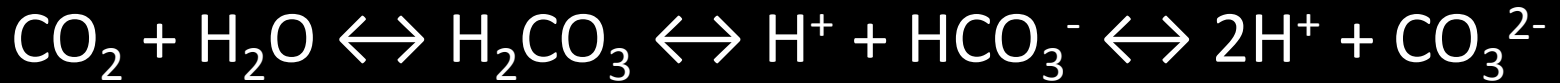


C Cycling in the Arctic Ocean



Ocean Carbon Chemistry

Definitions



Aqueous phase inorganic carbon

- **Dissolved Inorganic Carbon (DIC):** $[\text{CO}_{2(\text{aq})}] + [\text{H}_2\text{CO}_3] + [\text{HCO}_3^-] + [\text{CO}_3^{2-}]$
- **Total Alkalinity (A_T):** $\approx [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}] + [\text{B}(\text{OH})_4^-] + [\text{OH}^-] - [\text{H}^+]$
- **pH:** $-\log [\text{H}^+]$
- **$p\text{CO}_2$:** $\frac{[\text{CO}_{2(\text{aq})}]}{K_0}$

Measure 2 → Calculate 2

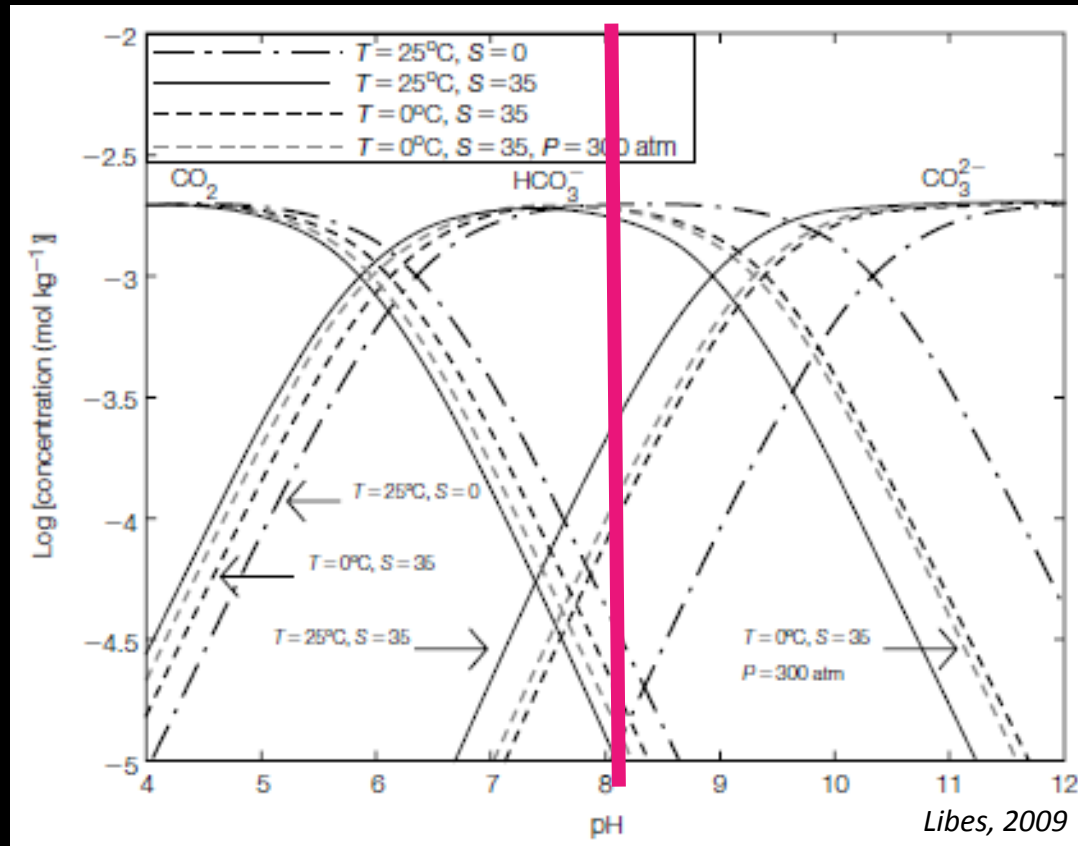
Ocean Carbon Chemistry

Definitions

- **Dissolved Organic Carbon (DOC):** 0.7 or 0.2 μm filtered
- **Particulate Organic Carbon (POC):** what's left on the filter after acid treatment
- **Particulate Inorganic Carbon (PIC):** solid minerals and salts of the CO_3^{2-} ion, *e.g.*, CaCO_3

