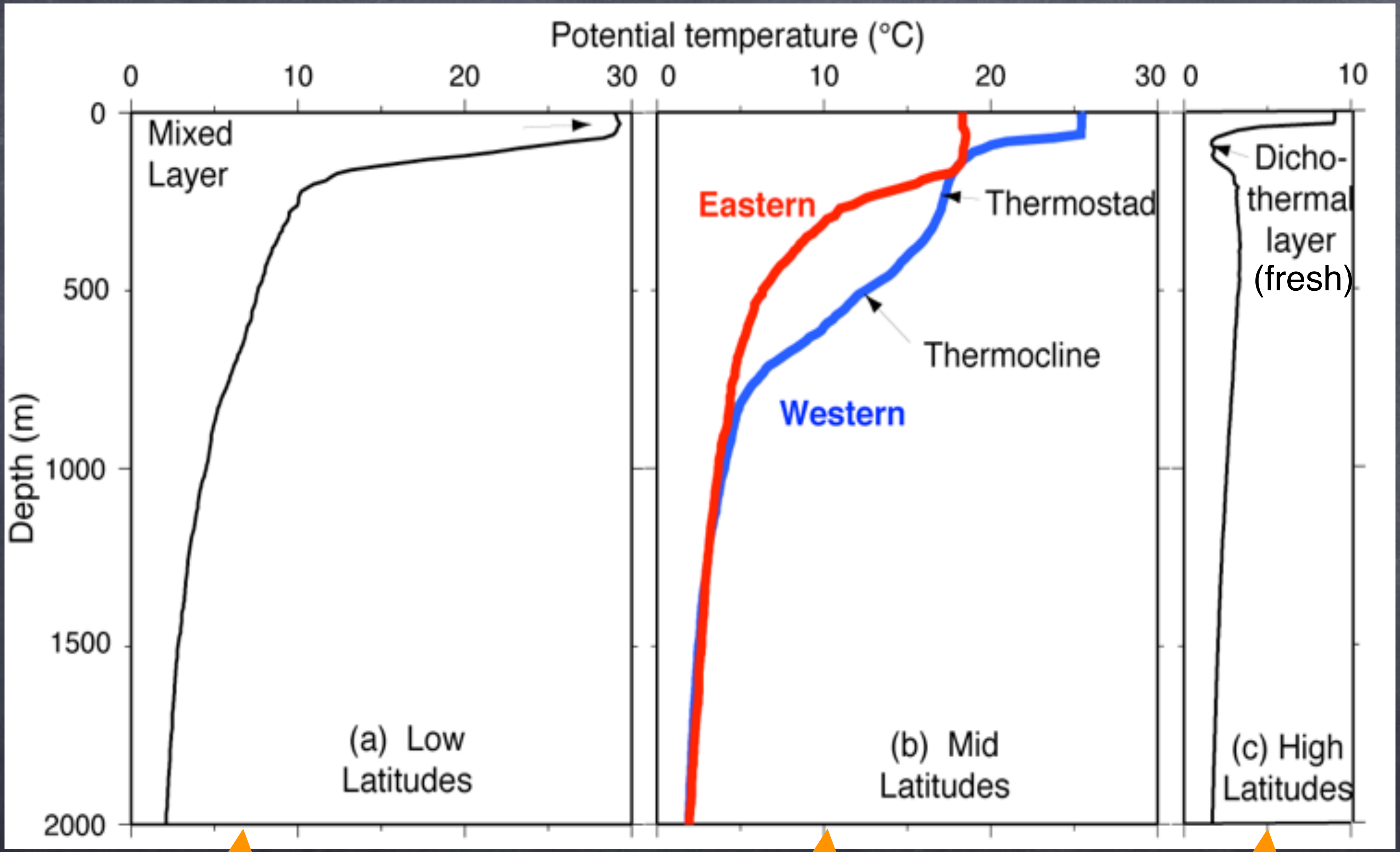
Property distributions, water masses, and tracers

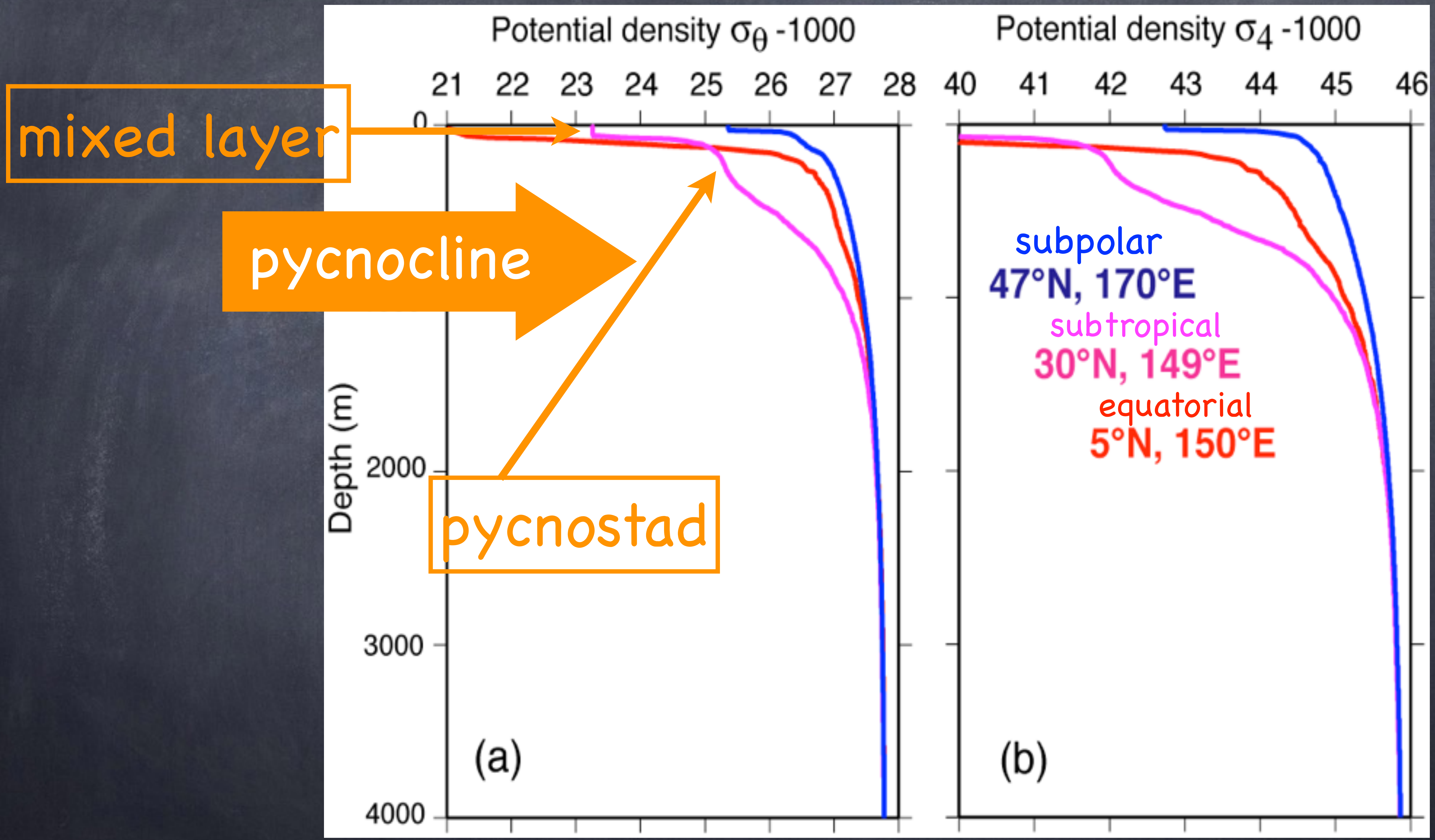
Lecture 5

Typical potential temperature profiles



tropics gyres polar oceans

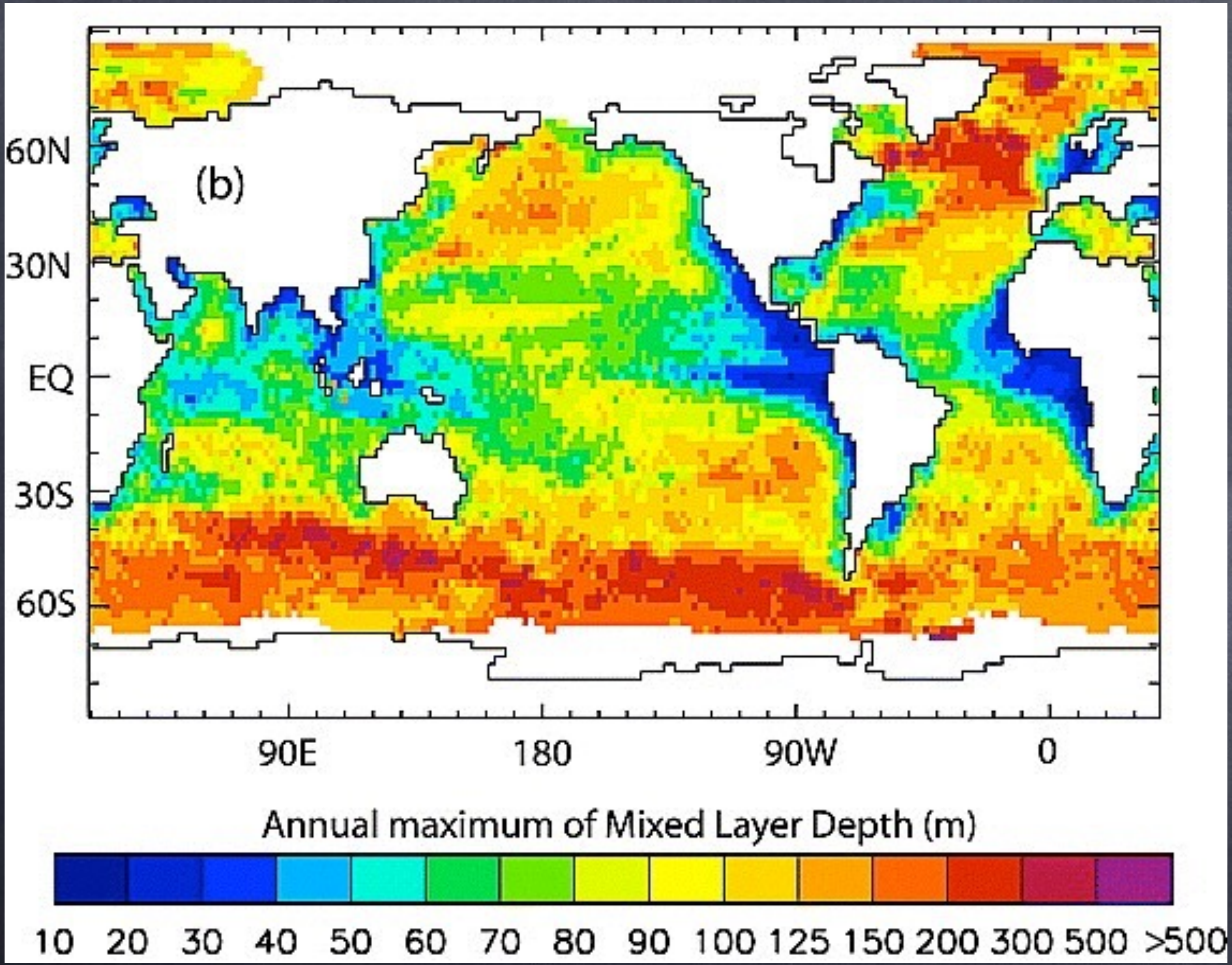
Typical potential density profiles



Mixed Layer

- at surface, typically about 100 m thick, but up to 300-400 m thick seasonally in some regions and <30 m near eastern boundaries.
- layer of water with homogeneous properties
- well-mixed by surface cooling (destabilizes water column) and mechanical wind mixing.

Maximum mixed layer depth



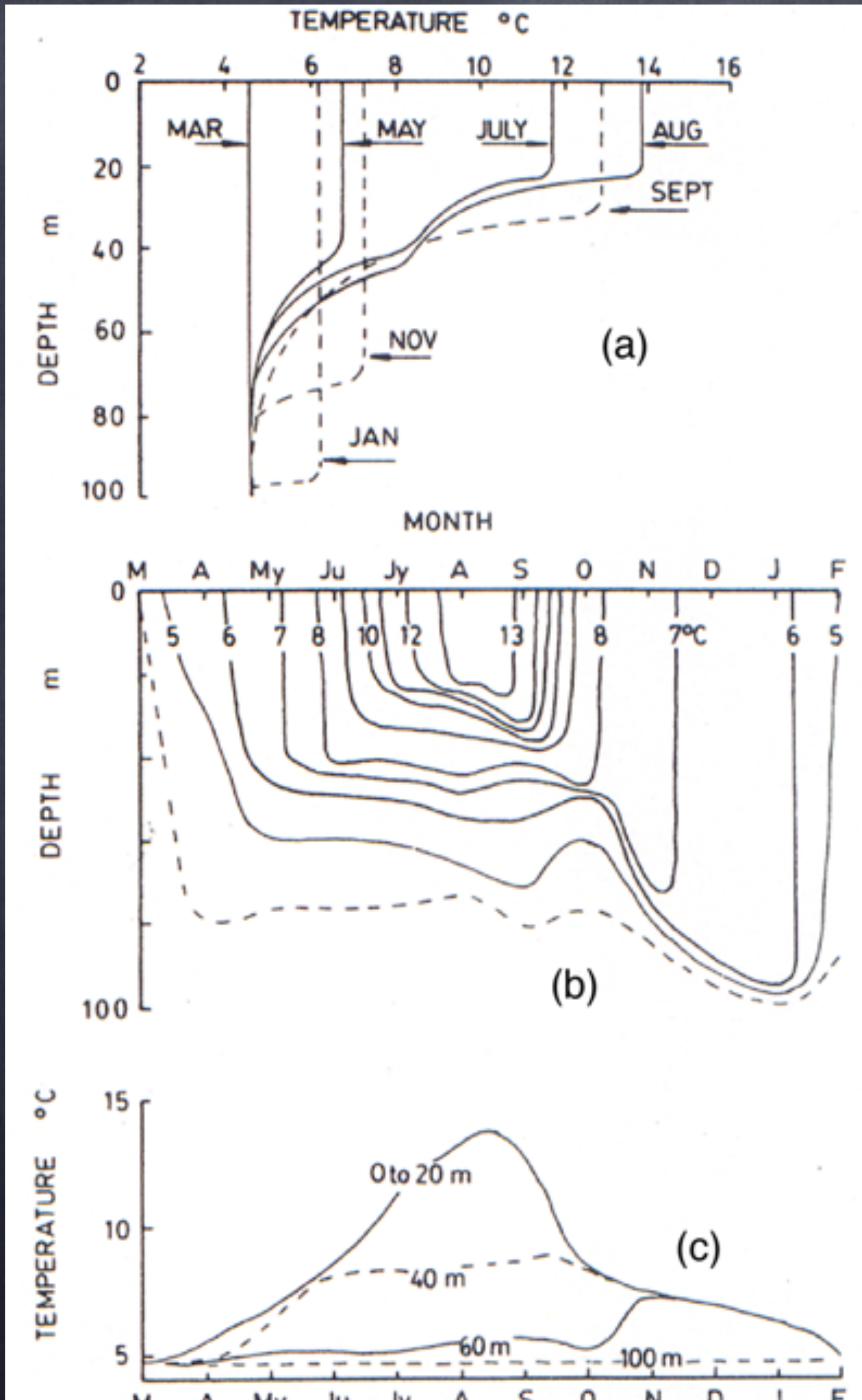
Thickest mixed layers in Southern Ocean, subpolar N. Atlantic, and in downwelling subtropical gyres.

Thinnest along upwelling Eastern boundary regions.

