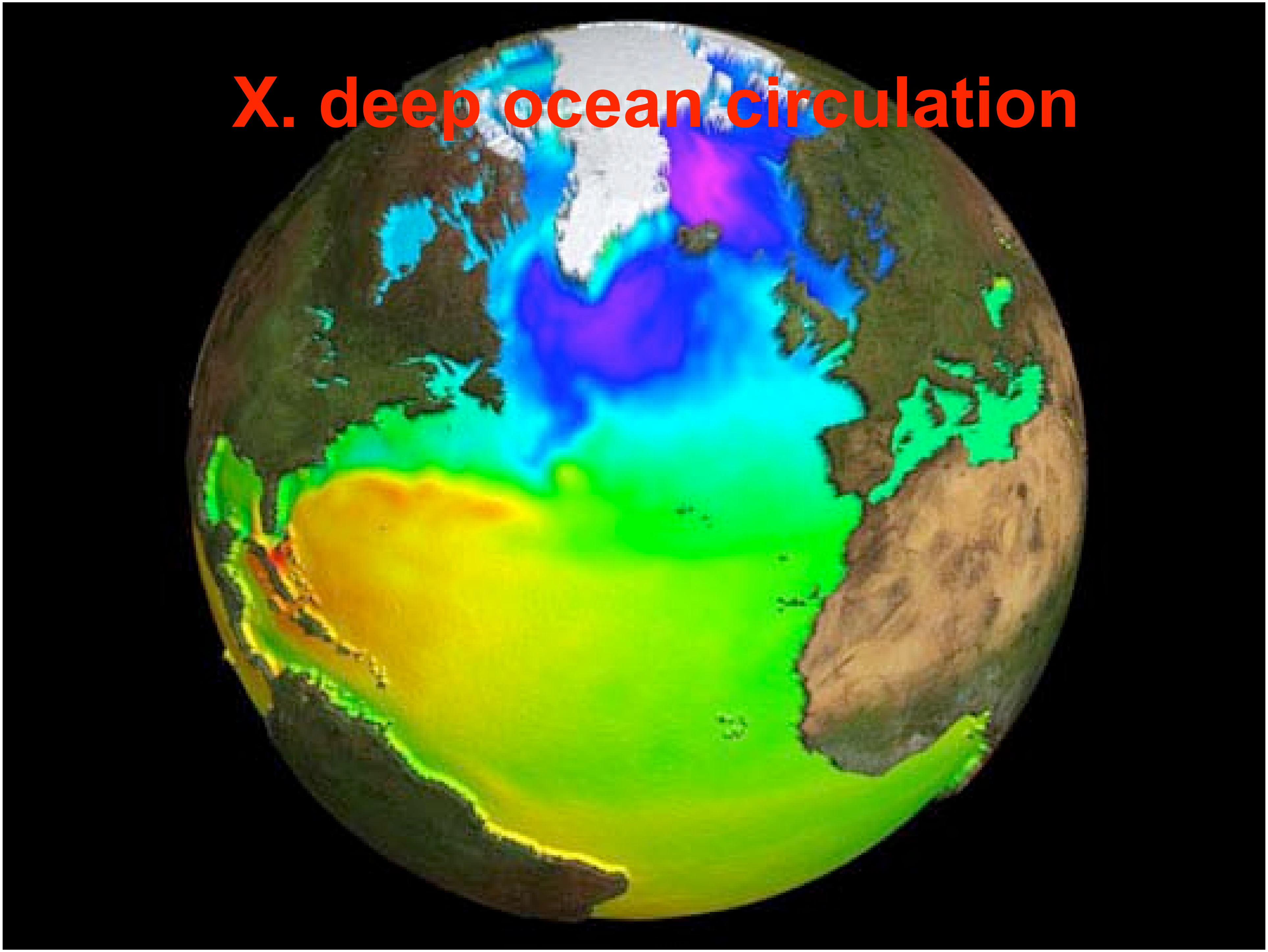
X. deep ocean circulation



clicker question:

Which forces influence Ekman transport?

a) wind stress

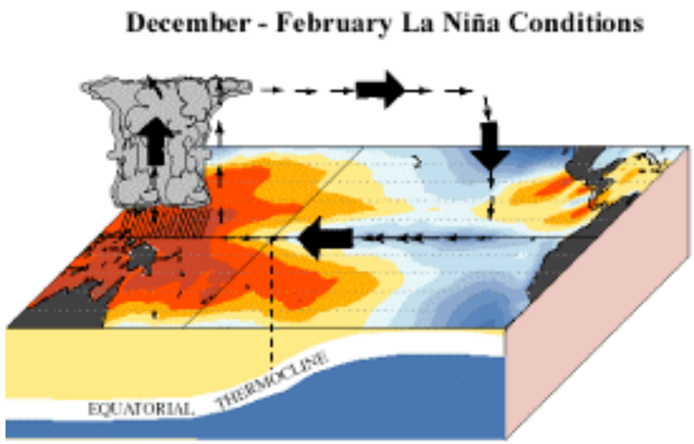
b) Coriolis effect

c) friction

d) all of the above

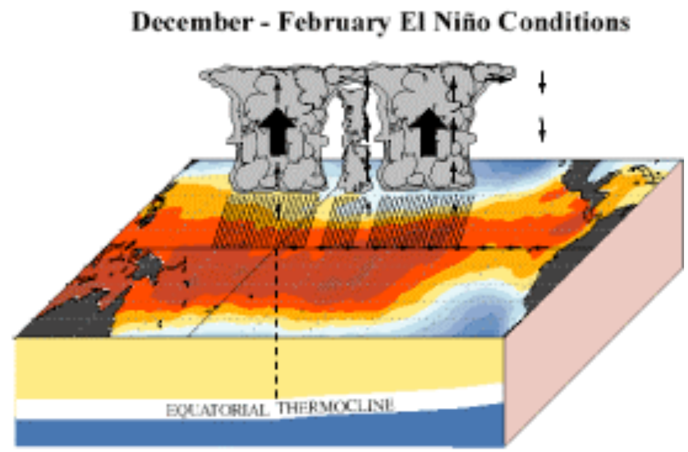
e) none of the above

La Niña



Strong easterlies
Strong eastern upwelling (cold SSTs)
Heavy rainfall in western warm pool

El Niño



Weak easterlies
Weak eastern upwelling (warm SSTs)
Eastward shift in rainfall

El Nino is marked by a) failed upwelling, b) warming of the E. Pacific, c) eastward migration of rainfall, d) changes in the Walker Circulation, e) <u>all of the above</u>

deep circulation

- deep water properties largely determined by conditions at the surface
- when the density of waters at surface exceeds that of the ocean interior deep sinking (deep water formation) can occur
- high surface densities occur in areas of *large heat loss* to atmosphere (low temperature) and adequate salinity
- this tells us that deep circulation may influence climate and *vise versa*!

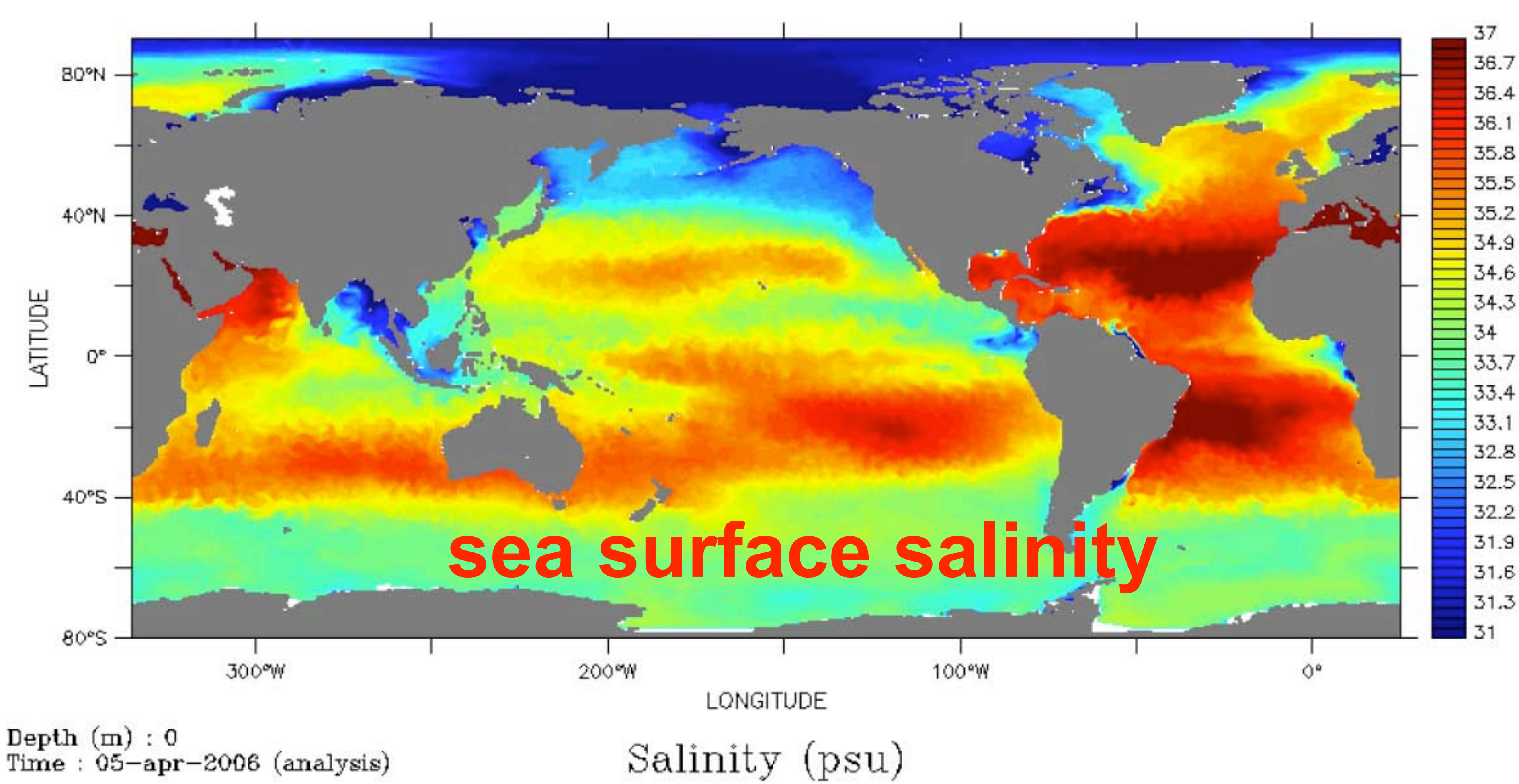
seawater density

- salinity increases water's density from ~1.0 g/cm^3 to ~1.02-1.03 g/cm^3 (2-3%)

- seawater density increases as it gets colder (even below 4°C)

