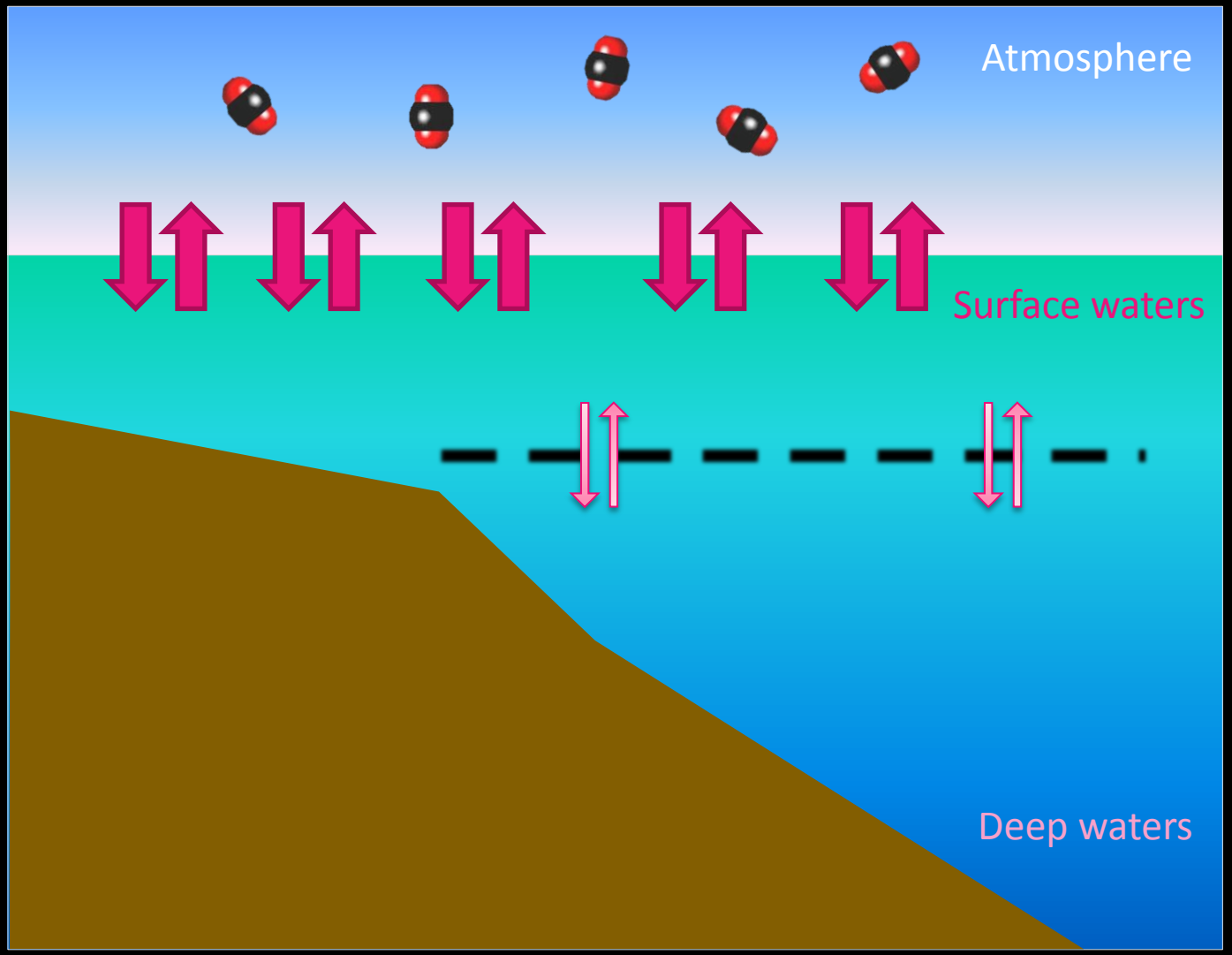
Climate Change Feedbacks in the Arctic Ocean Carbon Cycle

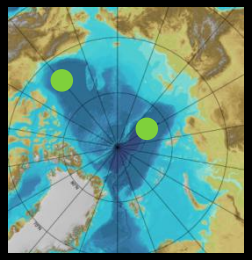
Photo: K. Cherewyk

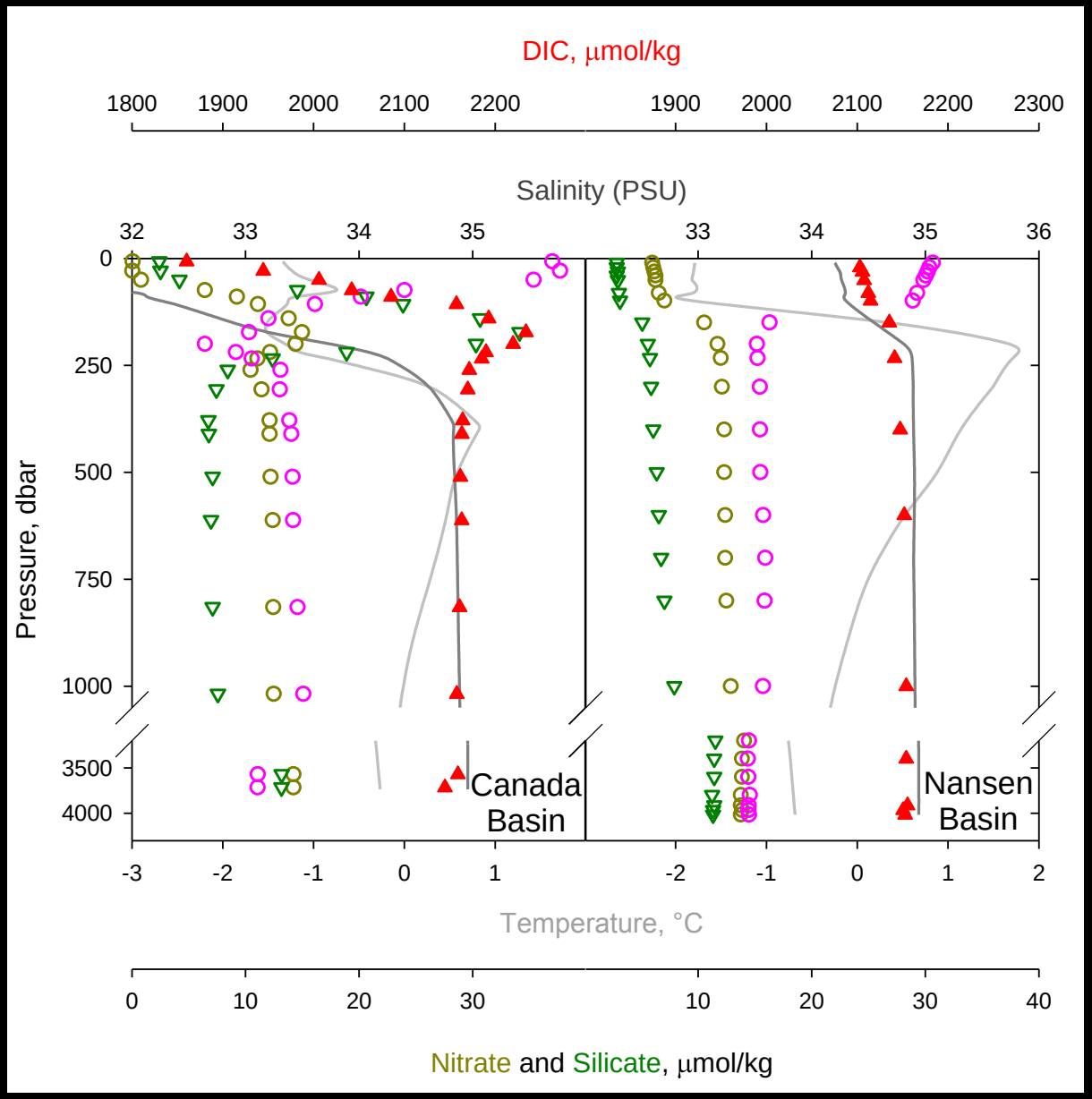
Oceanic Carbon export



Carbon ‘Pumps’

Ocean Carbon “Pumps”