Ocean Carbon Chemistry

Seawater as a buffered solution



Ocean Carbon Chemistry

Carbonate Minerals

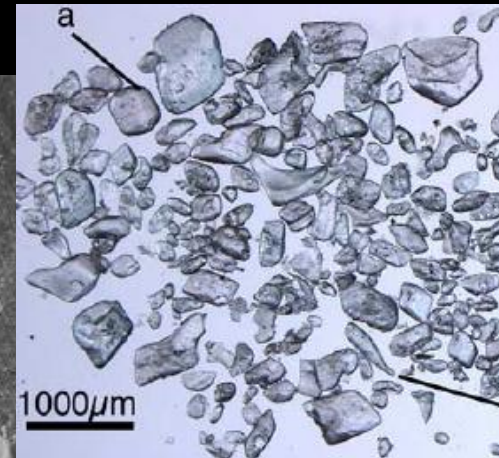
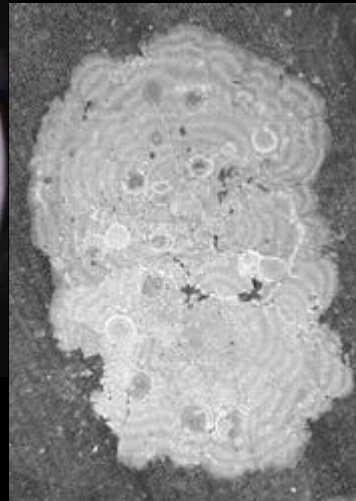
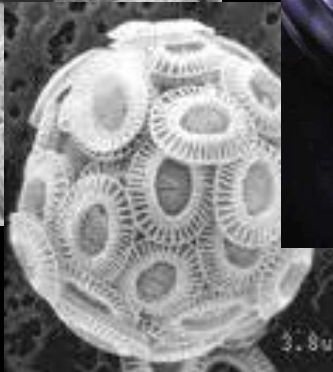
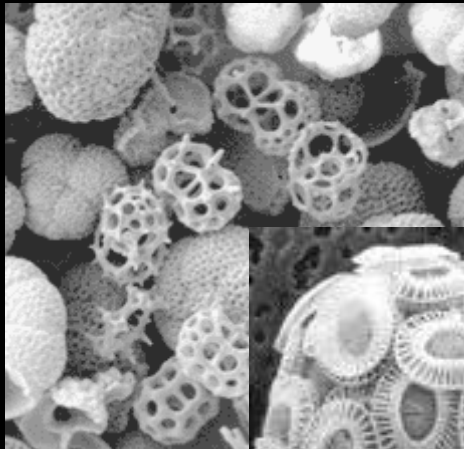


Calcite

Aragonite

Mg-Calcite

Ikaite



Ocean Carbon Chemistry

Carbonate Minerals

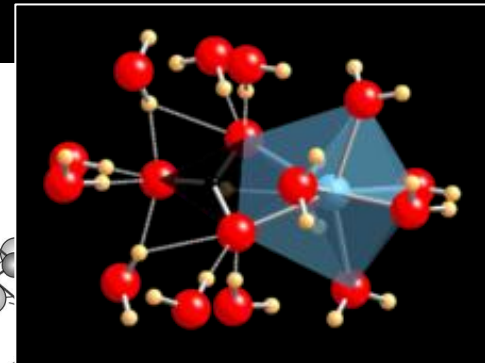
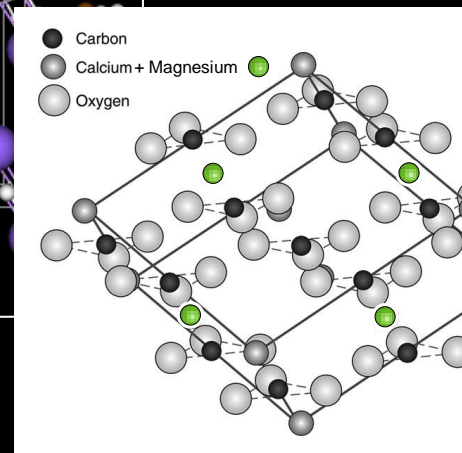
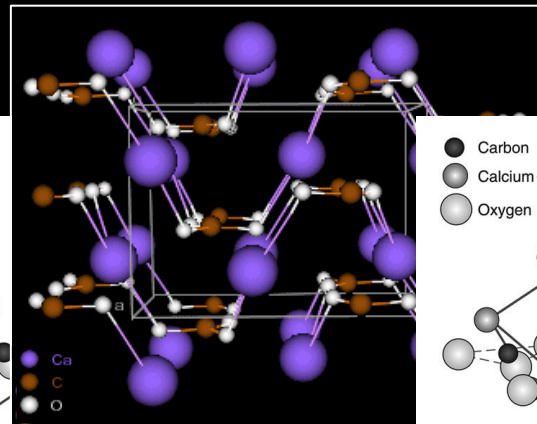
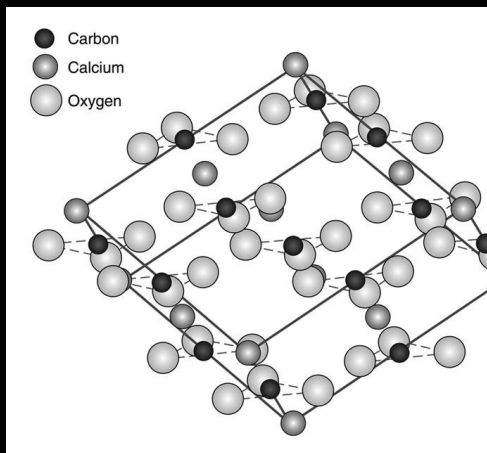