- pressure can increase density slightly, by up to ~2% at 10 km

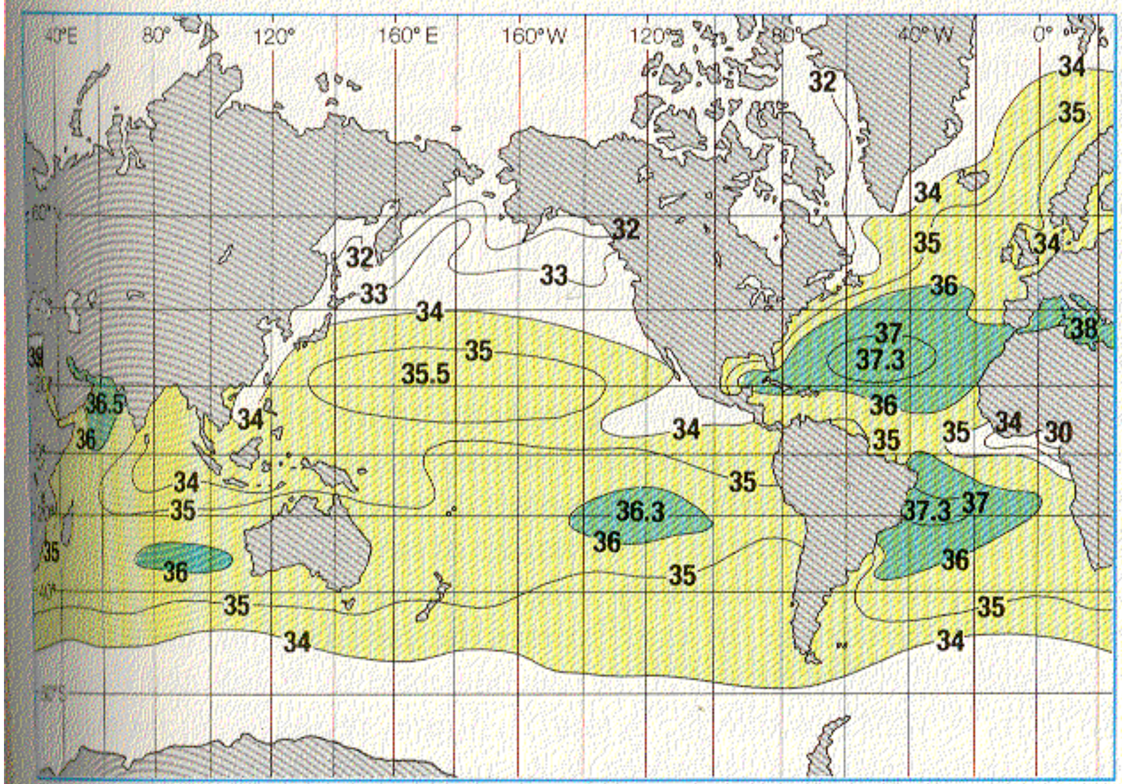
clicker question

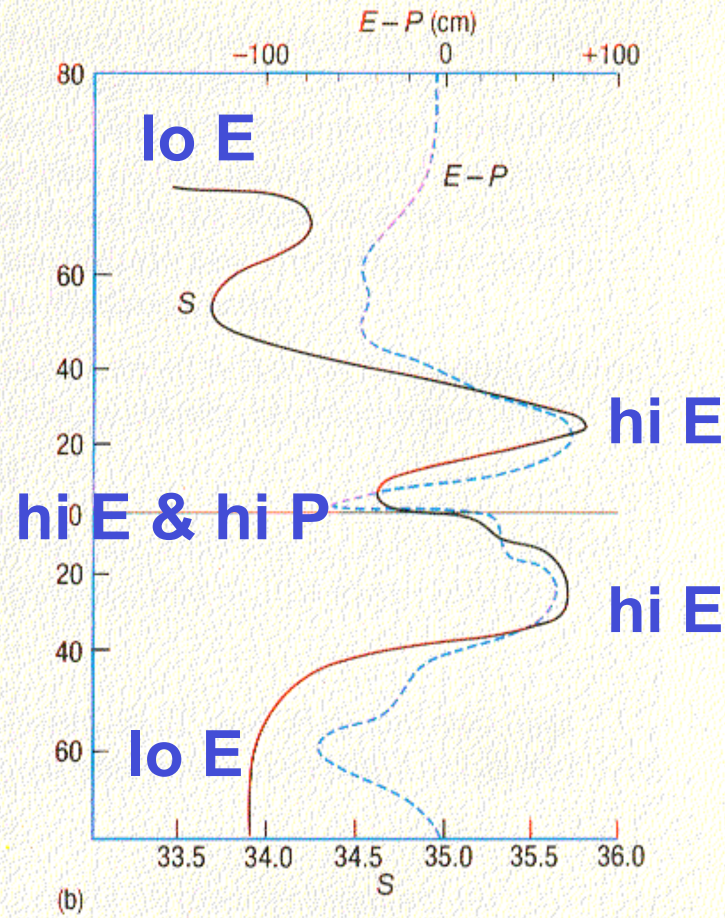


areas of high salinity are likely to be associated with a) areas of descending dry air, b) areas where dry air comes off the continents, c) areas of ocean warmth, d) areas of excess evaporation, e) <u>all of the above</u>

SSS depends mainly on balance of evaporation and precipitation

sea surface salinity **evap-precip**





SSS

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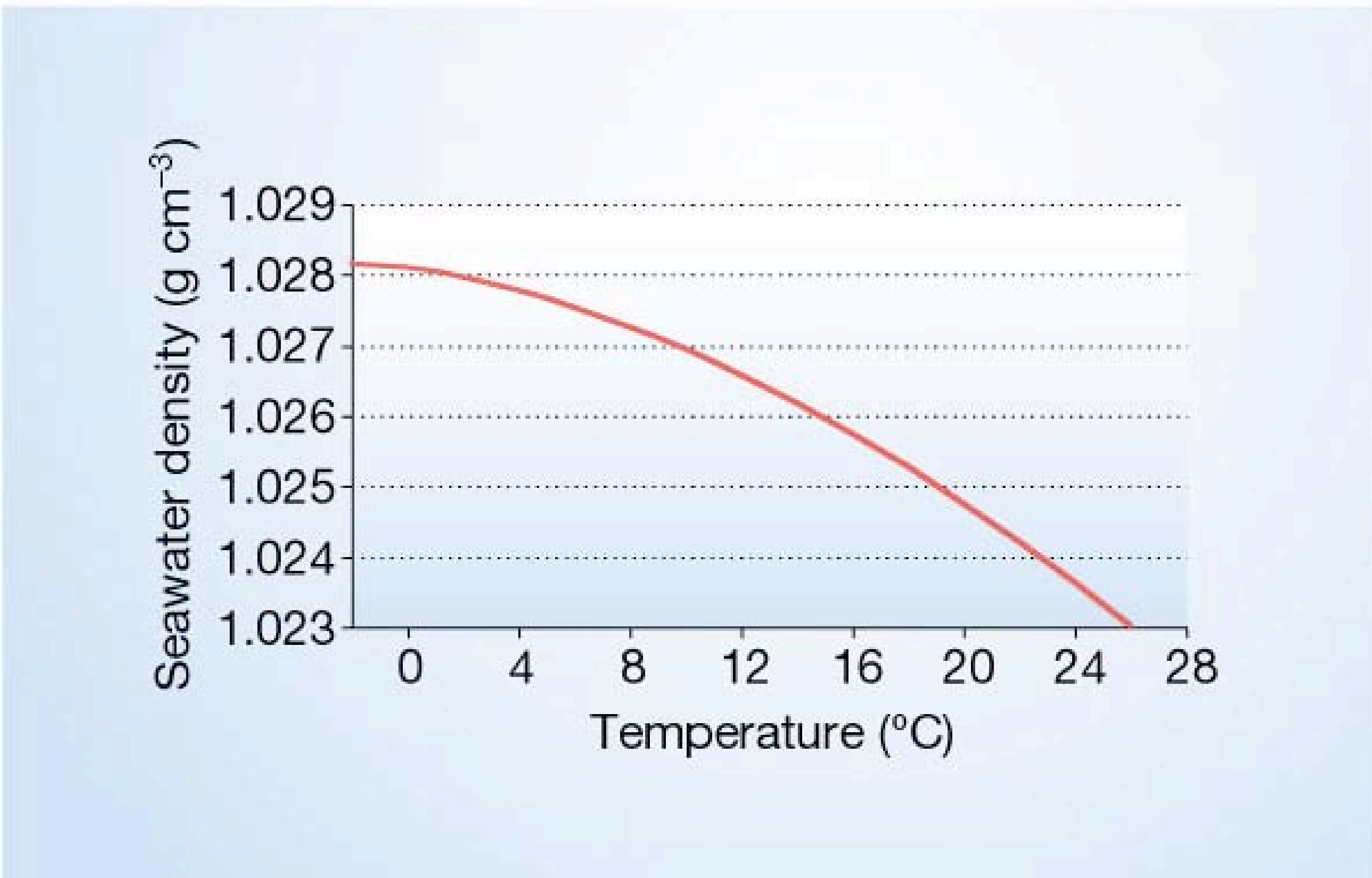
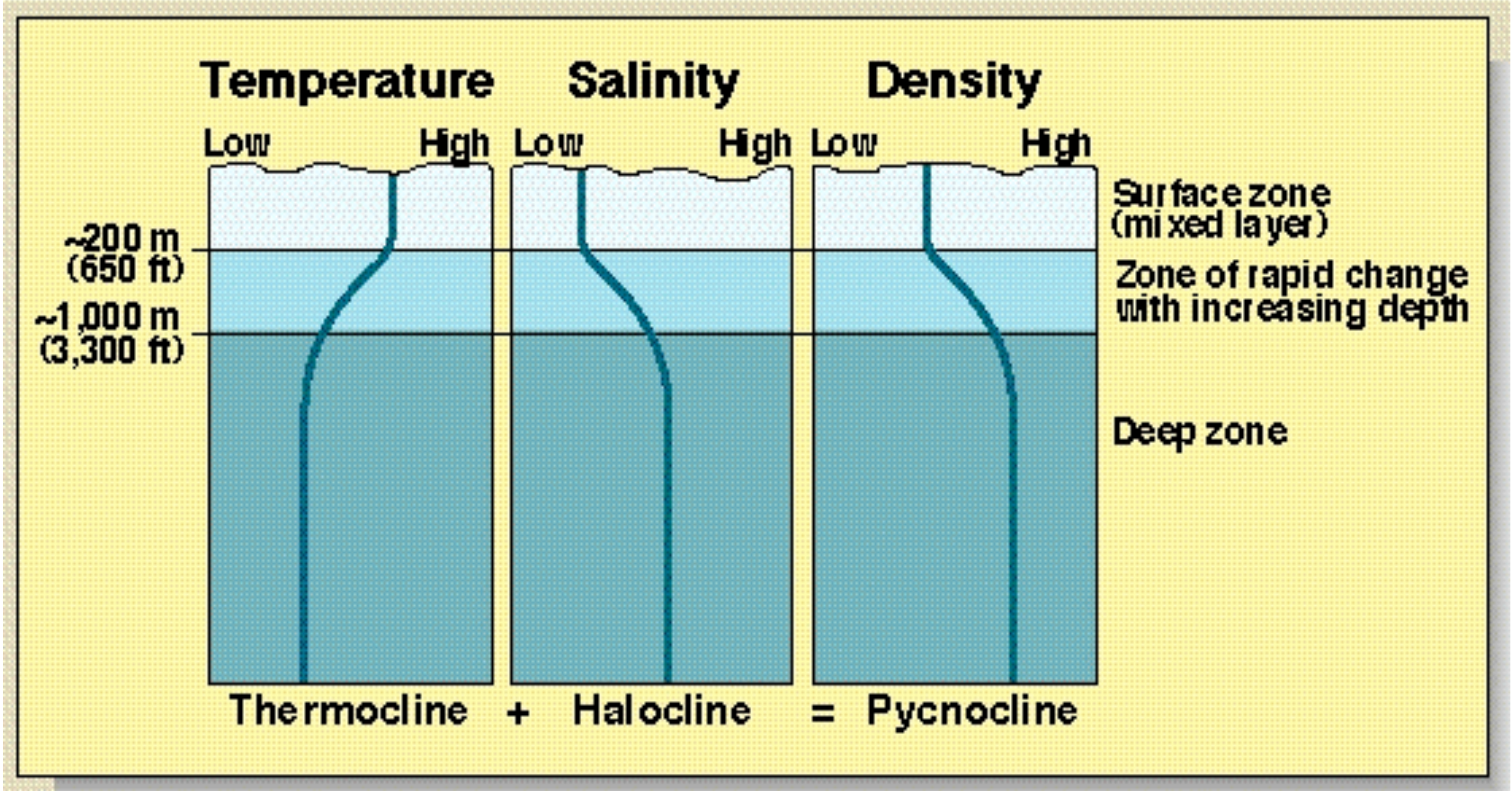
sea water density v. T



idealized ocean profiles

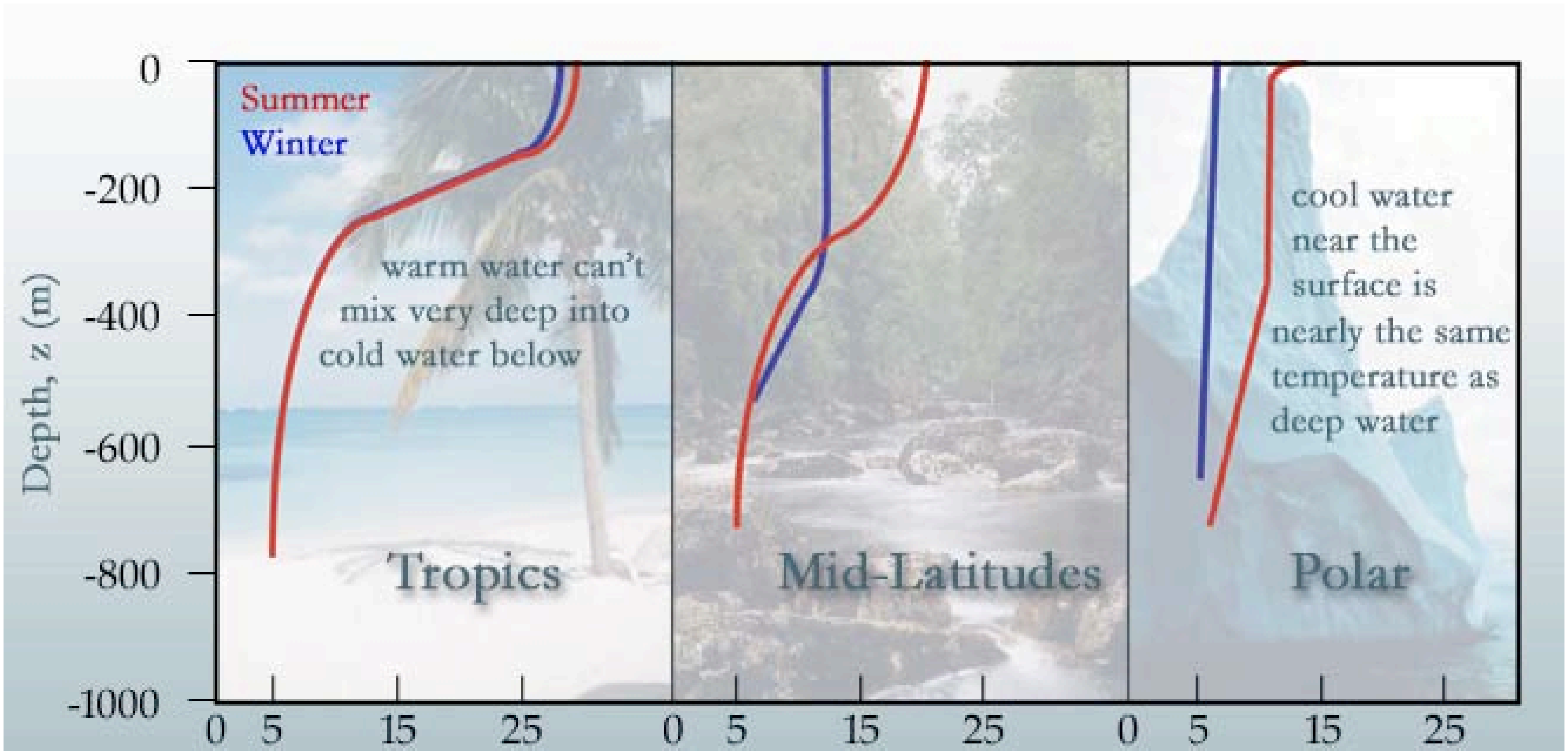


varies significantly by latitude

formation of deep water

- ocean generally heated from top, stable
- except polar regions where there is cooling at the top

