Ch 5: Oceans

Circulation of oceans is closely related to circulation of the atmosphere.

Both are important in transferring energy from the equator towards the poles.

Oceans

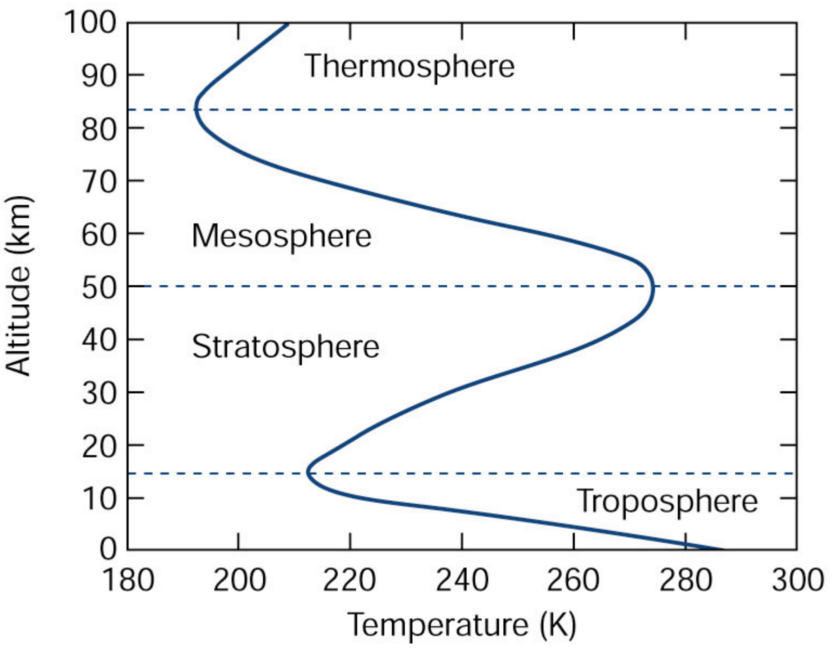
- Shallow circulation
- Deep circulation
- Ocean circulation and climate

1. Shallow ocean circulation

Solar heating warms ocean surface; 90% of radiation is absorbed in top 100 m.

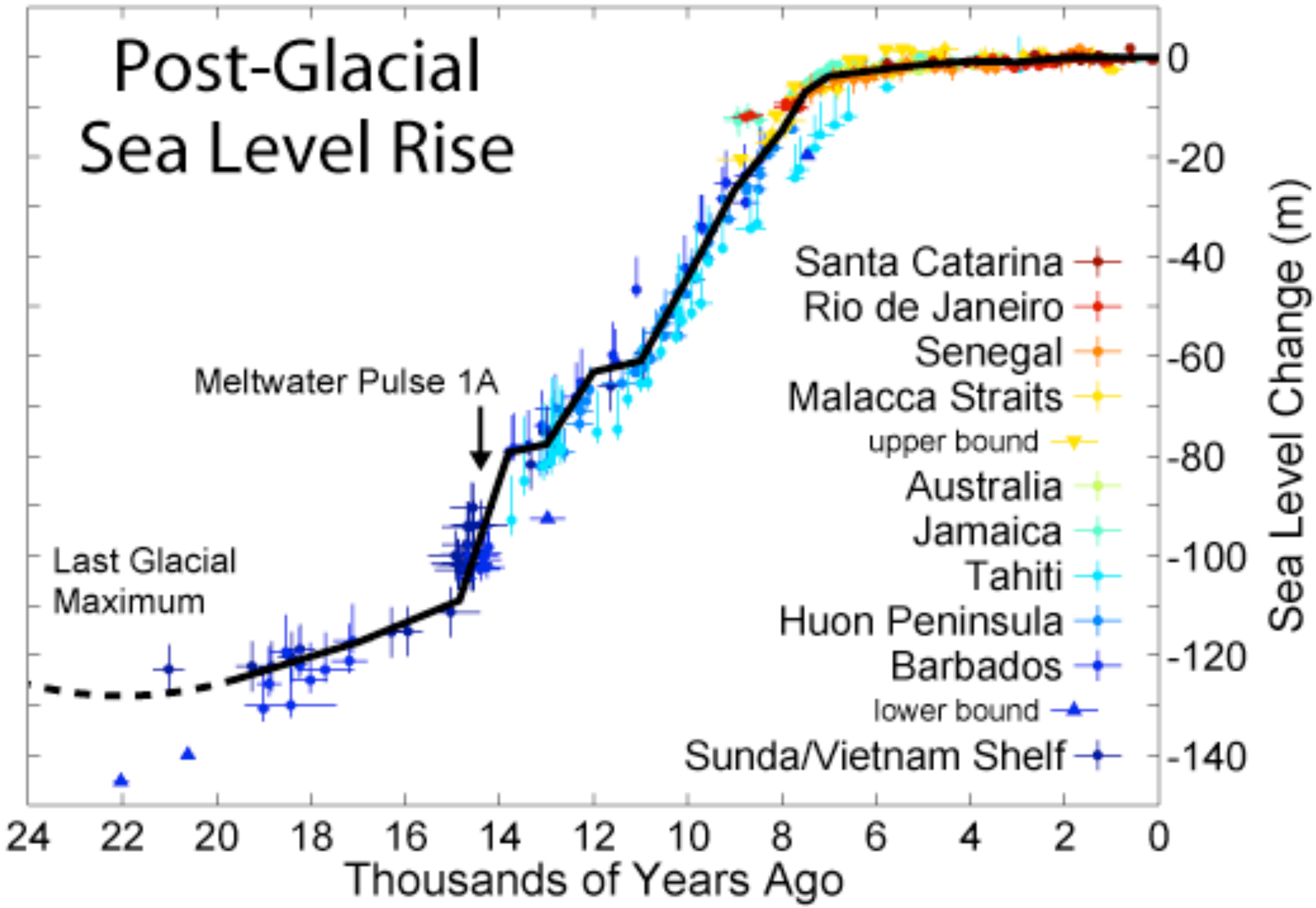
Warm water on cool water is stable, like stratosphere is stable.

Circulation of shallow ocean is driven by atmospheric winds via friction



(b)

End of the last ice age led to subtantial sea-level rise!



Stanford, J. D., et al. (2010) Global and Planetary Change doi:10.1016/j.gloplacha.2010.11.002

98% of water on land is in the form of ice. If Greenland and Antarctic ice melted, sea level would rise 60-70 m, and the oceans would flood New York City, Philadelphia, Baltimore and Washington DC.

Surface ocean currents flow the same way the winds move.

Fig 4-11

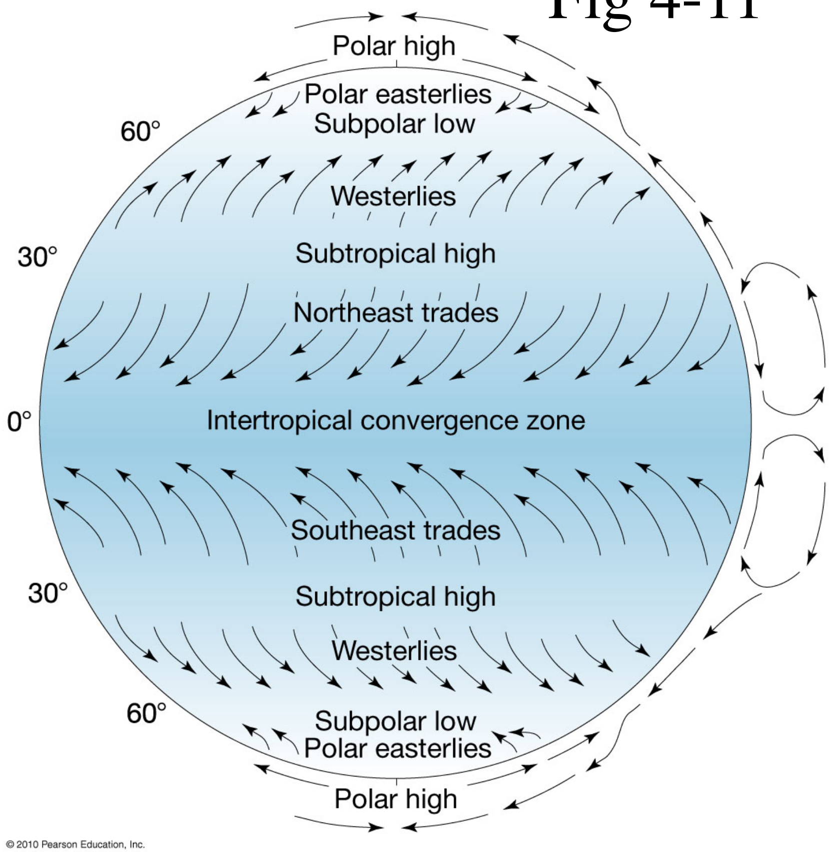
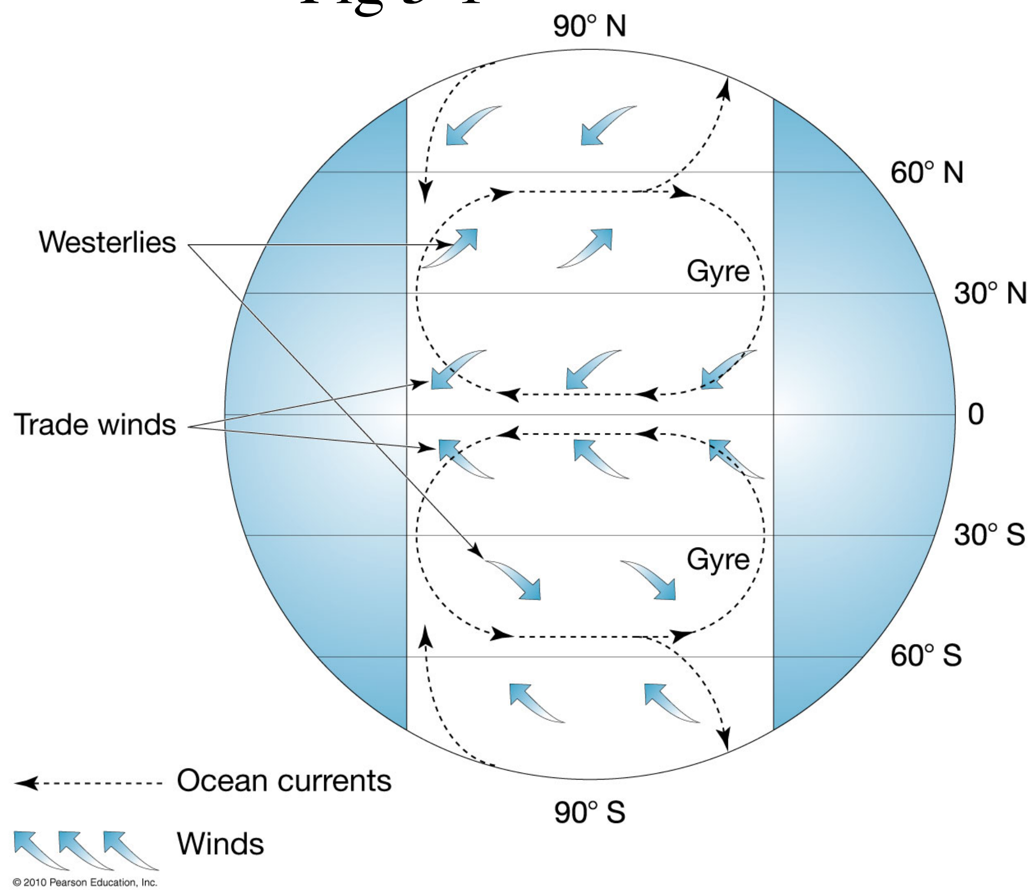


Fig 5-1



Note curved paths…

Coriolis: A repeat! Several different influences, including:

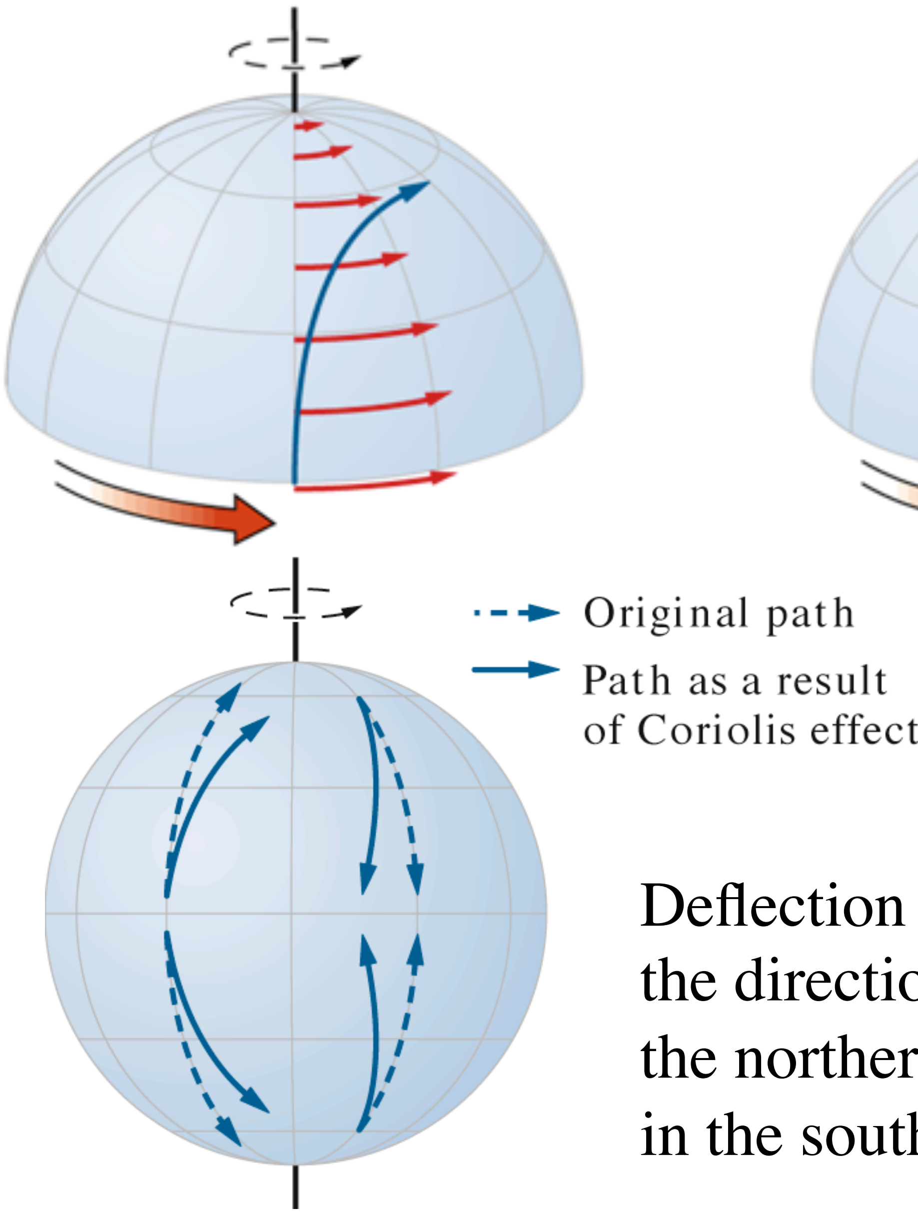


Fig 4-9

Deflection is always to the right of the direction of initial motion in the northern hemisphere and left in the south

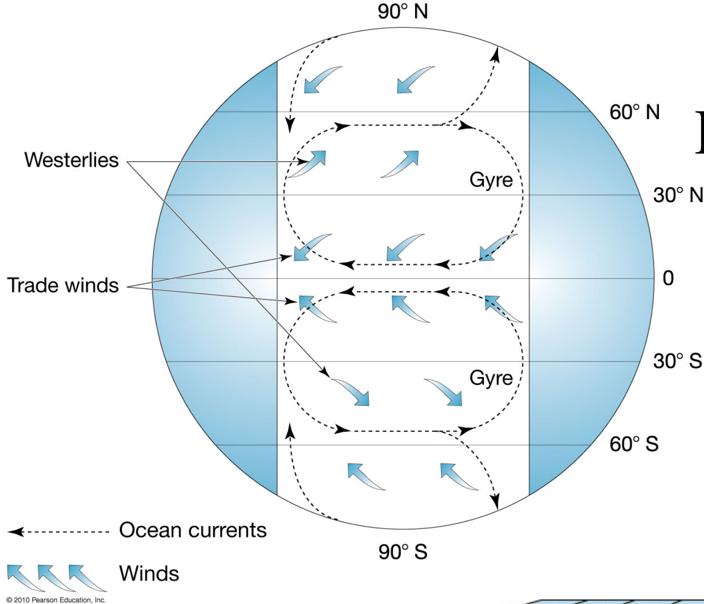
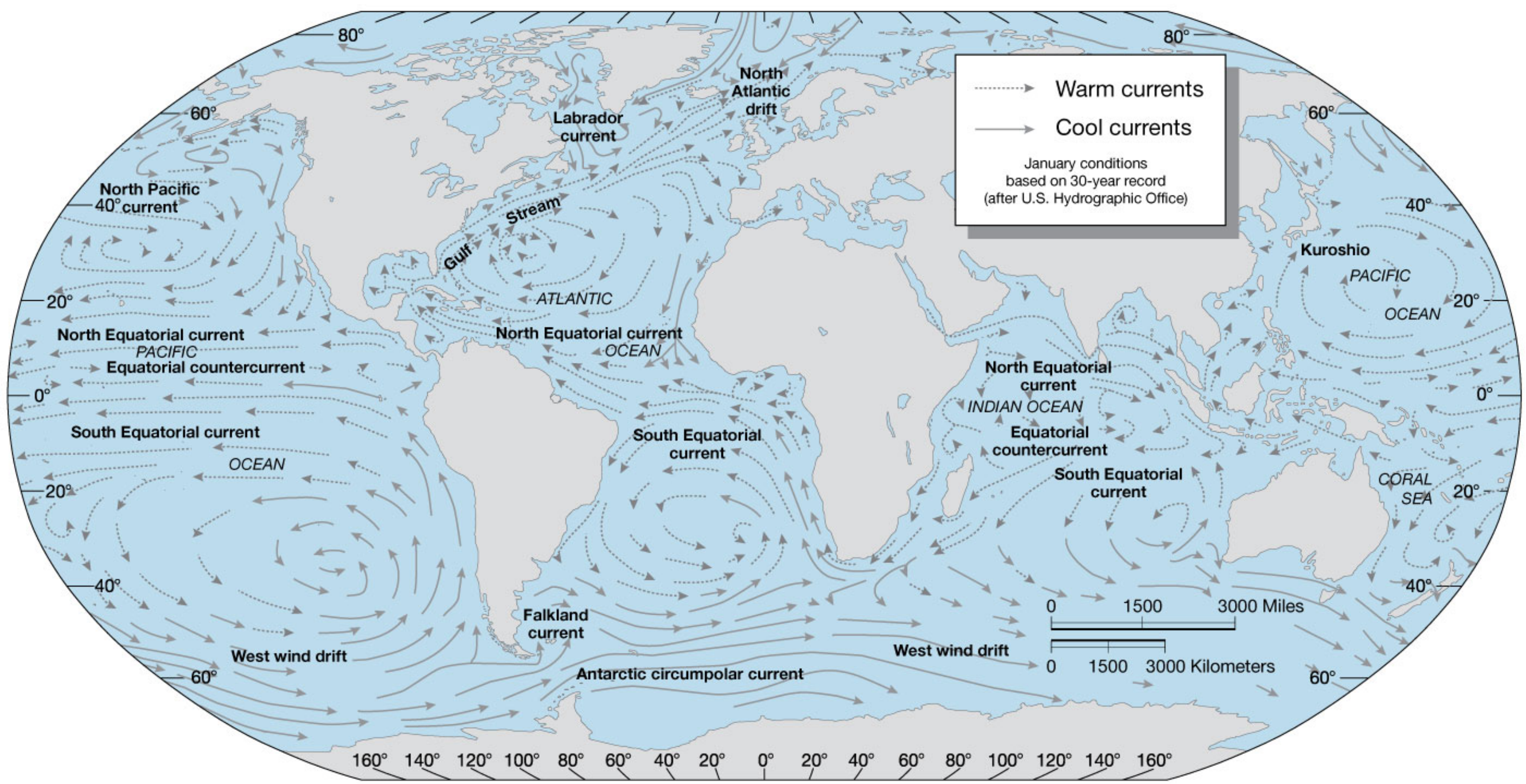


Fig 5-1

Land disrupts circulation, especially in the Northern Hemisphere

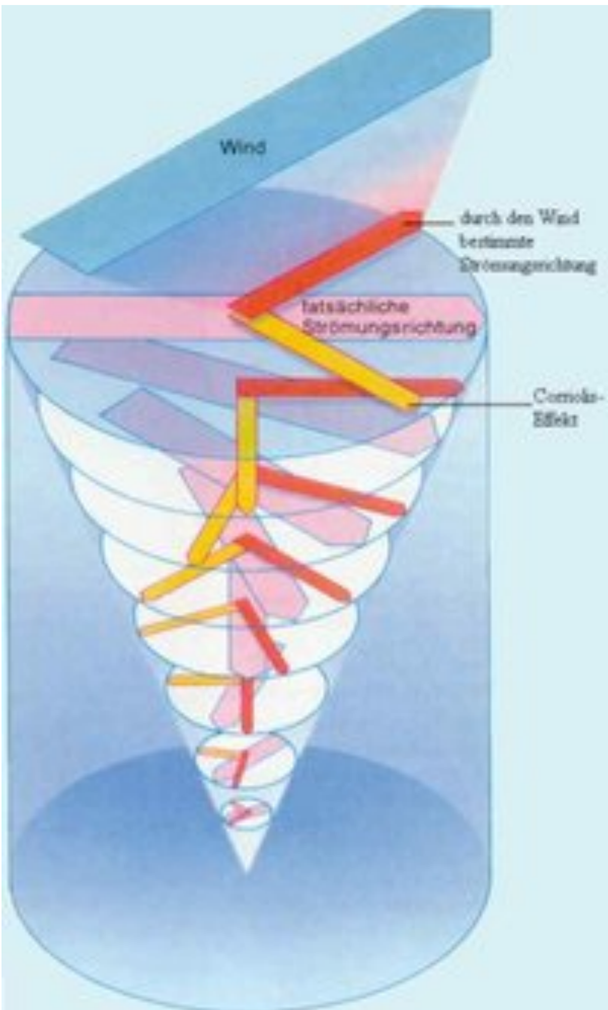
Note *gyres*:

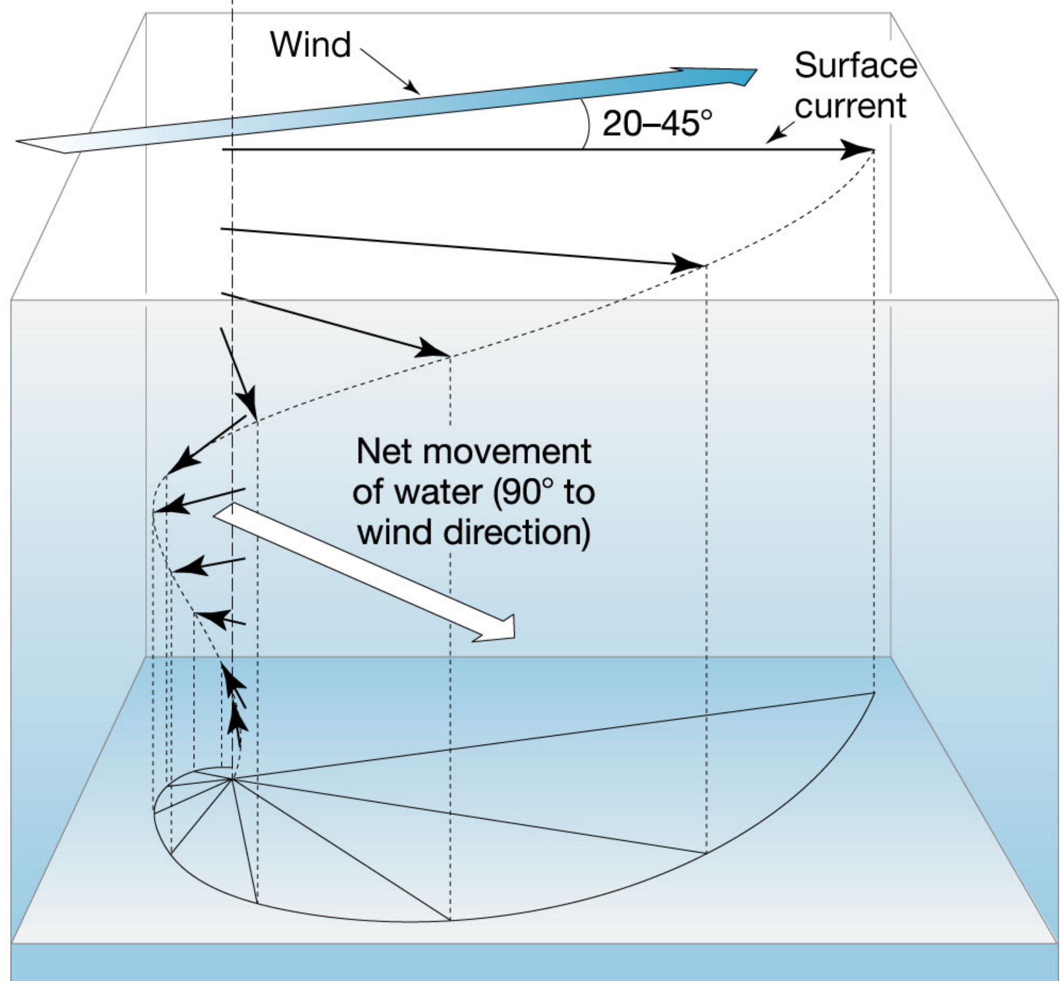
Fig 5-2



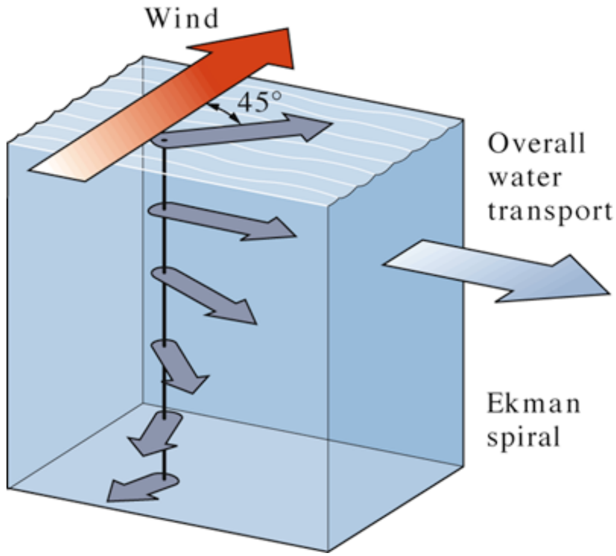
Processes causing surface gyres:

1. Surface winds drag water at ocean surface, and these drag layers below. Effect penetrates 100-200 m
2. Coriolis diverts flow to the right in the northern hemisphere
3. Viscous drag repeats the effect into deeper layers (100-200 m deep)



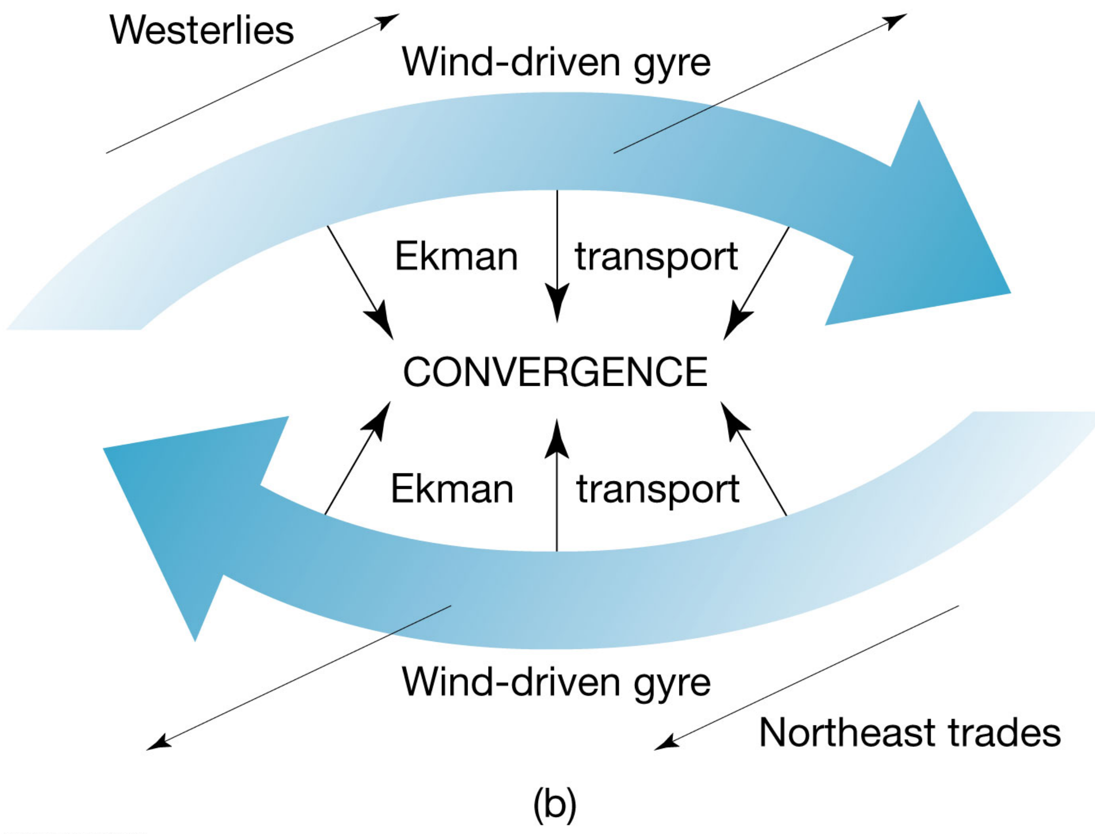


(a)

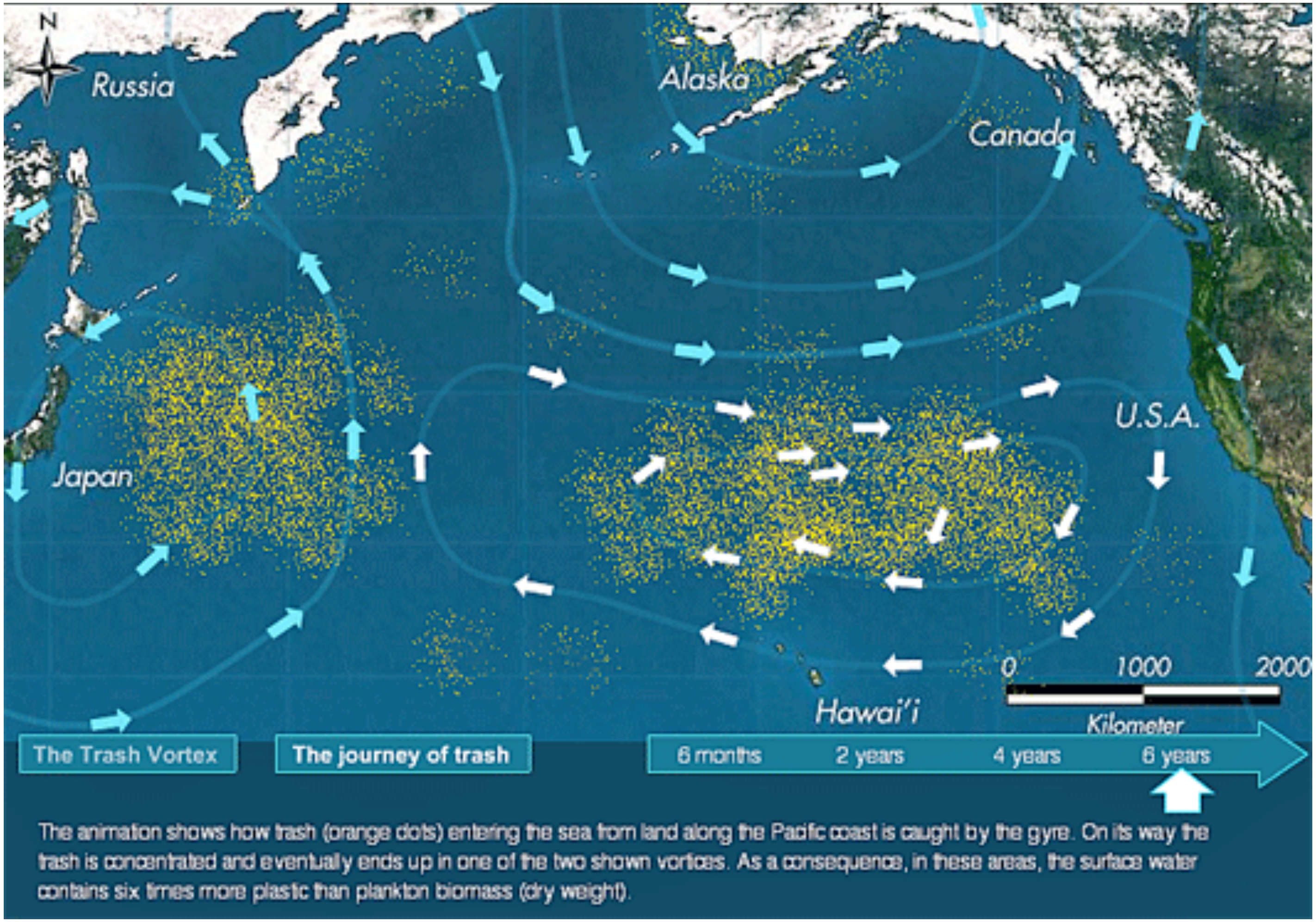


4. When you add up all the movements of the layers of water, the net direction is 90° to the wind direction.

5. In a clockwise gyre in the Northern Hemisphere or a counter-clockwise gyre in the Southern Hemisphere the water is pushed into ("converges" in) the middle of the gyre.



Great Pacific Garbage Patch…



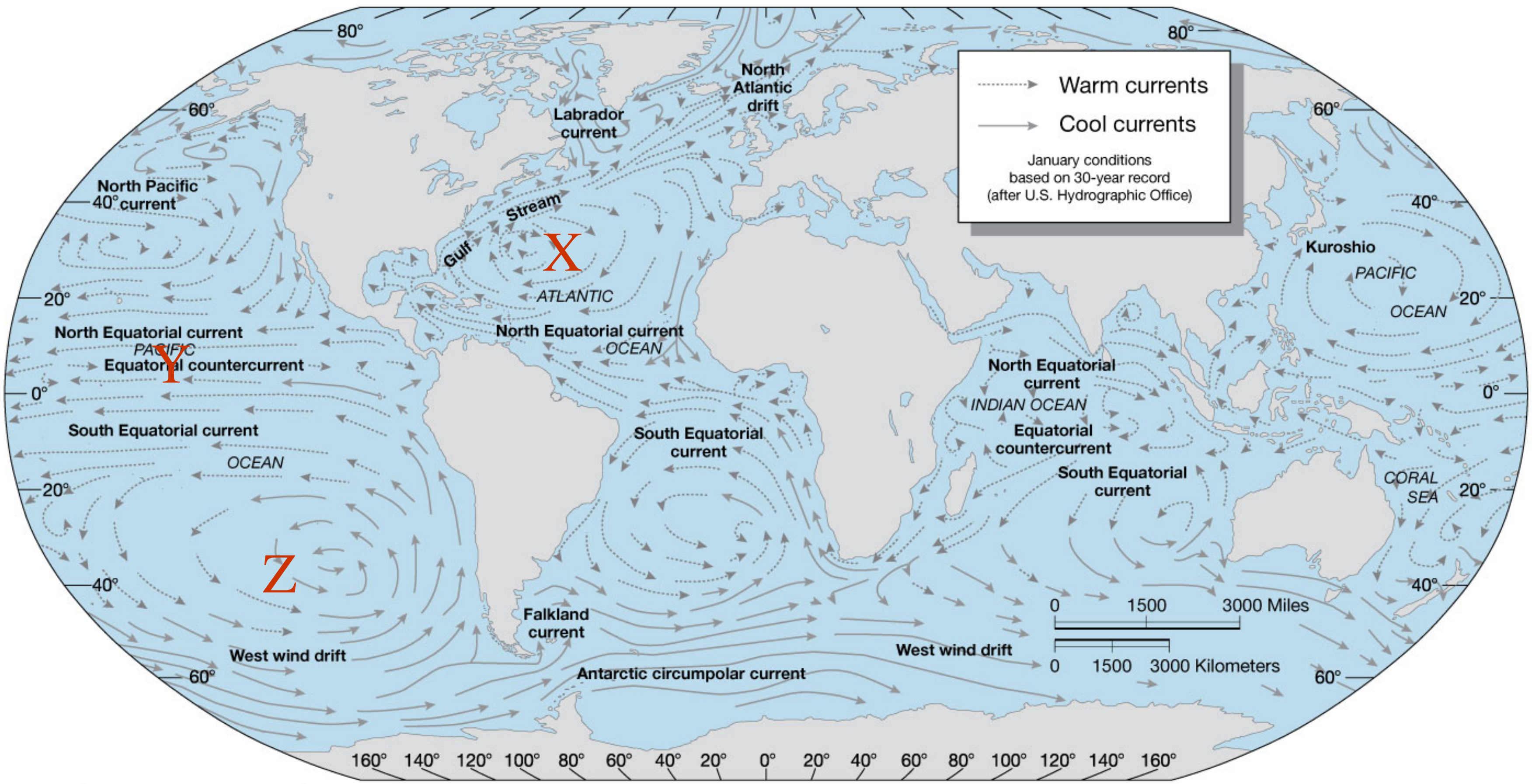
The world produces about 200 billion pounds of plastic each year, and about 10% of that ends up in the ocean…

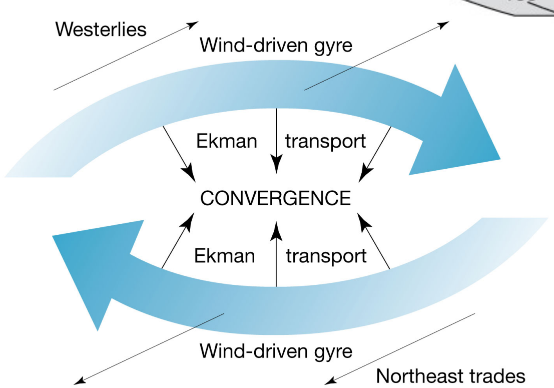
Floating trash in ocean gyres… a major problem!!!

Marine Pollution Bulletin; Stephanie Avery-Gomm, lead author, UBC Department of Zoology. The latest findings indicate a substantial increase in plastic pollution over the past four decades.

Necropsies on 67 beached northern fulmars found that 92.5% had plastics — such as twine, styrofoam and candy wrappers — in their stomach. An average of 36.8 pieces per bird were found. The averag total weight of plastic was 0.385 grams per bird. One bird was found with 454 pieces of plastic in its stomach.

Are X, Y, Z, zones of convergence or divergence?



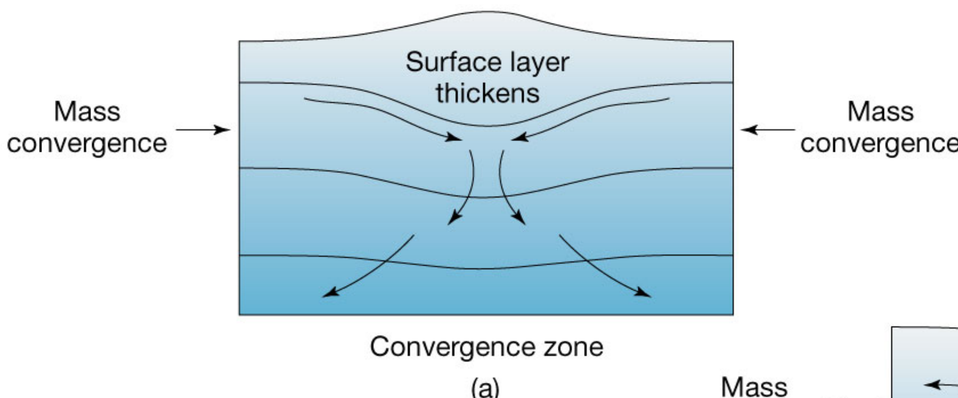


(b)

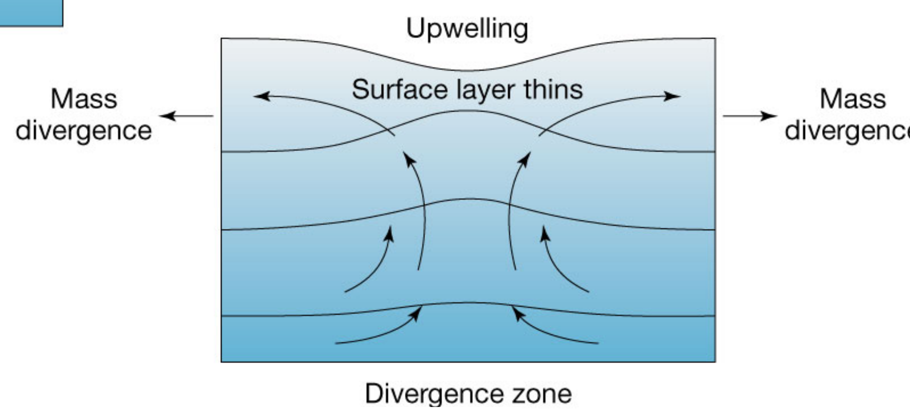
6. Ekman transport causes convergence and divergence.

Differences in elevation of the sea surface are small- only ~50 cm higher in the middle of a gyre- but this is enough for gravity to cause a downslope force on the water.

Fig 5-4



Convergence --> downwelling



Note geostrophic current…
We'll look at that after upwelling.

Divergence --> upwelling

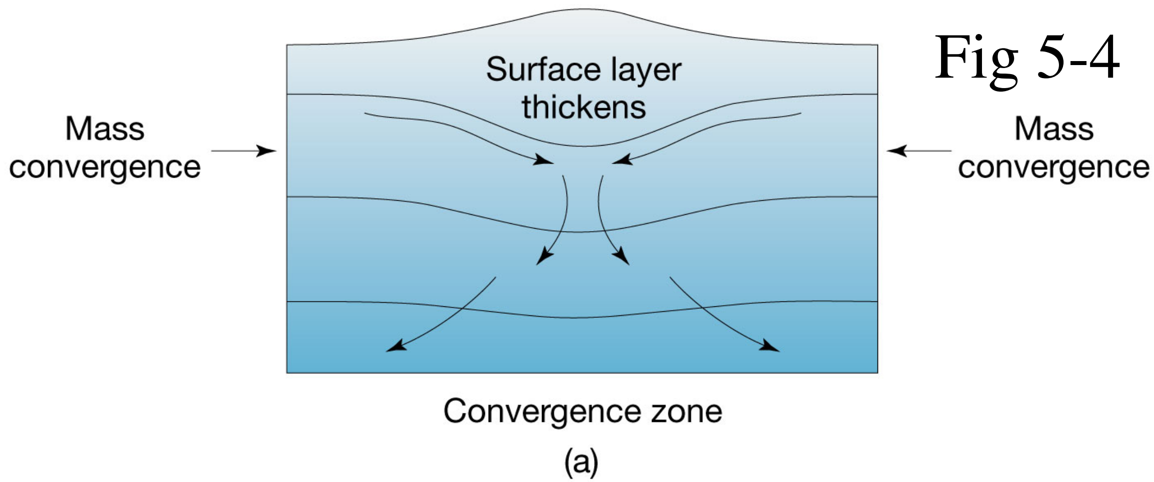
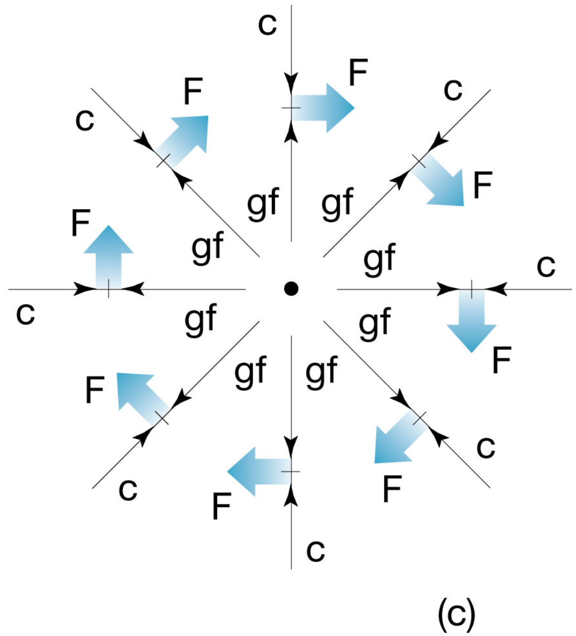


Fig 5-4

7. Gravity drives geostrophic currents, Coriolis deflects them.

Water flows off the piles of water in the convergence zones, but these geostrophic currents are deflected by the Coriolis effect.