Calcite

Aragonite

Mg-Calcite

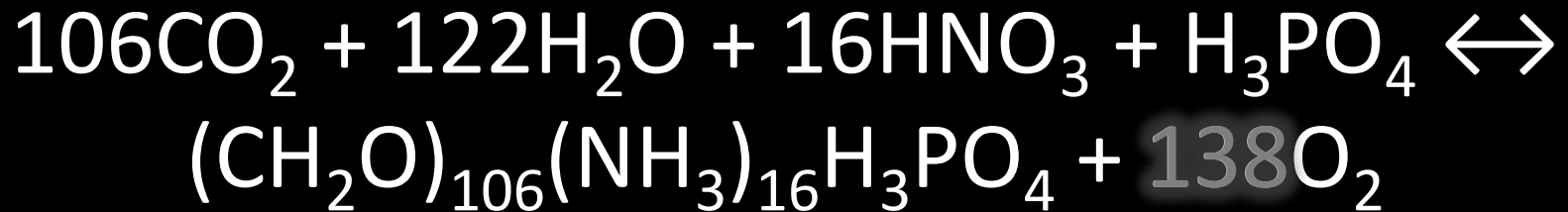
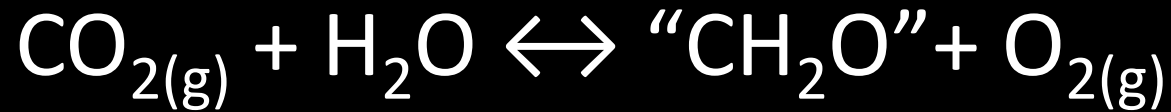
Ikaite