Using delta T = 0.2°C

deBoyer Montegut et al. (JGR, 2004)

Seasonal Mixed layer development



Winter: Development of mixed layer by surface cooling and mechanical wind stirring. Near-surface stratification is eroded, gradually deepening the mixed layer to maximum depth at the end of winter (Feb. to April depending on location)

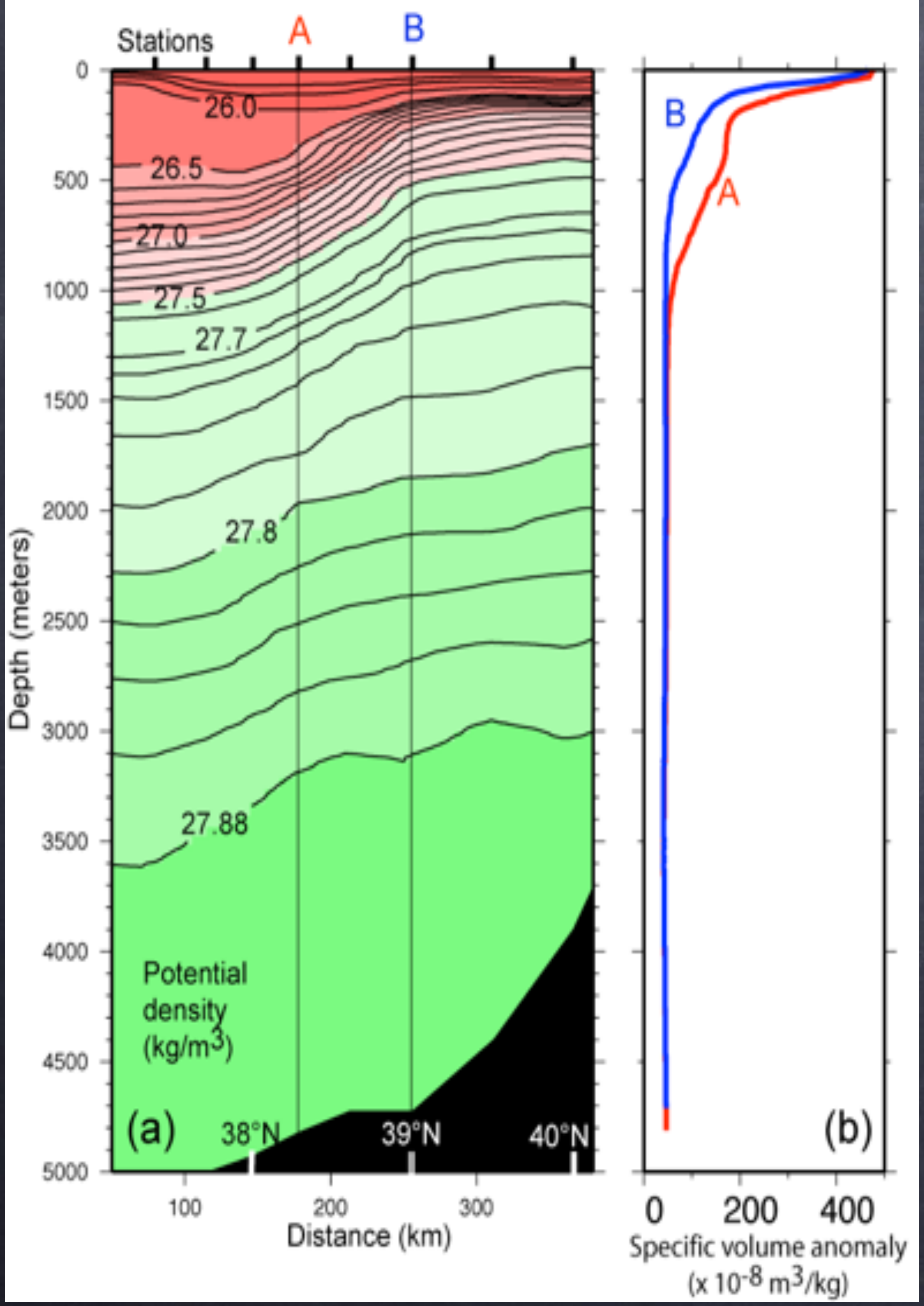
Summer: Surface warming restratifies the water column (seasonal thermocline/pycnocline), usually leaving a remnant of winter mixed layer below.

Talley et al Figure 4.7

Mode Waters (pycnostad/thermostad)

- Found within thermocline, typically 100 to 500 m thick.
- Layer of homogeneous water properties subducted from bottom of winter mixed layer.

Thermostad development: Subtropical Mode Water (Eighteen Degree Water)

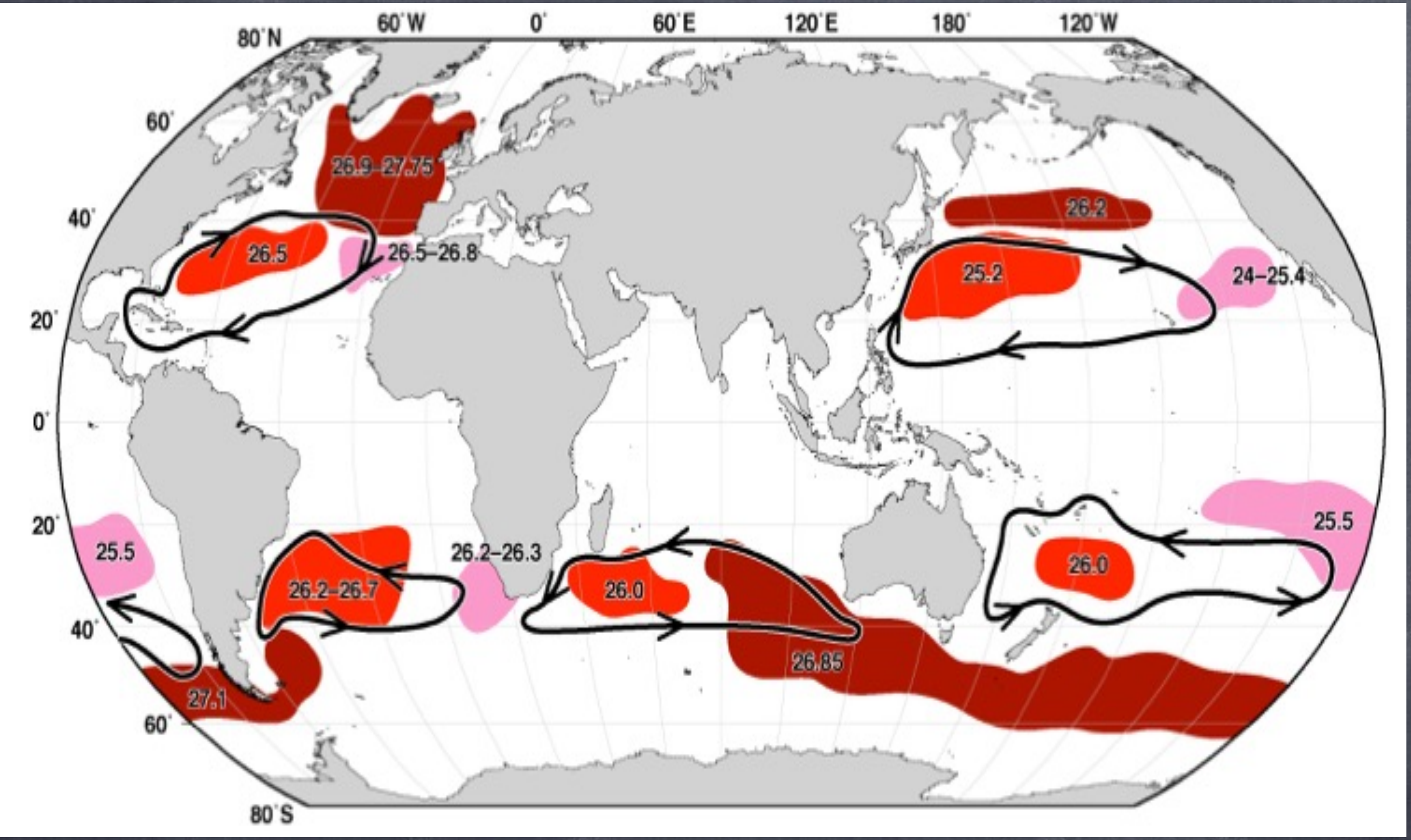


Meridional section across the Gulf Stream

- Thickening of layer between isopycnals is the thermostad
- It forms at surface as a thick mixed layer on the southern flank of the Gulf Stream in late winter.
- Subducts into the interior south of the Gulf Stream along isopycnals.

Talley et al Figure 8.21

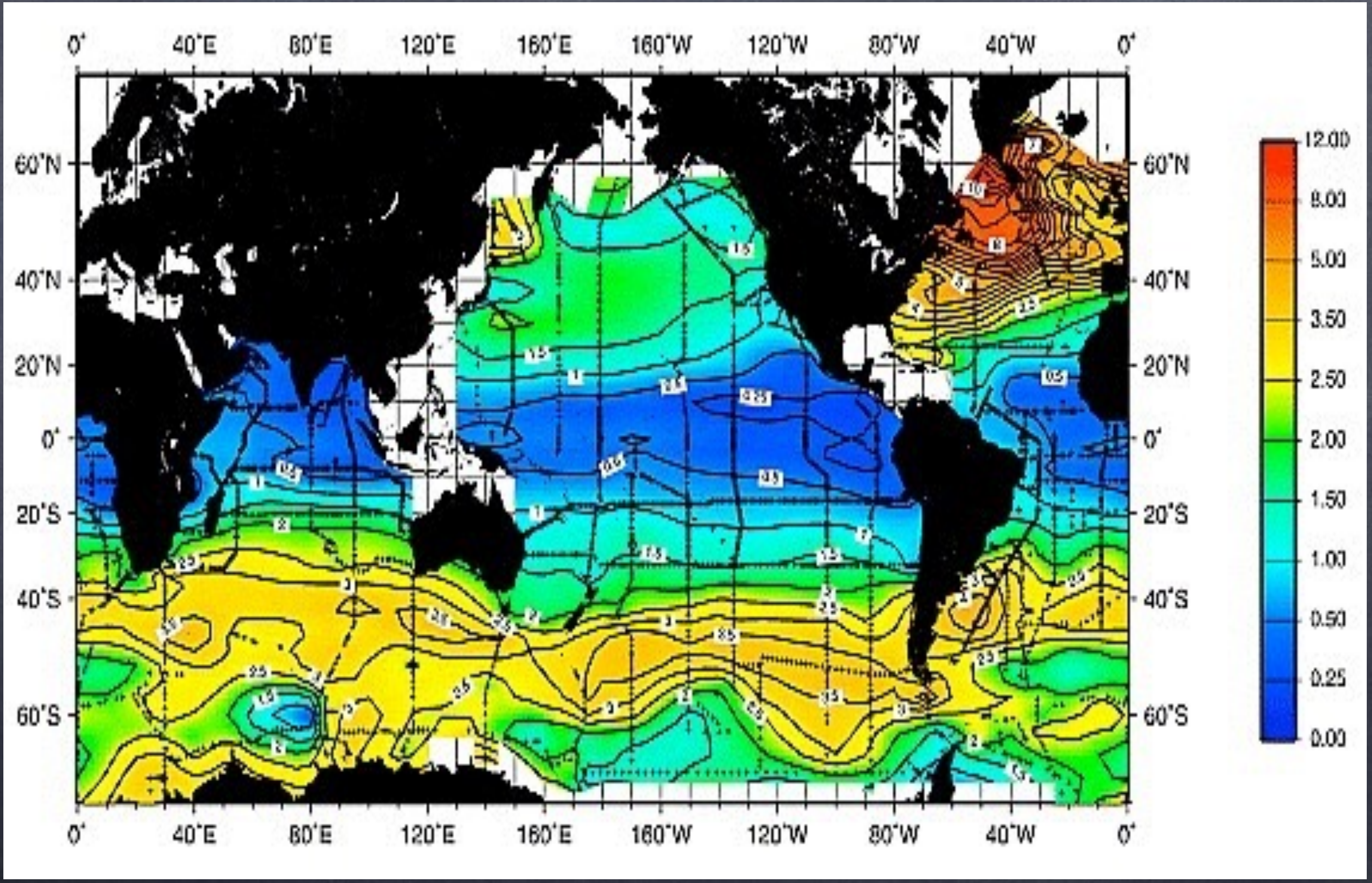
Mode Waters



Location of pycnostads derived from thick winter mixed layers that then spread into the interior along isopycnals. Numbers are neutral densities

Importance of mode waters for dissolved gas inventories

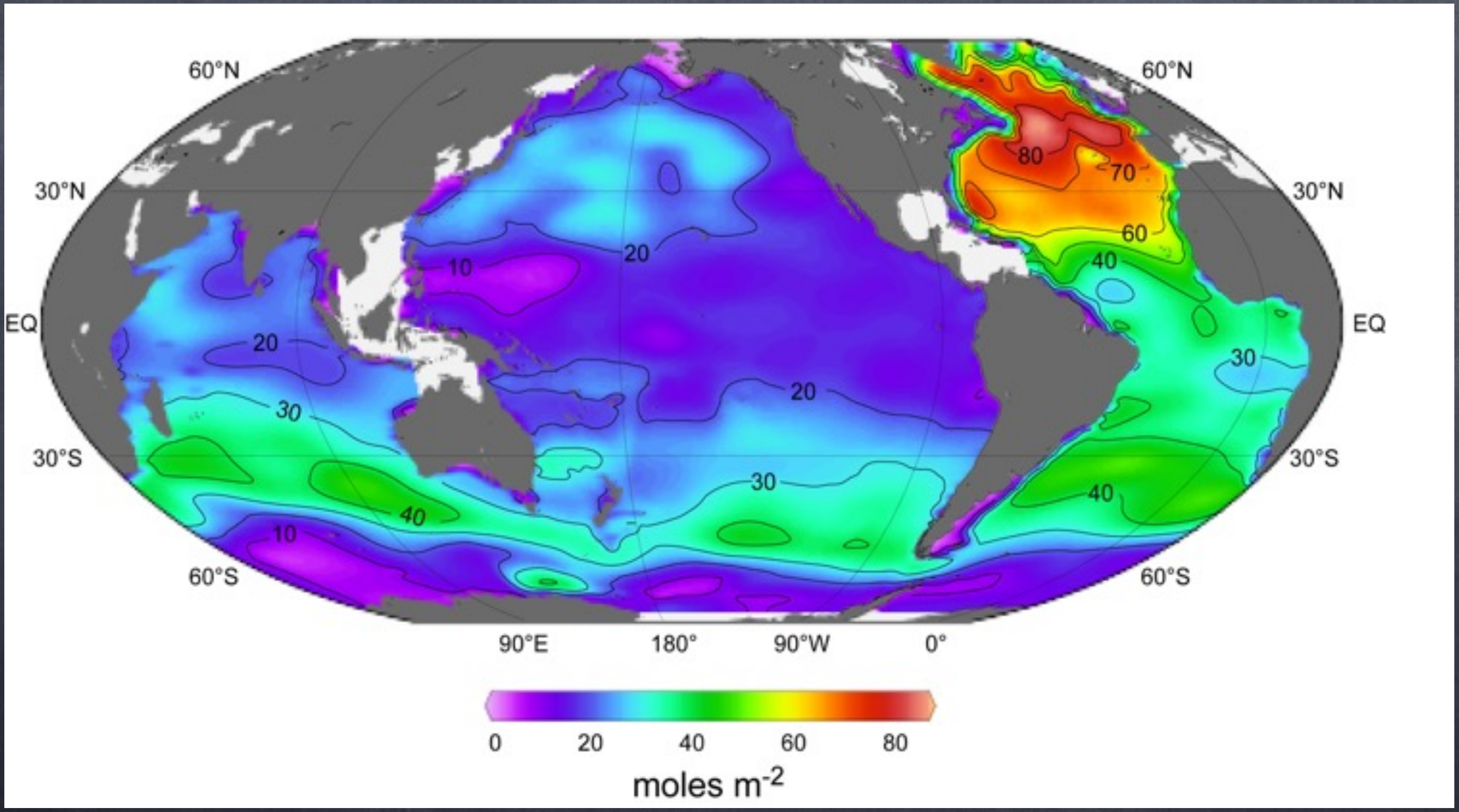
CFC water column inventories



Willey et al. (GRL 2004)

Importance of mode waters for dissolved gas inventories

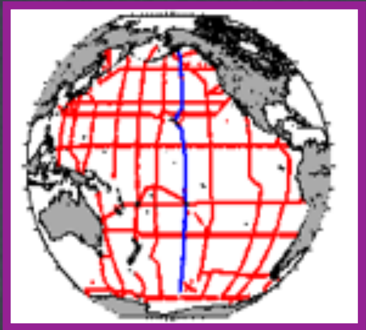
Anthropogenic CO2 water column inventories



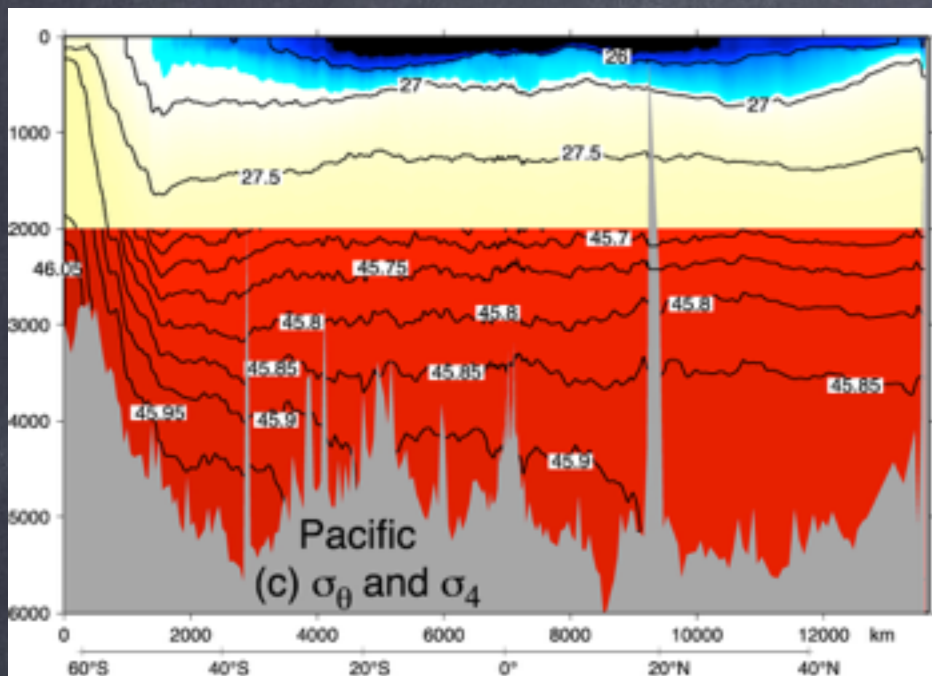
Sabine et al. (Science 2004)

