Gases in sea ice

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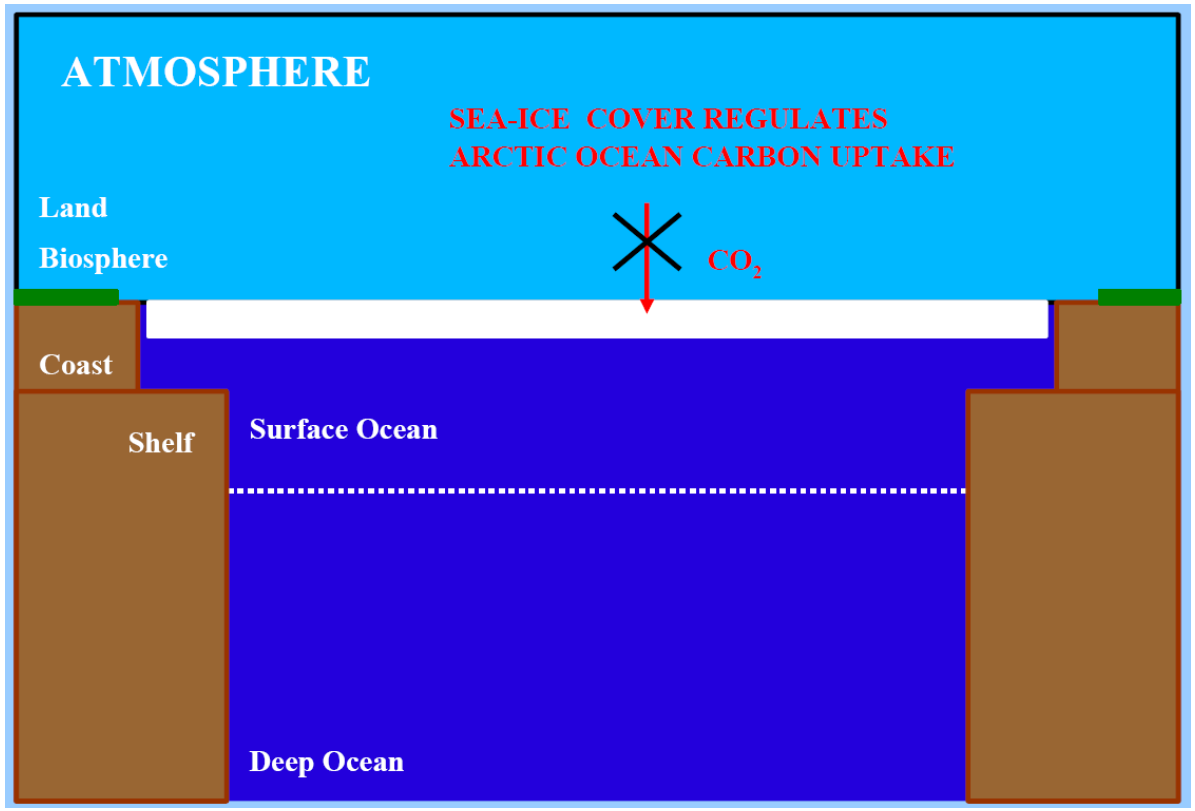
BEPSII

BIOGEOCHEMICAL EXCHANGE PROCESSES
AT SEA ICE INTERFACES

SCOR WG152
ECV-Ice
Since 2016

Essential Climate Variables in sea ice



Modeling and quantifying the contemporary CO_2 sink of the Arctic Ocean (1996-2007). Manizza et al. 2009

"First assumption: sea ice cover regulates arctic ocean CO_2 uptake by preventing CO_2 exchanges"

N_2
O_2
Ar

Major gases
Controls the transport of the other gases

CO_2
CH_4
DMS
N_2O

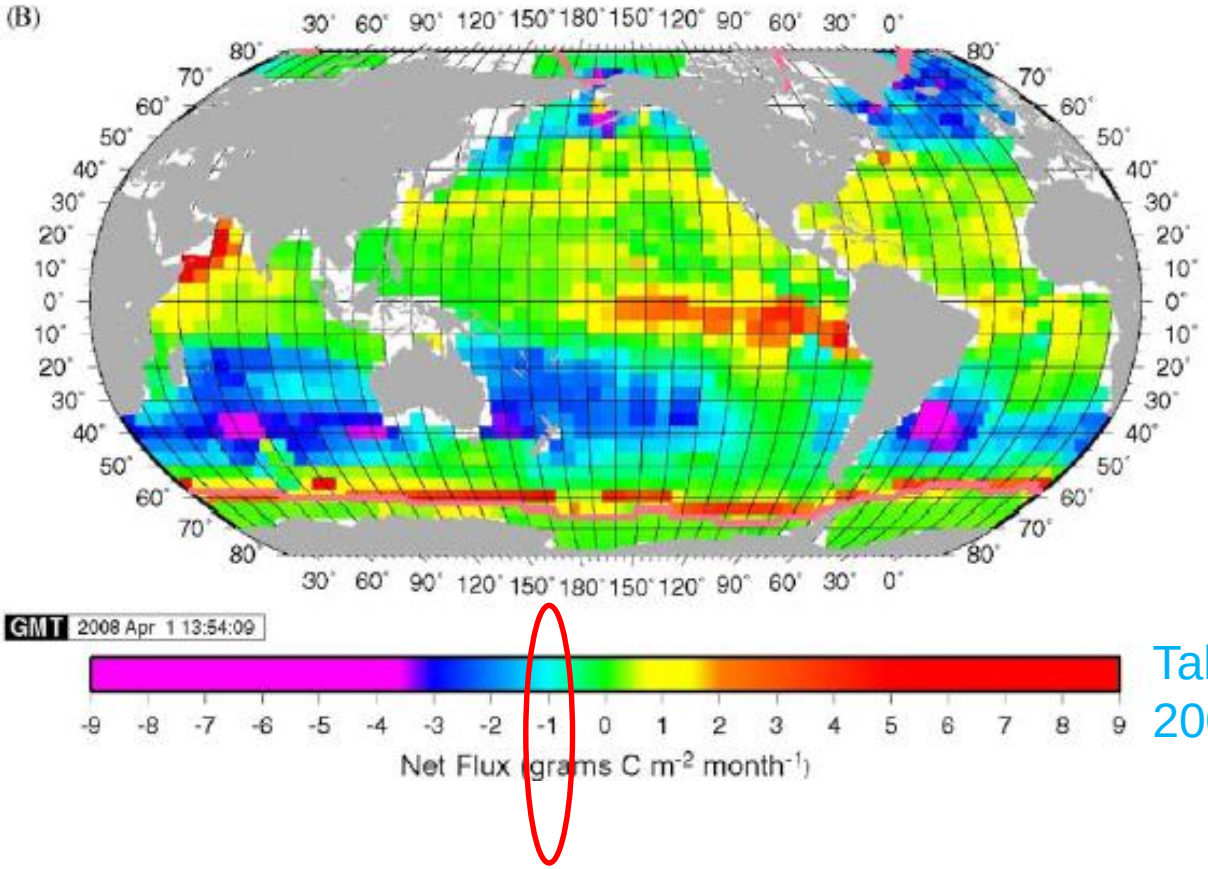
Climate gases

Ozone depletion (stratosphere)

IO, BrO
Halocarbons (CHBr3, CH2Br2, CH3I)

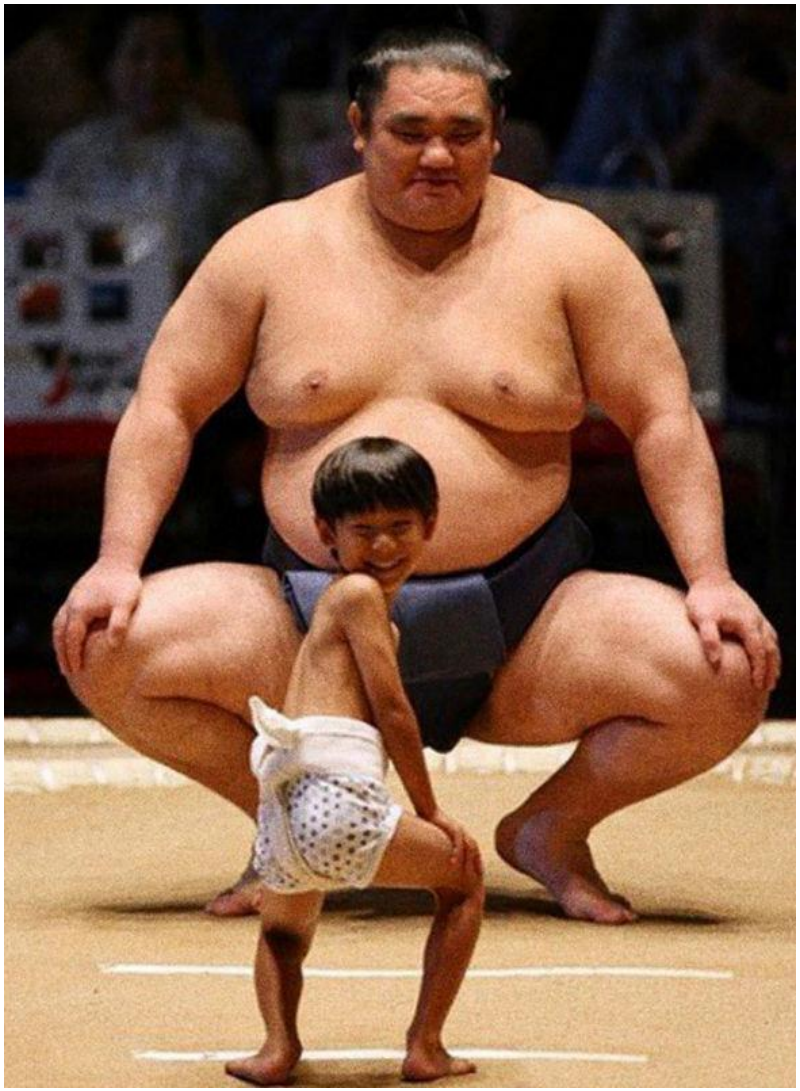
Ozone depletion (troposphere)

