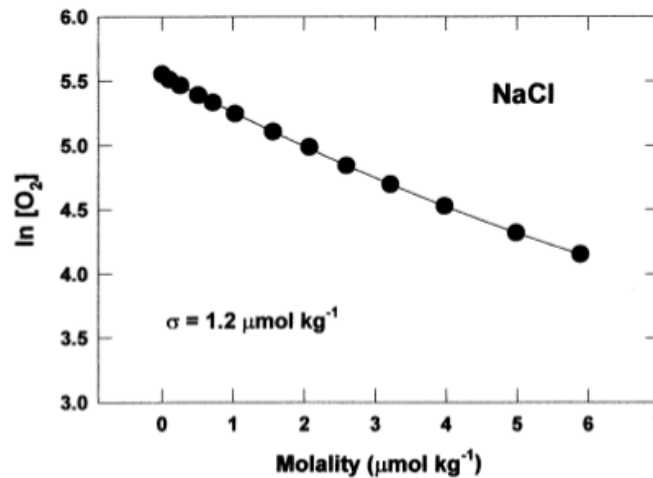
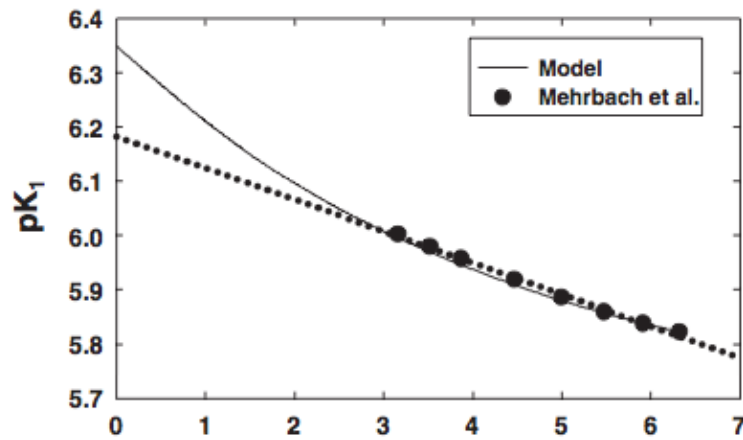


Vertical and ice-air transfer

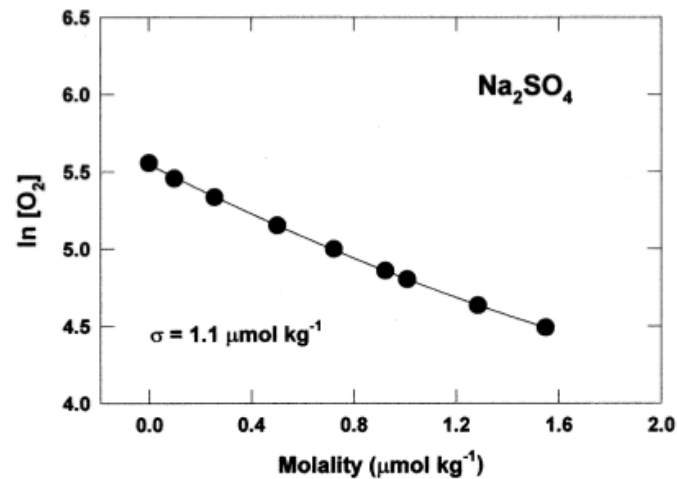
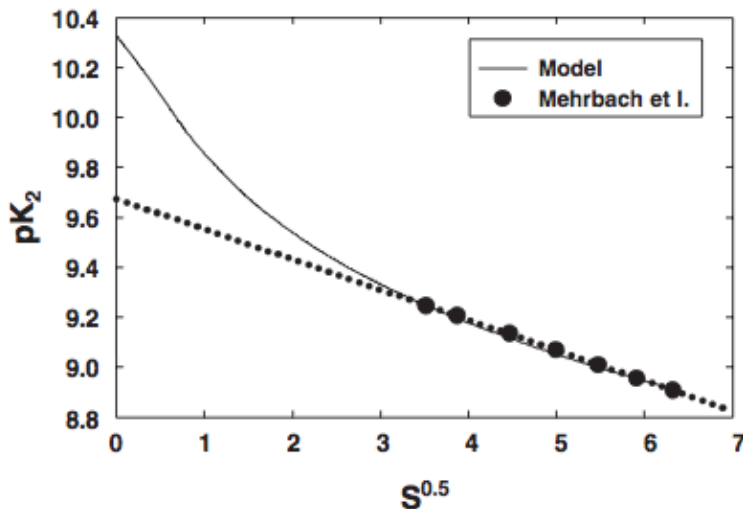
All hypersaline: Pitzer eqs.

Extreme Thermochemistry

Carbonic Acid



$$\ln \gamma_N = 2 \sum_n \lambda_{Nn} m_n + 2 \sum_c \lambda_{Nc} m_c + 2 \sum_a \lambda_{Na} m_a + 3 \sum_n \mu_{Nnn} m_n + 6 \sum_n \sum_n' m_n m_{n'} \mu_{Nnn'} + 6 \sum_n m_n \mu_{Nnn} + 6 \sum_n \sum_c m_n m_c \mu_{Nnc} + 6 \sum_n \sum_a m_n m_a \mu_{Nna} + 6 \sum_c \sum_a m_c m_a \zeta_{Nca} + \sum_{c < c'} m_c m_{c'} \eta_{Ncc'} + \sum_{a < a'} m_a m_{a'} \eta_{Naa'}$$

