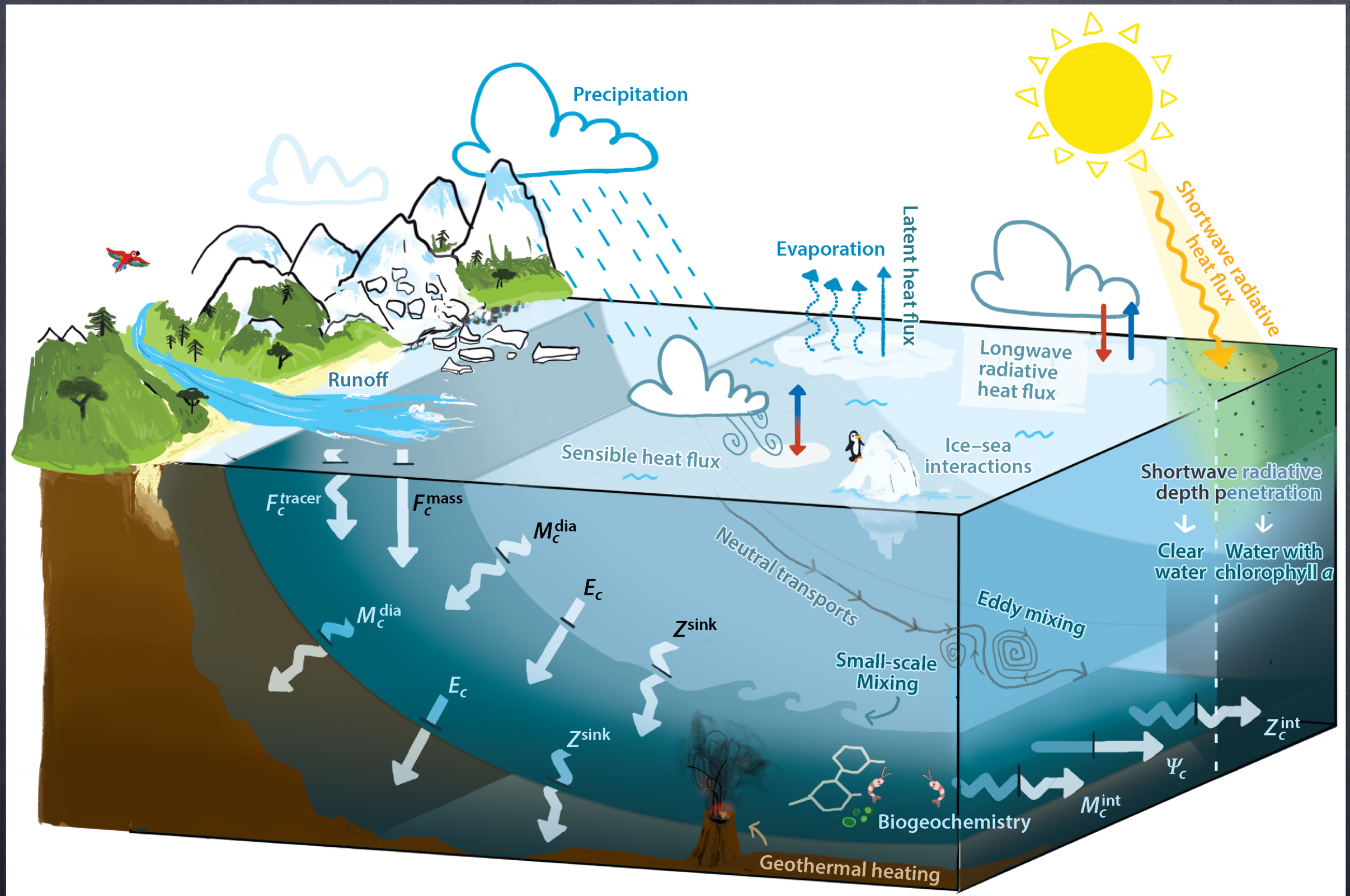
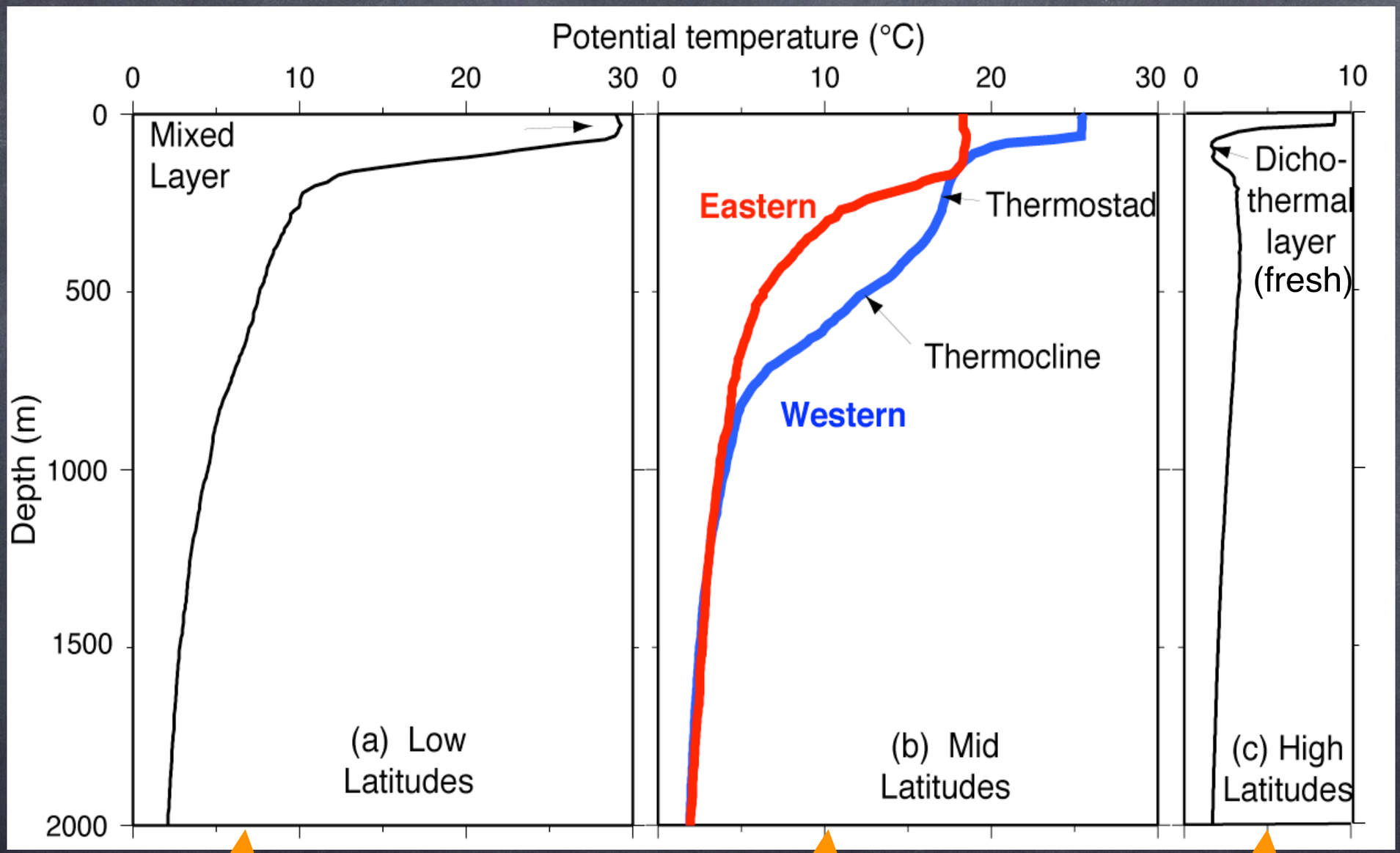
Property distributions, water masses, and tracers in the ocean