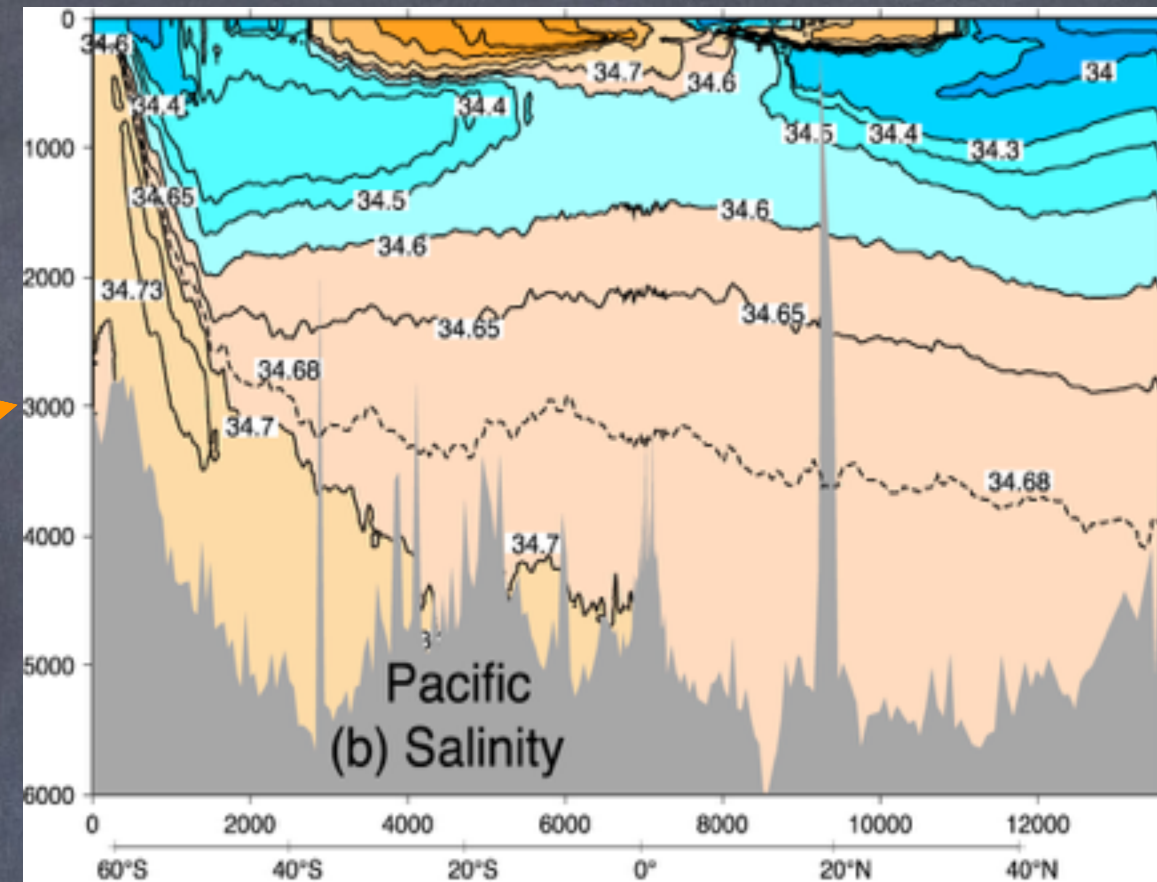
Ventilation

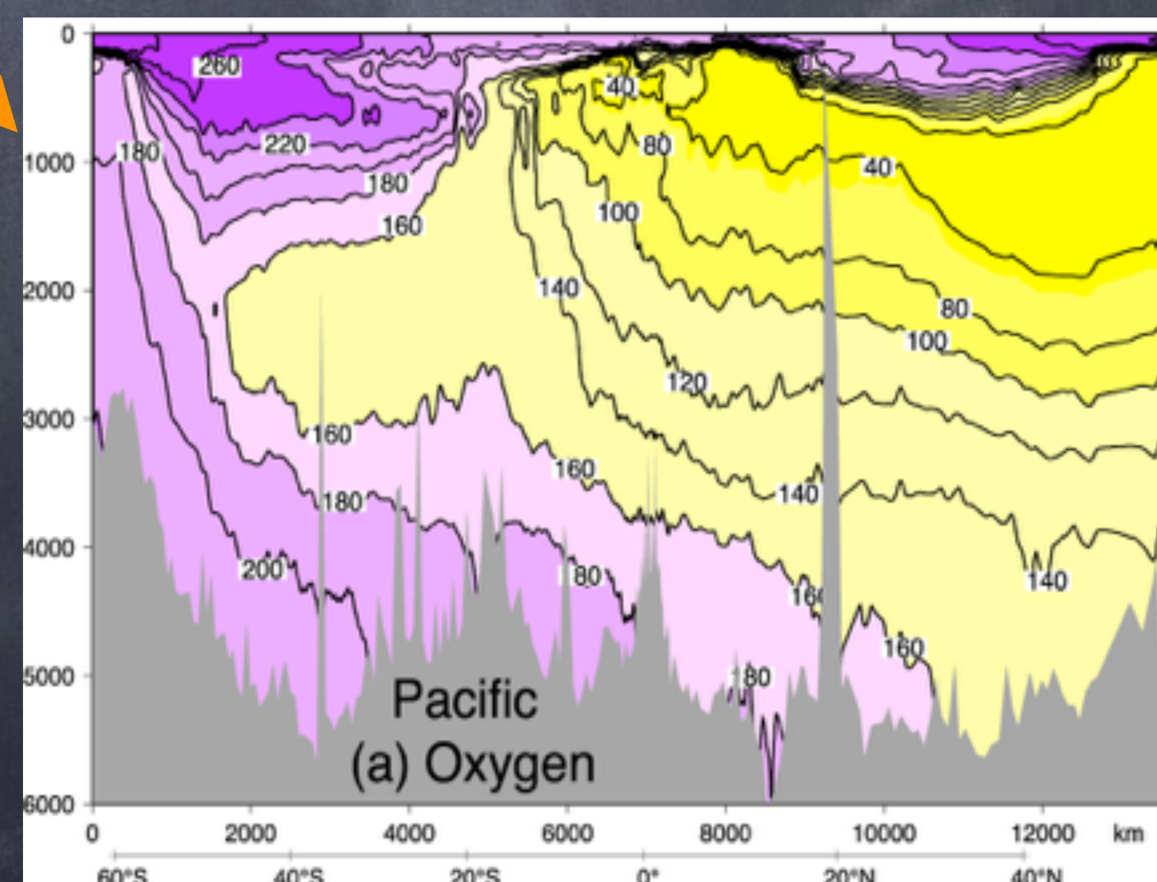
- Waters subducted away from the ocean surface along isopycnals.
- No diapycnic mixing leads to very thin layers.



Ventilation: an isentropic process







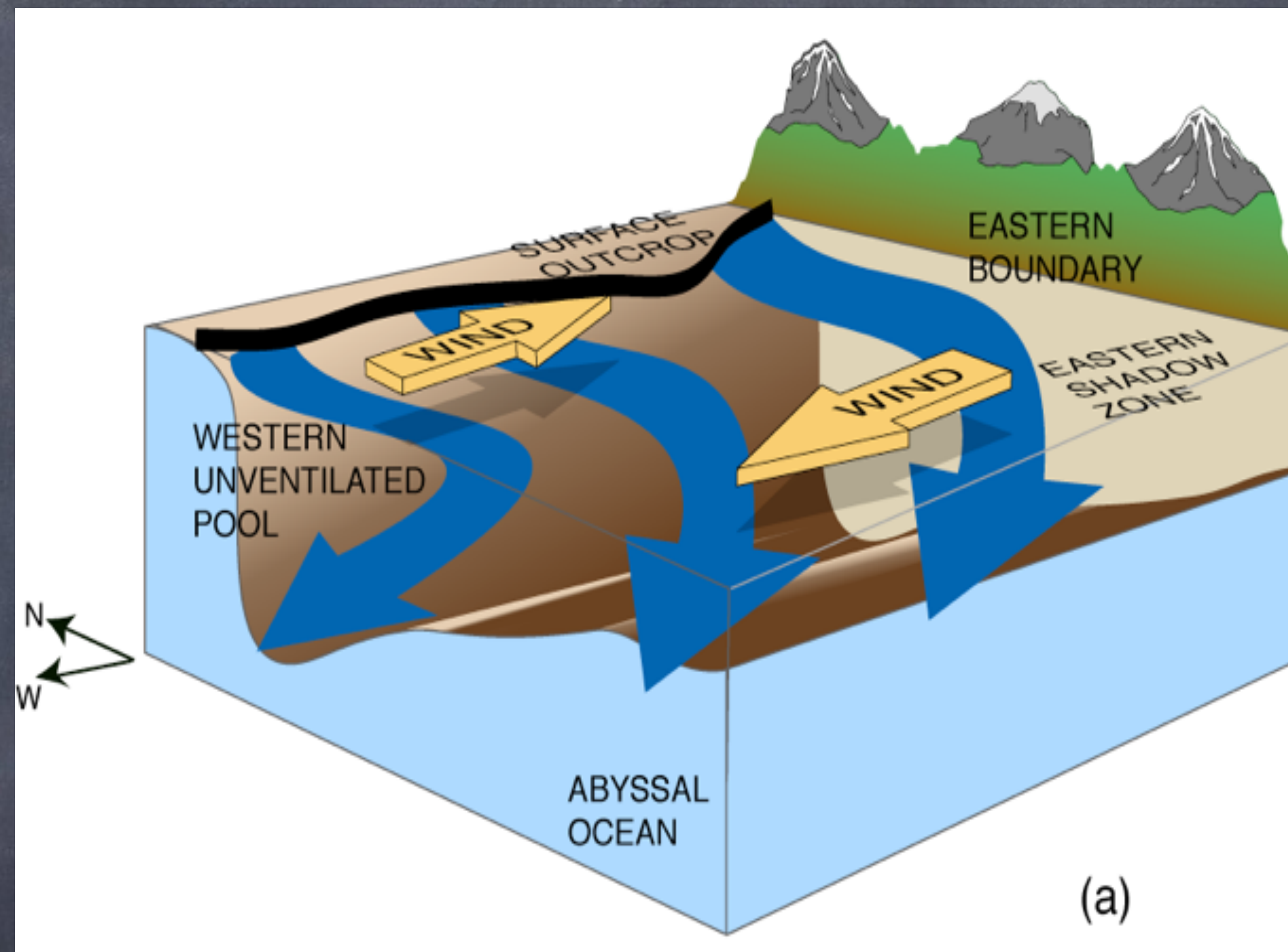
Flow will be along isopycnals (potential density surfaces) if there is no mixing.

- Mixing across isopycnals is observed to be much weaker than along isopycnals. Therefore, observations suggest that isopycnal flow is a good assumption.

Ventilation: an isentropic process

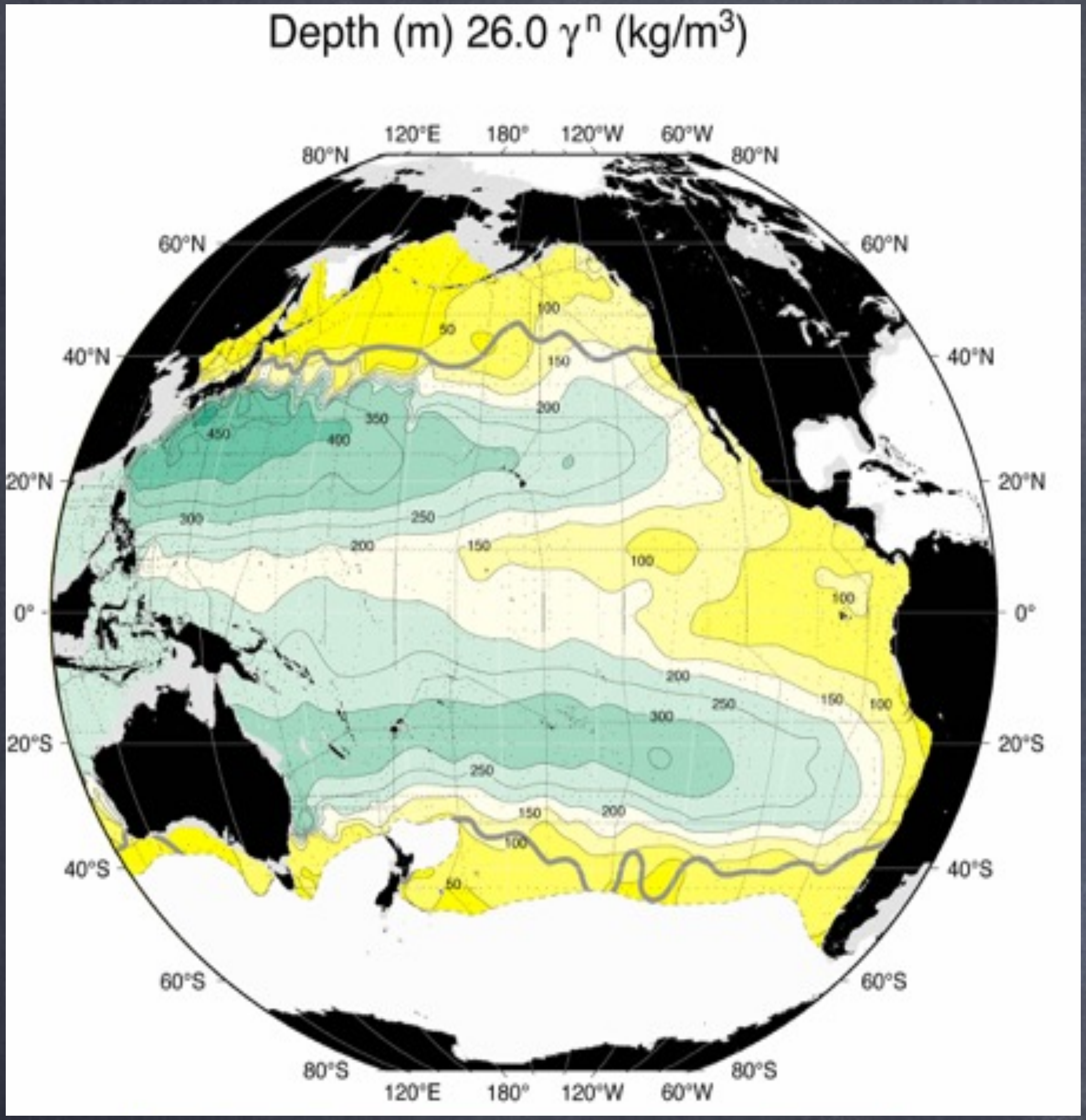
Flow from surface into interior is along isopycnals.

