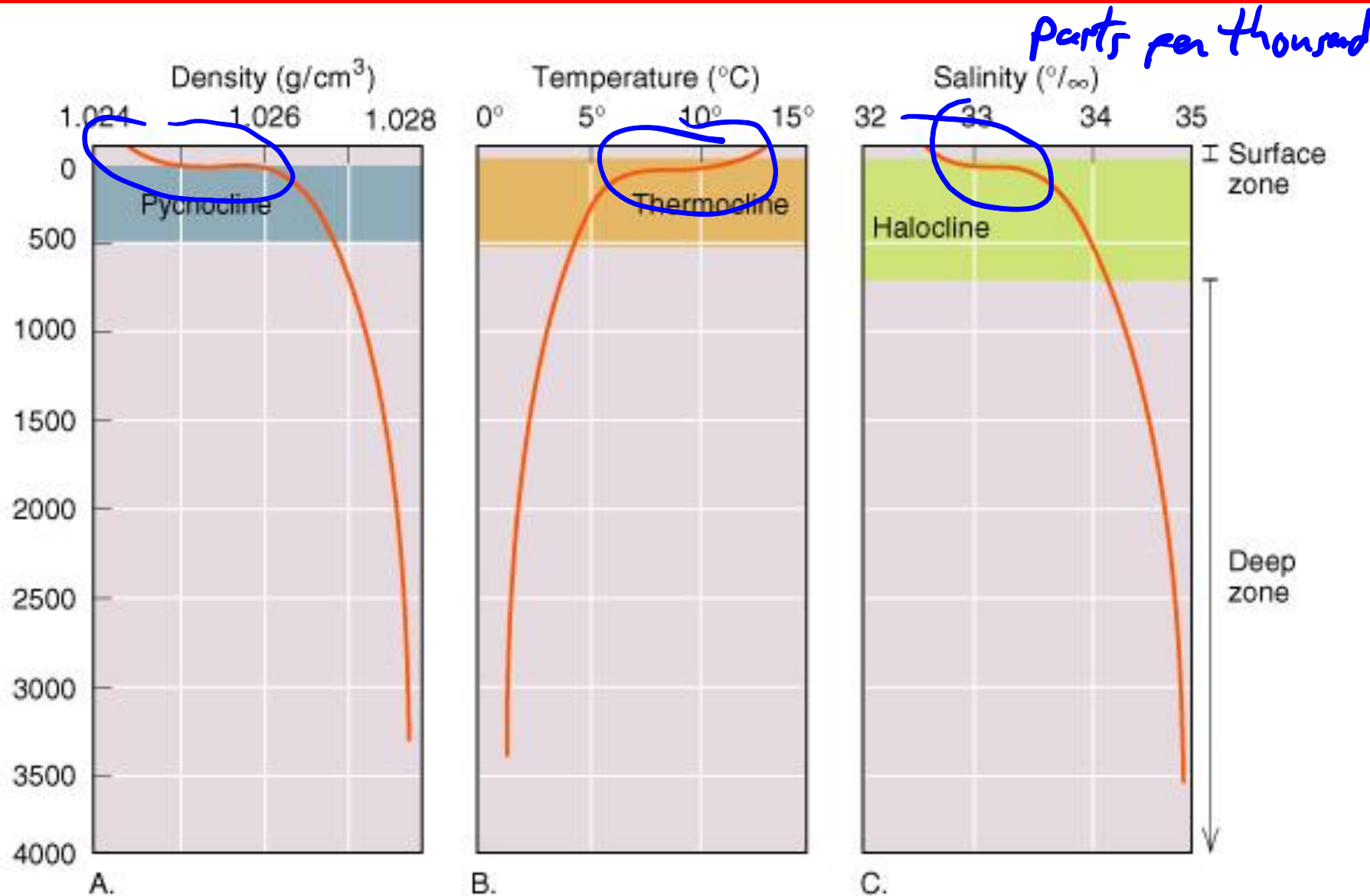


Deep Ocean Circulation

- A SLOW process
 - Lots of water ($1.37 \times 10^9 \text{ km}^3$) and suppressed vertical mixing
 - Timescale to overturn ~ 1000 years
- Driven by formation of cold salty surface water