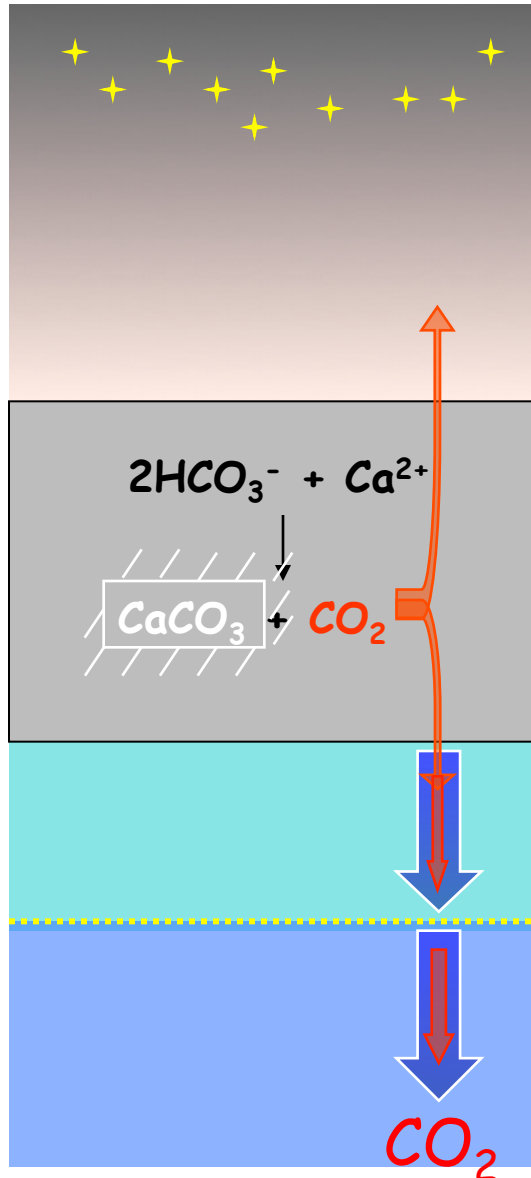


Millero et al., several ? No, CRREL as usual
Pitzer equations -just Debye-Huckel on steroids

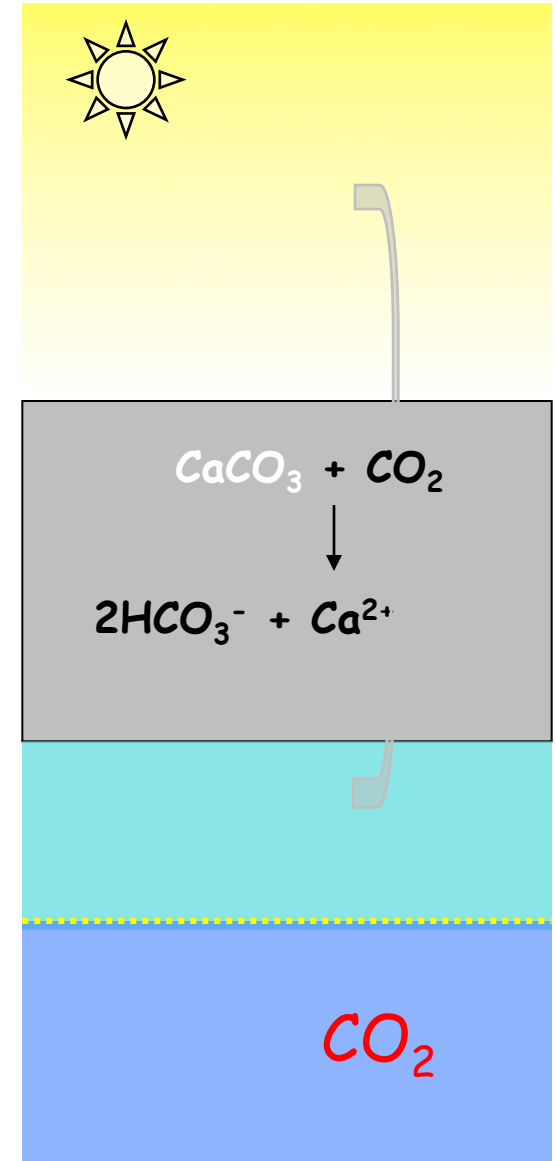
GAS COMPOSITION IN SEA ICE

A potential abiotic CaCO_3 Carbon pump

fall/winter



spring

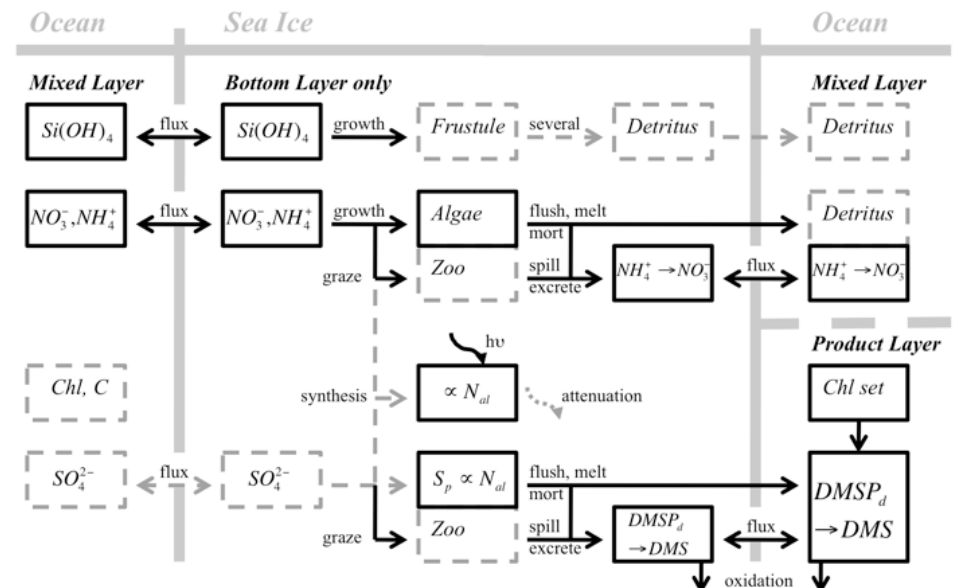
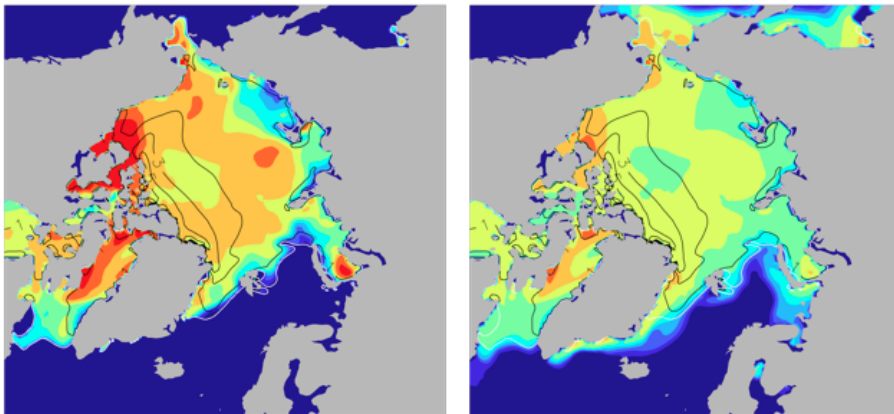
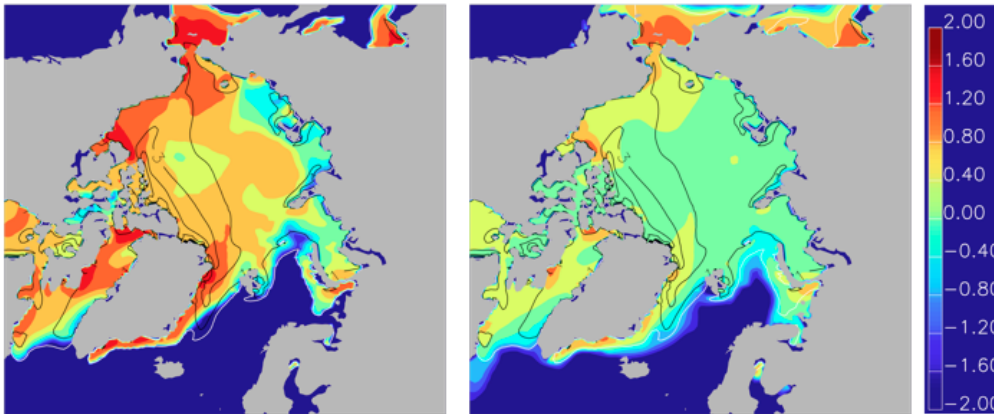