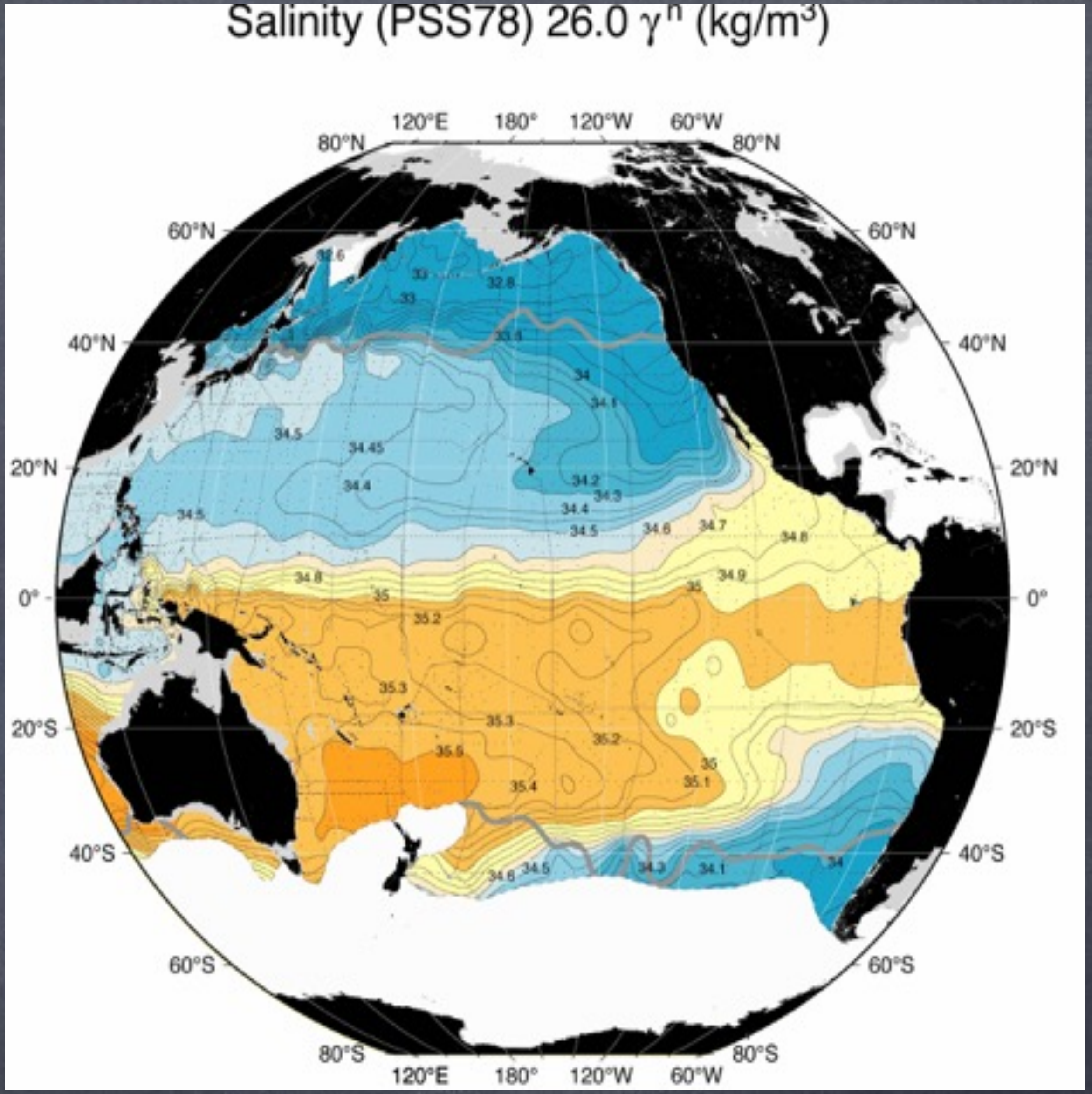
Where isopycnals outcrop, water is "ventilated" - refreshed with oxygen and other trace gases, and its salinity is set by precipitation-evaporation.



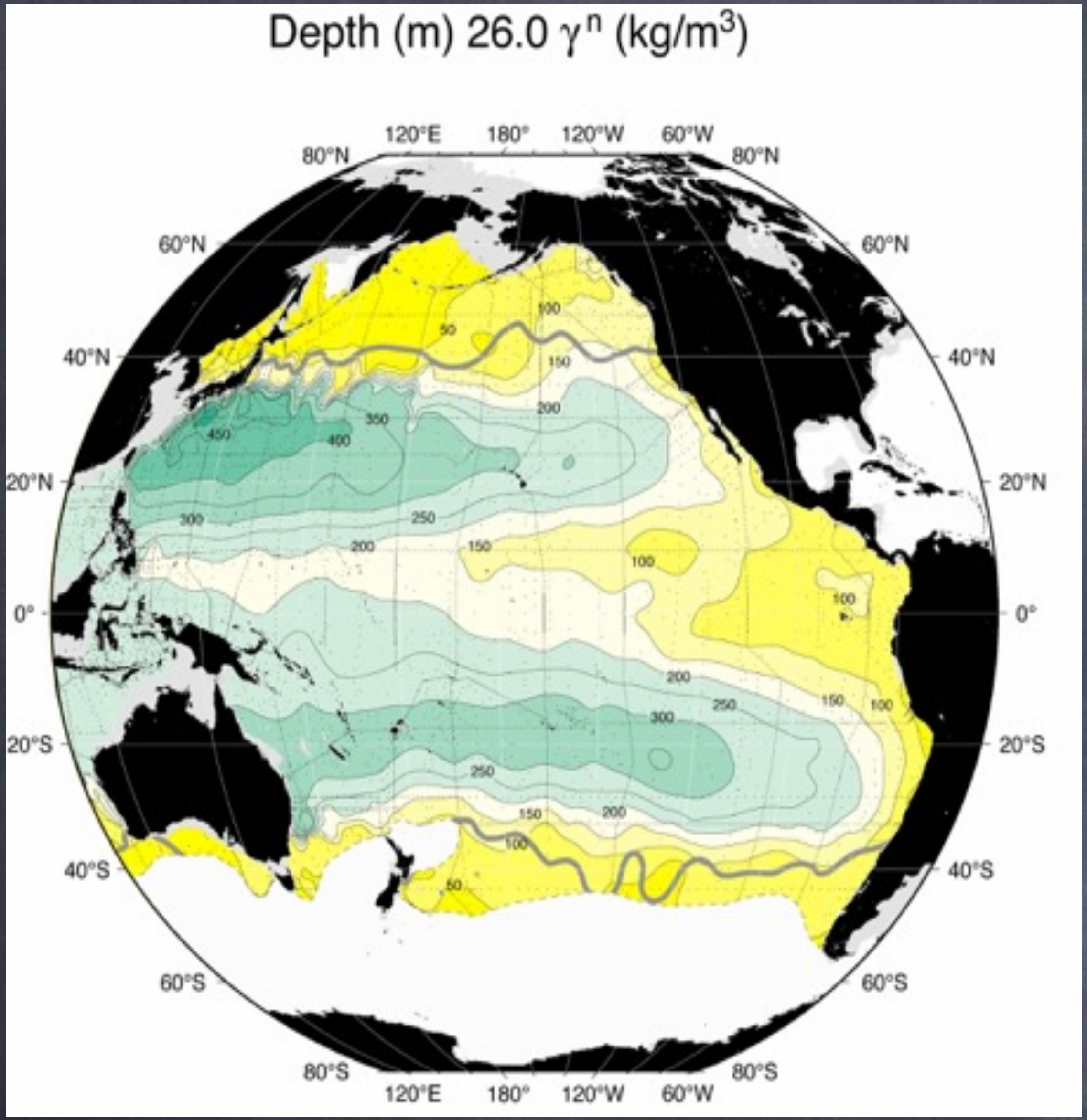
Emery, Talley, Pickard figure 8.35

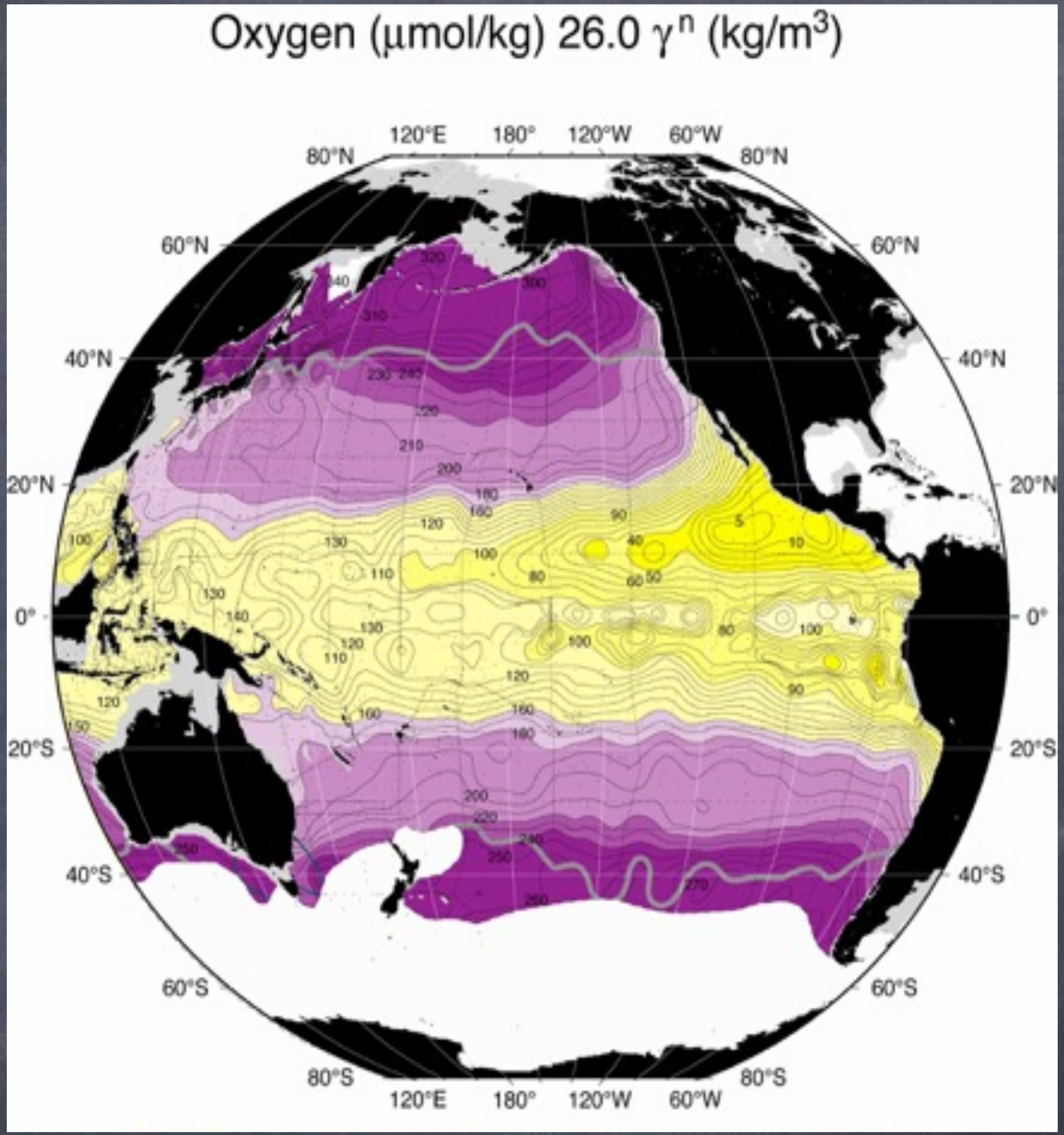
Ventilation: an isentropic process



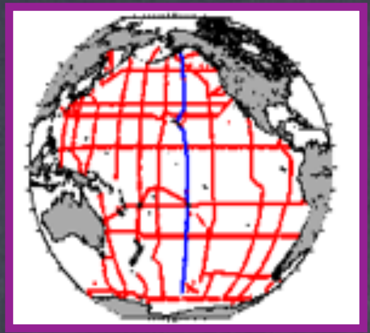


Ventilation: an isentropic process

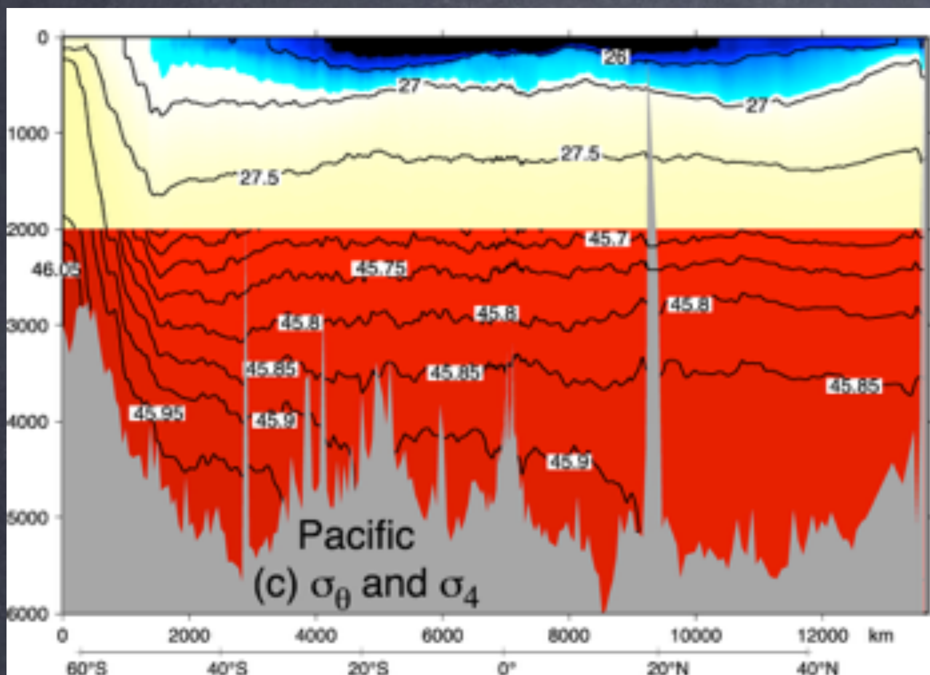




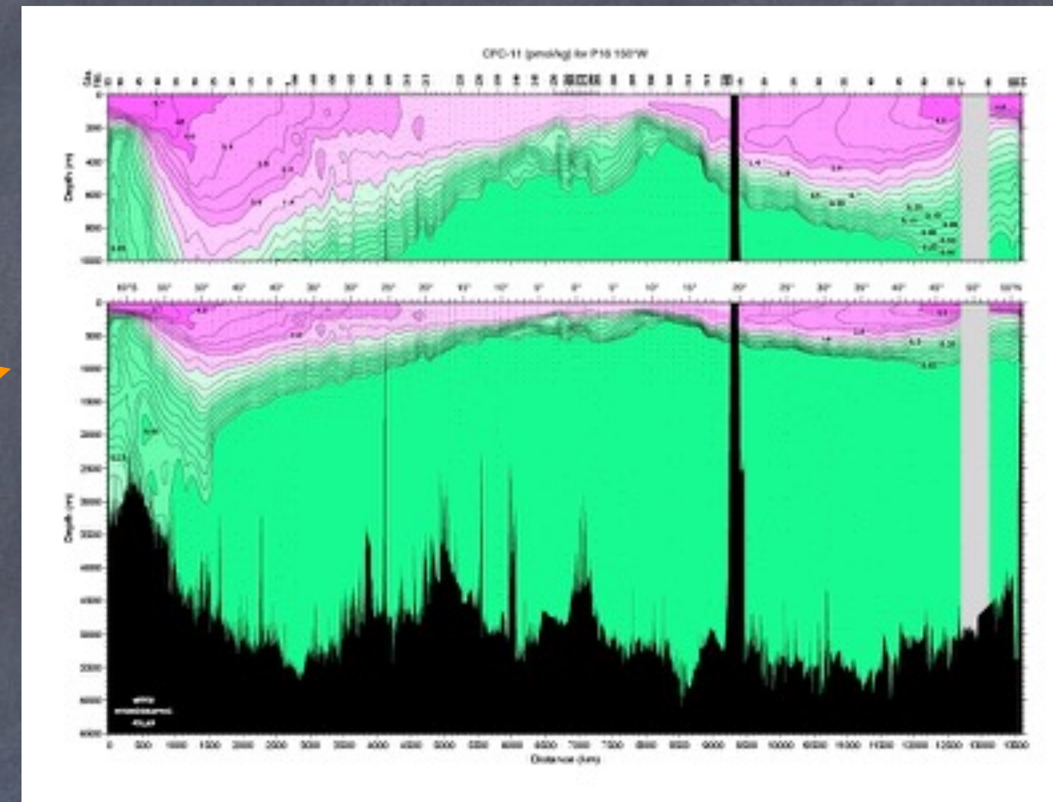
Oxygen is a non-conservative tracer. The general regions of newly ventilated versus older waters can be seen, but the picture is muddied by oxygen utilisation near the eastern boundary.