Ocean Properties versus Depth



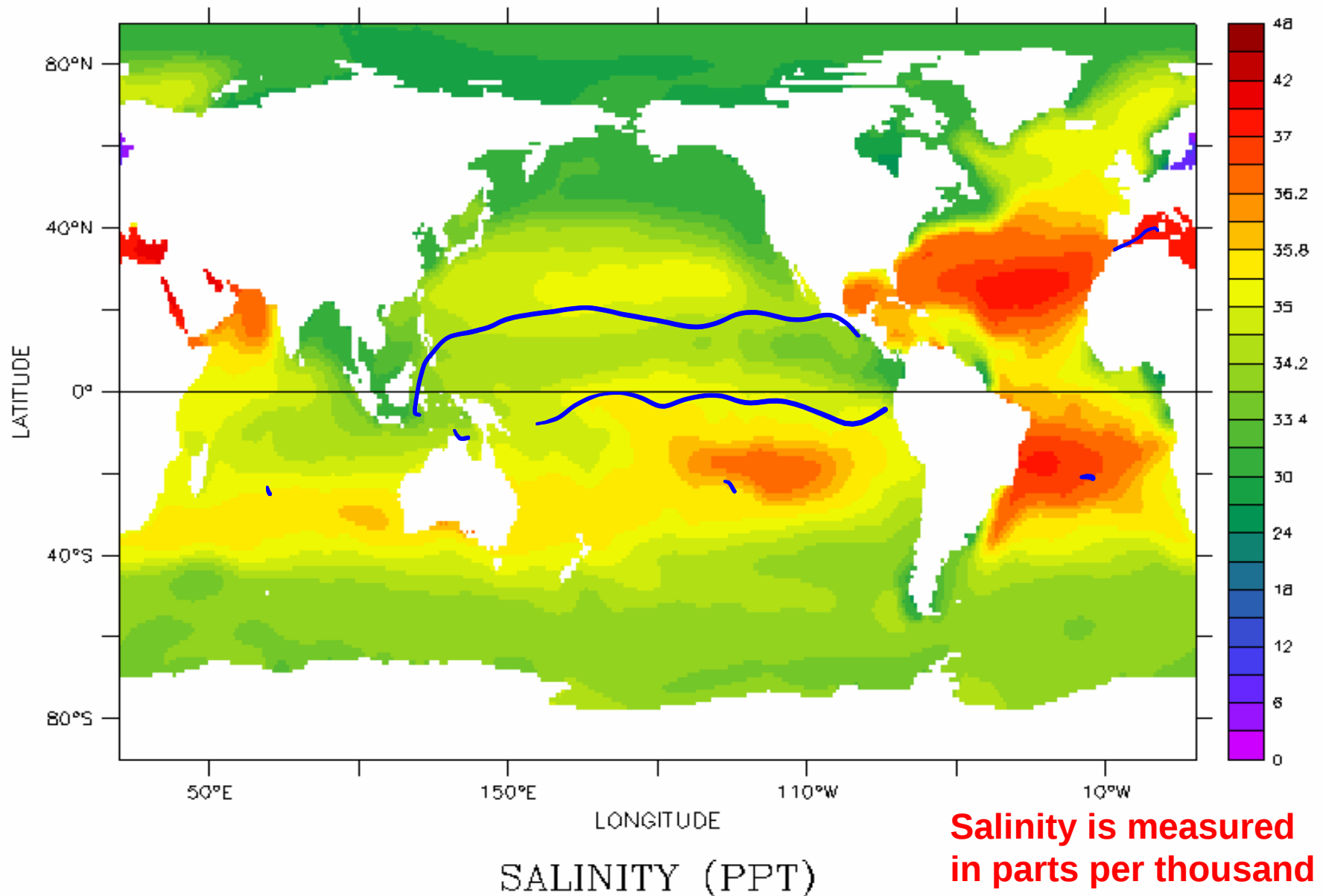
Deep Ocean Mixing Concepts

Vertical motion requires buoyant forces
(i.e. density differences)

warmer, less salty water $\rightarrow$ less dense
colder, saltier water $\rightarrow$ more dense

because vertical mixing is driven density
 $\hookrightarrow$ thermo-haline circulation

Salinity in Mixed Layer (surface layer)



Convection w/heavy saltwater

Ice cube convection

convection and density

Floating Ice and Sinking Ice

Thermo-haline Circulation

(heat-salty)