Fig 5-5



Clockwise gyre resulting from geostrophic flow

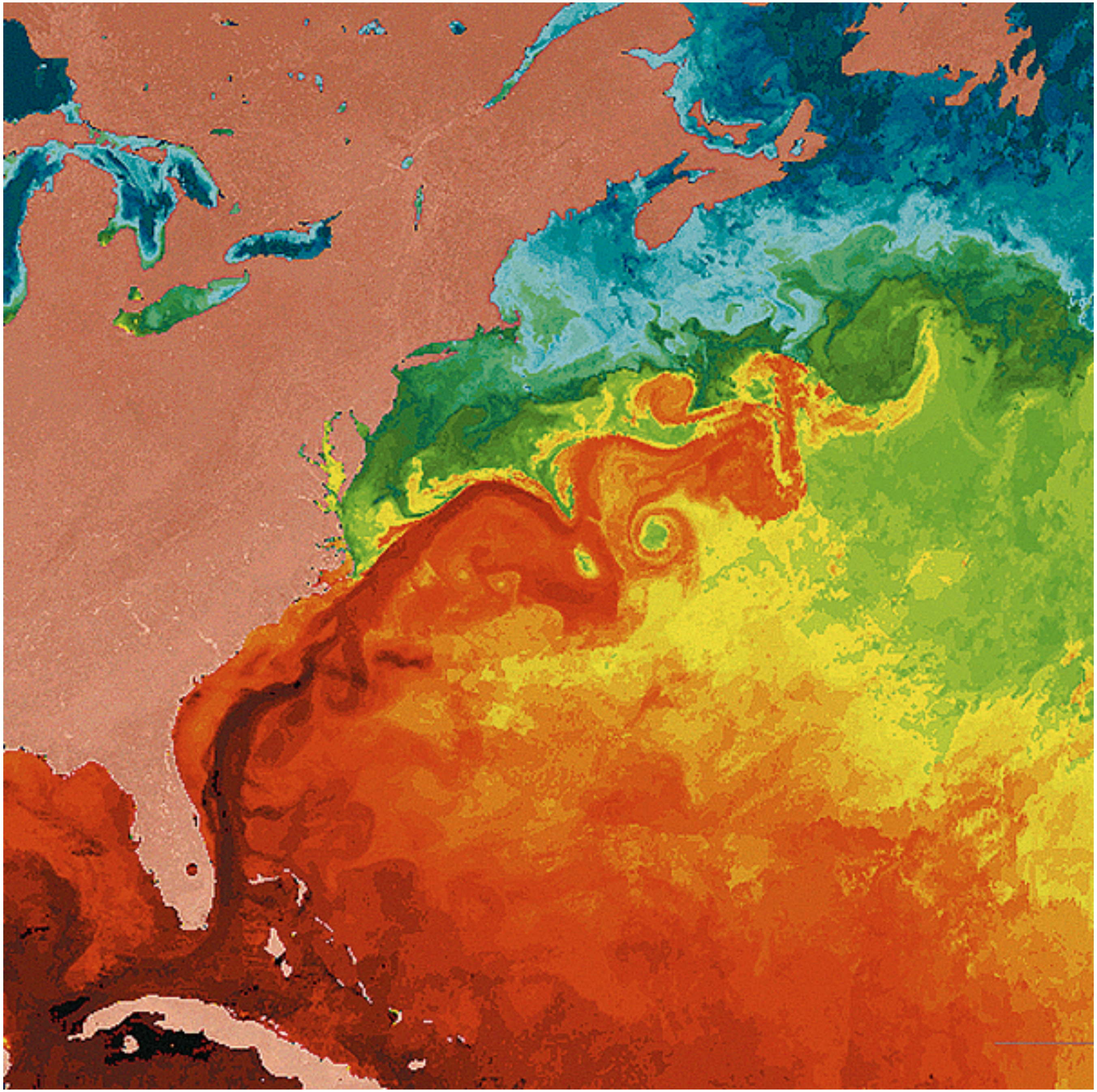
Gulf stream:

a well-known ocean gyre.
It is narrow (50-75 km wide) and fast-flowing (3-10 km/hr)

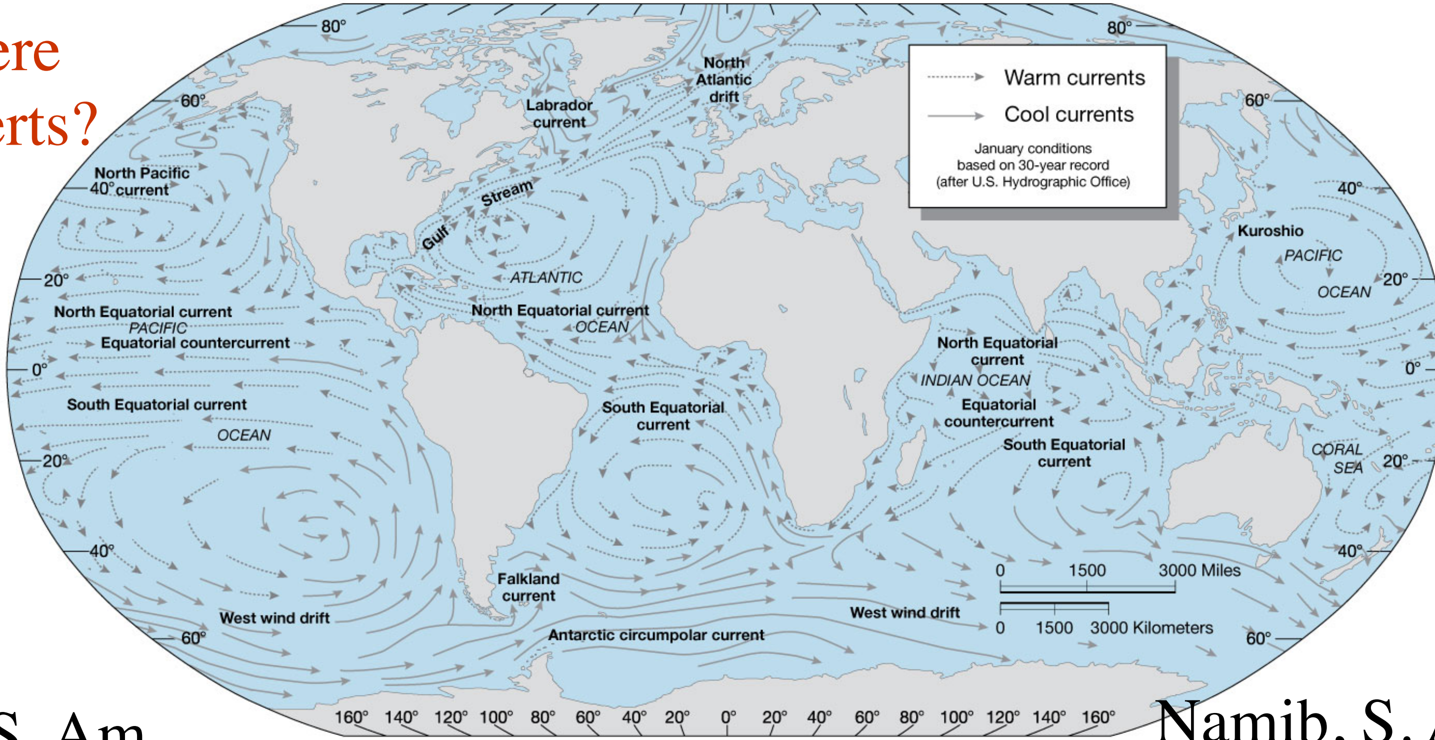
Center of gyre is Sargasso Sea, covered with seaweed, has only weak currents.

Gyres carry warm water from equator to middle latitudes, cooler water towards the equator.
Gulf Stream warms N Europe.

(red = warm)

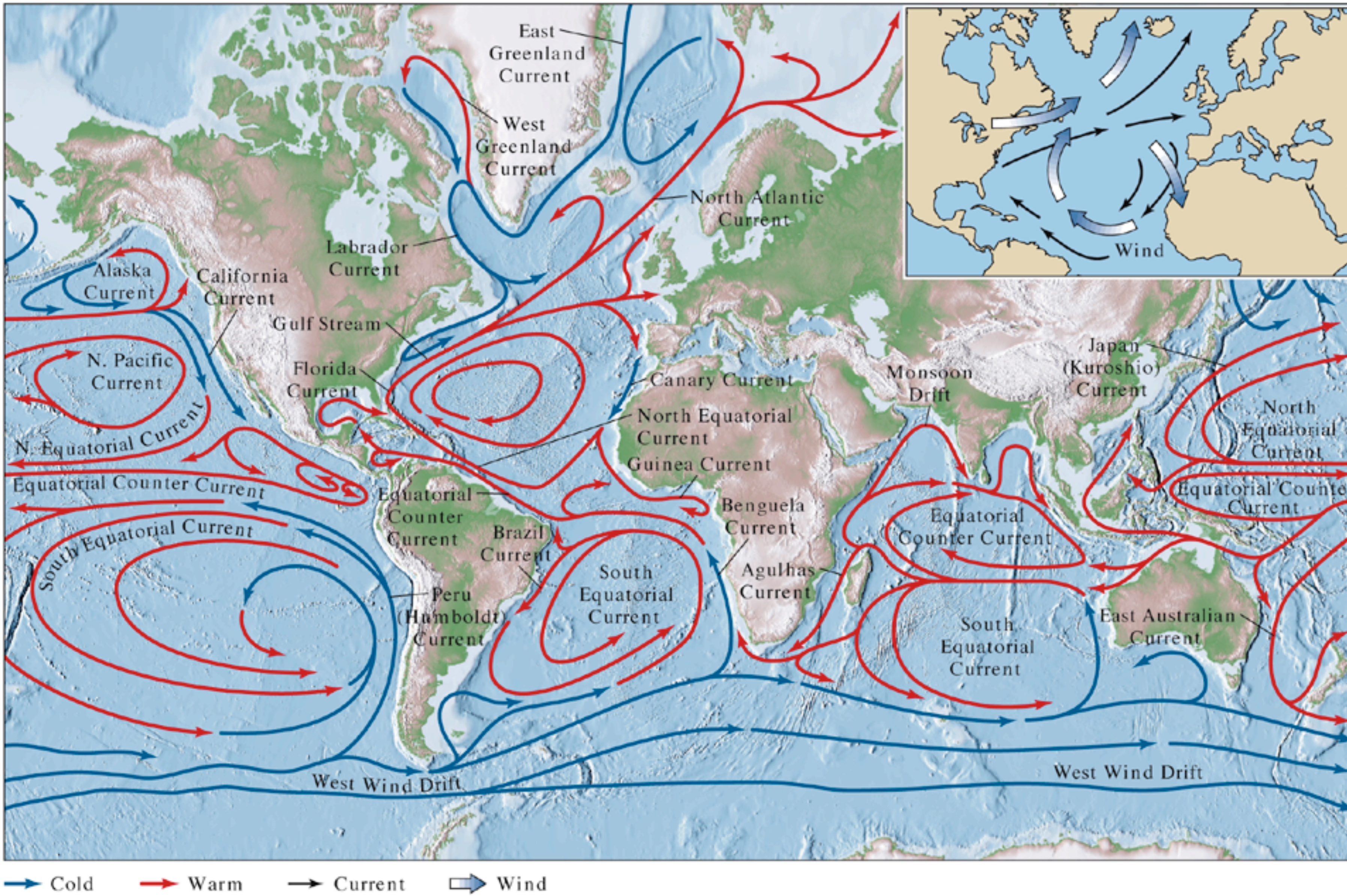


Why are there coastal deserts?



Atacama, S. Am.

Namib, S. Afr.



East Greenland Current
West Greenland Current
North Atlantic Current
Labrador Current
Alaska Current
California Current
Gulf Stream
N. Pacific Current
Florida Current
Canary Current
North Equatorial Current
N. Equatorial Current
Guinea Current
Equatorial Counter Current
Equatorial Counter Current
Benguela Current
South Equatorial Current
Brazil Current
Agulhas Current
South Equatorial Current
Peru (Humboldt) Current
South Equatorial Current
East Australian Current
Monsoon Drift
Japan (Kuroshio) Current
North Equatorial Current
Equatorial Counter Current
Equatorial Counter Current
West Wind Drift
West Wind Drift
Wind
Cold
Warm
Current
Wind

Circulation of deep ocean

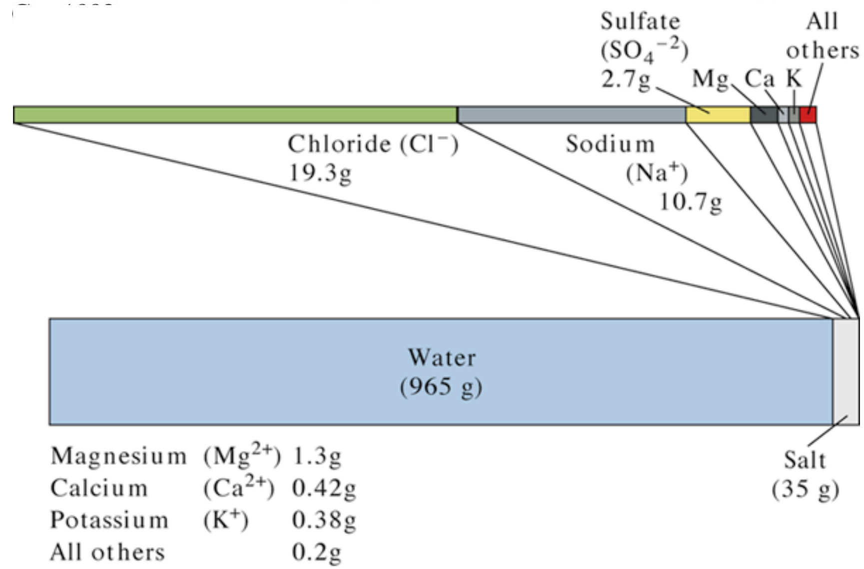
Driven by water density, a function of
•temperature
•salinity

Marine evaporite, Newfoundland

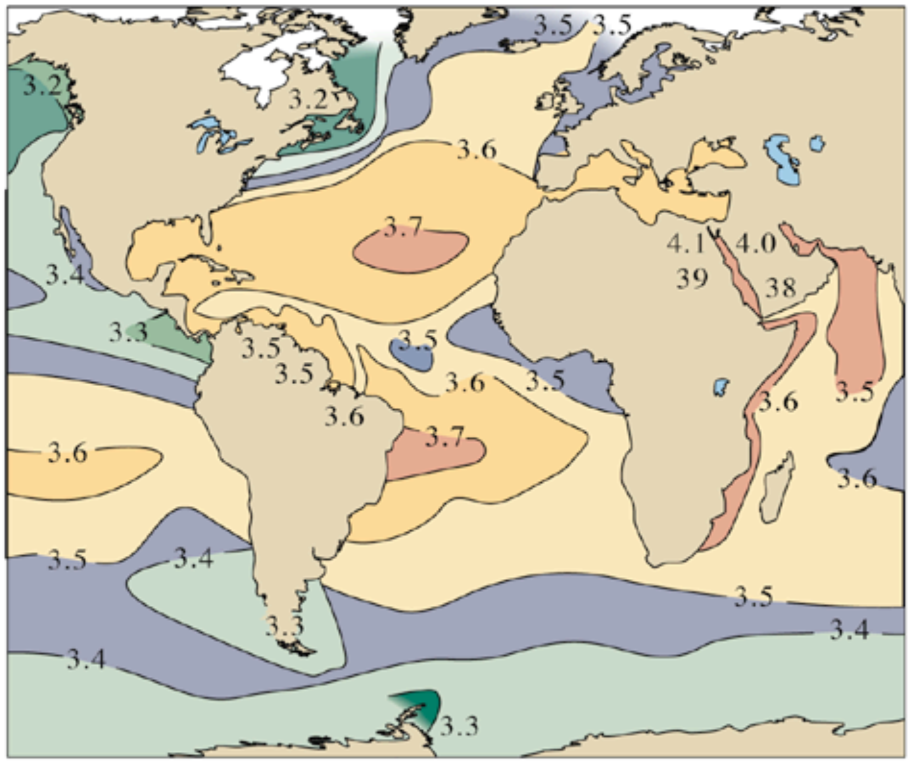
TABLE 5-1

Salt Content of the Earth's Oceans		
Salt Ion	***Grams per Kilogram (g/kg) of Ion in Seawater***	***Ion by Weight (%)***
Chloride (Cl^-)	18.980	55.04
Sodium (Na^+)	10.556	30.61
Sulfate (SO_4^{2-})	2.649	7.68
Magnesium (Mg^{2+})	1.272	3.69
Calcium (Ca^{2+})	0.400	1.16
Potassium (K^+)	0.380	1.10
Bicarbonate (HCO_3^-)	0.140	0.41
Bromide (Br^-)	0.065	0.19
Boric acid (H_3BO_3)	0.026	0.07
Strontium (Sr^{2+})	0.013	0.04
Flouride (F^-)	0.001	0.00
Total	34.482	99.99

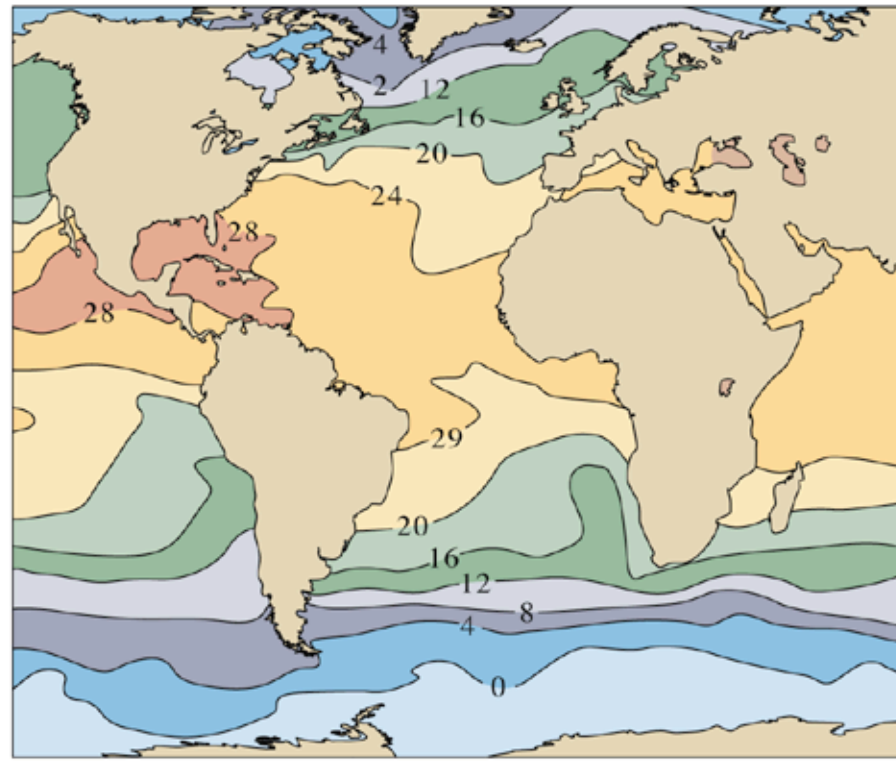
Source: PINET, P. R., *Oceanography*, St. Paul, MN: West Publishing



Variations in T and salinity:
salinity affected by evaporation, ppt, sea-ice fm and melting, rivers



Salinity (‰)



Temperature (°C)

Compare Red Sea and Baltic Sea

What is the age of the Earth determined from the salinity of the oceans?

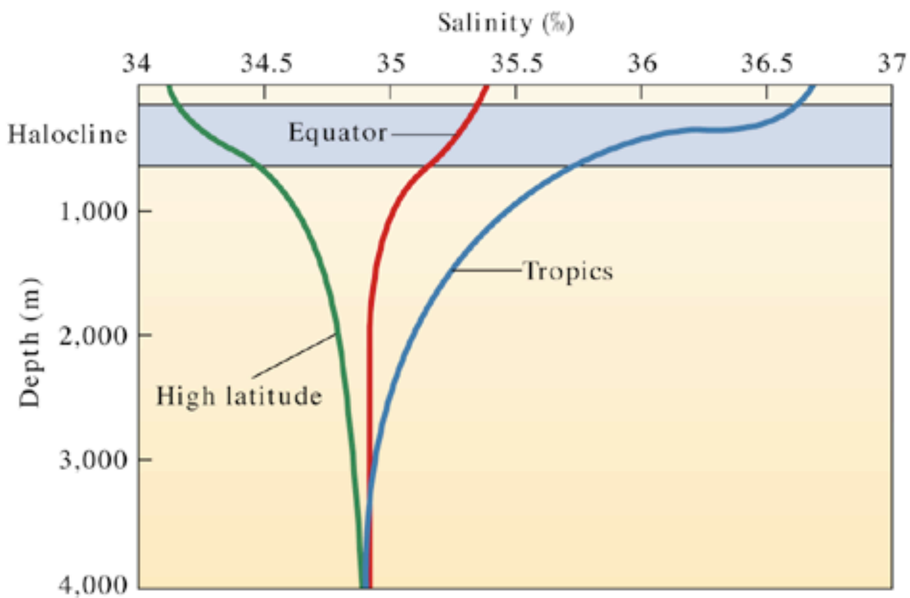
If the ocean has been accumulating salts delivered to it by rivers at a constant rate, how long would it take to attain its current salinity?

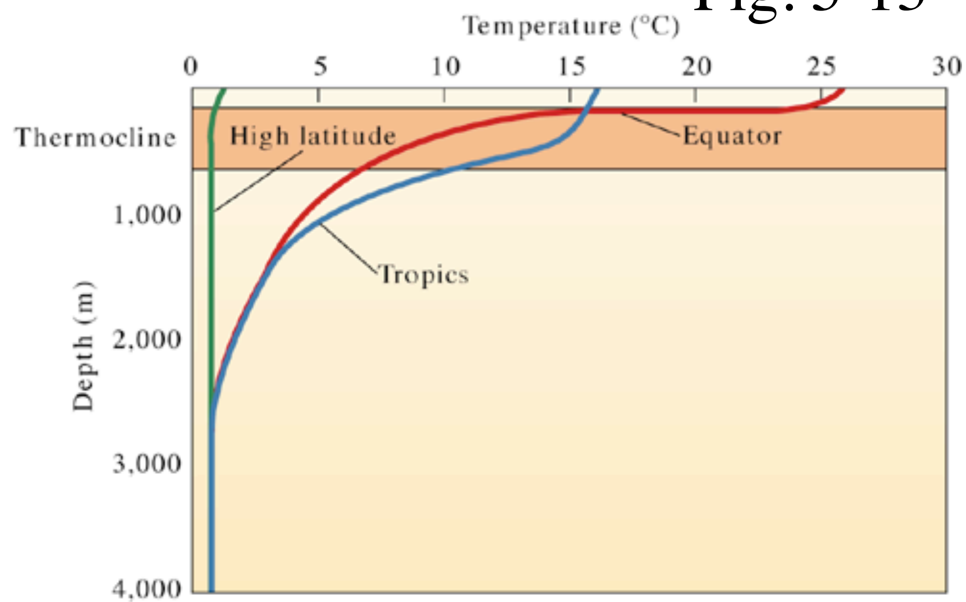
Total salt in oceans today: 5×10^{19} kg
Rate rivers deliver salt: 4×10^{12} kg/yr

How many years have rivers delivered salt?