Ventilation: an isentropic process

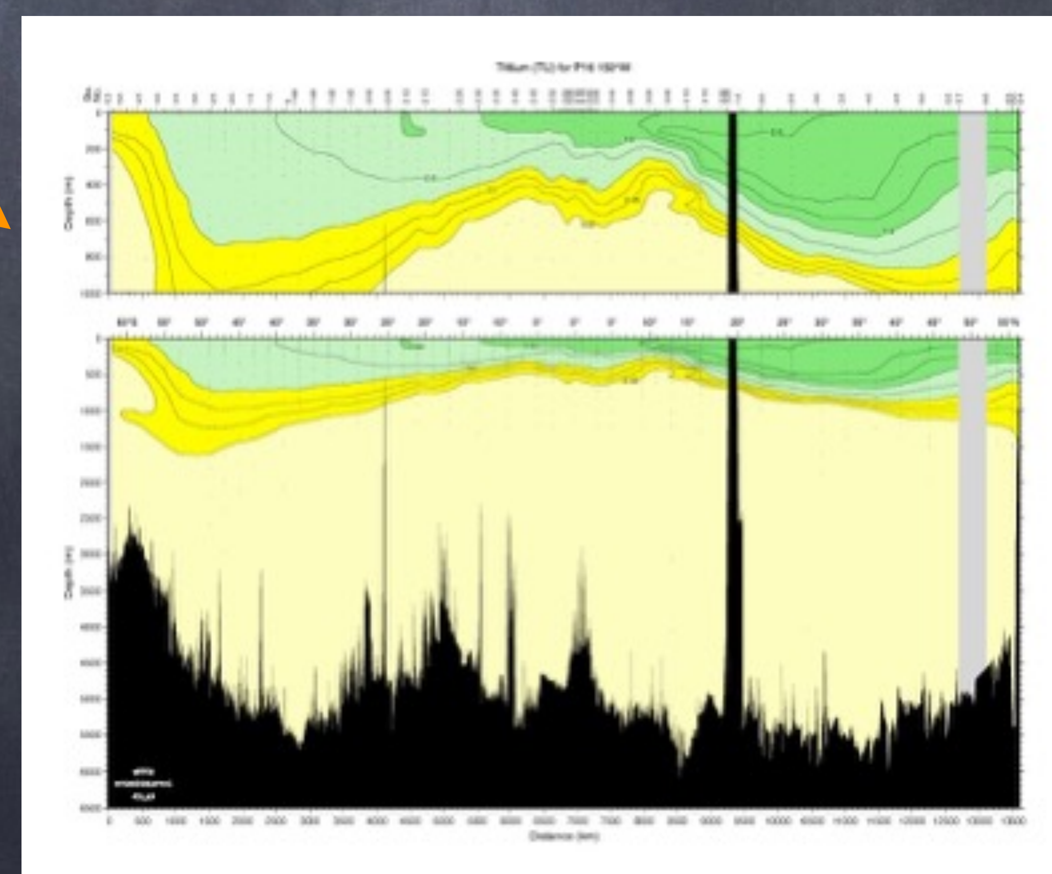


CFC-11



Ventilation observed in anthropogenic tracers

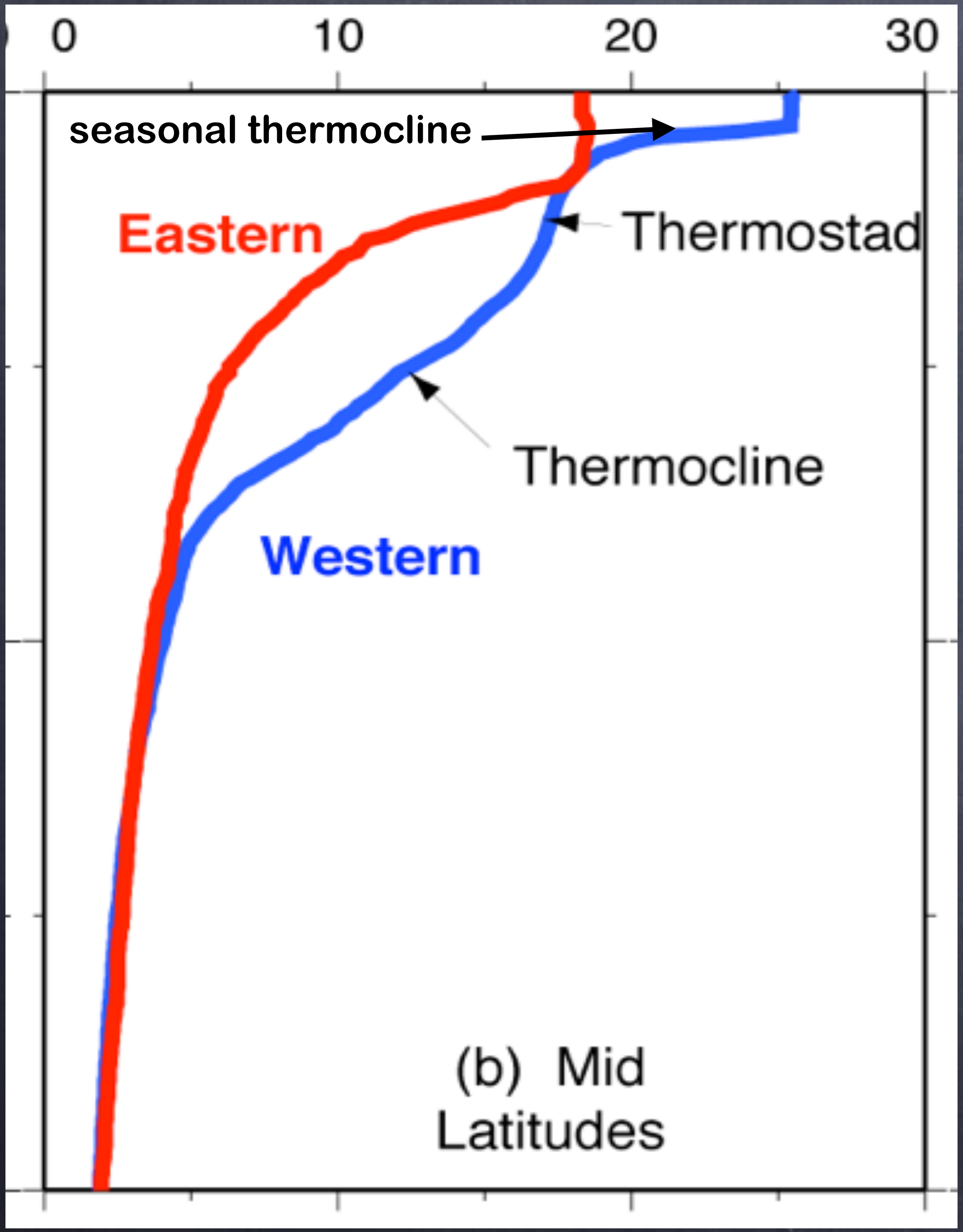
Tritium



Thermocline (pycnocline)

- Below mixed layer, about 1000 m thick.
- Region of high vertical density and temperature gradients.

Thermocline (pycnocline)



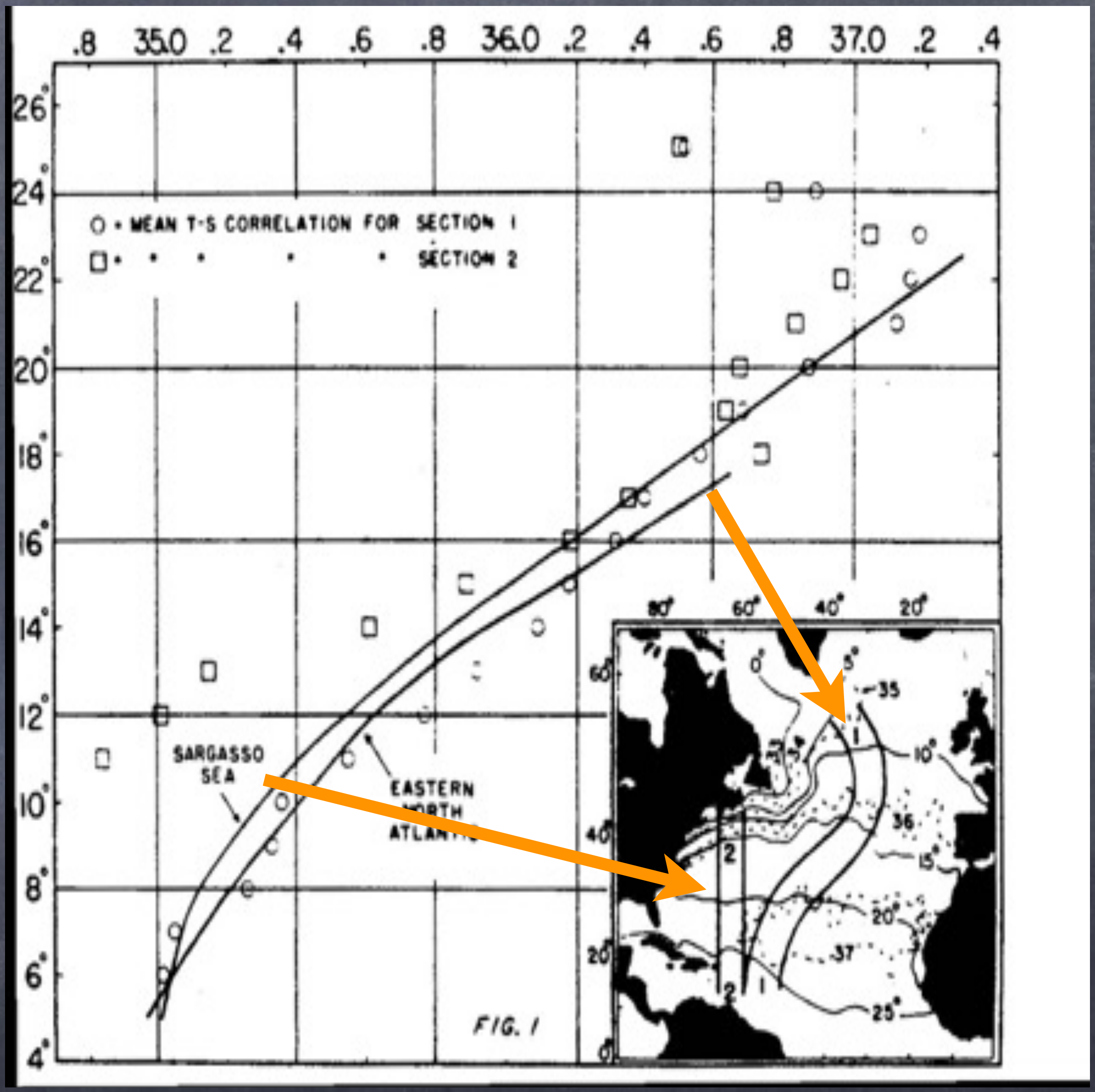
Two physical processes:

1. Vertical balance: mixing between warm, light surface waters and upwelling, cold, dense deep waters.

2. Subduction of surface waters into the interior along isopycnals and thus beneath the lower density surface layers

Thermocline (pycnocline)

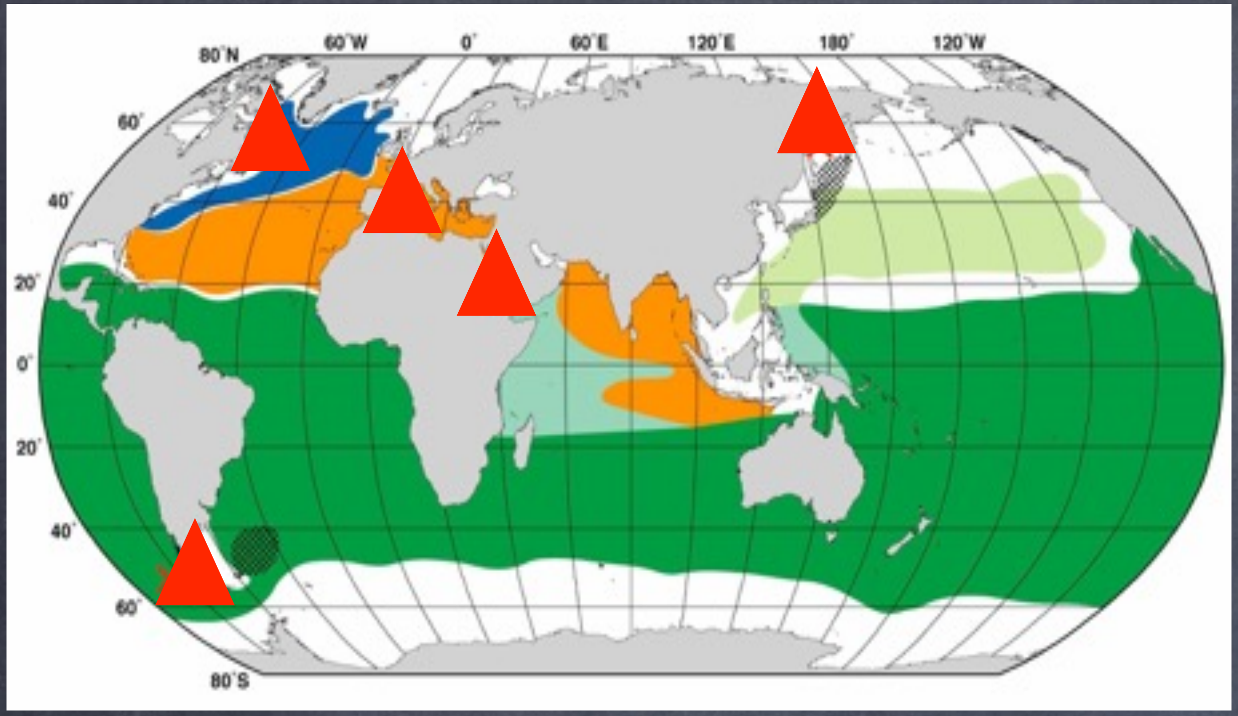
Iselin (1939): Equivalence of surface properties on transect through N. Atlantic with properties on a vertical profile in the subtropical gyre --> hypothesized that properties are advected into the interior from the sea surface.



Intermediate and Deep waters

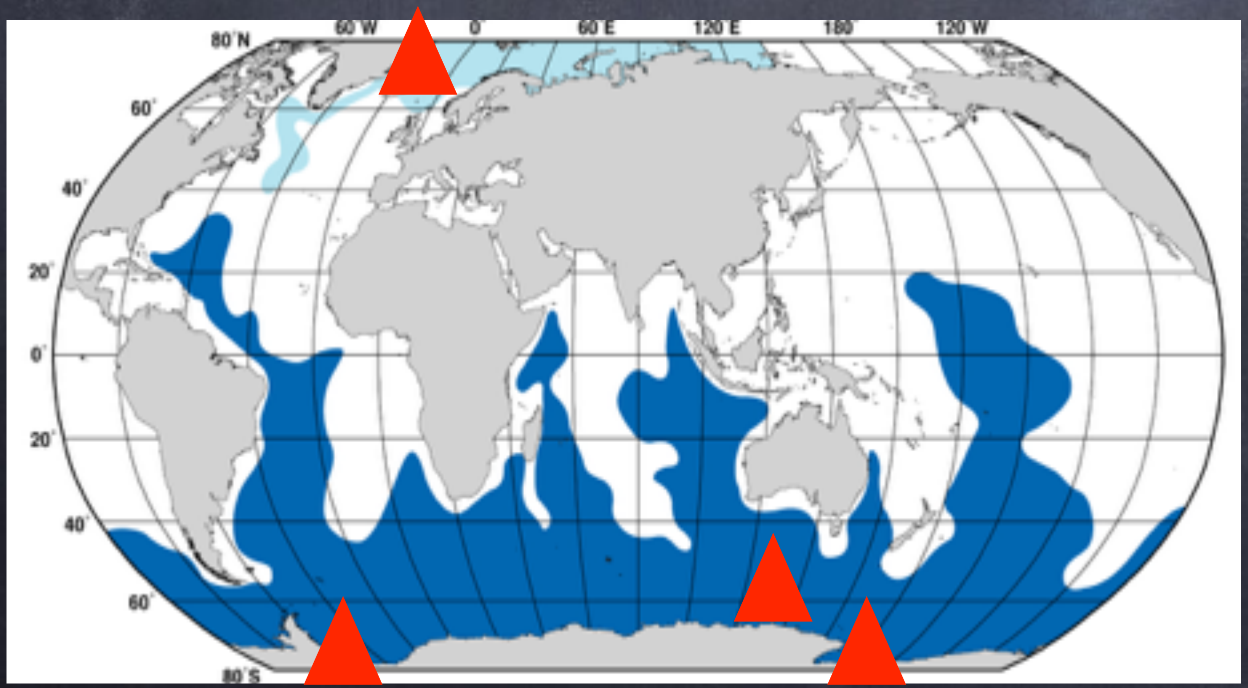
- Dense waters formed over small regions, typically by convection, that sink below the thermocline
- Intermediate: 1000 m - 2000 m depth
- Deep: below 2000 m
- Formed by extreme cooling at high latitudes or by high evaporation at mid and low latitudes.