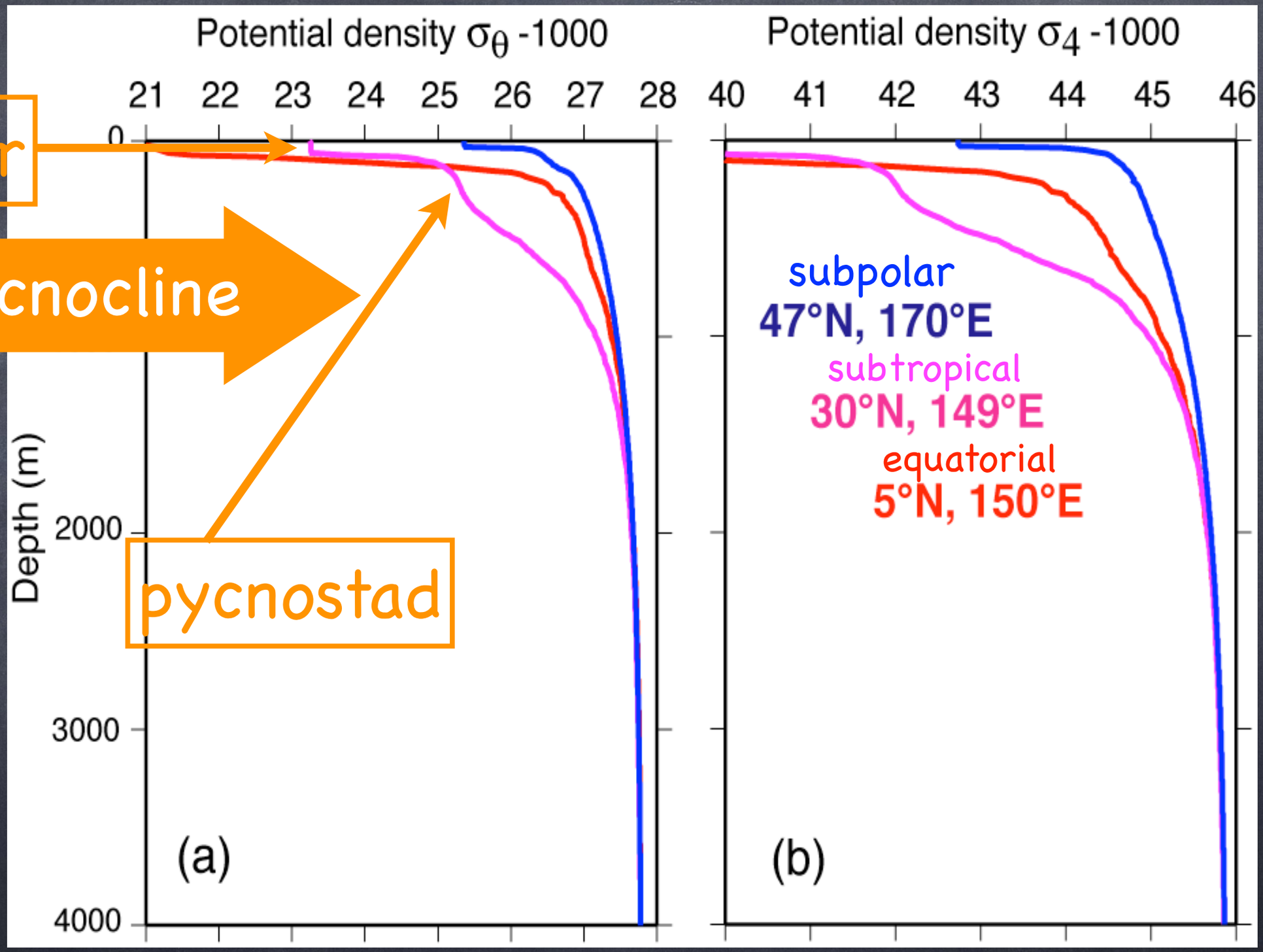
Groeskamp S, et al. 2019.
Annu. Rev. Mar. Sci. 11:271–305