halide salts
e.g. NaCl

ice rejects
salts

Ocean-to-Atm heat transfer

Cold salty water

upwelling
along equator

Mixed layer ~ 1 km deep

Sea ice

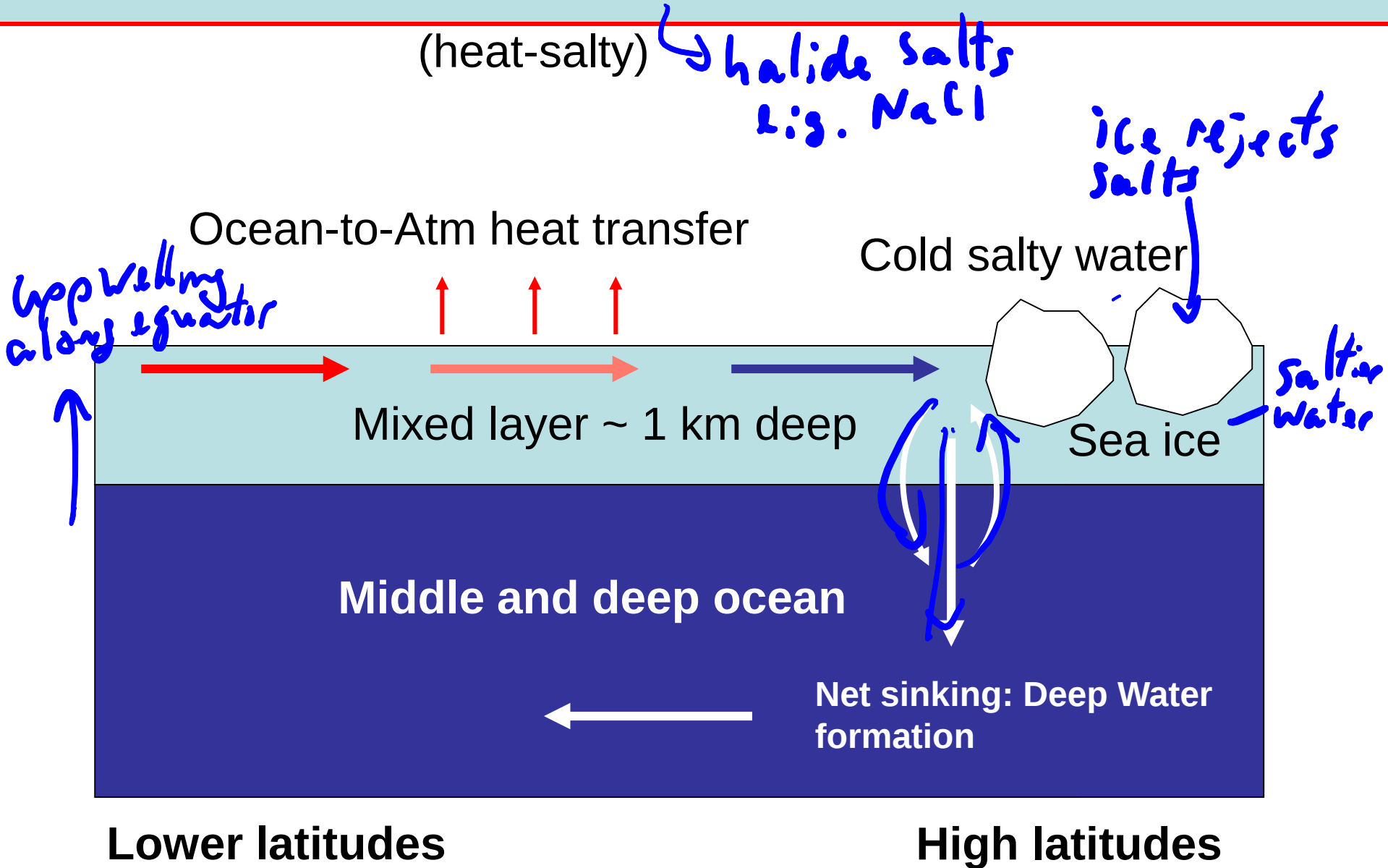
saltier
water

Middle and deep ocean

Net sinking: Deep Water
formation

Lower latitudes

High latitudes



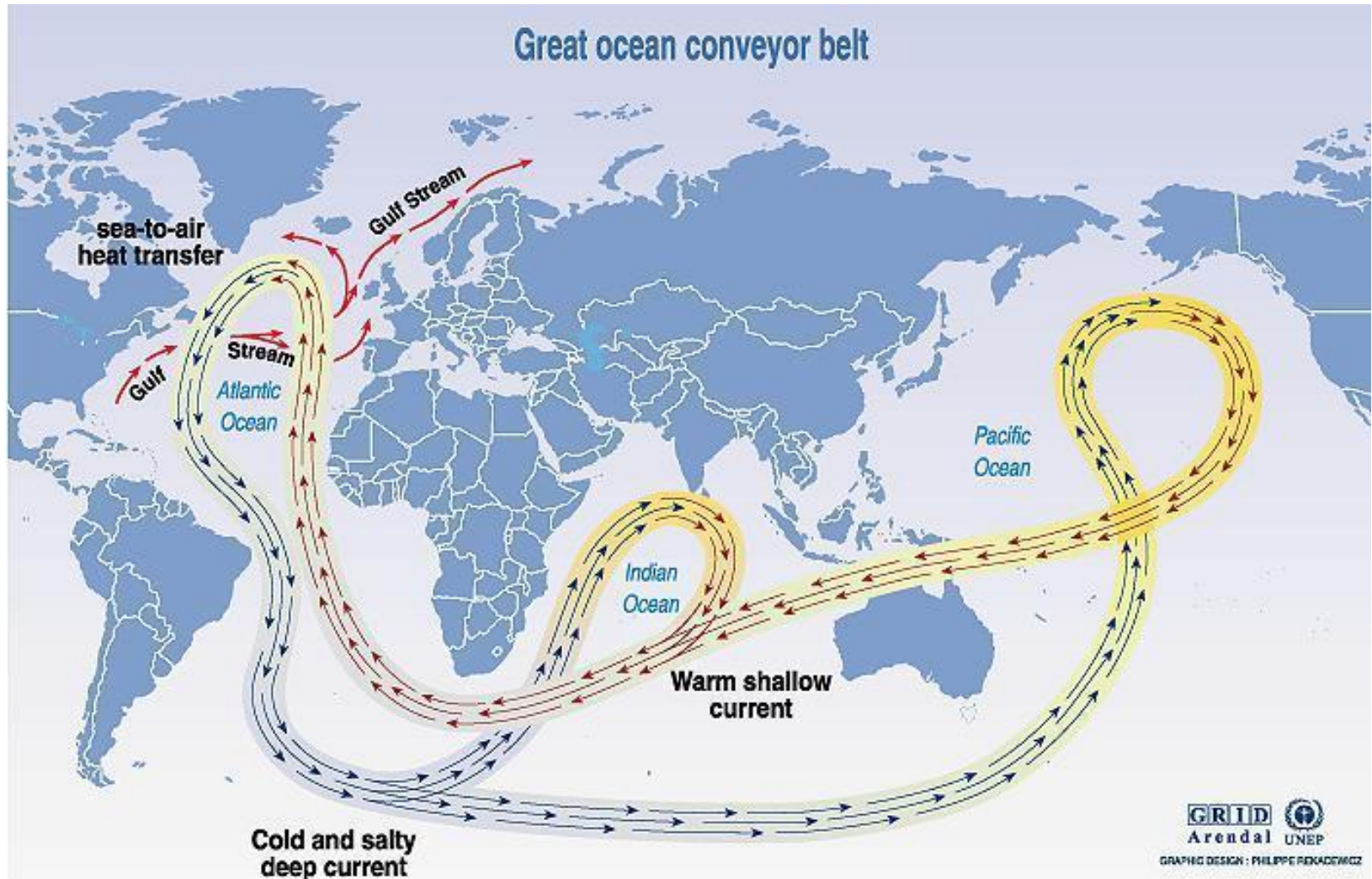
Convection w/heavy saltwater

Ice cube convection

convection and density

Floating Ice and Sinking Ice

Thermo-haline Circulation (THC)



Source: Broecker, 1991, in *Climate change 1995, impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change*, UNEP and WMO, Cambridge press university, 1996.