Intermediate and Deep waters



Intermediate water production sites:

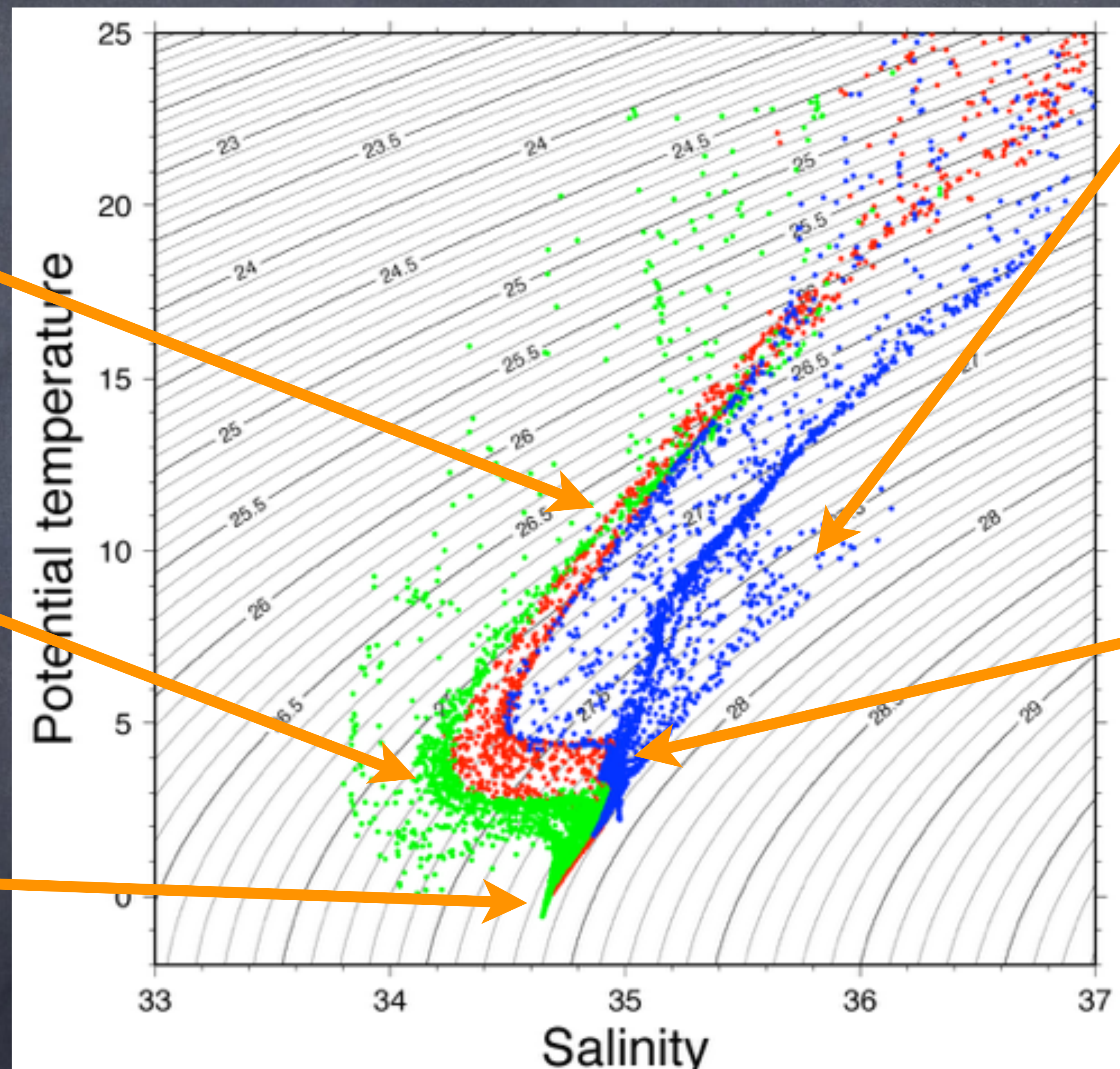
LSW = Labrador Sea Water
MW = Mediterranean Water
RSW = Red Sea Water
NPIW = North Pacific Intermediate water
AAIW = Antarctic Intermediate water



Deep and bottom water production sites

Arctic water (Norwegian/Greenland Sea) -> NADW
CDW = Circumpolar Deep Water
AABW = Antarctic Bottom Water