Air-Sea CO_2 Exchange

$$F_{CO2} = ks\Delta pCO_2$$

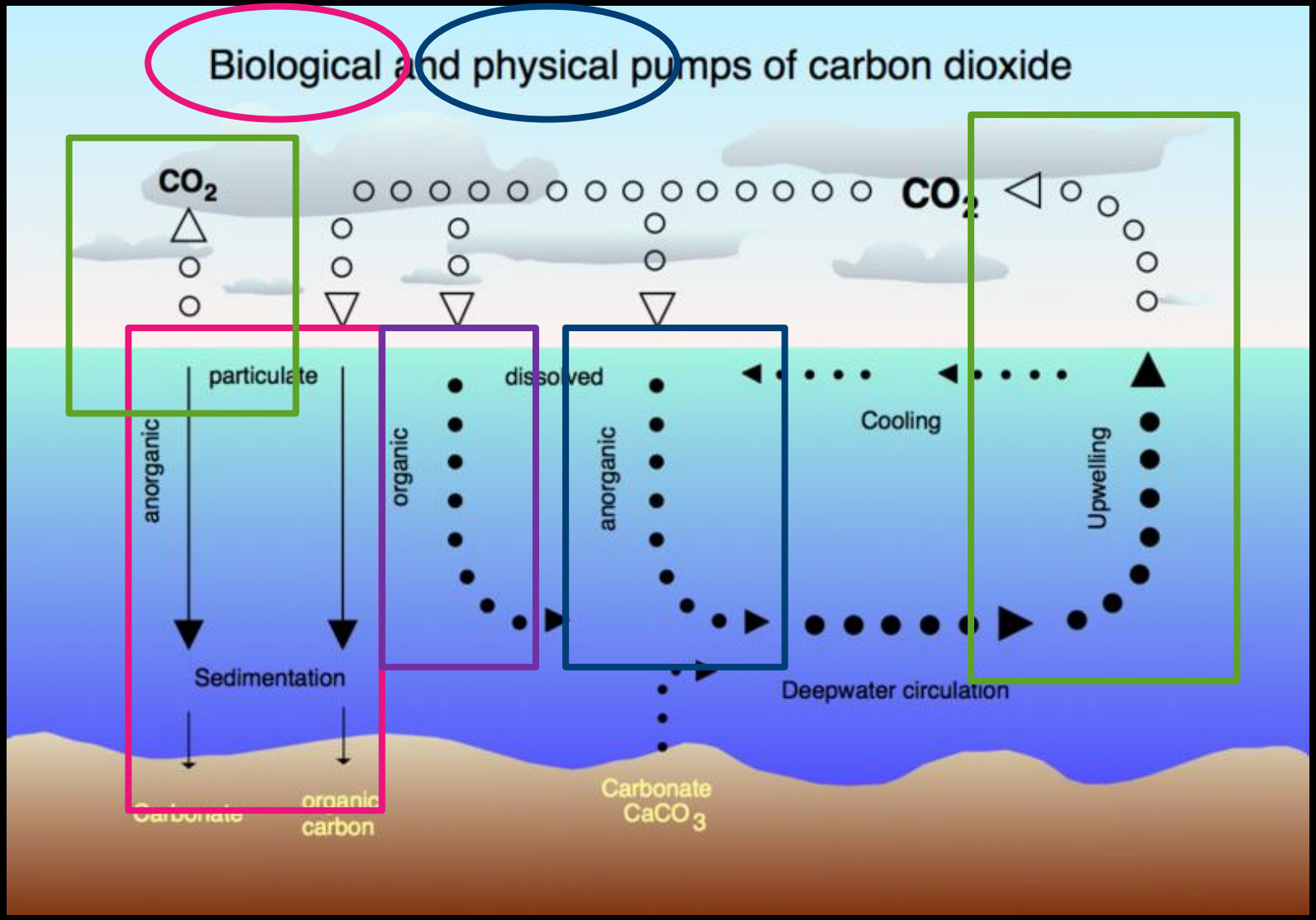
Flux

Rate constant

Solubility

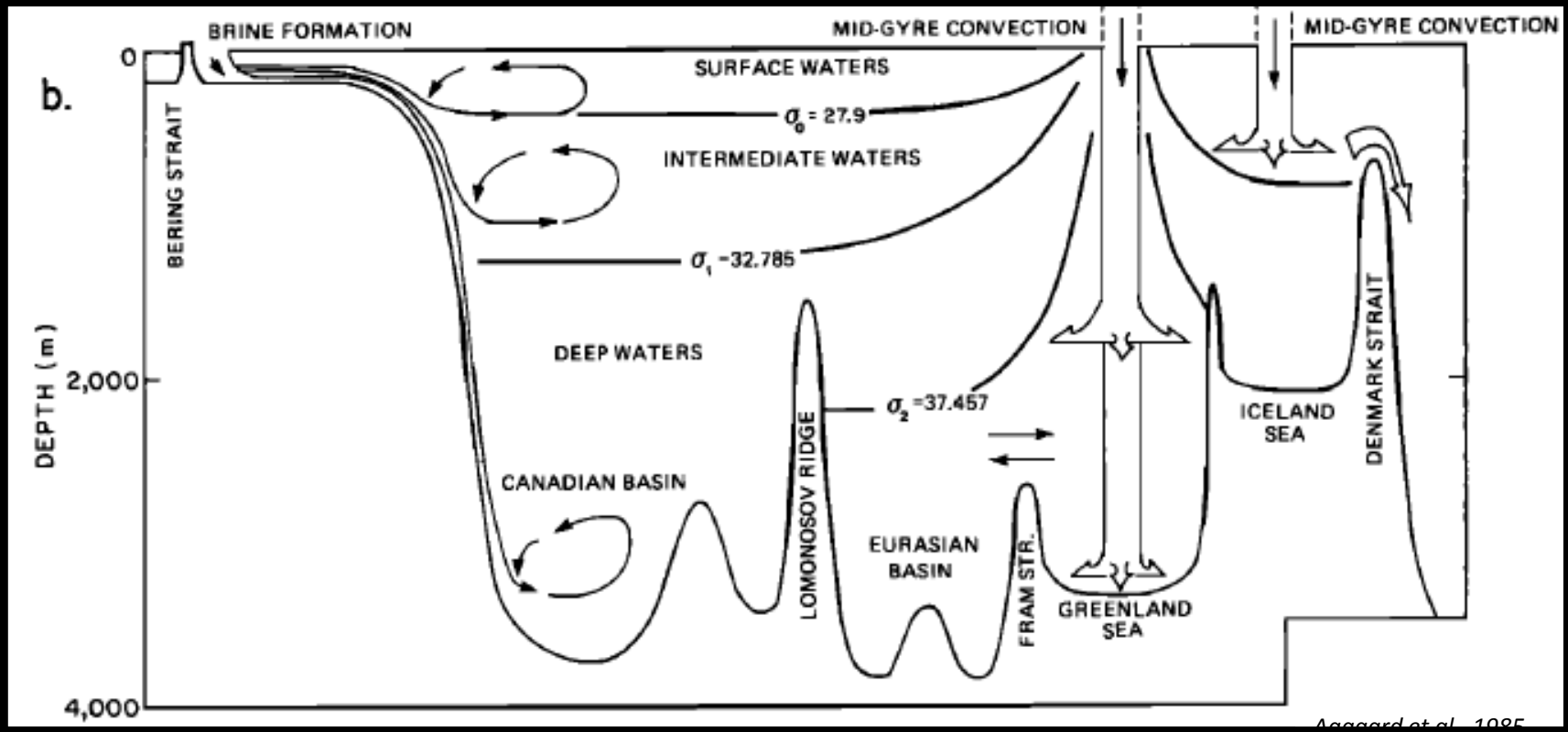
Gradient

Deep Ocean Carbon Pumps



Alfred Wegener Institute

Physical (Solubility) Pump in the Arctic



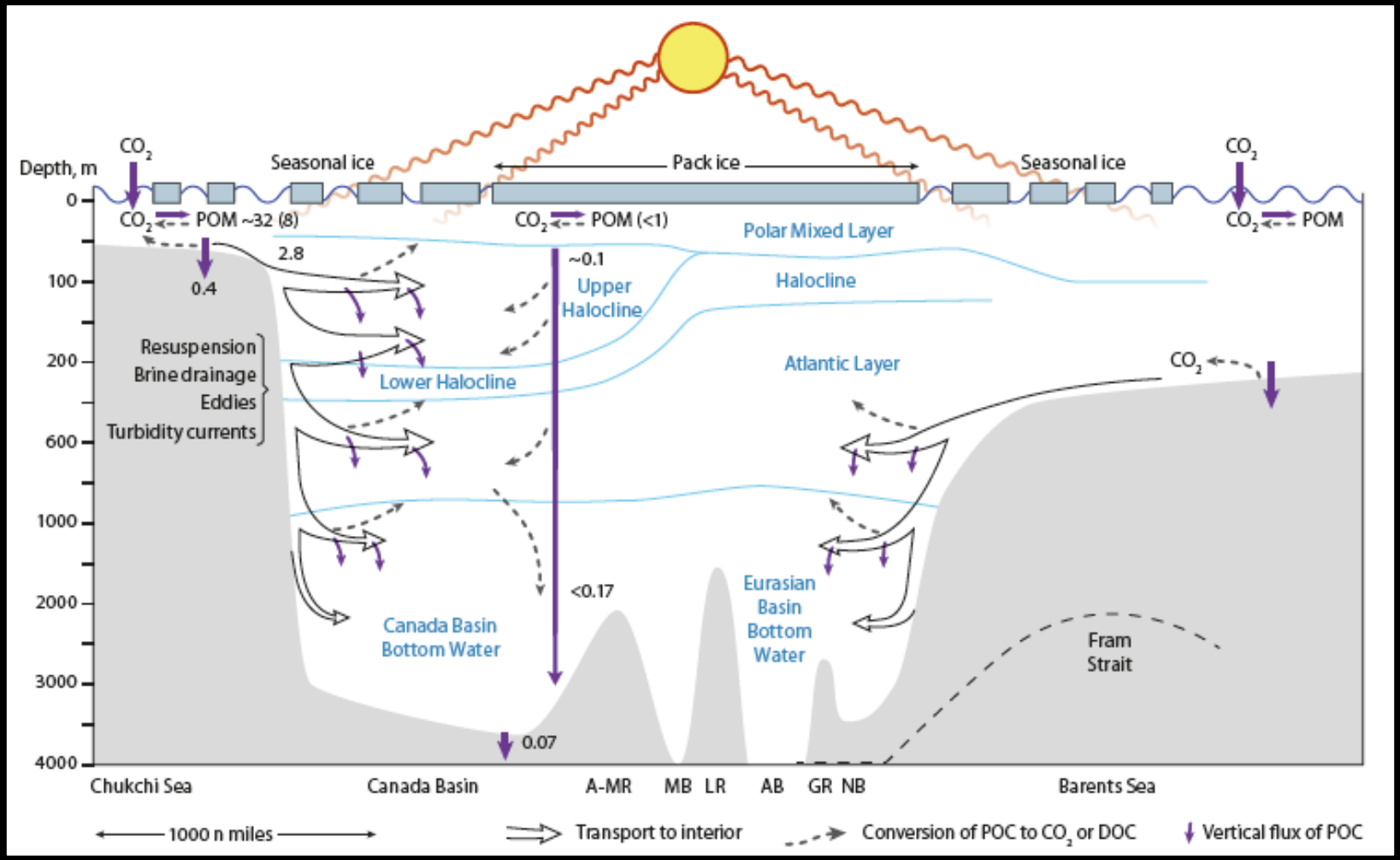
How well are cold surface waters able to equilibrate before convecting?