Sea ice exchanges CO_2 with the atmosphere



Takahashi et al. 2009

-1 gC m^{-2} $month^{-1}$



Size does matter

Sea ice in one of the largest biome on earth

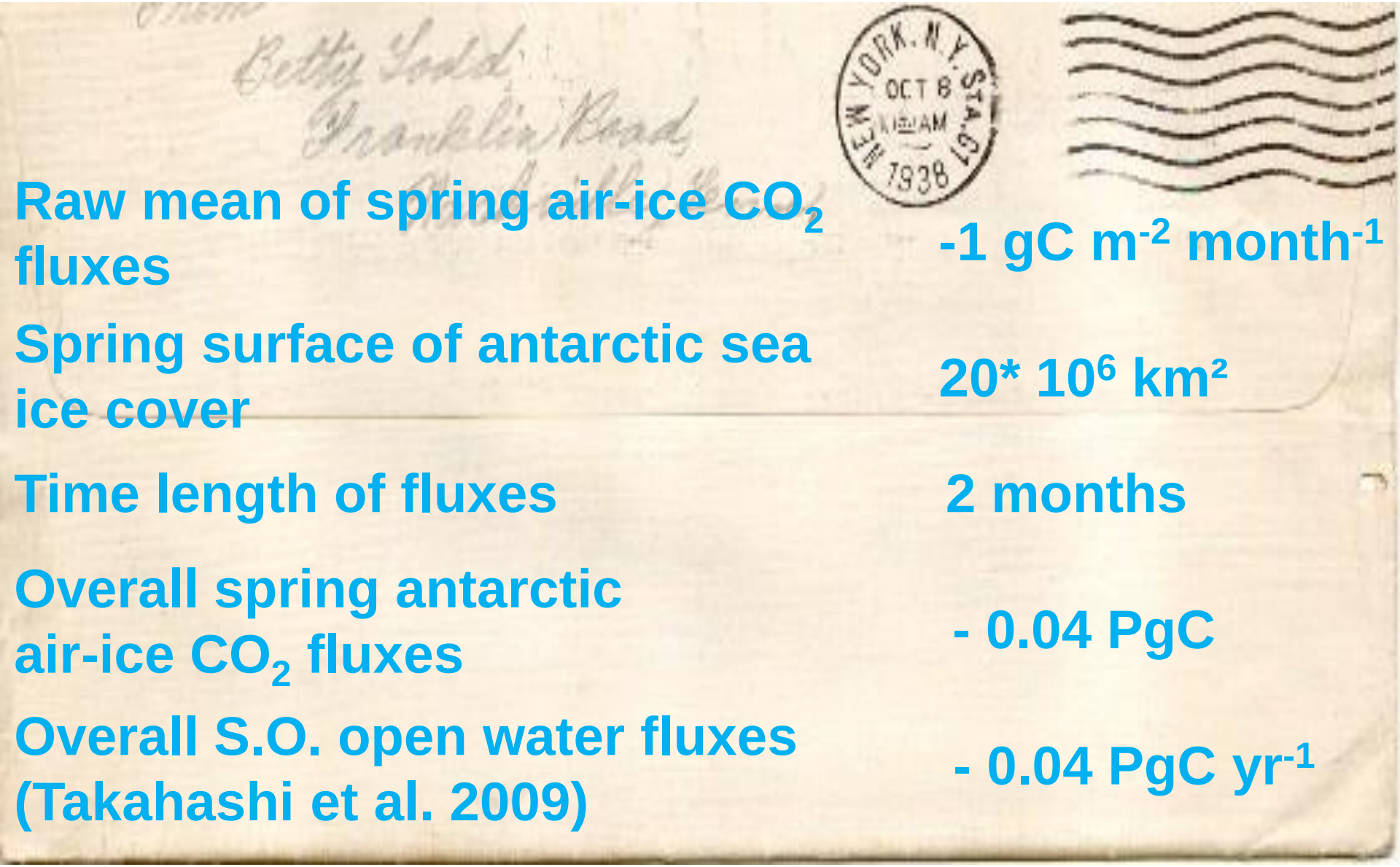
Sept.
(28 = 8+20)

Sea ice

Feb.
(18 = 14+4)

	10^6 km2 (IPCC, 2001)
 DESERT, SEMI DESERT	27.7
 TROPICAL SAVANNAS, GRASSLANDS	27.6
 COASTAL OCEAN	26.0
 TEMPERATE GRASSLANDS, SHRUBLANDS	17.8
 RAINFOREST	17.5
 CONTINENTAL ICE	15.5
 TAÏGA	13.7
 CROPLANDS	13.5
 TEMPERATE FOREST	10.4
 TUNDRA	5.6

Back of the envelope computation

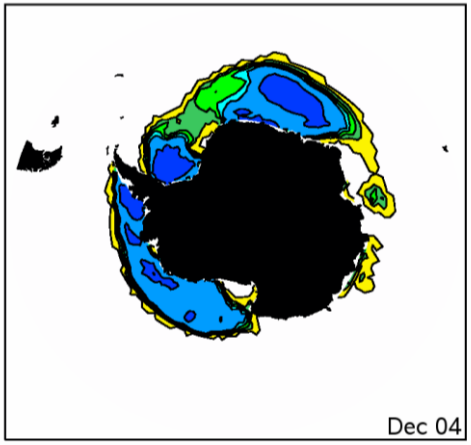


Raw mean of spring air-ice CO_2 fluxes	-1 gC m^{-2} $month^{-1}$
Spring surface of antarctic sea ice cover	20* 10^6 km^2
Time length of fluxes	2 months
Overall spring antarctic air-ice CO_2 fluxes	- 0.04 PgC
Overall S.O. open water fluxes (Takahashi et al. 2009)	- 0.04 PgC yr^{-1}

Independent budgets

Sea ice

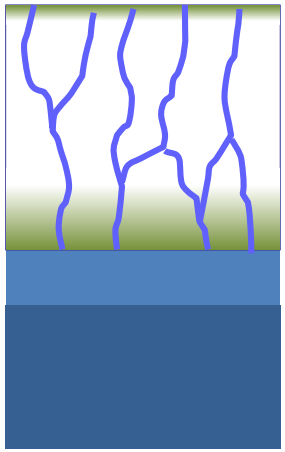
Direct air measurement of air-ice CO_2 fluxes, scaled using sea ice temperature derived the NEMO-LIM3 model



Delille et al. 2014

Air-ice fluxes:
-0.029 Pg

Simple box model approach

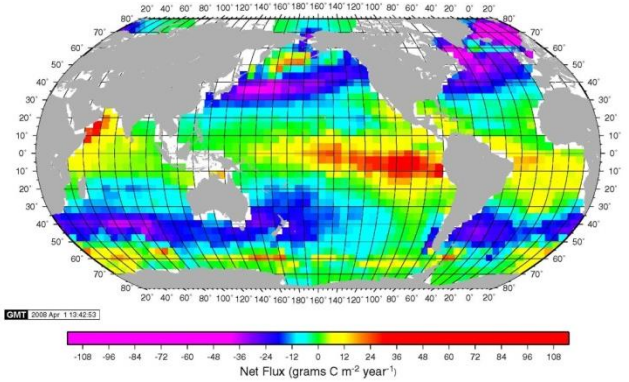


Rysgaard et al. 2012

Air-ice fluxes:
-0.019 to -0.052 Pg

Open ocean

pCO_2 climatology



Takahashi et al. 2009

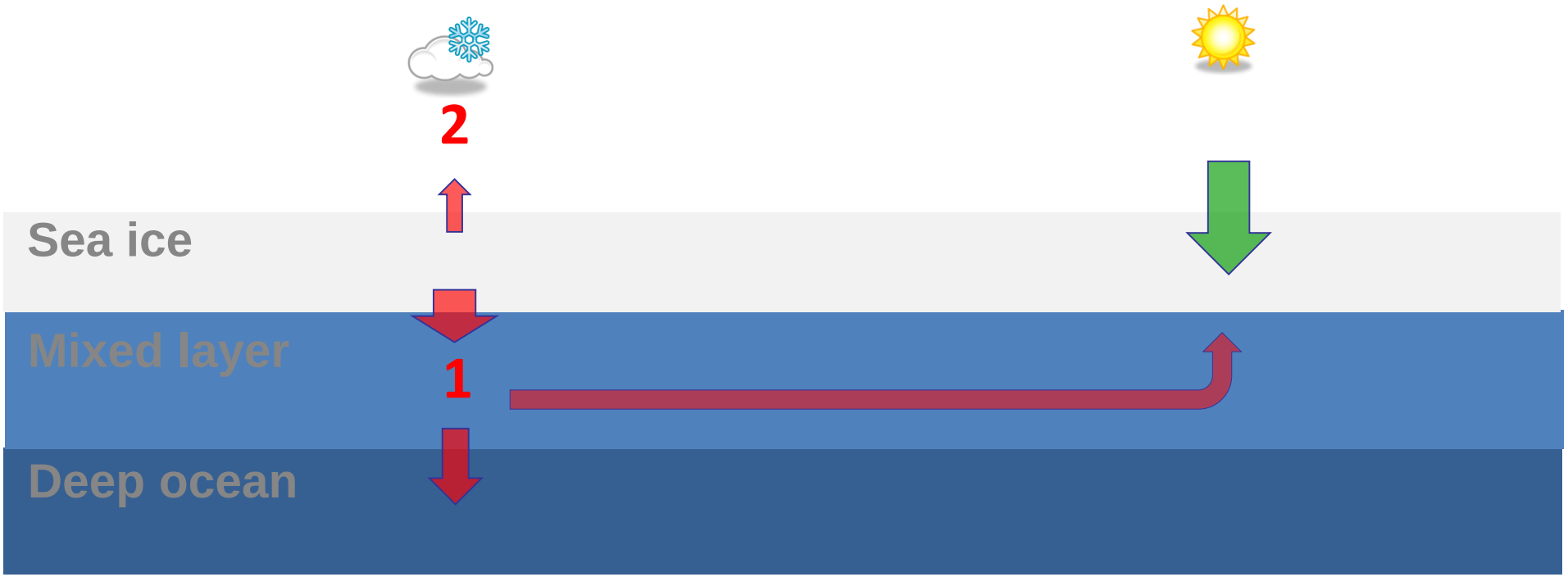
Air-sea fluxes south of 50°S:
-0.04 Pg yr-1

Sea ice in spring and summer accounts for 17 to 42 % of CO_2 uptake of the polar oceans (70% considering only the Southern Ocean)

Why such spring and summer fluxes ?