Typical potential temperature profiles



tropics gyres polar oceans

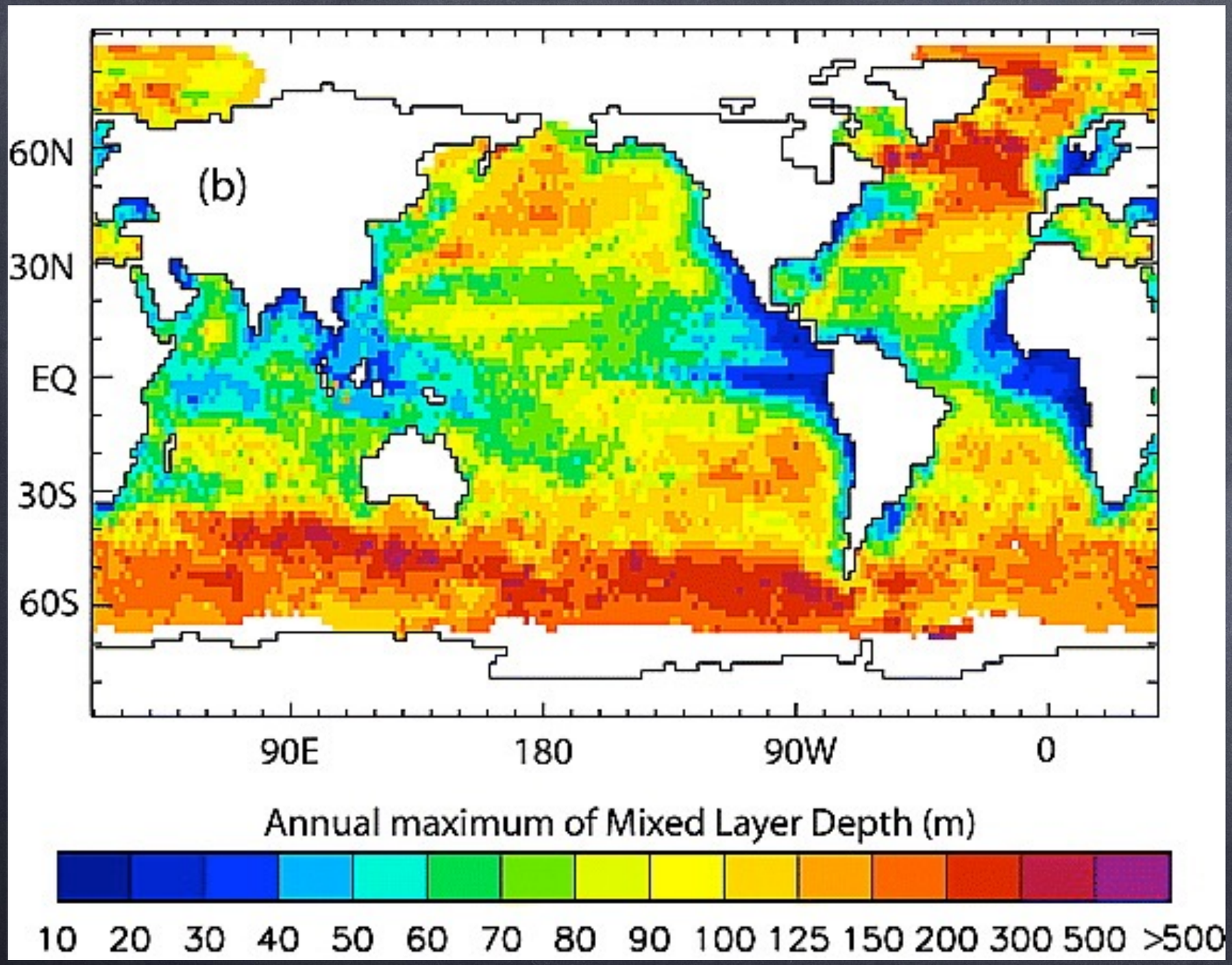
Typical potential density profiles



Mixed Layer

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

Annual maximum mixed layer depth



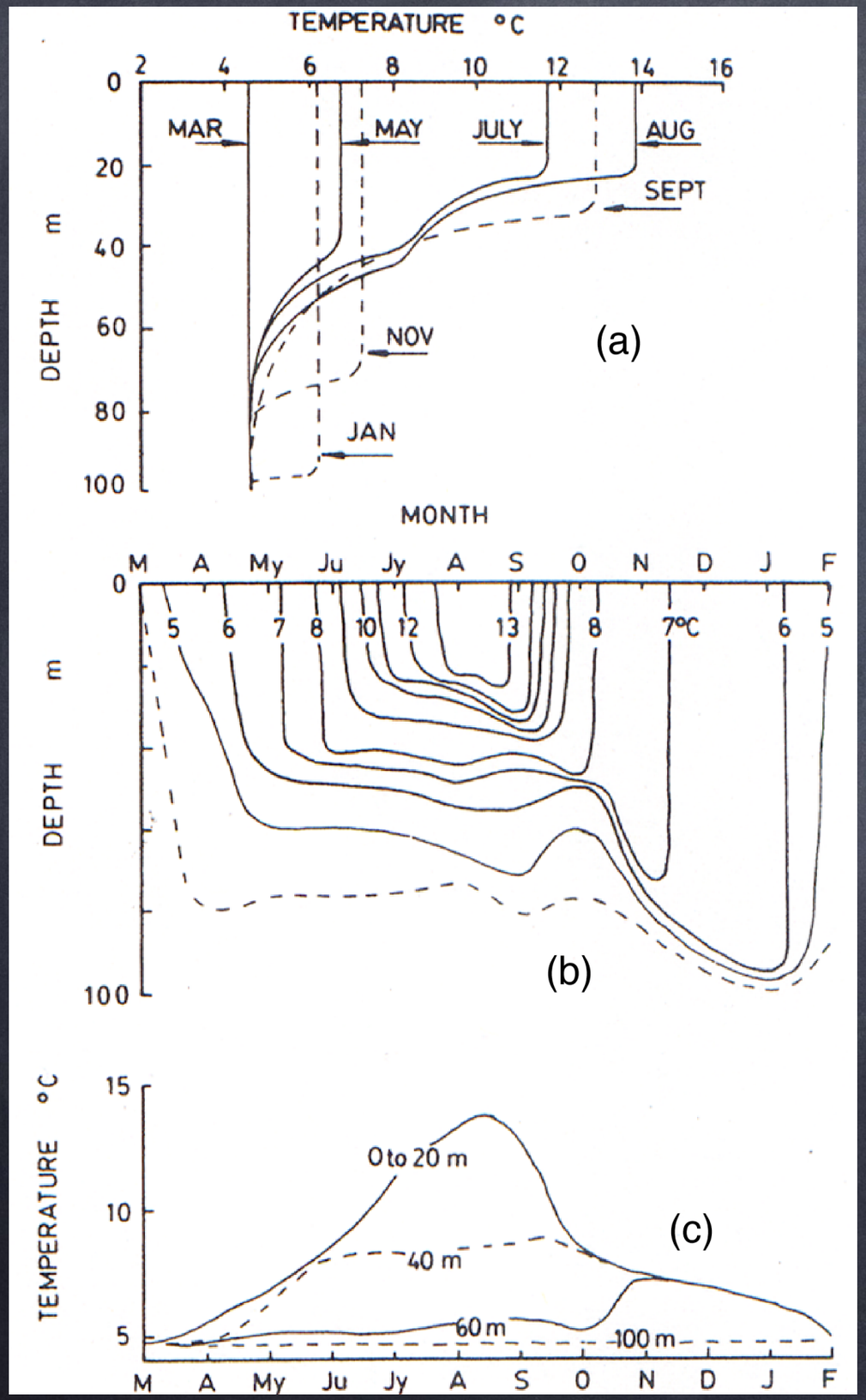
Thickest mixed layers in subpolar oceans, and in downwelling subtropical gyres.