Biological Pump in the Arctic

A Horizontal Pump

Wide Shelves

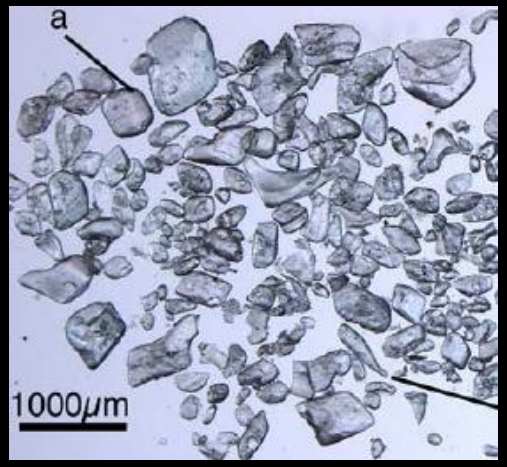
Stratification



AMAP, 2013

The Sea-Ice Carbonate Pump

Ikaite precipitation in sea ice

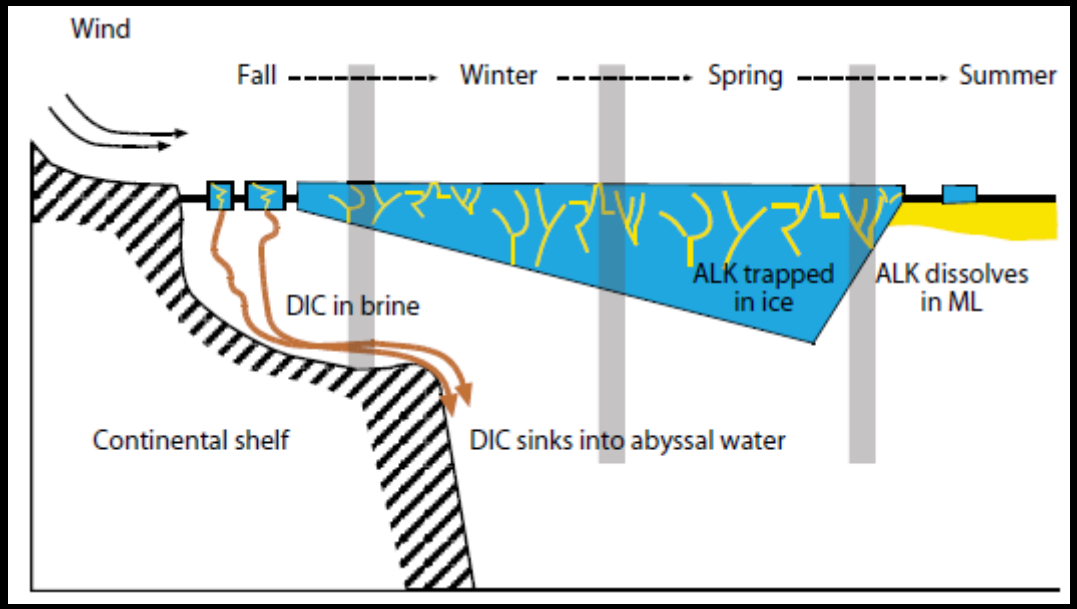


$$Ca^{2+} + 2HCO_3^- \leftrightarrow CaCO_3 + CO_{2(aq)} + H_2O$$

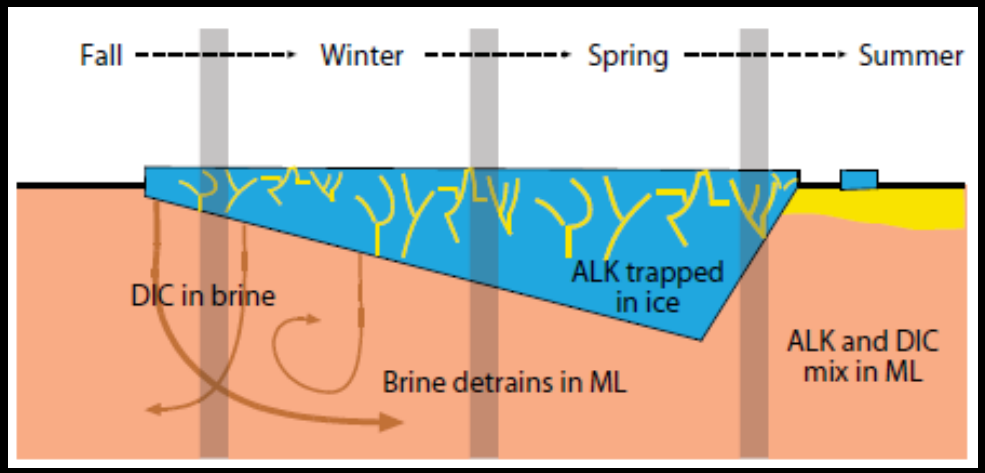
Removes:

- 1 mole DIC
- 2 moles alkalinity

The Sea-Ice Carbonate Pump

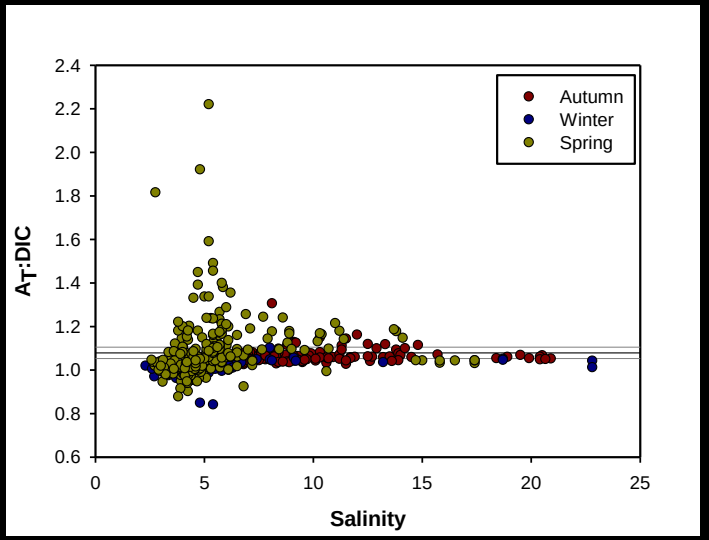


Loose et al., 2011



Dependent on:

- dense brines initiating shelf water formation
- alkalinity enrichment over DIC in the ice



Slow export process

The net atmospheric CO_2 sink in the Arctic Ocean

A result of:

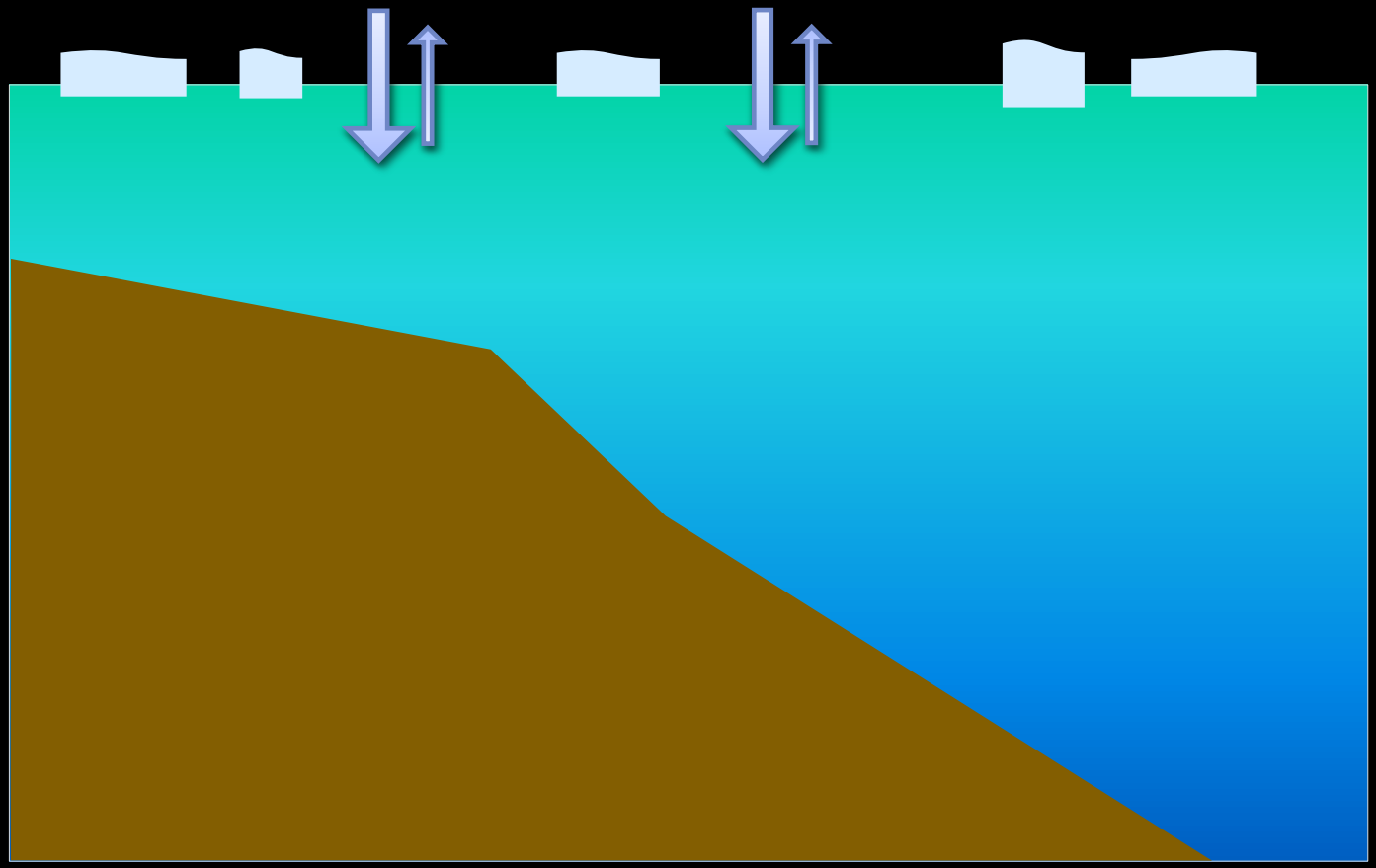
- Cold, productive waters
- Seasonal ice cover & deepwater formation

How will it change with climate?