Sea ice appears to be depleted in DIC and have high TA:DIC

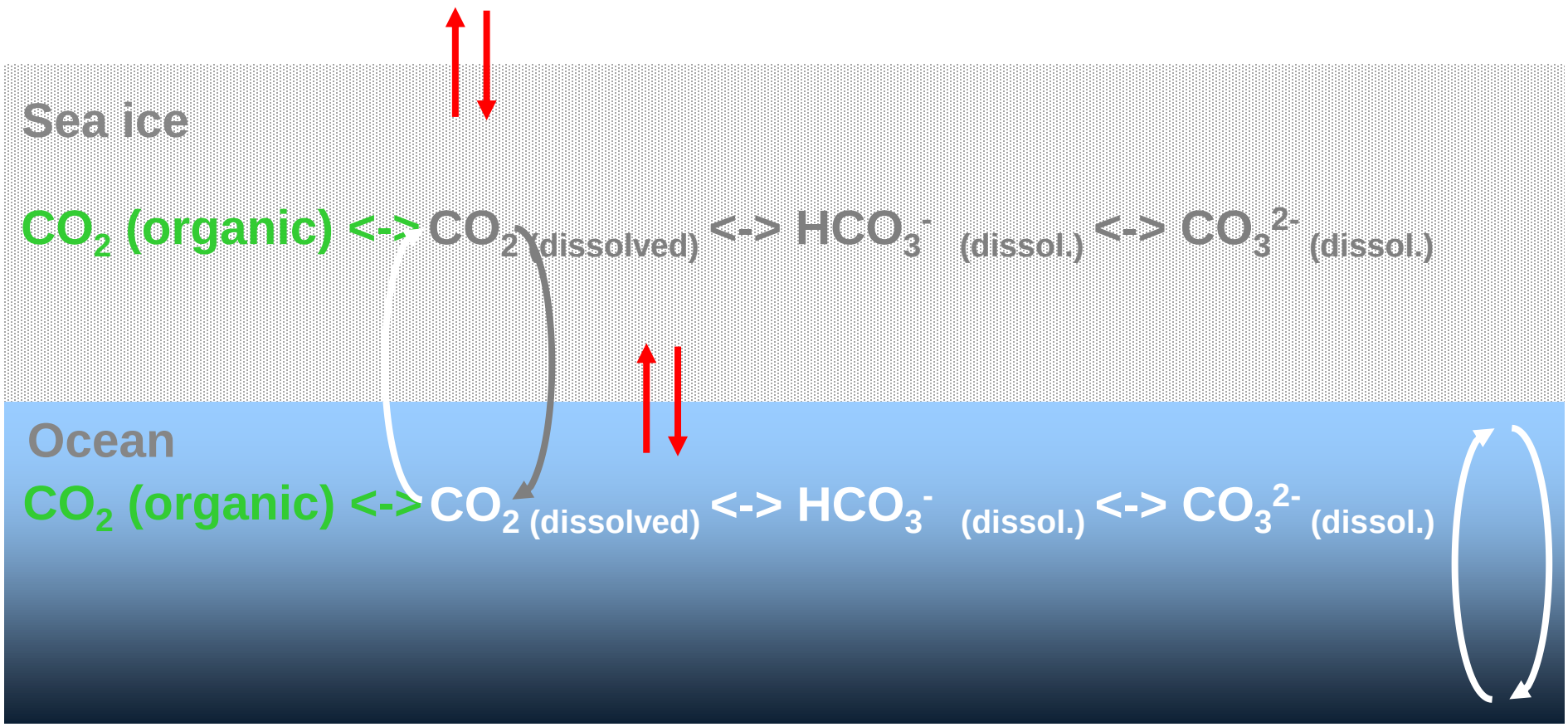
Sea ice absorbs CO_2 in summer because it lost CO_2 in winter



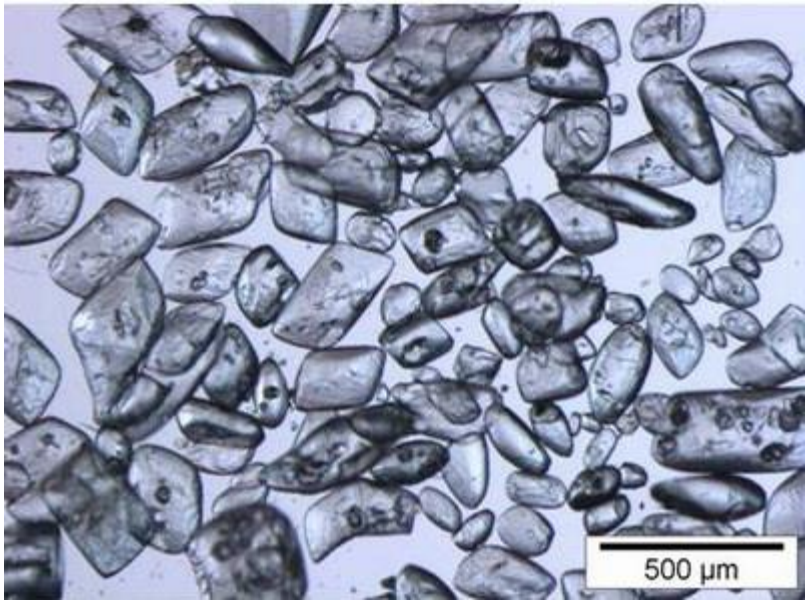
1? Fraction of brines rejected below the mixed layer?

2? Release of CO_2 to the atmosphere during ice growth

Why CO_2 fluxes through sea-ice are so puzzling ?

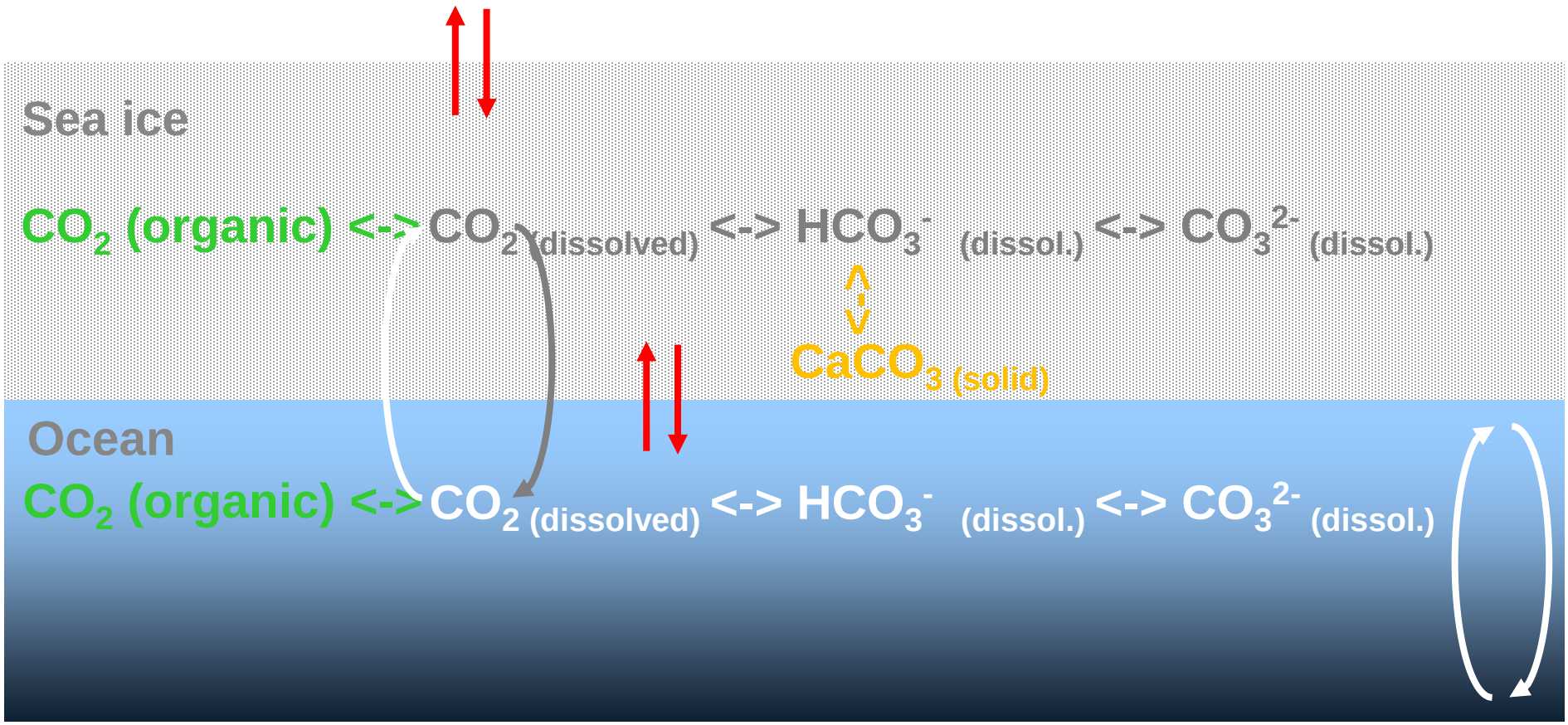


HCO_3^- precipitates in sea ice as Ikaite – a meta-stable form of calcium carbonate ($CaCO_3$)

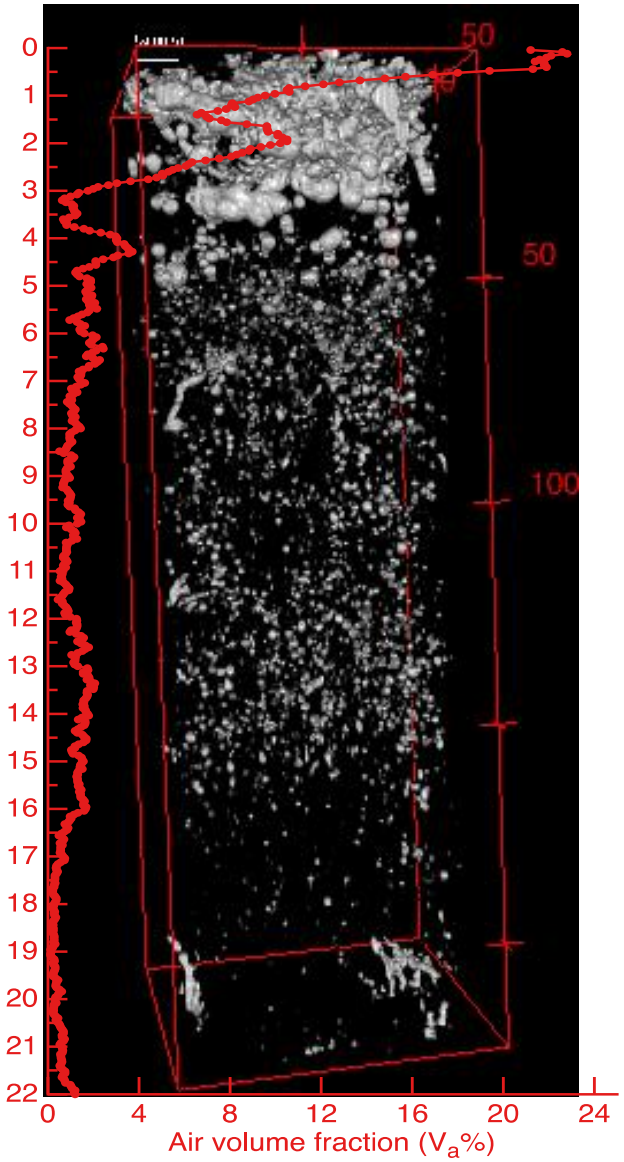


Dieckmann et al. 2010

Why CO_2 fluxes through sea-ice are so puzzling ?