- In spring, CaCO_3 trapped within sea ice dissolves. This process consumes CO_2 .

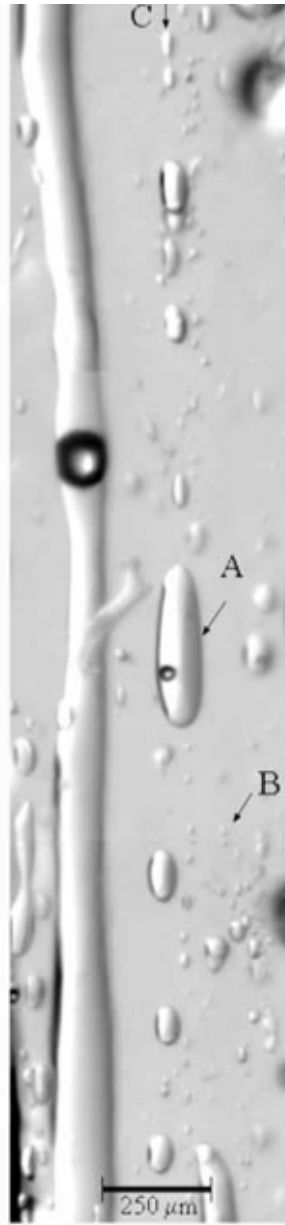
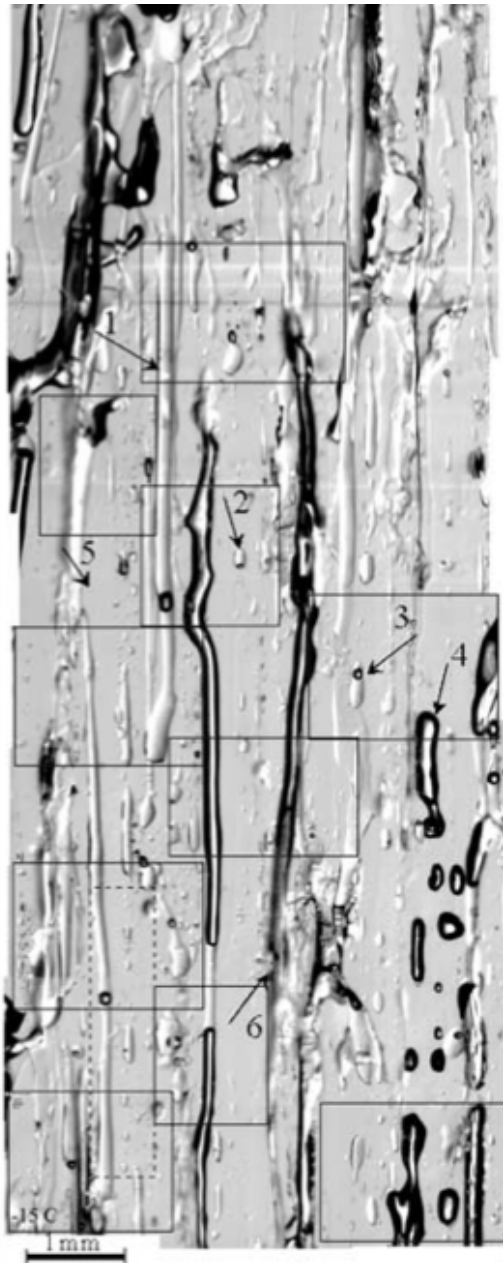
- Budget of winter and spring processes is a net sink of CO_2 . It depends on:

- 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.