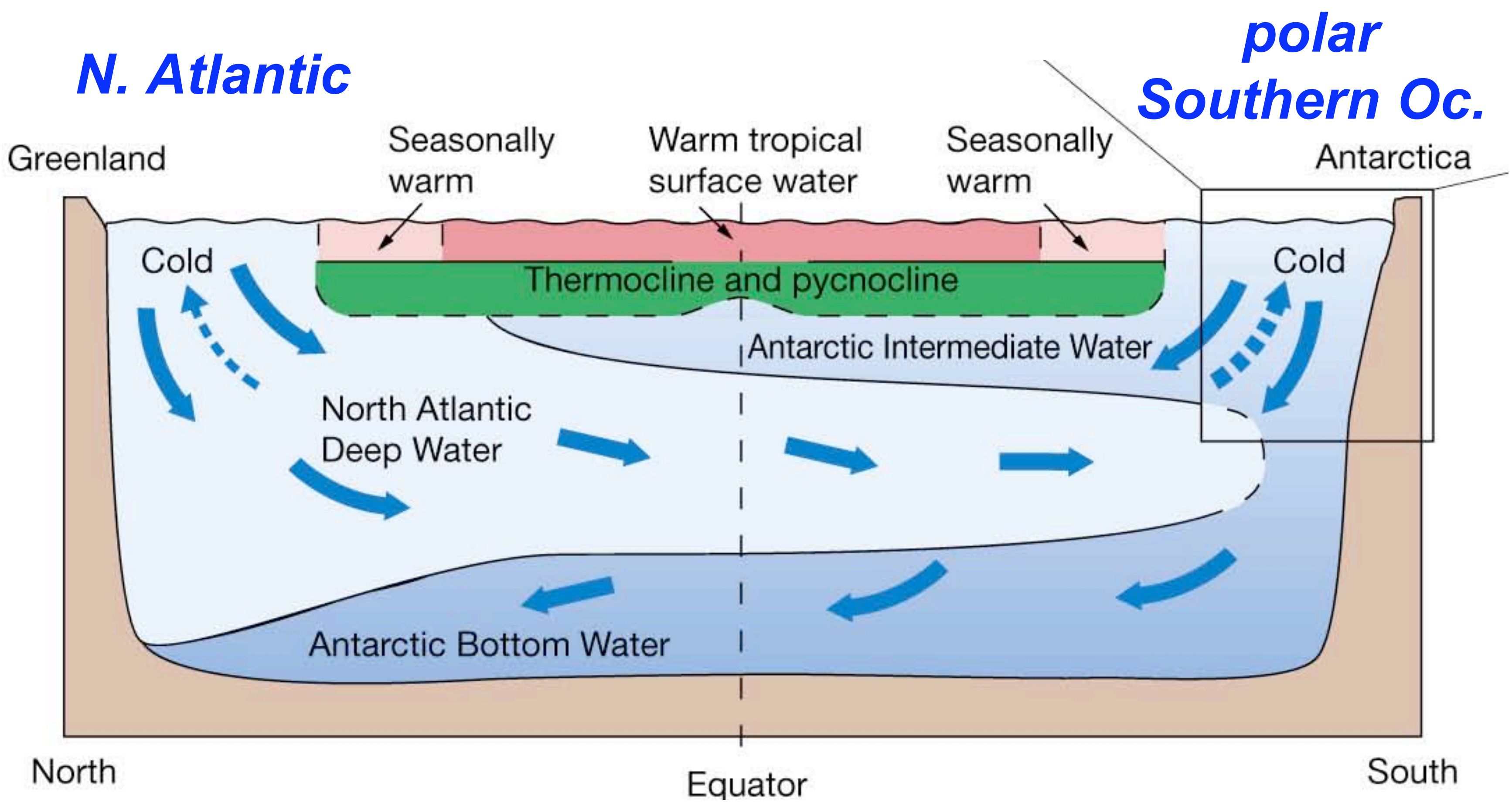
ocean temperature profiles



temperature (°C)

winter time cooling in polar latitudes can be sufficient to drive sinking due to increased density

polar sources of deep water

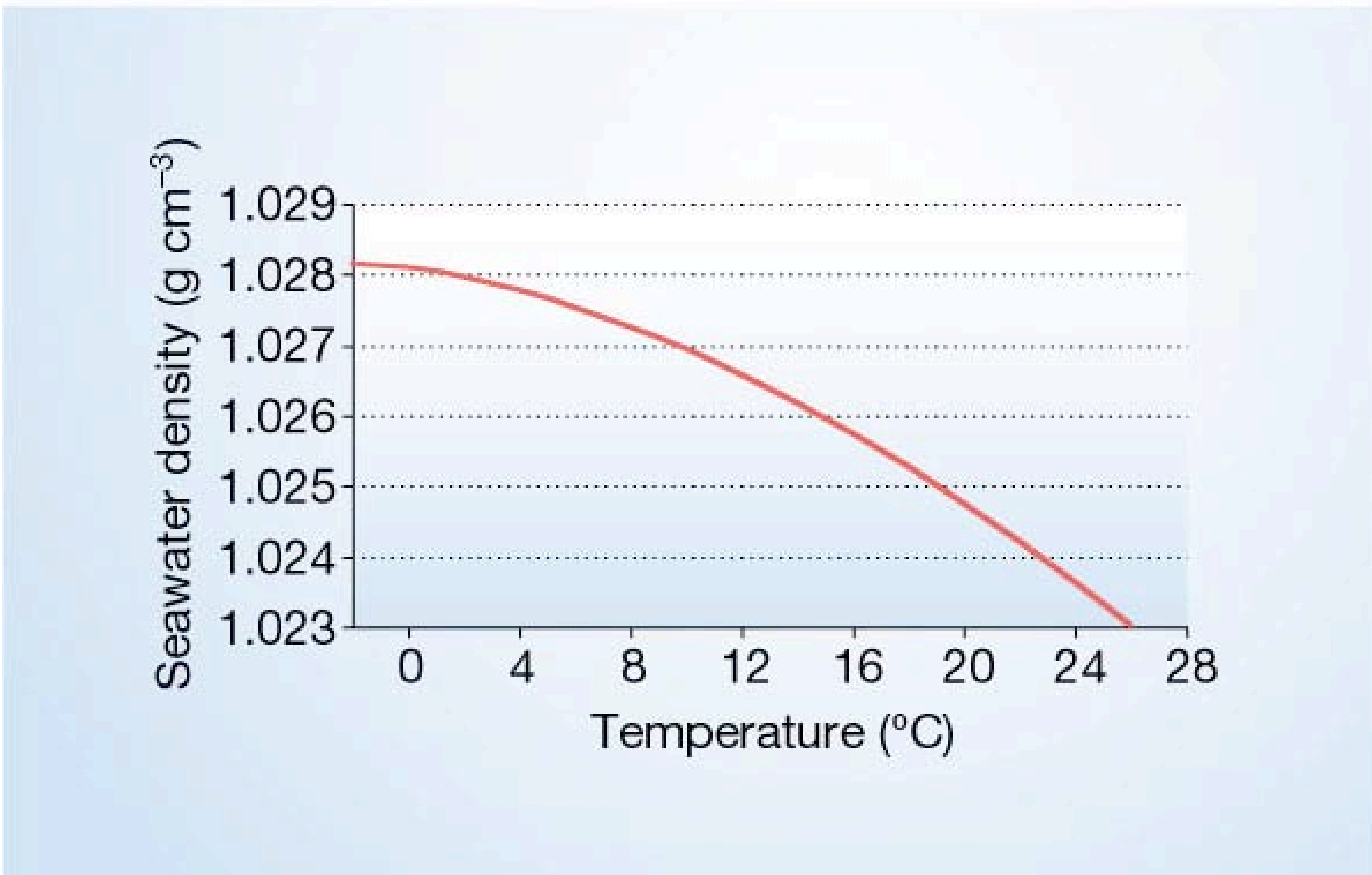


waters cooled at high latitudes fill the ocean interior with cold, dense water

formation of deep water

- ocean generally heated from top, stable
- except polar regions where there is cooling at the top
- but density is not v. sensitive to cooling a low temperatures
- low temperature required but not sufficient
- *need salt!*

sea water density



-2 °C water not much denser than 4 °C water !

sea surface temperature

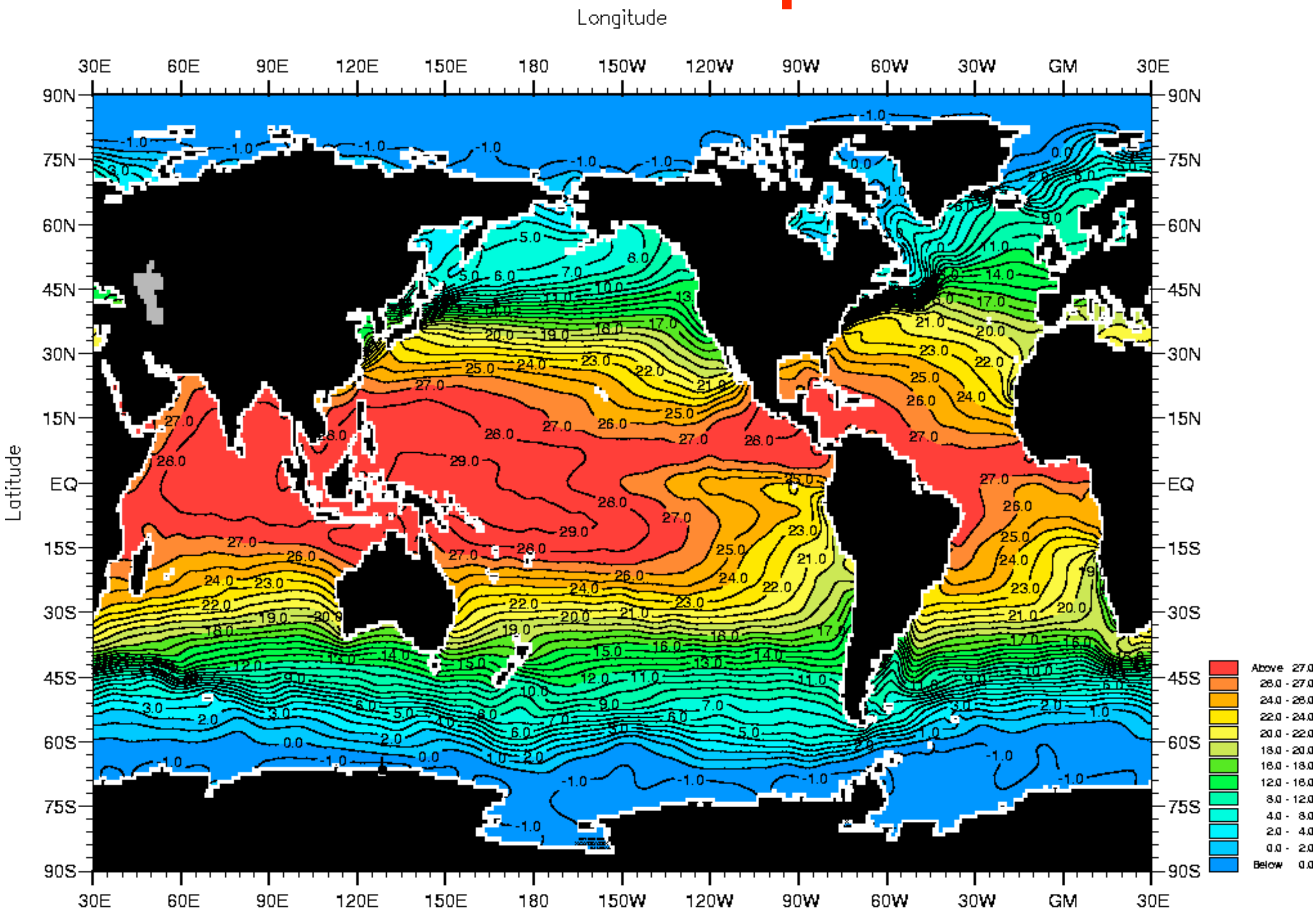


Fig. A2-1. Annual mean temperature (℃) at the surface .