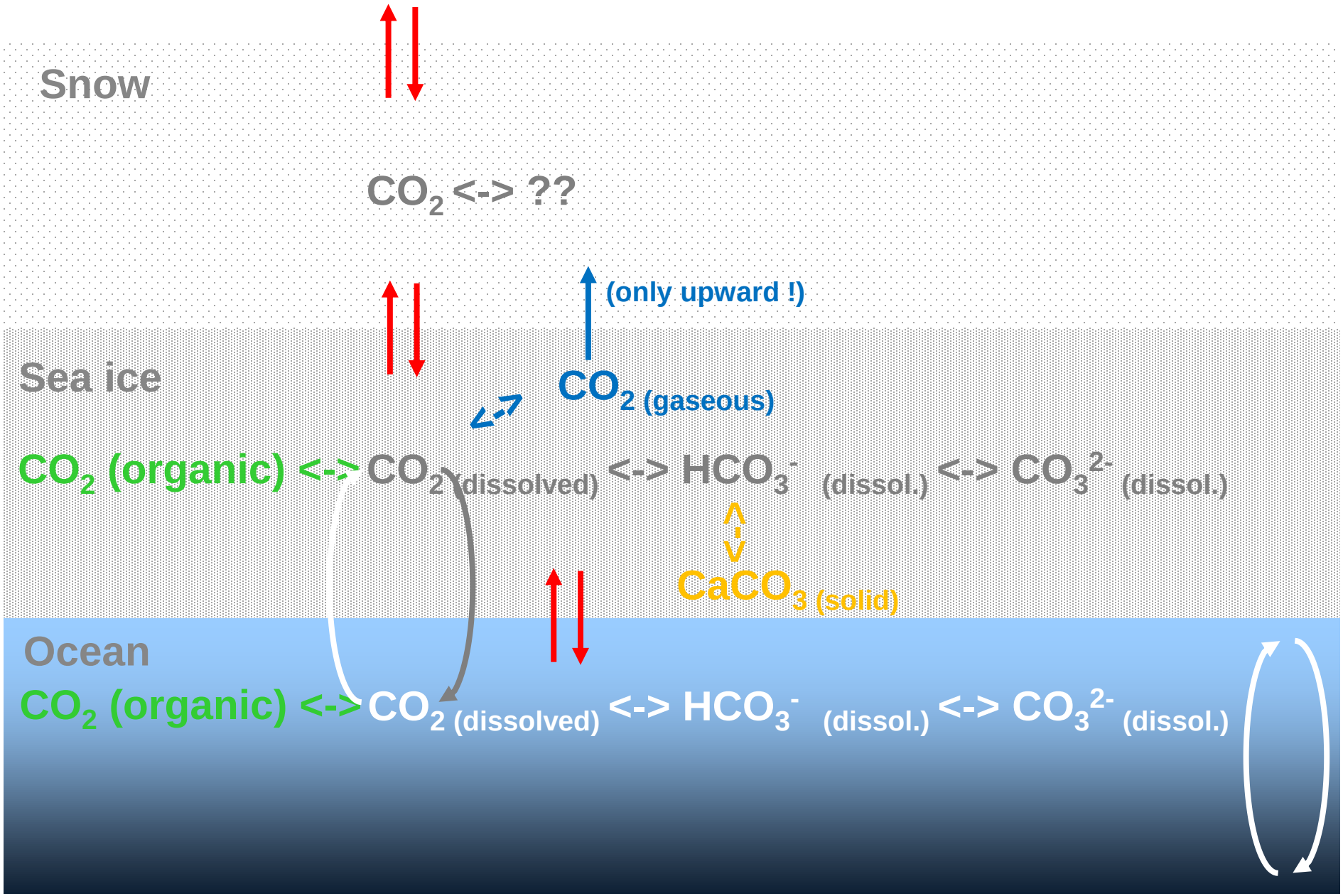


Gases in sea ice are both in the dissolved and gaseous phase (bubbles)



Crabeck et al. 2016

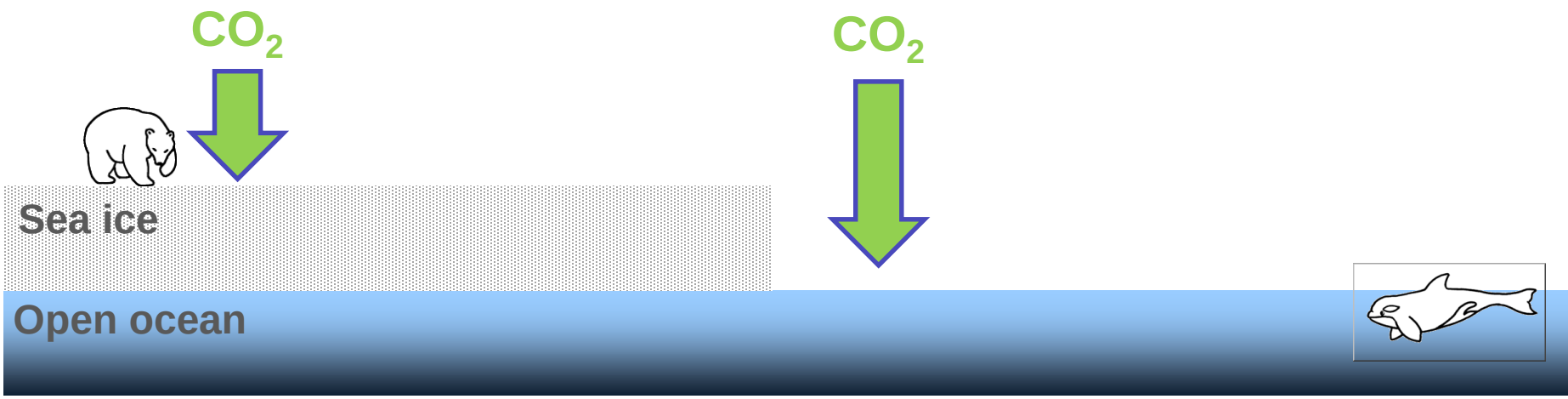
Why CO_2 fluxes through sea-ice are so puzzling ?



Why gas fluxes through sea-ice are so pullzing ?

Multiphase form of CO_2 within a bi-phase anisotropic heterogeneous medium.

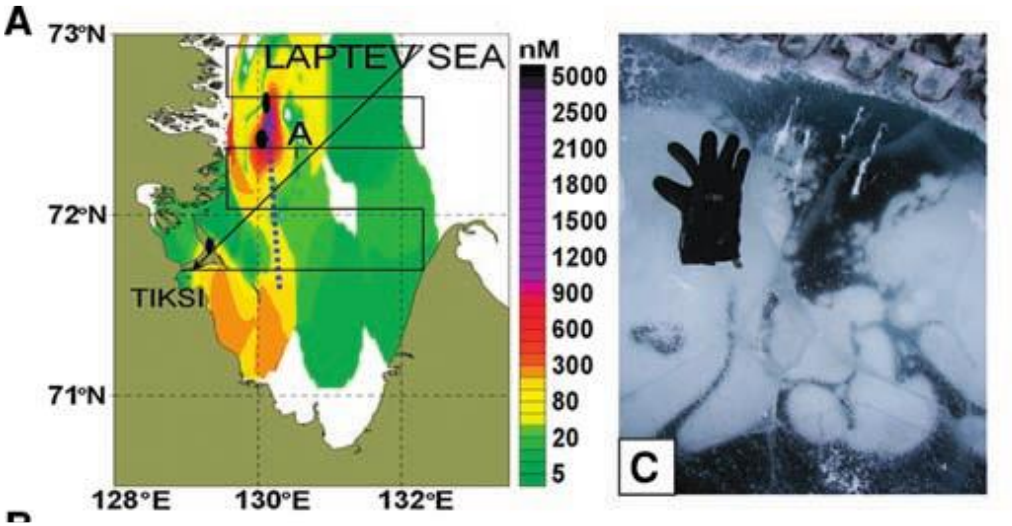
Fluxes through a triple interface


CO_2
CO_2
Sea ice
Open ocean

CH_4

"The total amount of methane in the current atmosphere is about 5 Gt. The amount of carbon preserved in the form of methane in the East Siberian Arctic Shelf is from hundreds to thousands Gt. What divides this methane from the atmosphere is a very shallow water column and a weakening permafrost, which is losing its ability to serve as a seal."

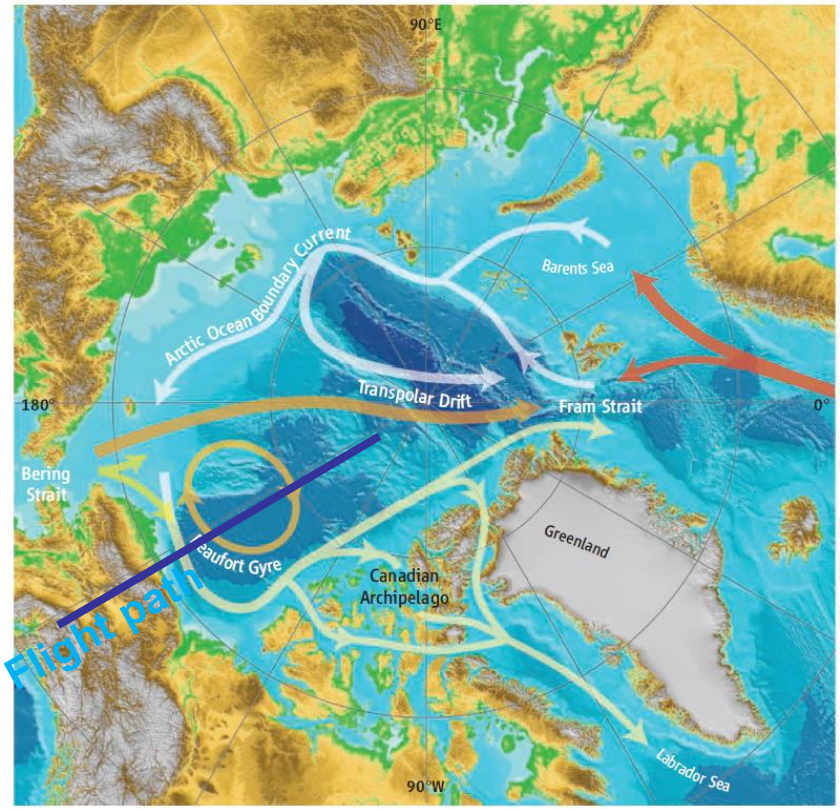
Shakhova N.

