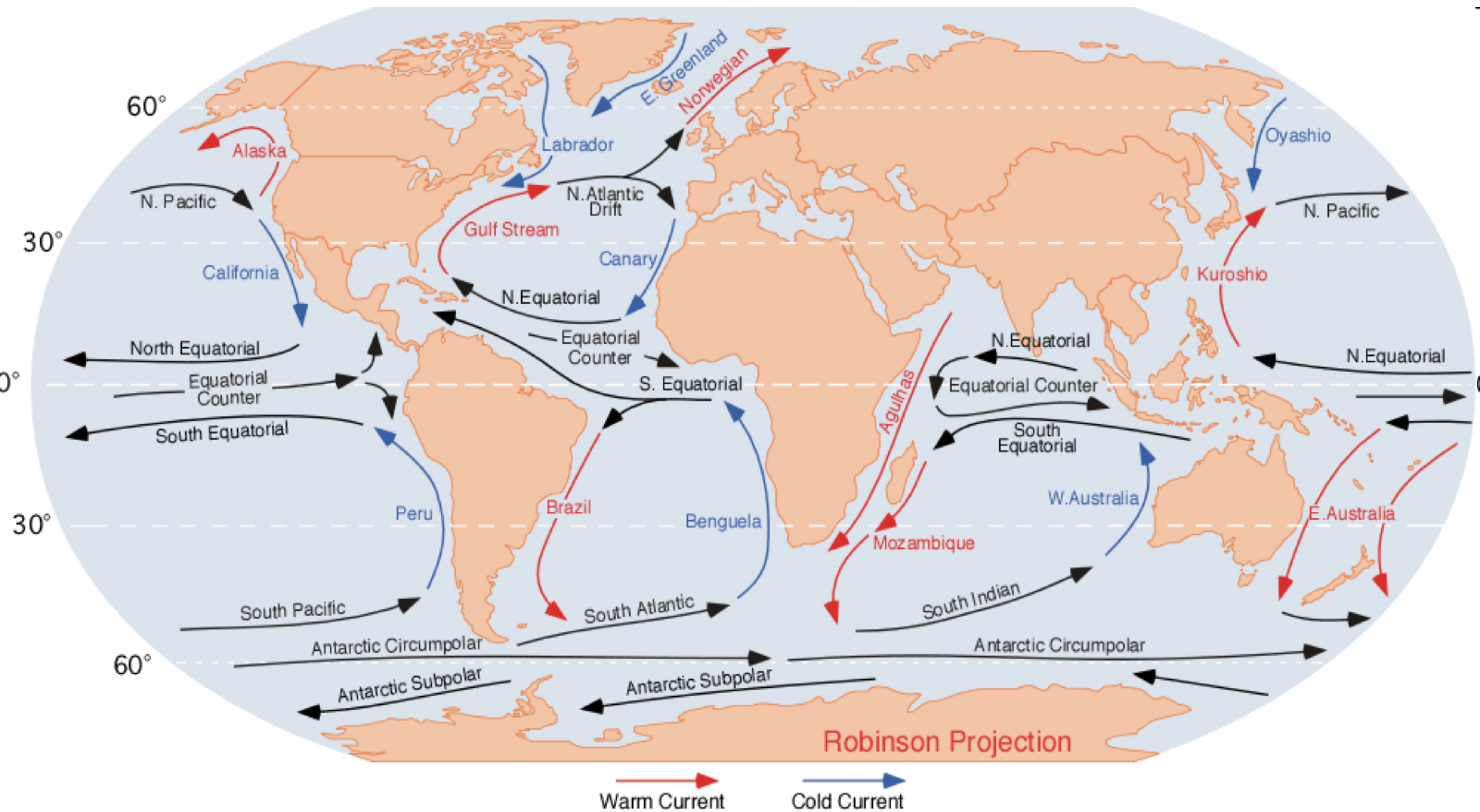
The Day After Tomorrow (2004)

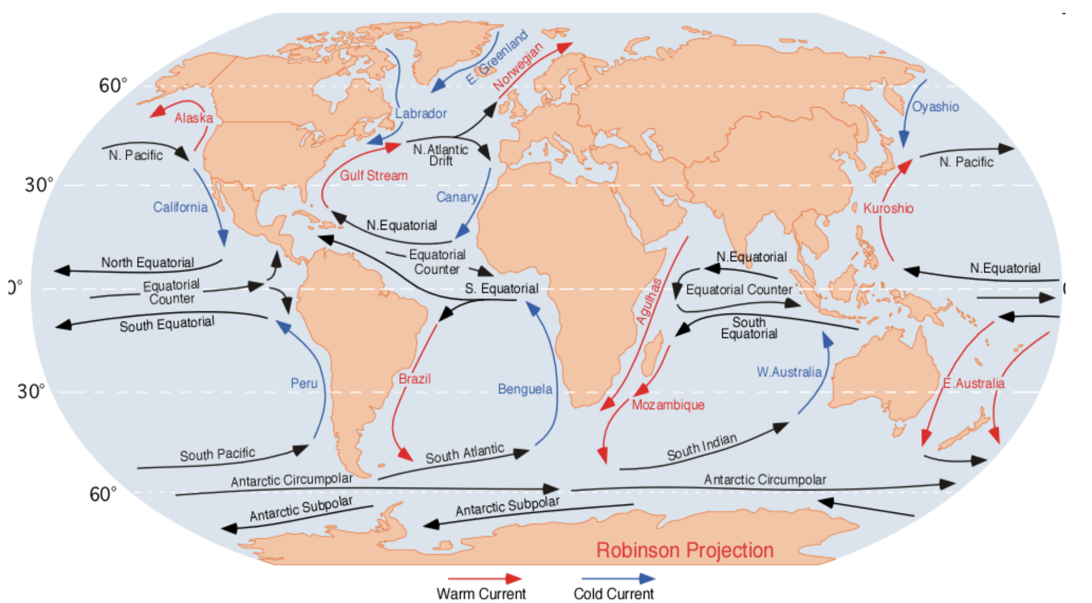
Trailer: http://www.youtube.com/watch?v=ZpP14TksGik

Review of horizontal wind driven circulation

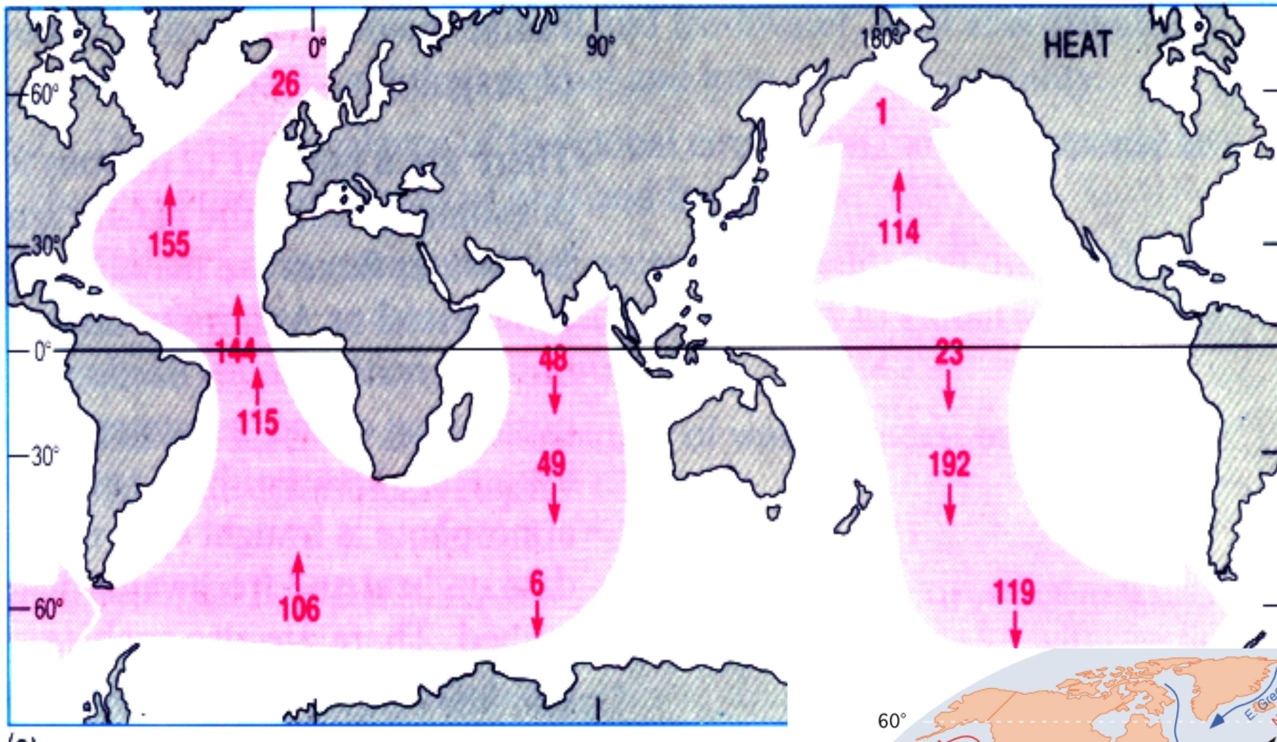
Surface ocean currents.



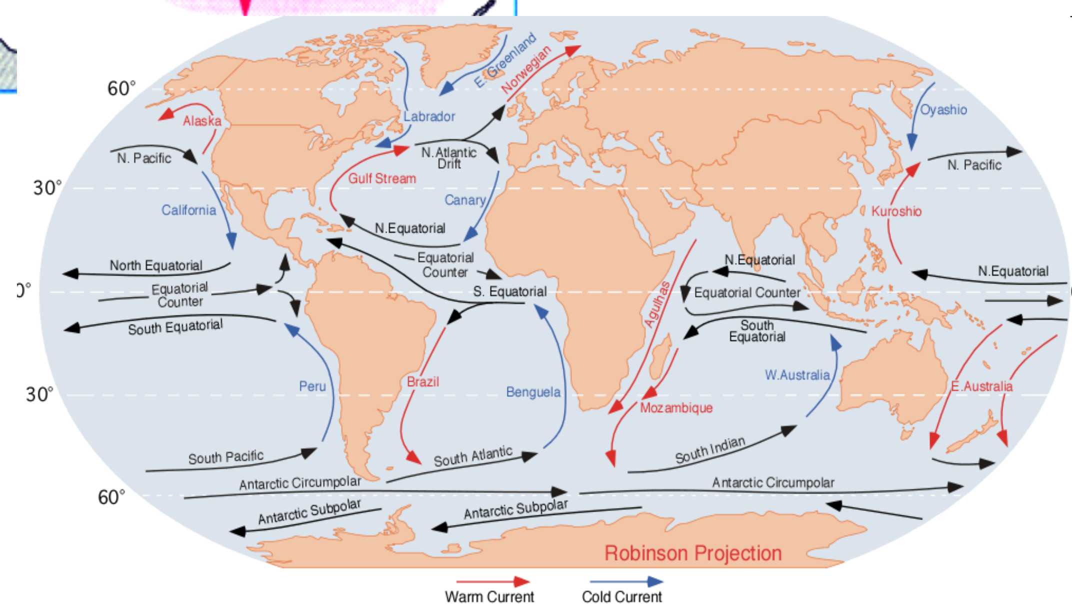
Surface Currents and Ocean Gyres



Heat transport in the ocean

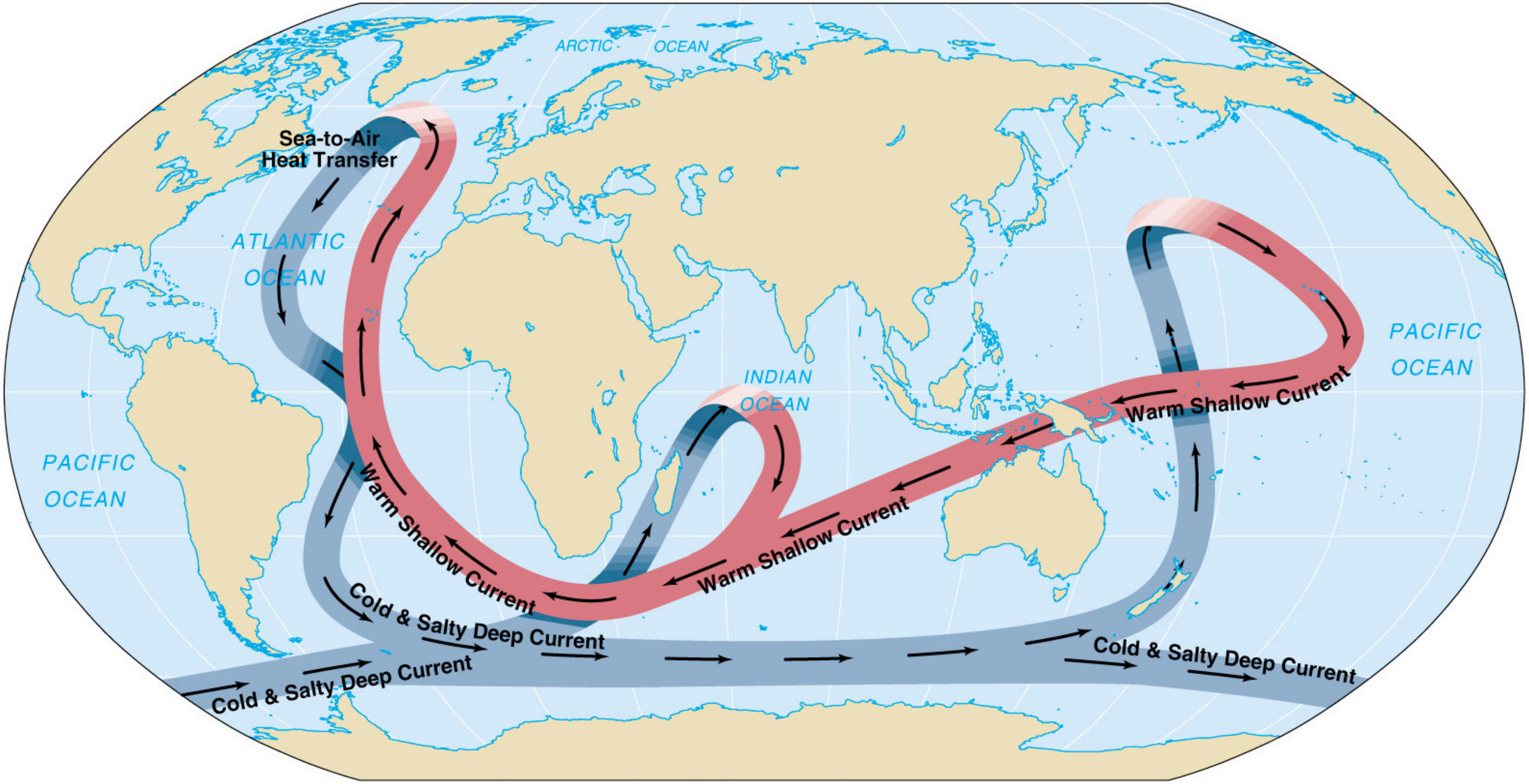


Surface Currents and Ocean Gyres



OVERTURNING MERIDIONAL CIRCULATION (MOC)

A CONCEPTUAL MODEL



The Ocean circulation below the surface:

OVERTURNING MERIDIONAL CIRCULATION (MOC)

OR

THE THERMOHALINE CIRCULATION

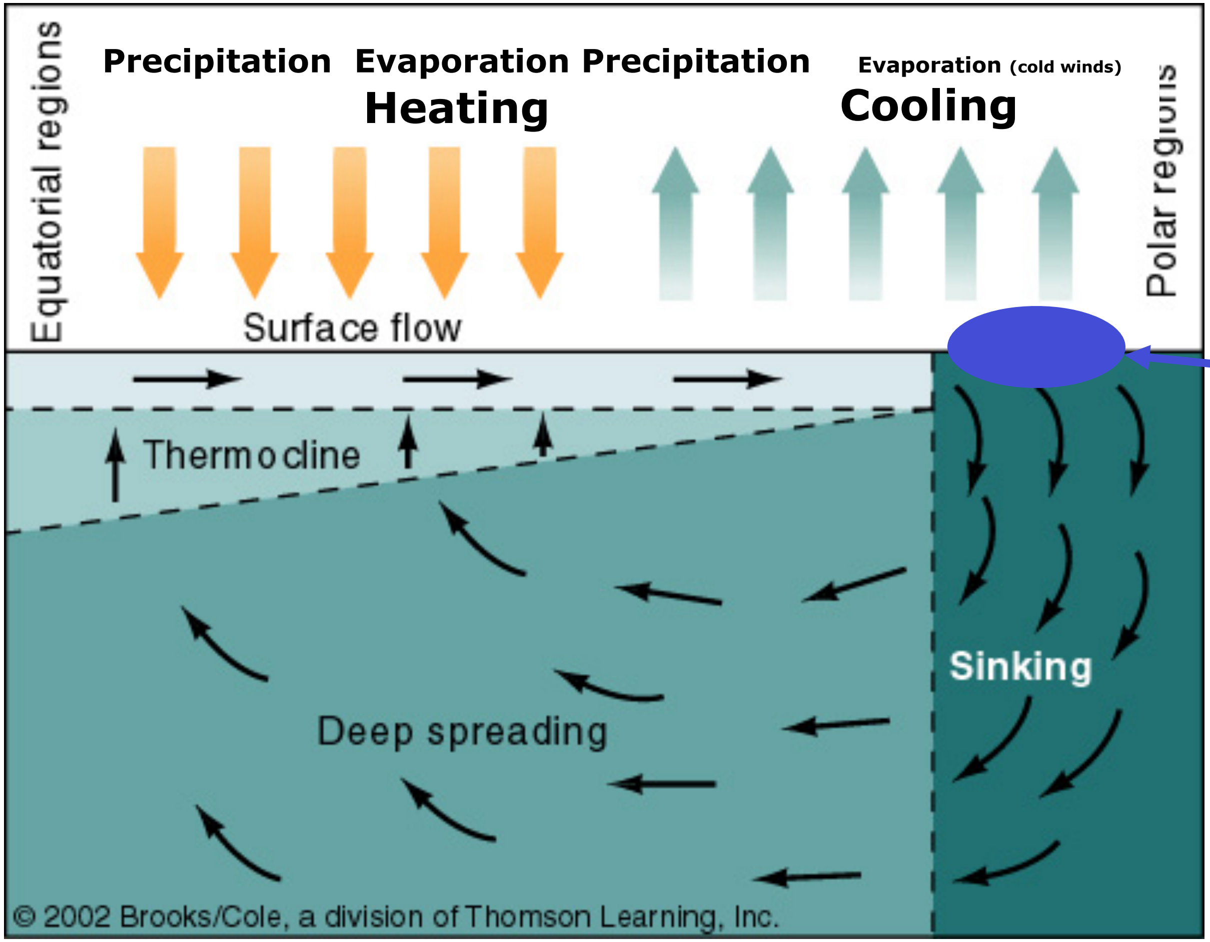
- **What is it and what causes it?**
- **Why important?**
- **Description and driving mechanisms**
  - Specific deep water masses
  - Global thermohaline circulation
- **Past and future changes and climate implications**

Why is MOC important?