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/spring

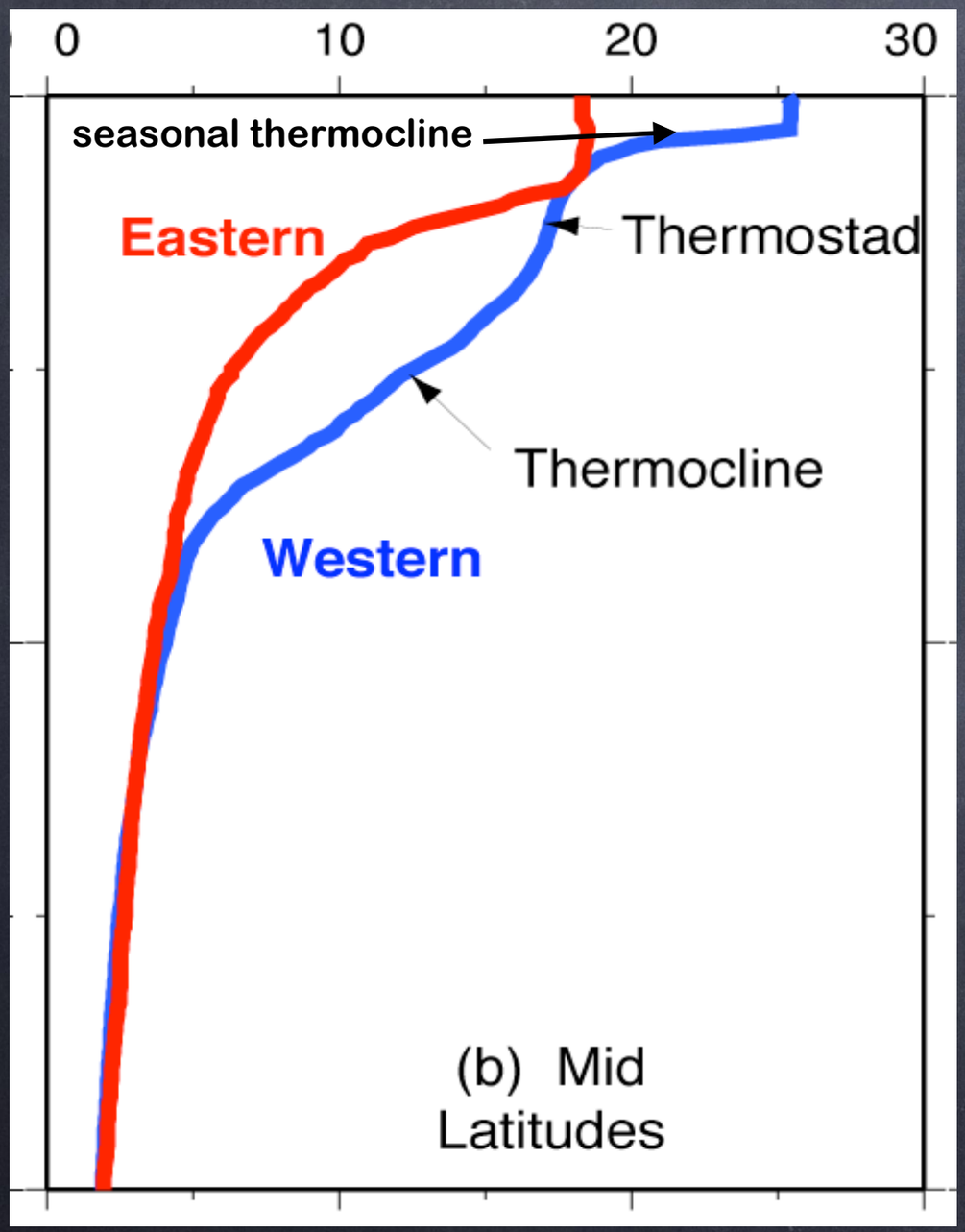
Summer: Surface warming restratifies the water column (seasonal thermocline/pycnocline), with a remnant of winter mixed layer typically subducted below.