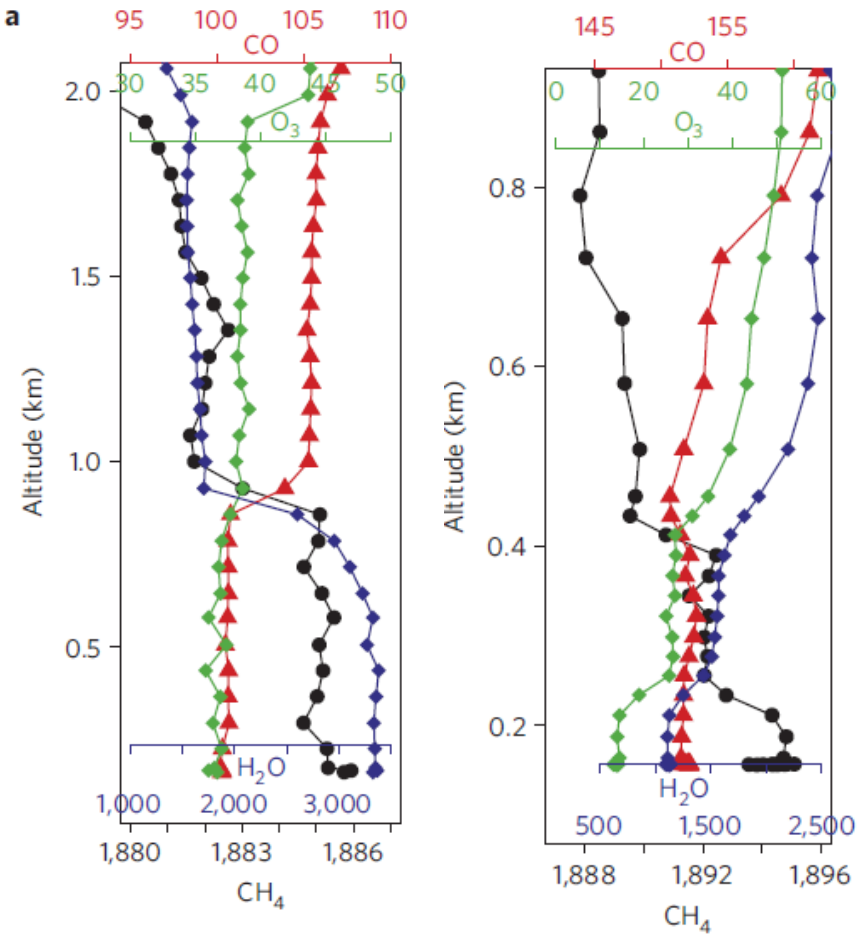


Shakhova et al. 2010

Air-sea flux of CH_4 11.8 mg d^{-1} m^{-2}

CH_4

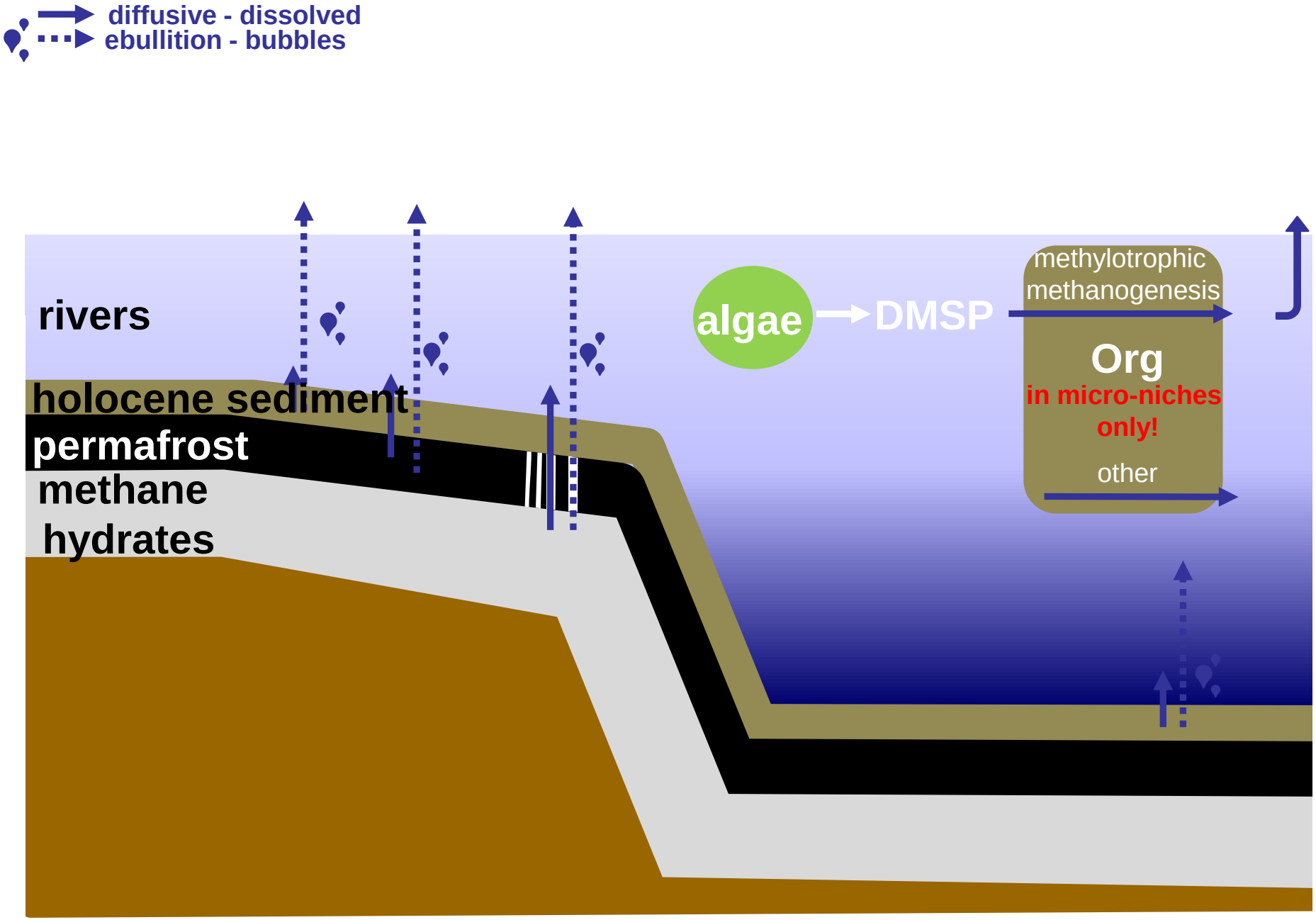




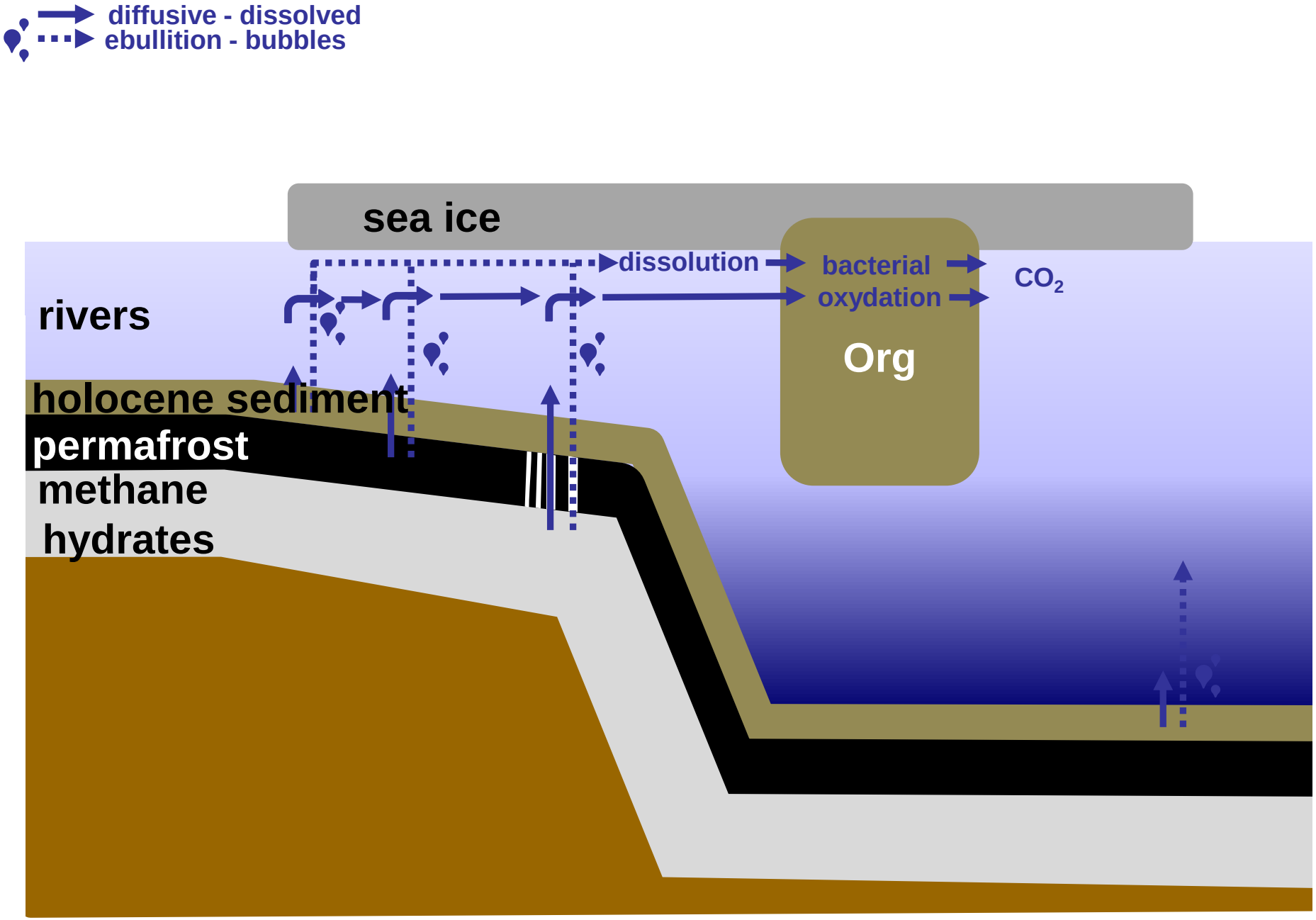
Air-sea flux of CH_4 2 mg d^{-1} m^{-2} ranging from 0.5 to 8 mg d^{-1} m^{-2}

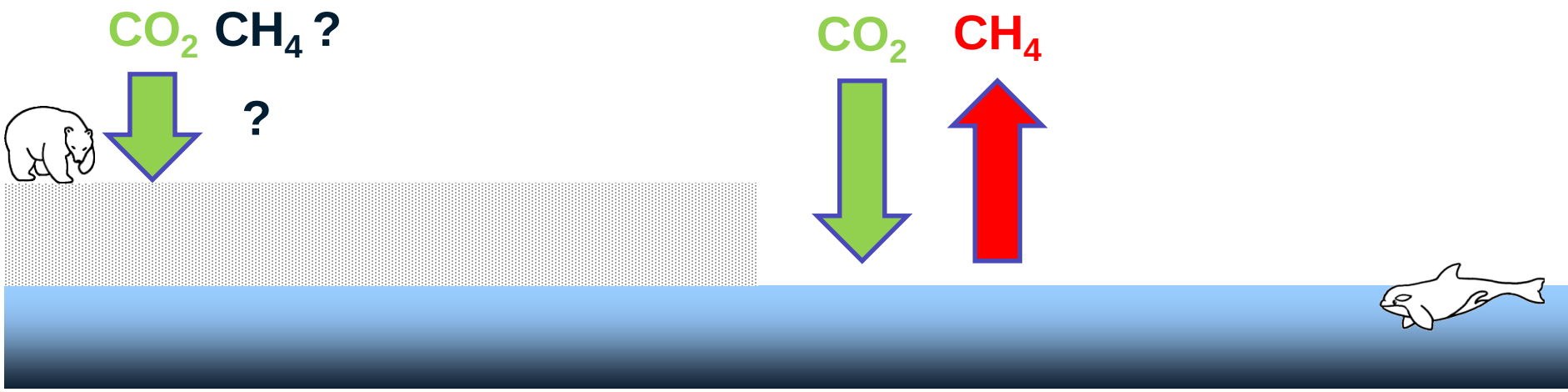
Kort et al. 2012
(map from Green and Pershing 2007)