- **Climate**:
  - Link to Gulf Stream in the poleward transport of heat
  - Large feedback in climate change (past and future): episodes of abrupt climate change
- **Ocean mixing**
  - Stirs the ocean from top to bottom (~1500 years)
  - Mixes in CO2, oxygen, heat, other biological material from surface

OVERTURNING MERIDIONAL CIRCULATION (MOC)

Buoyancy driven circulation

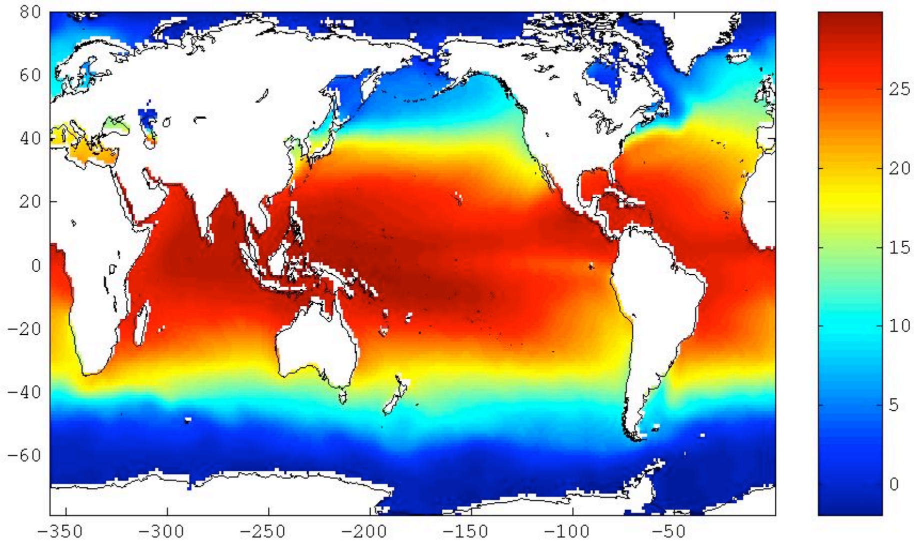


Dense water sinks

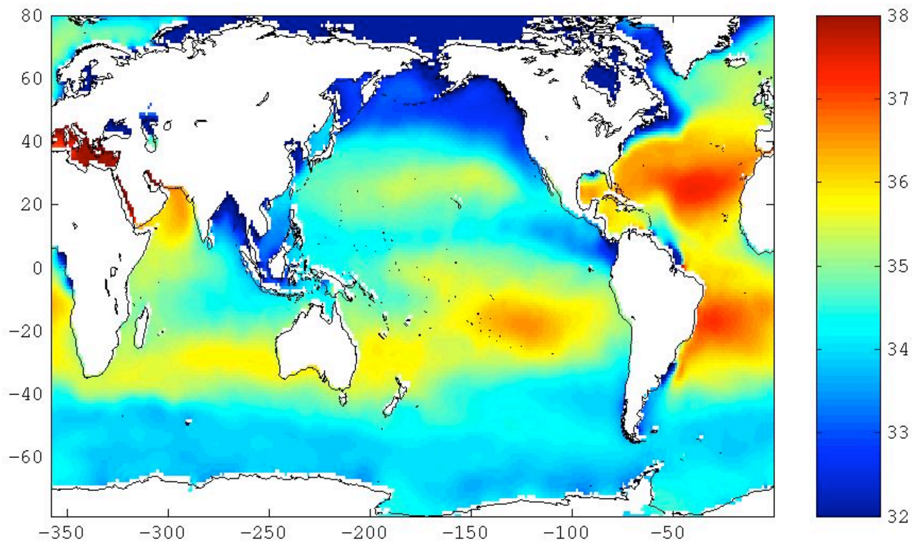
Overturning Meridional Circulation (MOC)

Key points

- Driven by ***density differences***
  - (what makes water dense? Less dense?)
- If water at surface becomes denser than water below, it will sink
- Deep waters exist as water masses with specific characteristics that reflect how they formed (***TS Diagrams***)
- Examples…



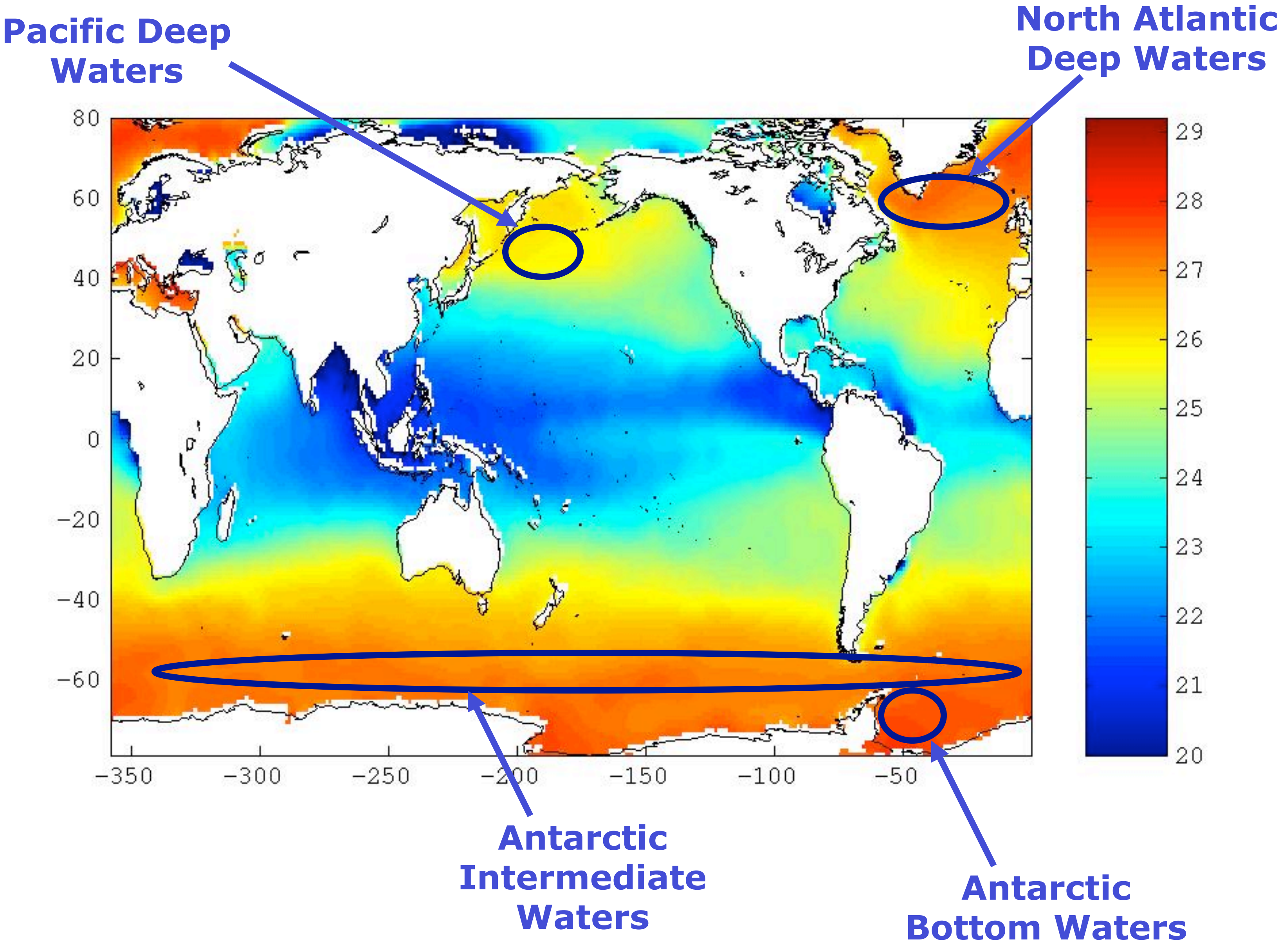
Temperature



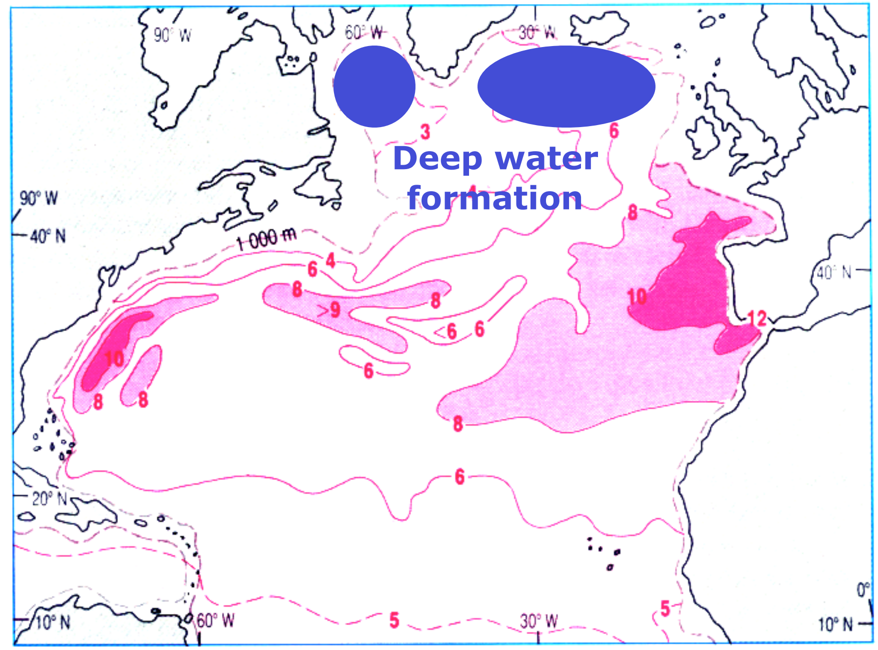
Salinity

The *density of surface* water is controlled by temperature and salinity.

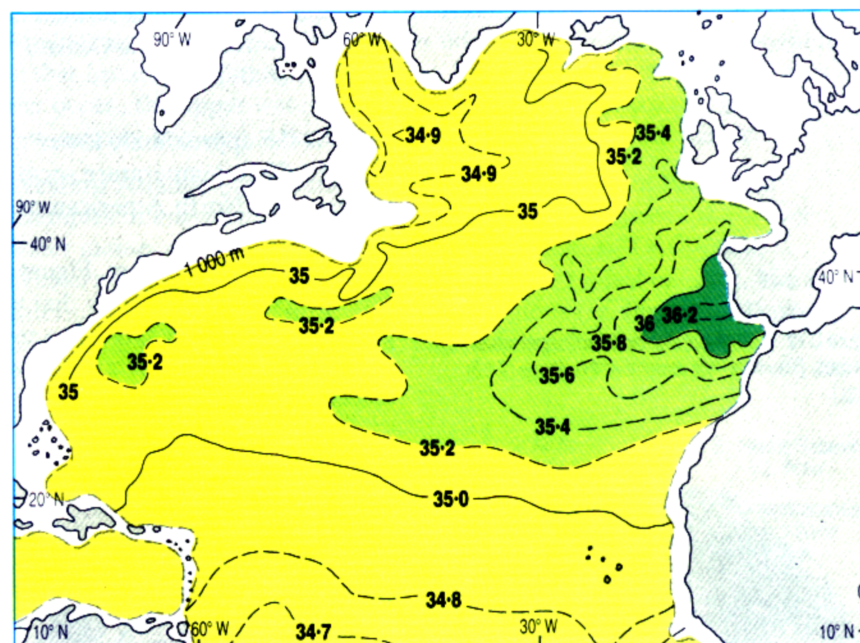
Density of surface waters



Temperature



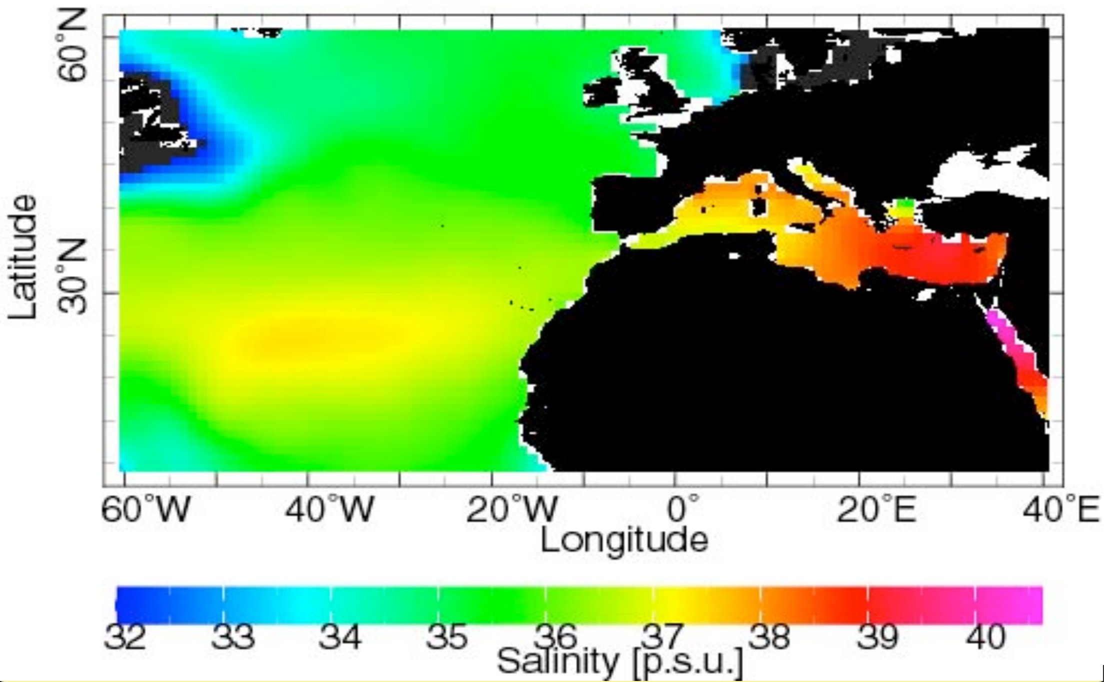
Salinity

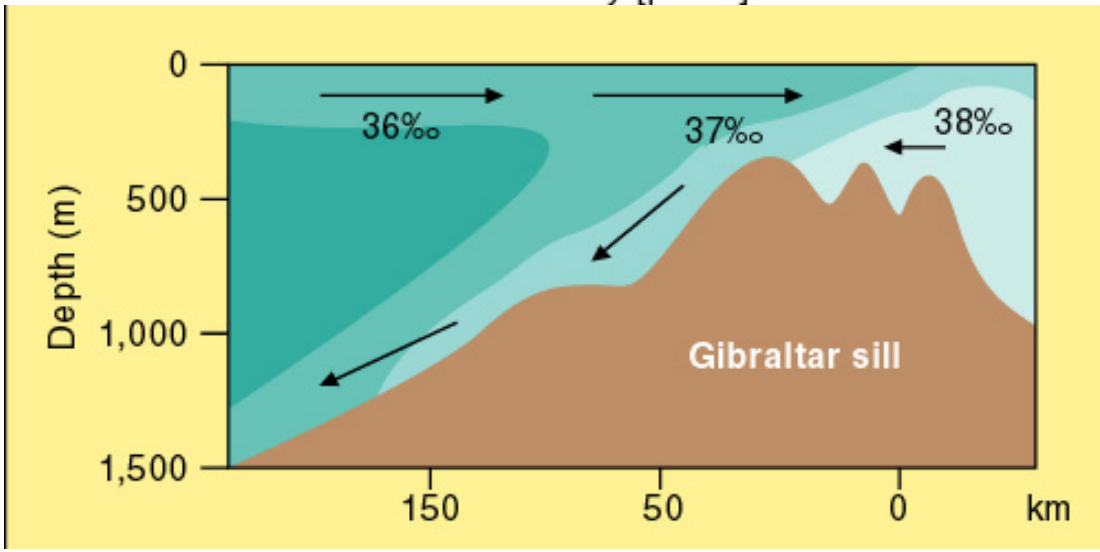


Spread of the Mediterranean salty waters:

A contributor (even if small) to the high density in the North Atlantic

Mediterranean Overflow Water (MIW)

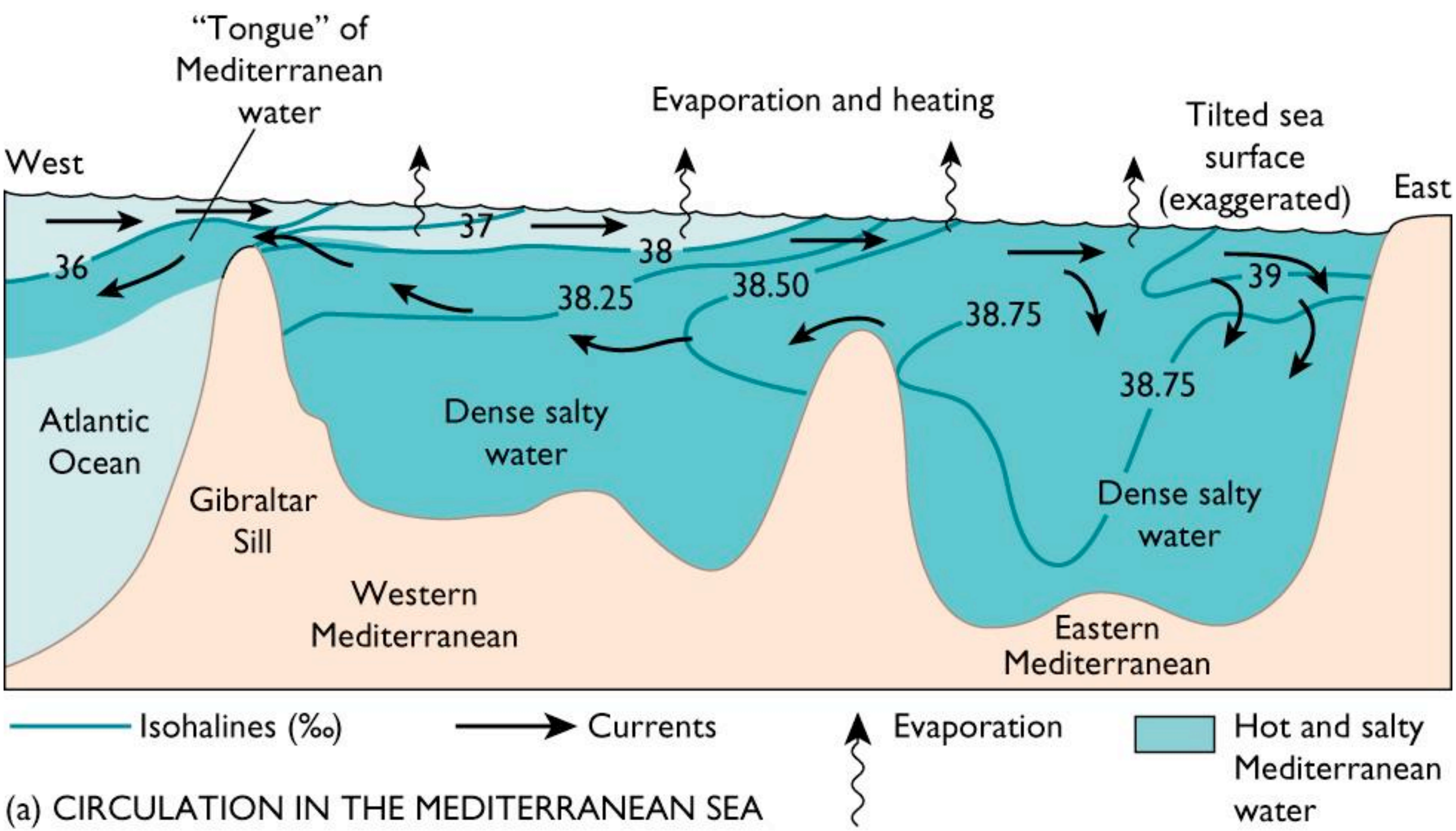




- Mediterranean is very salty (high evaporation)
- Water that leaves Med is saltier than surrounding Atlantic
- Sinks, but not too deep
- (not denser than NADW or AABW because it's warmer)

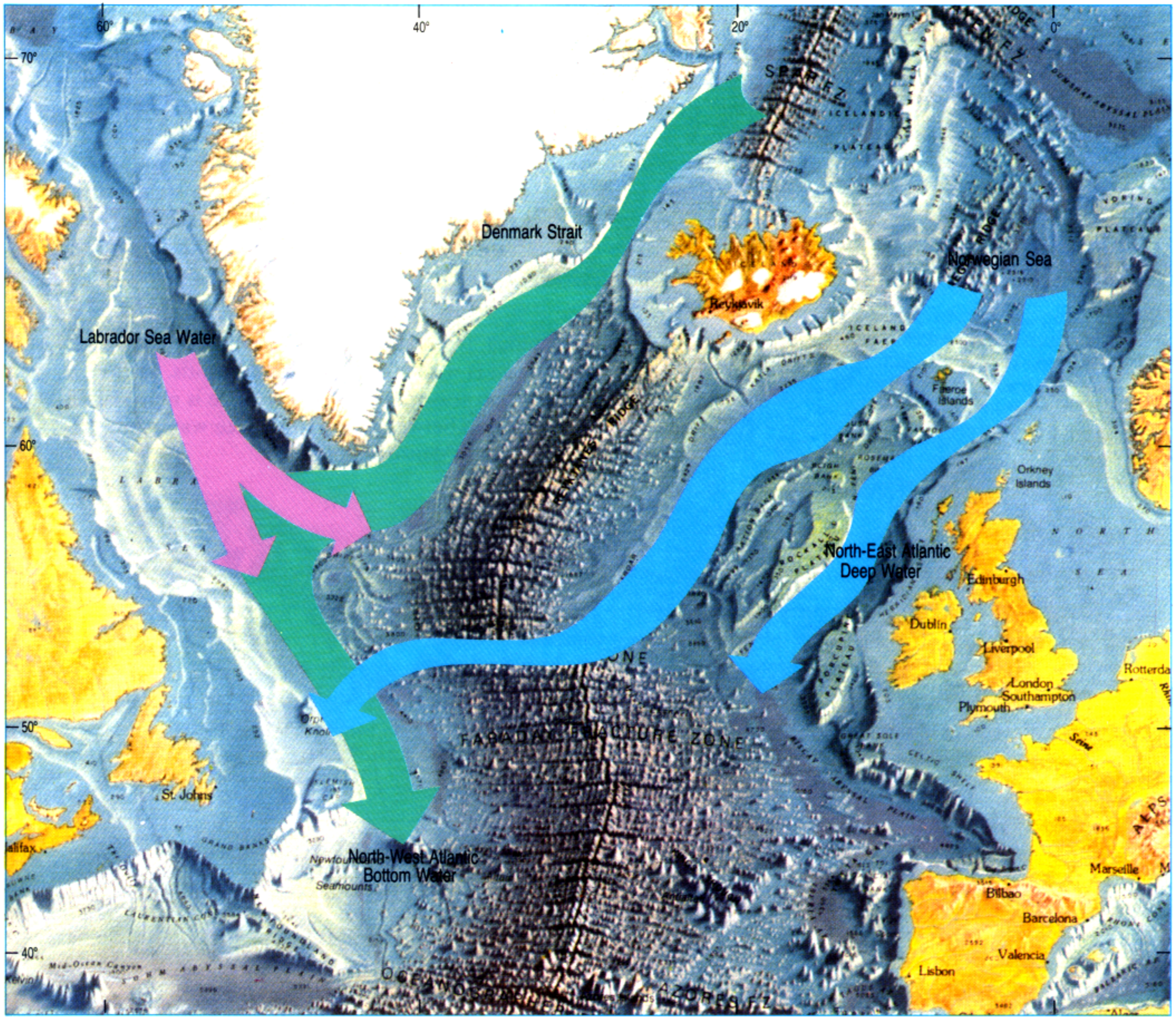
The outflow of Mediterranean Water

Surface and subsurface circulation in the Mediterranean Sea occurs because evaporation exceeds precipitation and river runoff combined.



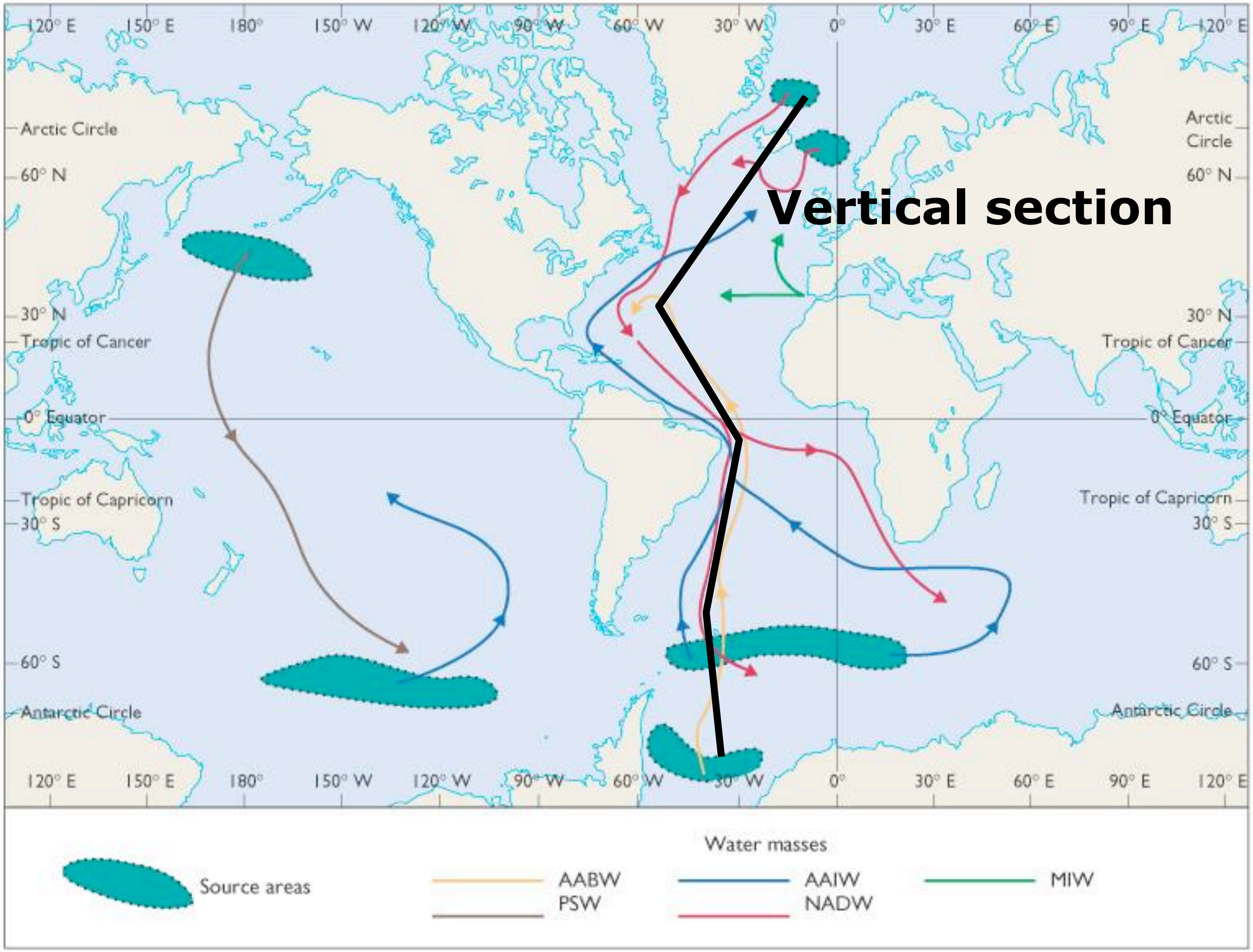
(a) CIRCULATION IN THE MEDITERRANEAN SEA

NADW (North Atlantic Deep Water)
a closer look



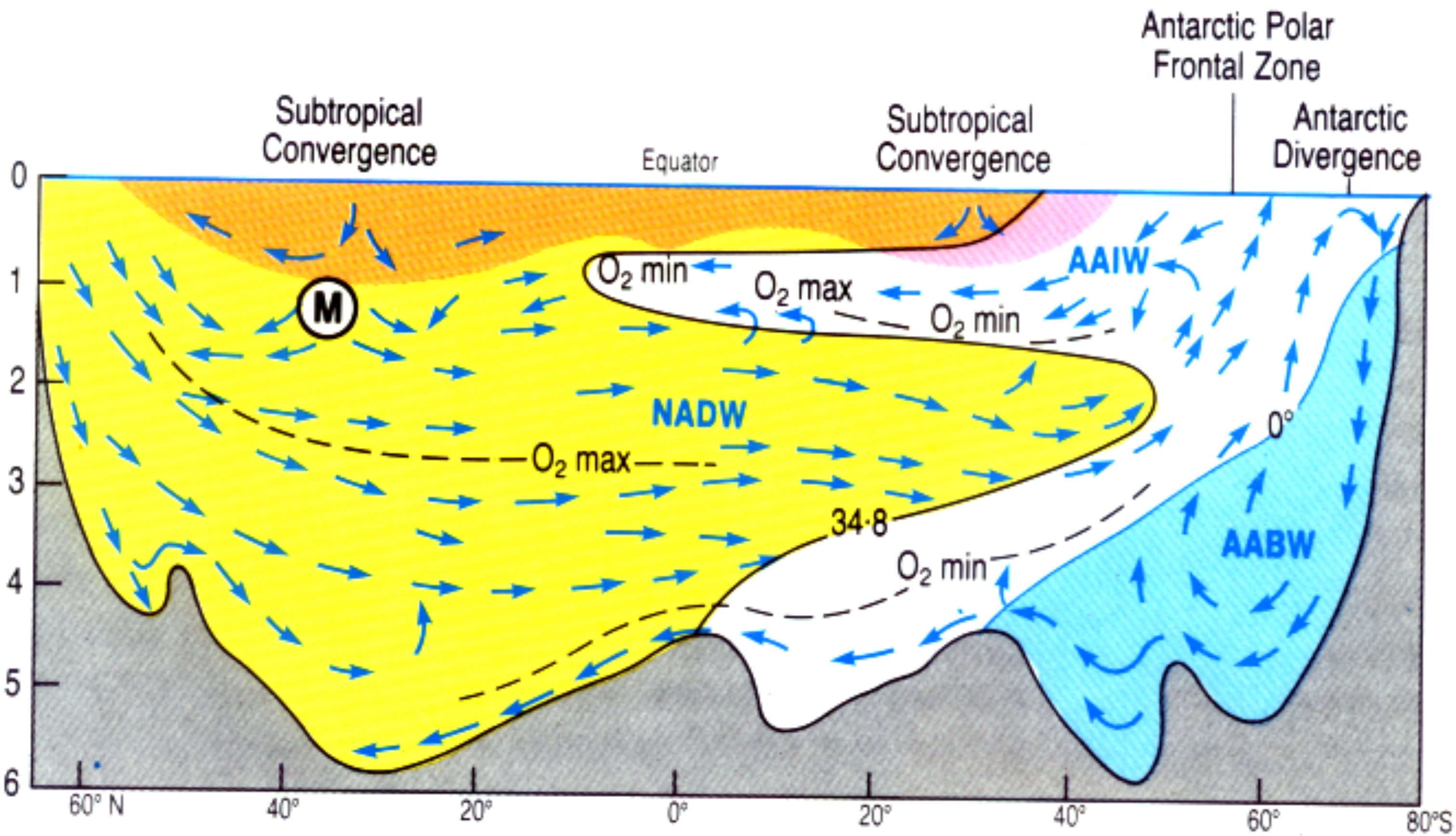
Review of horizontal wind driven circulation

This map depicts the flow paths of some deep-water masses.