DMS in May: Sensitivities below CICE



Major Elements

O₂, photo-radical chemistry

-Biological stress

Nitrogen redox:

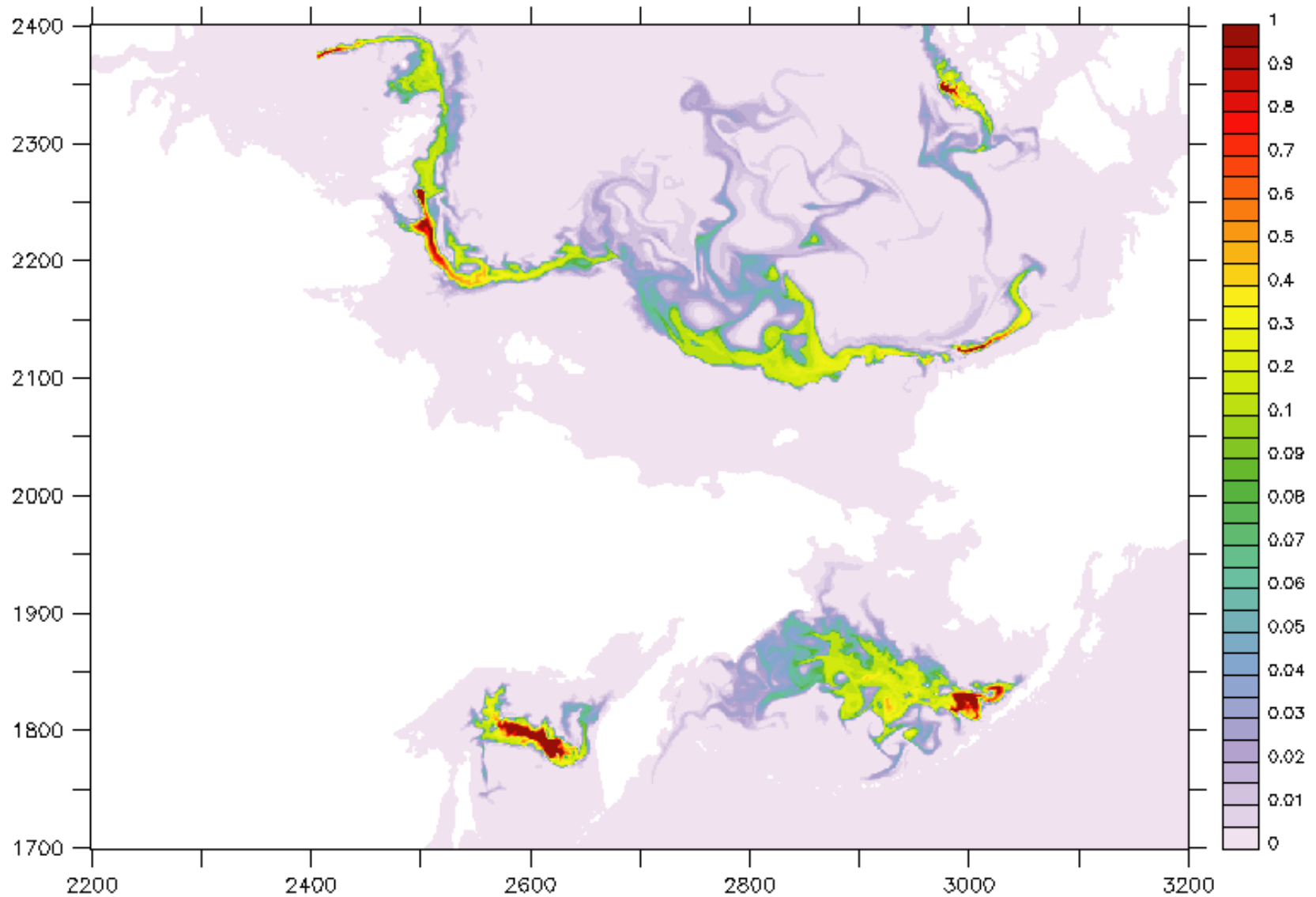
-denitrification, N₂O

(Which incidentally...

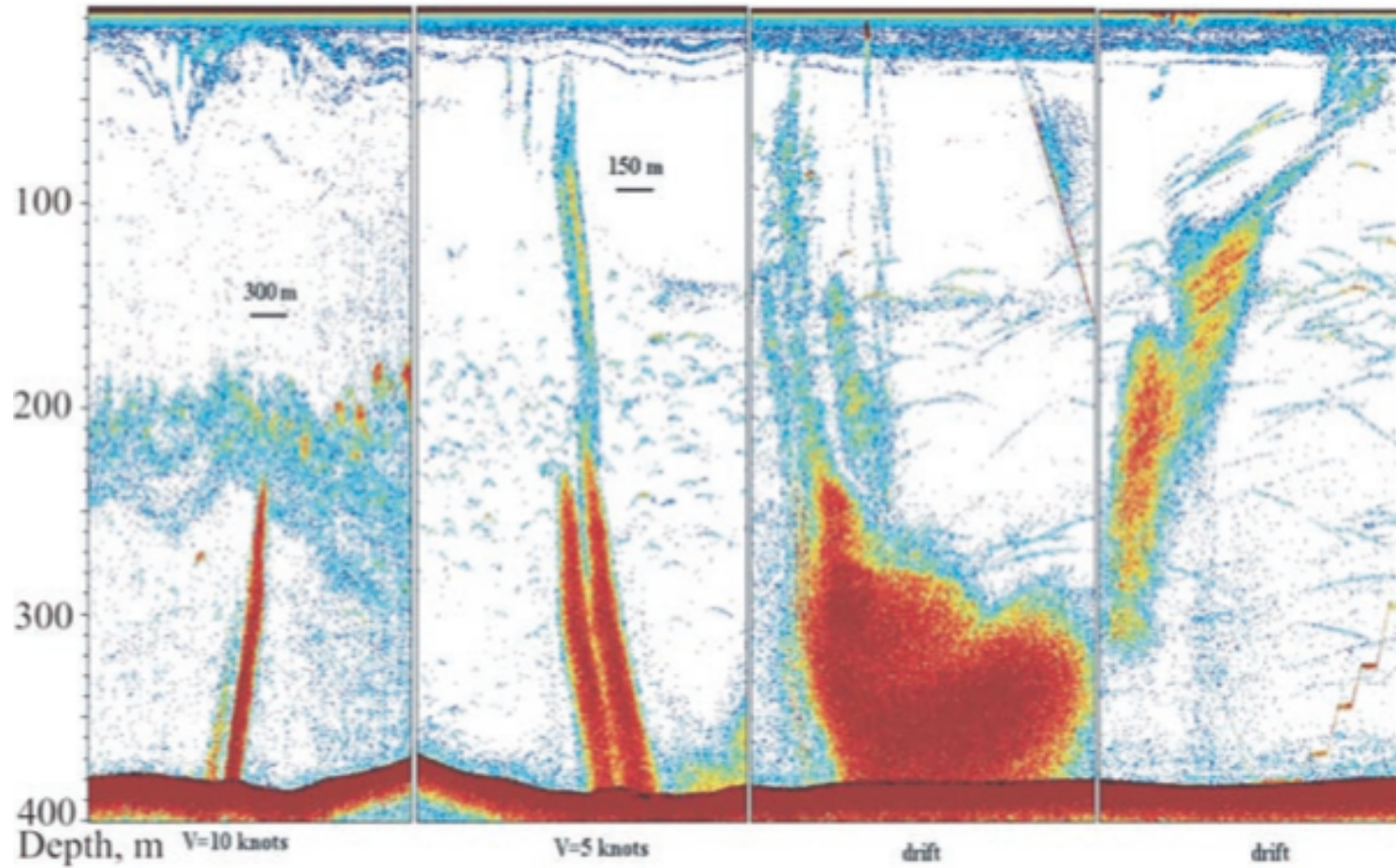
(Points to rest of N system...