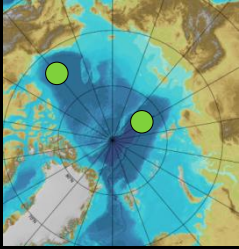
Increasing Solubility 

Ocean Carbon Chemistry

Photosynthesis/Respiration

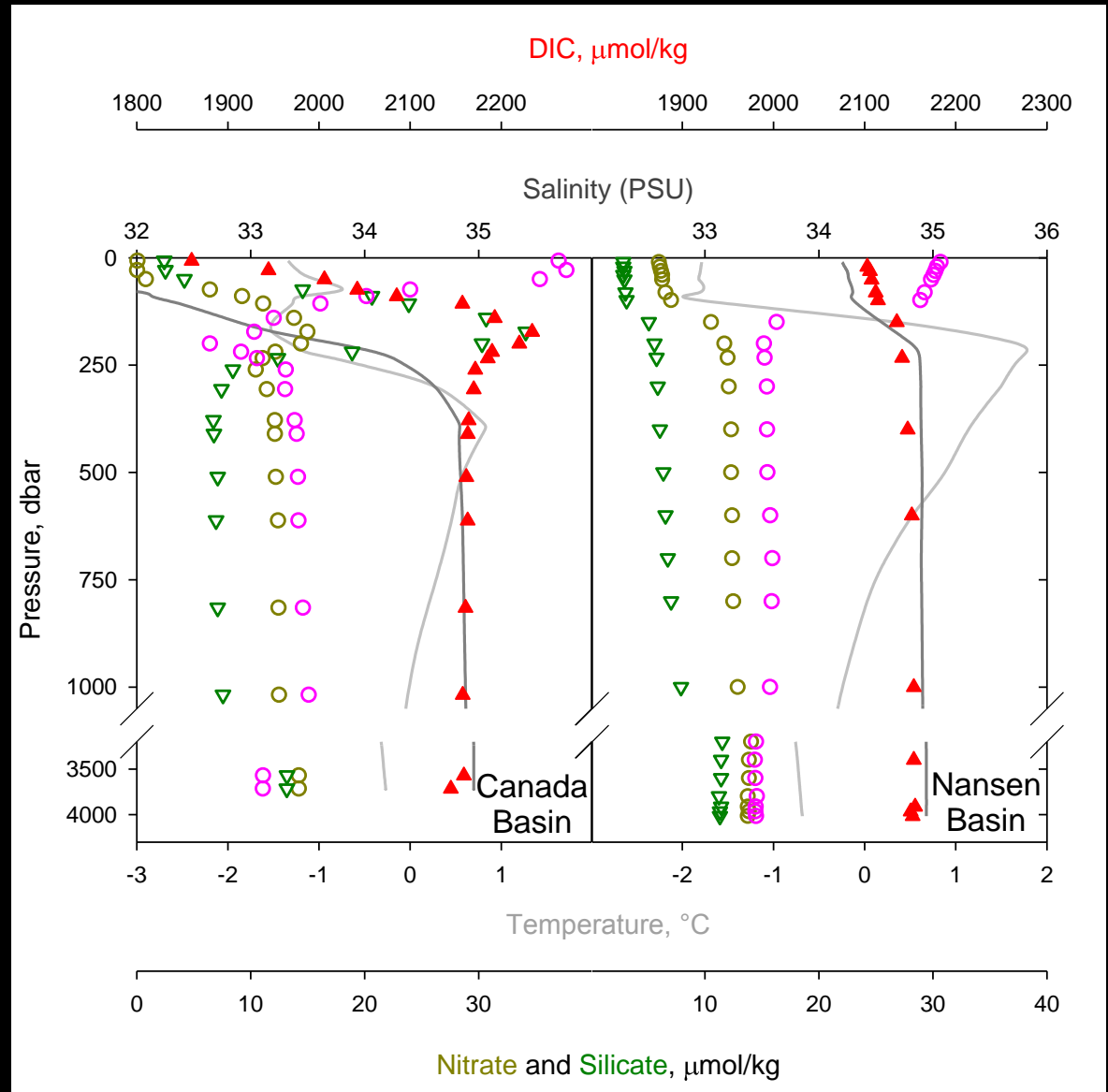


Organic carbon dynamics



C decoupled from nutrients

- air-sea exchange
- CaCO_3 precipitation
- sedimentary processes



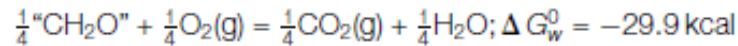
Organic carbon dynamics

Sediments

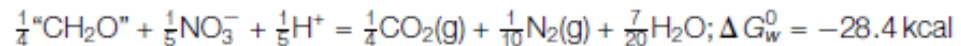
Decreasing
O₂

Table 7.6 Oxidation of Organic Compounds Represented Generically as "CH₂O".^a

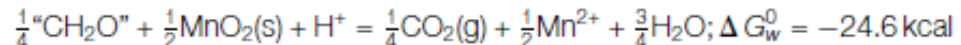
Aerobic respiration



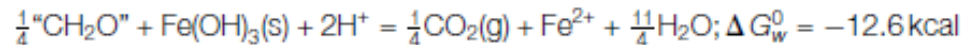
Denitrification



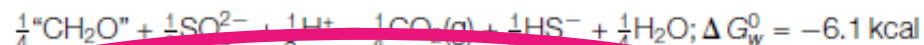
Manganese respiration



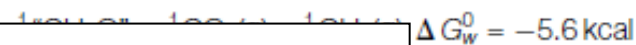
Iron respiration



Sulfate reduction

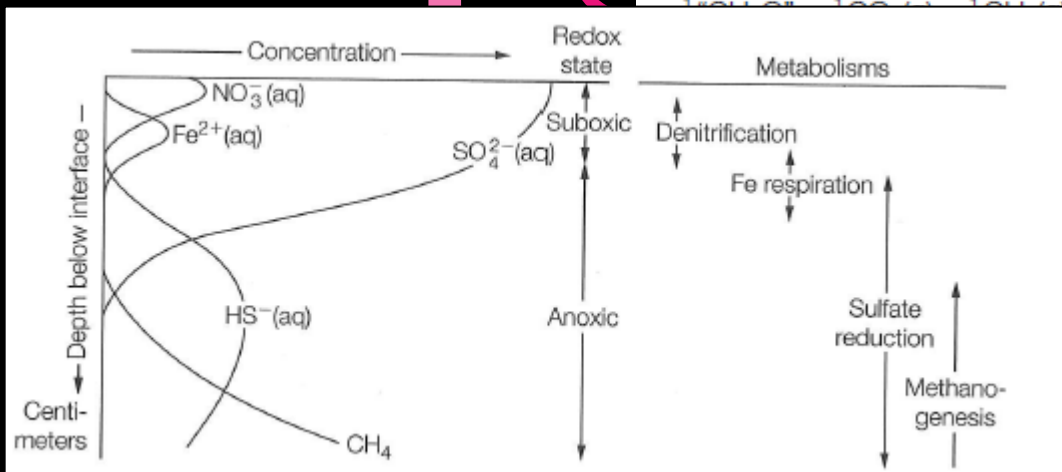


Methane fermentation



*g*anotrophs, all heterotrophs.