Sea ice



Iceberg

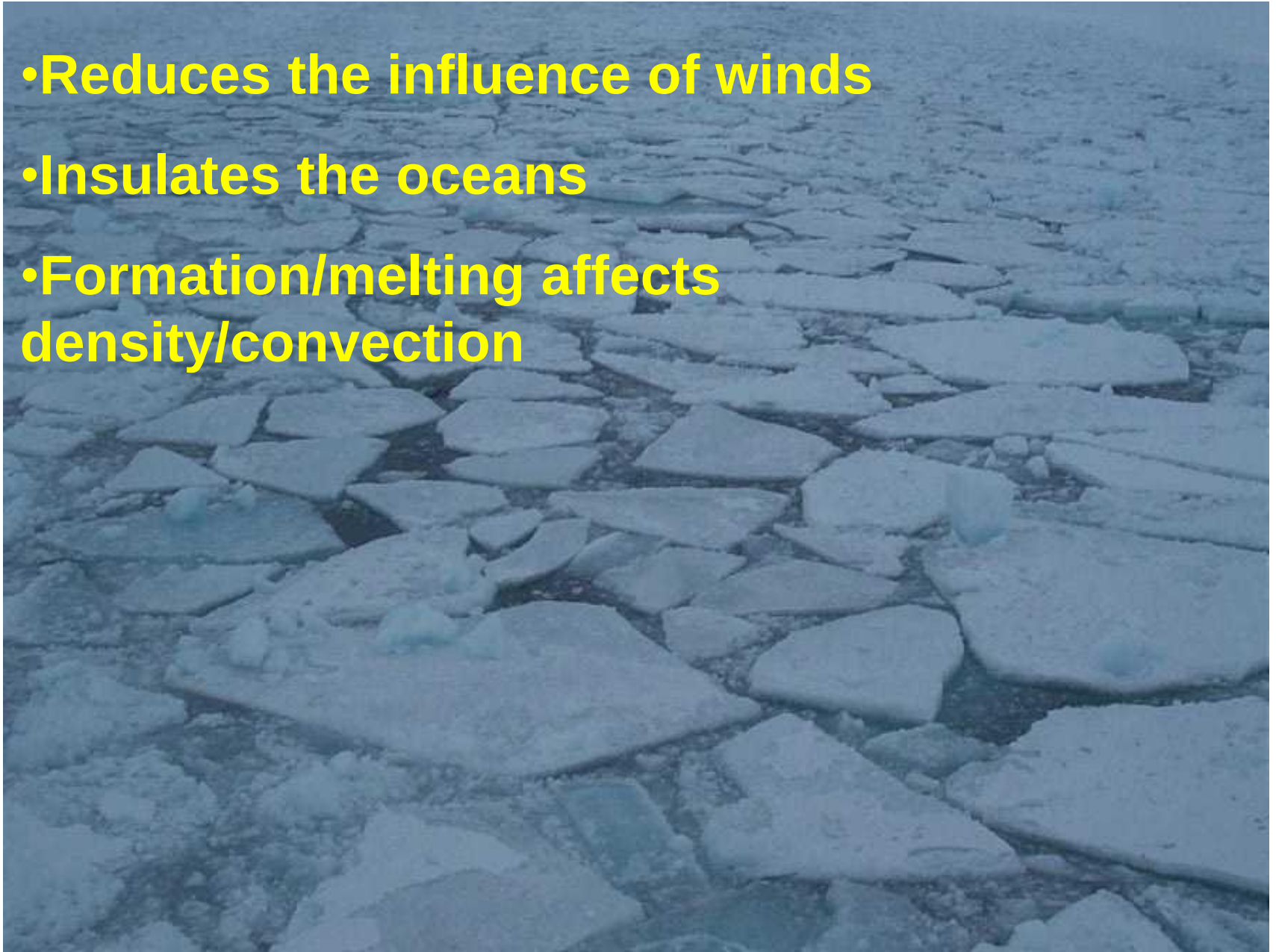
Sea Ice

Sea Ice

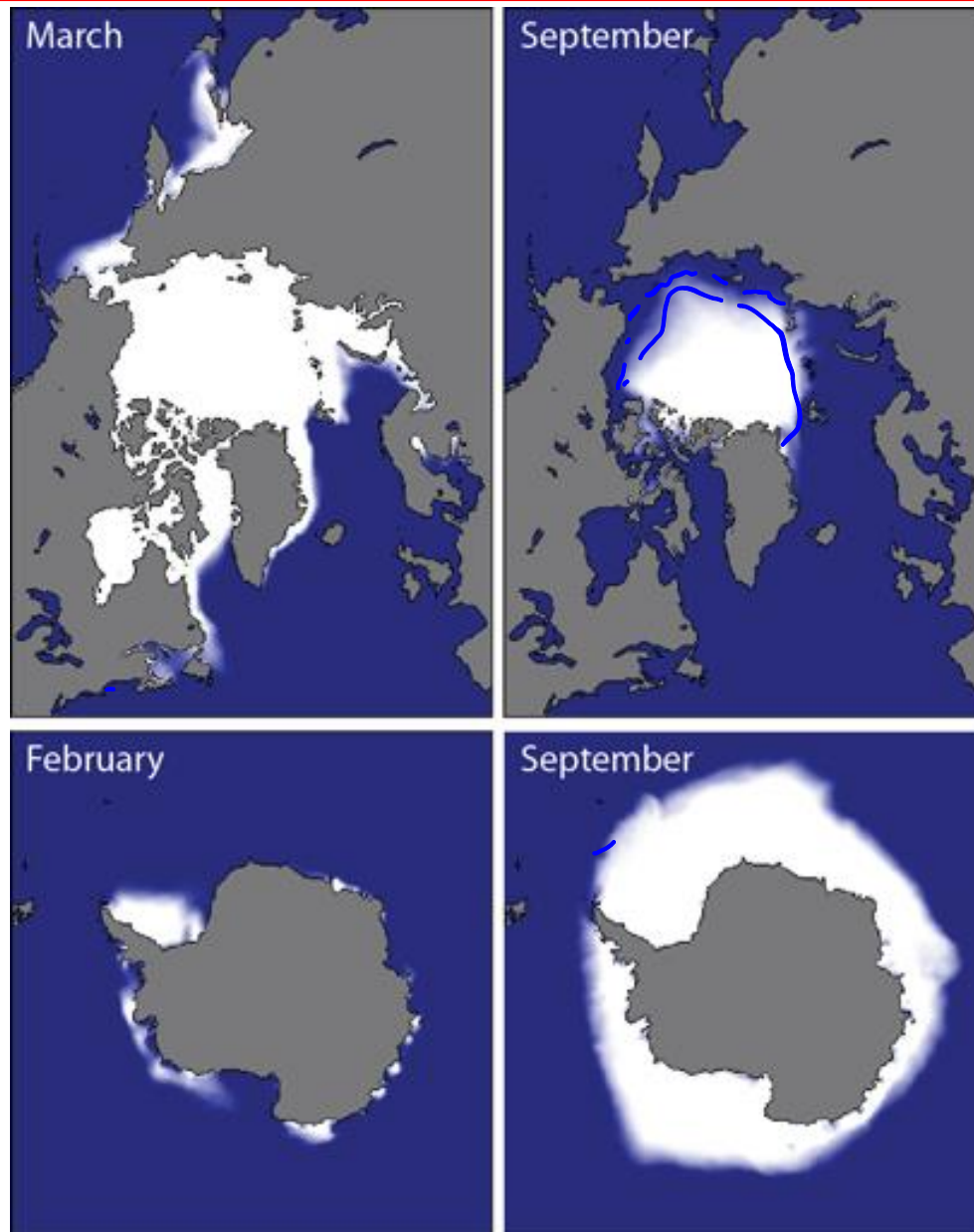
- Forms from freezing ocean water, rejecting salt
 - Not the same as icebergs, which break off land-based ice
- Floats on the ocean surface
- Grows over winter in high latitudes, melts (partially) in summer
- 0.3 to 3 m thick

Sea ice influence on the ocean

- Reduces the influence of winds
- Insulates the oceans
- Formation/melting affects density/convection