(a) THERMOHALINE CIRCULATION

Vertical (70N-80S) section of the Atlantic



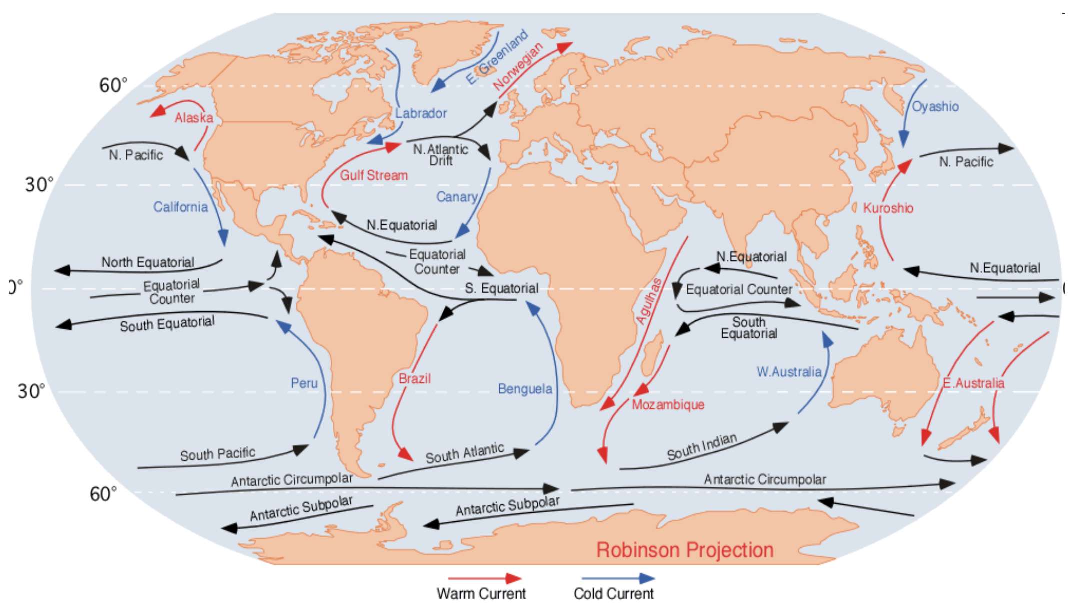
North Pole

South Pole

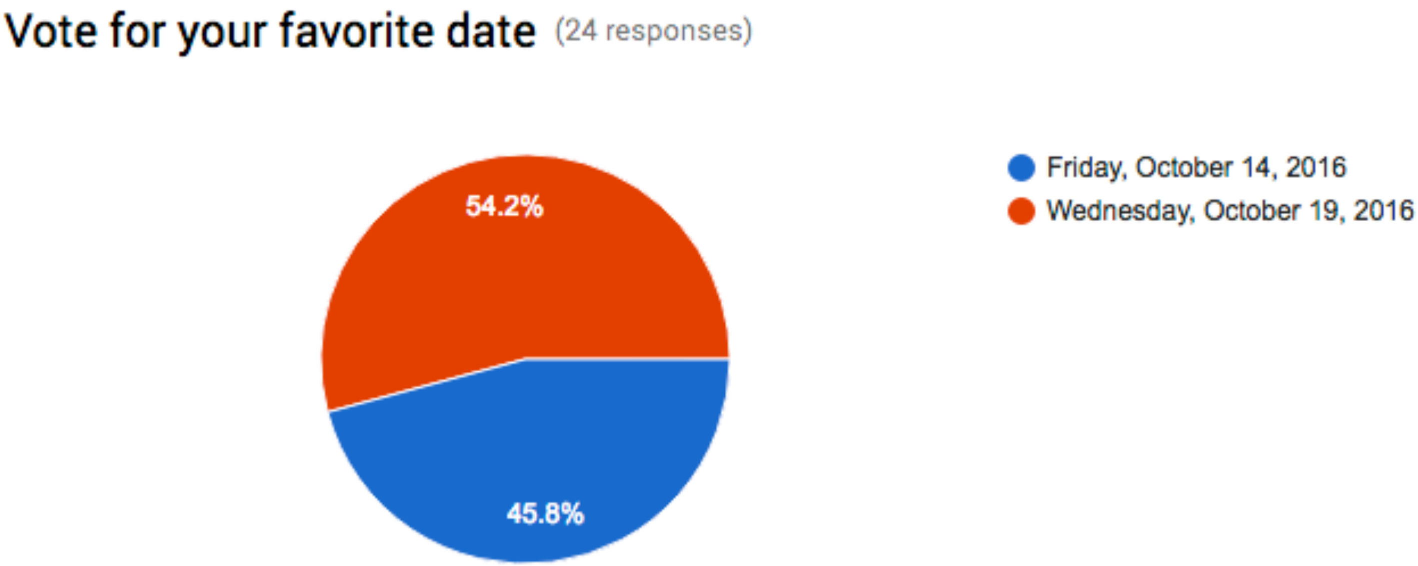
Mechanism of formation

- The Gulf stream (then NA current) brings warm, salty water from the tropics to the North (remember the shape of the Atlantic subtropical gyre)
- In winter this salty, surface water is cooled down by the storms and cold air that blow from America towards Europe
- The surface water is now cold and salty: it can sink

Surface Currents and Ocean Gyres



EAS-4300 Oceanography Midterm

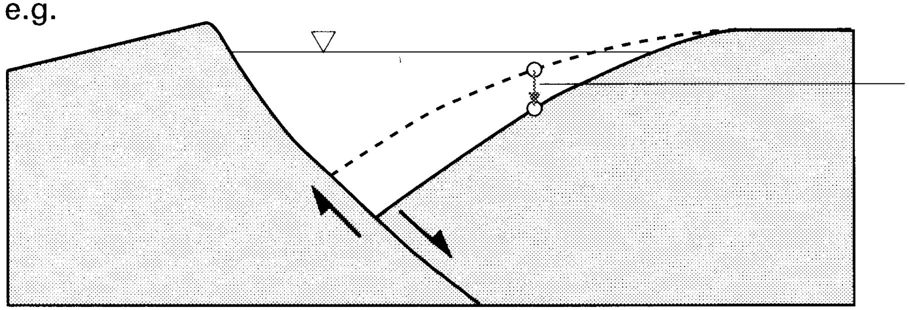


Wednesday, October 19, 2016

CAUSES OF SEA LEVEL CHANGE

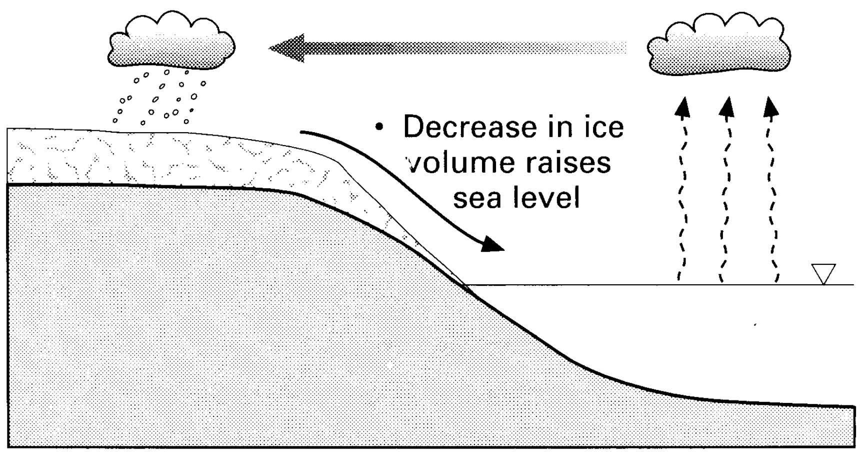
Local tectonics

e.g.



Very variable rates and magnitudes of relative sea level changes

Continental ice caps



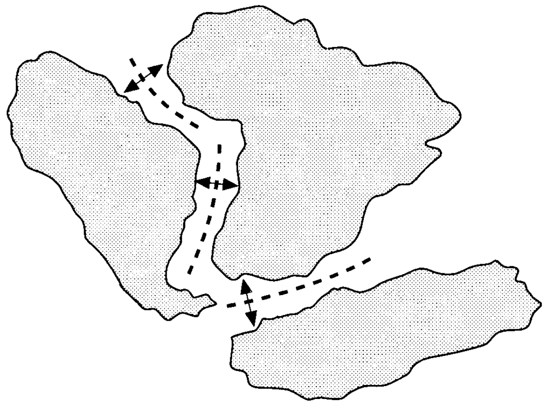
• Increase in ice volume lowers sea level

Around 100 m sea level change over 100 ka

100 meters over 100 ka

10-100 meters over 10-100 ma

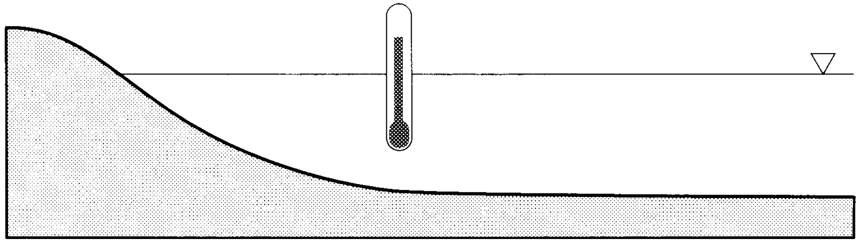
Global scale thermo-tectonic



- Formation and breakup of supercontinents
- Changes in rates of formation of ocean crust