Minimum Value= -1.93 Maximum Value= 29.90 Contour Interval: 1.00

sea surface salinity

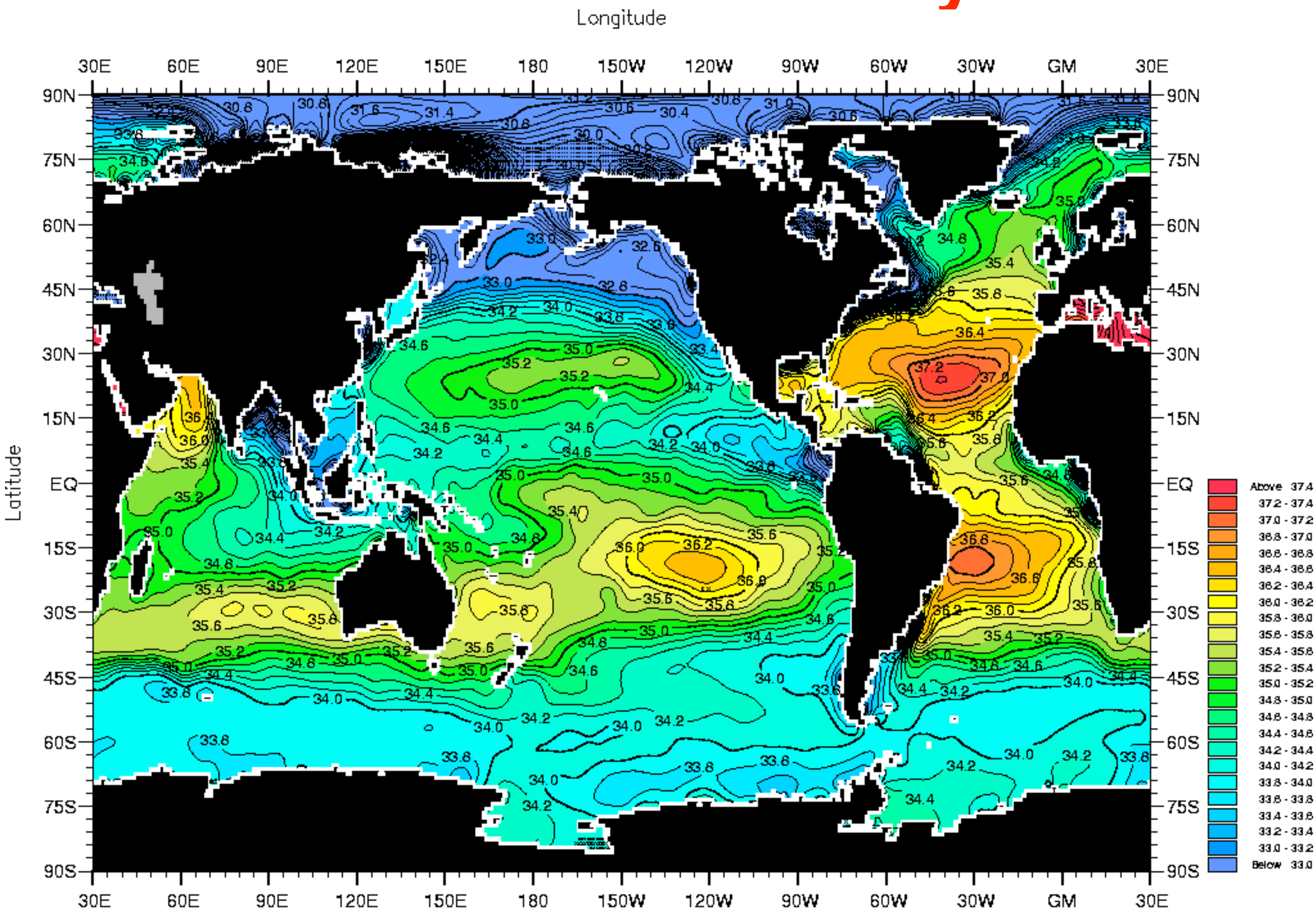
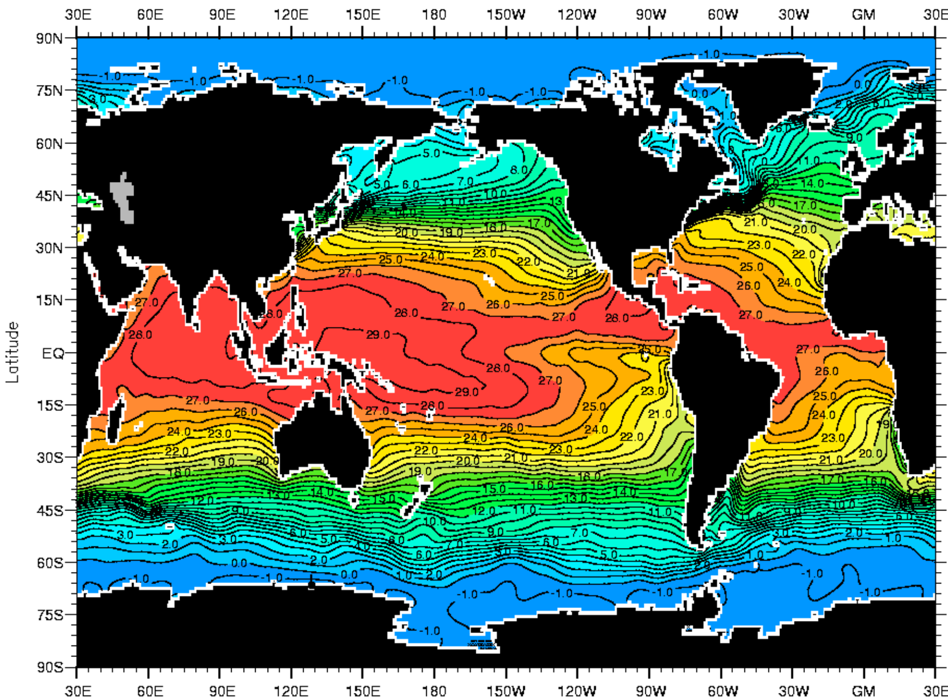


Fig. A2-1. Annual mean salinity (PSS) at the surface .

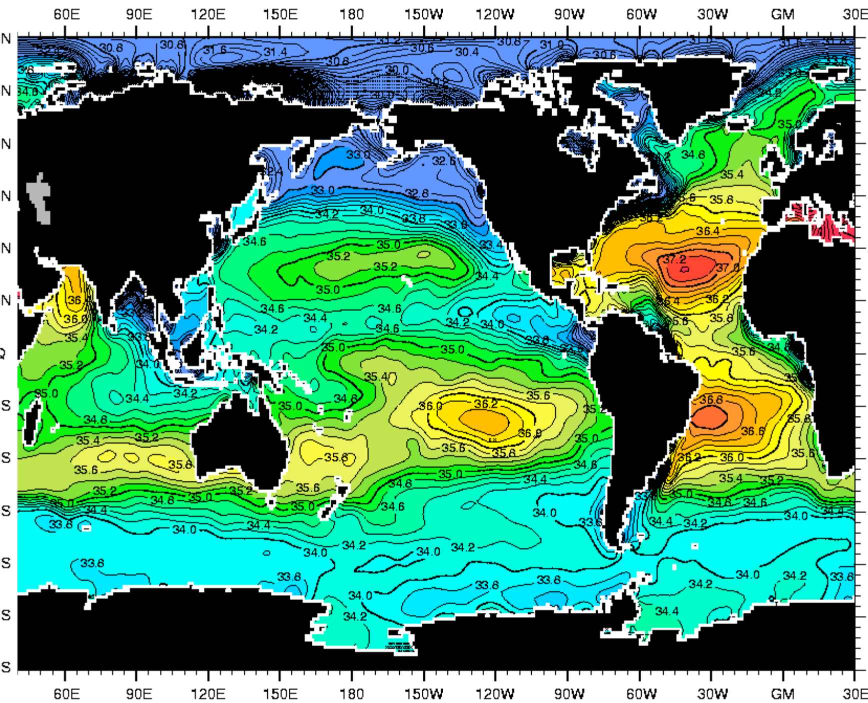
Minimum Value= 3.57 Maximum Value= 40.02 Contour Interval: 0.20

clicker question:

temperature



salinity



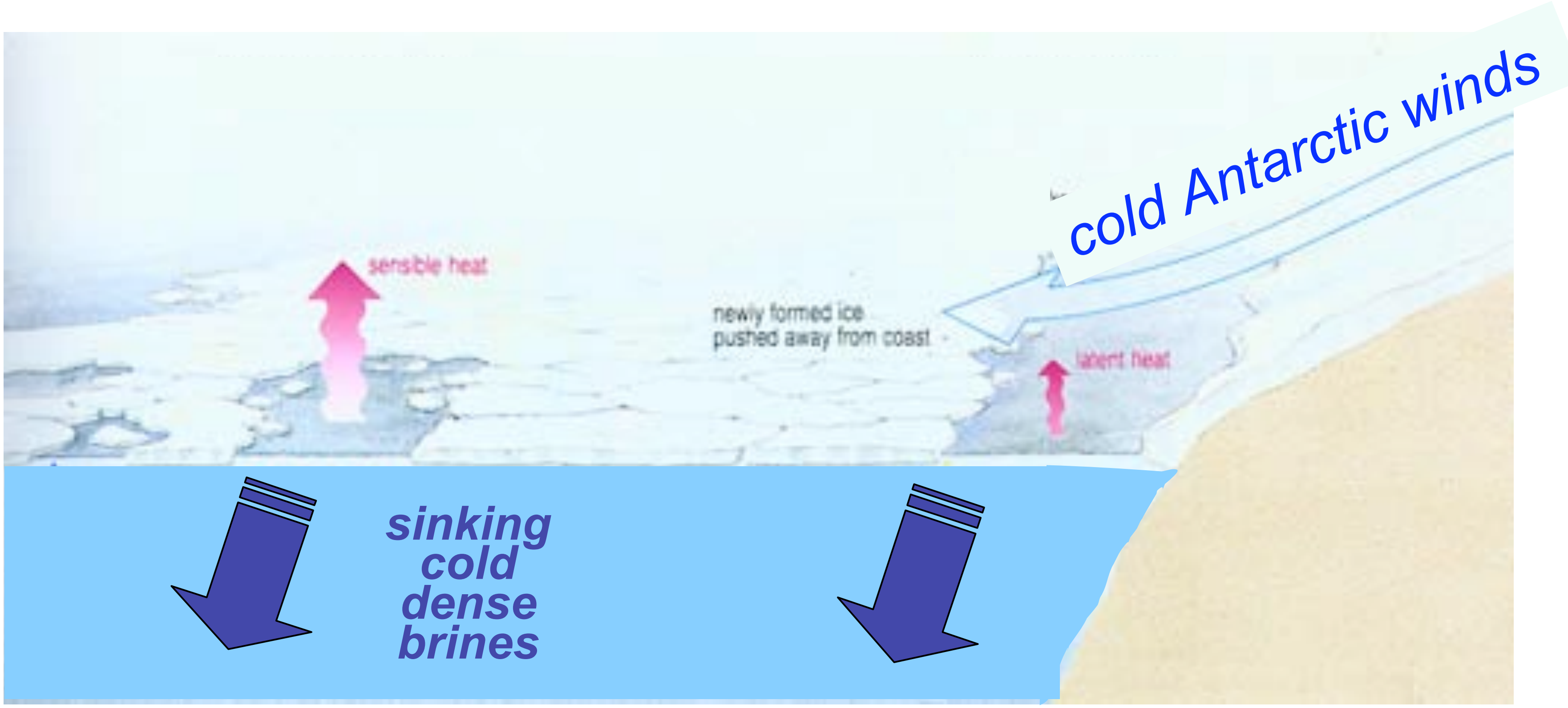
surface waters are cold throughout the high latitudes, so why might deep water formation occur in the N. Atlantic but not in the N. Pacific?

a) not *really* cold in N. Pac, b) not windy enough, c) Coriolis wrong direction, d) <u>not salty enough</u>, e) too sunny

answer

- deep water does not form in N. Pacific because it is too fresh
- deep waters do form, however, around Antarctica where it is very cold and formation of sea-ice supplies extra salt (brine-rejection)