CH_4

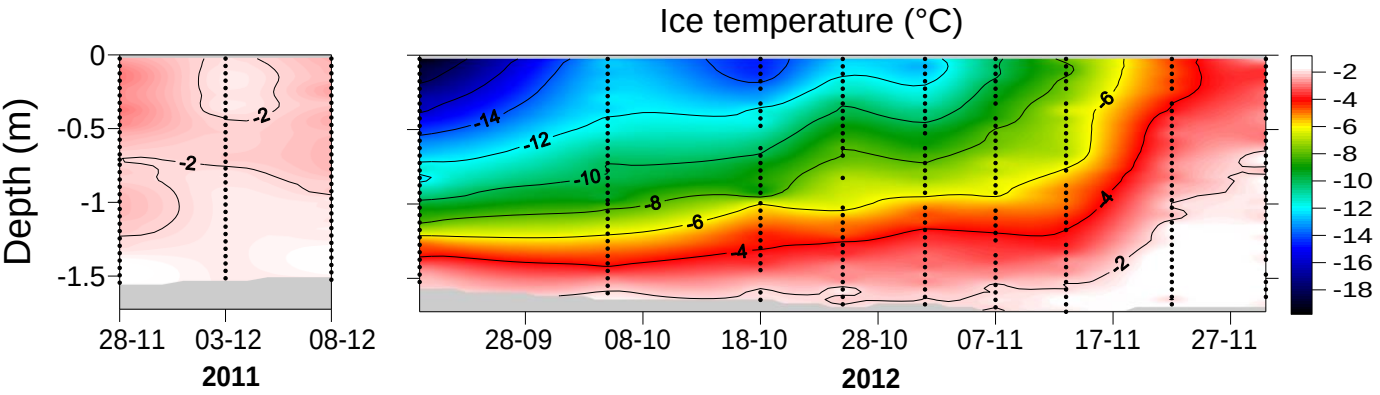

diffusive - dissolved
ebullition - bubbles
rivers
holocene sediment
permafrost
methane
hydrates
algae
DMSP
methylotrophic
methanogenesis
Org
in micro-niches
only!
other

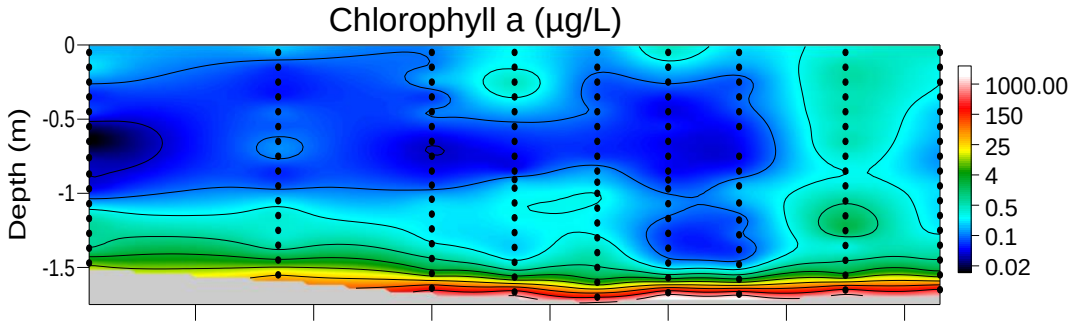
Methane


diffusive - dissolved
ebullition - bubbles
sea ice
dissolution
bacterial
oxydation
CO_2
Org
rivers
holocene sediment
permafrost
methane
hydrates


CO_2 CH_4 ?
?
CO_2
CH_4

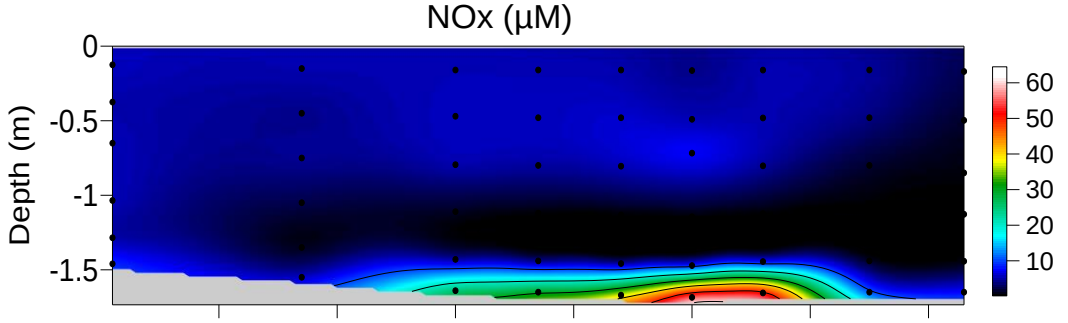
N_2O ?