10–100 m sea level change over 10–100 Ma

Sea water temperature

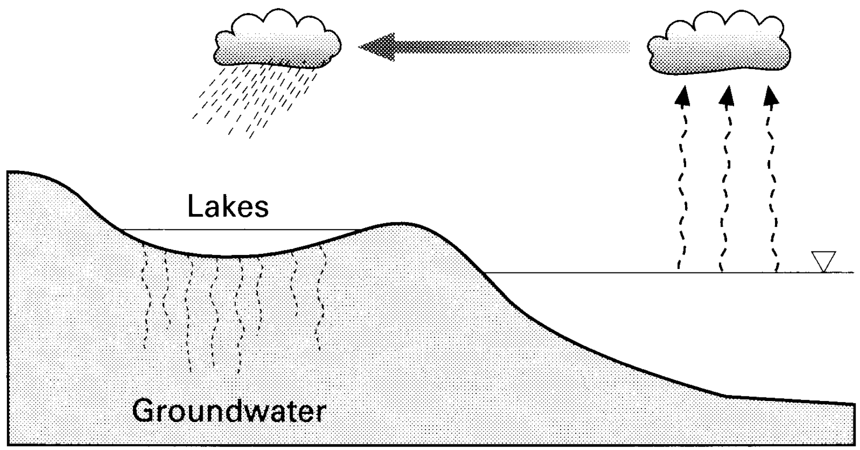


- Changes in sea water temperature cause thermal expansion/contraction

Centimetres to a few metres change over hundreds to thousands of years

cm to a few meters over 100 years

Exchange with water on continents

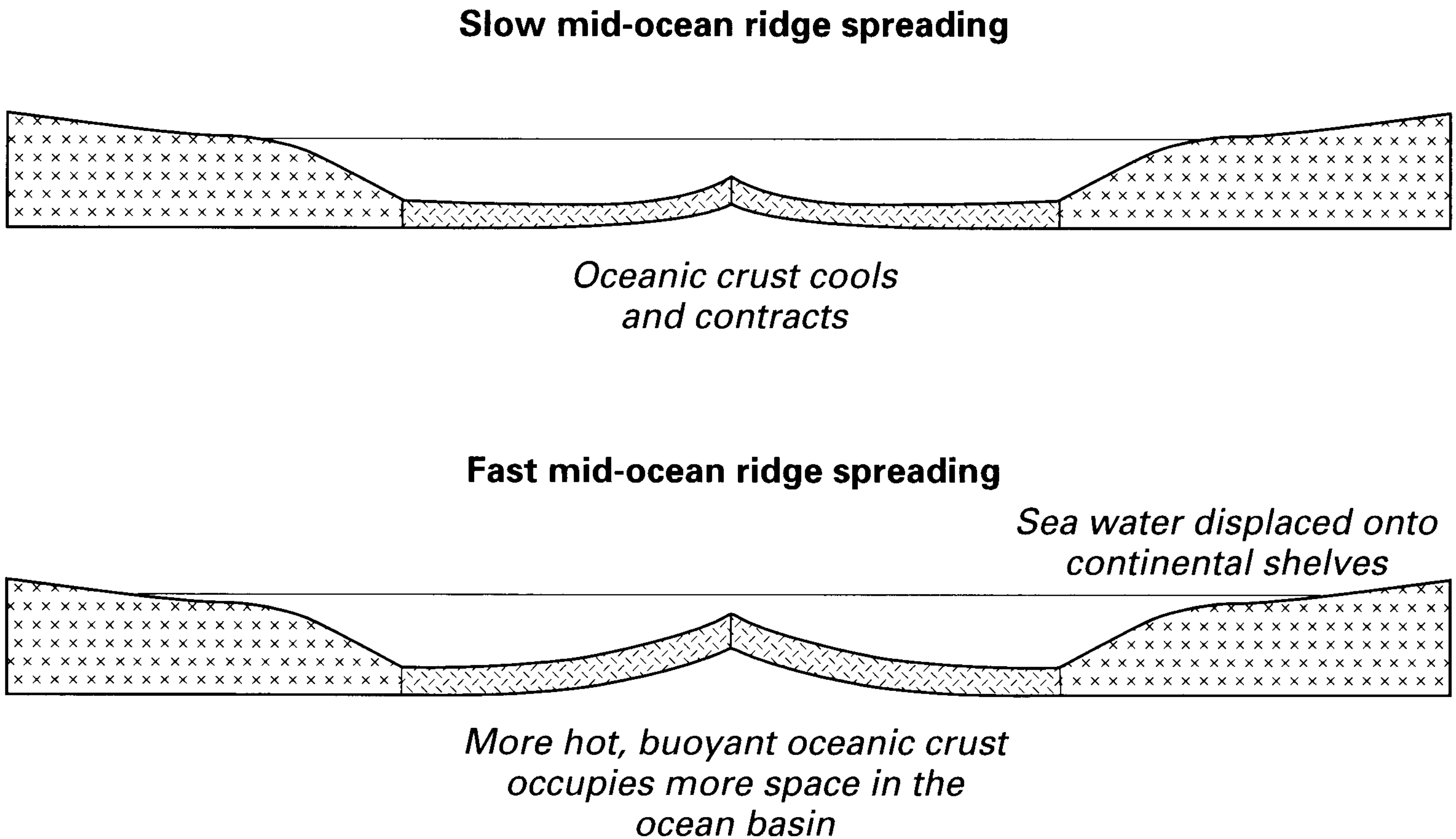


Centimetres to metres change over hundreds to thousands of years

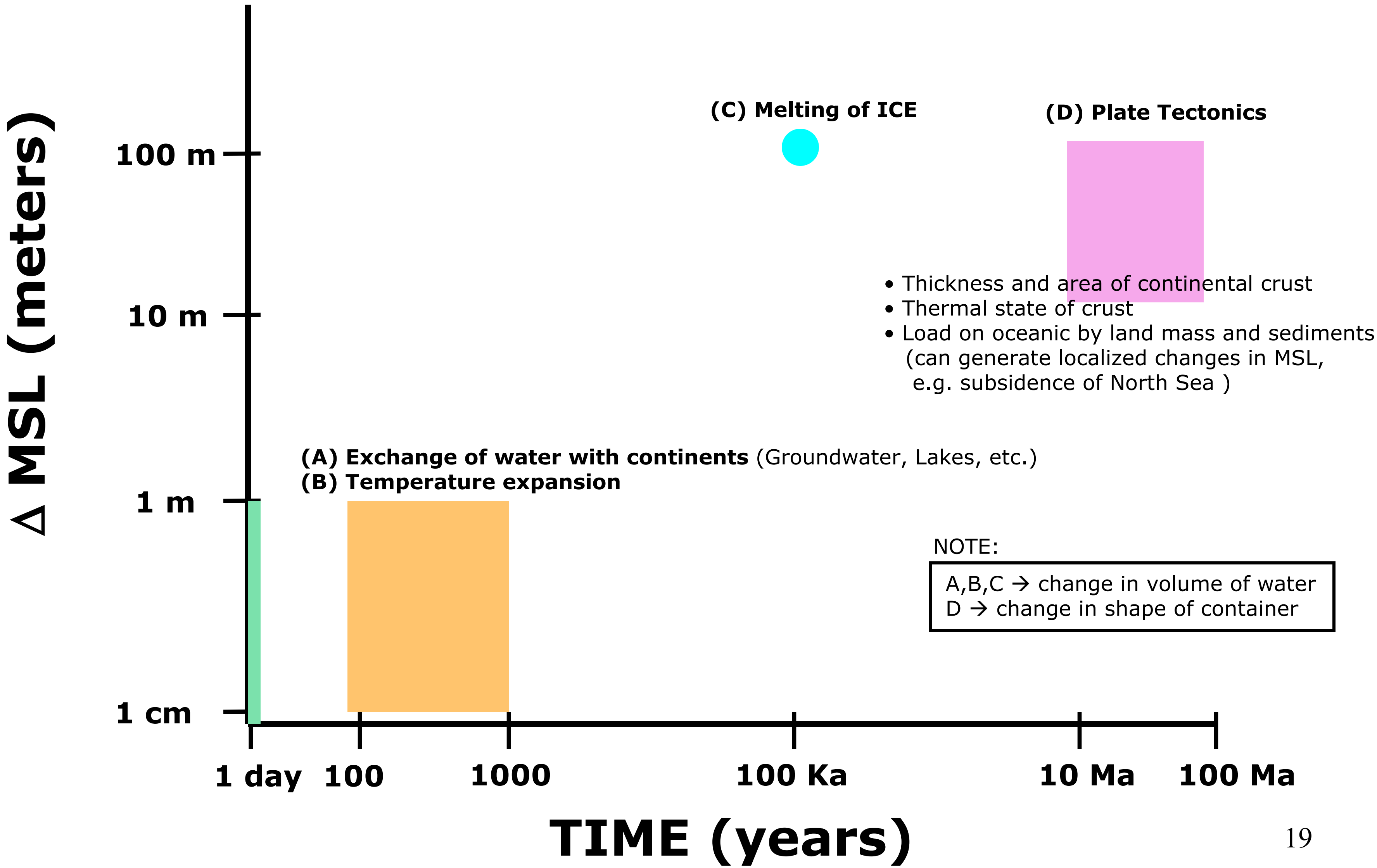
cm to a few meters over 100-1000 years

Other effects of plate tectonics

e.g. Upper Cretaceous (90 Ma) MSL > 300 m

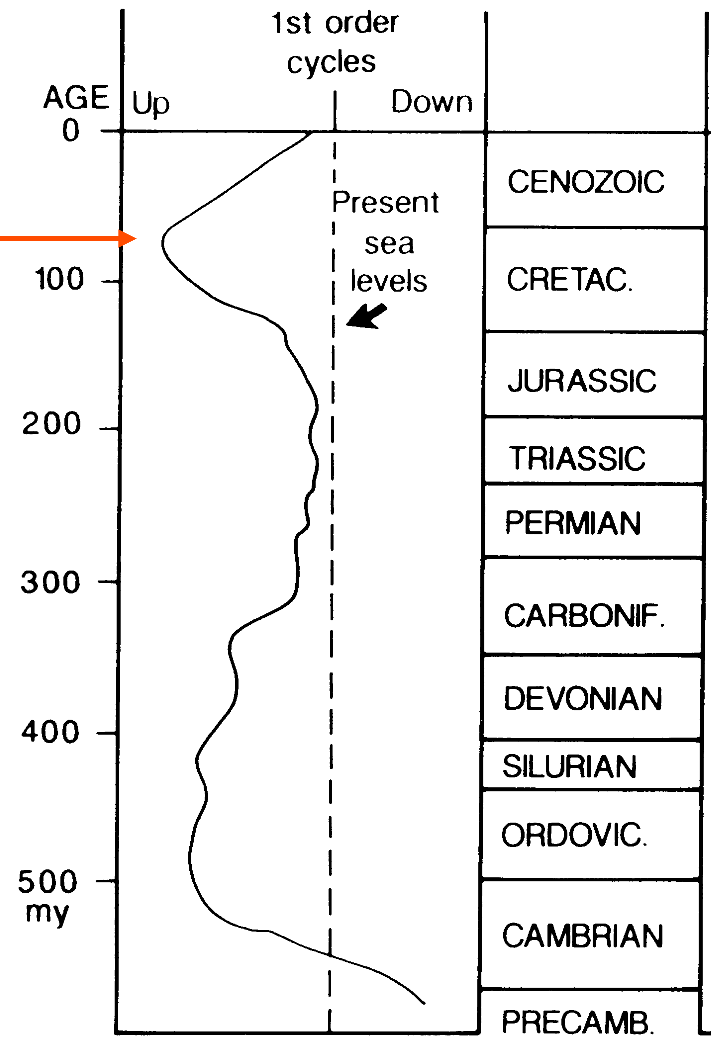


Summary of spatial-temporal scale of processes contributing to Mean Sea Level



Sea Level Change

?



Antarctic Bottom Water (AABW)

- When sea ice freezes, it leaves salt behind
- Adds salt to coldest water on earth around Antarctica
- Becomes the densest water in the ocean and sinks

Deep water formation in **Weddell** and **Ross** seas

Antarctic Bottom Water (AABW)

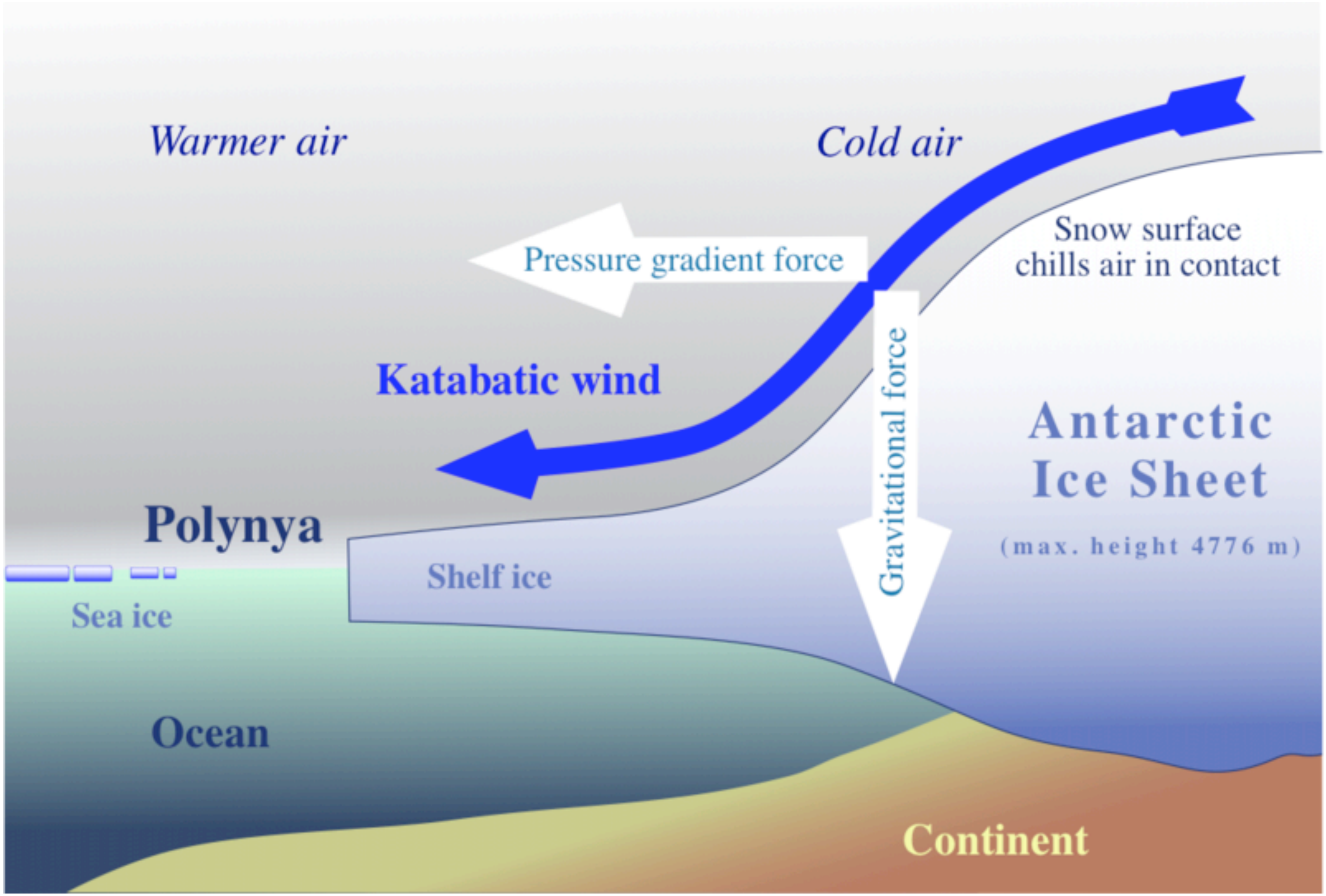
- **Polynya: body of open water through most of winter surrounded by sea ice.**
- **Polynyas size: few square kilometres to hundreds of thousands of square kilometres.**
  The 350,000 Km^2 Weddell Sea Polynya near the Greenwich Meridian, which occurred from 1974 to 1976, was the largest polynya ever observed.

How do Polynyas form?

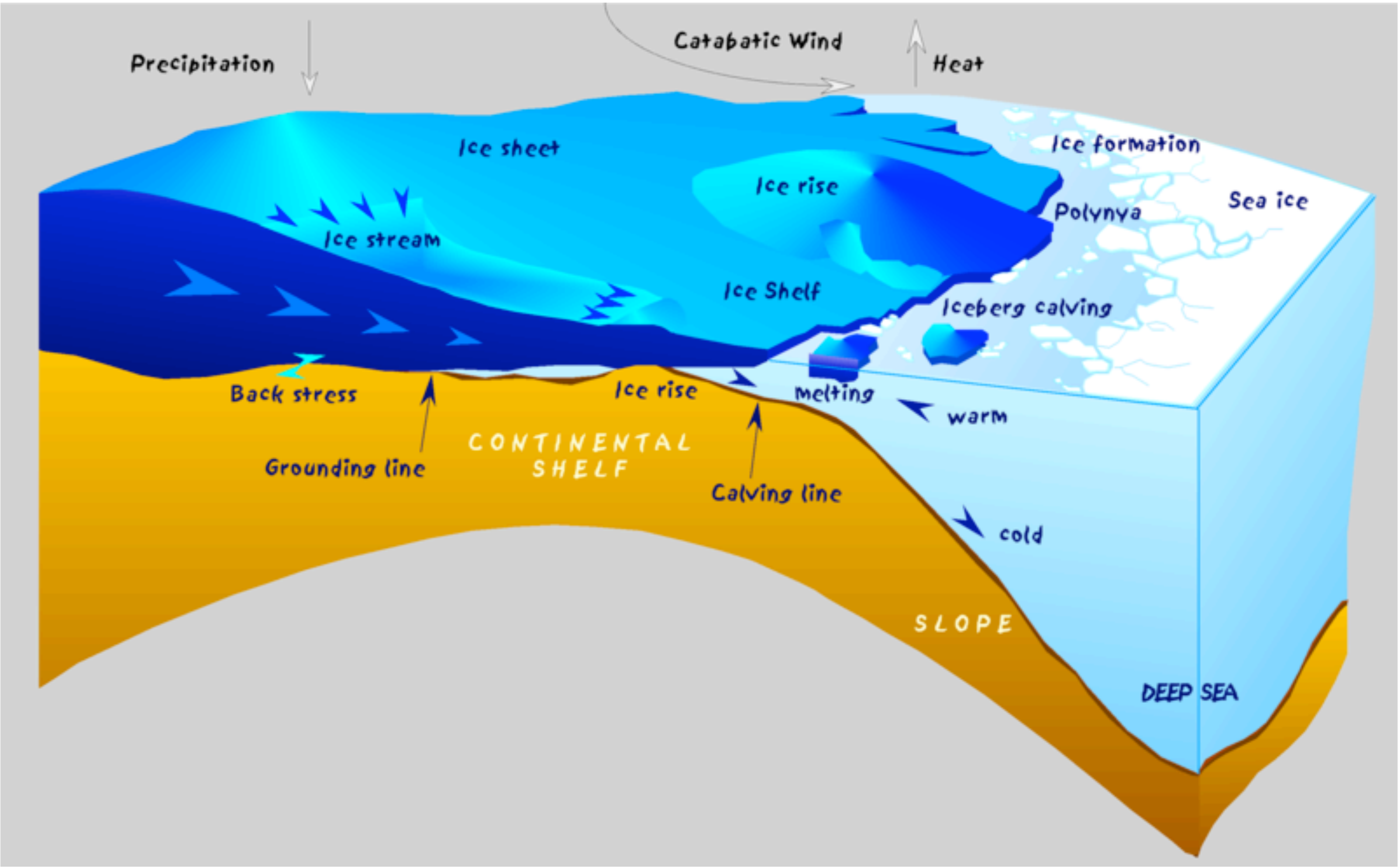
- **Sensible heat** polynyas: formed by the upwelling of warm water, which makes the surface water warm enough to melt existing ice and/or prevent new ice from forming. <u>*These are areas of low ice production*</u>.

- **Latent heat** polynyas: form in areas in which sea ice is removed by winds and/or ocean currents as quickly as it forms. Very high rates of sea ice formation. They are called the ‘ice factories’ of the Antarctic sea ice zone.

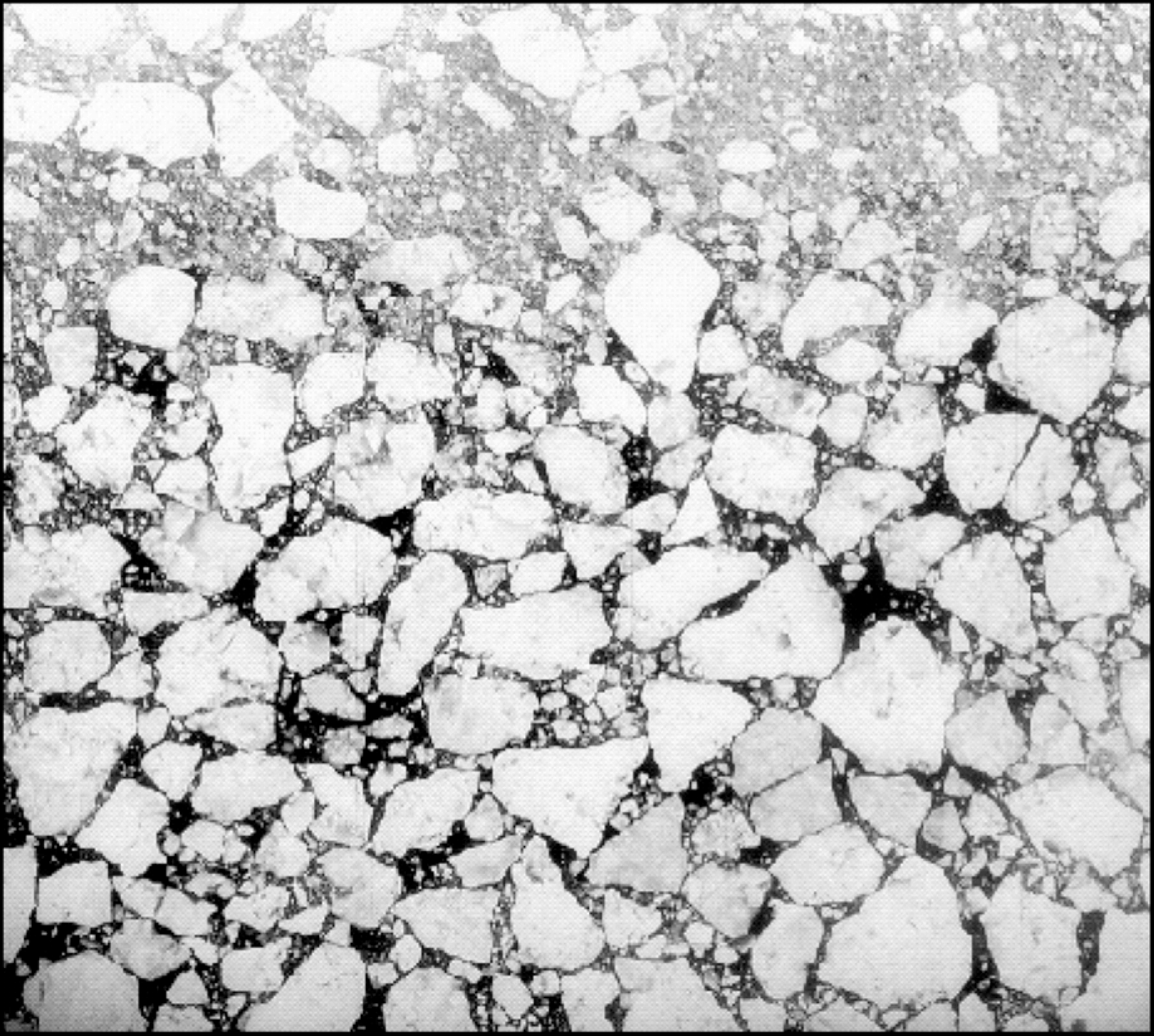
  LH polynyas have two distinct regions – a central open-water area where ice is constantly being formed (the ‘active polynya’) and an outer ring where the ice piles up as it is moved from the centre (the ‘young ice’ area).


Warmer air
Cold air
Pressure gradient force
Snow surface
chills air in contact
Katabatic wind
Gravitational force
Antarctic
Ice Sheet
(max. height 4776 m)
Polynya
Shelf ice
Sea ice
Ocean
Continent

Polynya (schematic)

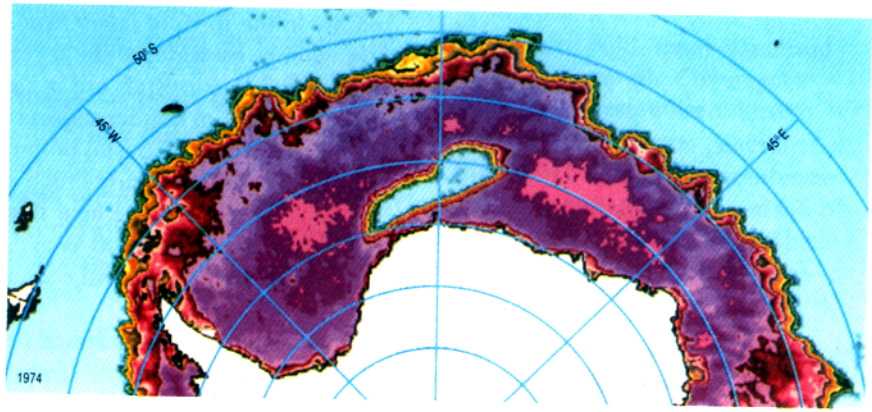


How the ice move in an Antarctic Polynya?