(Reduced gases too, NH₃/NH₄⁺)

Clathrate destabilization for DOE Impacts and Fossil

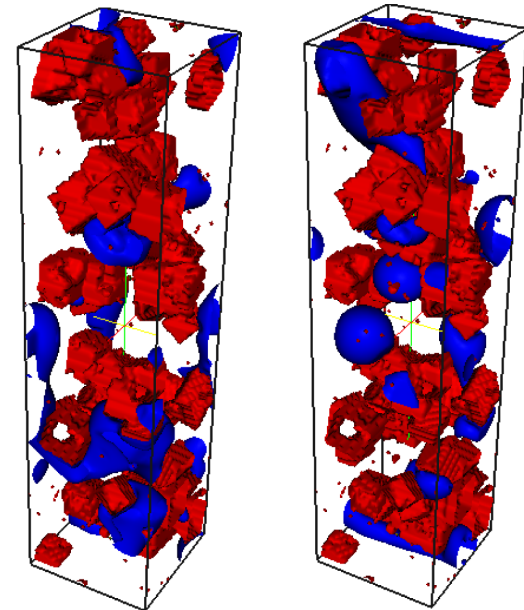
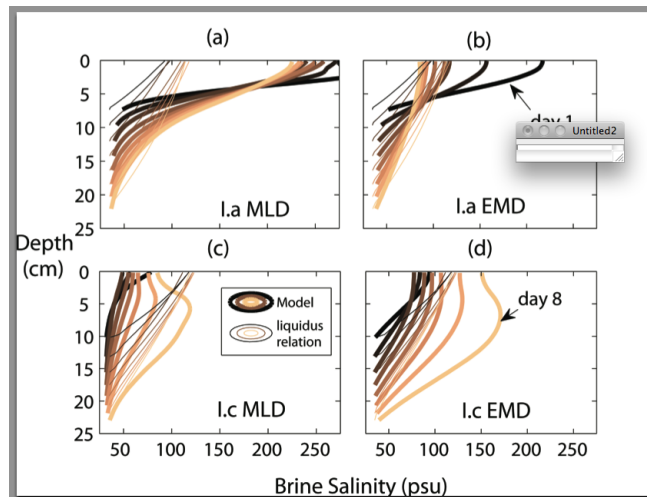
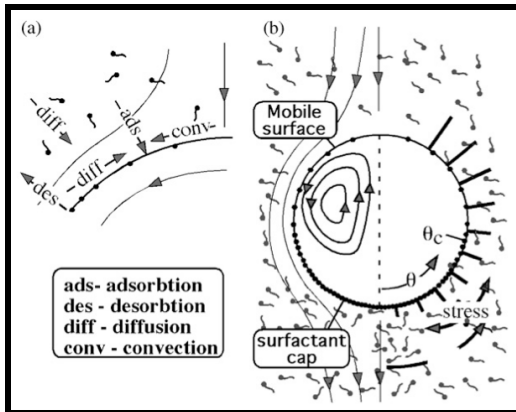