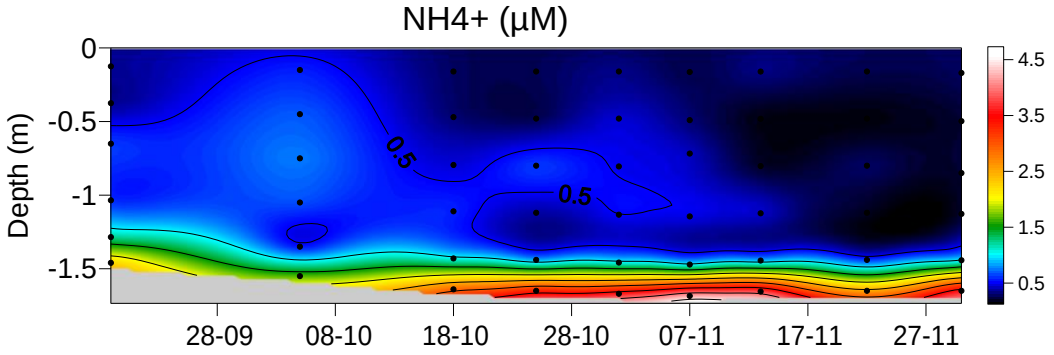
Highly productive

10 to 100 times open ocean values



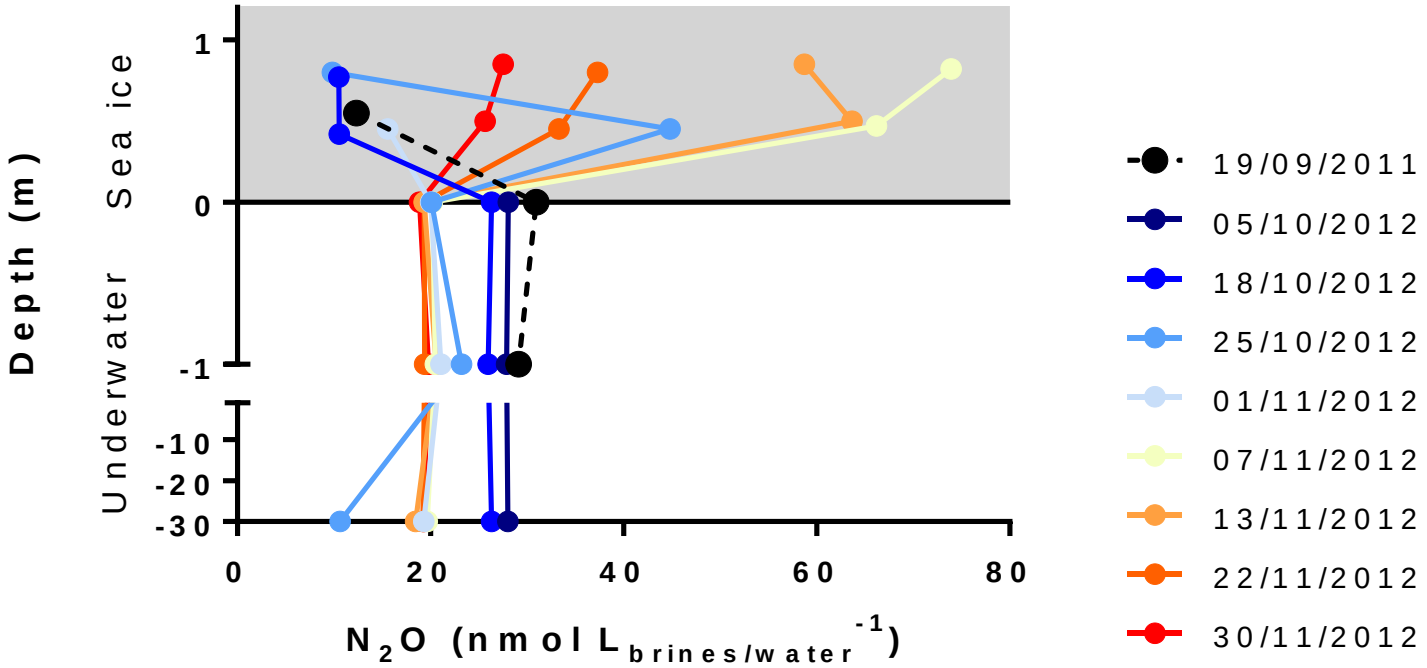
Intense remineralization

8 times increase of nitrate

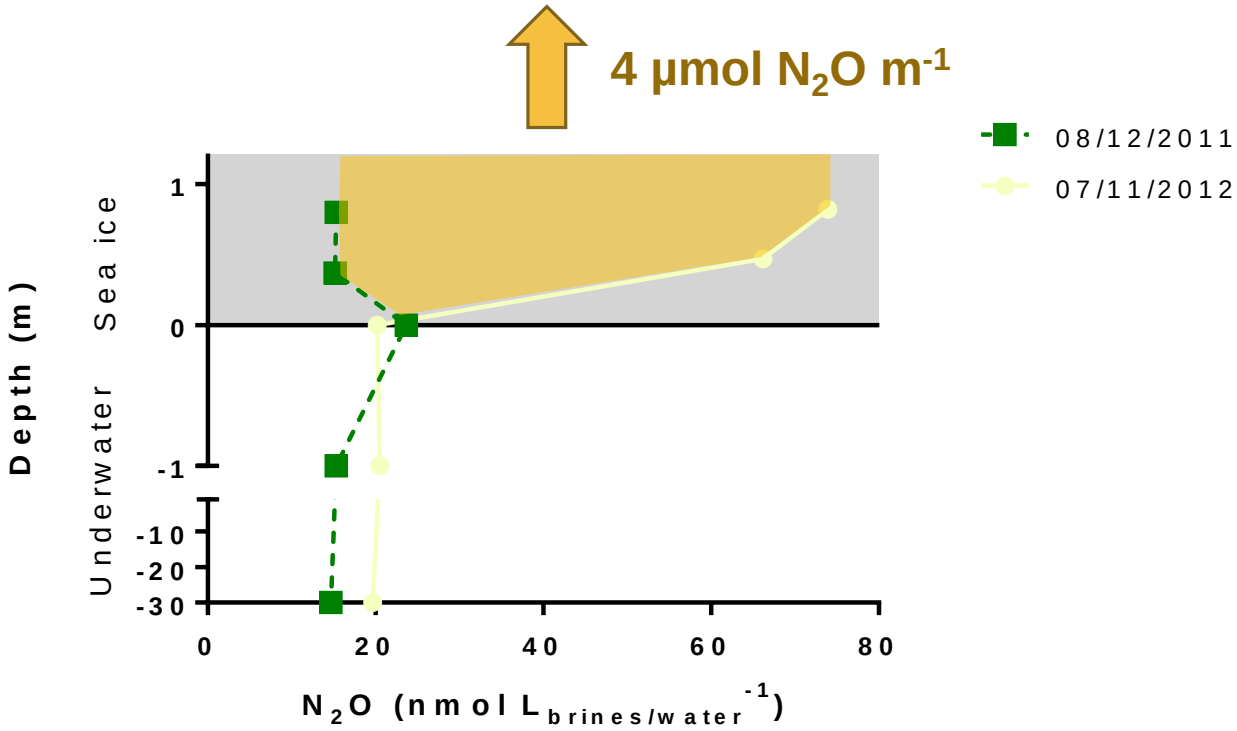


Strong nitrification

N_2O

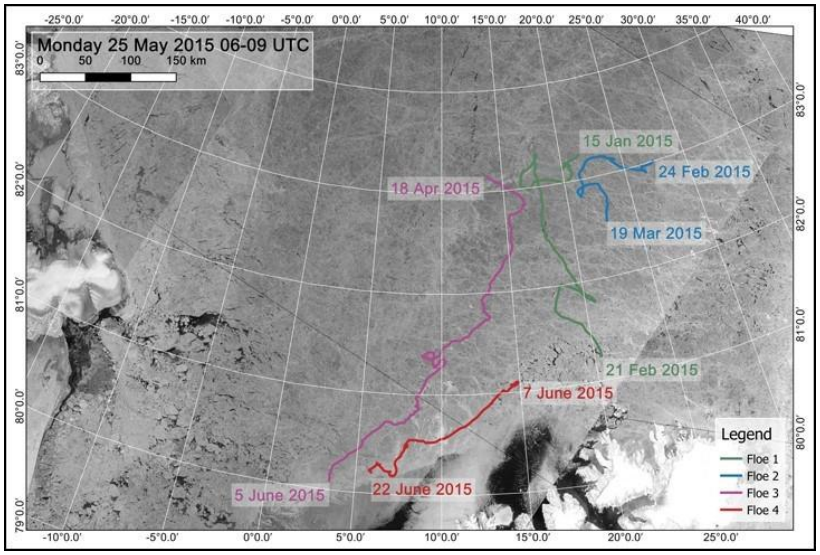

Depth (m)
Sea ice
Underwater
1
0
-1
-10
-20
-30
0
20
40
60
80
N2O (nmol Lbrines/water-1)
19/09/2011
05/10/2012
18/10/2012
25/10/2012
01/11/2012
07/11/2012
13/11/2012
22/11/2012
30/11/2012

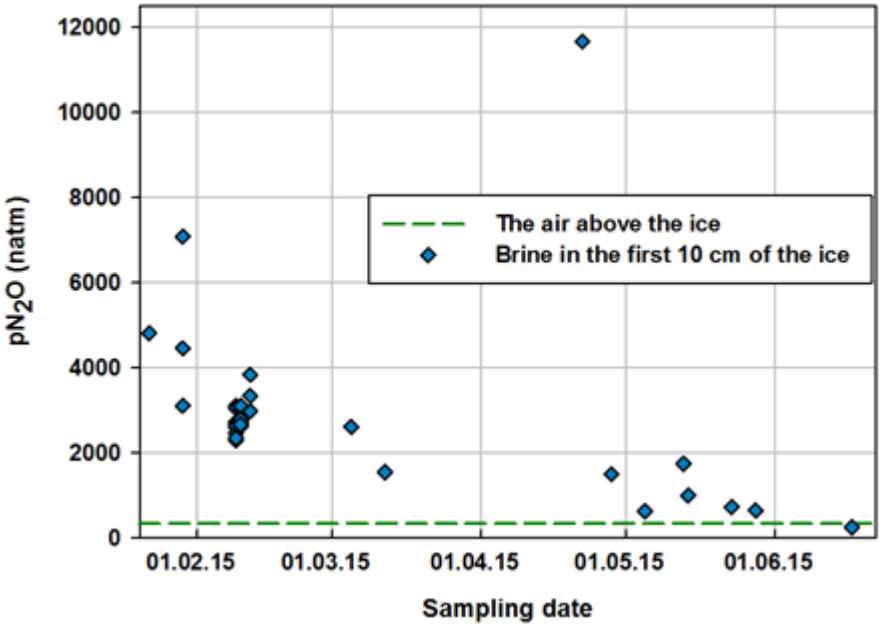
N_2O



N_2O produced in october/november is likely to be released to the atmosphere as the ice become permeable.
N_2O release in spring is about 4µmol N_2O m^{-1}.

N-ICE 2015
NORWEGIAN YOUNG SEA ICE CRUISE



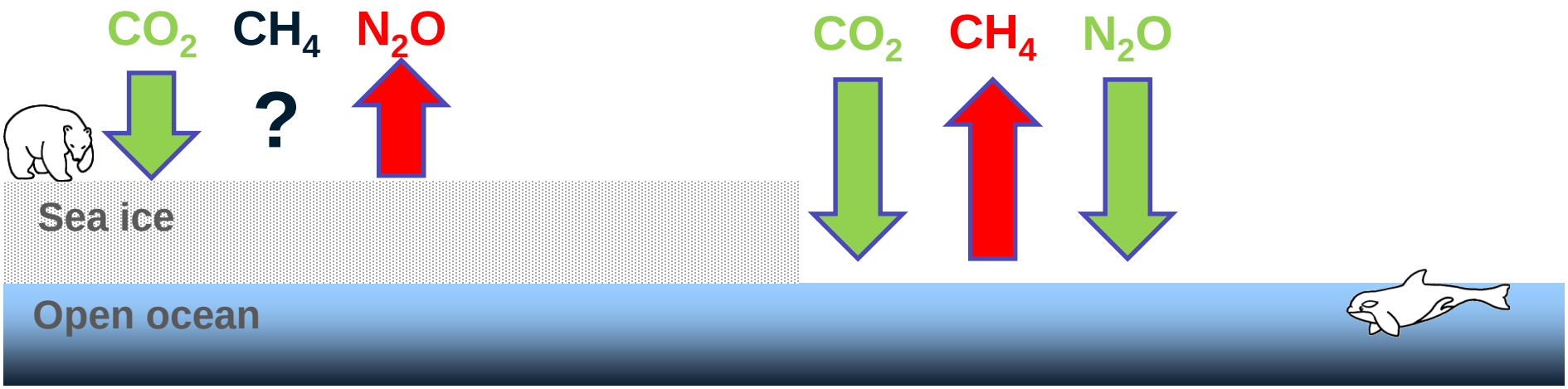


N_2O

Sea ice

N_2O

Open ocean


CO_2
CH_4
N_2O
?
Sea ice
CO_2
CH_4
N_2O
Open ocean

DMS ?

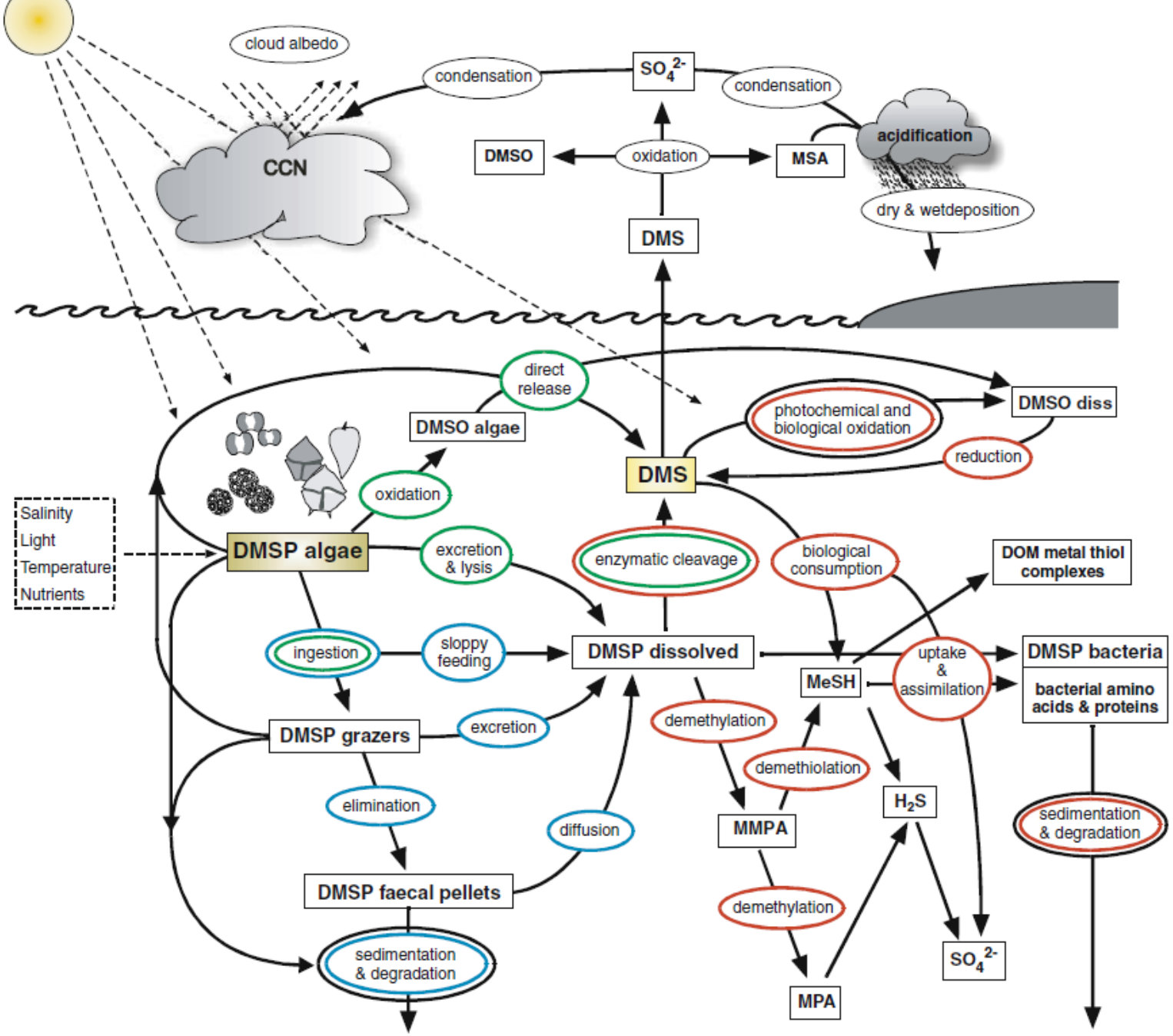
DMS is produced from DMSP that is an important component of marine microorganism.