John Joly (1899) used this method to determine the age of the Earth. Why was he incorrect?

Fig. 5-13





Below the well-mixed surface zone (0-100 m), there are changes in *salinity, T and density*. The transition depth is called the *halocline*, *thermocline and pycnocline*, respectively.

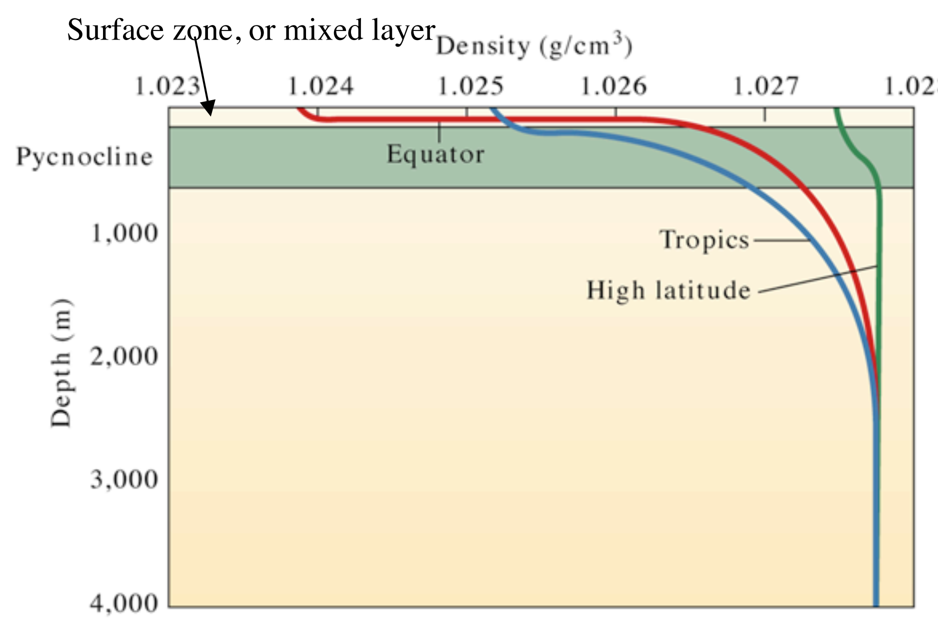
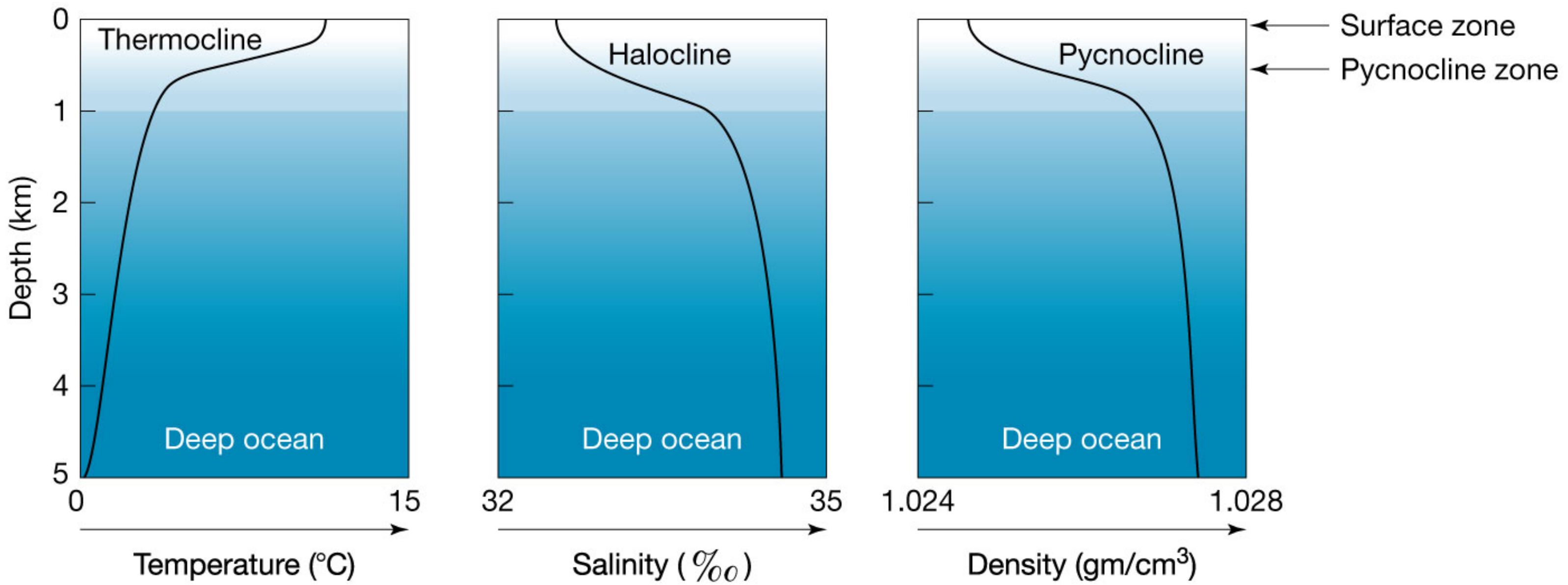


Fig. 5-13



0
1
2
3
4
5
Depth (km)
Thermocline
Deep ocean
0
15
Temperature (°C)
Halocline
Deep ocean
32
35
Salinity (‰)
Pycnocline
Deep ocean
1.024
1.028
Density (gm/cm3)
Surface zone
Pycnocline zone

Temperature profiles

Do polar oceans have surface, thermocline and deep zones?

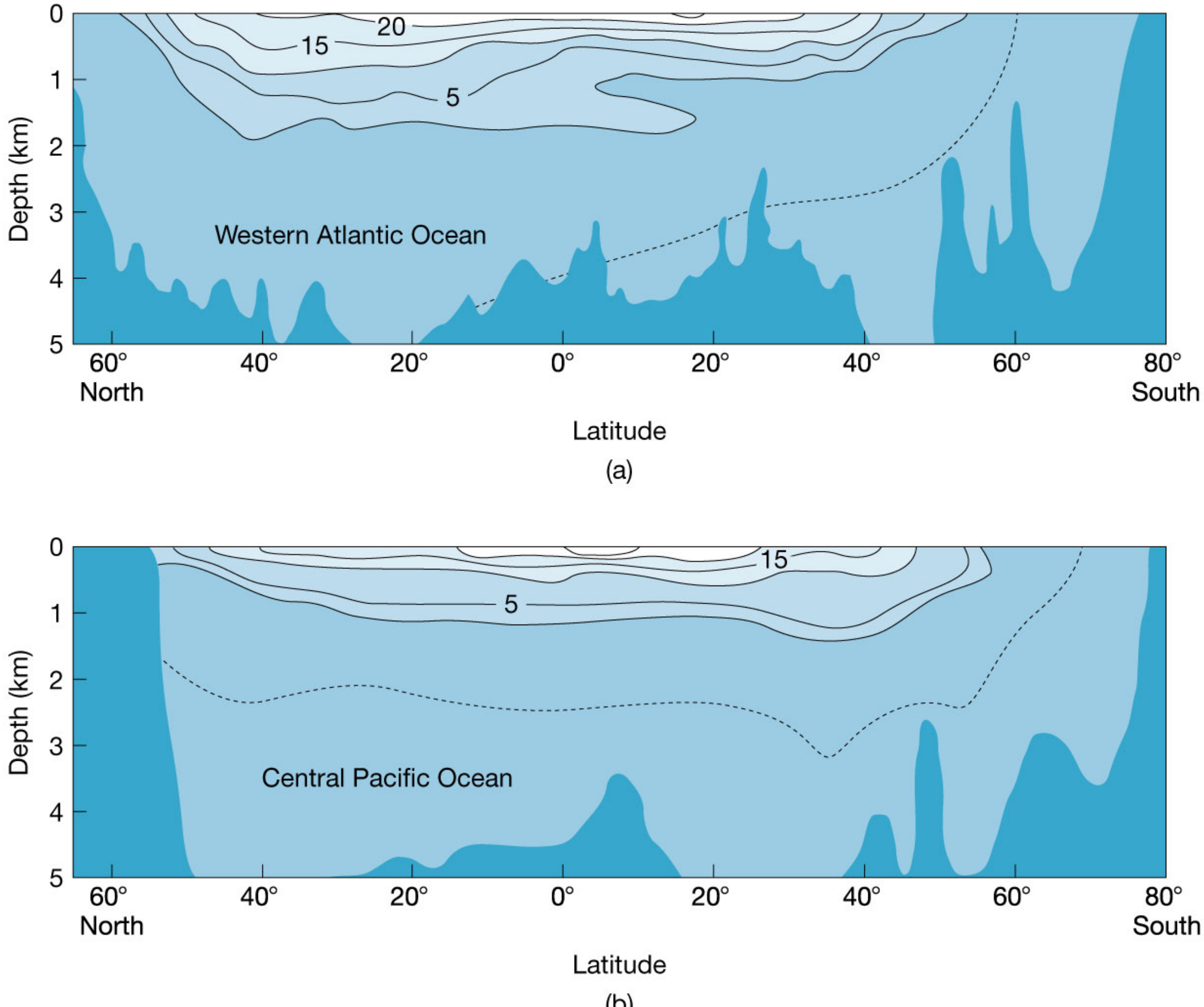


Fig. 5-14

Salinity profiles

Where is the most saline water?

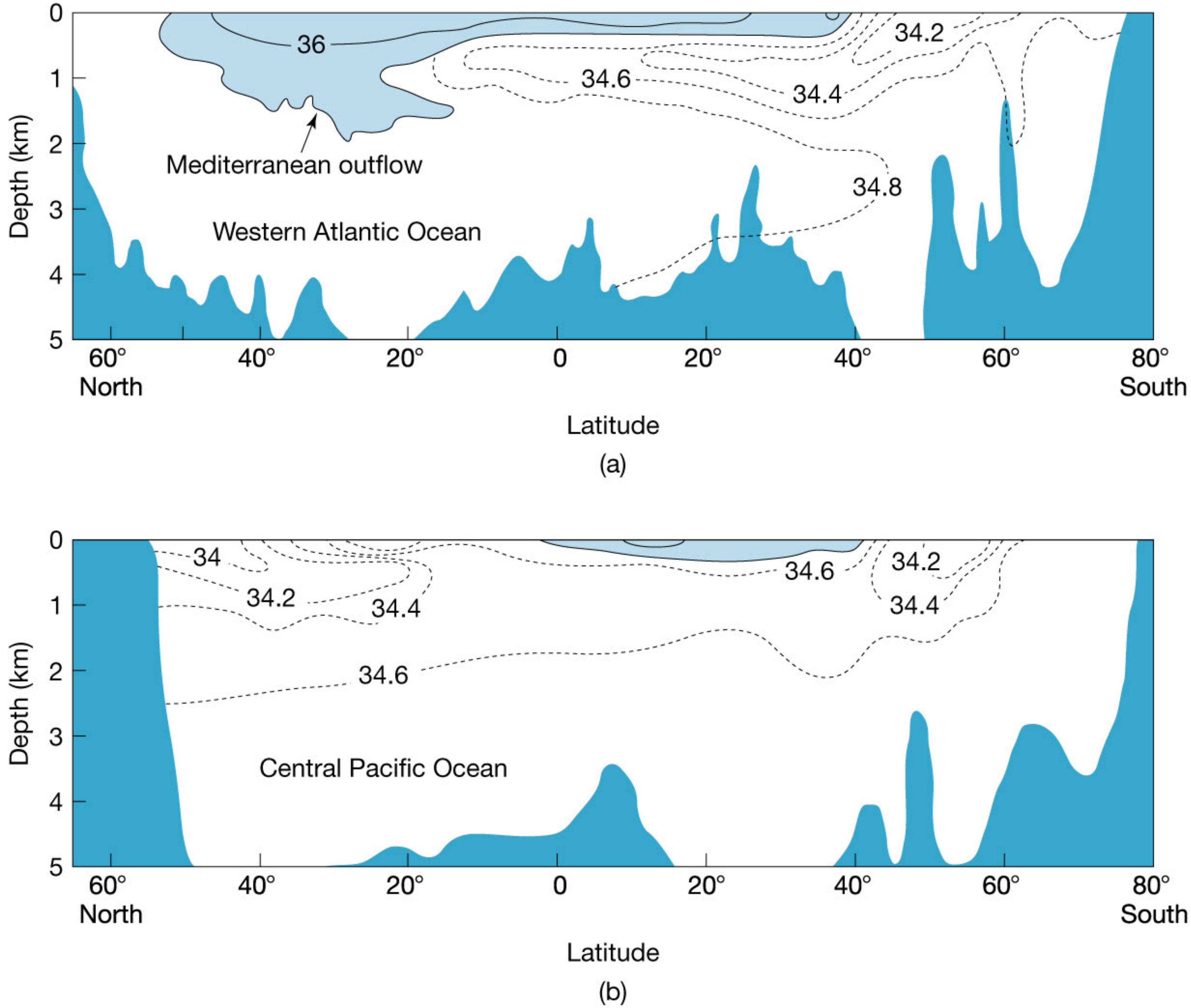
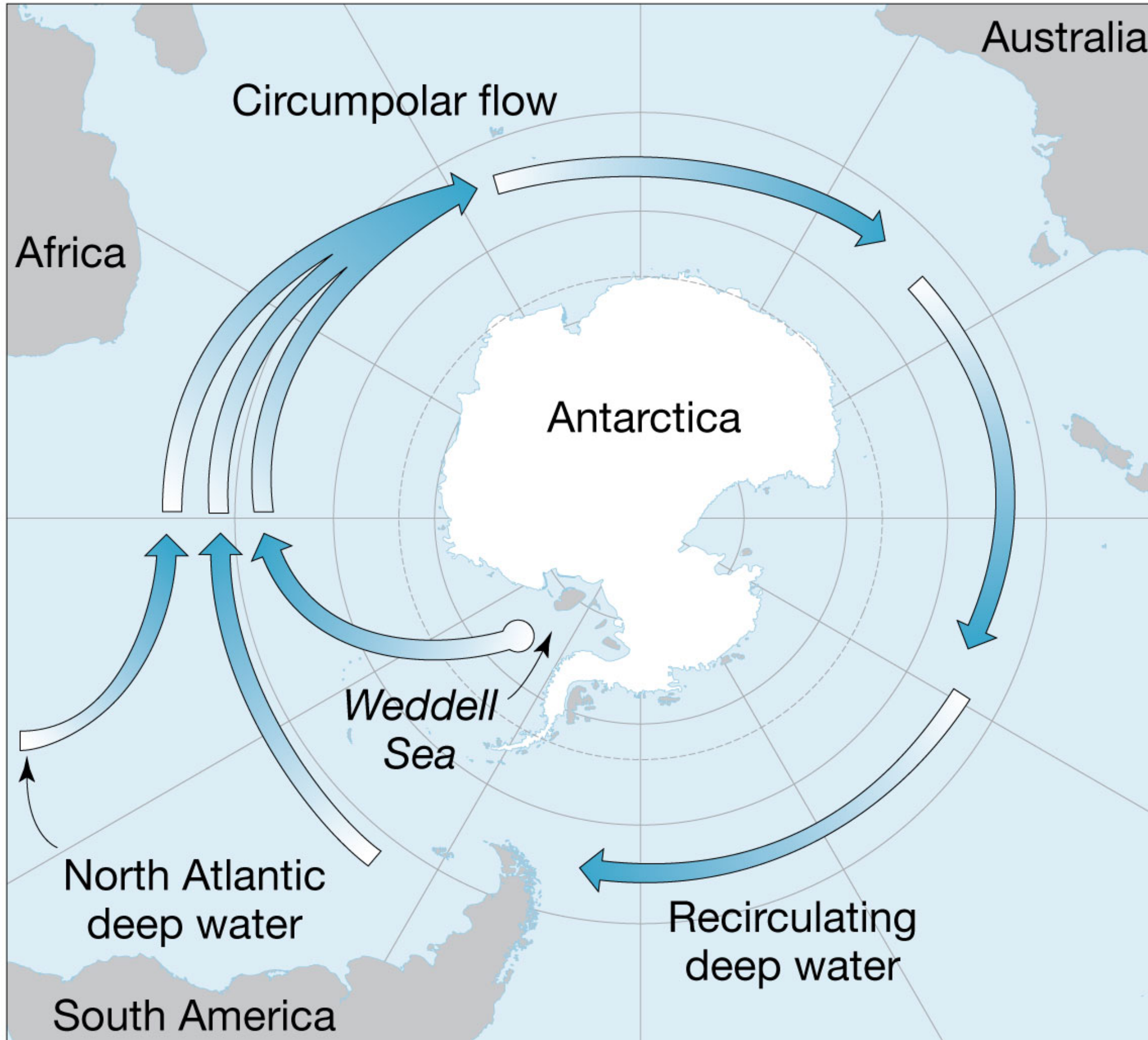


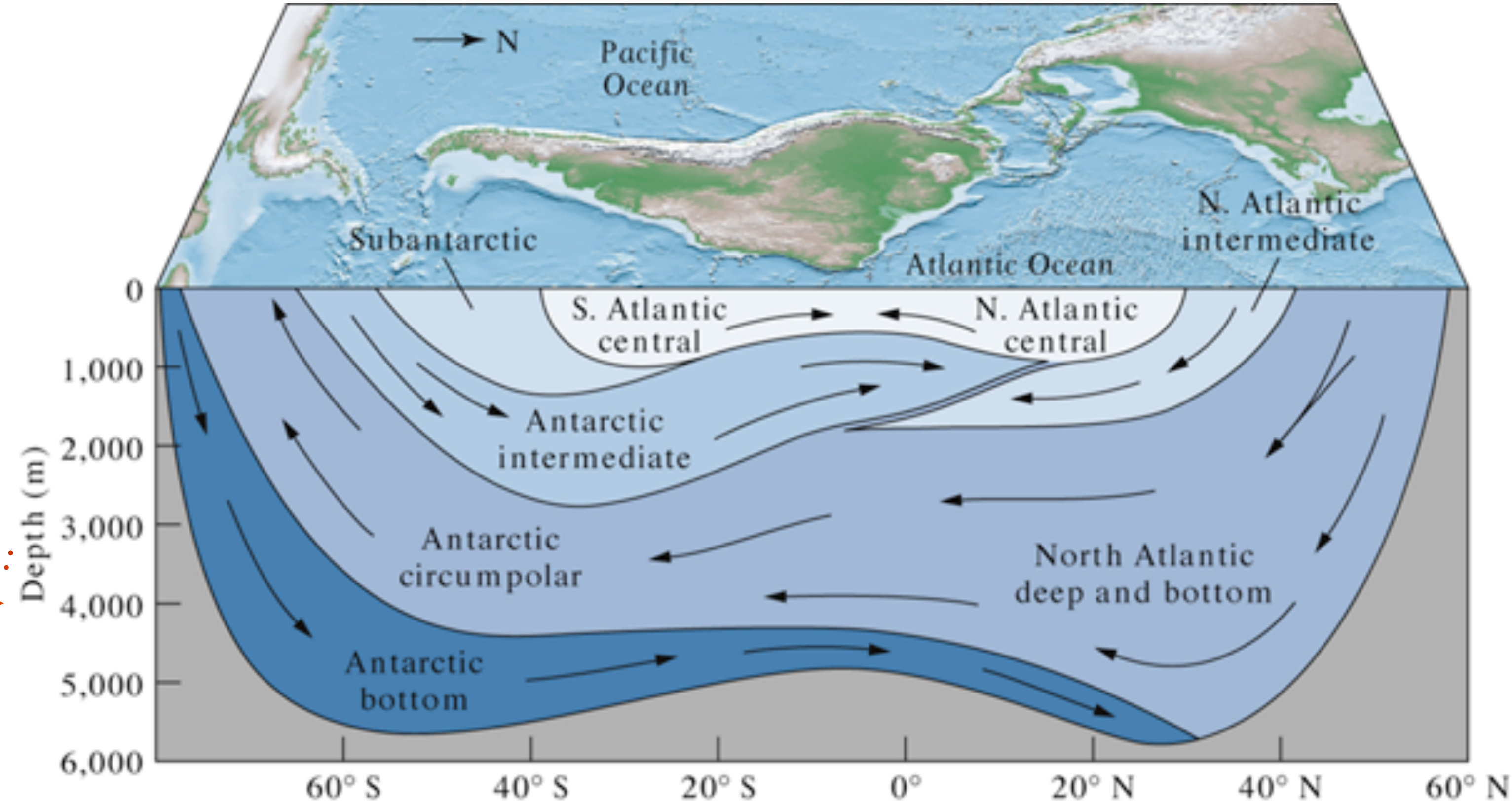
Fig. 5-15

Cold, salty water forms at the poles:
•Ice forms, tend to exclude salts
•Cold, salty water is left
•Water sinks