Libes, 2009



Organic carbon dynamics

Methane in the Arctic Ocean

Source

- Microbial methanogenesis
- Outgassing from sediments
- Clathrates



Sinks

- Oxidation to CO_2
- Release to the atmosphere



12x stronger greenhouse gas than CO_2

Organic carbon dynamics

Terrestrial Organic Carbon

Rivers



Beaufort Sea (M. Fortier)

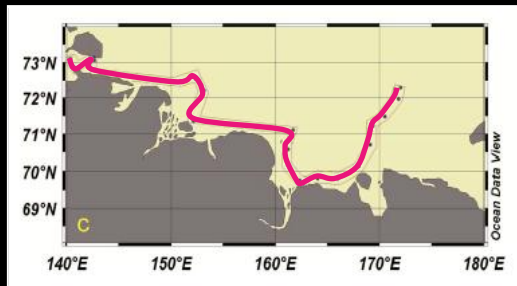
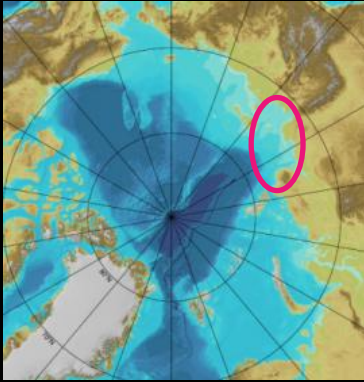
Erosion



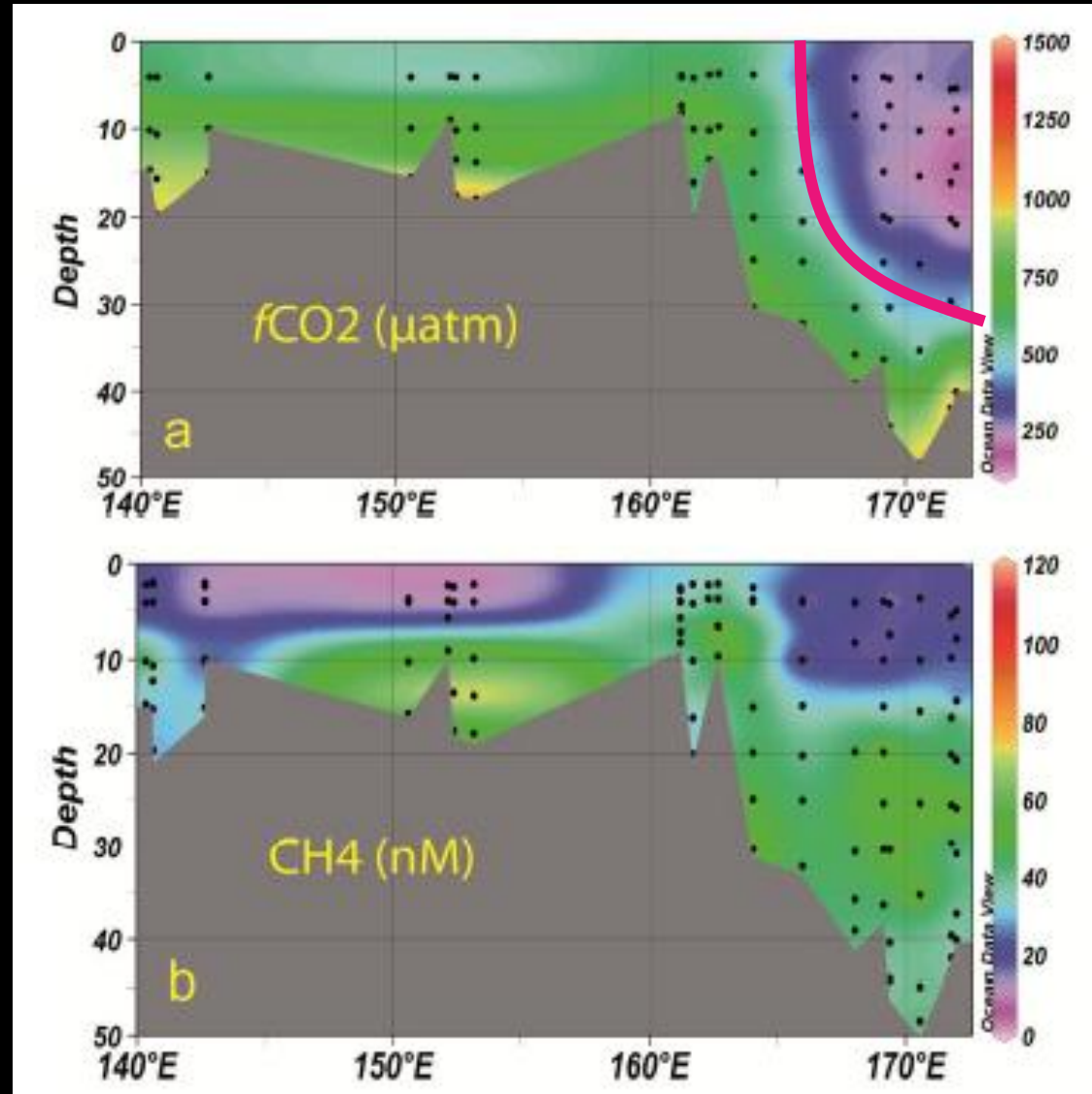
Semiletov et al., 2012

Organic carbon dynamics

Terrestrial Organic Carbon



The Arctic as a
net
heterotrophic
ocean?