It has been suggested that DMSP can act

- **as an active osmolyte and cryoprotectant at the same time (Dickson and Kirst 1986)**
- **an antioxidant that protects cells during oxidative stress conditions:**

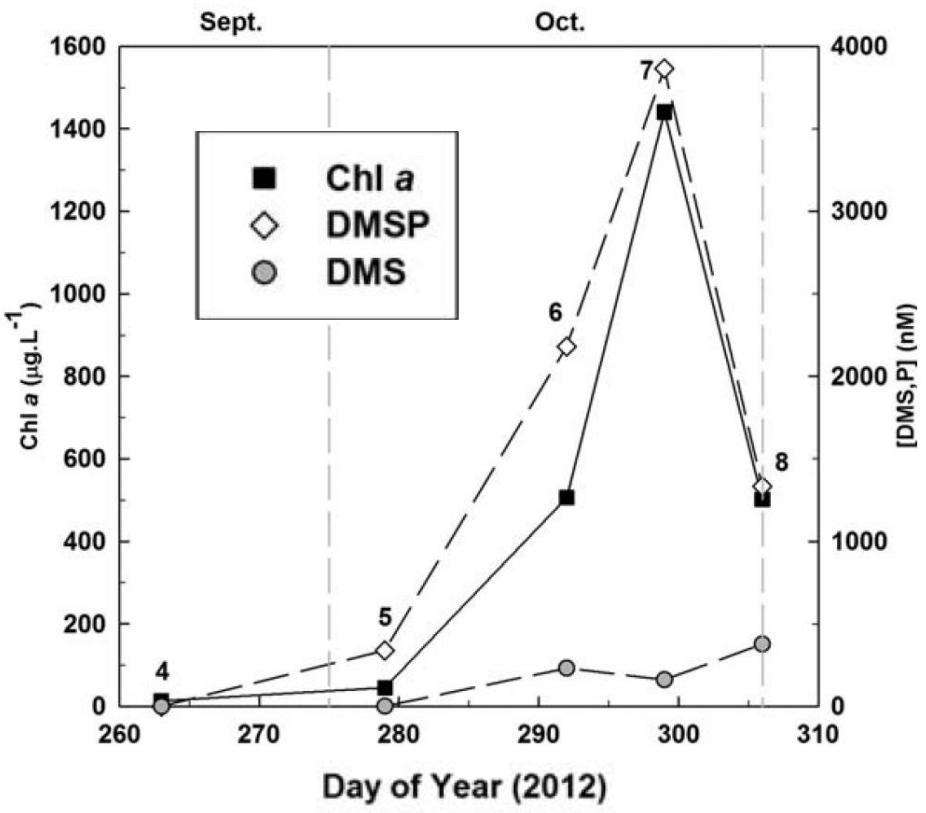
- ultraviolet radiation
- CO_2 limitation
- Fe limitation
- high Cu^{2+} and H_2O_2 concentration Sunda et al. 2002)

- a grazing-activated chemical defense precursor
- or a "trashcan" for reduced compounds and excess energy (Stefels 2000).

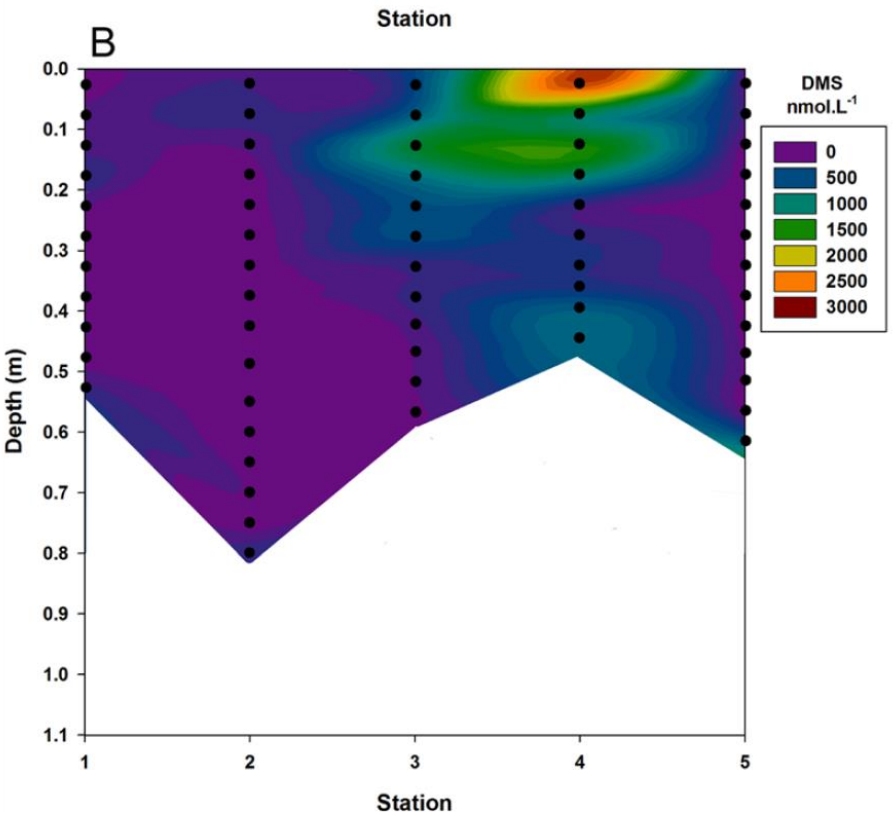


Stefels et al. 2007

Land fast ice (McMurdo sound)
Bottom 5cm



Pack ice (Beligshausen sea)

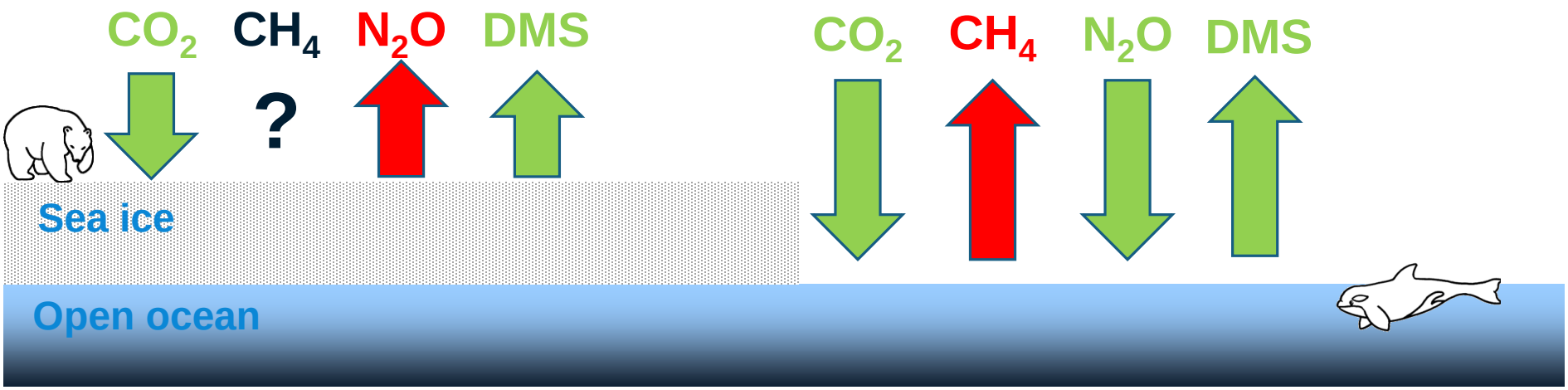


Seawater DMS concentration
< 0.3 nM (vs 250 nM in the ice)

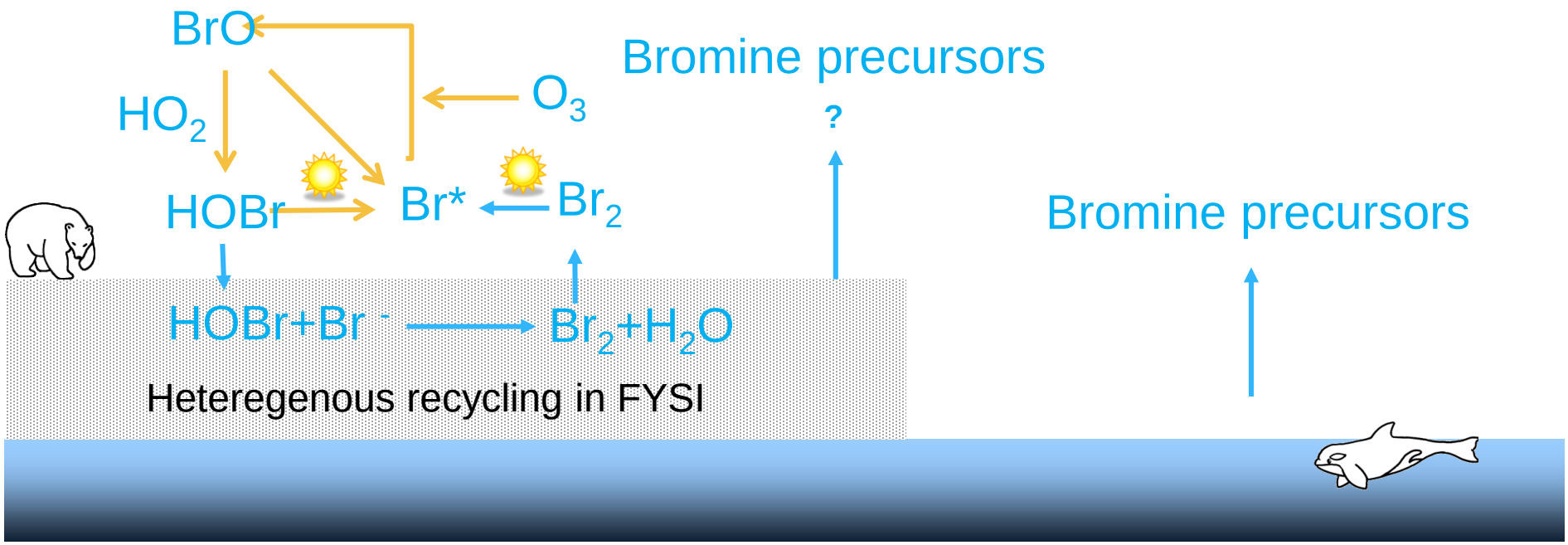
Carnat et al. 2014

~50 nM (vs 3000 nM in the ice)

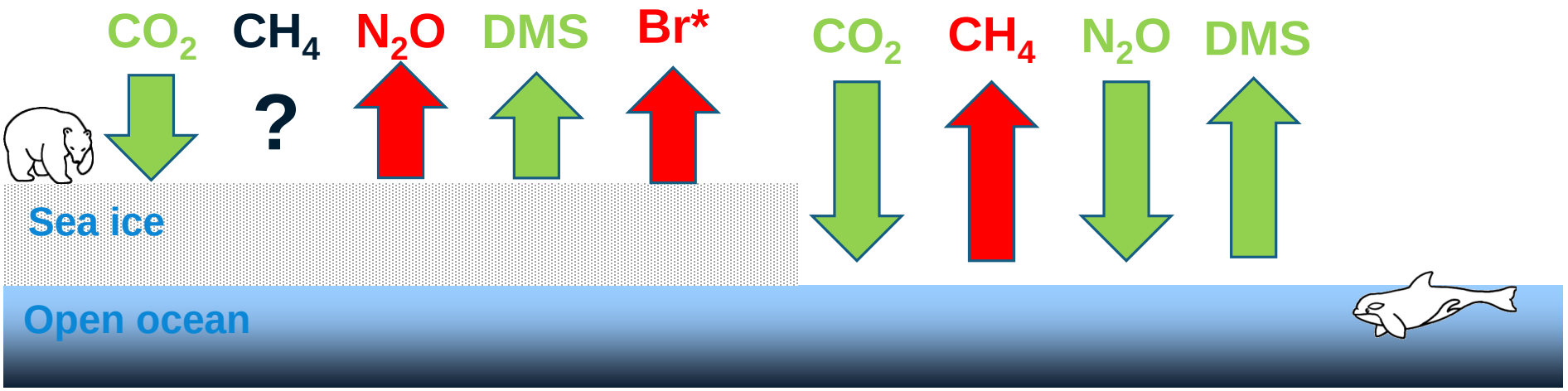
Carnat et al. 2016


CO_2
CH_4
N_2O
DMS
?
Sea ice
Open ocean
CO_2
CH_4
N_2O
DMS

Ozone Depletion Events



After Spolaor et al. and Simpson et al. 2007



Thank you