Negative Feedbacks: Increasing the sink

- Less ice, more open water
- More wind?
- More broken, mobile ice cover

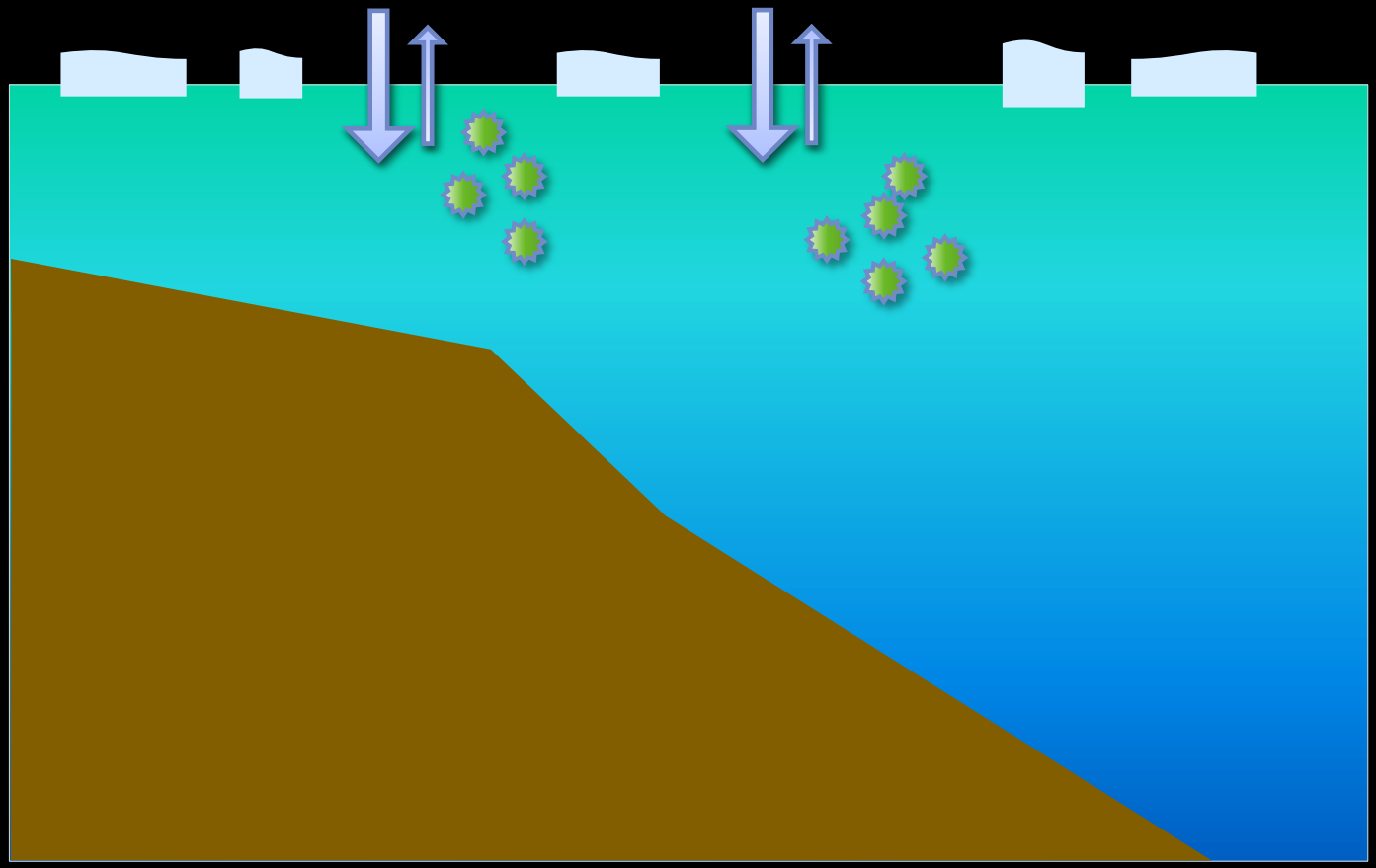
More air-sea exchange?



Negative Feedbacks: Increasing the sink

- Less ice, more light
- More wind mixing?, more nutrients
- More river run-off, more nutrients

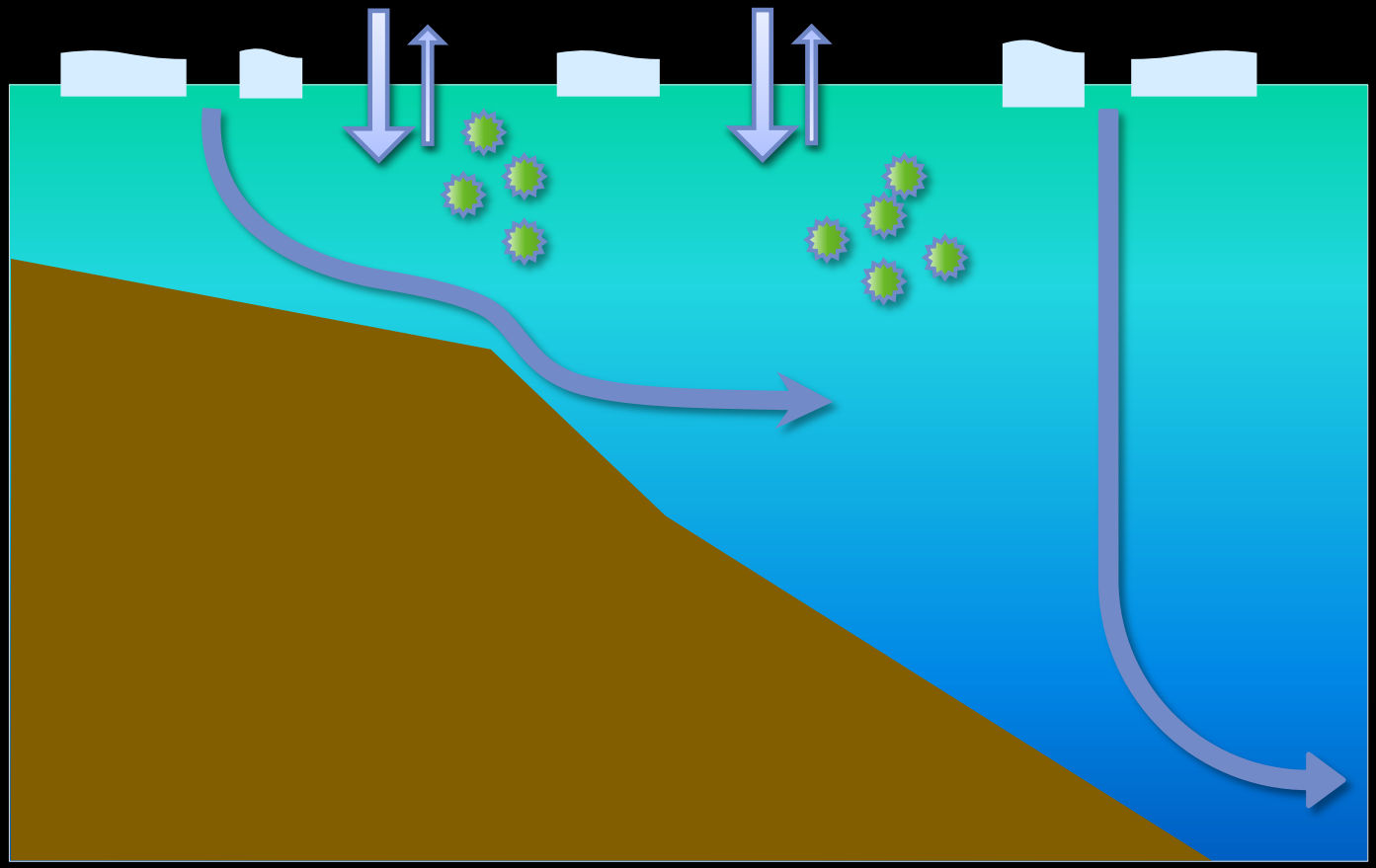
More primary production?



Negative Feedbacks: Increasing the sink

- More seasonal ice
- More ice formation
- More brine export

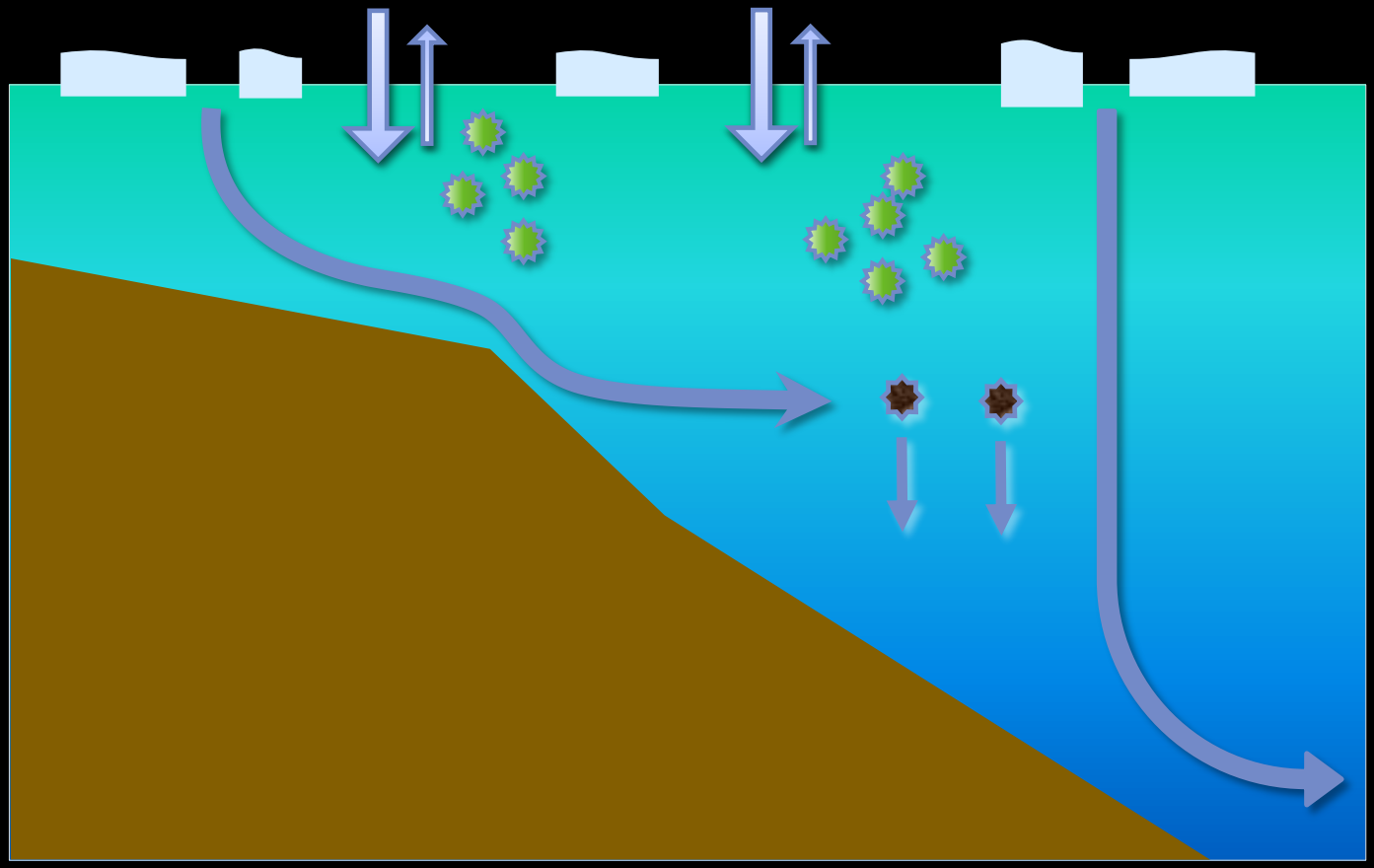
More deepwater formation?