Fig. 5-16

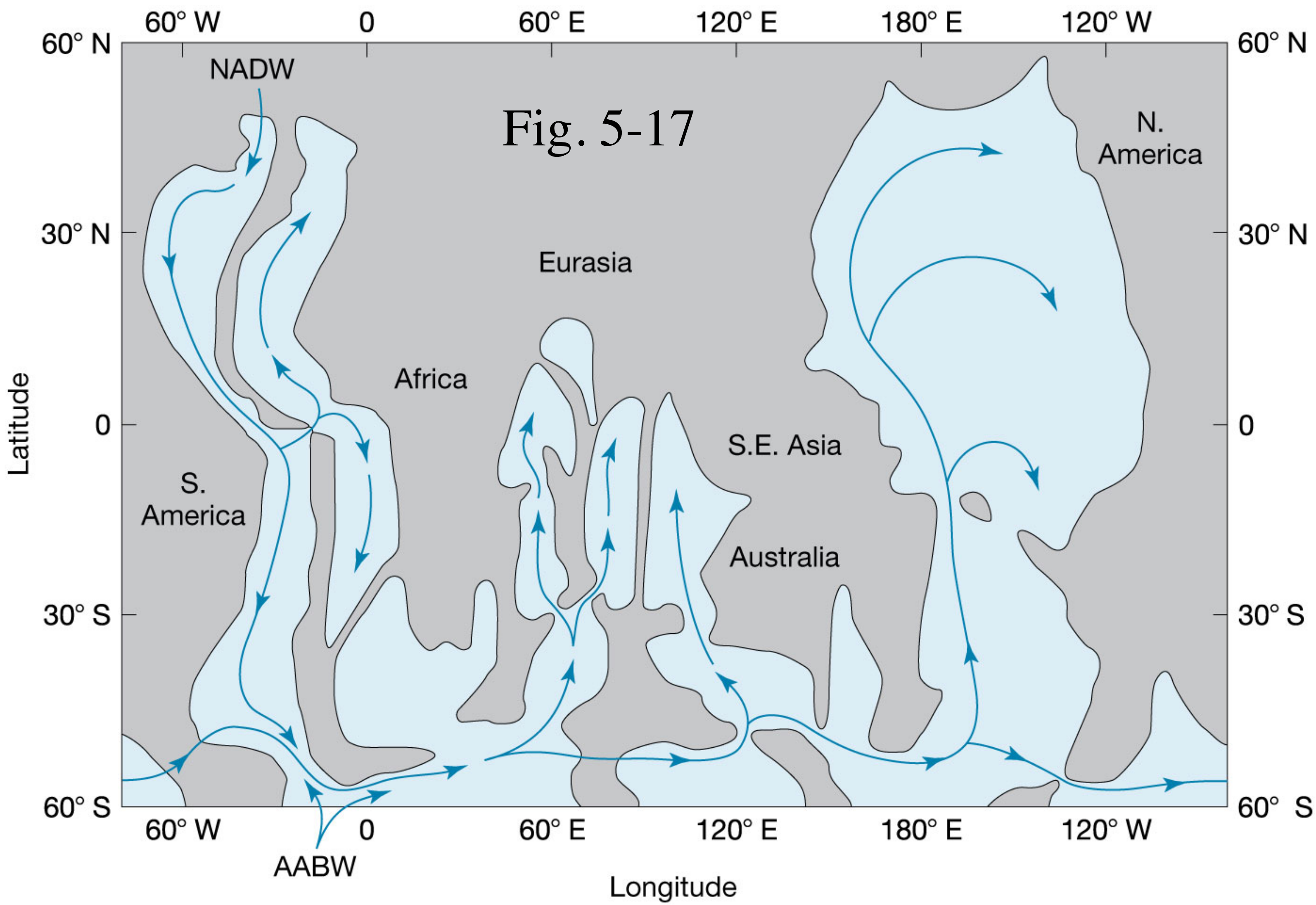


Wind flowing off ice cap blows sea ice out to sea. Exposed water freezes rapidly



Next slide: →

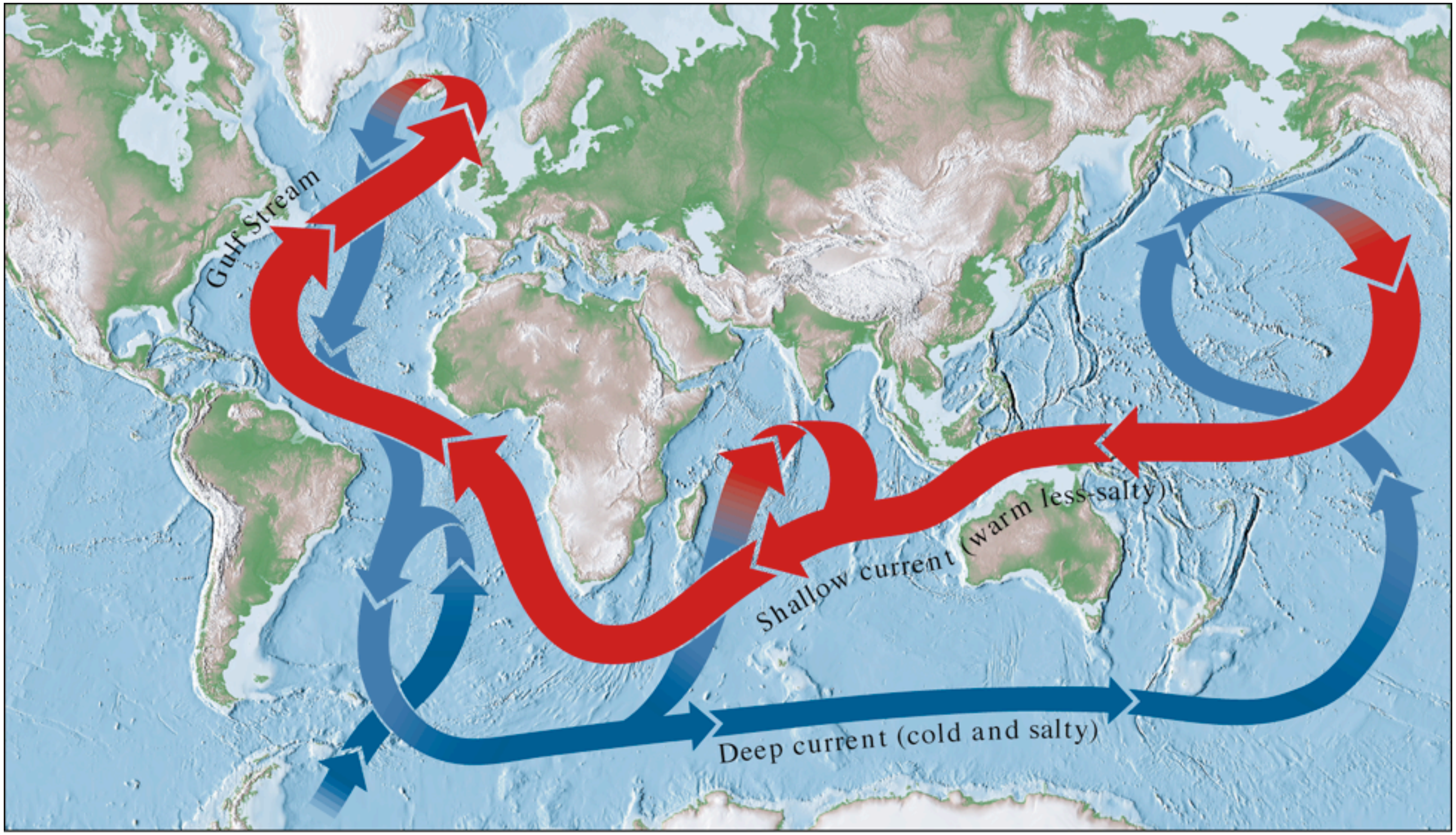
Cold, dense water sinks both at Antarctica (AABW) and at North Atlantic (NABW), in about equal volumes.



Flow at 4 km depth: NADW flows S, joins AABW. Some deep water circles Antarctica, some goes into Indian and Pacific O. Residence time for deep ocean water is ~500 years.

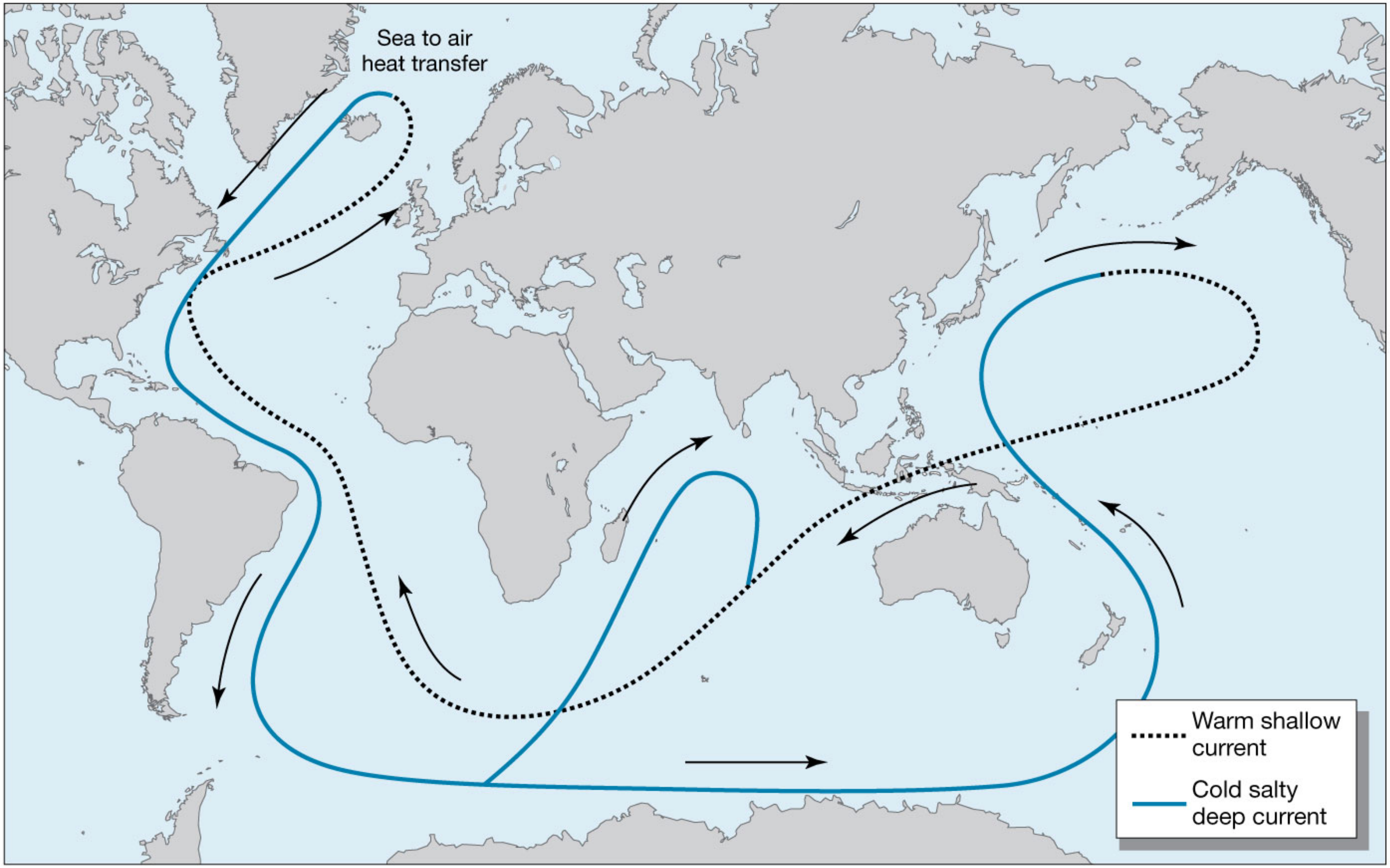
"Thermohaline conveyor belt"

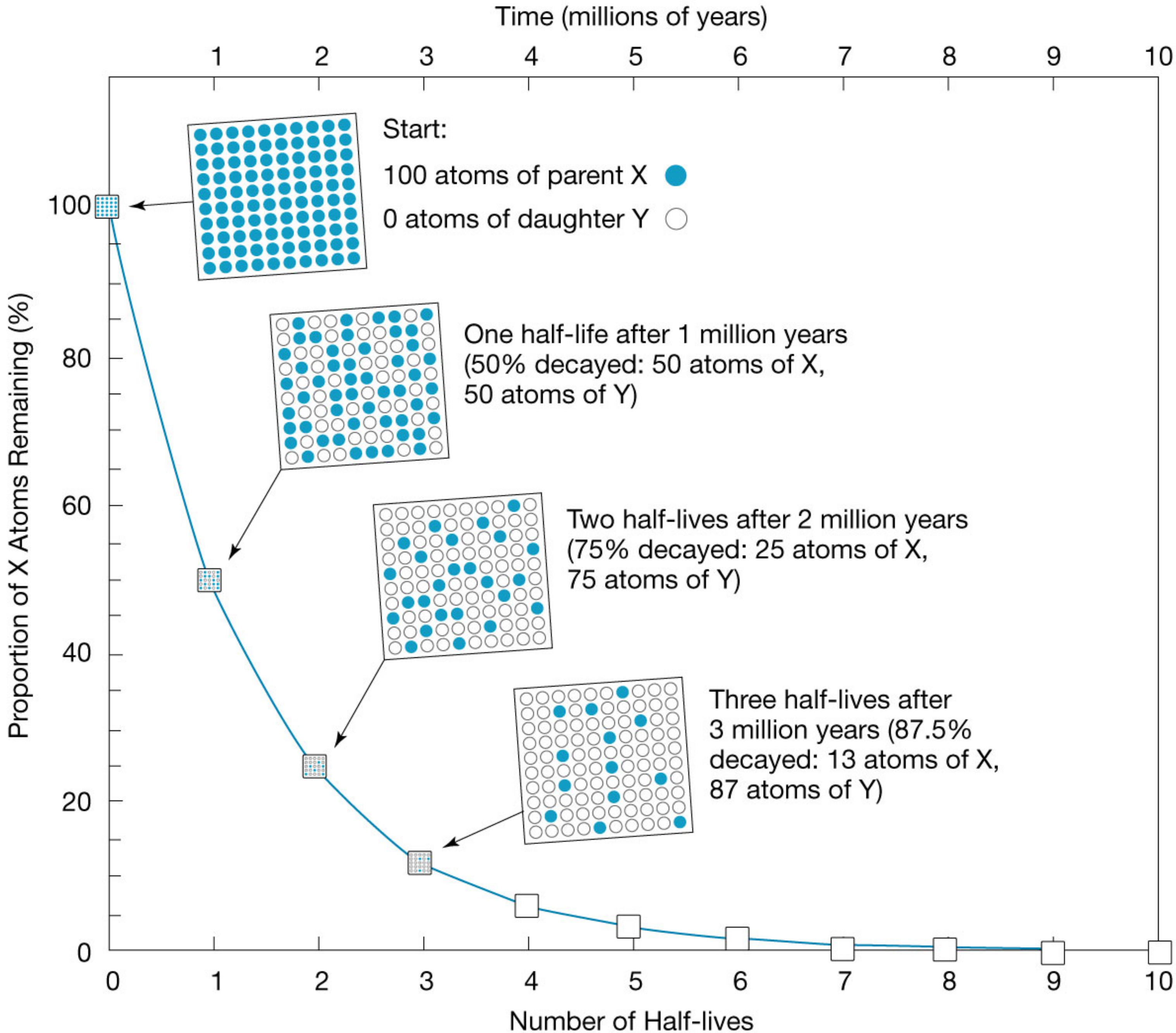
Fig. 5-19



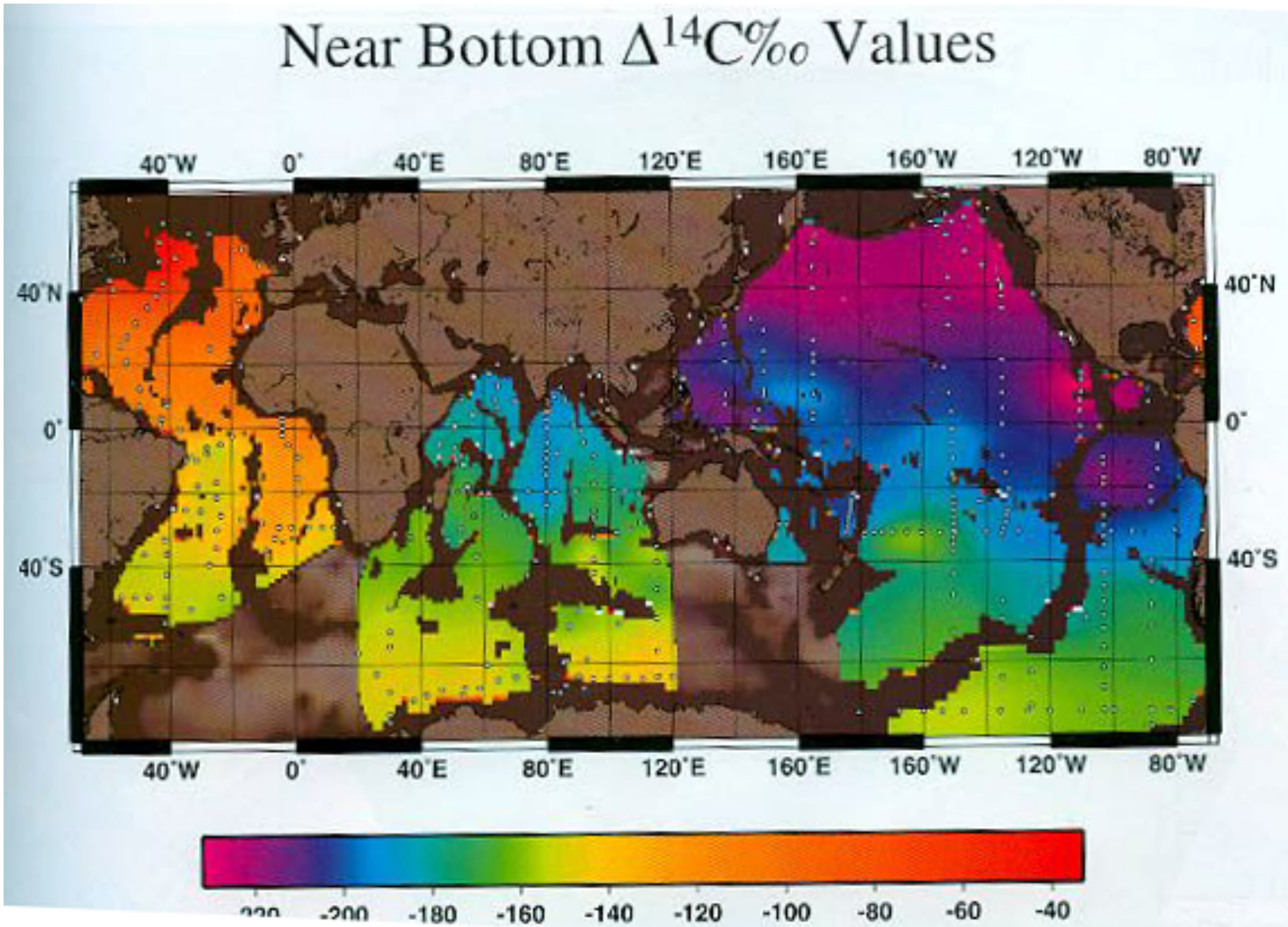
Downwelling at N Atlantic and Antarctic creates bottom water,
Upwelling moves nutrients up from depth…