Obzhirov et al., Sea of Okhotsk off Sakhalin CH₄ bubble flares

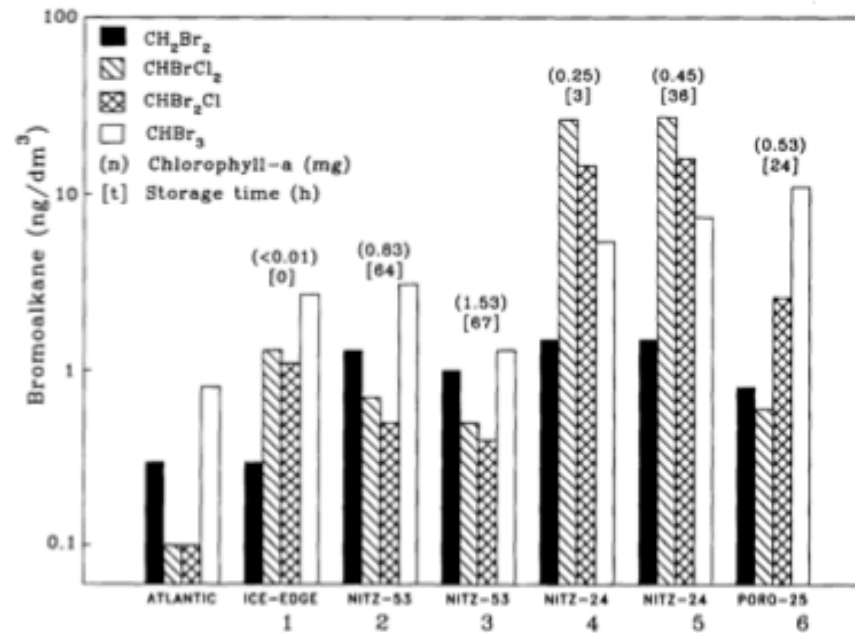
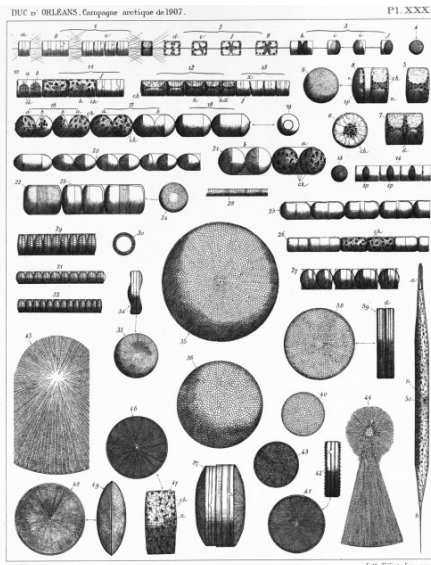
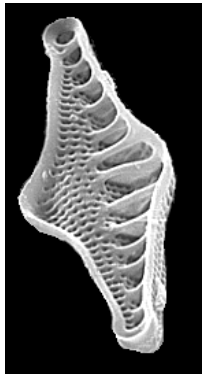
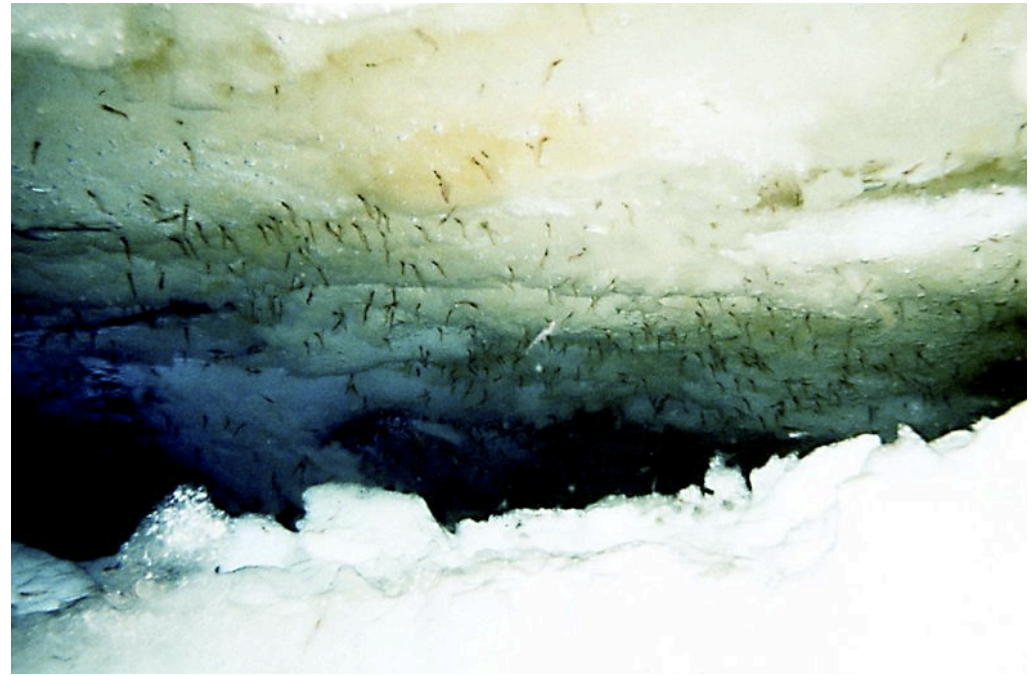
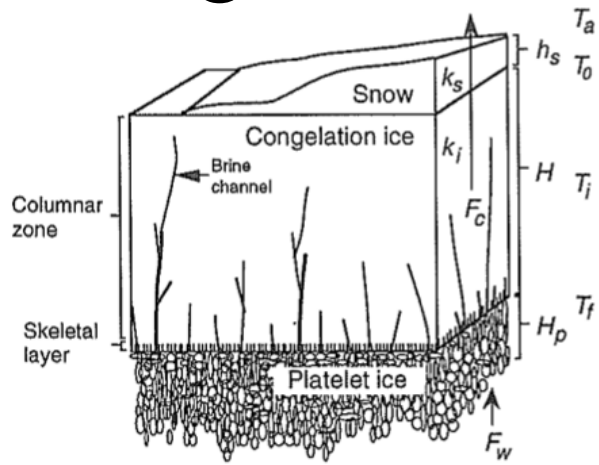


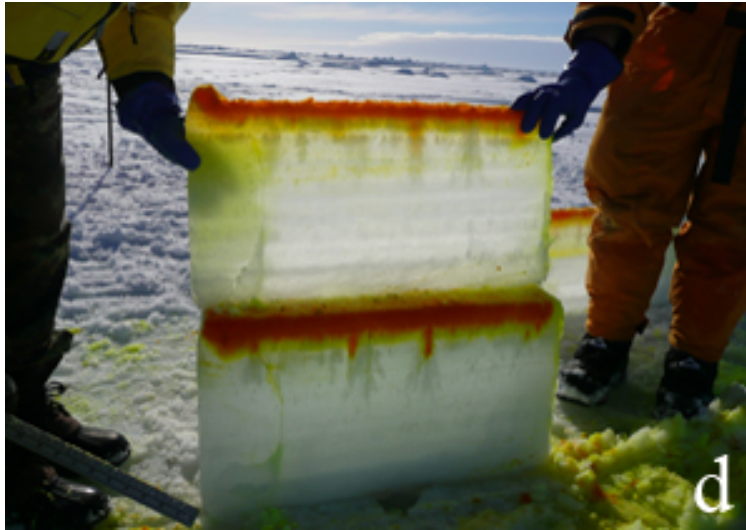
Bubbles and Futures

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	300 m	>300 m
				(floor up)	(Δ100)	
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