Talley et al Figure 4.7

Thermocline (pycnocline)

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

Thermocline (pycnocline) theory



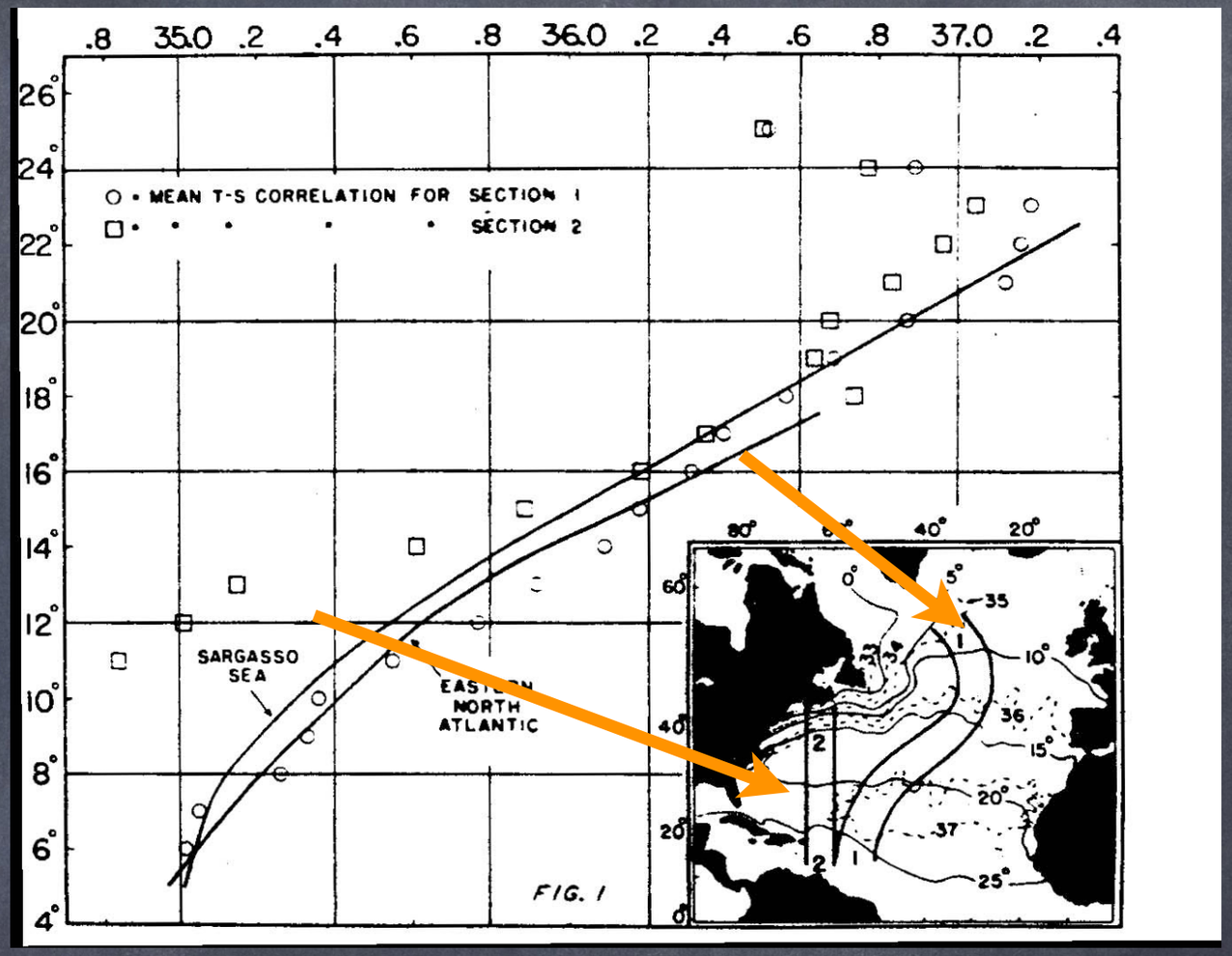
Two physical models:

1. Vertical balance of mixing and diffusion (Munk): Downward diffusion of warm surface waters and upward mixing of cold, dense deep waters.

2. Ventilated thermocline (Iselin): Subduction of surface waters into the interior along isopycnals.

Ventilated Thermocline (pycnocline)

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



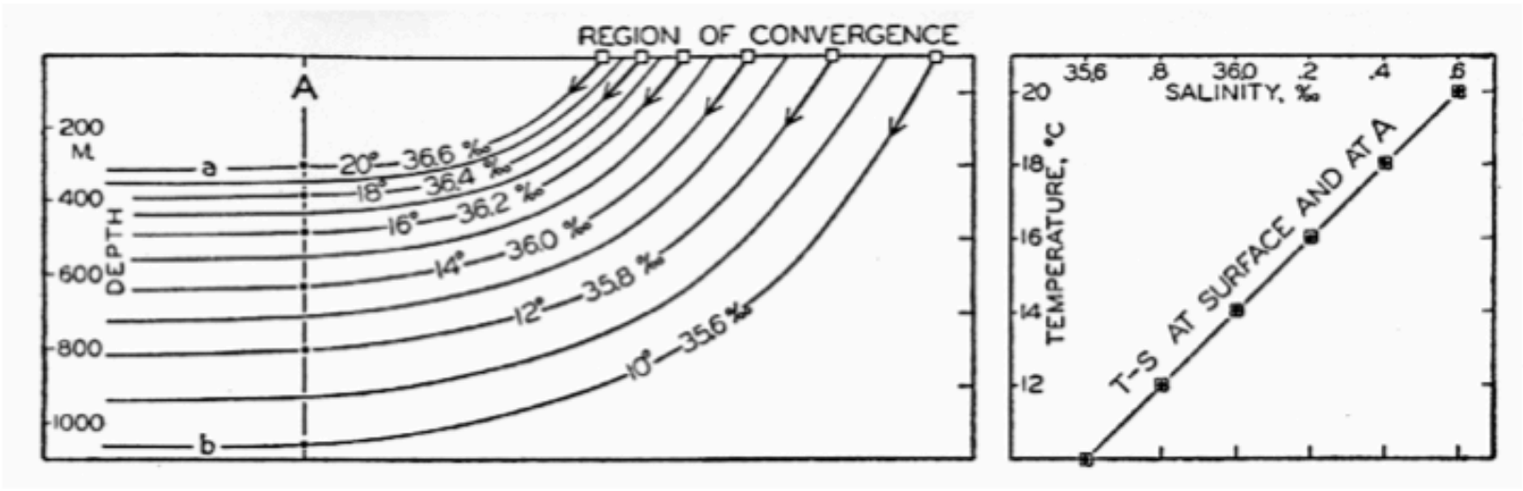


Fig. 1. Schematic representation of water mass formation due to water sinking along isopycnal surfaces (Iselin, 1939).