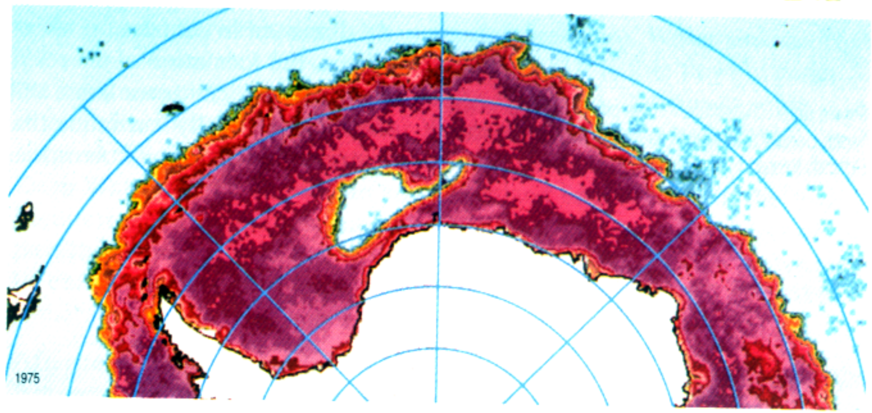


Weddell Sea Polynya (winters)

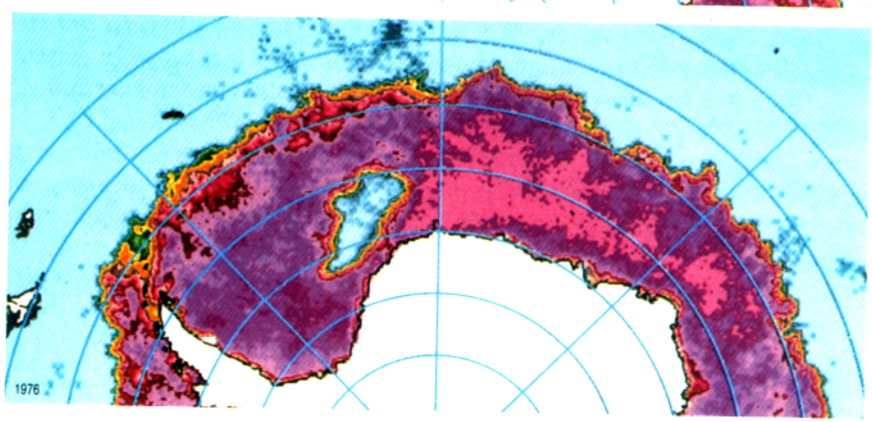
1974



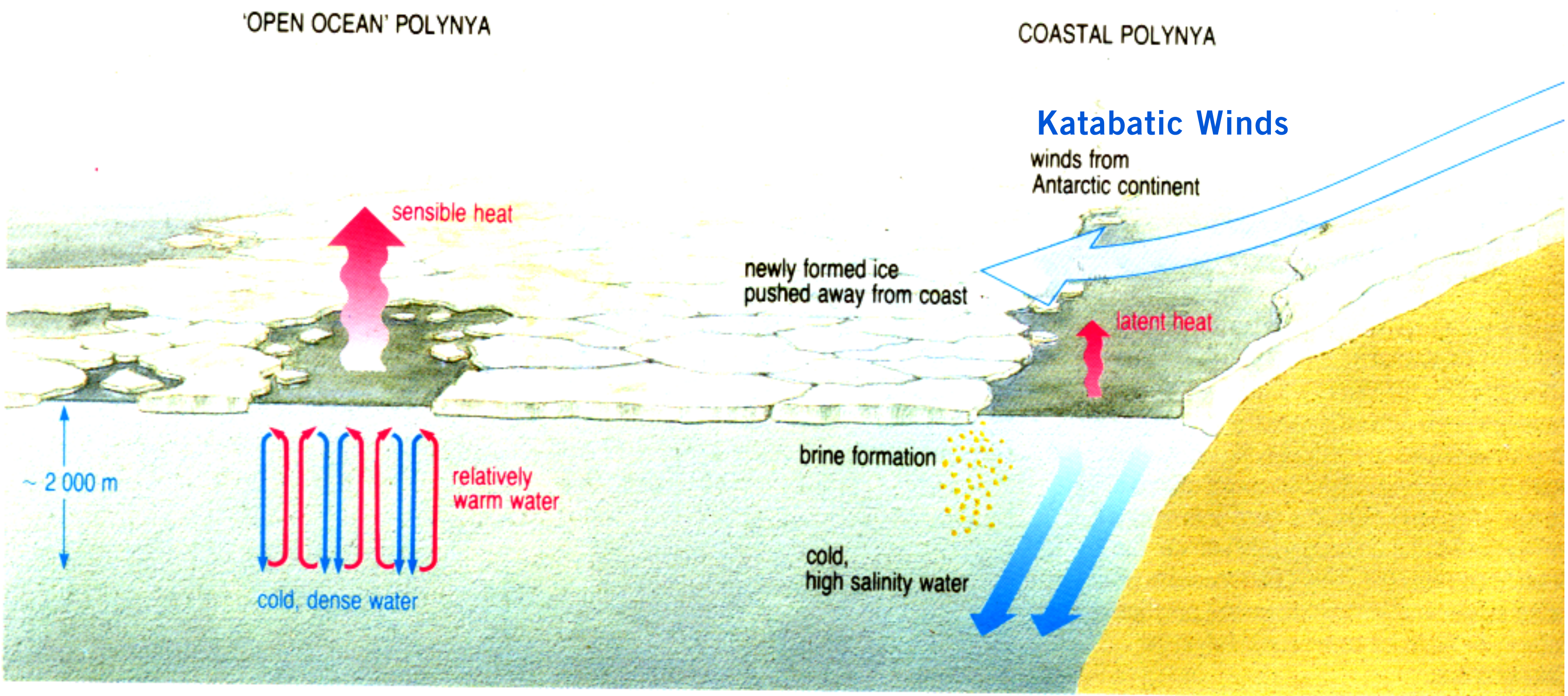
1975



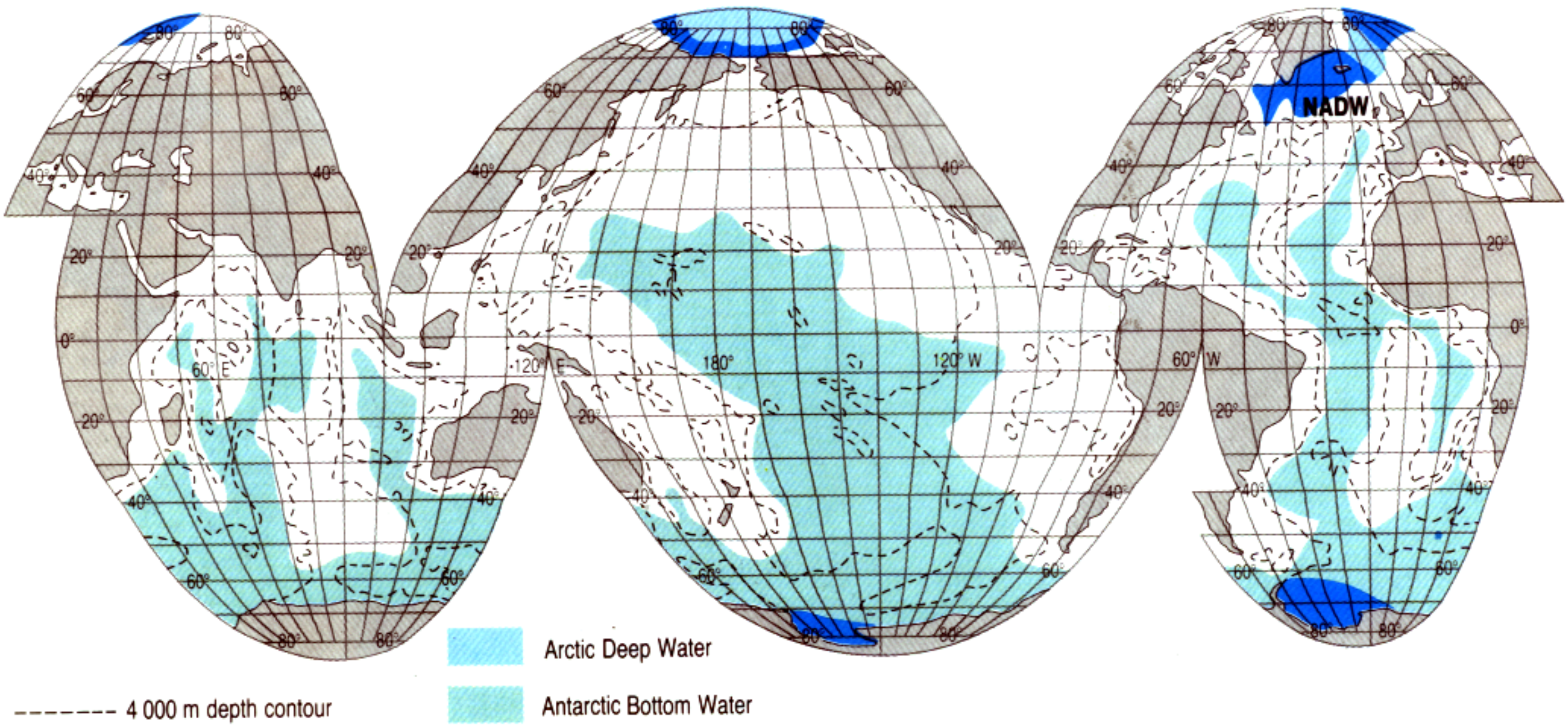
1976



Formation of Antarctic Bottom Waters

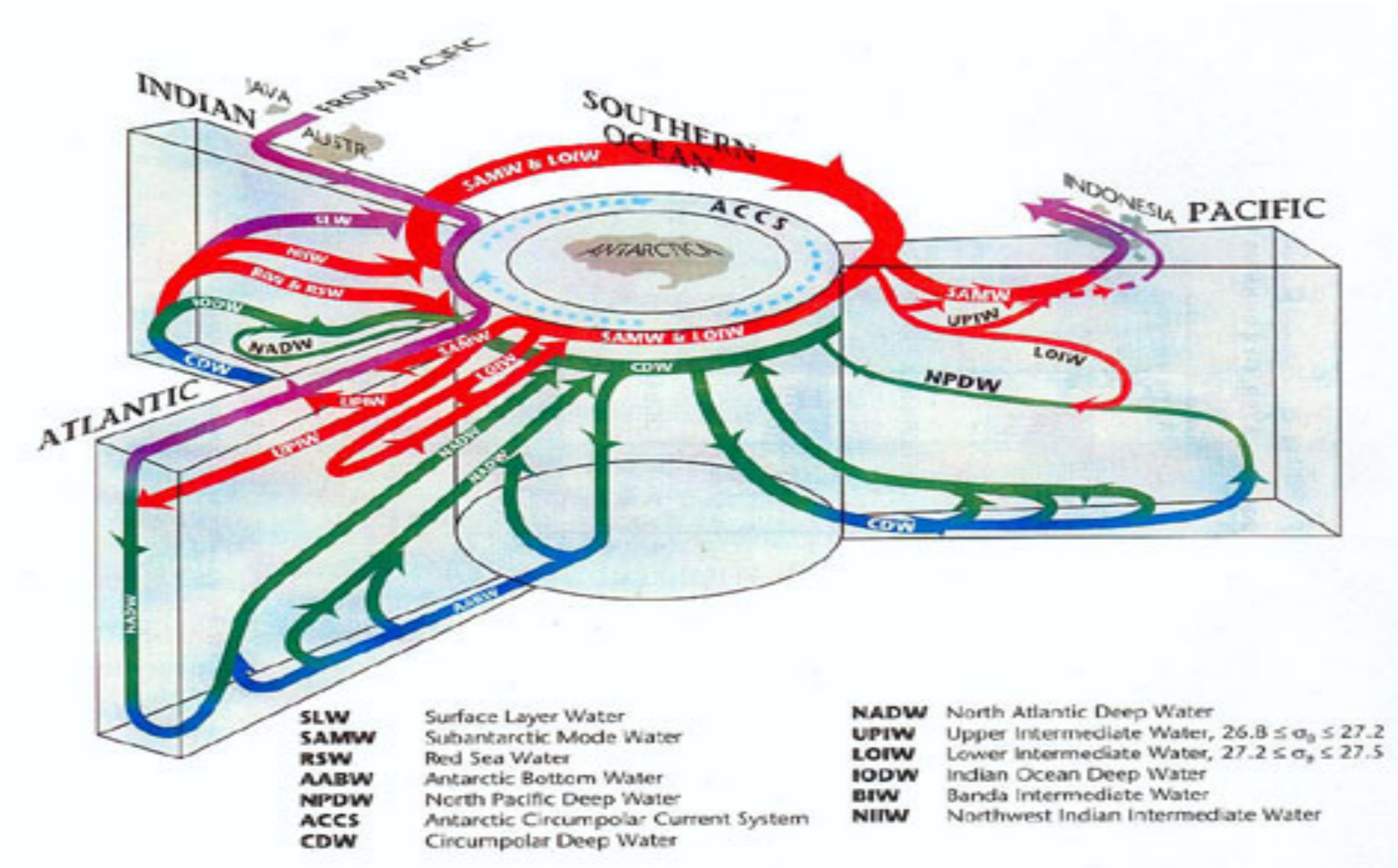


Spread of the AABW



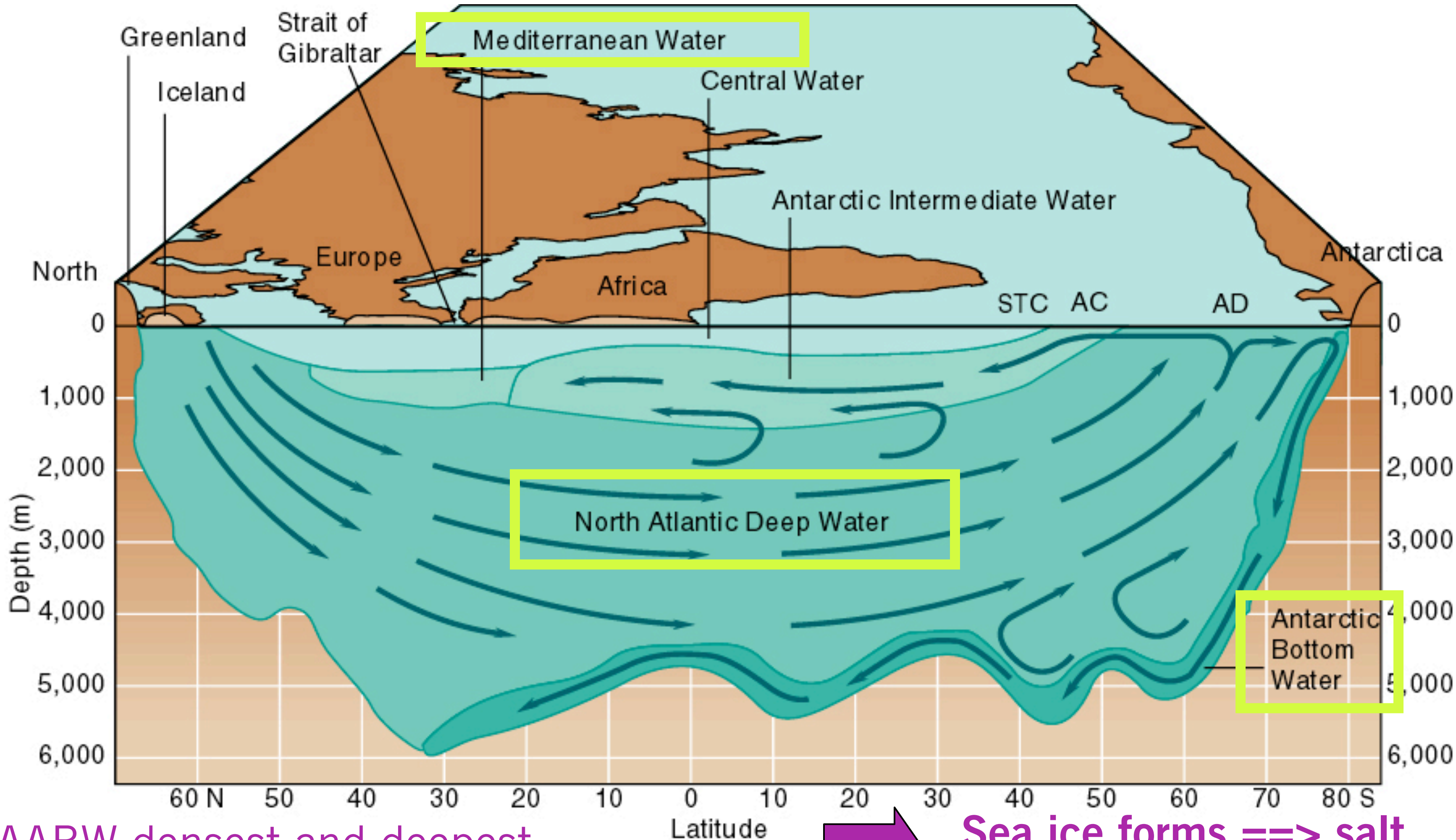
Why deep water form in the North Atlantic and not in the North Pacific?