Potential temperature-salinity at 25°W in the Atlantic Ocean



thermocline

Antarctic Intermediate Water

Antarctic Bottom Water

Mediterranean Overflow Water

North Atlantic Deep Water

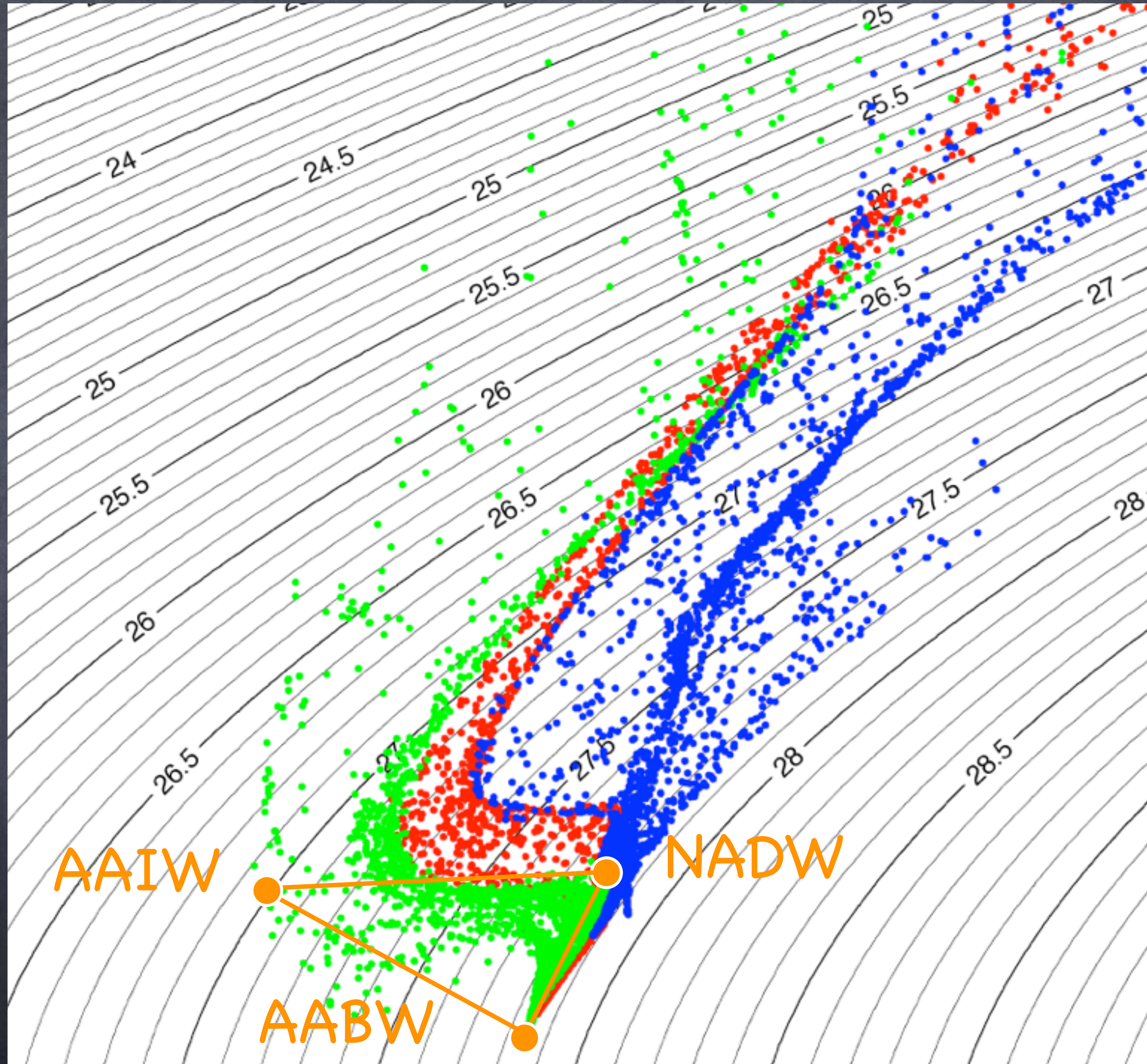
Blue: N. Atlantic > 15°N

Red: 15°S-15°N

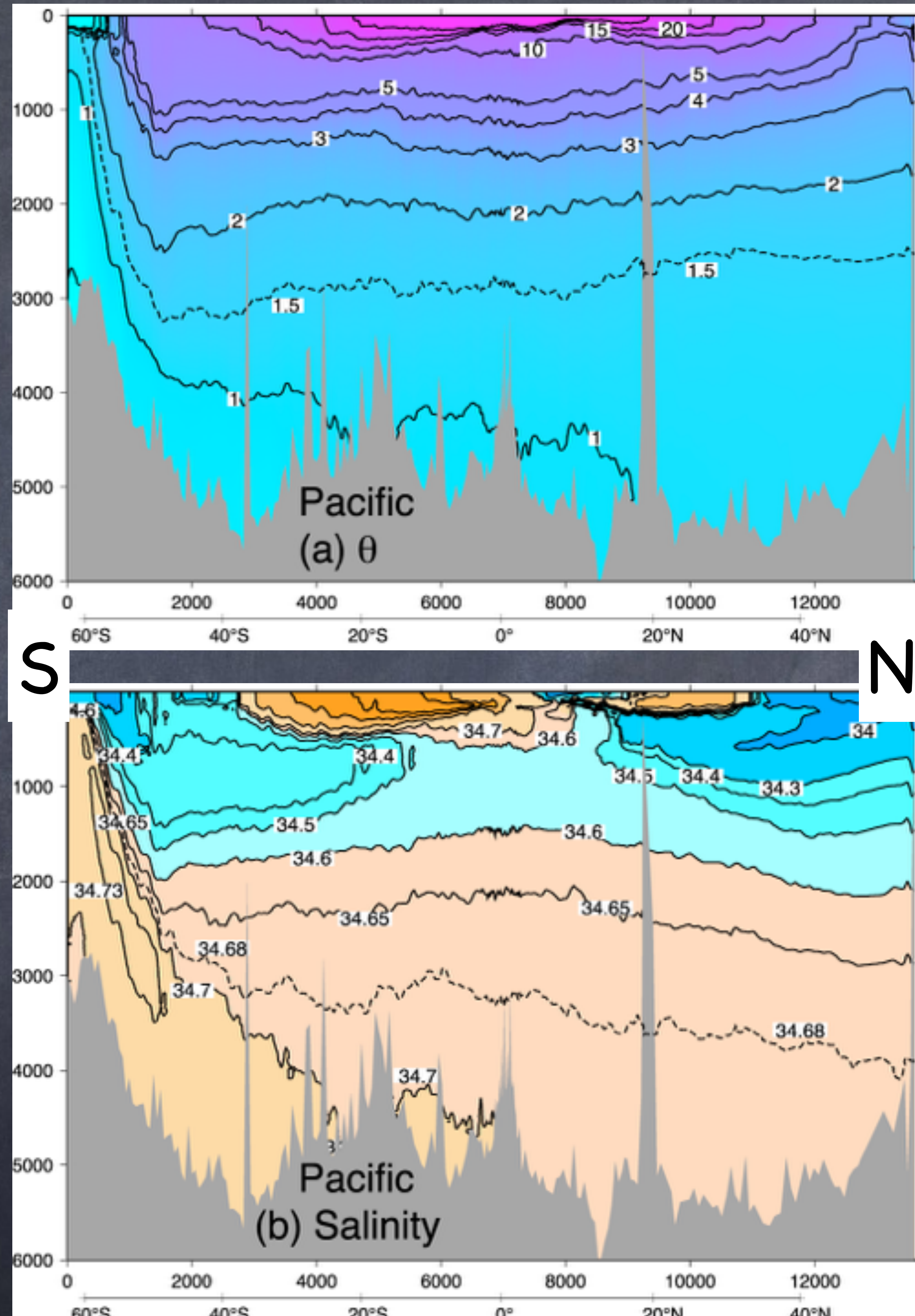
Green: S. Atlantic < 15°S

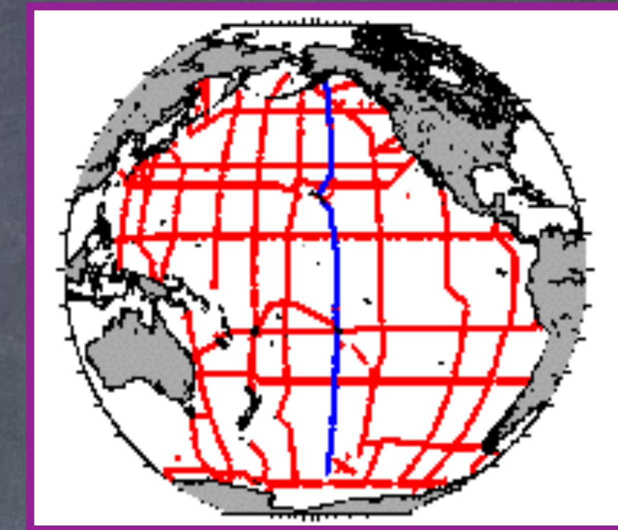
Water mass mixing

on straight lines in T/S diagram



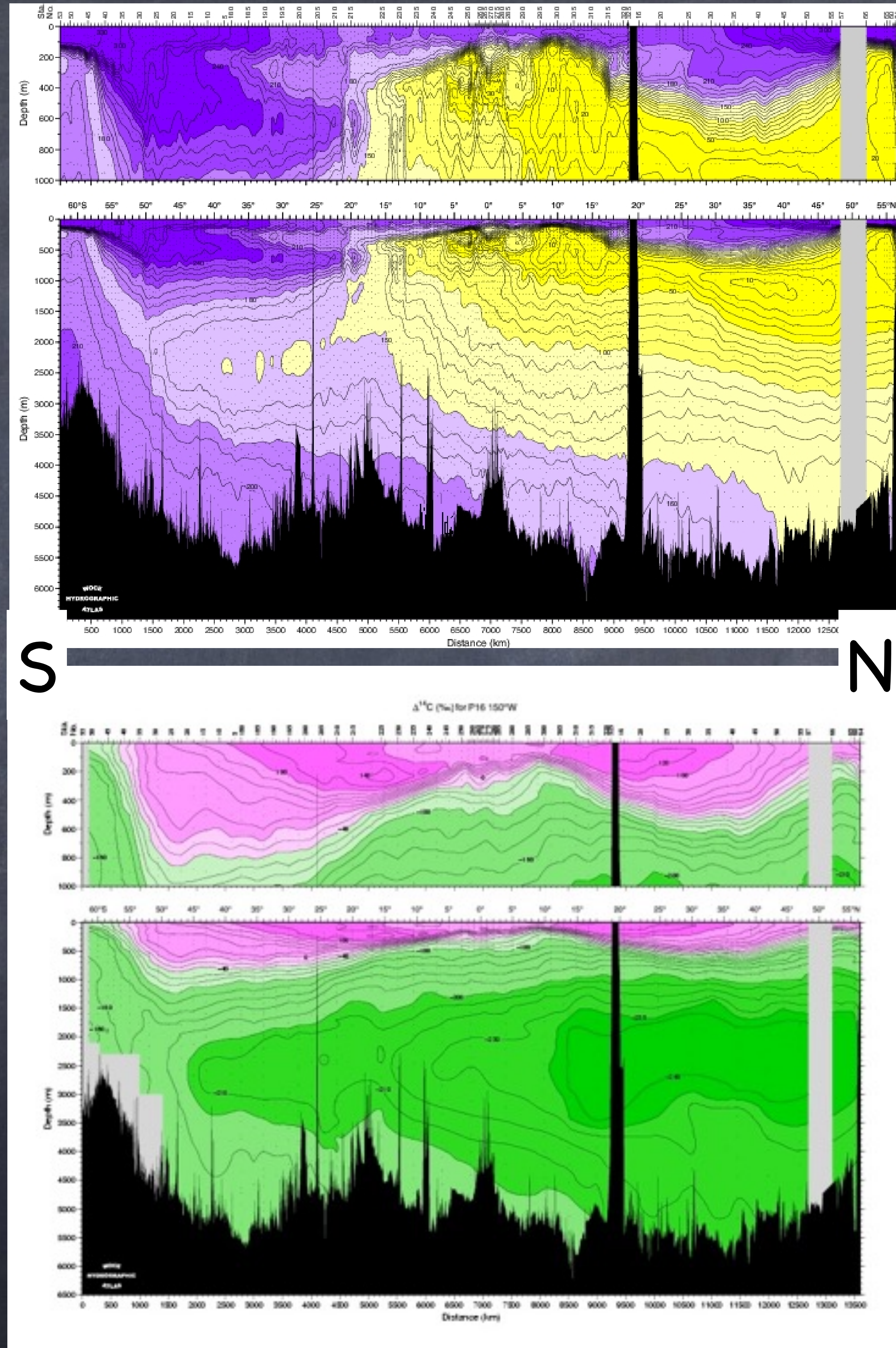
thermocline
STUW
AAIW
NPIW
AABW
CDW

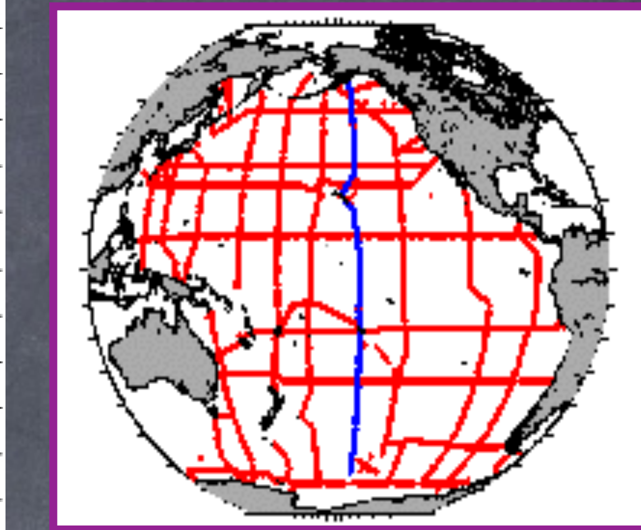




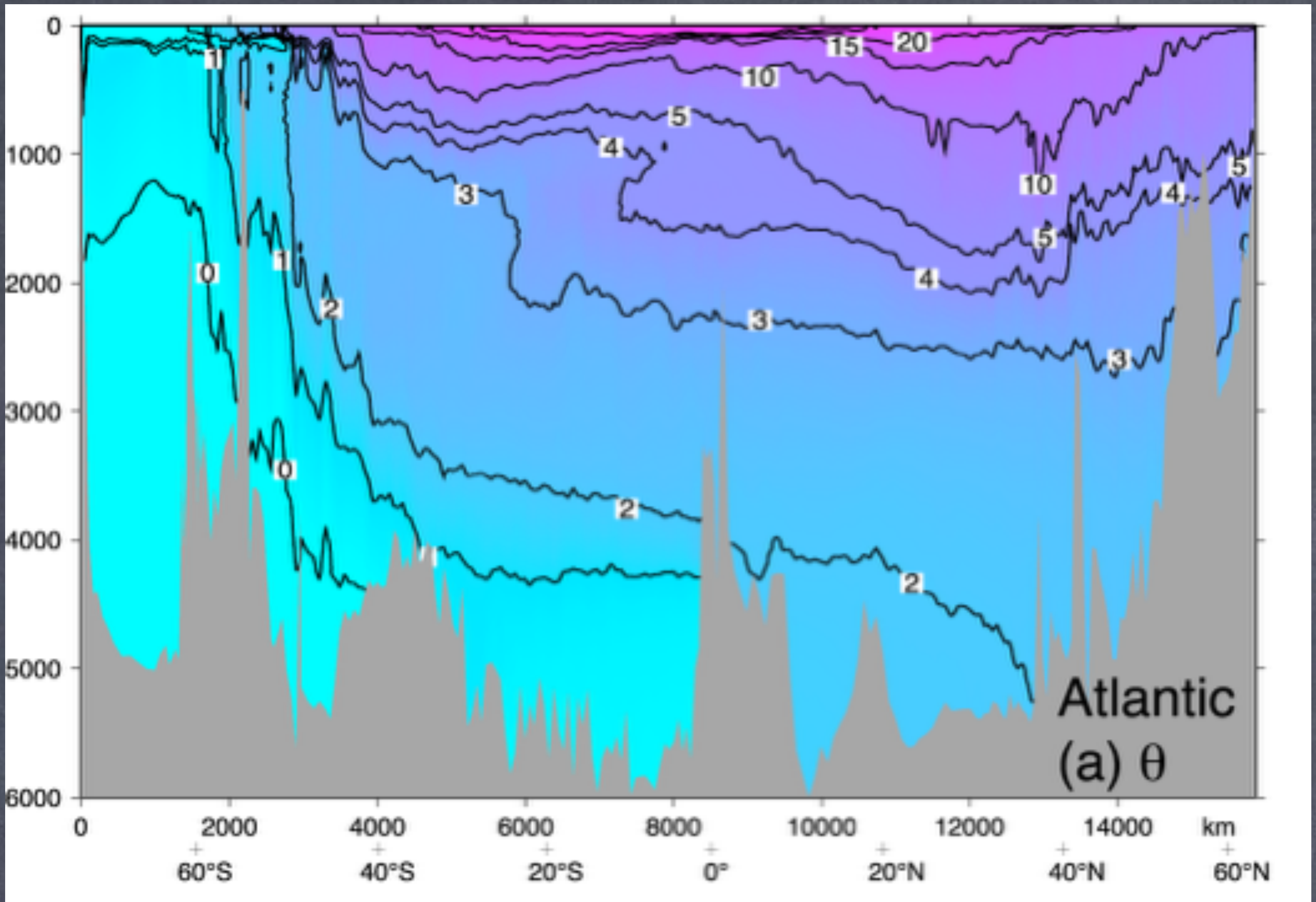
Oxygen

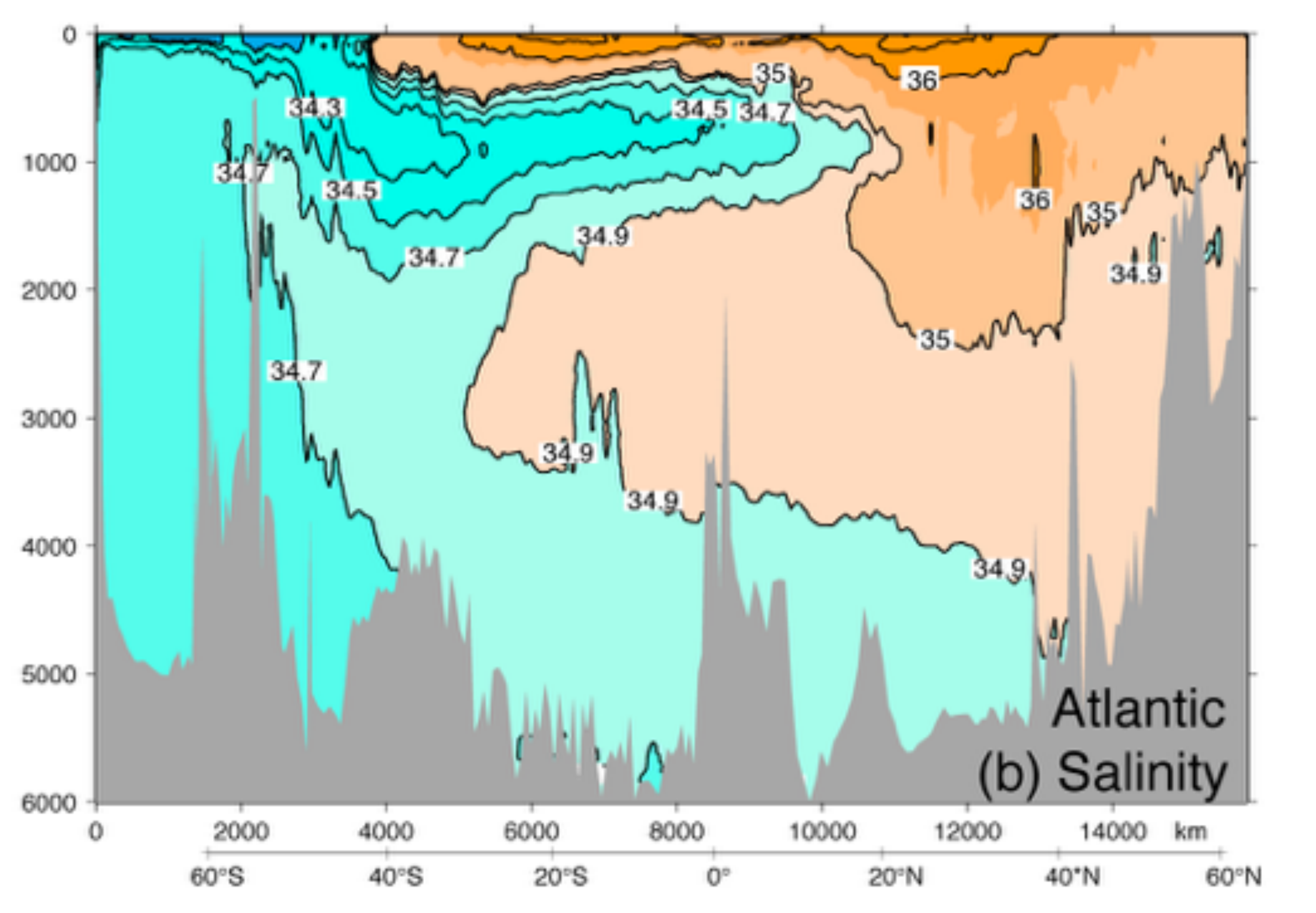
Carbon 14

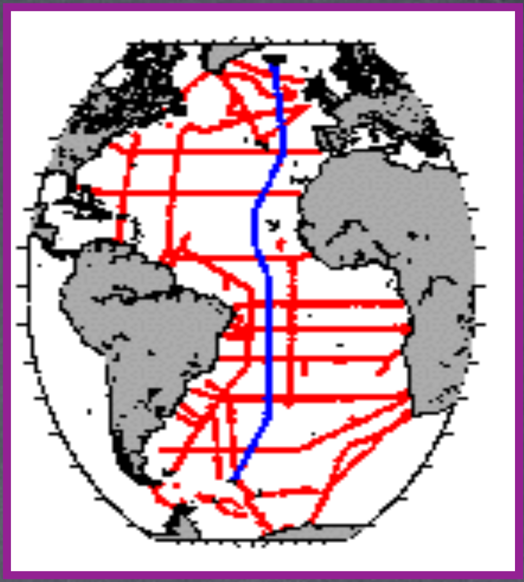




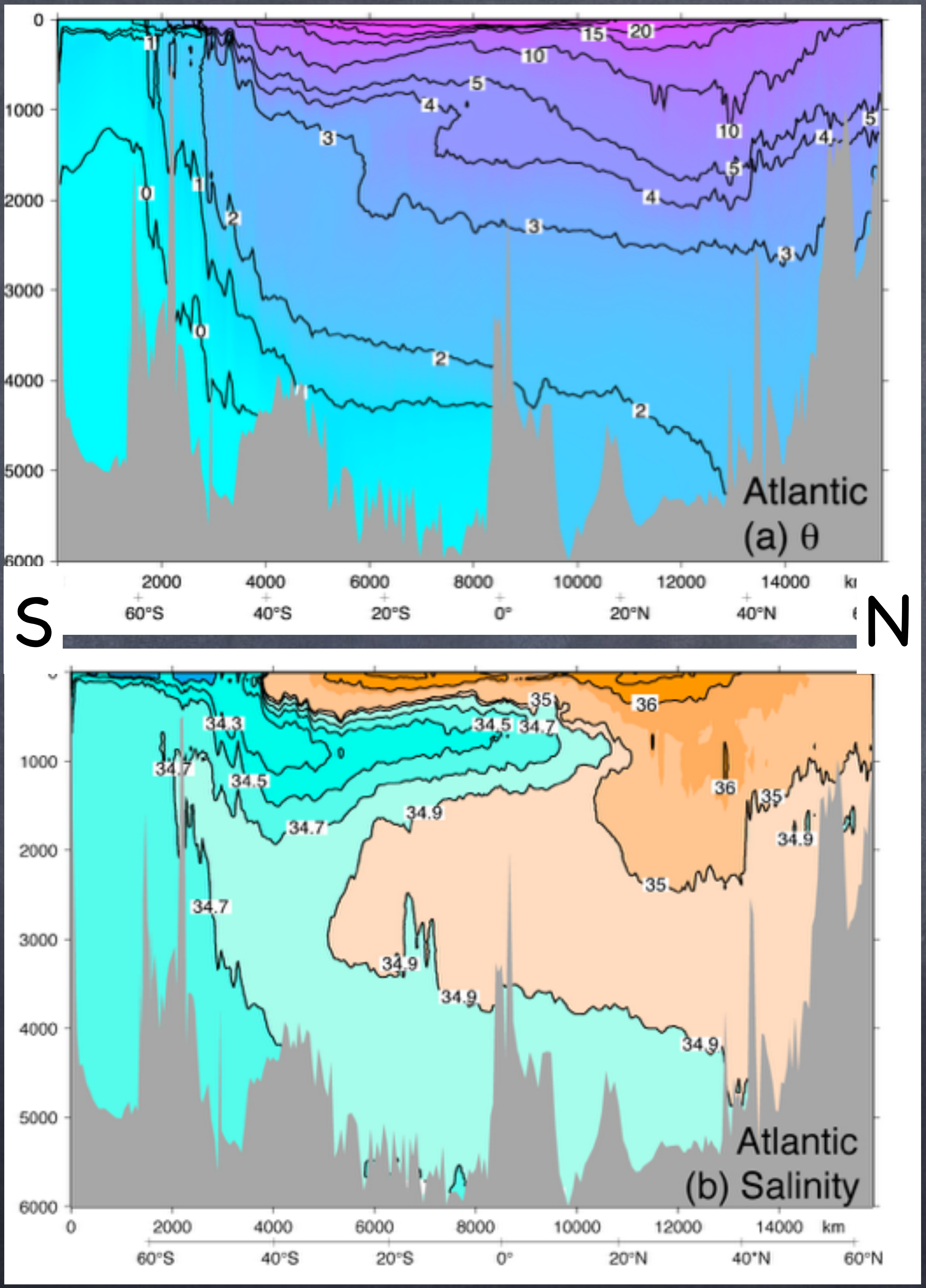
thermocline
STUW
AAIW
NPIW
AABW
CDW

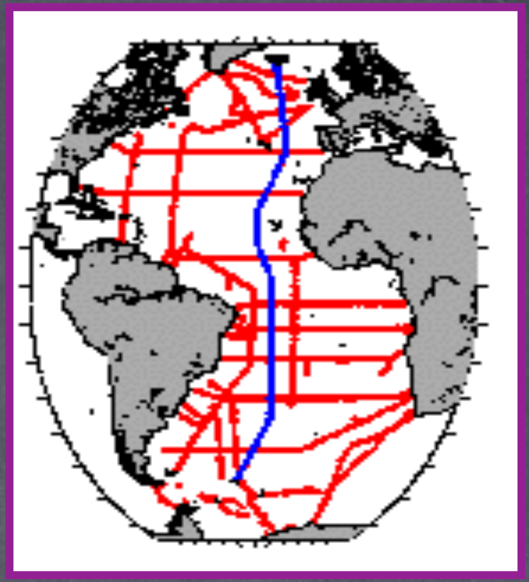

Atlantic
(a) θ
0
1000
2000
3000
4000
5000
6000
0 2000 4000 6000 8000 10000 12000 14000 km
60°S 40°S 20°S 0° 20°N 40°N 60°N
20
15
10
5
4
3
2
1
0


Atlantic
(b) Salinity
0
1000
2000
3000
4000
5000
6000
0 2000 4000 6000 8000 10000 12000 14000 km
60°S 40°S 20°S 0° 20°N 40°N 60°N
36
35
34.9
34.7
34.5
34.3