Fig. 5-19

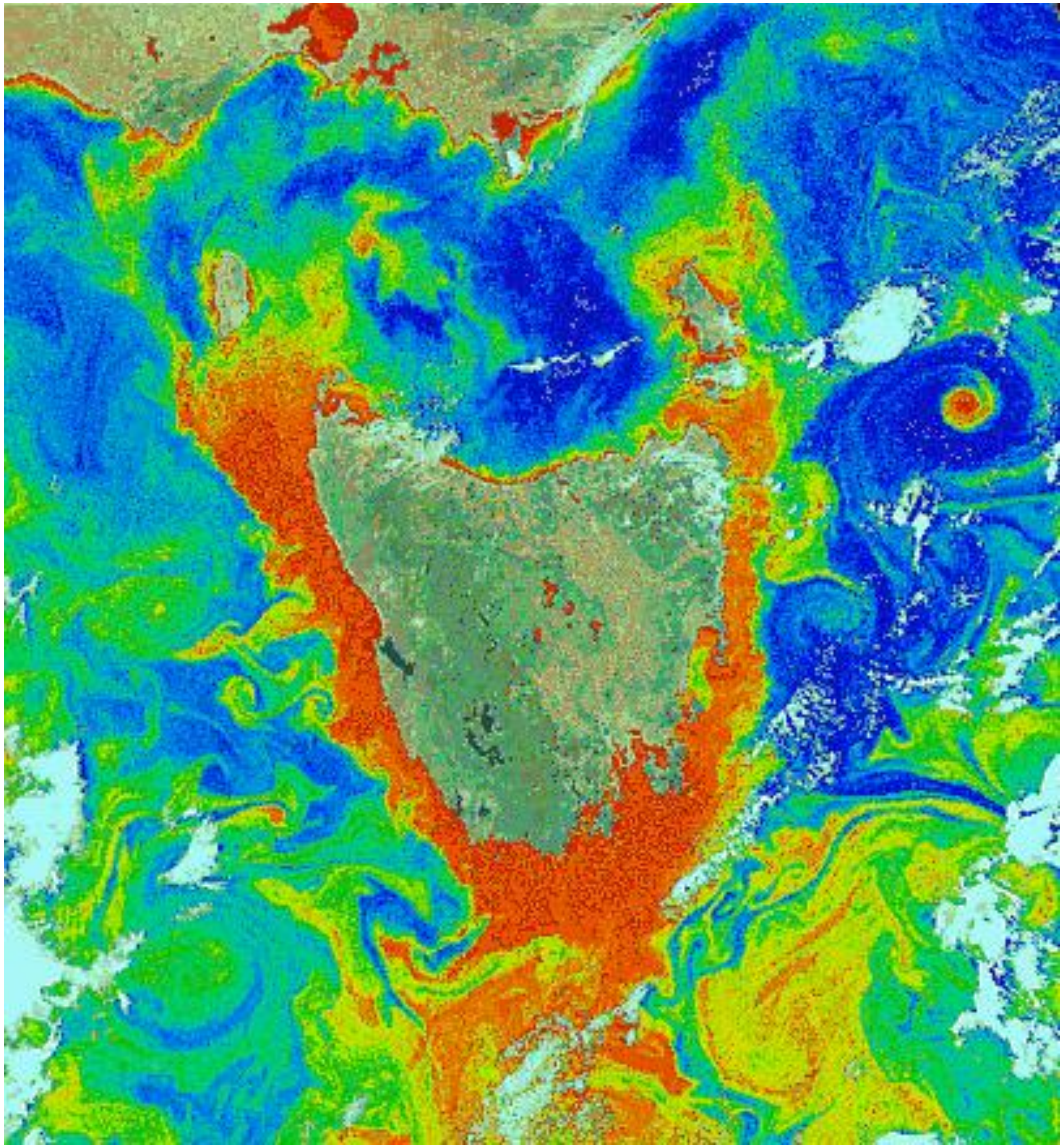

Sea to air
heat transfer
Warm shallow
current
Cold salty
deep current

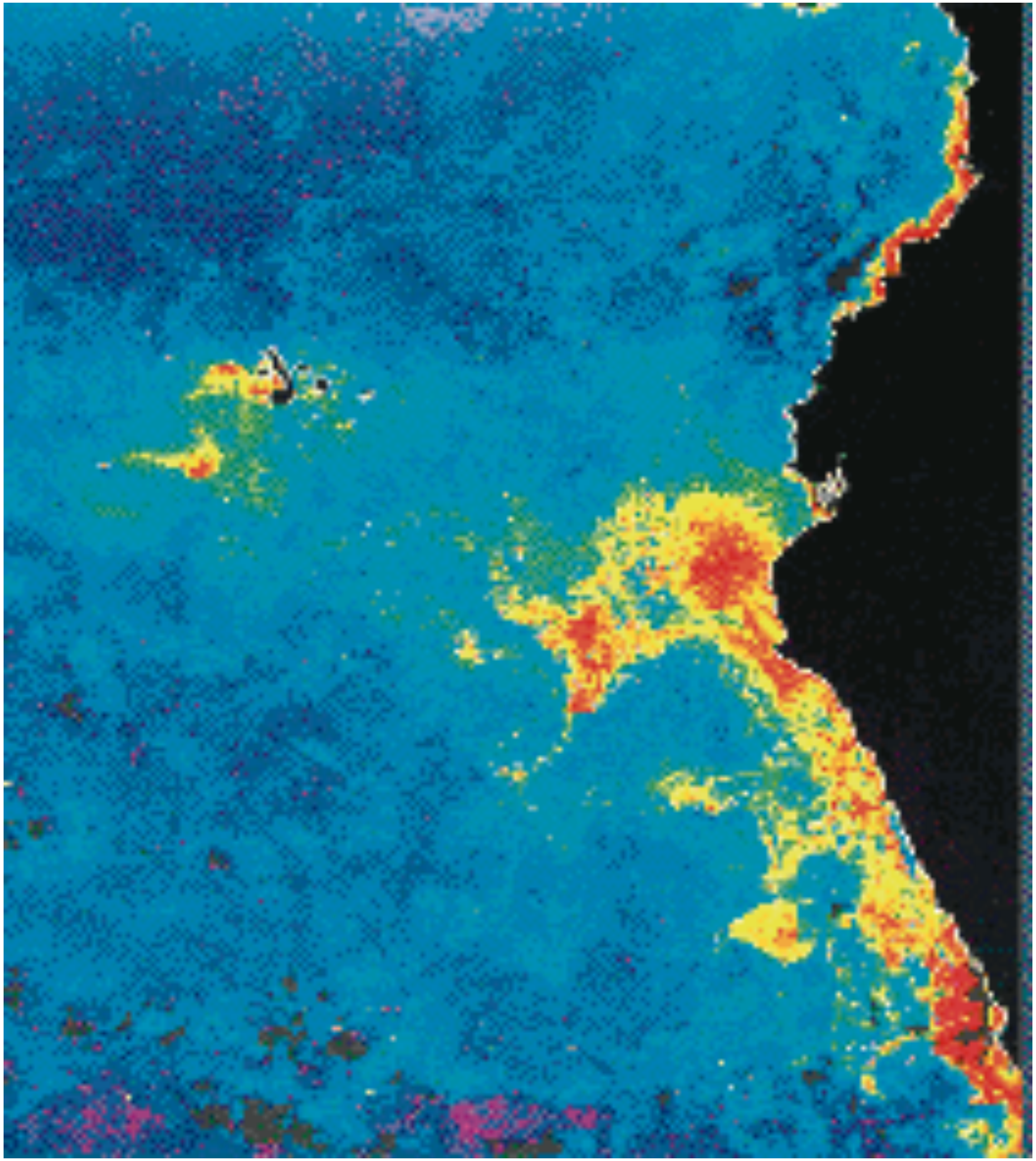

Time (millions of years)
1
2
3
4
5
6
7
8
9
10
Start:
100 atoms of parent X
0 atoms of daughter Y
One half-life after 1 million years
(50% decayed: 50 atoms of X,
50 atoms of Y)
Two half-lives after 2 million years
(75% decayed: 25 atoms of X,
75 atoms of Y)
Three half-lives after
3 million years (87.5%
decayed: 13 atoms of X,
87 atoms of Y)
Proportion of X Atoms Remaining (%)
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
Number of Half-lives

^{14}C age of near-bottom ocean water…



Upwelling is mainly along continental margins, but deep water also moves up slowly through the pycnocline over the whole ocean.

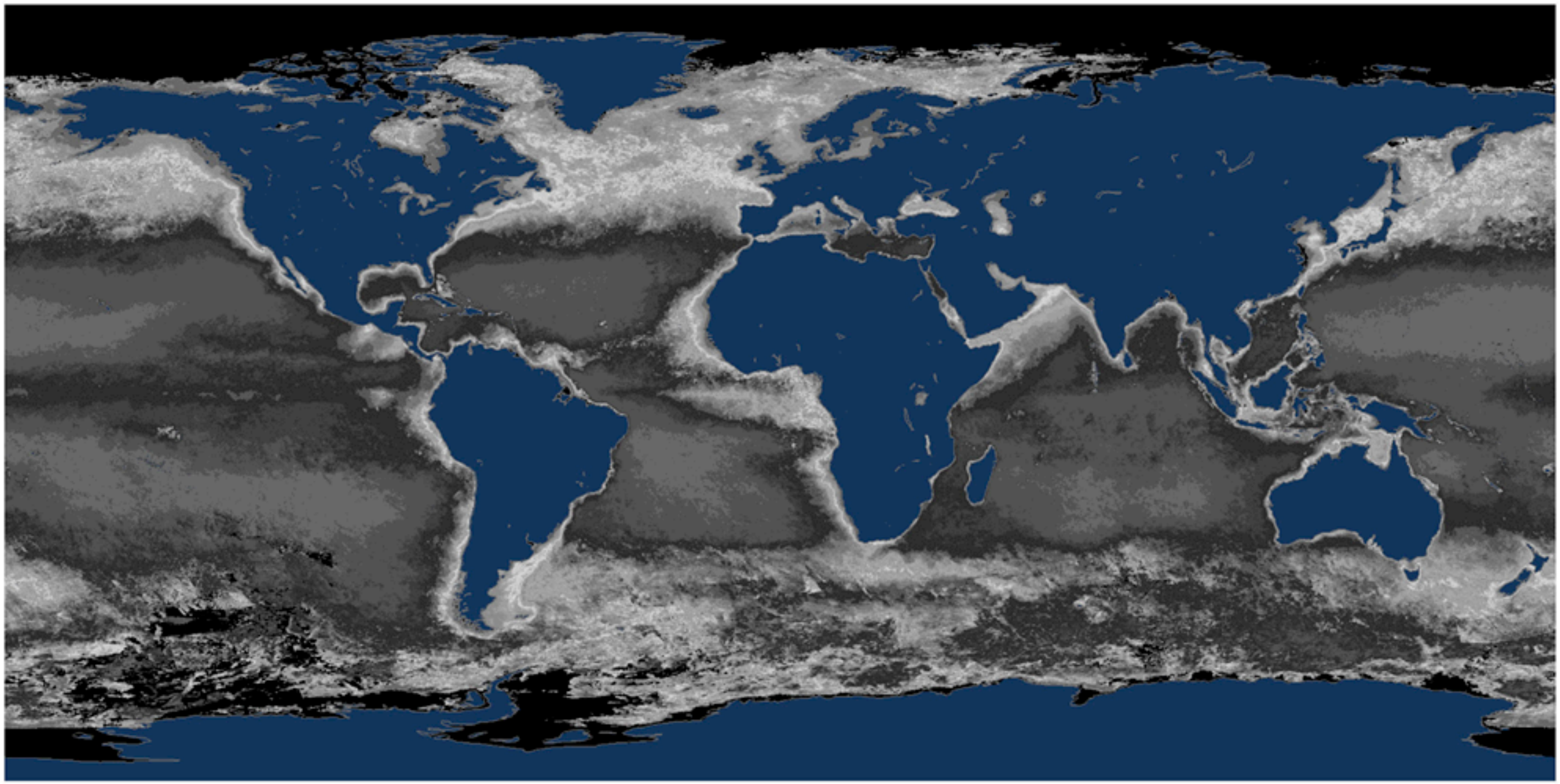




Upwelling along the coast of Peru.

Red color indicates a greater amount of algae fed by nutrients brought up with the deep, cool water.

Regions of greatest productivity are where nutrients are, NOT necessarily in the tropics!!



A curious complexity:

T at 1 km depth

Salinity at 1 km depth

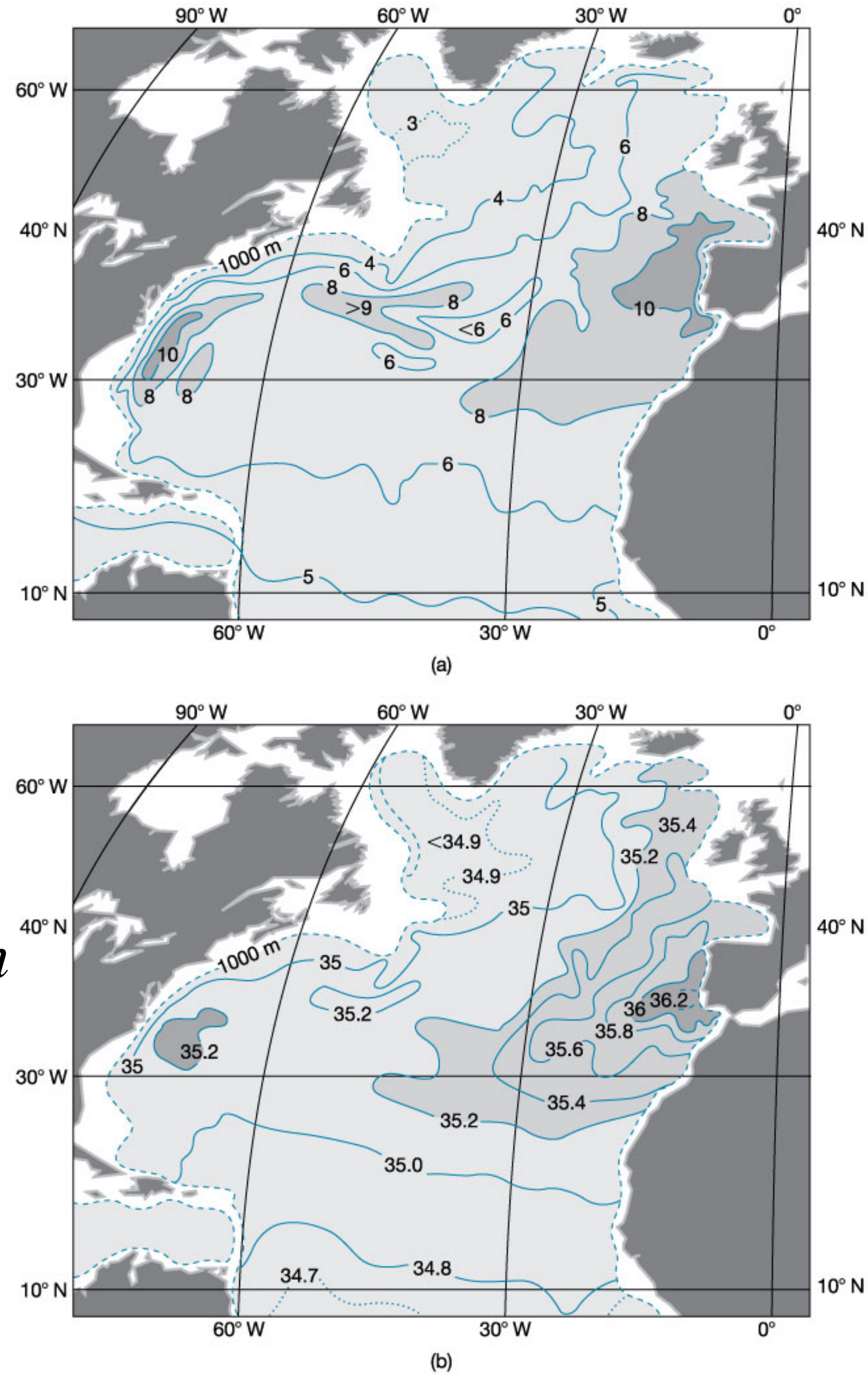
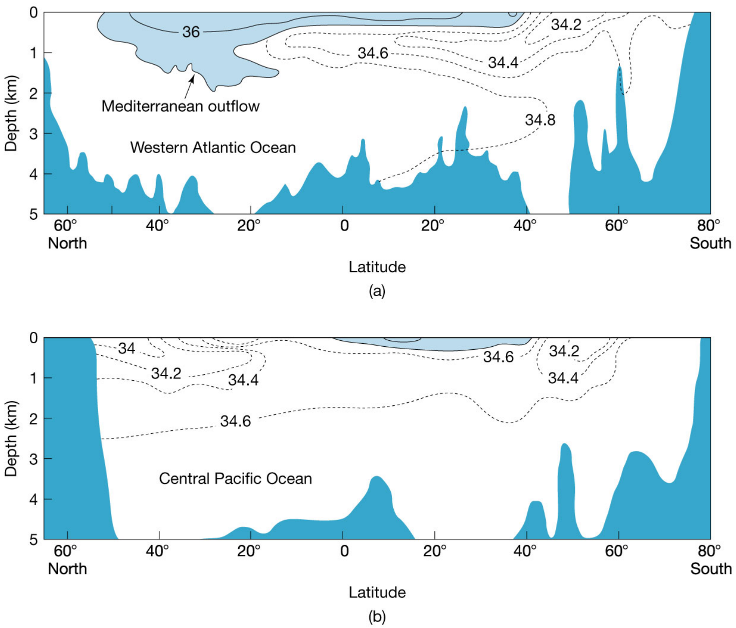
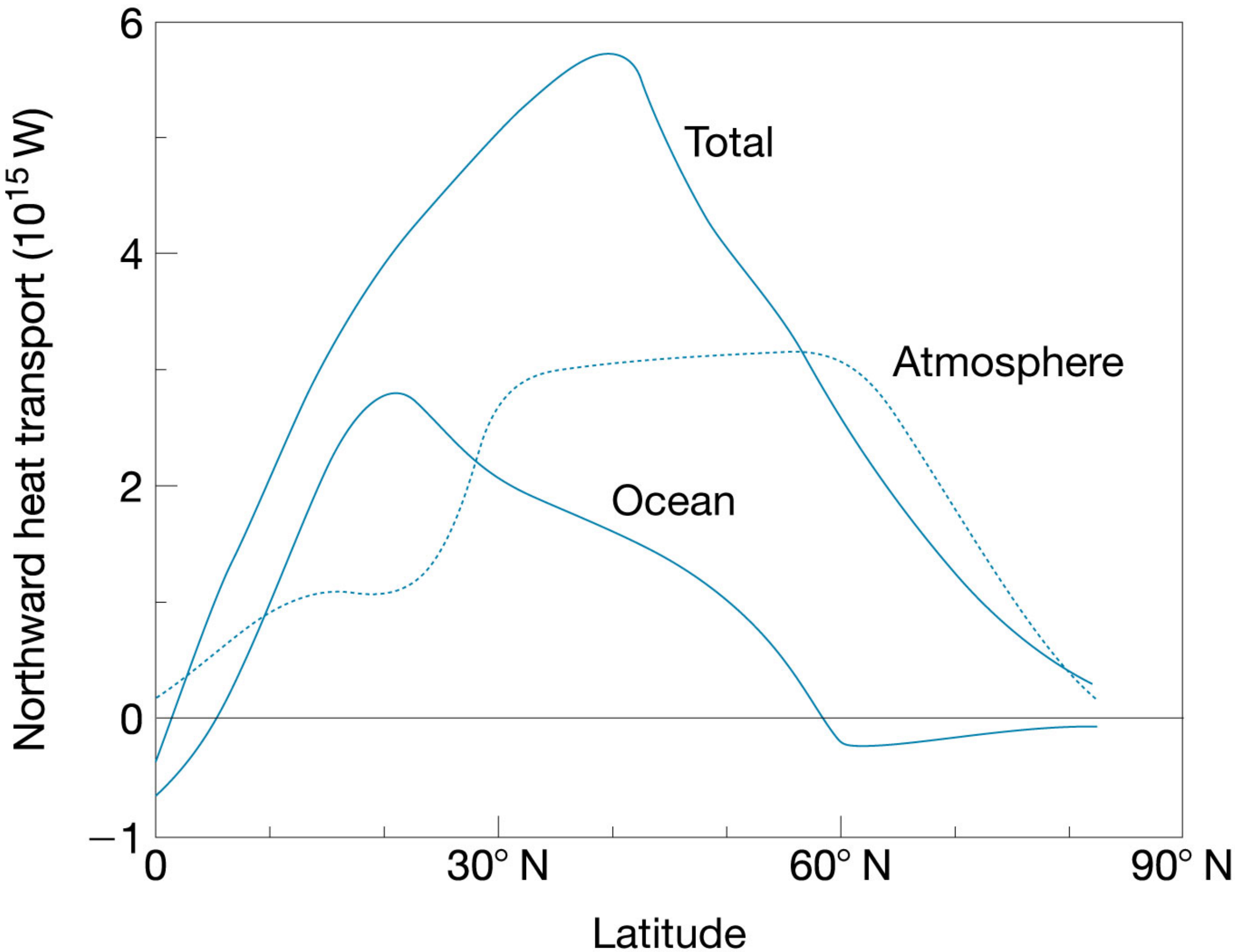


Fig. 5-14

Mediterranean outflow



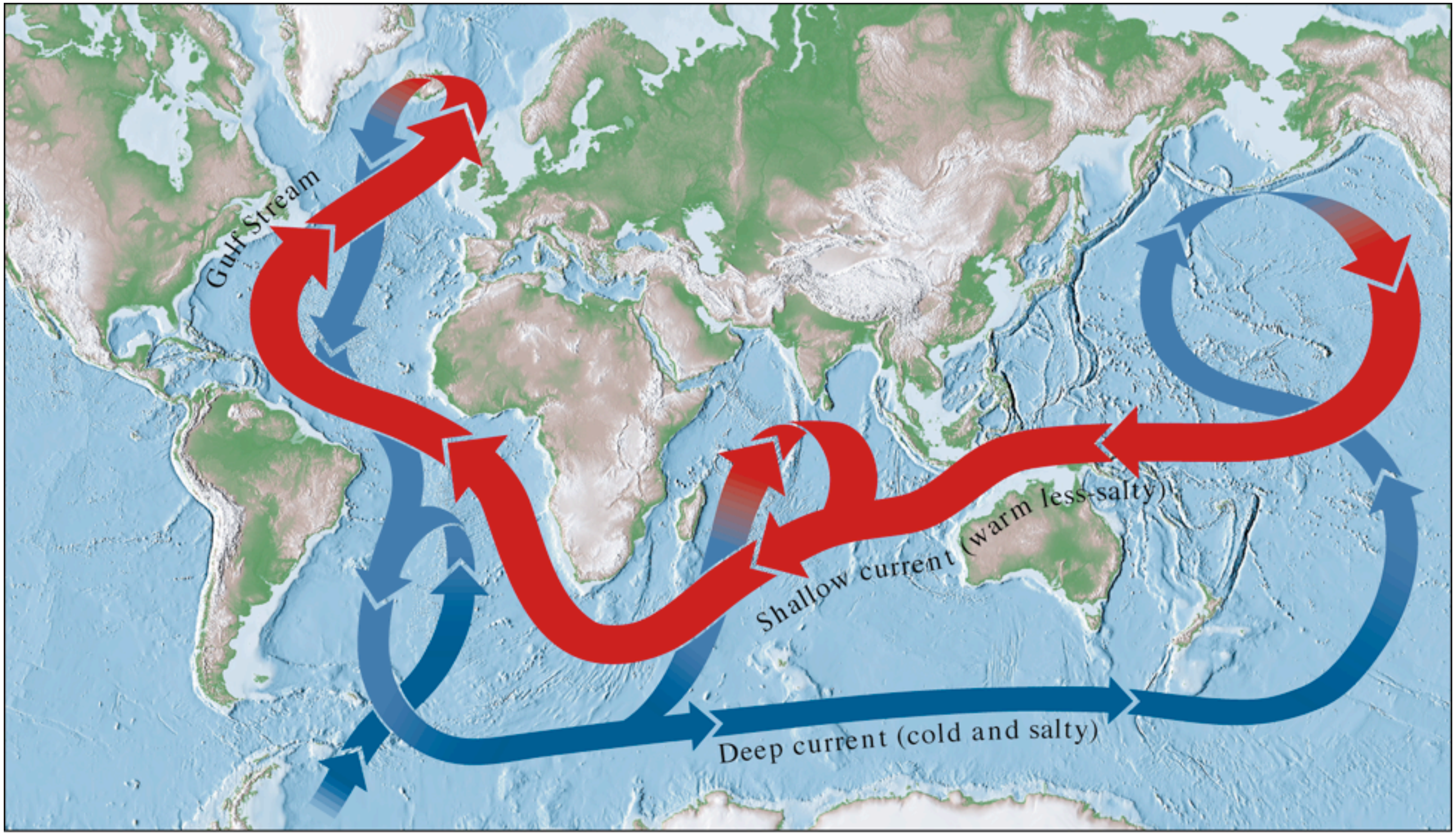


Ocean carries as much heat towards poles as atmosphere, and heat transport in oceans is especially important at low latitudes.