A Halogen Tale

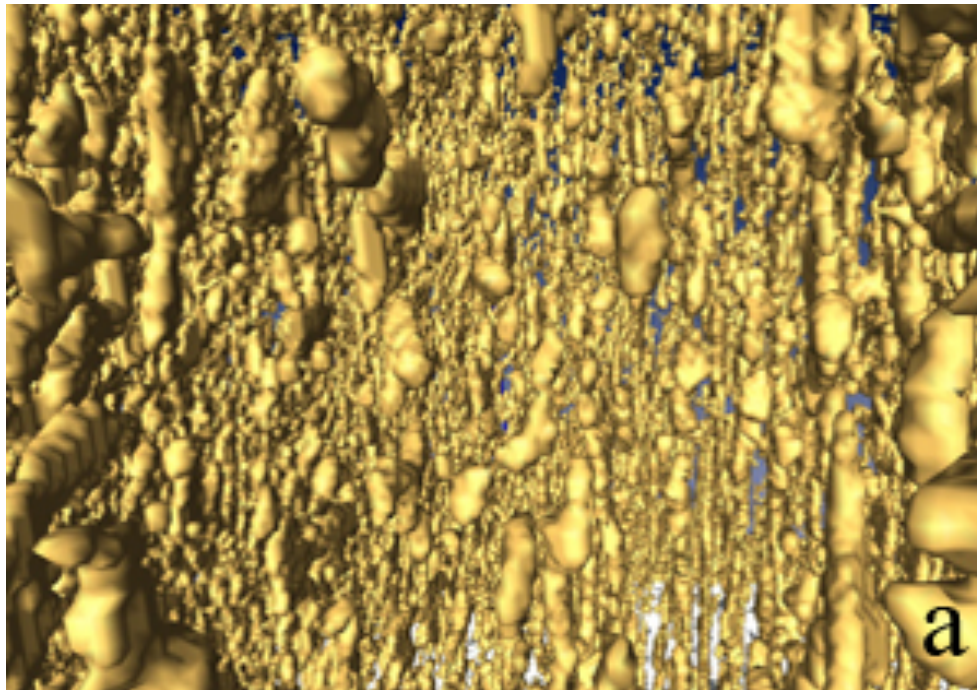


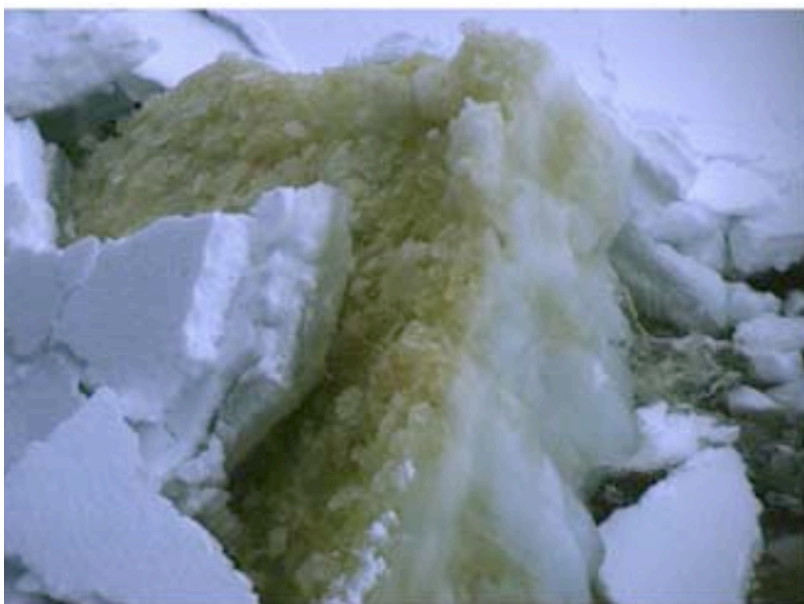


The Brine

A complex salt dynamic
-salinities to 300 psu

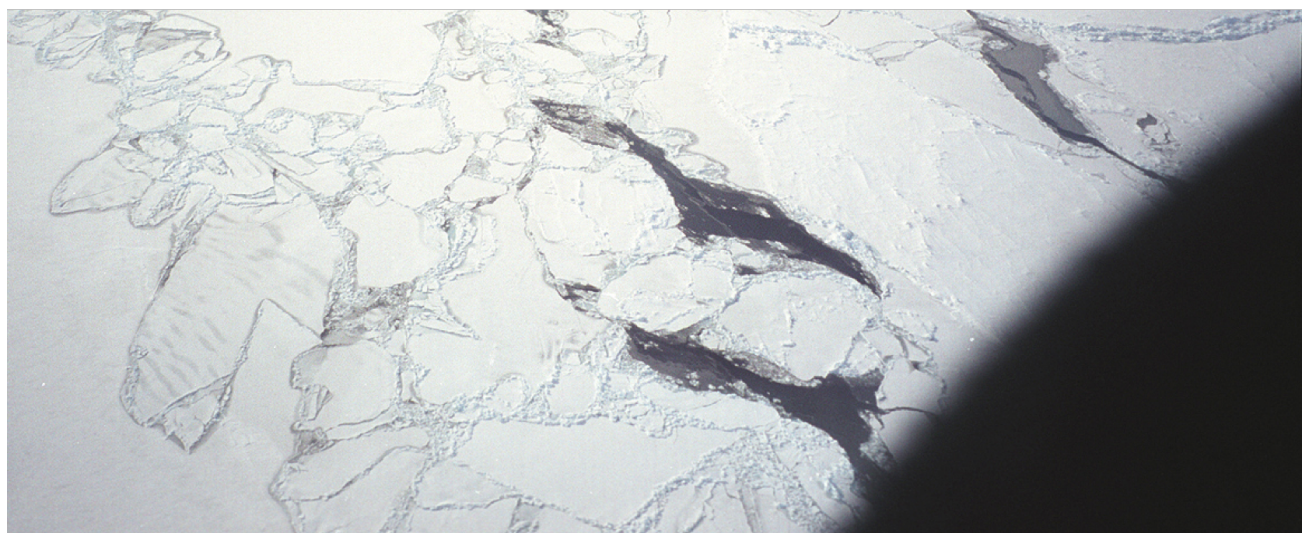
Convection, flush, headspace
-then snow layers
-melt ponds