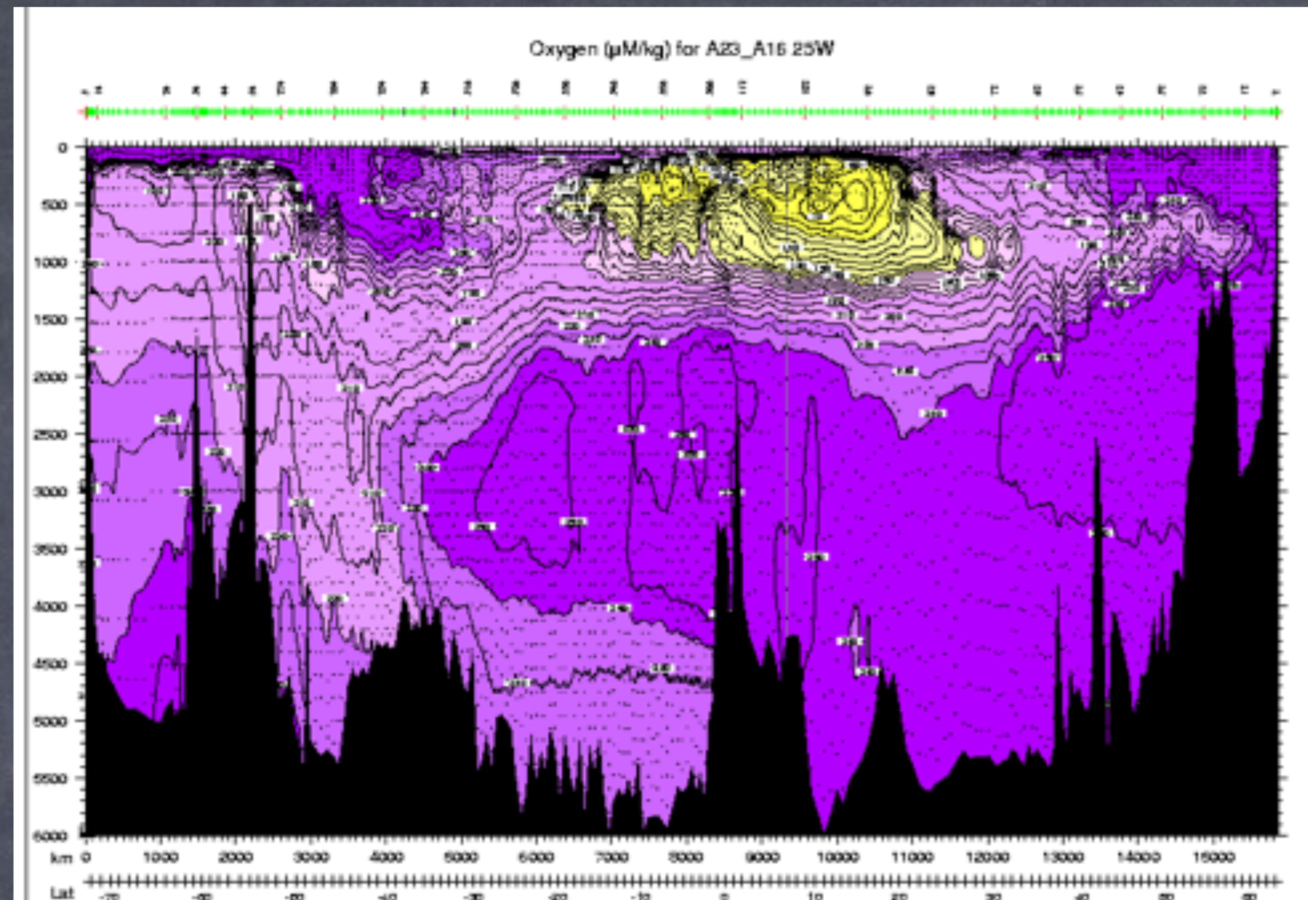


STUW
MW
AAIW
NADW
AABW

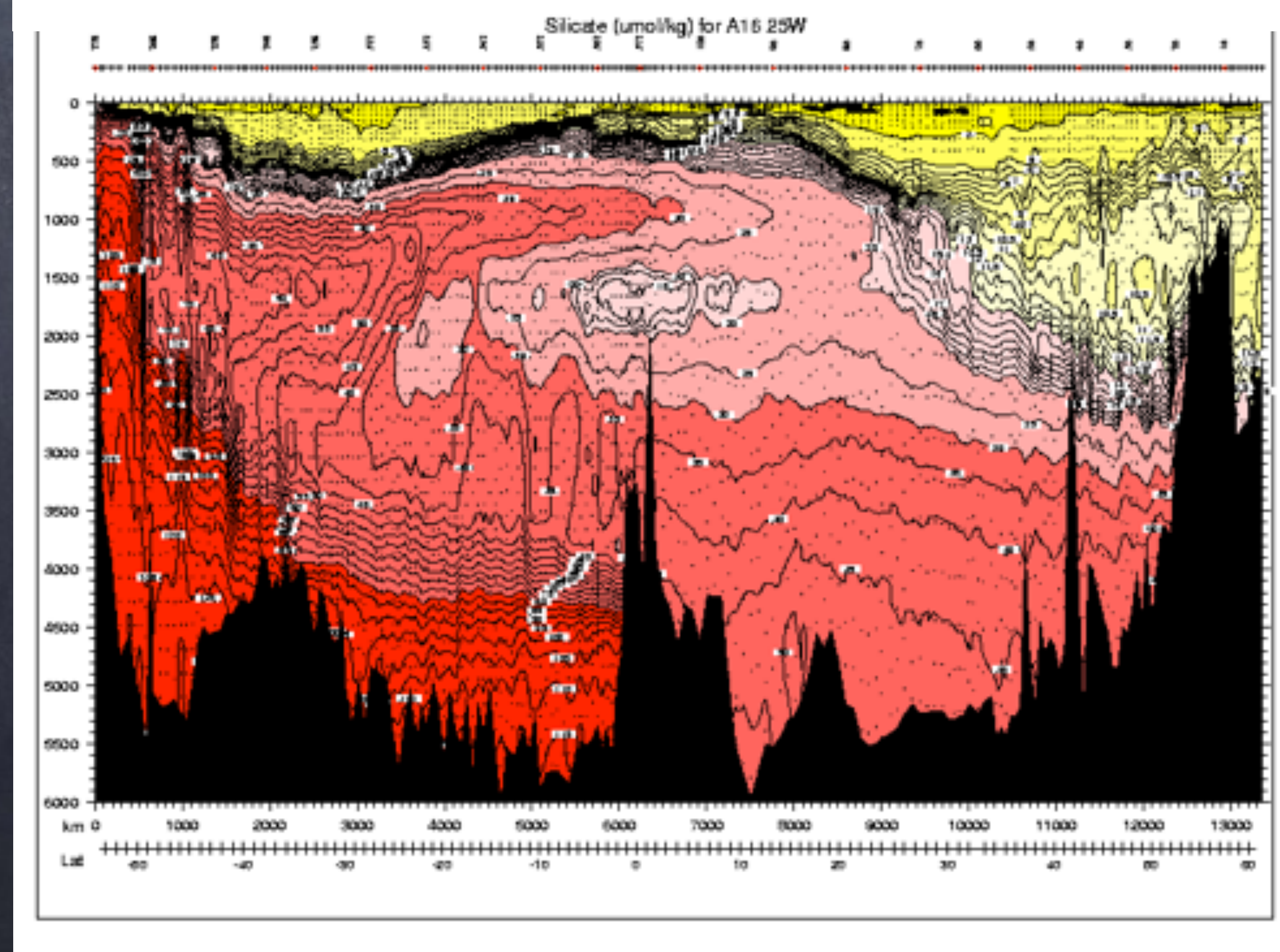




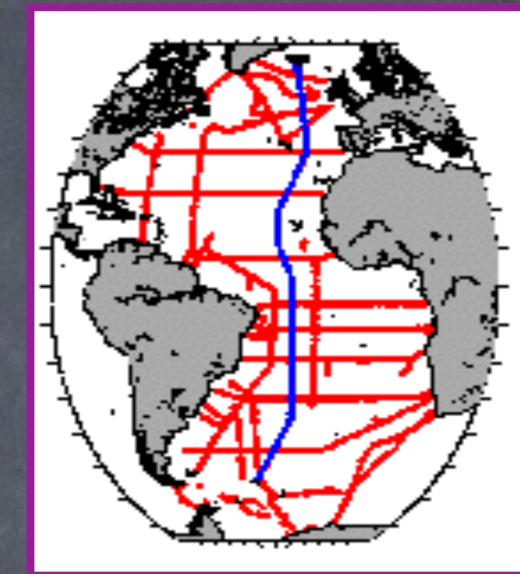
Oxygen



S N



Silica

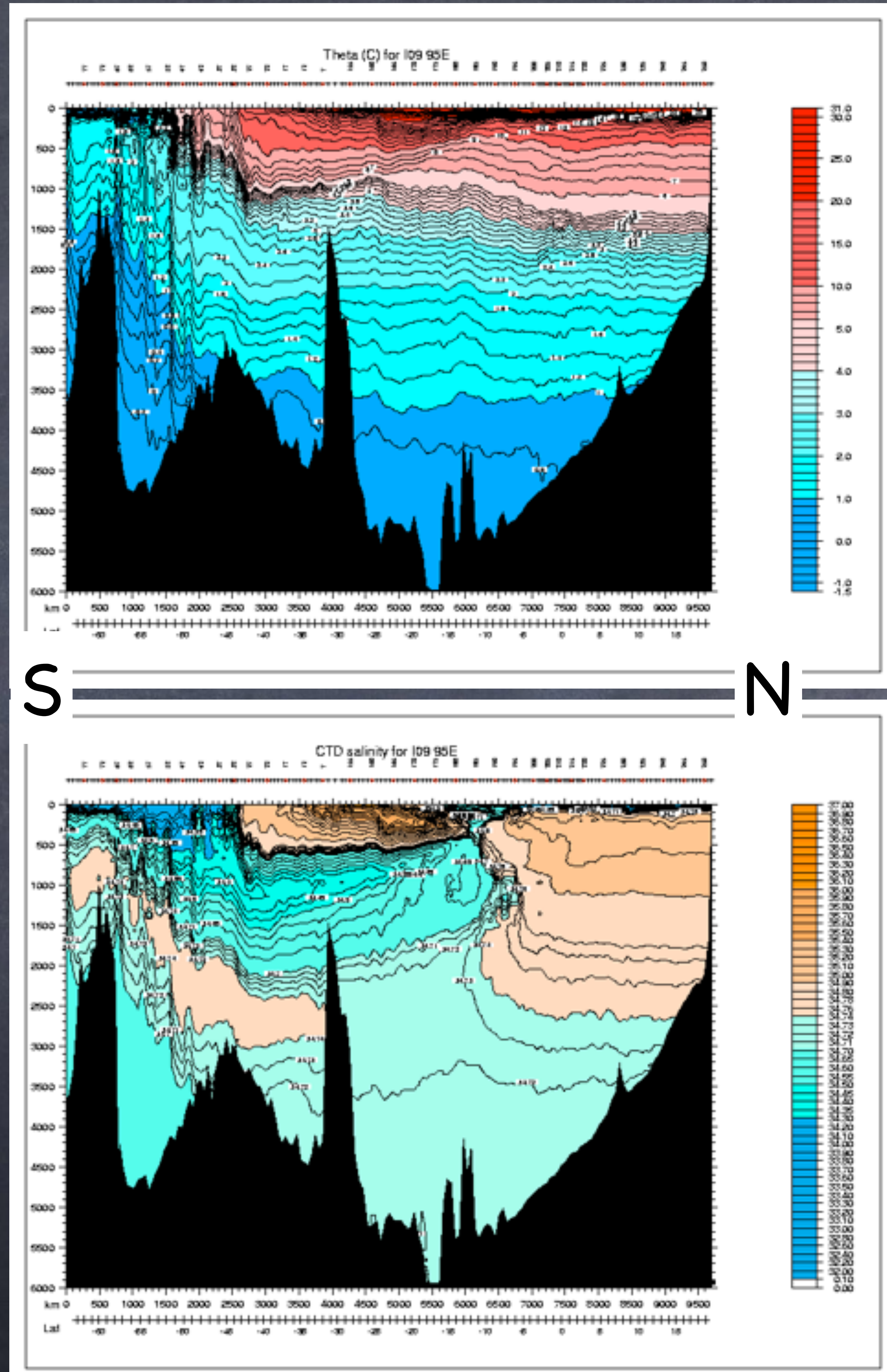


STUW
MW
AAIW
NADW
AABW

Indian Ocean 95 E

theta

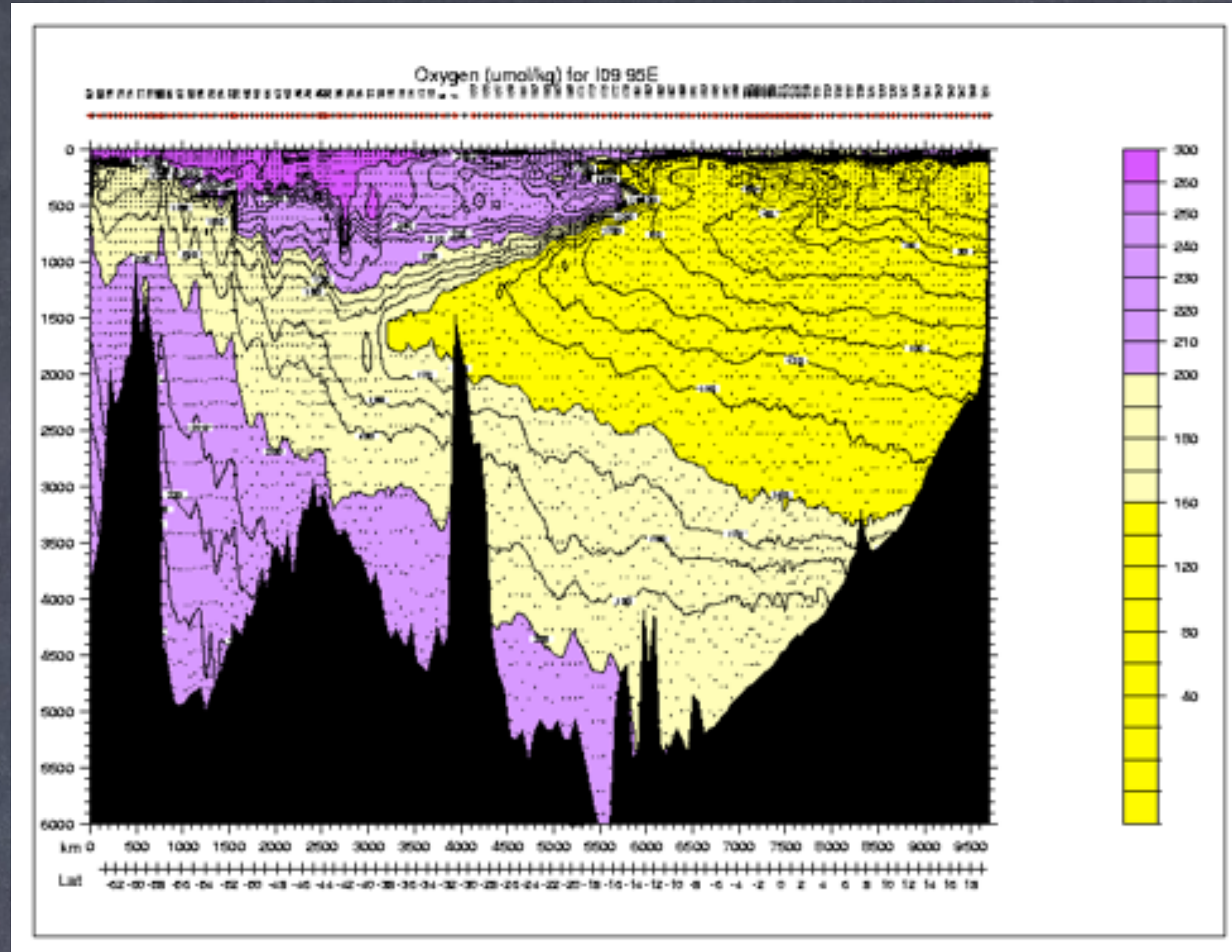
salinity

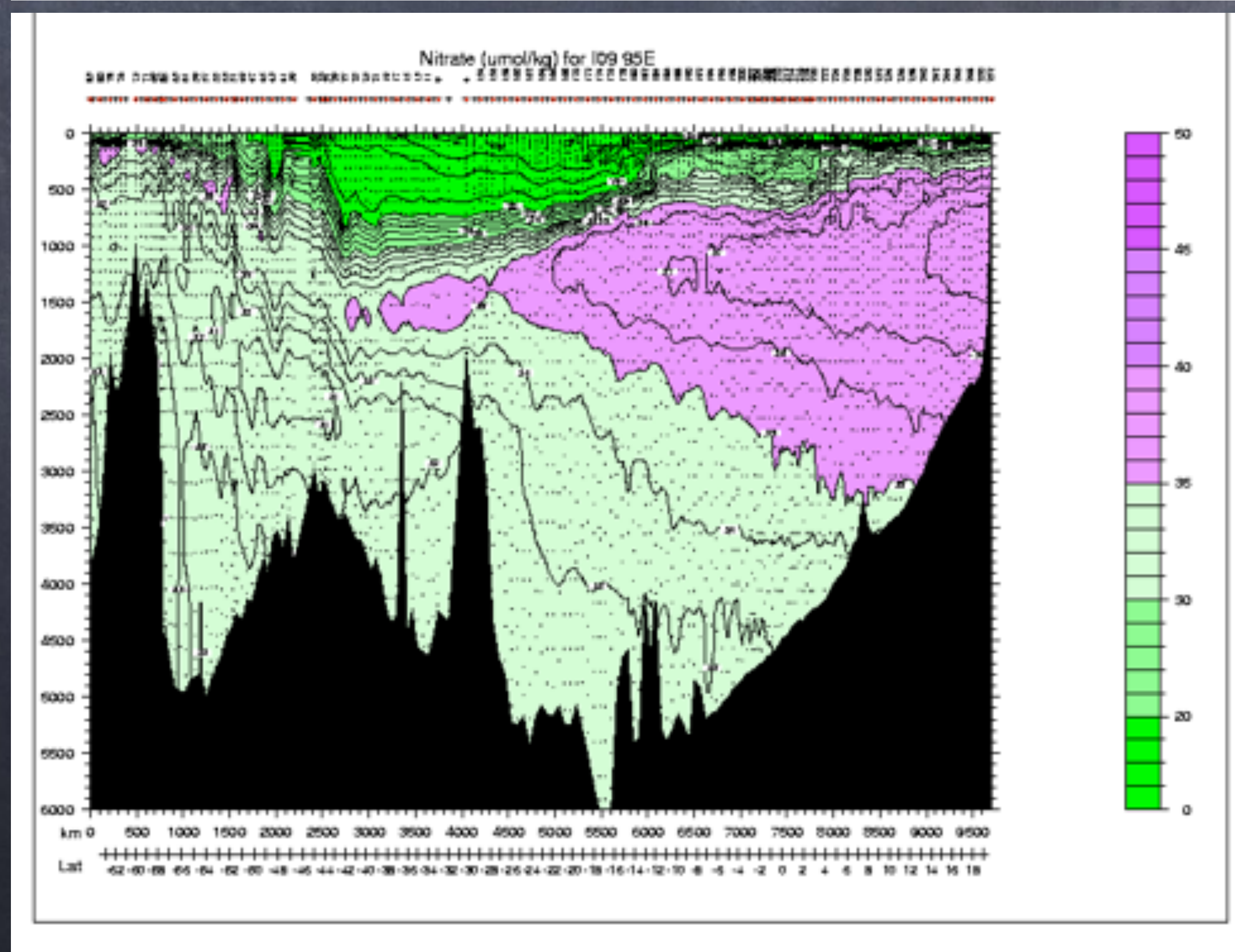


STSW
RSW
ITF
AAIW
CDW
NIDW
AABW

Indian Ocean 95 E

Oxygen





Nitrate

STSW
RSW
ITF
AAIW
CDW
NIDW
AABW

On line resources for Ocean Property Distributions

- WOCE Atlases: http://woceatlas.ucsd.edu
- Java Ocean Atlast: http:// joa.ucsd.edu
- Ocean Data View: https://odv.awi.de