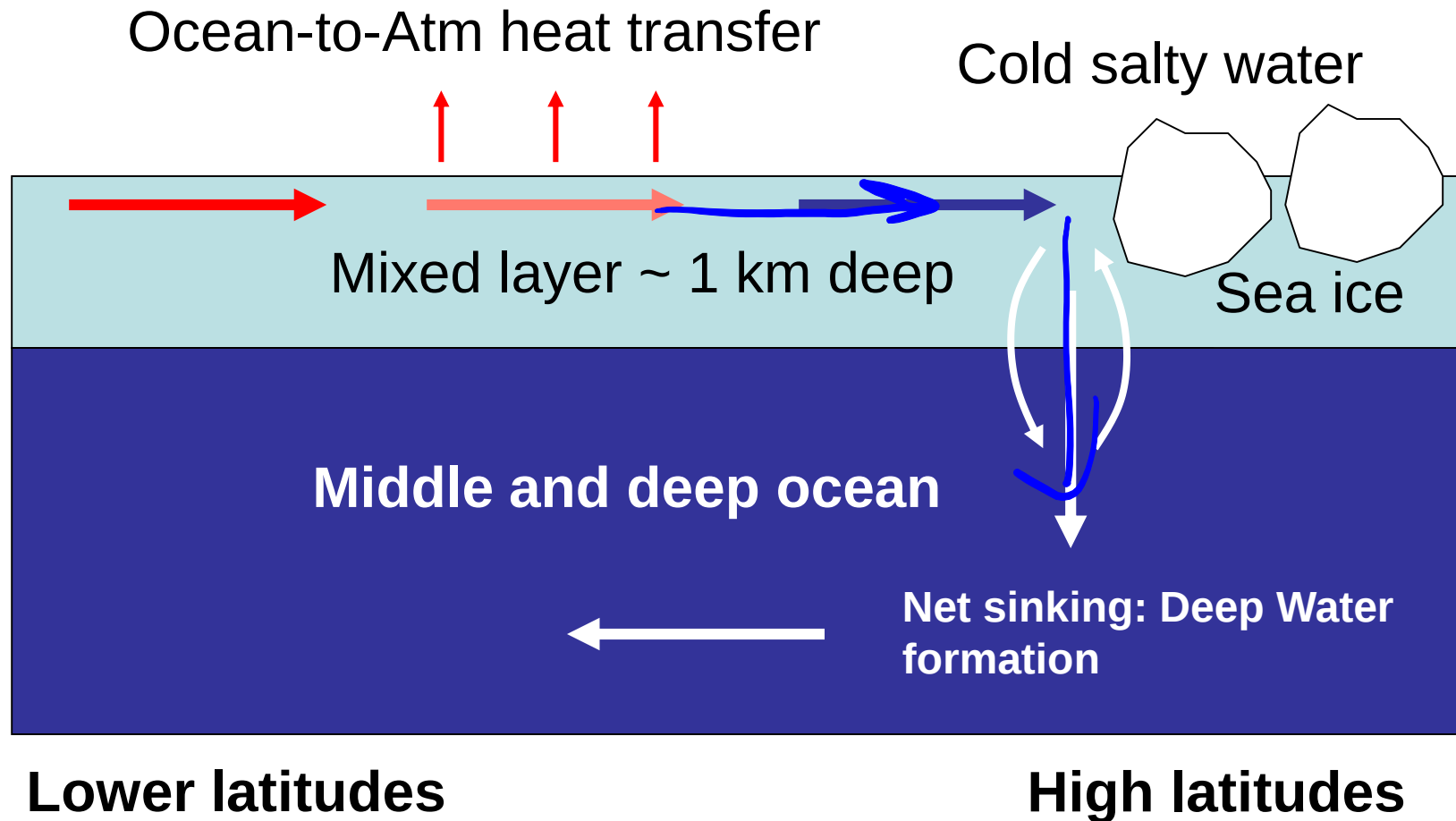
Seasonal Sea Ice Extents



1981 – 2010
Averages

From NSIDC

Thermo-haline Circulation



Poll Question

W Global Warming could cause the thermohaline "overturning" circulation to slow

 When poll is active, respond at **PollEv.com/joelathornto254**
 Text **JOELATHORNTO254** to **22333** once to join



True

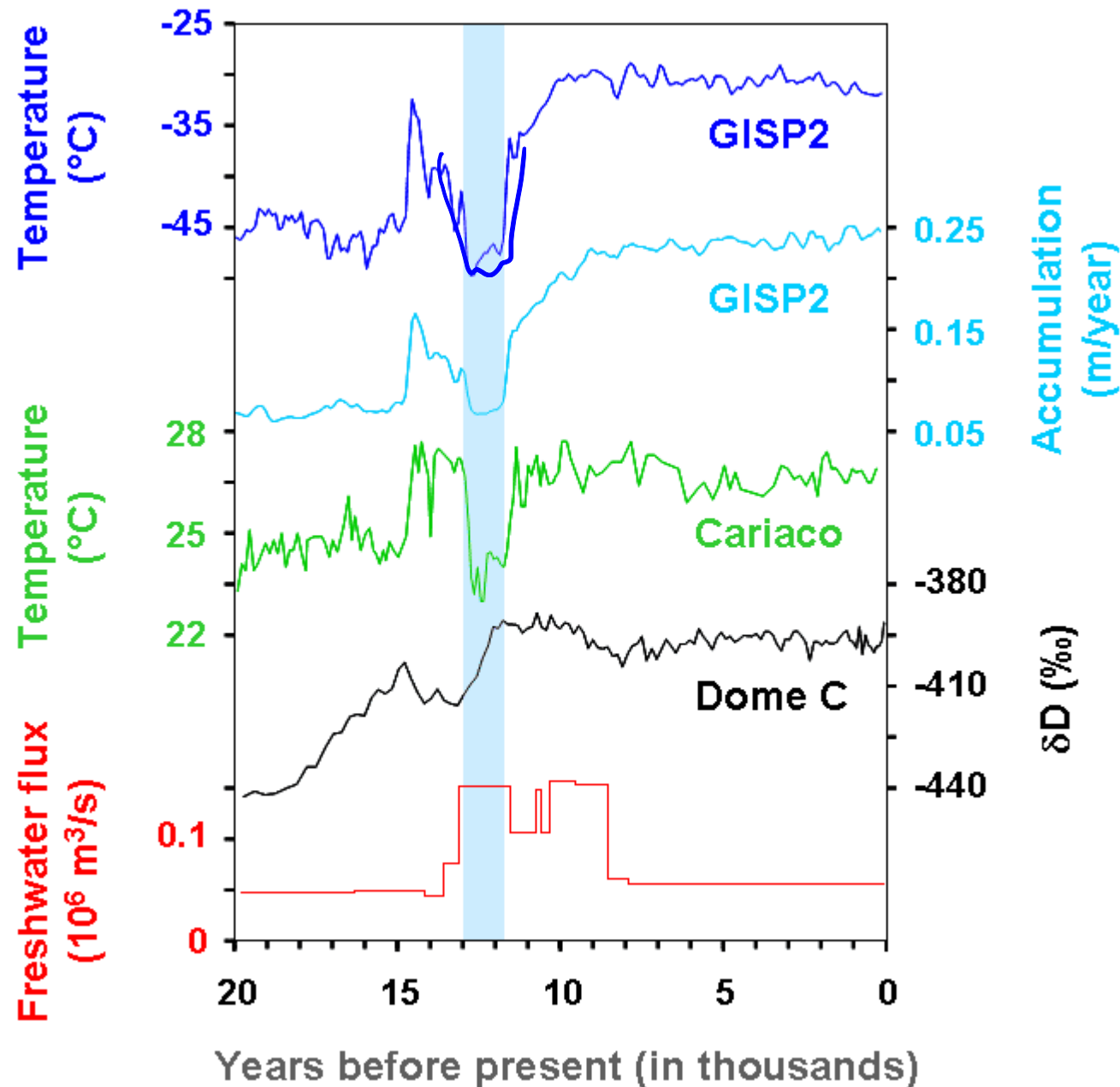
False

Total Results: 0

Thermohaline Circulation Importance

- **Deep ocean is an enormous reservoir for heat and dissolved gases like CO₂**
- **THC exposes atmosphere to this large reservoir which soaks up CO₂ and heat (or releases them!)**
- **Overturning brings nutrients up to biota in surface waters → photosynthetic uptake of CO₂**
- **Maintains heat transport to higher lat's, moderating latitudinal T gradients**

Younger Dryas – Abrupt Climate Change



THC Slowdown and Climate

- Unclear Younger Dryas mechanism → “flood” or prolonged shift in fresh water delivery
- Unclear if “Global Warming” will lead to same response → delivery of freshwater will not be similar as past