- Convective Precipitation: over 80% of it happens in the Pacific
- The surface waters that from the tropics move to higher latitudes in the Pacific are fresher



(From Siedler, 2001, figure 1.2.7, as taken from Schmitz, 1996).

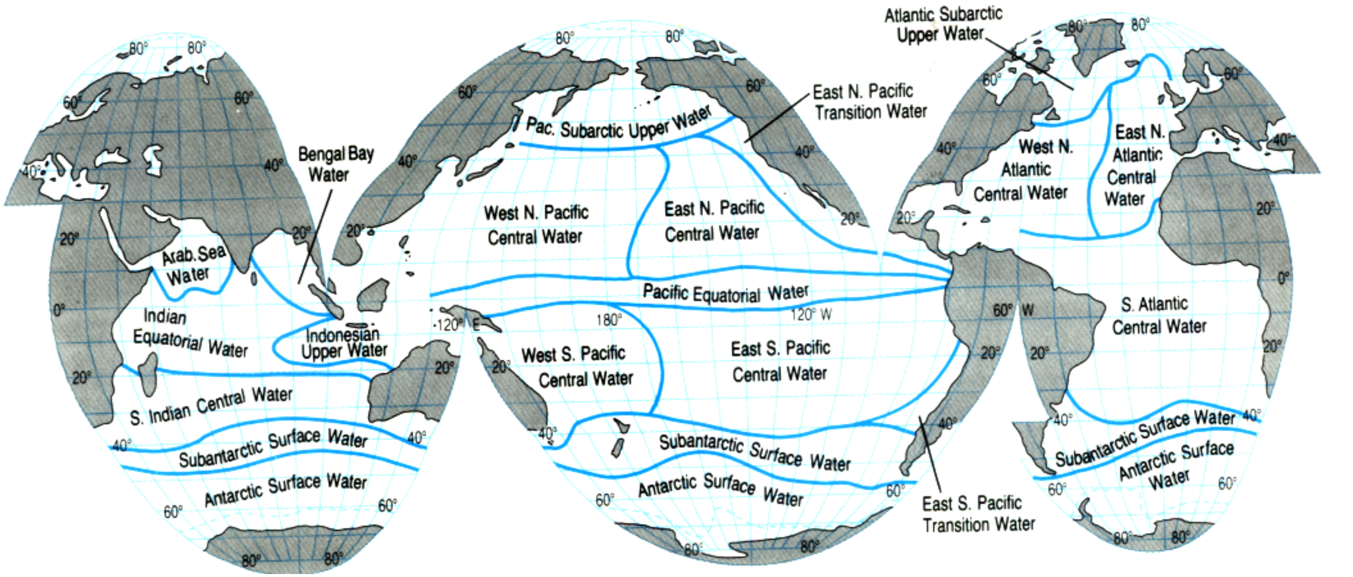
SUMMARY of Water Masses in the Atlantic



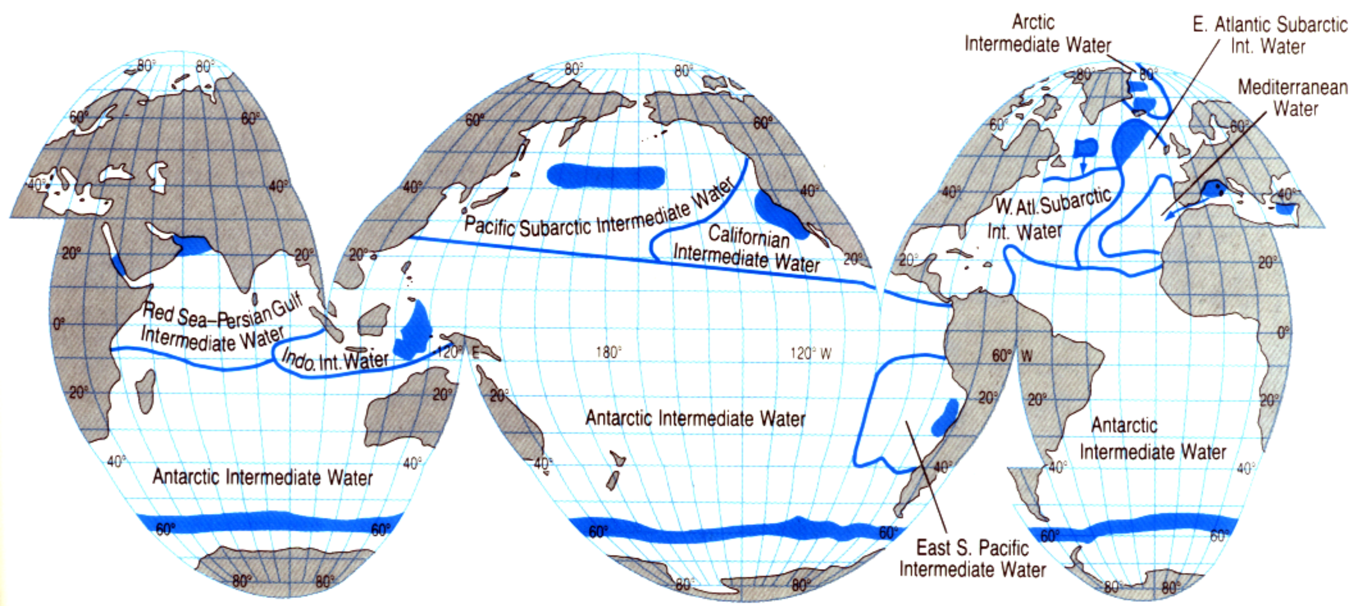
- AABW densest and deepest → **Sea ice forms ==> salt**
- NADW second, fills most of deep Atlantic → **Salty water moving north**
- MOW saltiest but not as dense - sits with other water masses at medium depths → **Evaporation ==> VERY salty**

Water masses are found at different depths because of their different density

Upper ocean

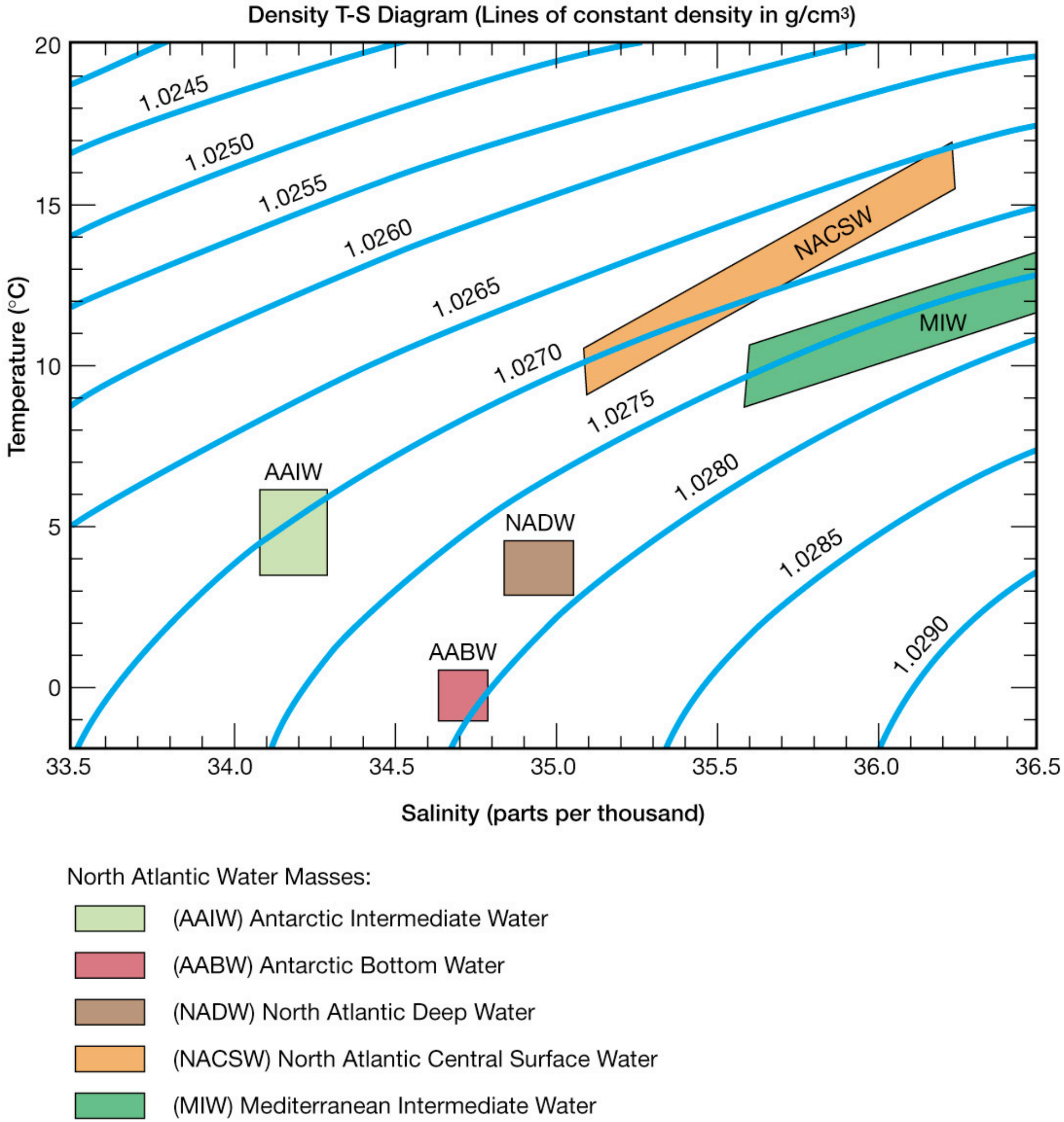


Intermediate



Labeling the world oceans Water Masses

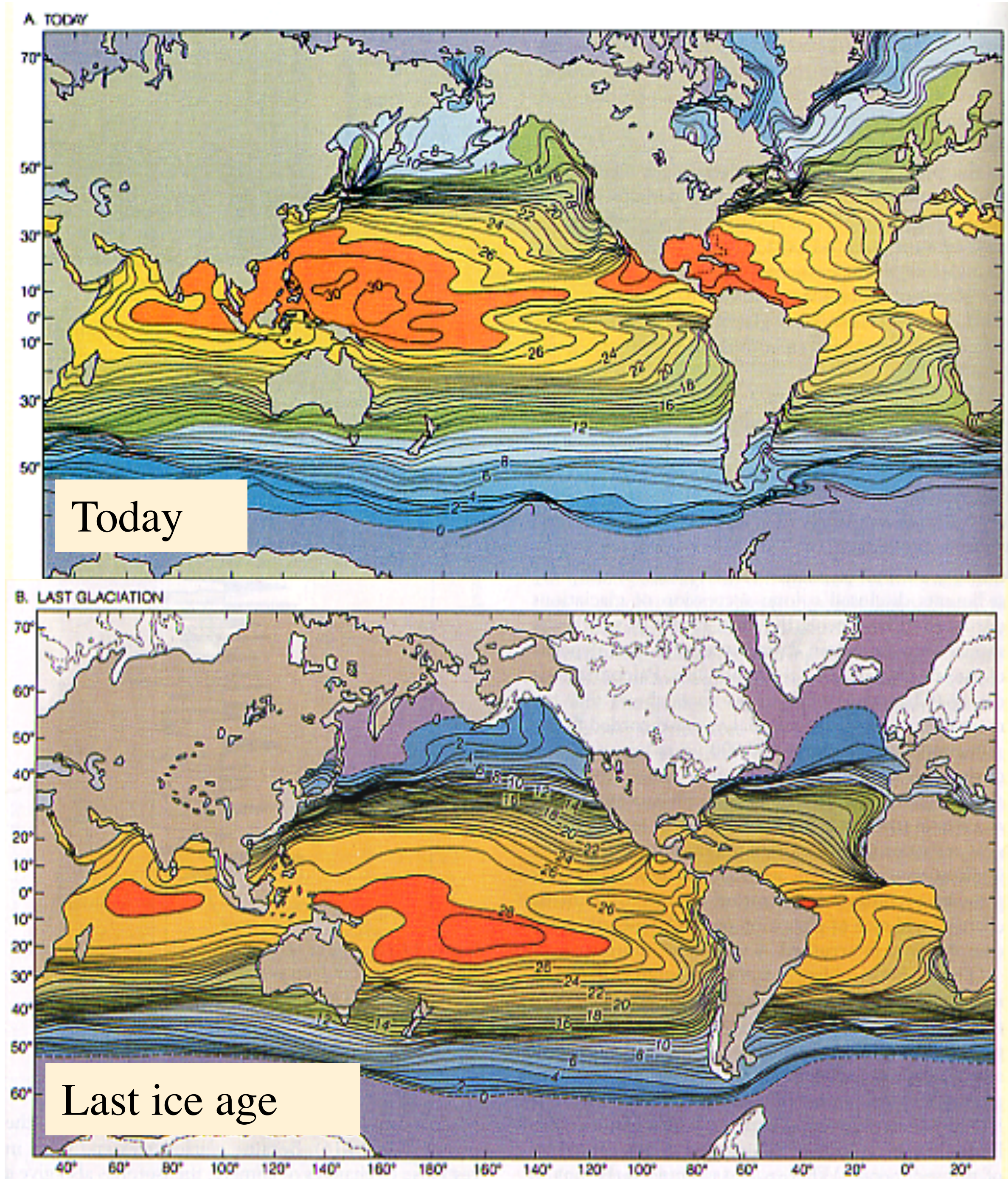
TS Diagrams



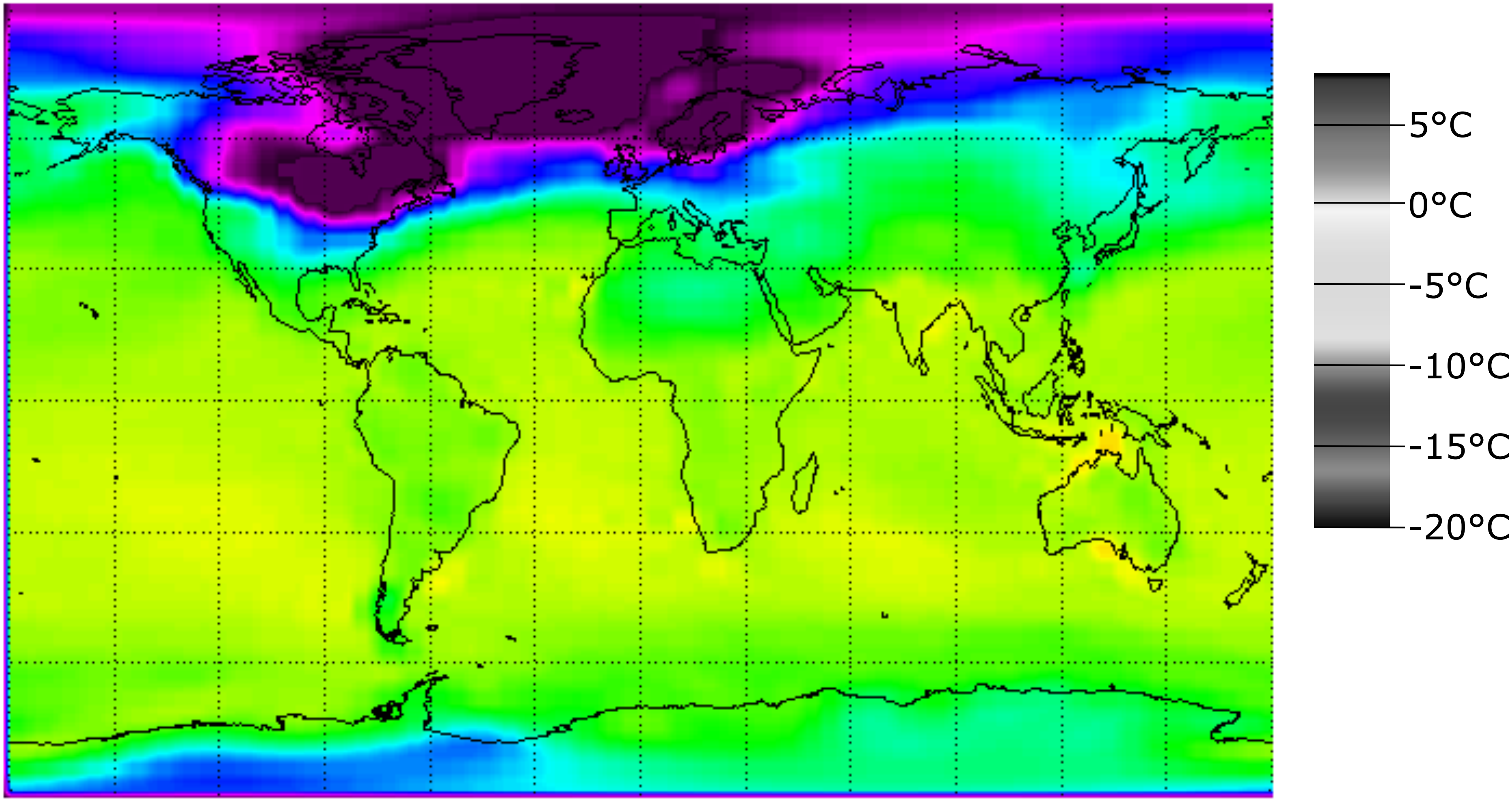
Implications of MOC on Past and Future Climate