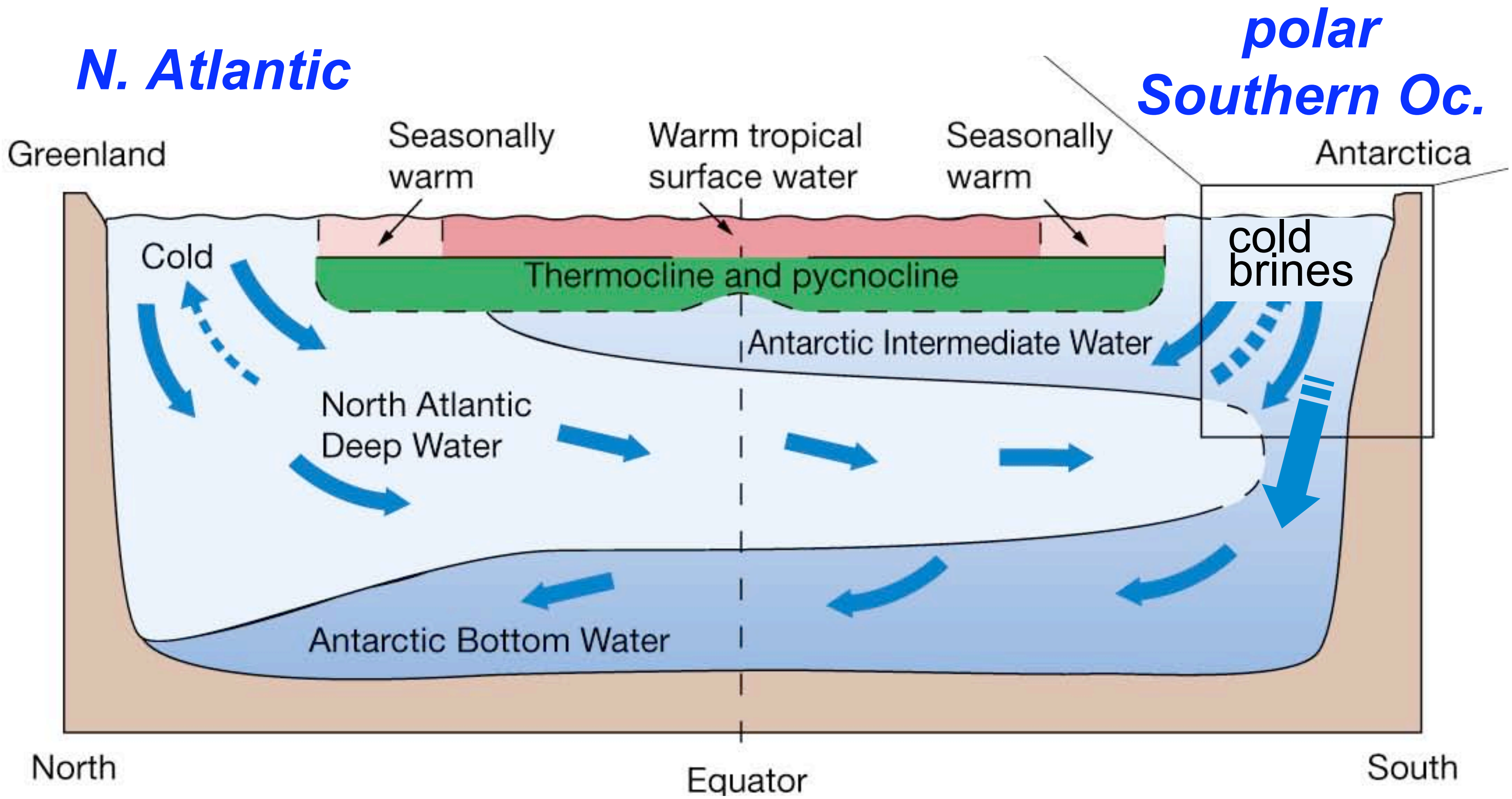
the Antarctic sea-ice factory



cold winds blow sea-ice out to sea as it formed, allowing continual formation of new sea ice… as sea ice is formed from sea water, salt is rejected, enriching salt content below

the extra salt promotes deep water formation (i.e. "Antarctic Bottom Water")

polar sources of deep water



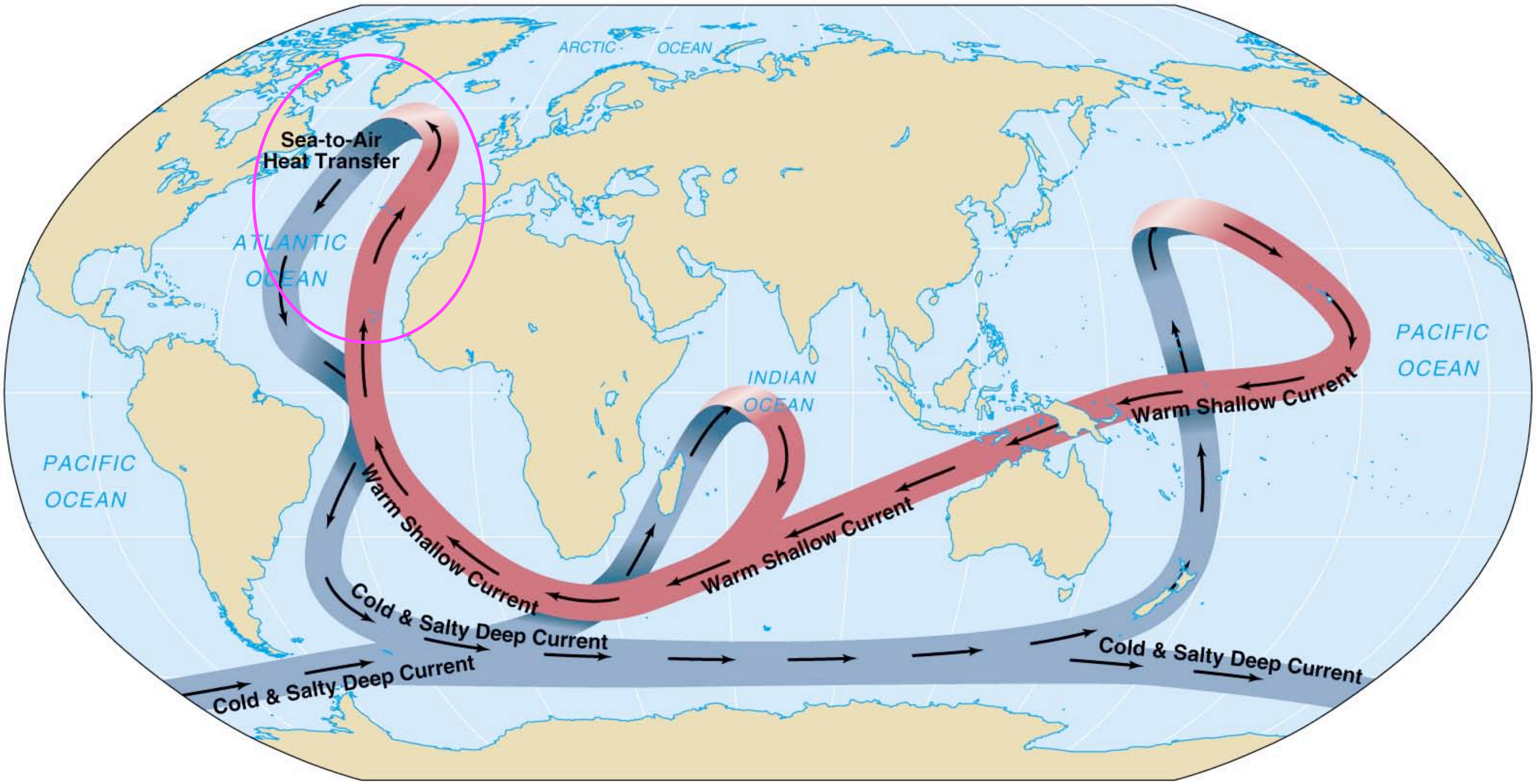
waters cooled at high latitudes fill the ocean interior with cold, dense water

deep ocean water masses form and circulate as part of the

thermo-haline circulation

- driven by **T** and **S** (i.e., density)
- a.k.a. deep ocean circulation
- surface waters may sink if they become denser than waters below them via:
    - cooling (polar regions)
    - sea ice formation: removal of fresh water into ice leaves remaining seawater very salty (brine rejection) (polar)
    - intense evaporation (Mediterranean)

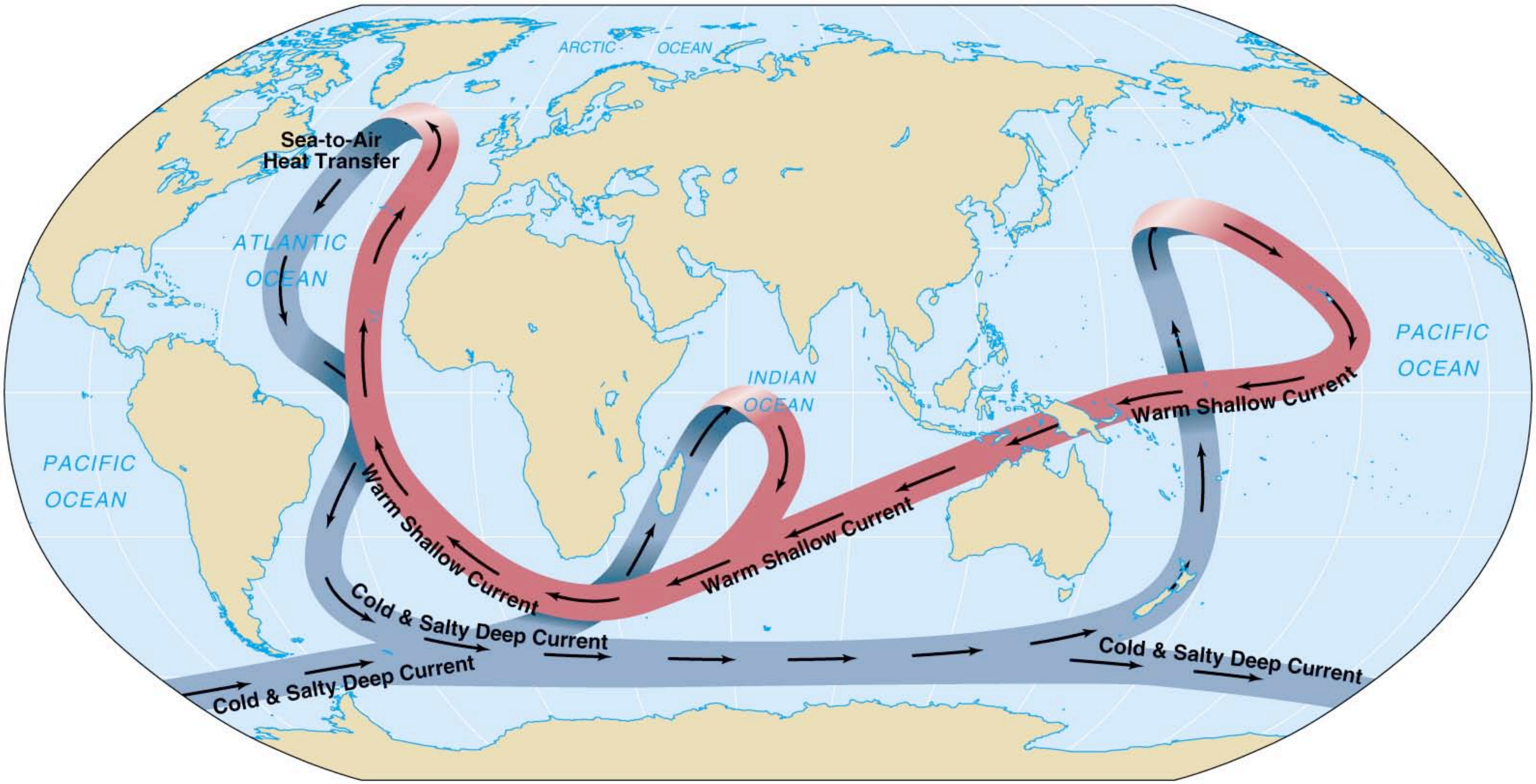
the ocean "conveyor belt"



deep circulation dominated by a continuous circuit associated with formation of deep water in the N. Atlantic (i.e. NADW)