Negative Feedbacks: Increasing the sink

- More primary production?
- Changing biological community?

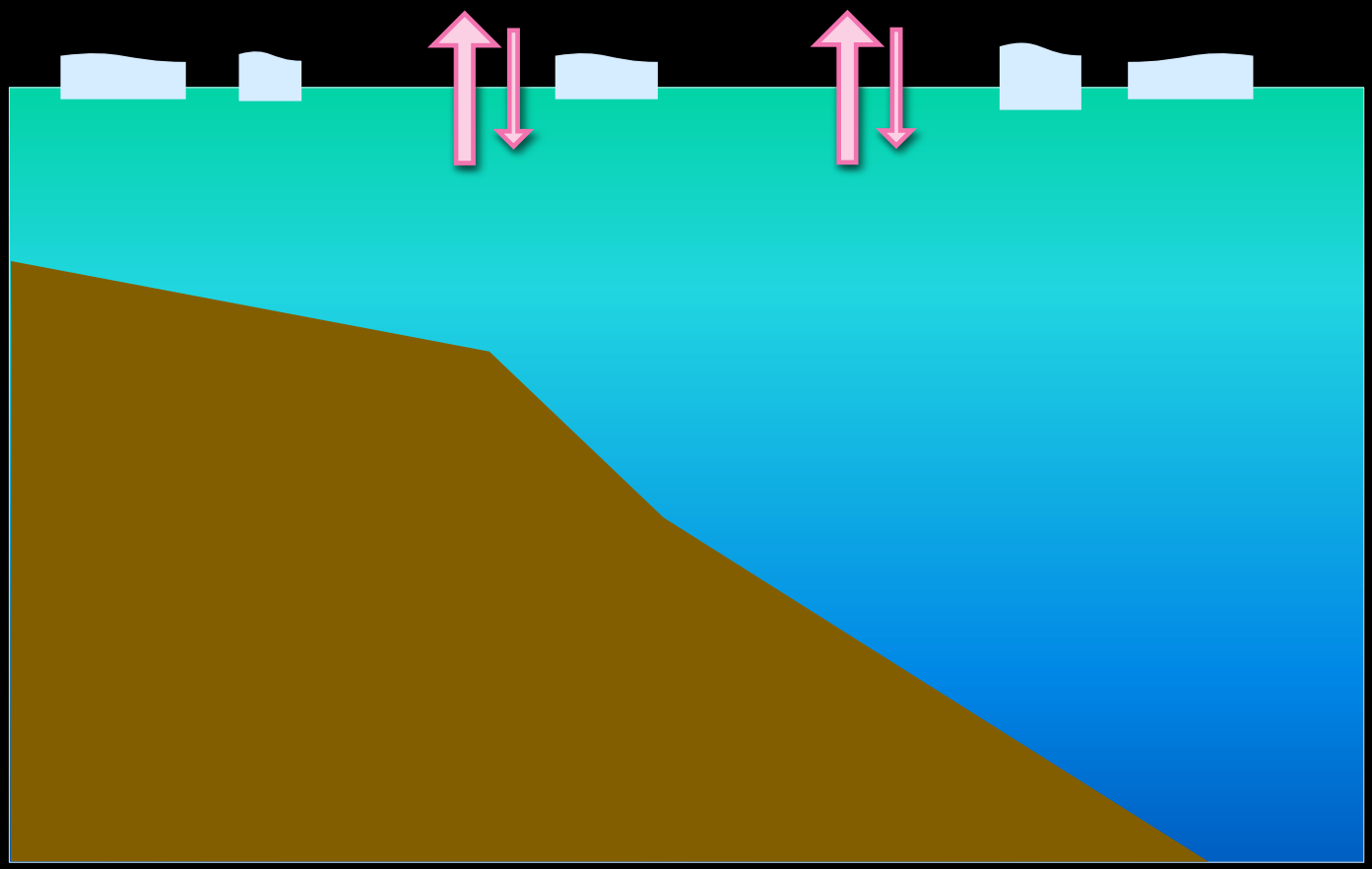
More POC export?



Positive Feedbacks: Decreasing the sink

- More open water in winter
- More river run-off, more organic C
- More wind?, more upwelling
- More summer warming

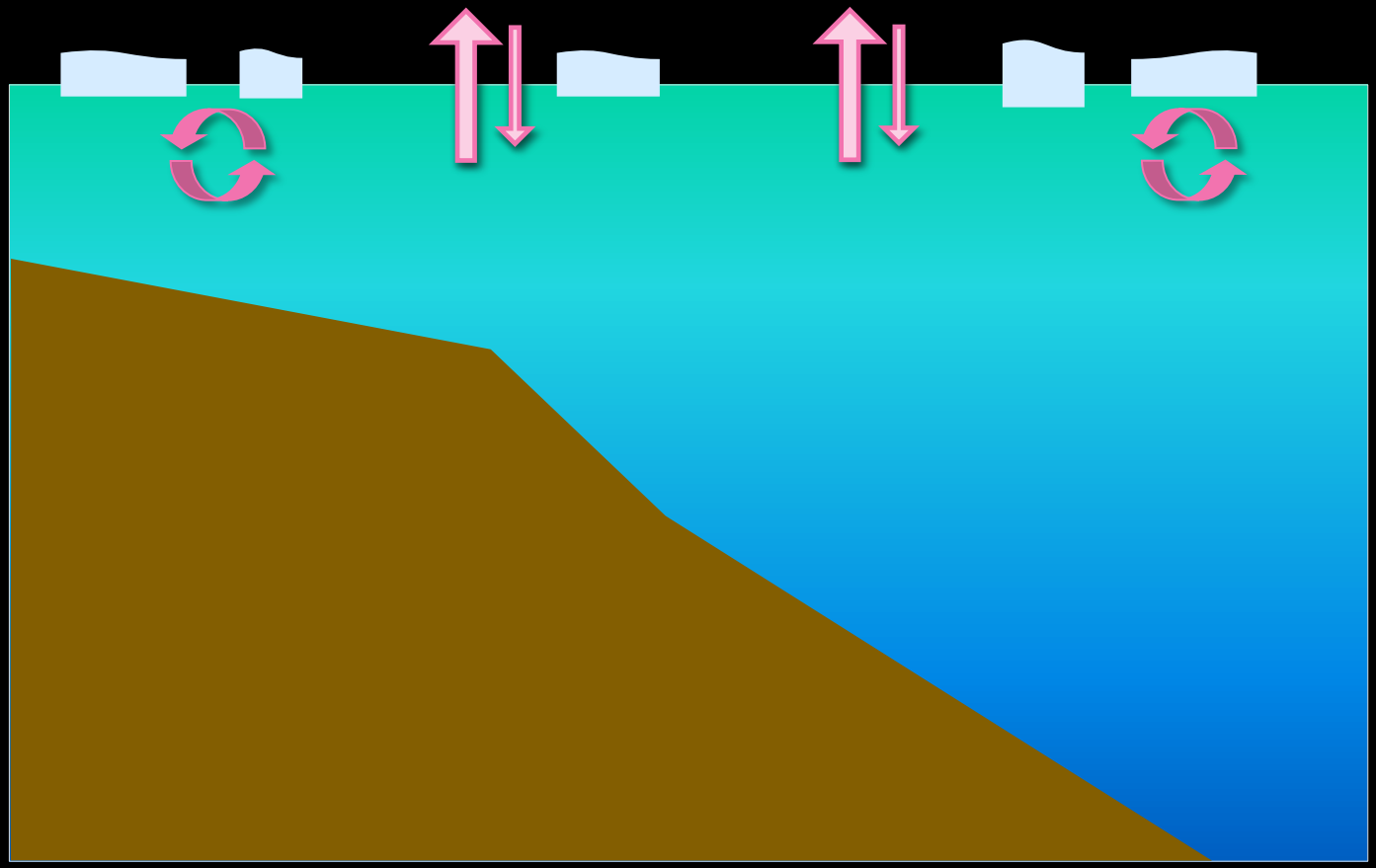
More outgassing?