Air-Sea CO₂ Exchange

$$F_{\text{CO}_2} = k_s \Delta p \text{CO}_2$$

Flux

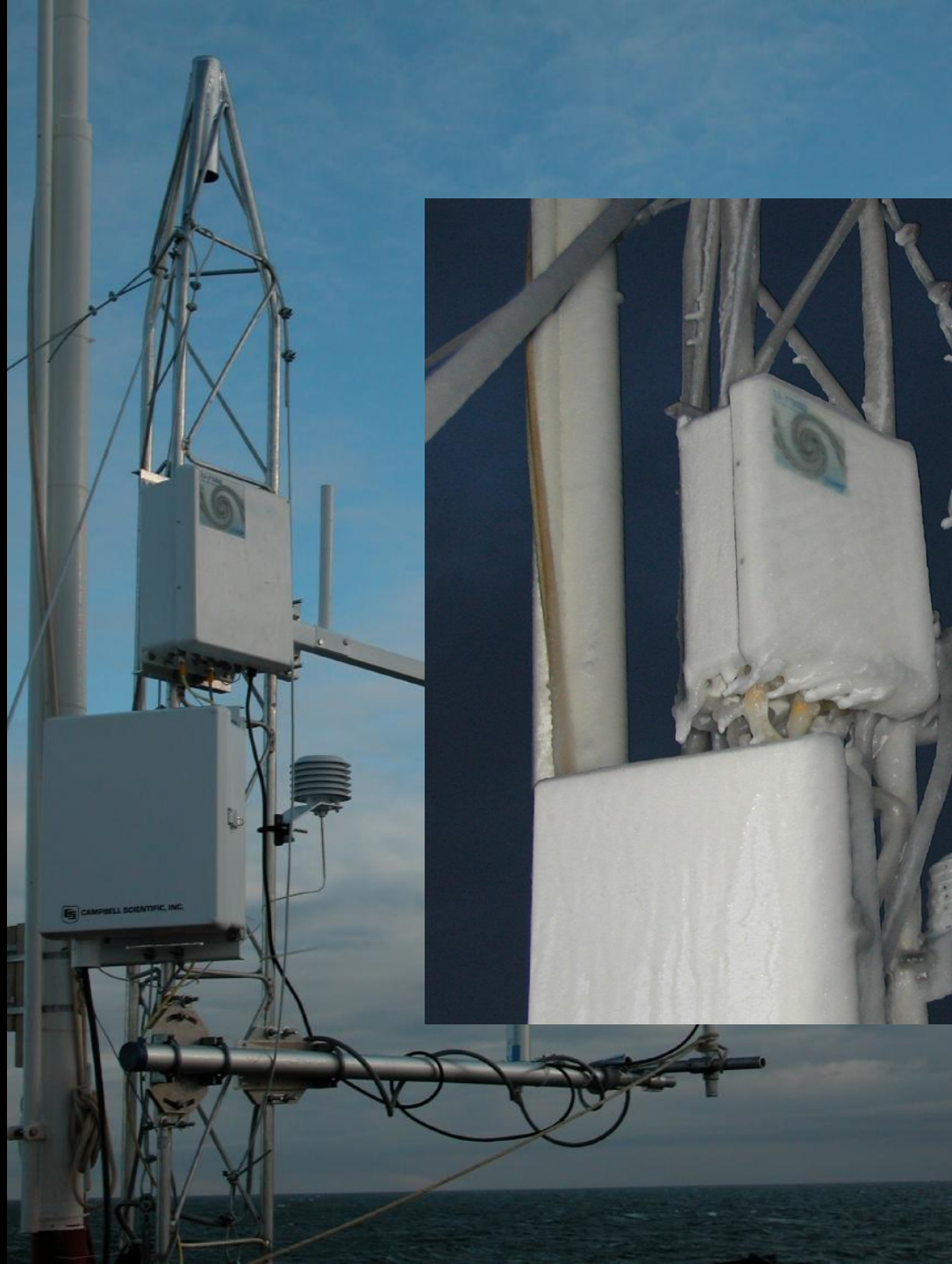
Gas transfer
velocity

Solubility

Gradient

k is a function of:

- wind speed
- skin temperature
- turbulence
- surfactant concentration



Air-Sea CO₂ Exchange

$$F_{\text{CO}_2} = k_s \Delta p \text{CO}_2$$

Flux

Gas transfer
velocity

Solubility

Gradient

100% Uncertainty

- skin temperature
- turbulence
- surfactant concentration

Air-Sea CO₂ Exchange

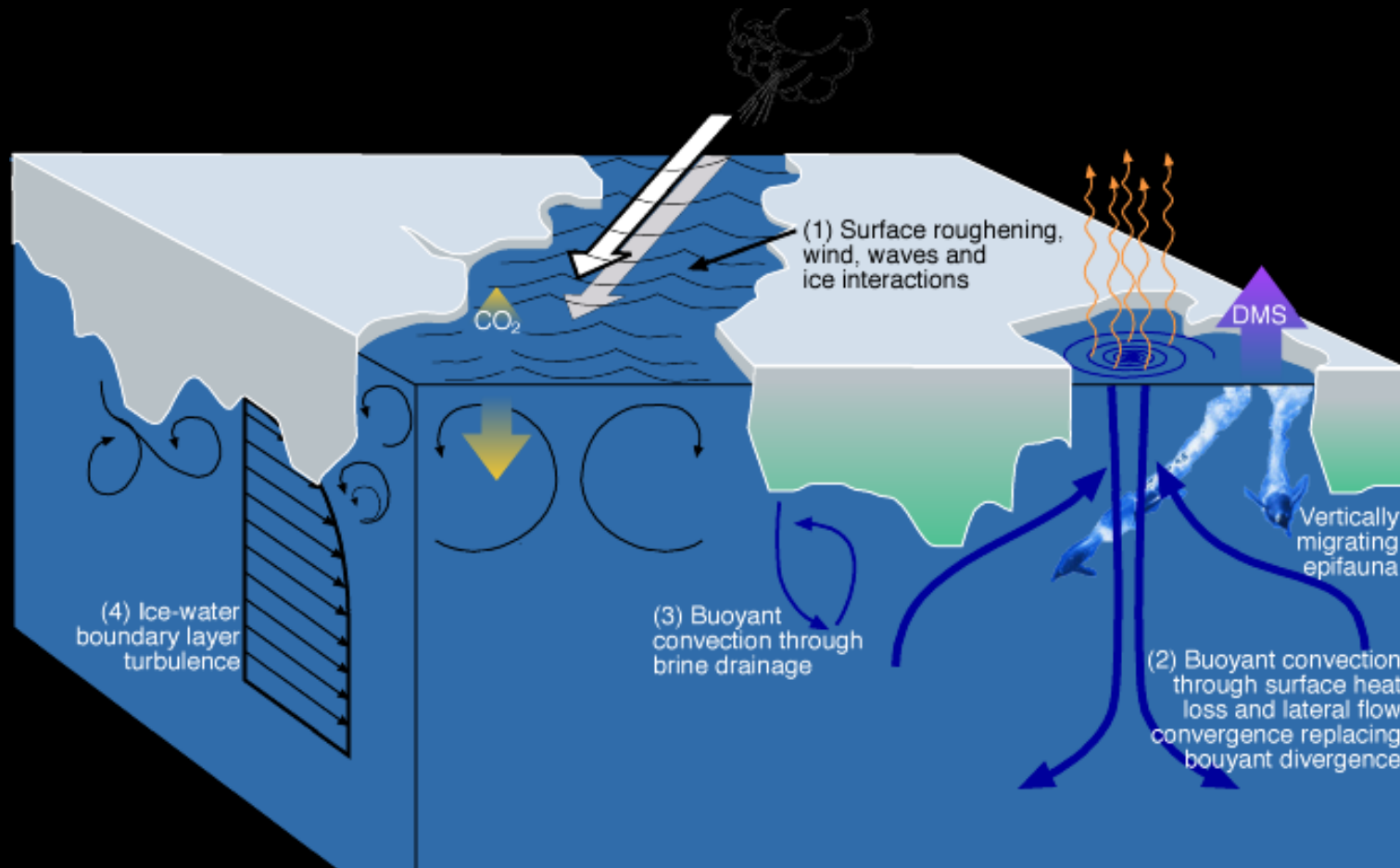
The Arctic as a net atmospheric CO₂ sink

Region	Sea-air exchange		Source
	(mmol/m ² /d) ^a	10 ¹² mol/y	
Central Basins	-0.3 to 1		Bates et al., 2006
Barents Sea	-3.7±0.9 ^b	-0.8 -2.4±1 -3.8±1.5 -4.3±0.7 -1.8±1	Fransson et al., 2001 Kaltin et al., 2002 Nakaoka et al., 2006 Omar et al., 2007 Kivimäe et al., 2010
Nordic Seas		-5.8	Jeansson et al., 2011
Kara Sea	-0.1 ^b		Fransson et al., 2001
Laptev Sea	-1.2 to 1.7	-2.1	Nitishinsky et al., 2007 Semiletov et al., 2007
East Siberian Sea	-2 to 10	0.04 to 0.28	Pipko et al., 2011
Chukchi Sea	-30 to -90 -15 to 15 -18 to 3	-2.6 to -3.8 -1.8	Bates, 2006 Pipko et al., 2002 Murata and Takizawa, 2003 Kaltin and Anderson, 2005
Beaufort Sea	-2 -17 to 0 -17 to 3 -25 to -9		Mucci et al., 2010 Murata and Takizawa, 2003 Shadwick et al., 2011 Else et al., 2011
Canadian Archipelago	-7 to 0 -140 to 18		Miller et al., 2002 Fransson et al., 2009
All Arctic Ocean		-2 to ~ -8	McGuire et al., 2009

^a Data are from the summer period with limited ice coverage; ^b annual mean estimate.