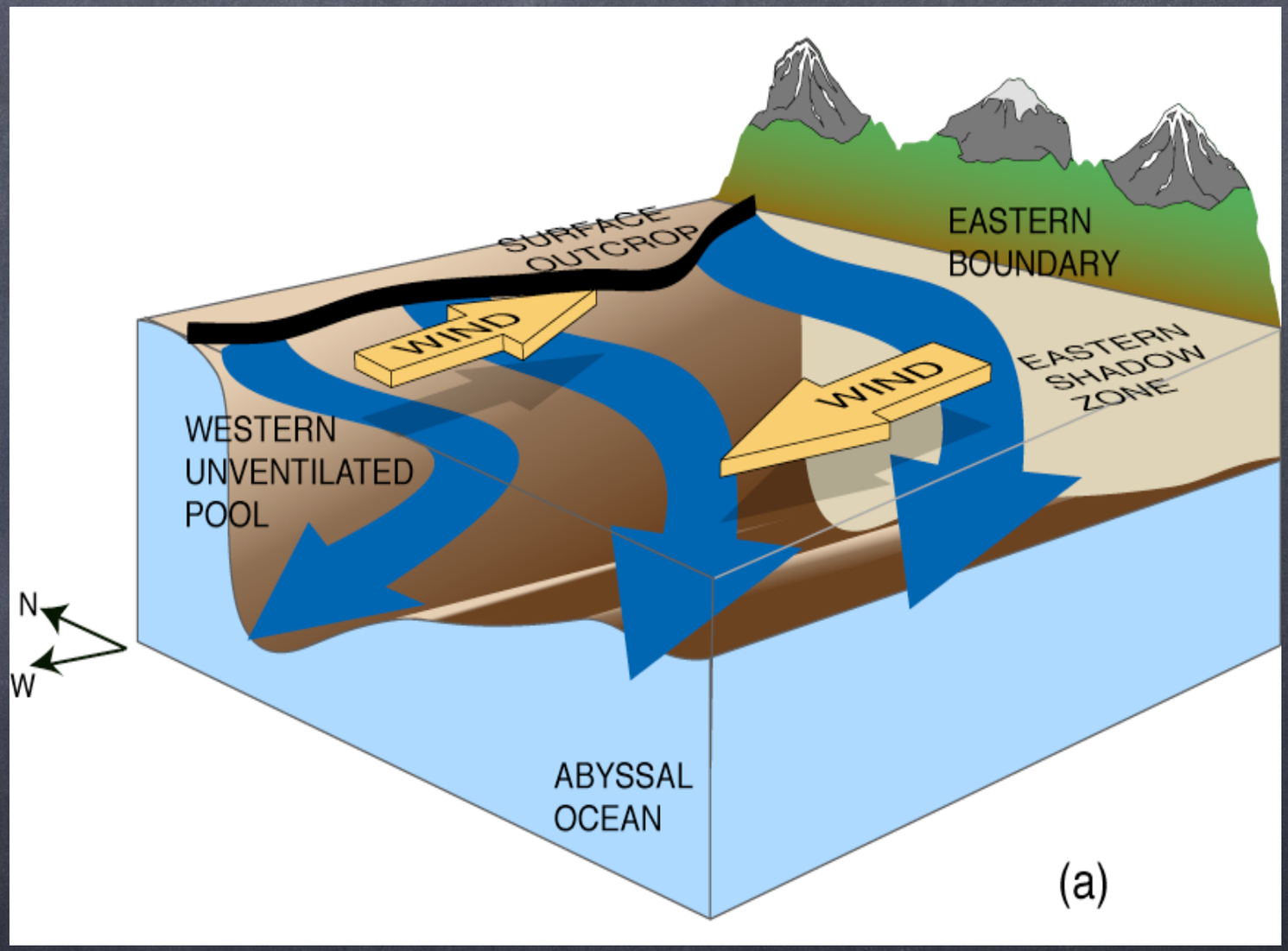
Ventilation

- Waters are subducted away from the ocean surface mixed layer along isopycnals.
- Small vertical/diapycnic mixing leads to thin density layers.
- The thermocline/pycnocline is ventilated with dissolved gases from the atmosphere.

Ventilation: an isentropic process

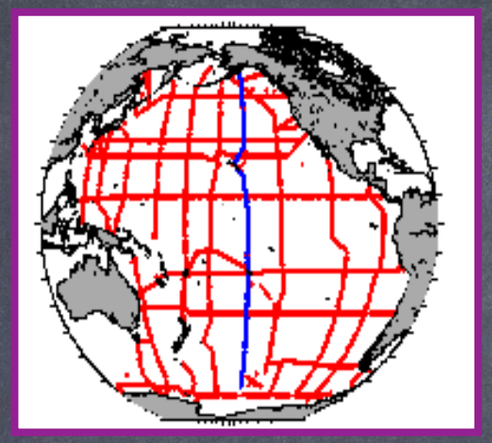
Flow from surface mixed layer into interior is along isopycnals.