Recent data suggest N. Atlantic circulation slowing

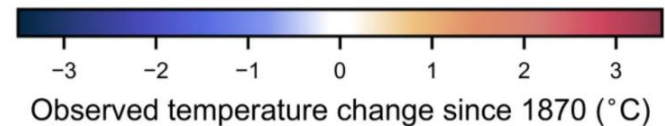
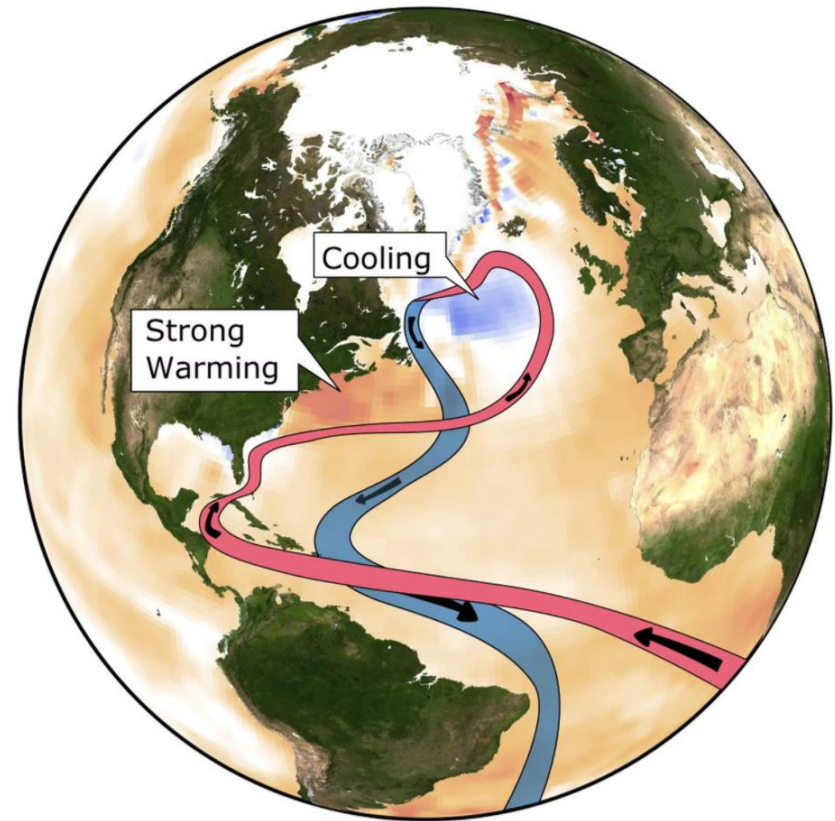
The Washington Post
Democracy Dies in Darkness