Air-Sea CO₂ Exchange

Impact of a Broken, Mobile Ice Cover

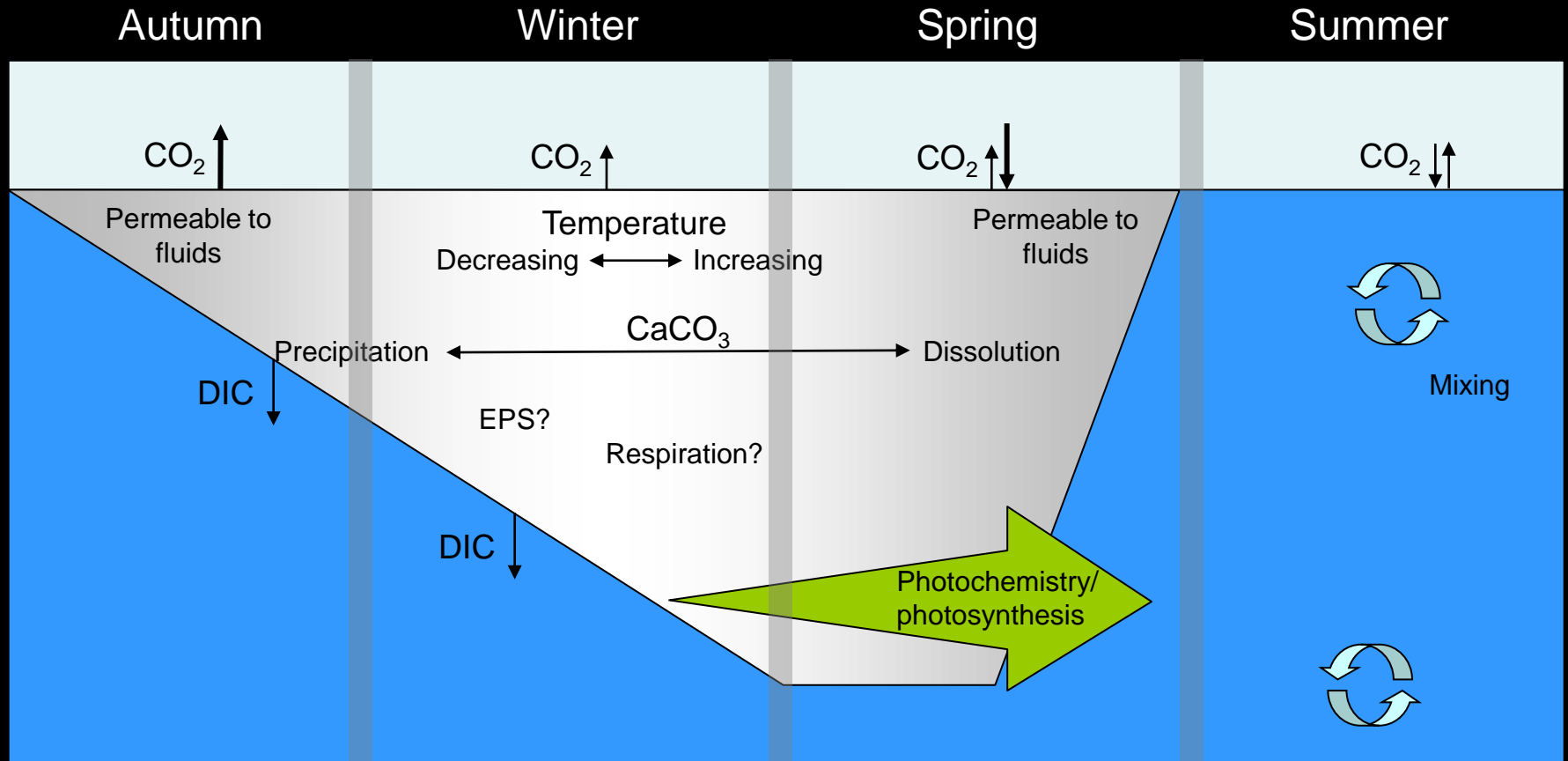


B. Loose

Measured fluxes **10x** those estimated from the air-sea $p\text{CO}_2$ gradient and open water parameterizations

Air-Sea CO₂ Exchange

Sea-ice C dynamics



The Deep Ocean Carbon Pumps