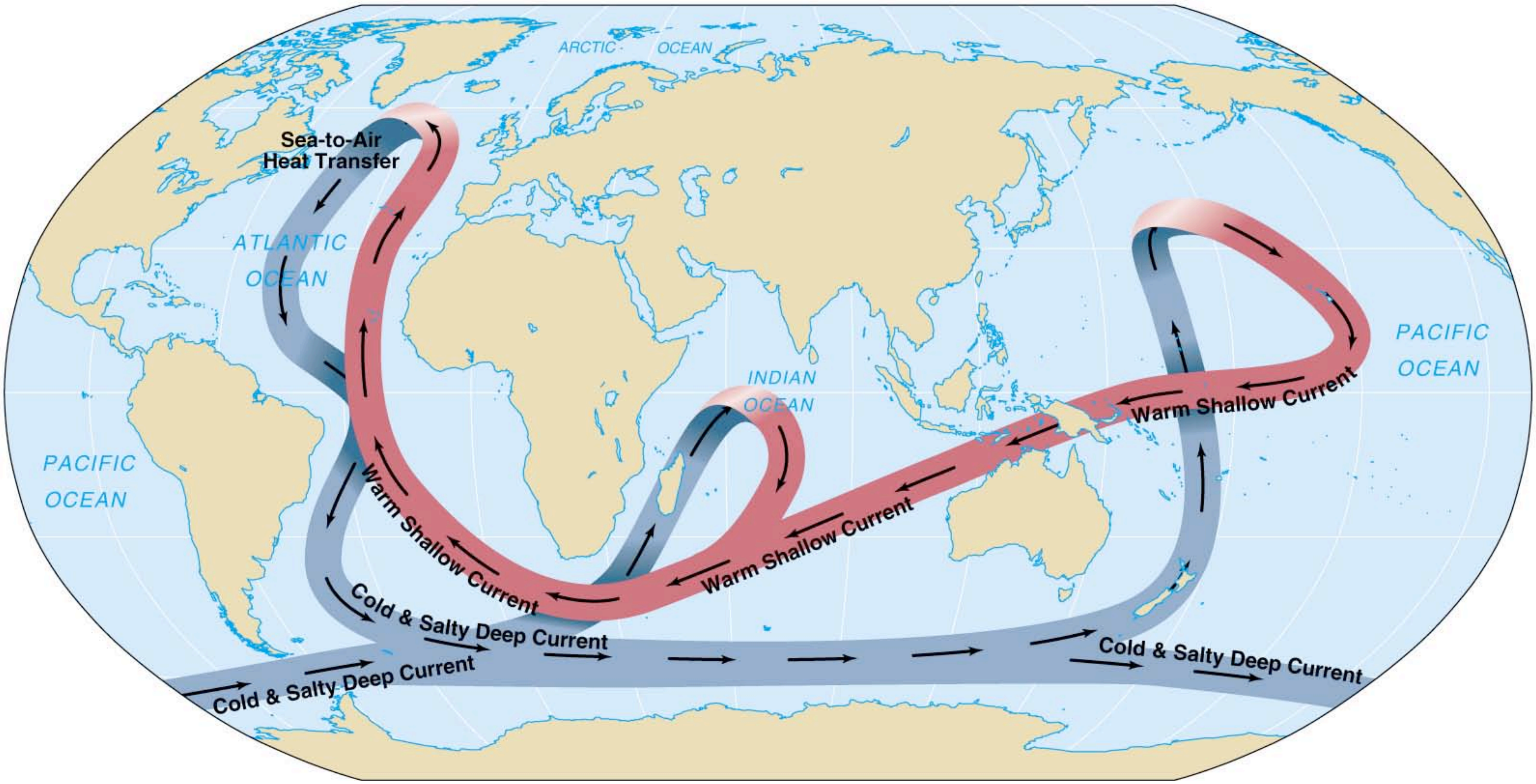
"what goes around comes around"

the ocean "conveyor belt"



How much water moves through the circuit?
15-20 million m^3/sec (i.e. 15-20 Sverdrups)
about 100 Amazons!

the ocean "conveyor belt"

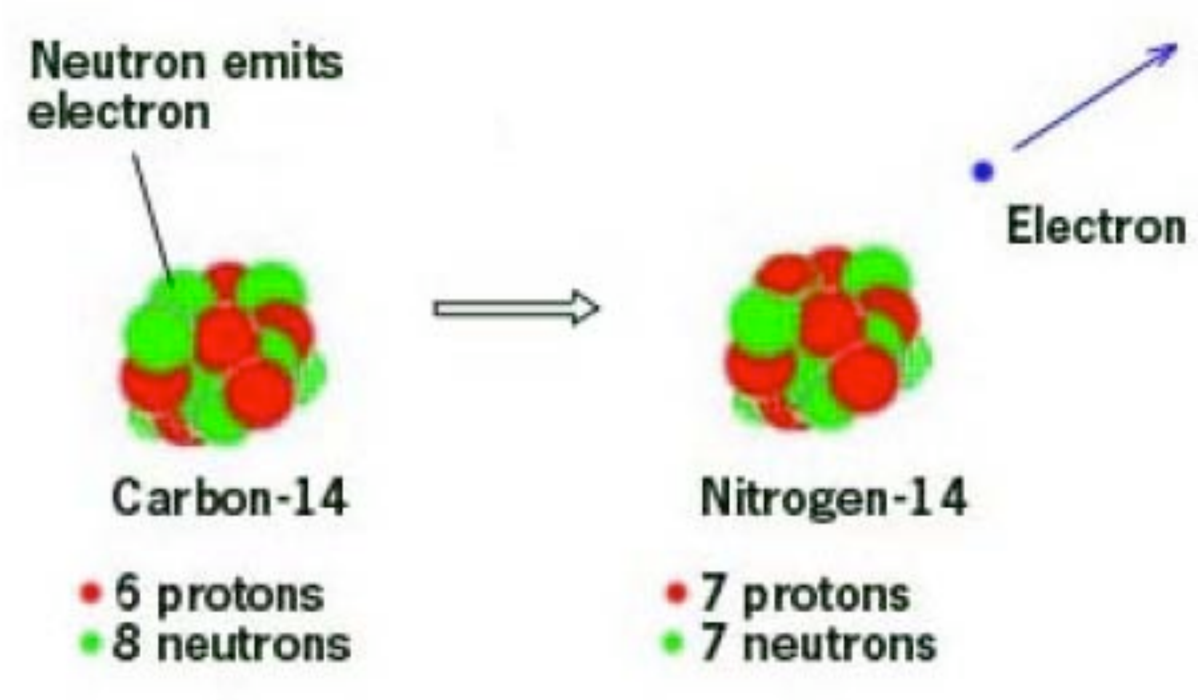


long route implies long time to complete circuit

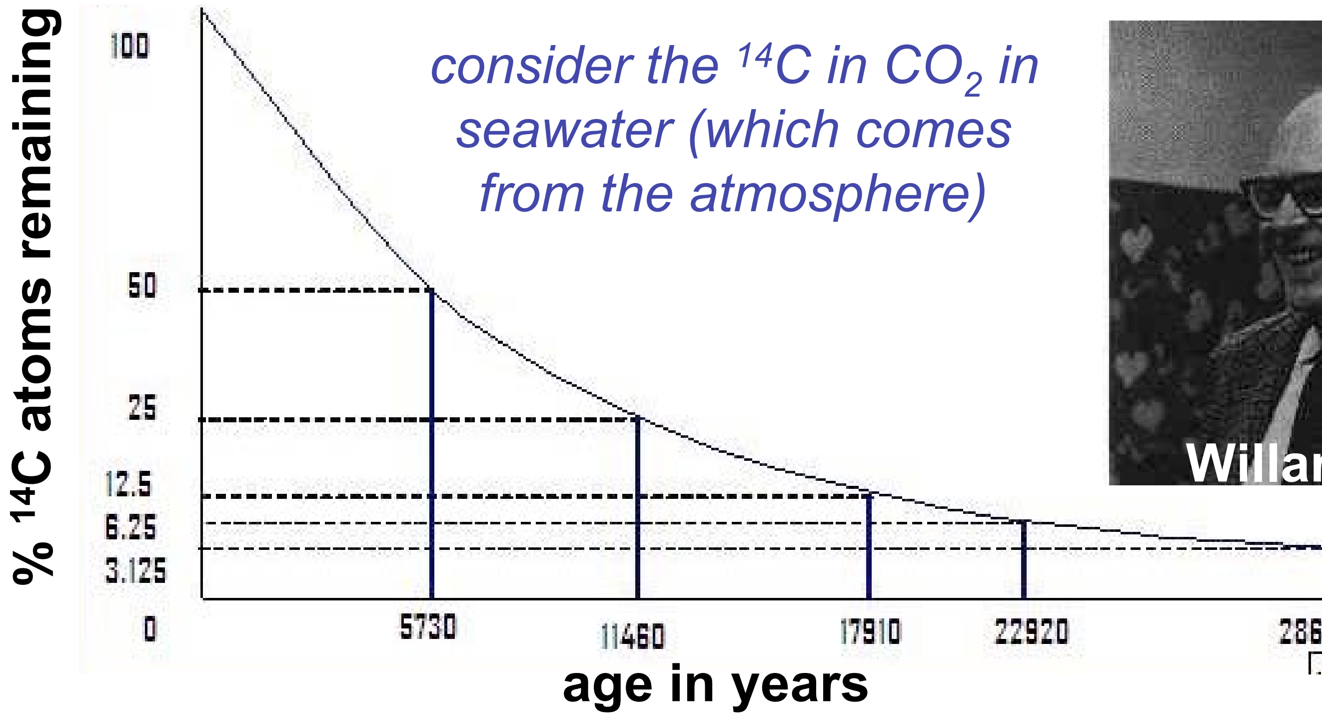
how long?

how old is the deep ocean?

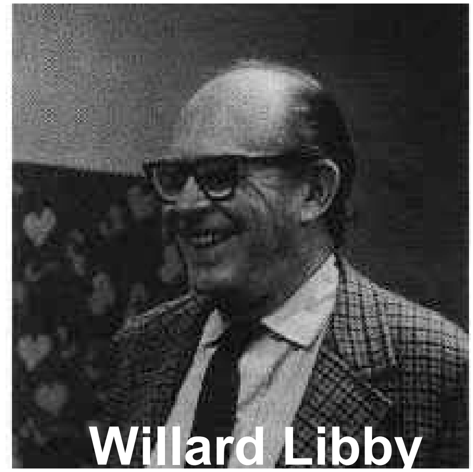
- need measurements that record time
- how do we date archaeological artifacts?
- measure ^{14}C as compared to normal carbon
- extra neutrons make the ^{14}C atom *unstable*
- that means it will undergo radioactive decay



how old is the deep ocean?



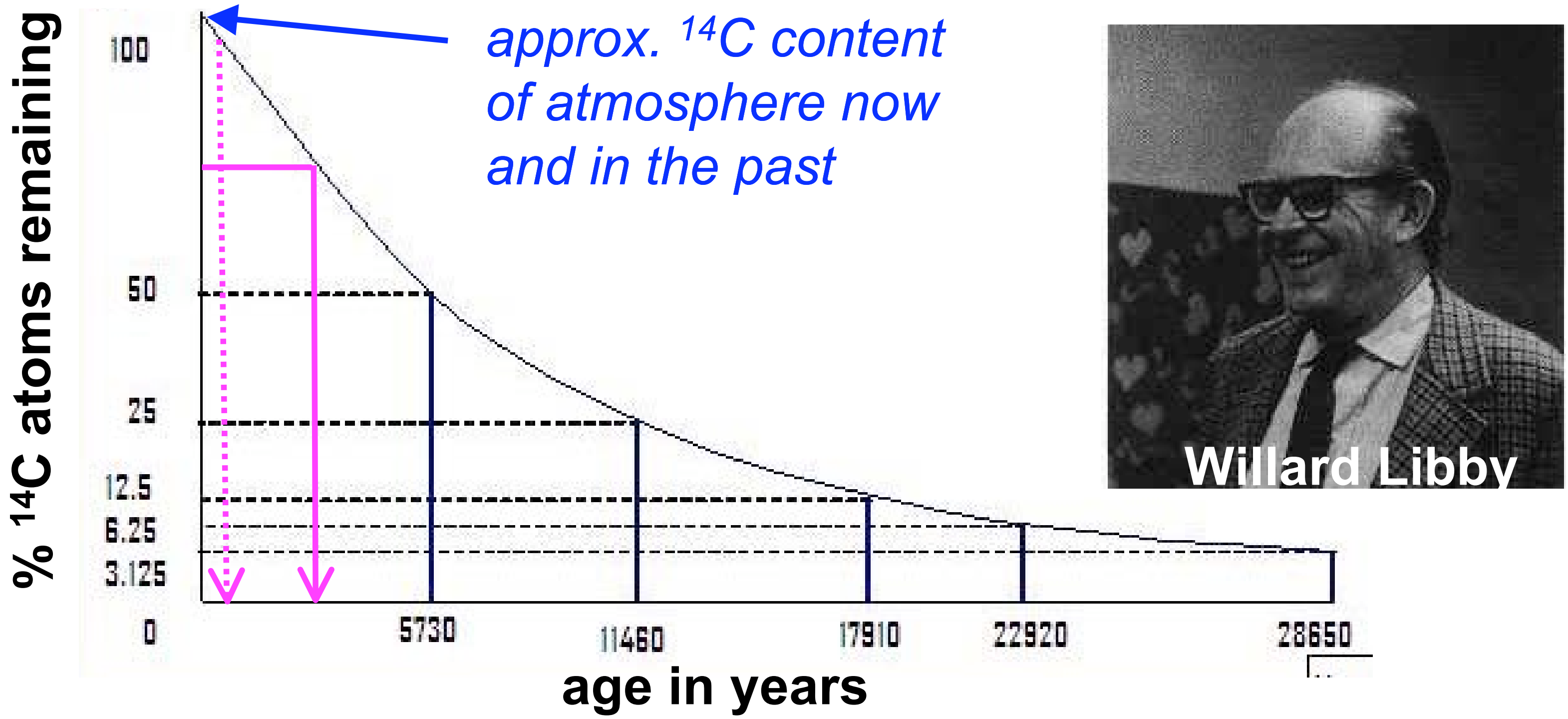
consider the ^{14}C in CO_2 in seawater (which comes from the atmosphere)