Fig. 5-15

"Thermohaline conveyor belt"

Fig. 5-12



Downwelling at N Atlantic and Antarctic creates bottom water, Upwelling moves nutrients up from depth…

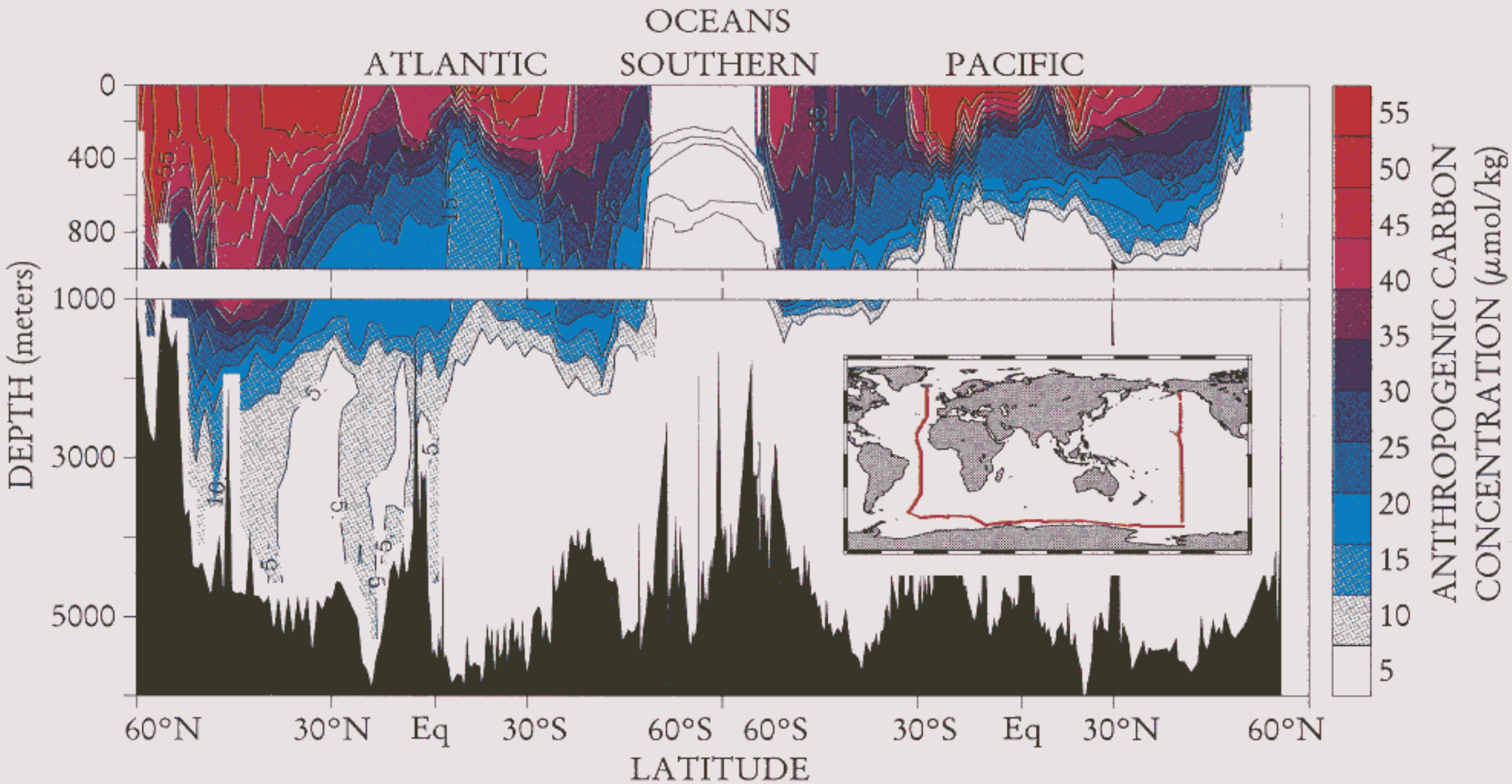
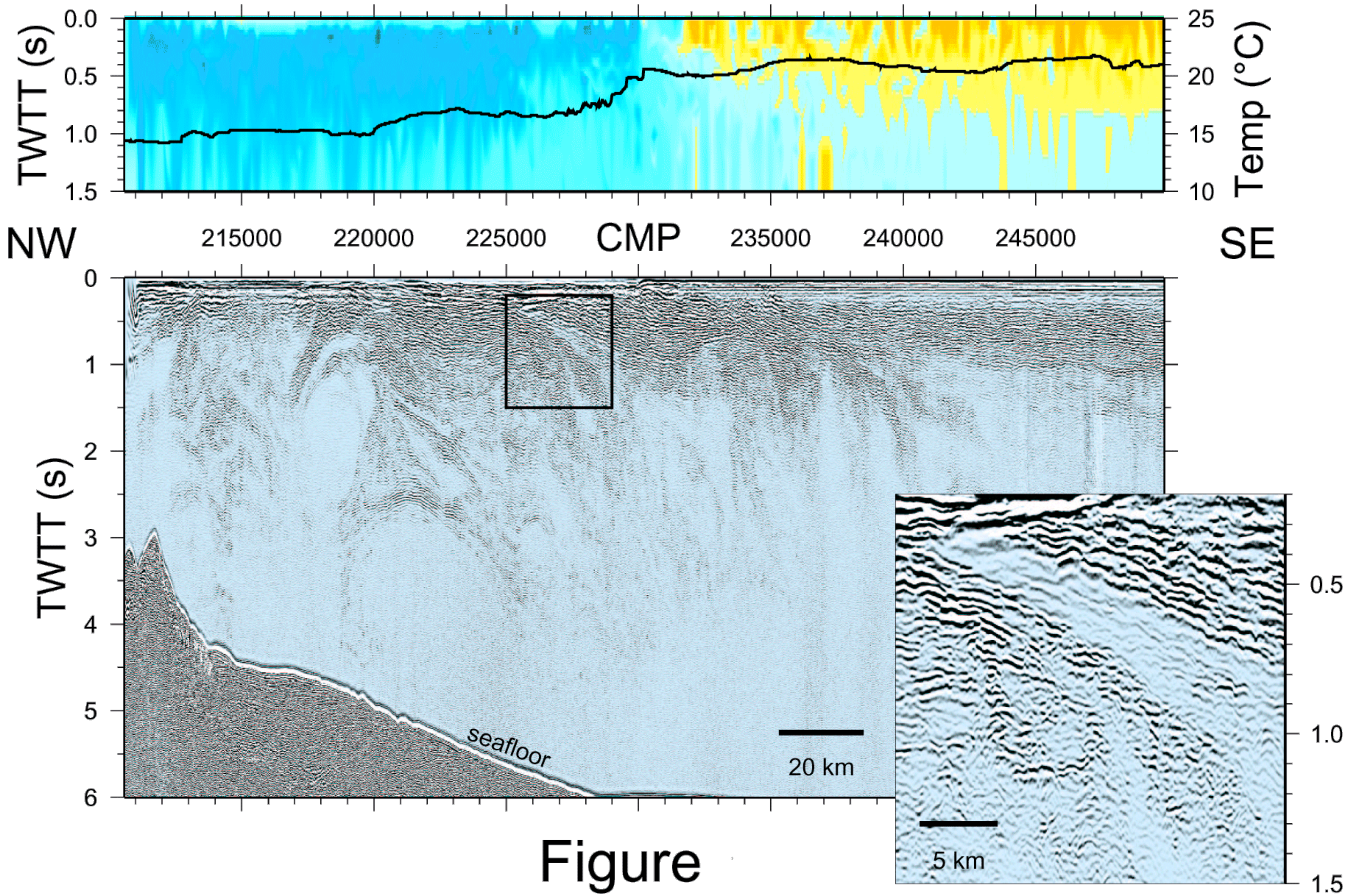


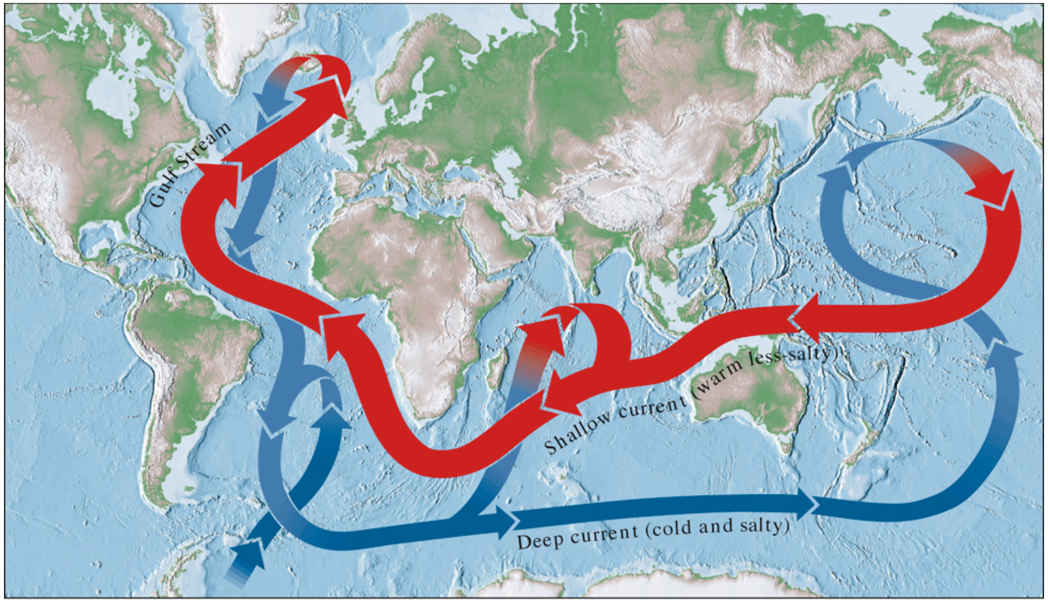
FIGURE 4. ANTHROPOGENIC CARBON CONCENTRATIONS IN THE OCEAN along the track shown as a red line in the inset.[18] The black area represents the depth of the ocean floor. The anthropogenic carbon dioxide concentrations are separated from the natural background by using a recently developed analysis[18] applied to high-precision measurements of dissolved inorganic carbon. Uncertainties in this separation technique are so large south of 60° S that they are shown there as contour lines only. Anthropogenic carbon has penetrated significantly below about 2000 meters of the water column only in the North Atlantic, where surface waters sink directly into the abyss.

Seismic Oceanography - a science started by UW geophysicist Holbrook!



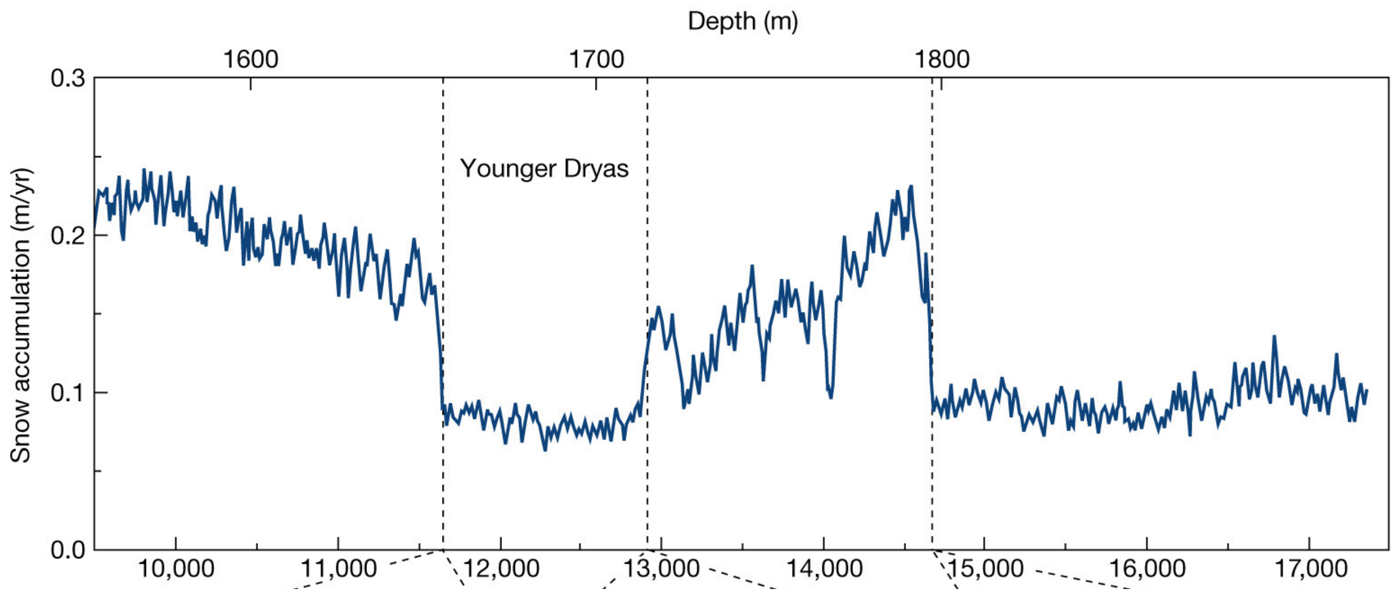
Figure

Oceans and Global Climate



Can the conveyor belt shut off?

- Retreating glaciers
- Cold meltwater enters N. Atlantic
- Less saline surface layer is stable but cold
- More ice forms
- N. Atlantic drift can't go so far north
- N. Europe is COLD



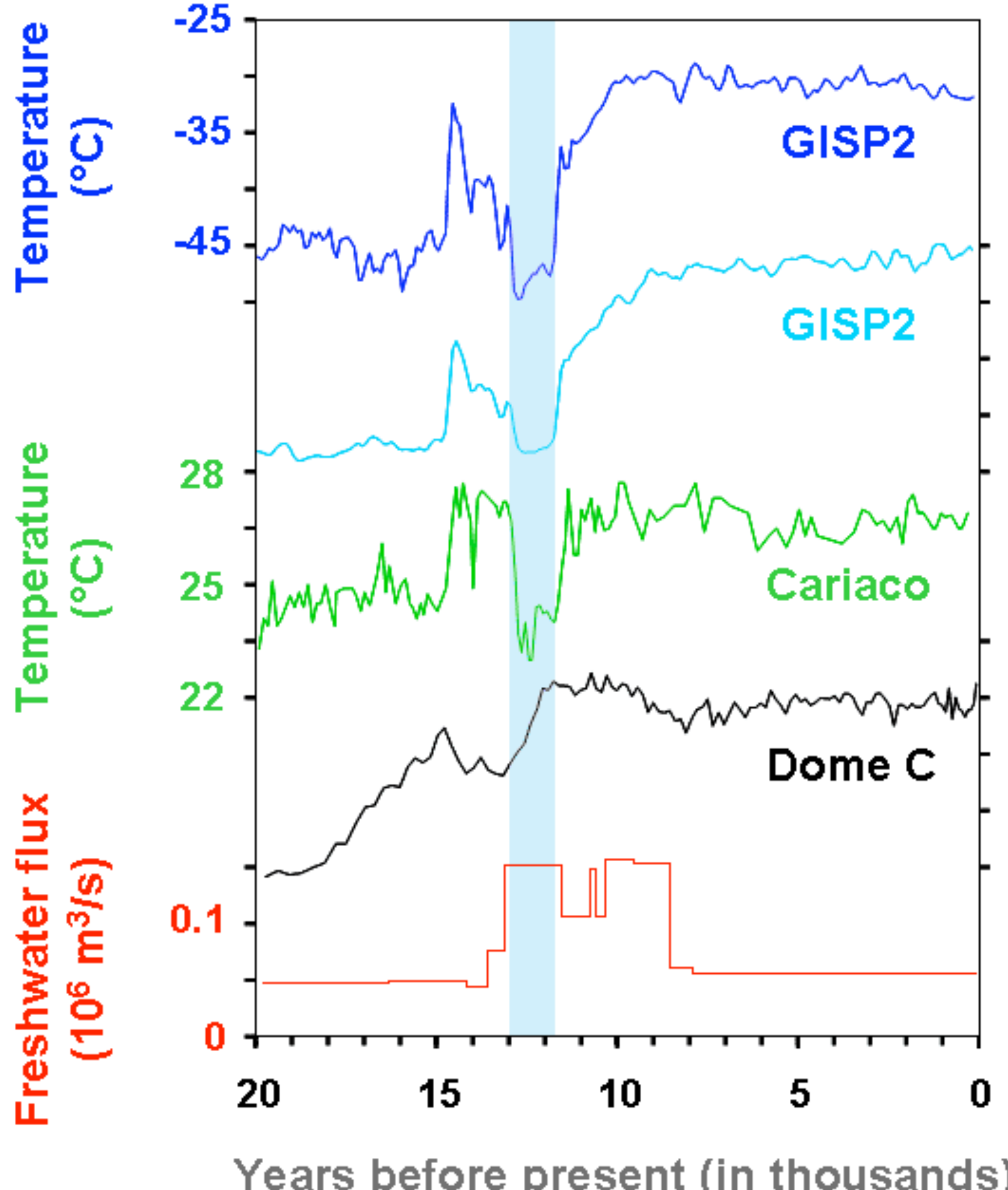
Younger Dryas: abrupt cooling in Europe possibly related to freshwater interruption of NADW formation (10 years or less!).

Atm T gradient from equator to pole intensified.

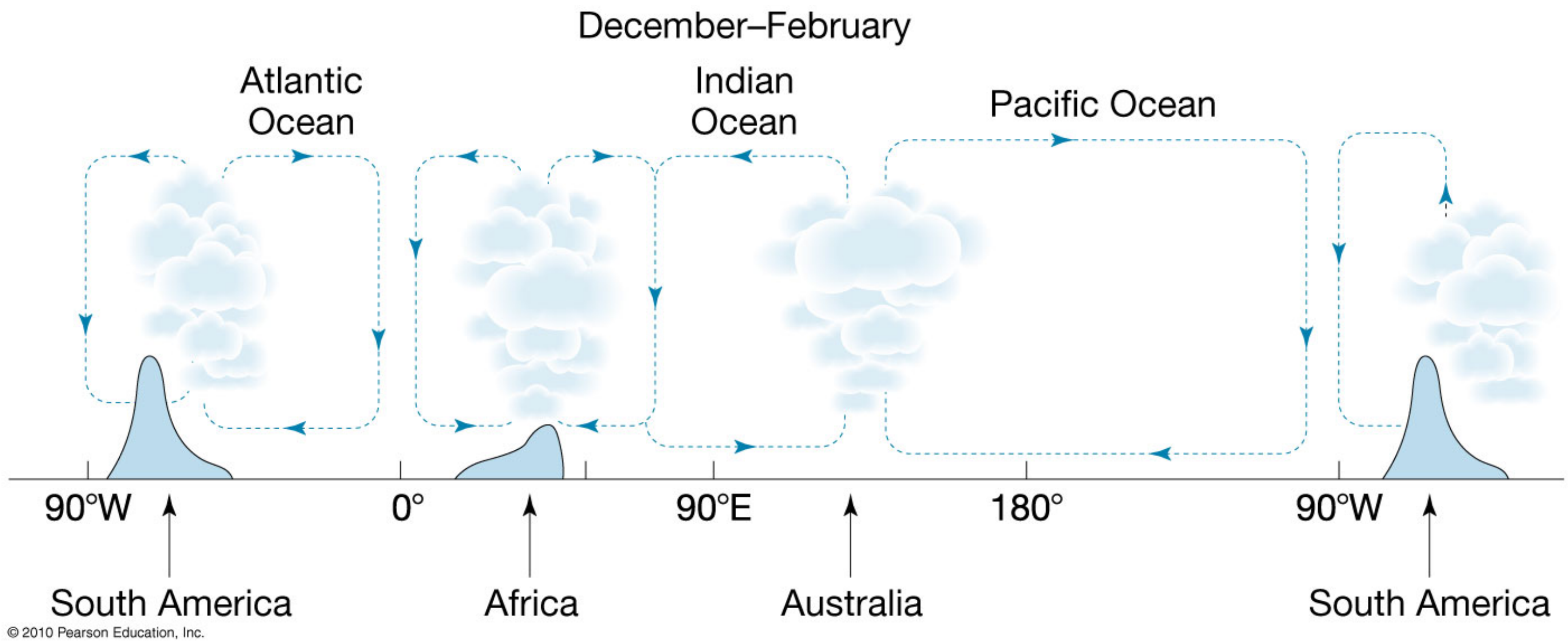
CO_2 in atmosphere also dropped--why?

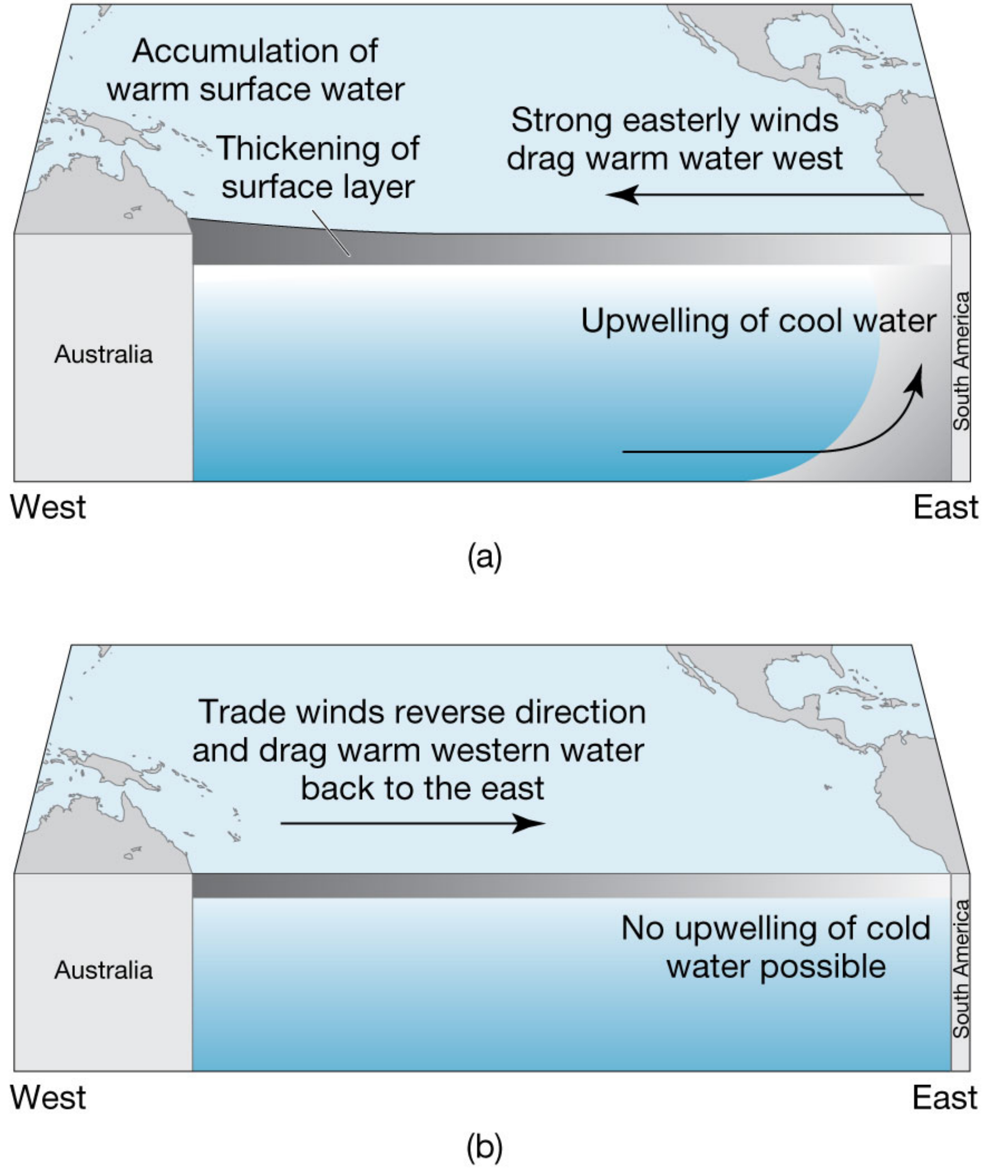
Bottom line: climate changes can be *FAST* because ocean circulation can change abruptly.