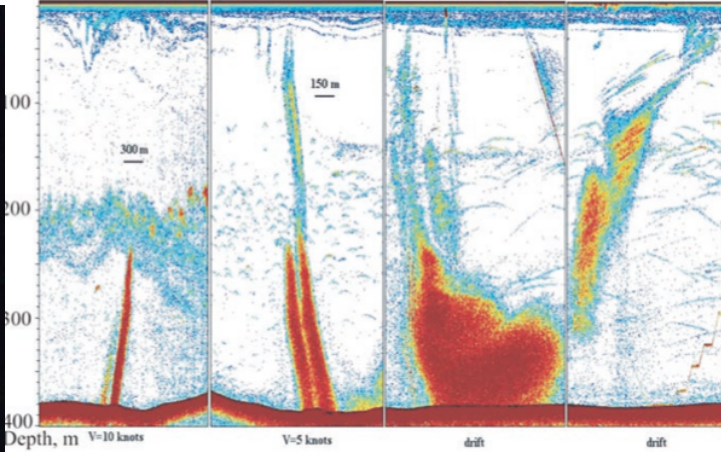
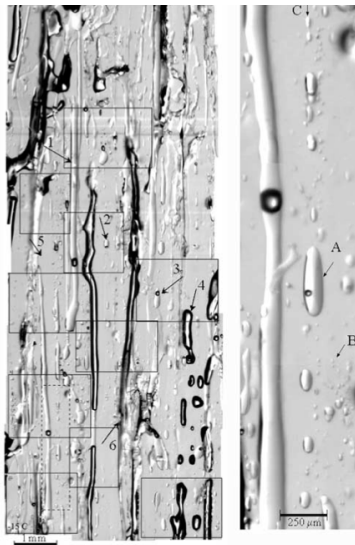
...and (ever) more

Organic surface chemistry
Transfer from leads
Aerosol/cloud systems





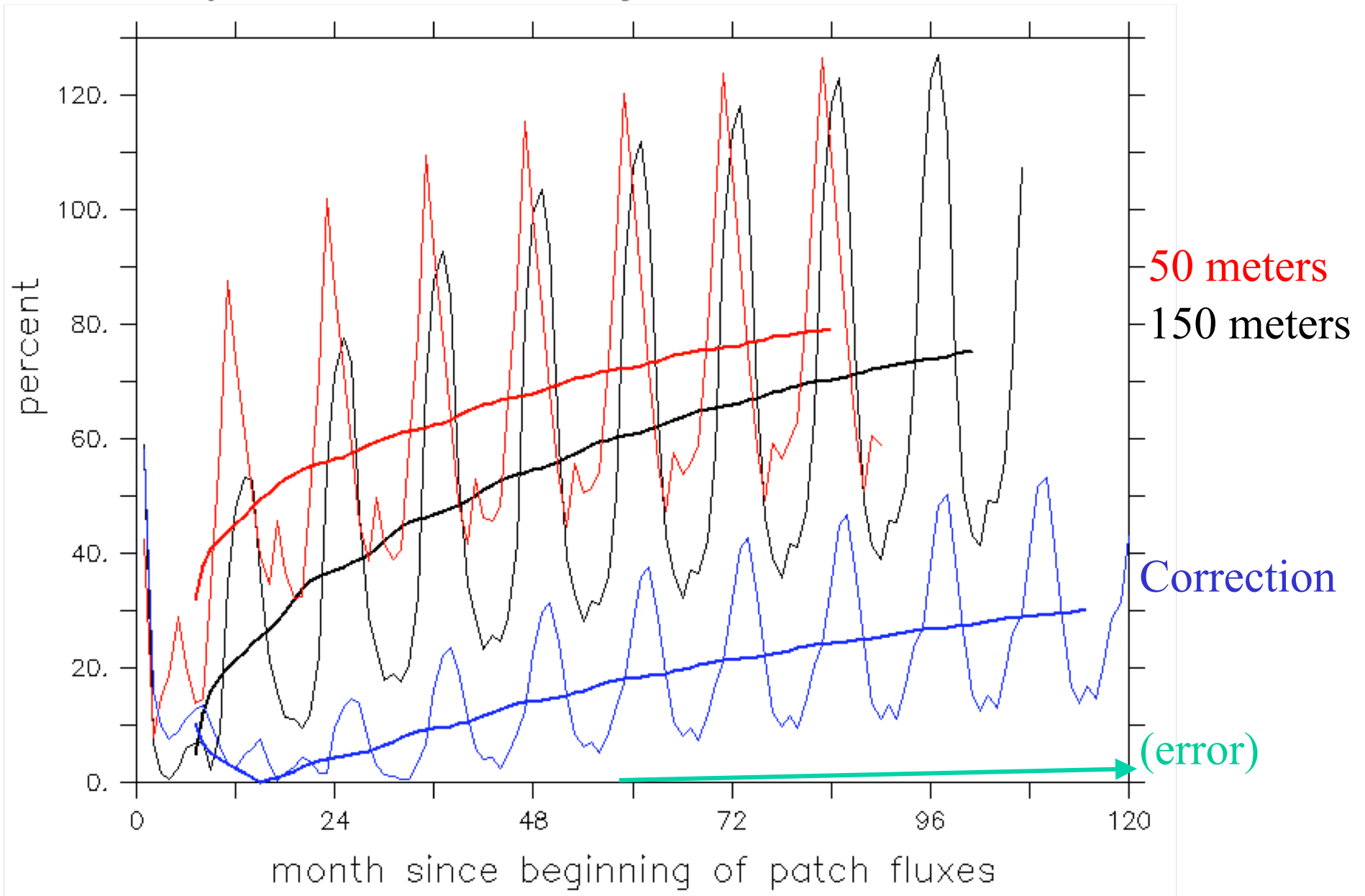
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Integrated escape to Arctic atmosphere from JGR patches

Ten years, sea floor then injections, $z = 150$ and 50 meters



Scott--here they are on 1 plot. black is injection at 150m, red at 50m, blue is just flux from the bottom. the gaussians have a 50m width. all are inert. -mat