- half the ^{14}C decays away every 5730 years

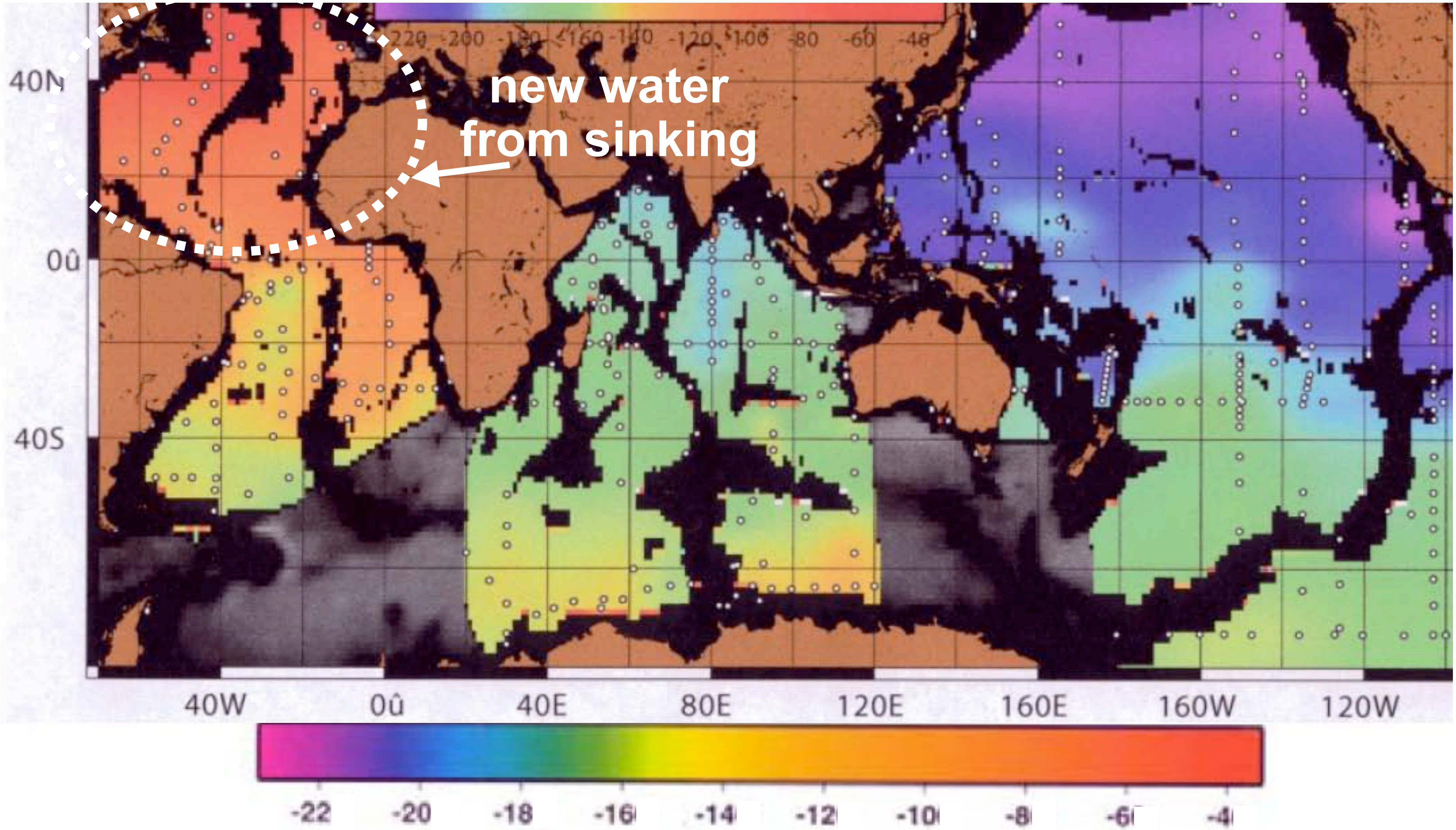
father of radiocarbon dating method

how old is the deep ocean?



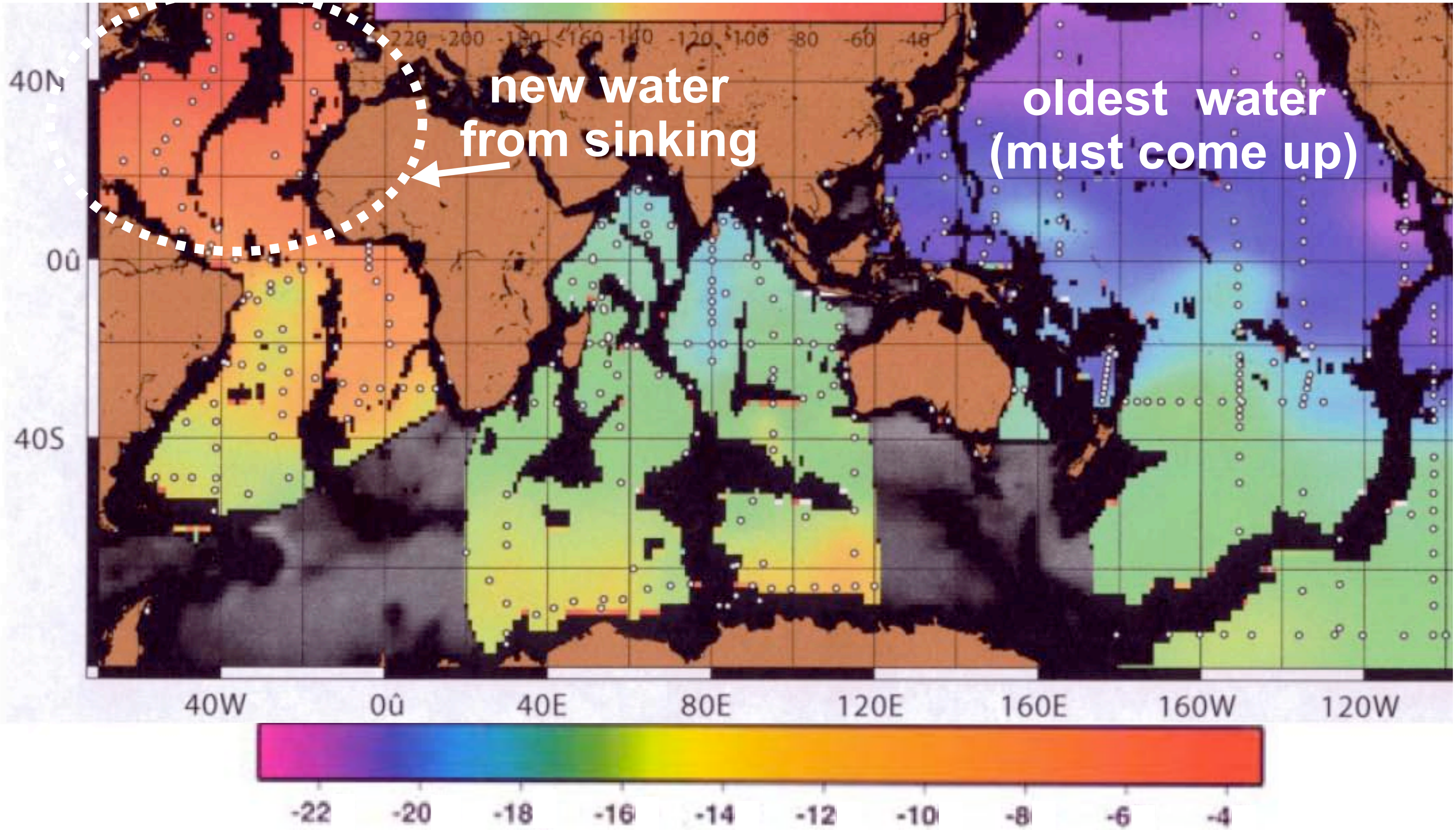
- half the ^{14}C decays away every 5730 years
- so measuring how much ^{14}C tells us how long since water absorbed new carbon (as CO_2) at the surface
- more ^{14}C means water was at the surface more recently
- less ^{14}C means water was at the surface less recently

less ^{14}C means older water!



near bottom ^{14}C (% deviation from modern)

less ^{14}C means older water!



near bottom ^{14}C (% deviation from modern)

can estimate avg. timescale of deep circulation is 1000 years!

time scales

- **weather**
  days

- **atmospheric circulation**
  weeks to months

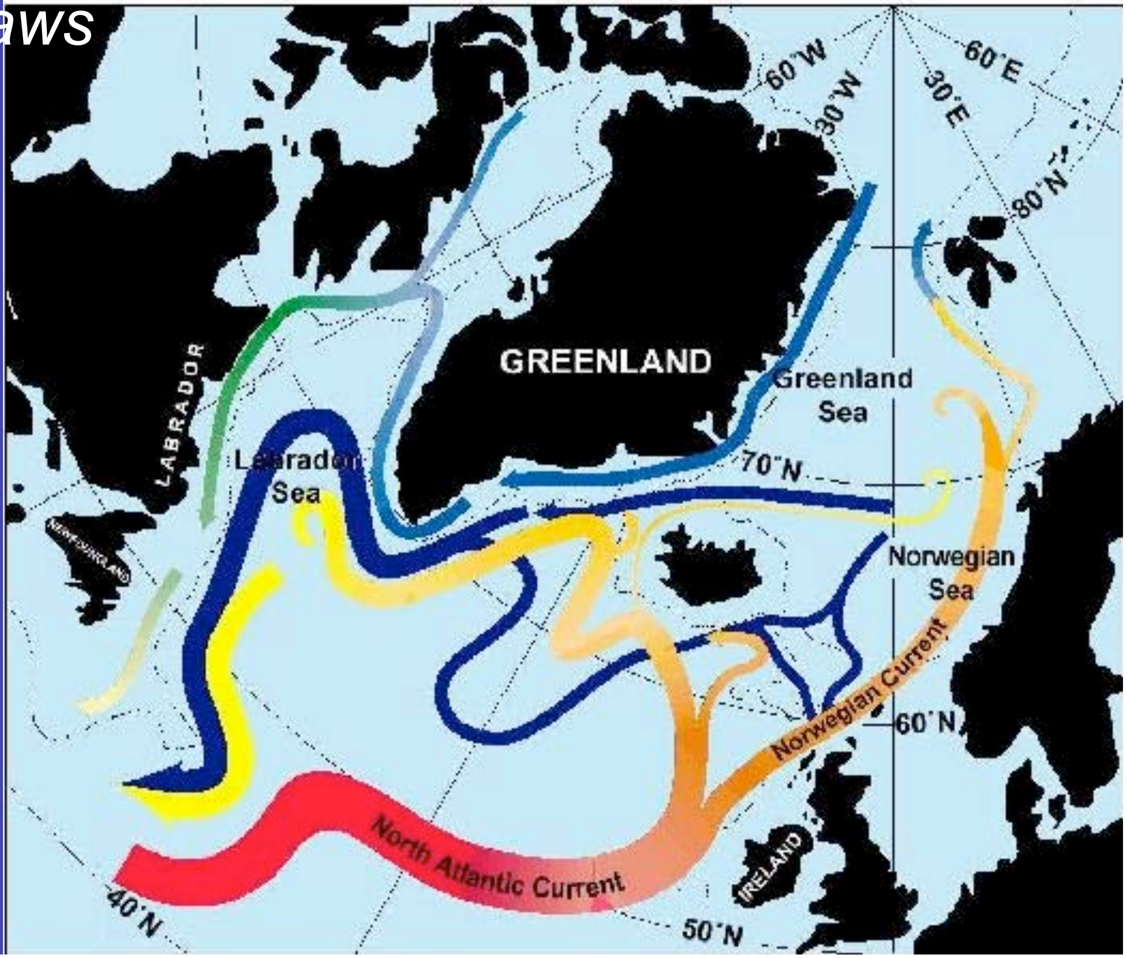
- **ocean surface circulation**
  months to year