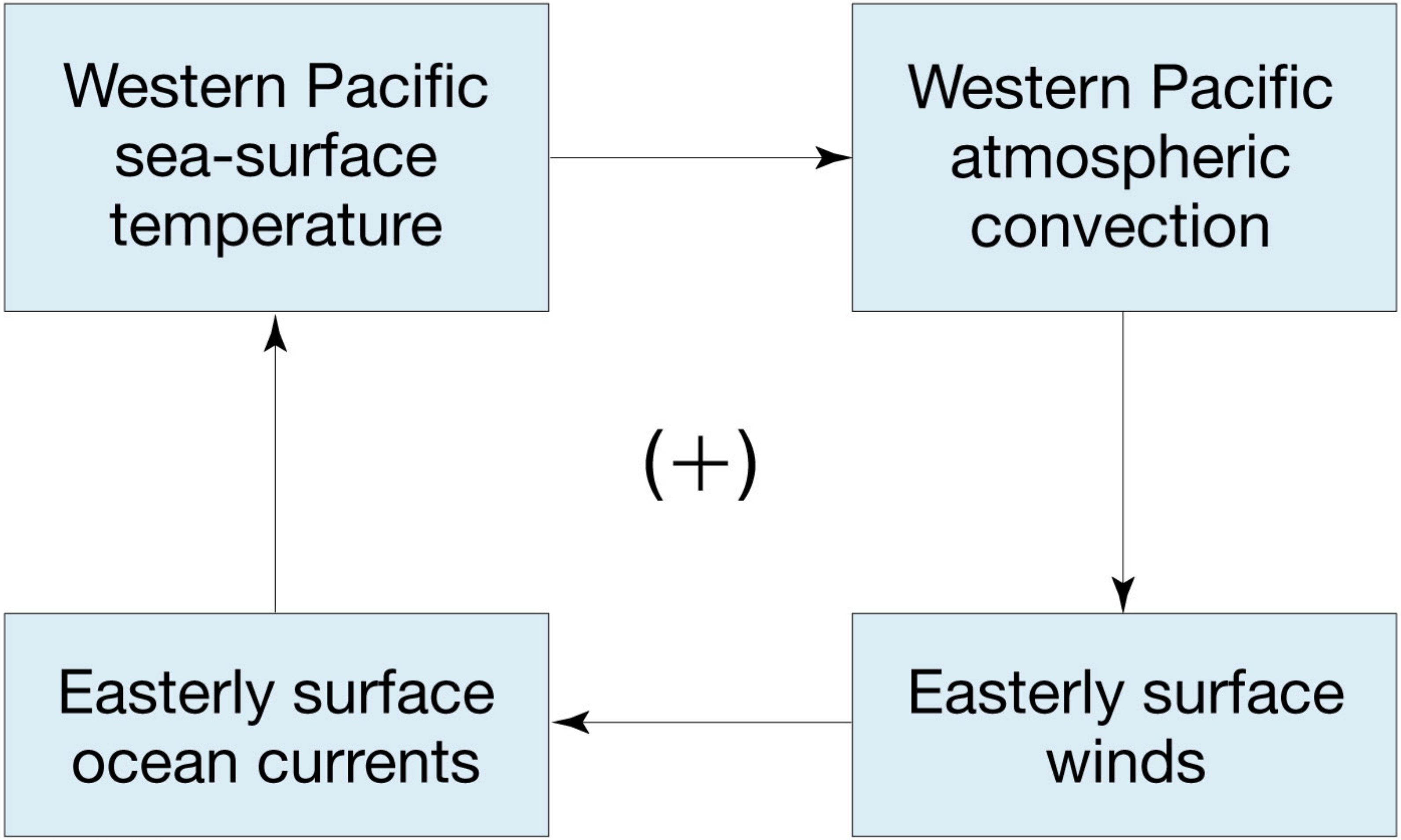
http://www.ncdc.noaa.gov/paleo/abrupt/images/data4-climate-changes-lg.gif

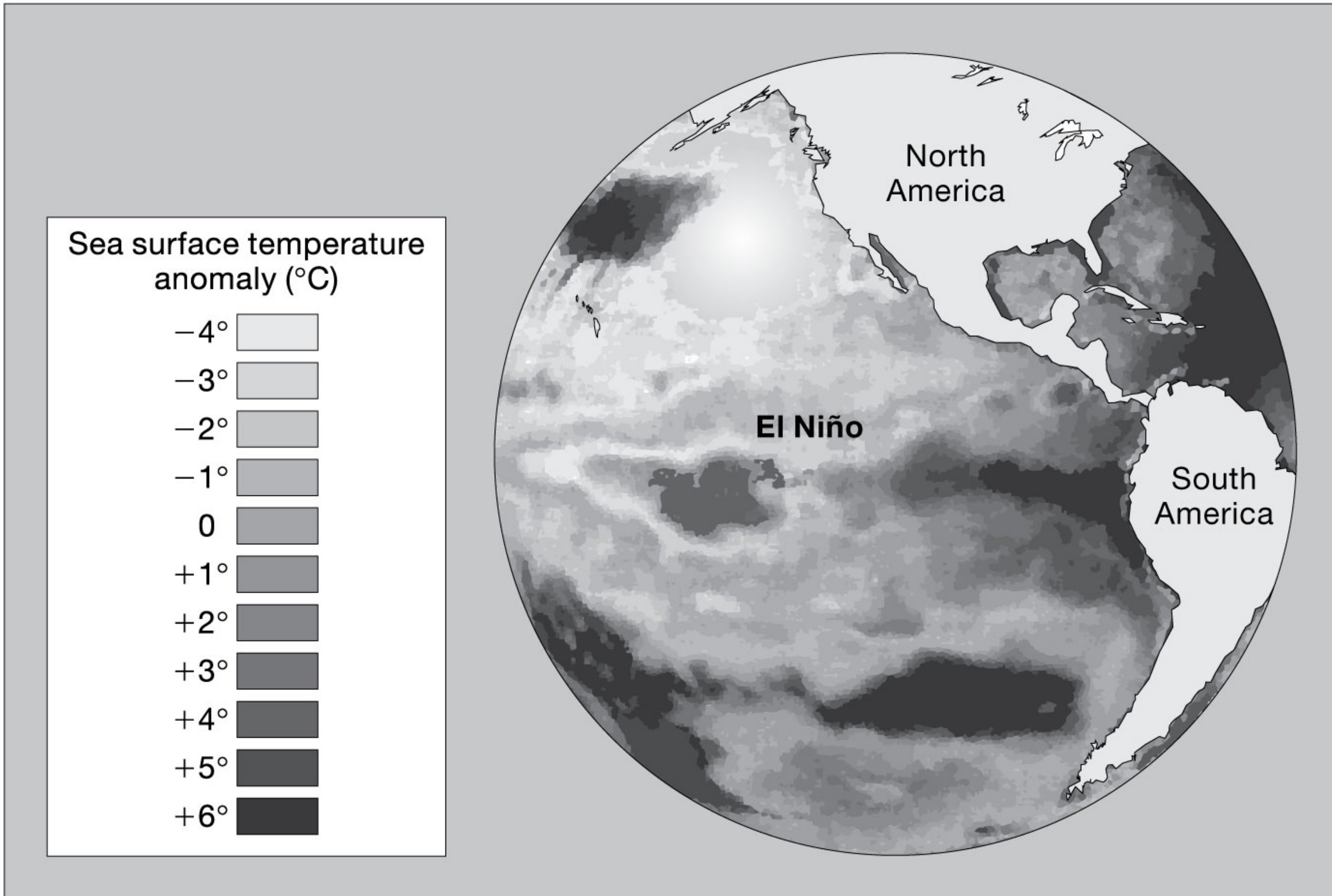


Equatorial Pacific…"normal":

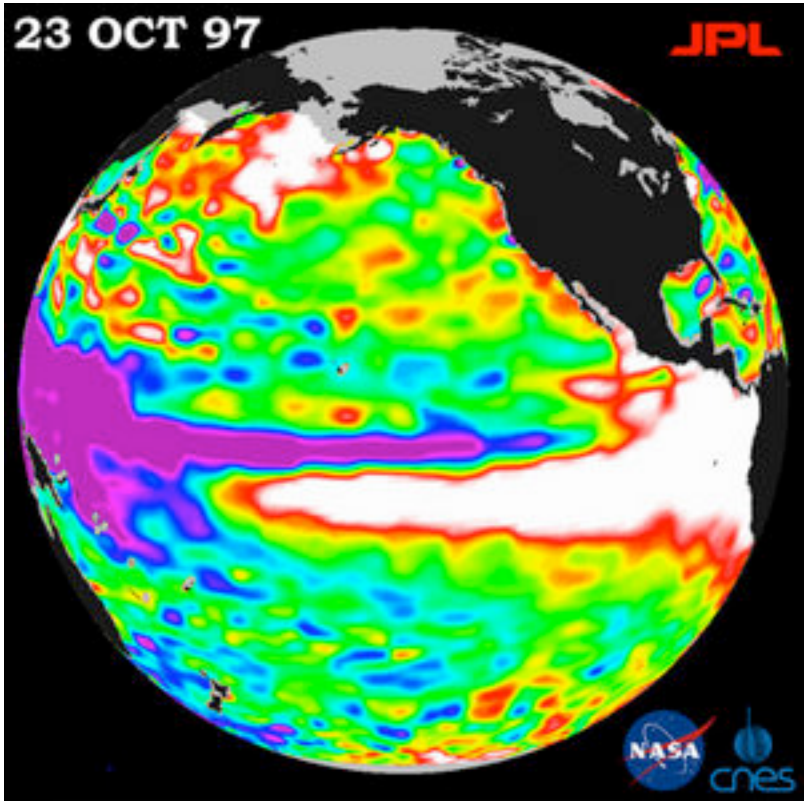


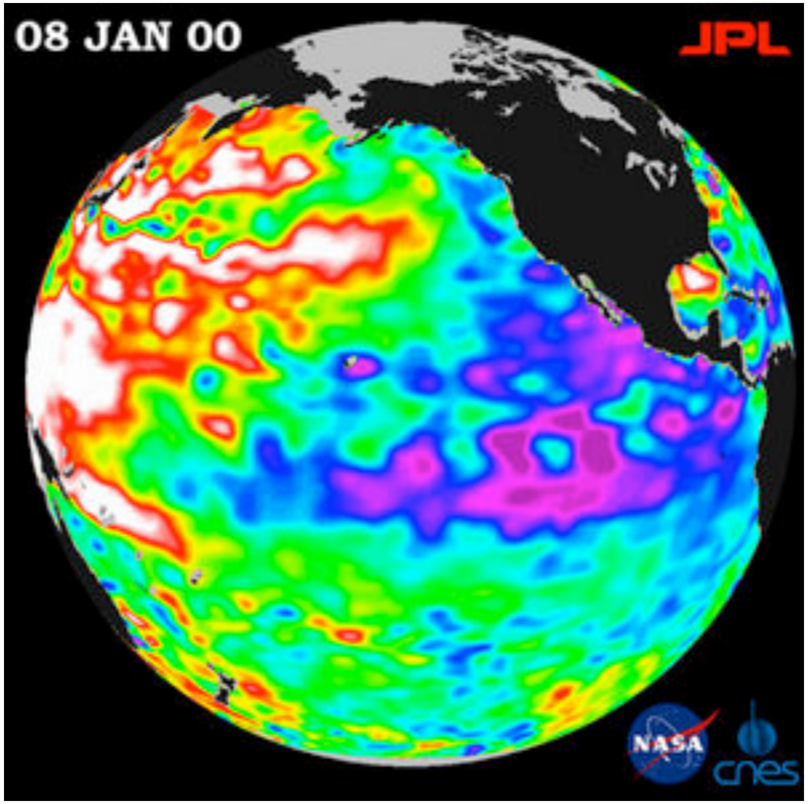

Accumulation of
warm surface water
Thickening of
surface layer
Strong easterly winds
drag warm water west
Australia
Upwelling of cool water
South America
West
East
(a)
Trade winds reverse direction
and drag warm western water
back to the east
Australia
No upwelling of cold
water possible
South America
West
East
(b)


Western Pacific sea-surface temperature
Western Pacific atmospheric convection
(+)
Easterly surface winds
Easterly surface ocean currents

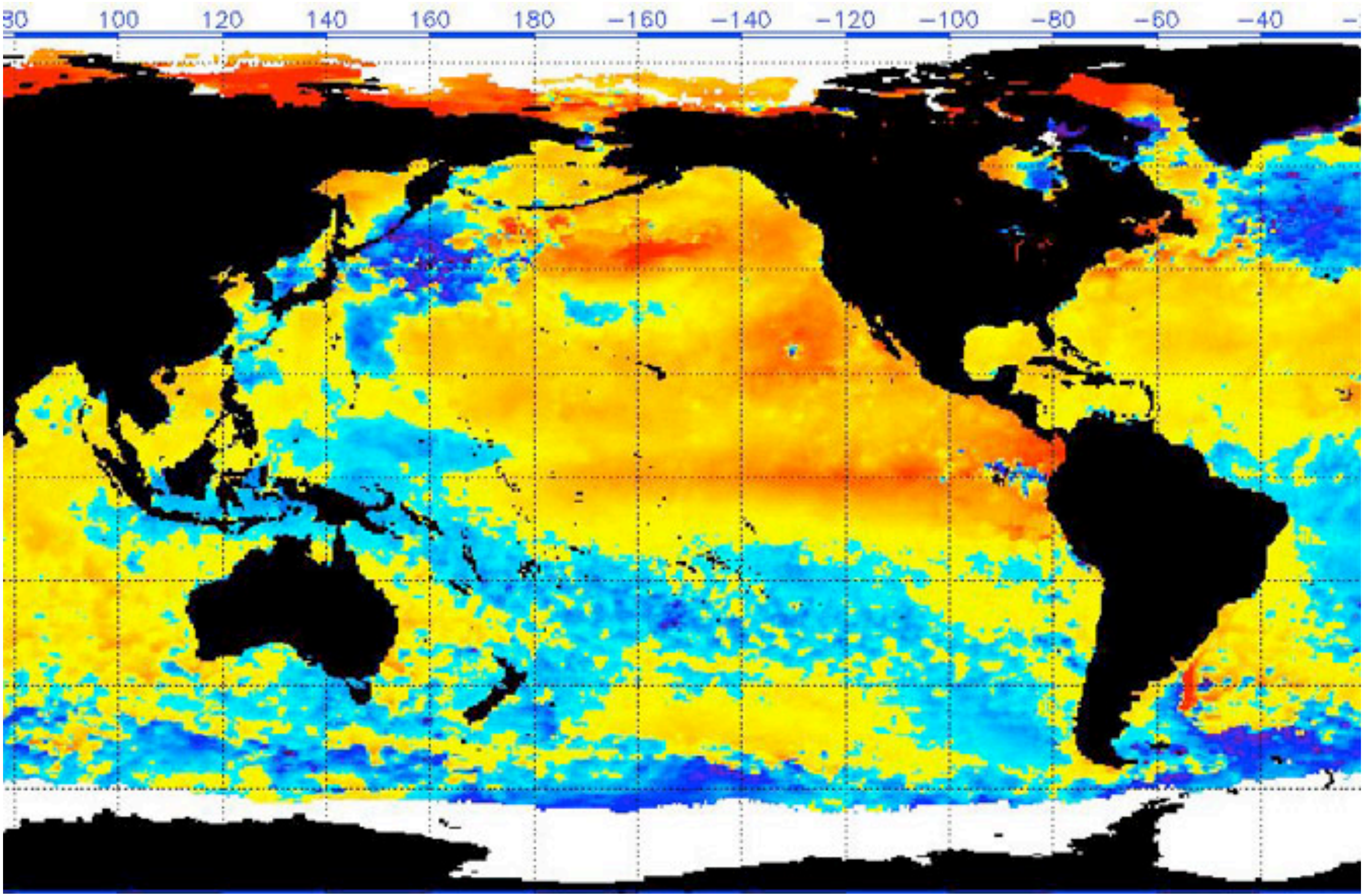

Sea surface temperature anomaly (°C)
−4°
−3°
−2°
−1°
0
+1°
+2°
+3°
+4°
+5°
+6°
North America
El Niño
South America

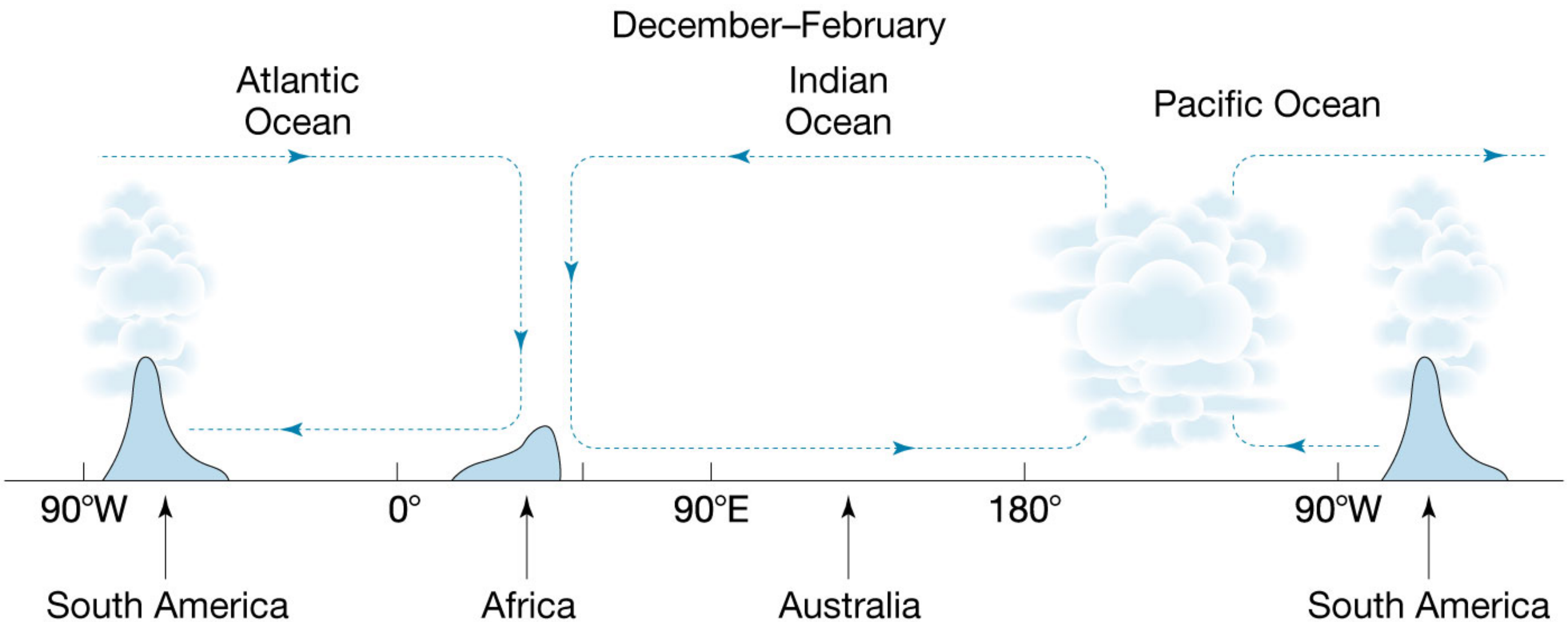
El Nino La Nina

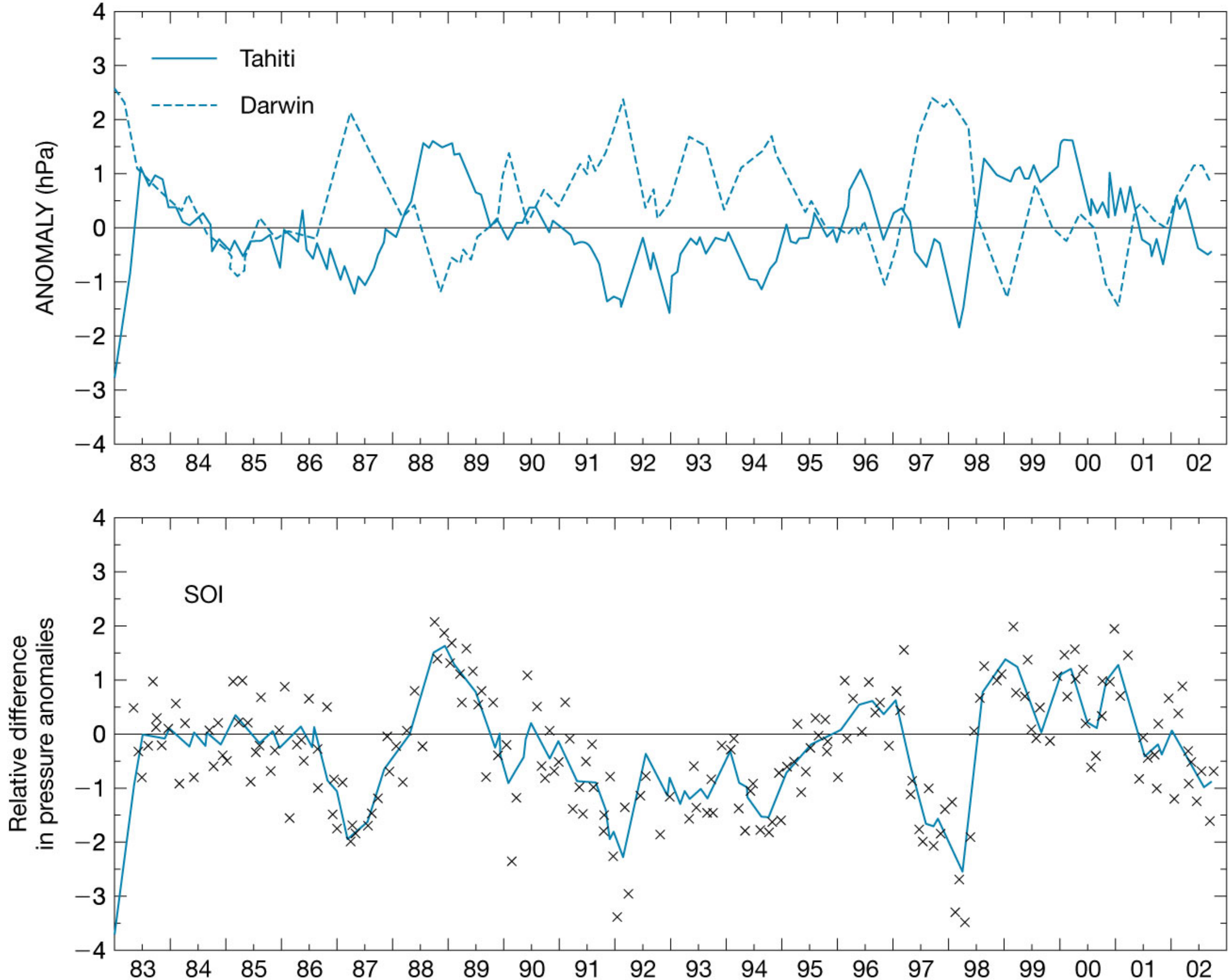




Sept. 2, 2015




December–February
Atlantic Ocean
Indian Ocean
Pacific Ocean
90°W
0°
90°E
180°
90°W
South America
Africa
Australia
South America



Tahiti
Darwin
ANOMALY (hPa)
4
3
2
1
0
−1
−2
−3
−4
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
00
01
02
SOI
Relative difference in pressure anomalies

December–February