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



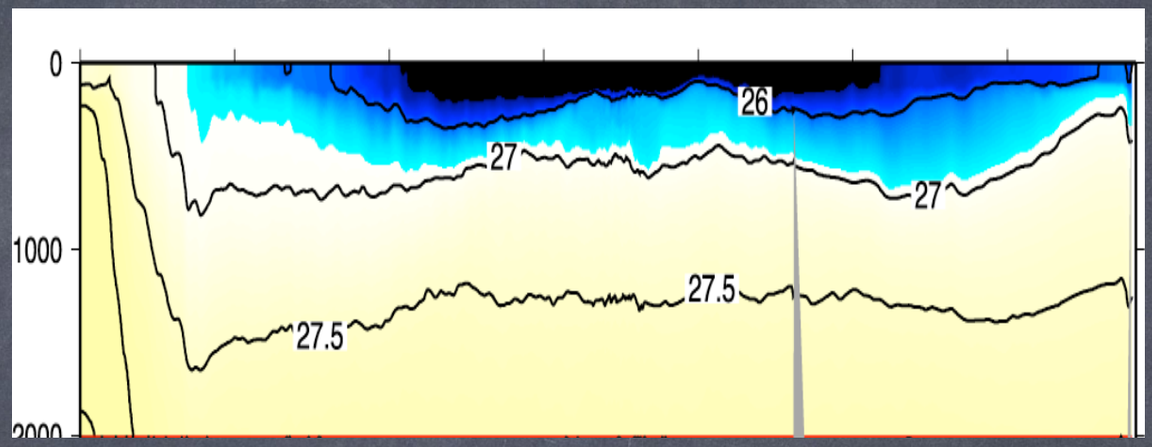
Emery, Talley, Pickard figure 8.35

Ventilation is an isentropic process

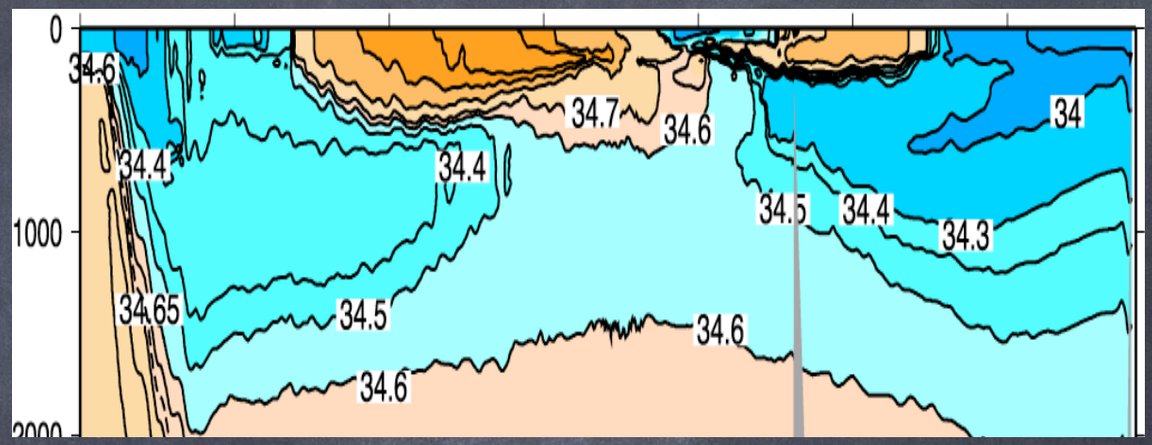


Flow in the ocean interior will be along isentropic surfaces, estimated by isopycnals (potential density surfaces), in the absence of mixing.