Positive Feedbacks: Decreasing the sink

- More ice melt
- Less ice export?
- More stratification

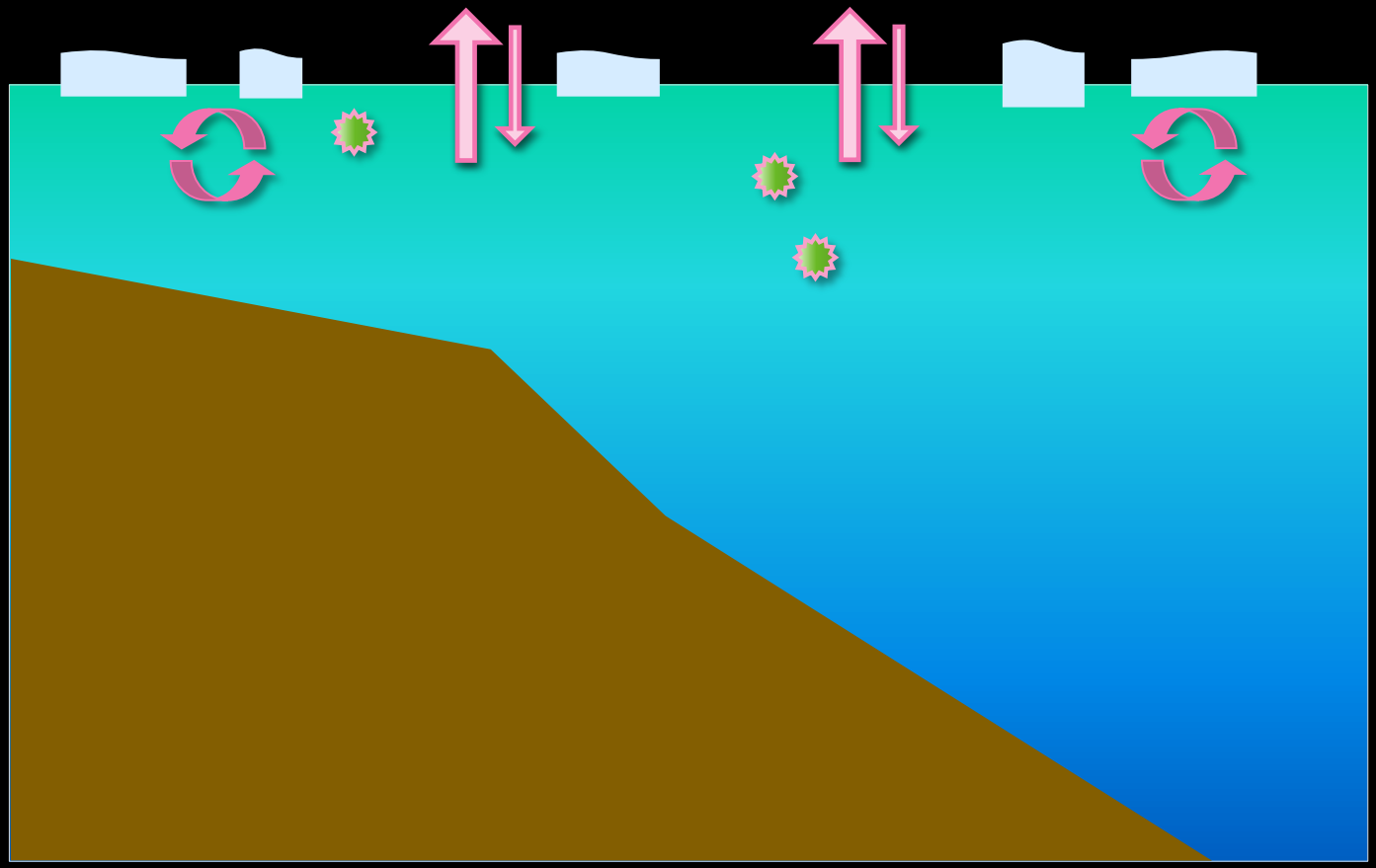
Less deepwater formation?



Positive Feedbacks: Decreasing the sink

- More river run-off, more turbidity
- More stratification, less nutrients

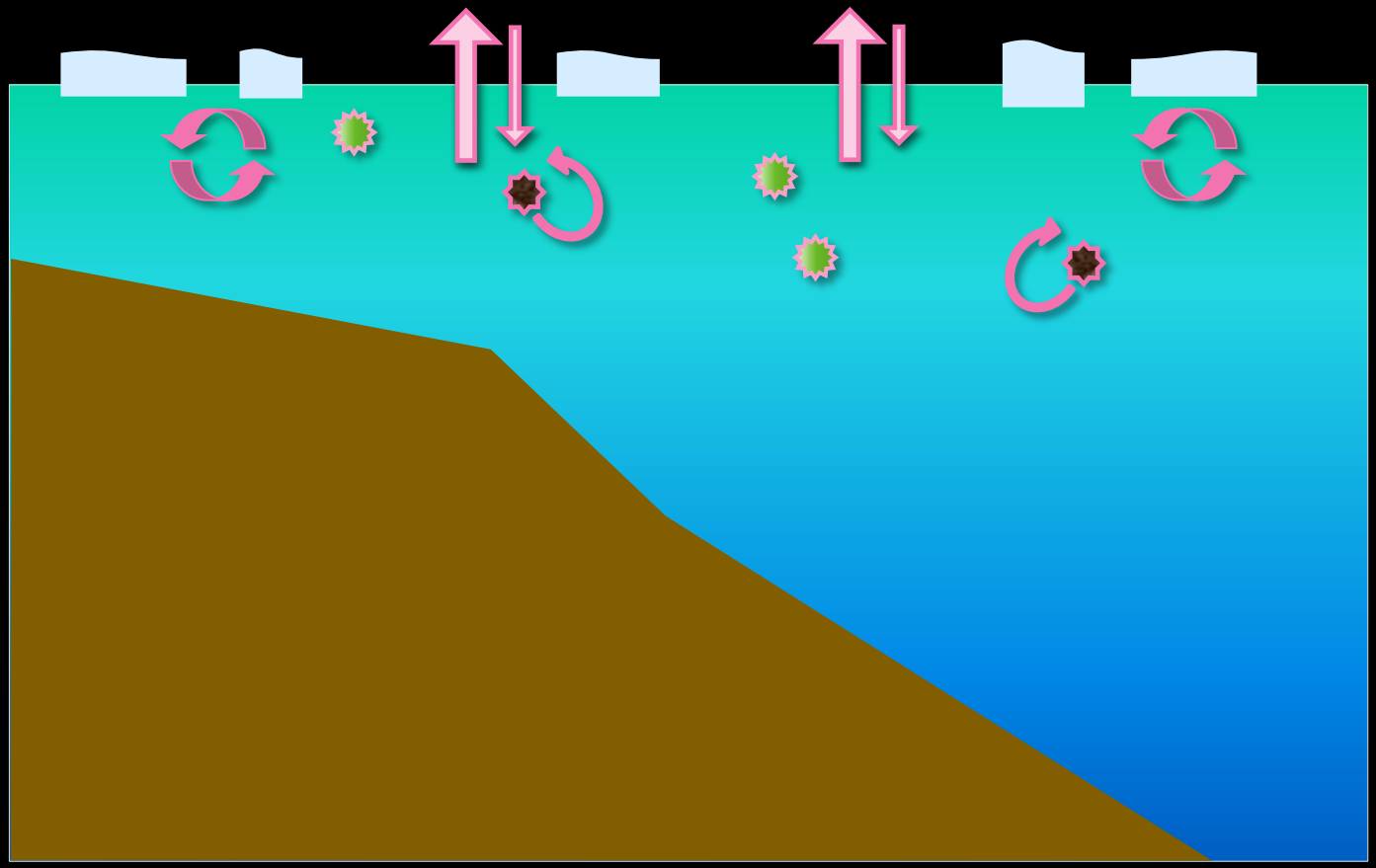
Less primary production?



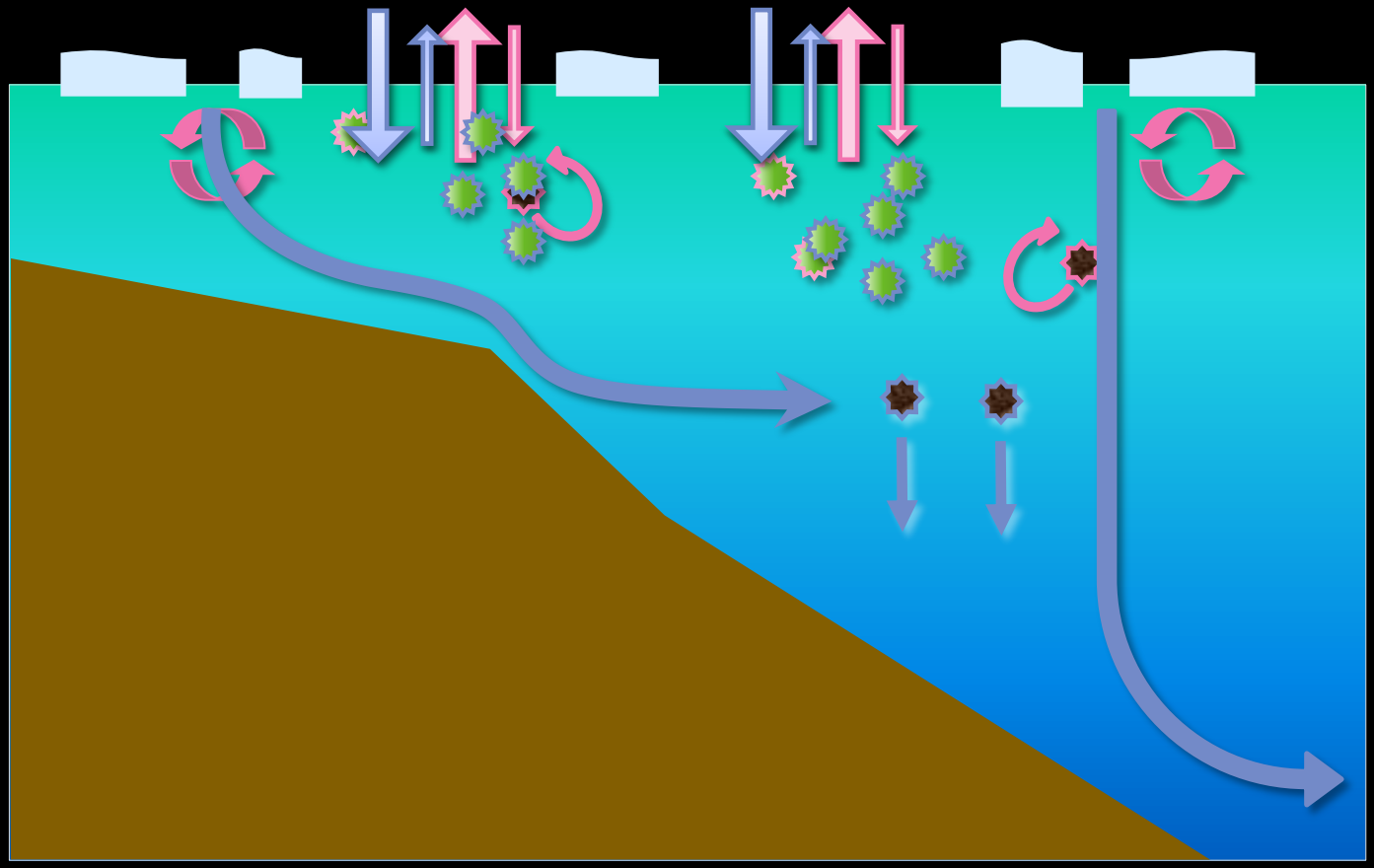
Positive Feedbacks: Decreasing the sink

- Less primary production?
- Changing biological community?