- **el Nino**
  several years

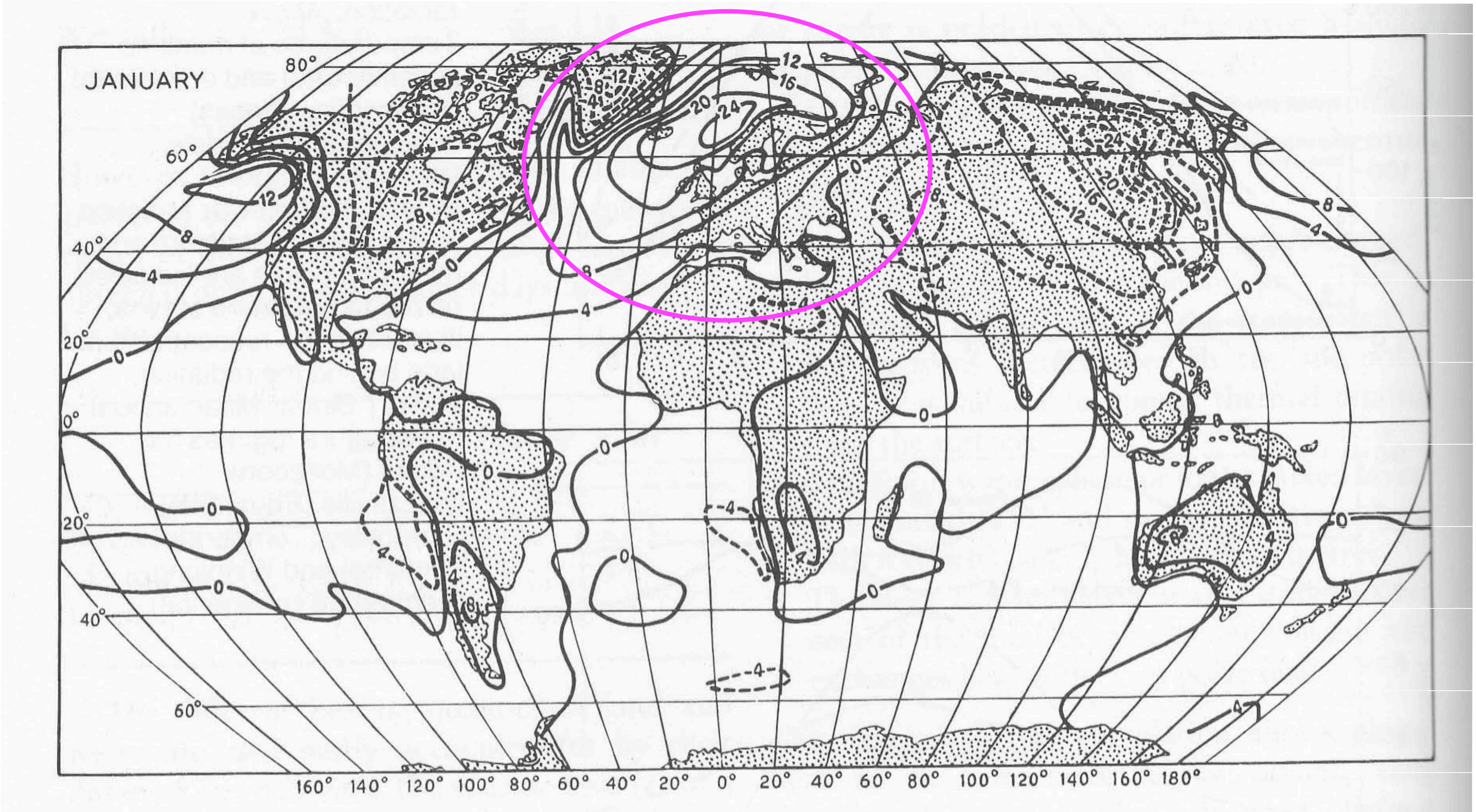
- **deep ocean circulation**
  500 - 3500 years!
  (but can switch on/off w/in a decade!)

NADW formation

- warm, salty Gulf Stream flows north
- cools → cold, salty (heat released to atmosphere)
- sinks and flows south as NADW
- flux ~15 Sv (water), ~1.2 PW (heat)
- *can say NADW fmtn. draws Gulf Stream northward*



NADW helps warm N. Atl. region

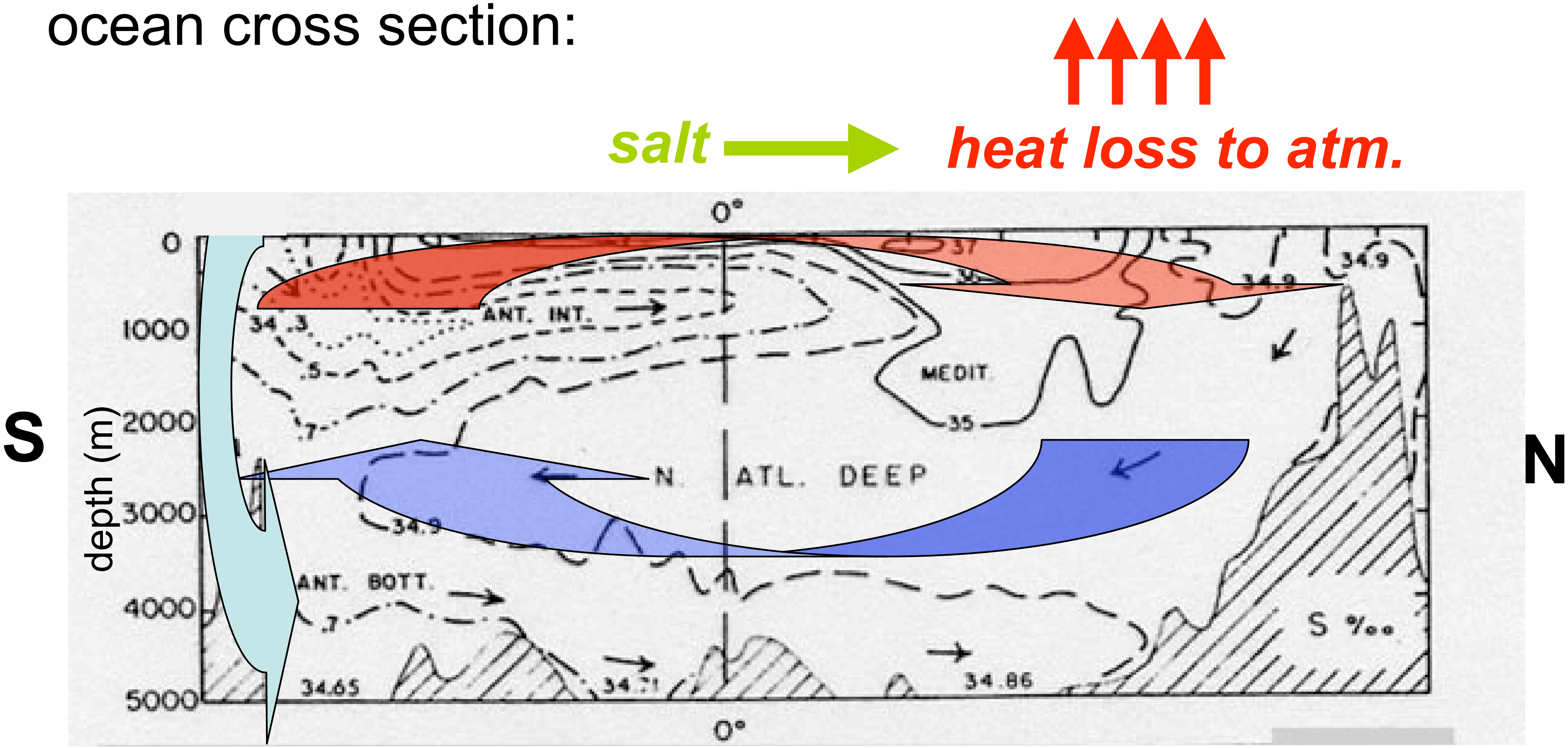


local deviation of Jan. temperature from latitude average (°C)

highlights local heating of atmosphere by ocean where deep water forms (N. Atlantic)

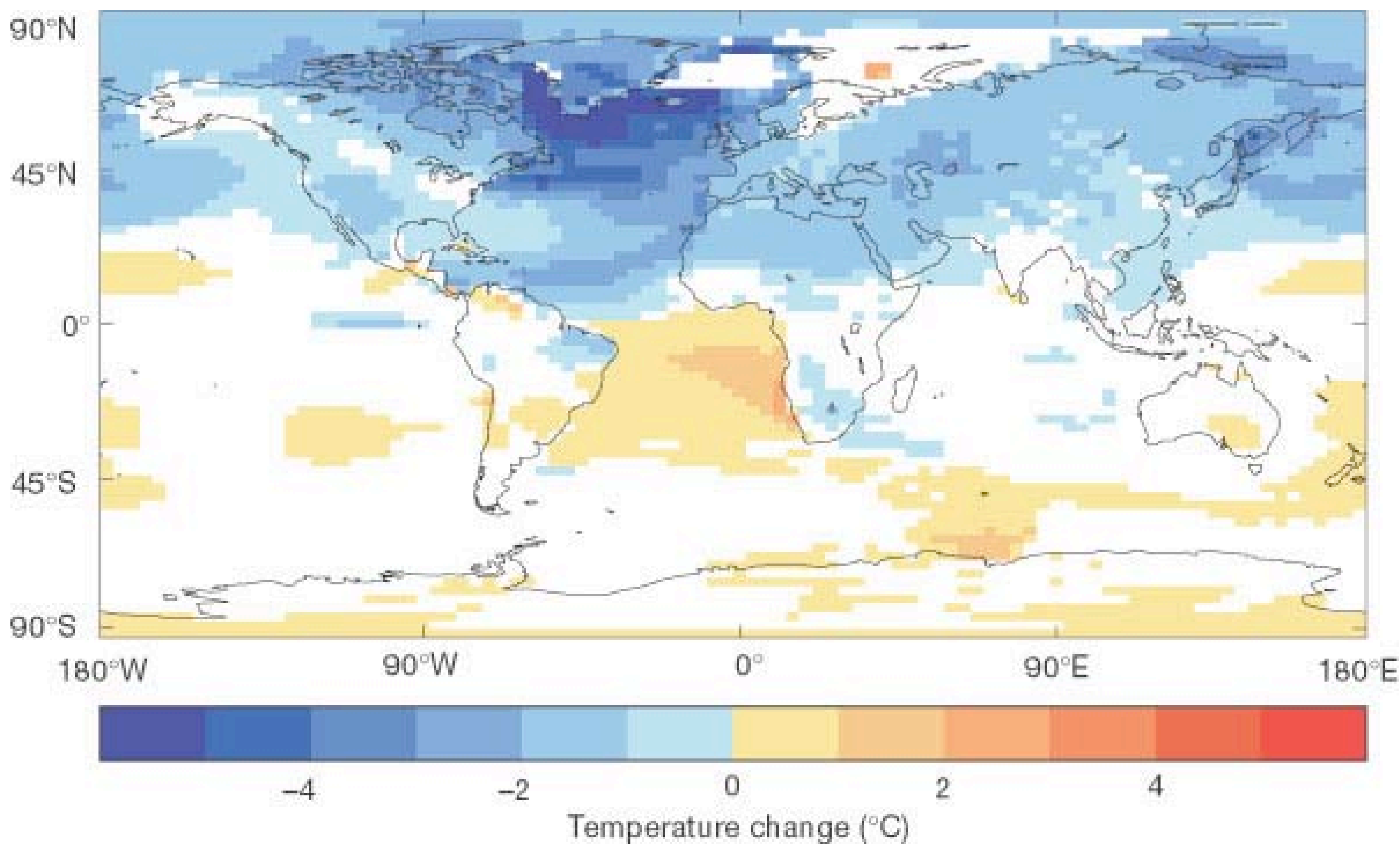
conveyor as simple heat/salt engine

ocean cross section:



conveyor carries poleward the salt needed
to maintain deepwater formation
at low temp. density depends strongly on salinity
is the situation stable?

NADW "off"



NADW collapse forced by excess meltwater, GHG's fixed at pre-Industrial levels

summary points

is our climate future in deep water?

- deep water properties largely determined by conditions at the surface
- density depends on temperature and salinity (salinity dominating at low T)
- surface waters sink to form deep waters when surface density exceeds that of ocean interior
- deep water forms in response to cooling in polar regions with adequate salinity
- part of the deep circulation follows a long “conveyor” circuit that supplies heat to the N. Atlantic region
- despite the long transit time in the circuit (~1000 yrs), parts of the circulation can stop nearly instantaneously

lecture 10 learning goals

- describe how temperature and salinity influence density and which is more important at very low temperature
- be able to explain why deep waters form in some high latitude regions and not others
- describe the use of a simple isotope “clock” in determining where the oldest waters are and how long it takes to complete a circuit along the conveyor loop
- describe the role of deepwater formation in warming the atmosphere above
- explain the possible influence of excess melt- and rain- water on deep water formation in the North Atlantic

next

- Tues.: Hour Exam

  bring no. 2 pencils!