Last Ice Age (~max 18000

- Ocean surface temperature maps
- Big difference: N. Atlantic much colder, Gulf



Global temperature change



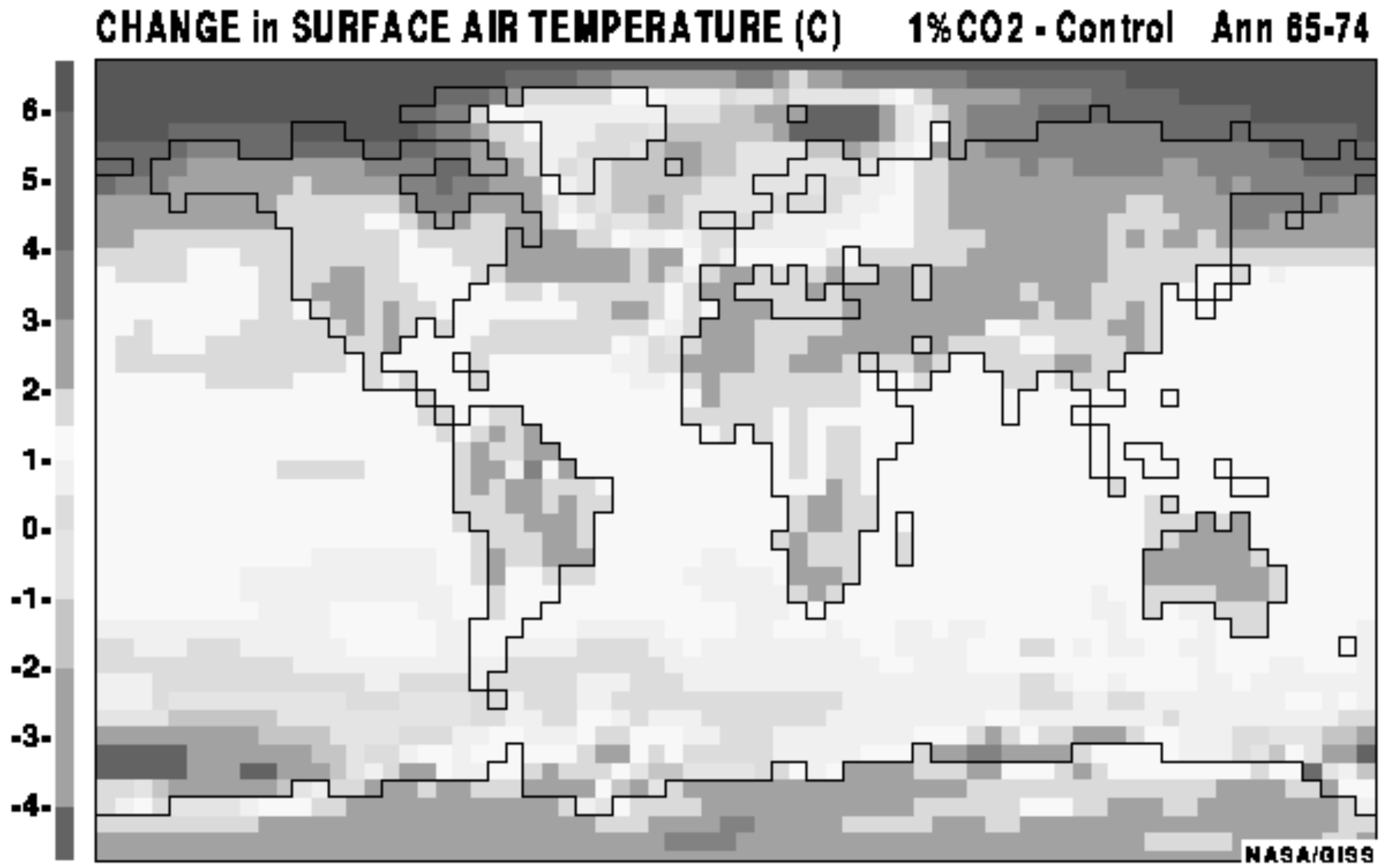
A global effect: Large at high and middle N latitudes, moderate at lower latitudes and in S Hemisphere.

What about the future?

- Global warming
  - Melting of glaciers
  - Probably more precipitation at high latitudes
  - Both cause lower salinity
  - Weaker thermohaline circulation?

- Global warming ==> Regional cooling?
  - MOC shutdown ==> a dramatic European cooling?

Predicted future global warming



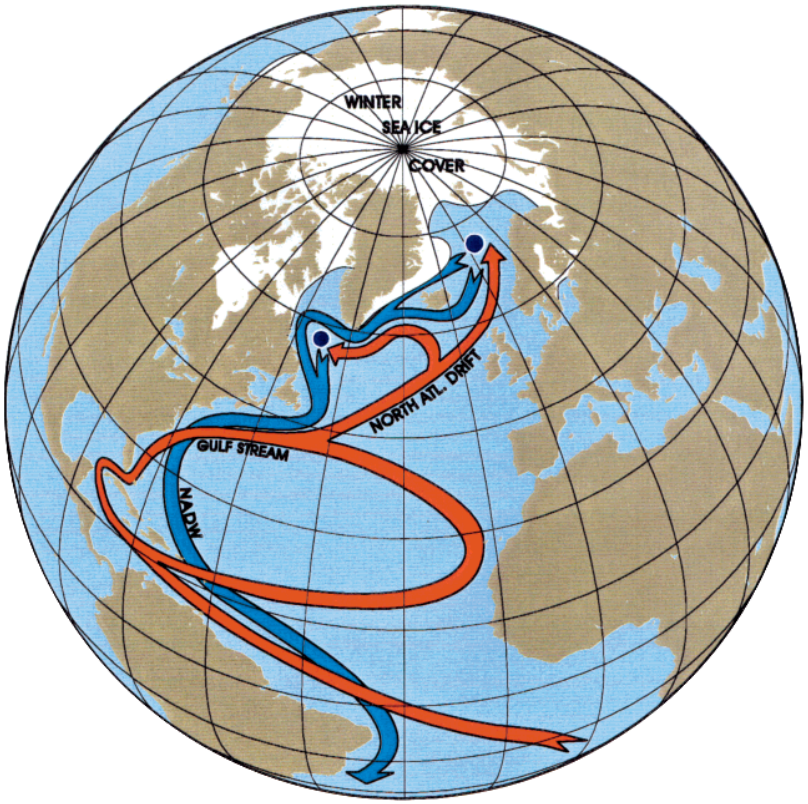
One possibility: In this prediction, the cooling of Europe is directly related to thermohaline collapse.

Ice ages of the past 2 million years

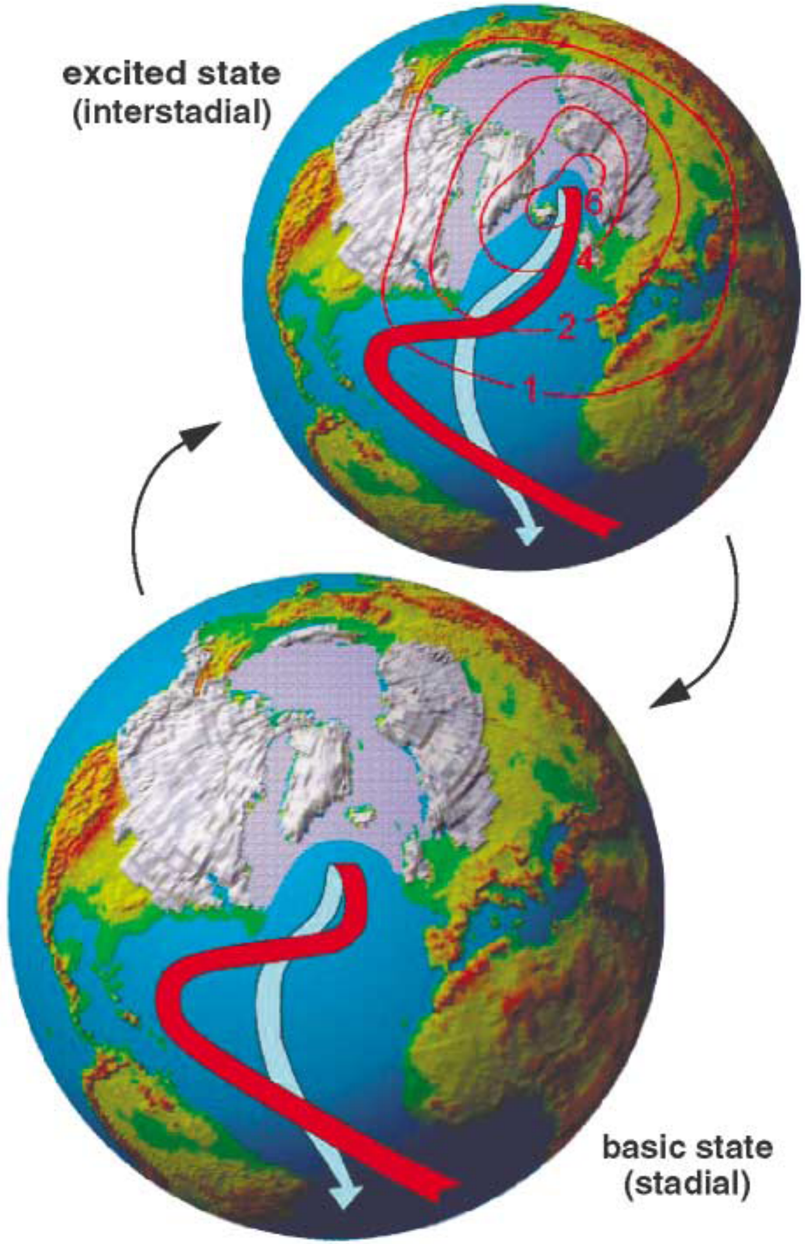
- Reminders :
  - Most recent: 20,000 years ago
  - Evidence from sediments for temperature, sea level, ice sheets
  - Sea level change: -120 m
  - Ocean circulation: conveyor shutdown

From Stefan Rahmstorf

http://www.pikpotsdam.de/~stefan/

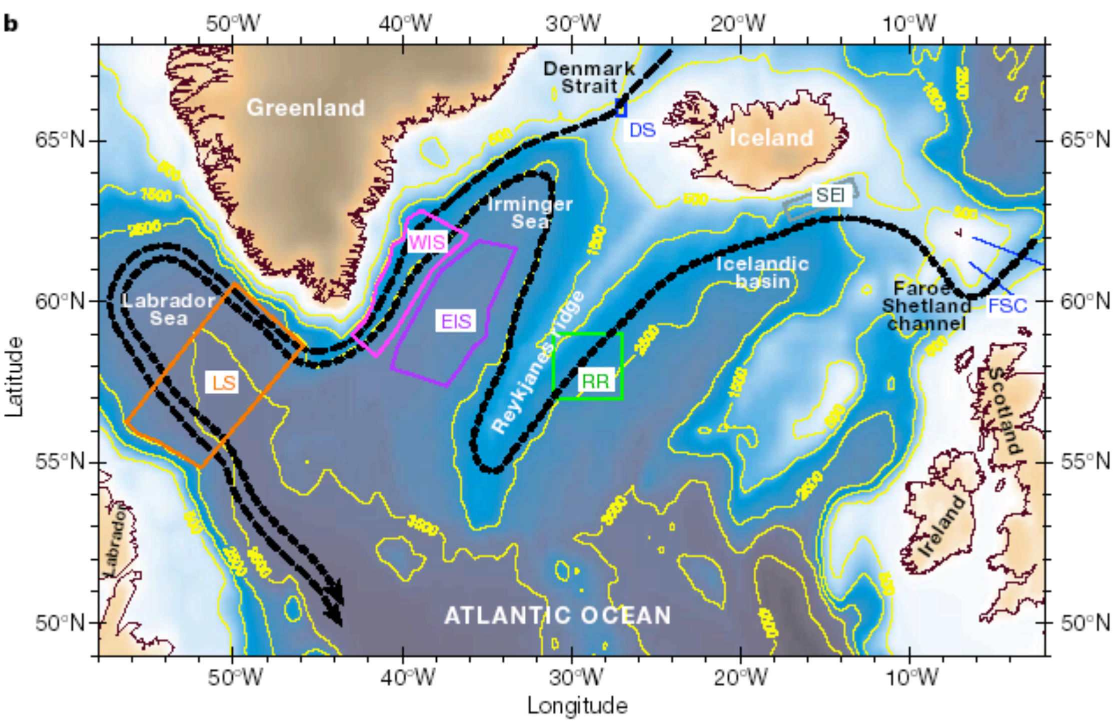


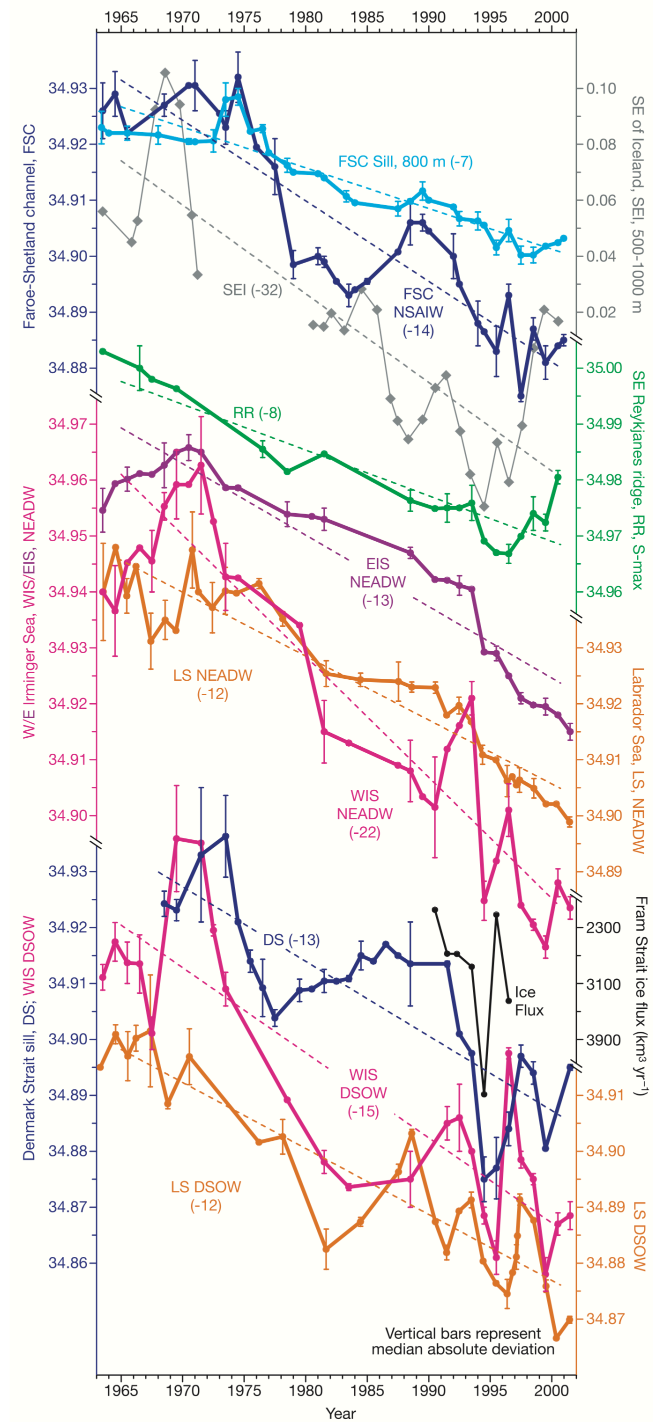
Today



Stadial and interstadial during ice age

- Modern N. Atlantic:
  - Salinity measured from many places (Dickson et al. 2002, *Nature*)
  - Data in plot extend from 1965-2000
  - Consistent pattern: North Atlantic is getting less salty





Recent MOC history

- 2004: U.S. satellite data seemed to show a slowing of the North Atlantic Gyre
- May 2005: Peter Wadhams reported to *The Times* that a submarine under the Arctic ice sheet measuring the convective plumes of cold dense water, found instead warm water. He and his team found the chimneys to have virtually disappeared. In past missions seven to twelve plumes were observed, but in winter 2004-2005 Wadhams found only two, both extremely weak.
- Dec 2005: Bryden et al report in Nature in **Slowing of the Atlantic meridional overturning circulation at 25° N** a 30% reduction in the warm currents that carry water north from the Gulf Stream from the last such measurement in 1992. The paper points also to large uncertainties but in News and Views is portrayed as "We may be close to a turn point"

- January 2006: a News Feature *Climate change: A sea change* by Quirin Schiermeier appeared in *Nature*, with reactions to the Bryden results. Key point to reject Bryden conclusions: 1) Modelling suggests that increase of fresh water flows large enough to shut down the thermohaline circulation would be an order of magnitude greater than current; 2) Bryden' results could be caused by natural variation, or "noise", that is, coincidence, because the measurements are not continuous in time; 3) even if the results are correct, MOC reductions will not have the drastic effects that have been predicted on European cooling (because Europe is not showing much cooling), possibly because of overall global warming.
- In 2008, Vage et al. reported in Nature Geoscience "the return of deep convection to the subpolar gyre in both the Labrador and Irminger seas in the winter of 2007–2008," employing "profiling float data from the Argo program to document deep mixing," and "a variety of in

End of lecture