Less POC export?



The Net Result Is Unknown




the OTHER COAST
THE ARCTIC IS THE BEST PLACE TO STUDY CLIMATE CHANGE.
HMM... THIS CORE SAMPLE DOESN'T TELL ME MUCH.
I'LL HAVE TO DRILL MORE CORE SAMPLES.
IT'S DEFINITE. THE ARCTIC ICE CAP IS RAPIDLY DISAPPEARING.
GLOBAL WARMING?
NO. MORE LIKE TOO MANY HOLES.

Arctic Ocean Acidification

The Arctic Monitoring and Assessment Program (AMAP), 2013

http://www.amap.no/

Arctic Ocean Acidification

Chemistry

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$$

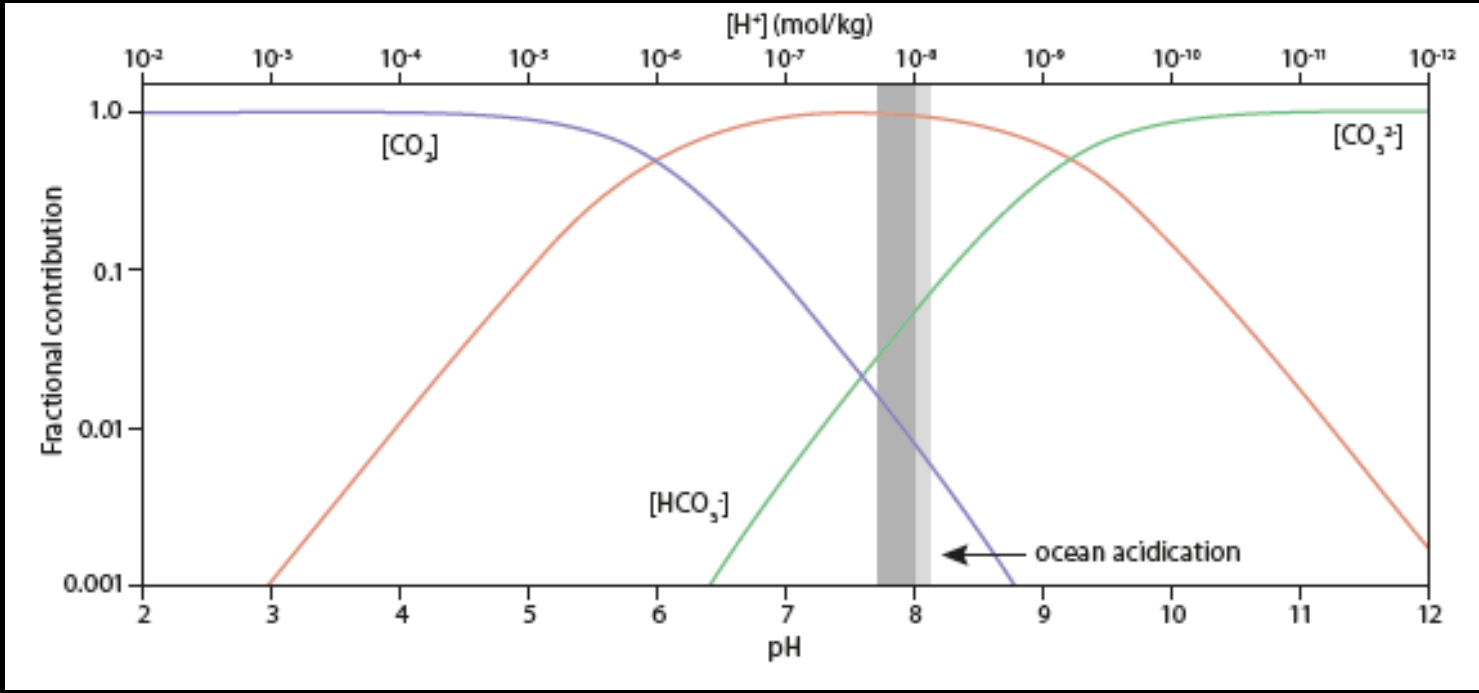
Aragonite

$$CaCO_3 \leftrightarrow Ca^{2+} + CO_3^{2-}$$

$$\Omega_{Ar} = \frac{[Ca^{2+}][CO_3^{2-}]}{K_{sp}'}$$

Arctic Ocean Acidification

Chemistry

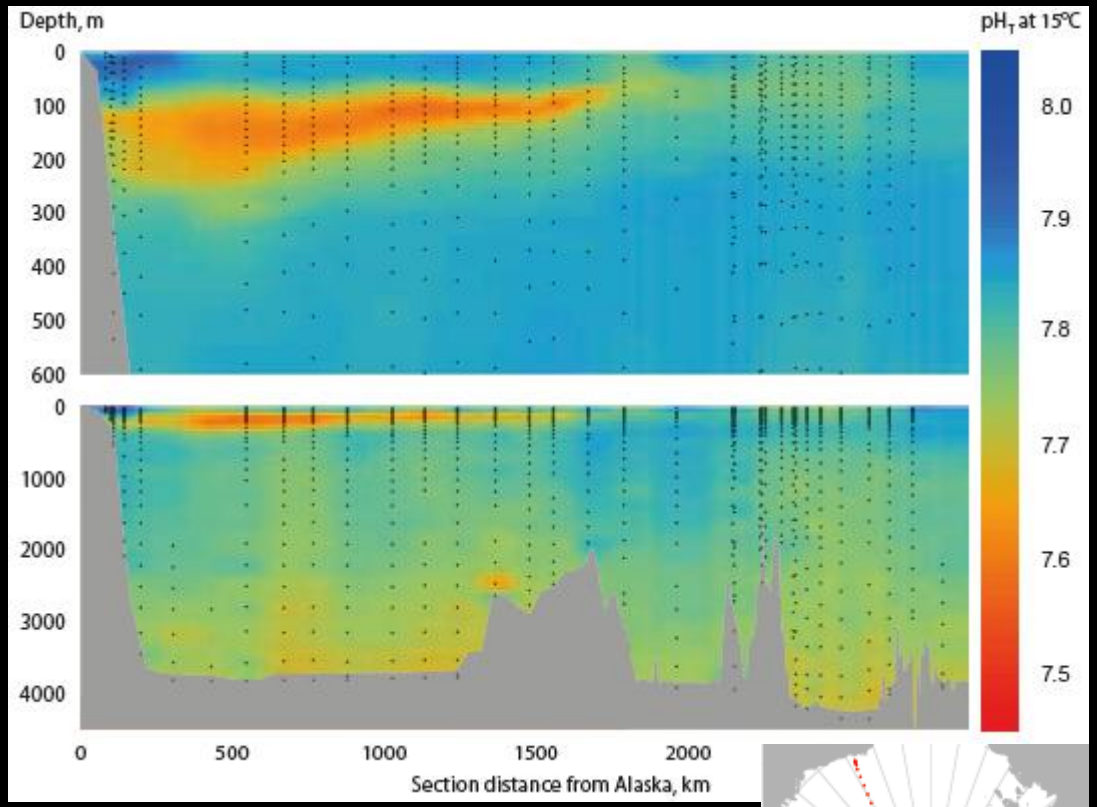


AMAP, 2013

pH changes at least as important as changes in $CaCO_3$ saturation state

Ocean Acidification
Arctic Vulnerabilities

- High CO_2 Pacific waters



AMAP, 2013

Ocean Acidification
Arctic Vulnerabilities

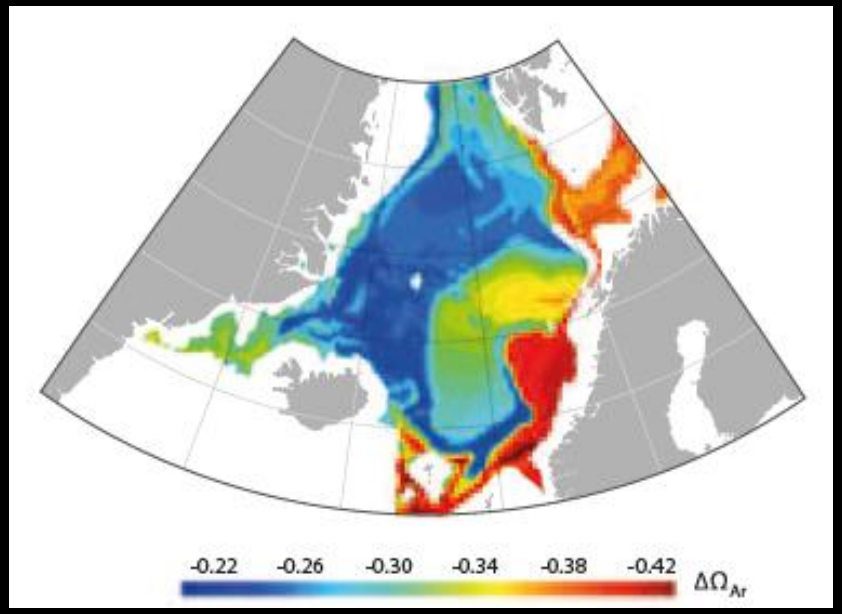
- High CO_2 Pacific waters
- Fresh waters (dilution & low buffering capacity)

$$CaCO_3 + CO_2 + H_2O \leftrightarrow Ca^{2+} + 2HCO_3^-$$

$$CO_2 + CO_3^{2-} + H_2O \leftrightarrow 2HCO_3^-$$

Ocean Acidification
Arctic Vulnerabilities

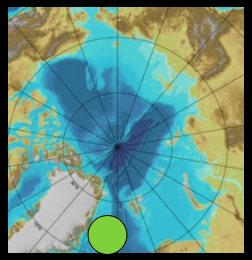
- High CO_2 Pacific waters
- Fresh waters (dilution & low buffering capacity)
- High anthropogenic CO_2 content in Atlantic inflow