April 11, 2018

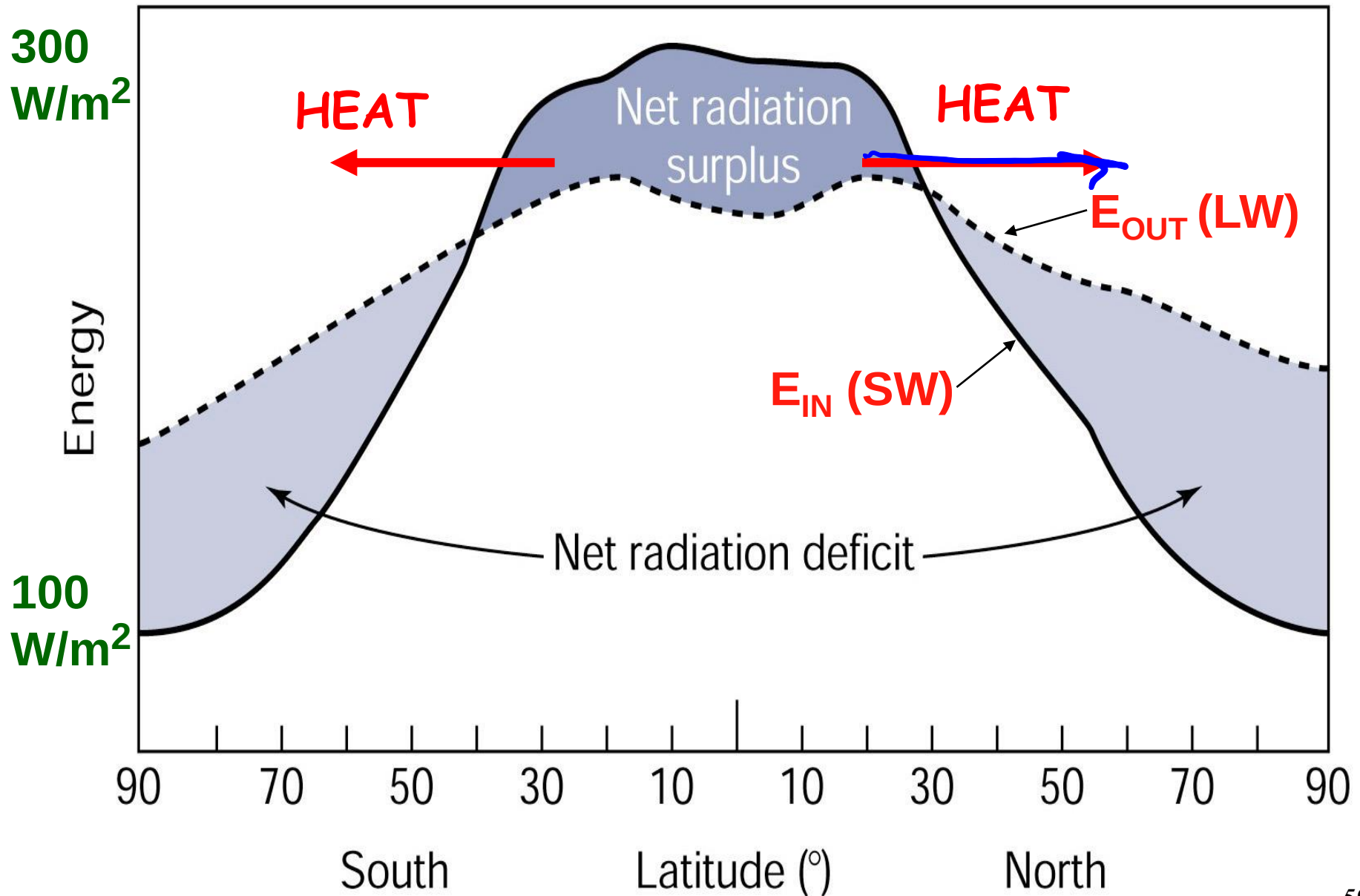
Energy and Environment

The oceans' circulation hasn't been this sluggish in 1,000 years. That's bad news.

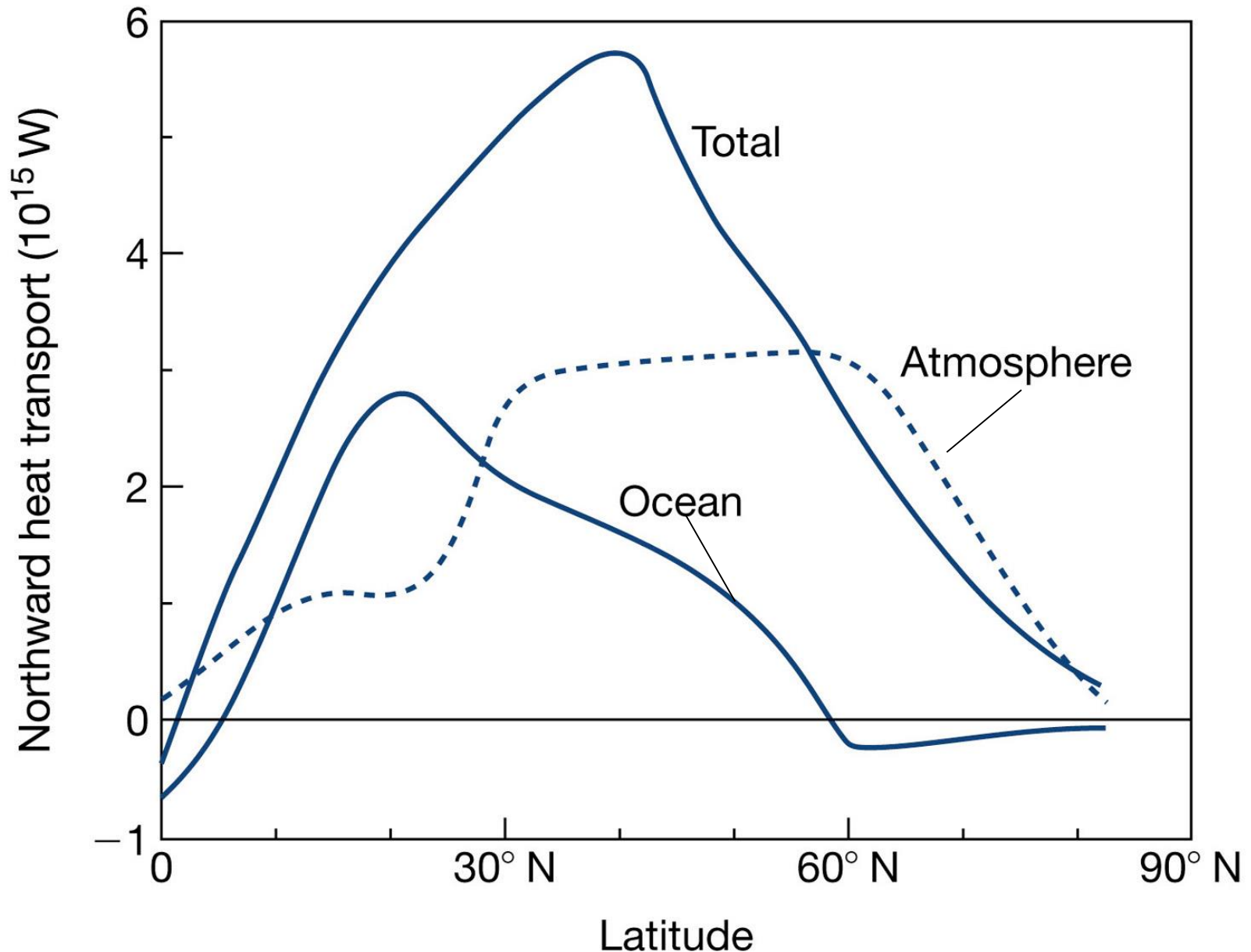
By **Chris Mooney** April 11 [Email the author](#)



Spatial Radiation Imbalance



Heat Transport by Ocean and Atmosphere



Atmosphere/Ocean Circulation Summary

- **Radiation imbalance with latitude causes net heat transport from Eq. to higher latitudes**
- **Atmosphere (e.g. Hadley circ) and oceans (gyres and T.H.C.) nearly equal in moving heat to higher latitudes (moderating climates there)**
- **Couplings between atmosphere and ocean (momentum, heat, material) form important pathways for climate feedbacks!**

Poll Question

W Is the THC slowdown part of a positive or negative feedback?

 When poll is active, respond at **PollEv.com/joelathornto254**

 Text **JOELATHORNTO254** to **22333** once to join

Positive

 Negative

Total Results: 0