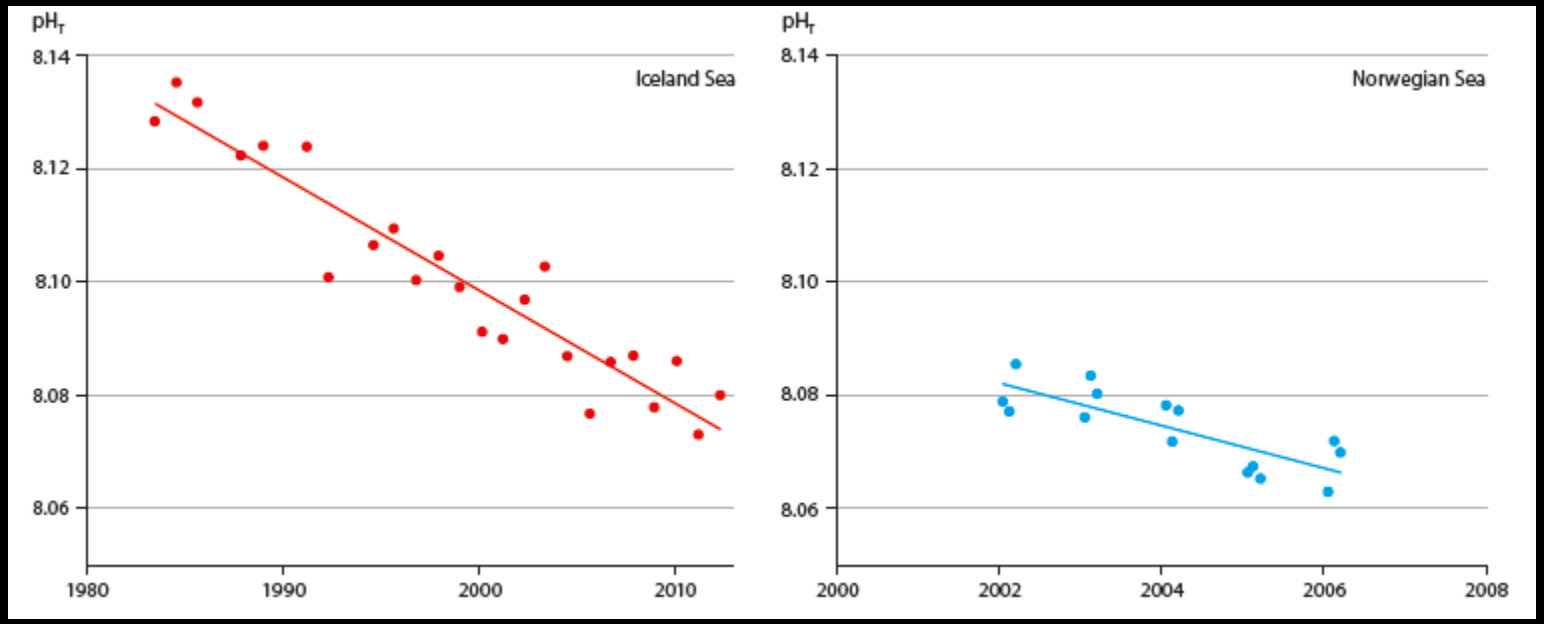
AMAP, 2013

Arctic Ocean Acidification

Historical Trends



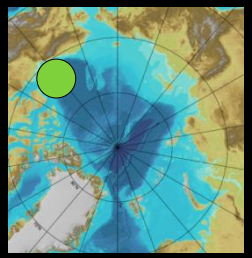
Surface waters

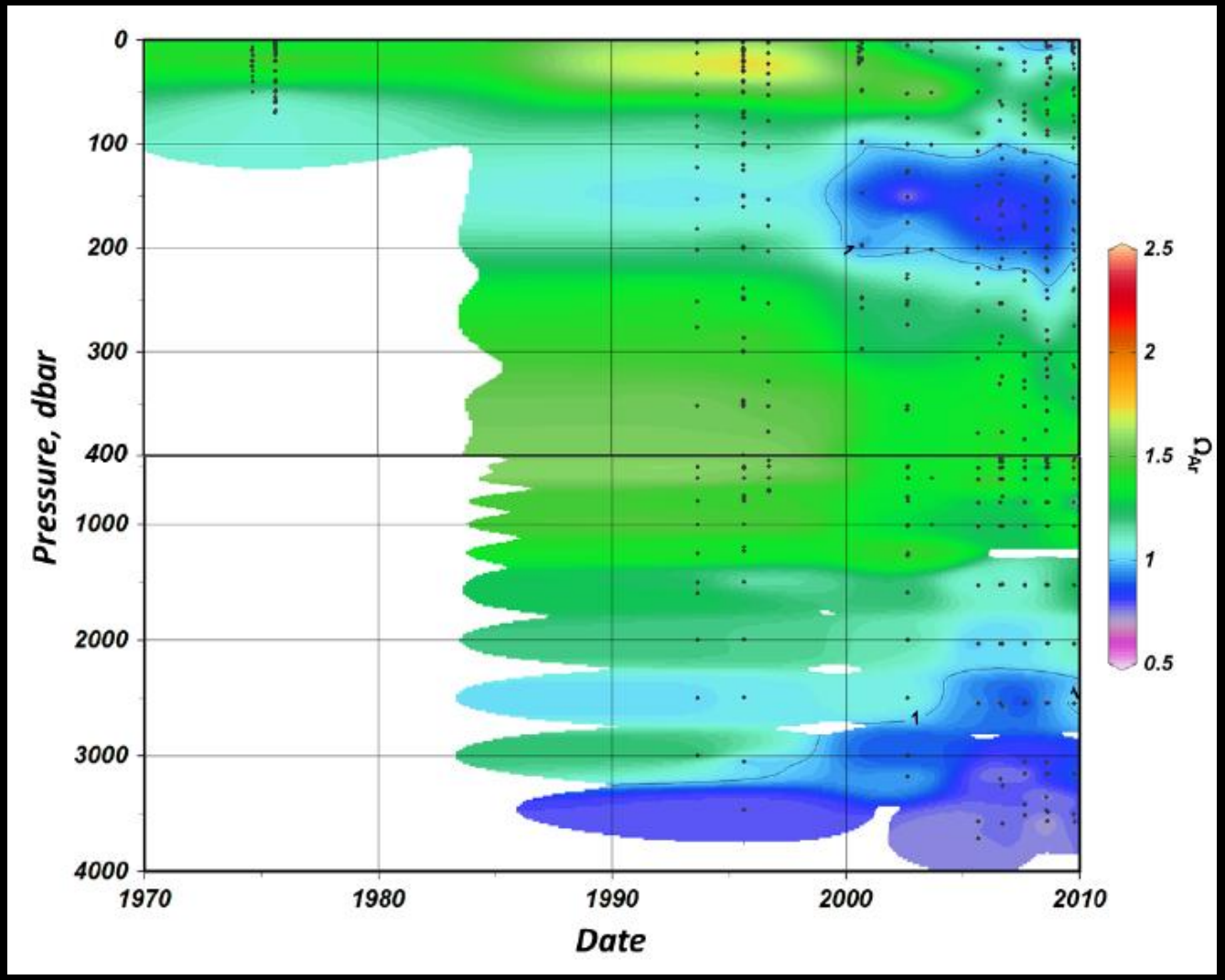


AMAP, 2013

Arctic Ocean Acidification

Historical Trends





Miller et al., in press

Arctic Ocean Acidification

Biological, Economic, and Cultural Implications

- Localized impacts can be very severe
- Large scale impacts may not be particularly significant

Arctic Ocean Acidification

Current Status

- Areas natural low in pH
- Additional anthropogenic decreases

Table 2.3. Observed pH and aragonite saturation states in Arctic seas.

Region	pH	Ω_{Ar}	Source
Nordic seas			
Surface	8.1-8.4	1.5-3.5	Olsen et al., 2009
Bottom	7.9-8.3	0.7-2.2	Olsen et al., 2009
Bering Sea			
Surface	7.9-8.3	0.7-2.[illegible]	Winn and Millero, 1993; Mathis et al., 2011a
Bottom	7.0-7.7	0.1-2.0	Winn and Millero, 1993; Mathis et al., 2011a
Siberian shelves			
Surface[a]	7.5-8.1	0.2-2.[illegible]	Anderson et al., 2011b
Bottom	7.4-7.9	0.2-1.4	Anderson et al., 2011b
Chukchi & Beaufort shelves			
Surface	7.9-8.4	0.8-2.[illegible]	Mucci et al., 2010; Shadwick et al., 2011; Bates et al., 2009
Bottom	7.8-8.1	0.8-2.0	Shadwick et al., 2011; Bates et al., 2009
Canadian Archipelago			
Surface	8.0-8.3	0.8-2.[illegible]	Chierici and Fransson, 2009; Azetsu-Scott et al., 2010
Bottom	7.6-8.1	0.6-1.4	Azetsu-Scott et al., 2010
Central Arctic			
Surface	8.0-8.2	1.3-1.8	Jutterström and Anderson, 2005
Deep[b]	8.1±0.02	0.6-1.0	Jutterström and Anderson, 2005

[a] Includes data from close to river mouths; [b] >2000 m.