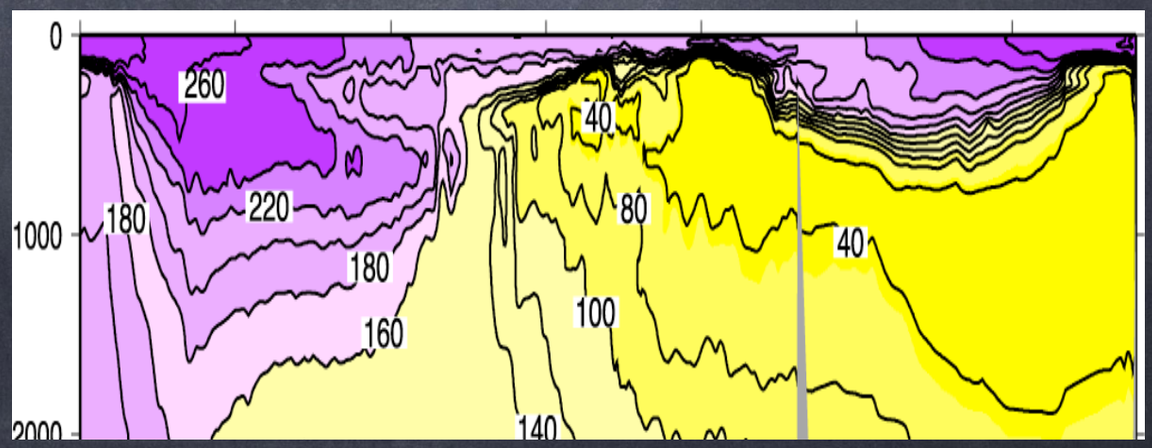
ρ



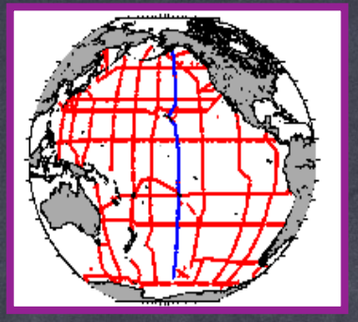
S



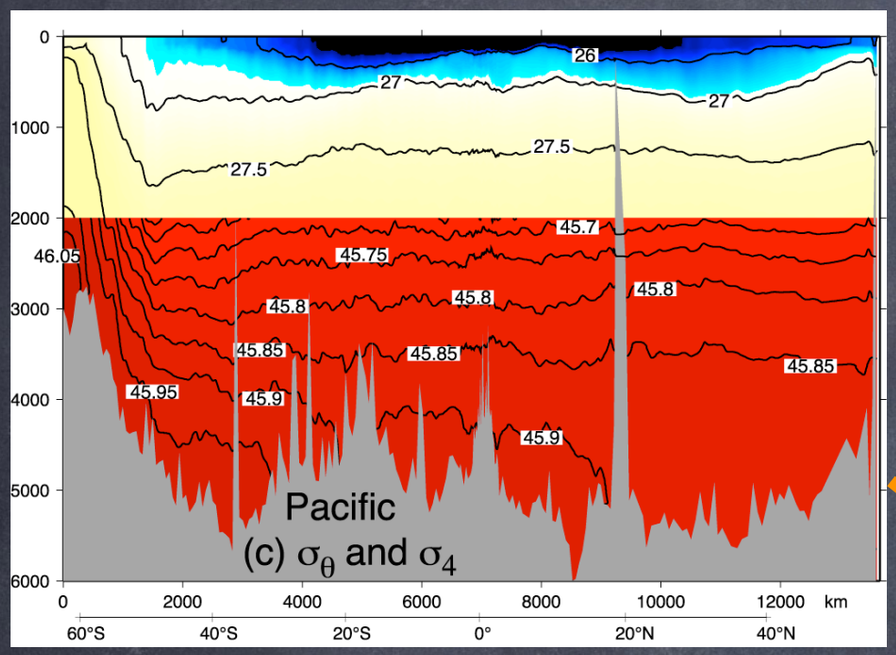
O2



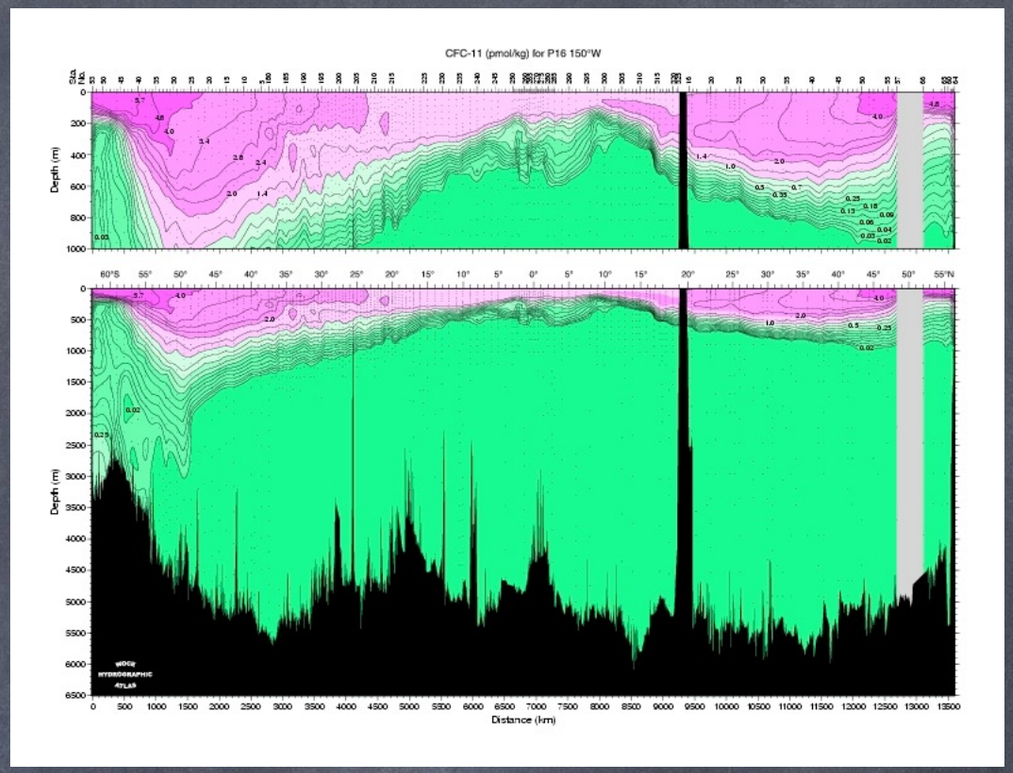
South North



Ventilation: an isentropic process

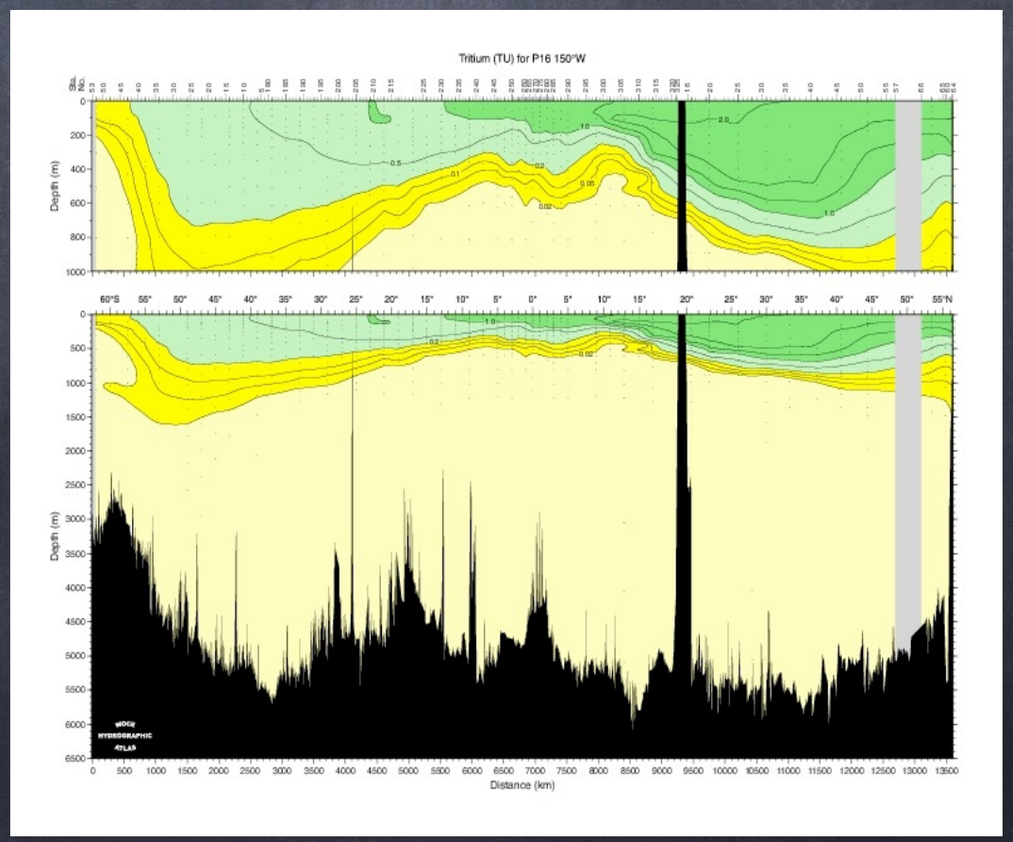


CFC-11

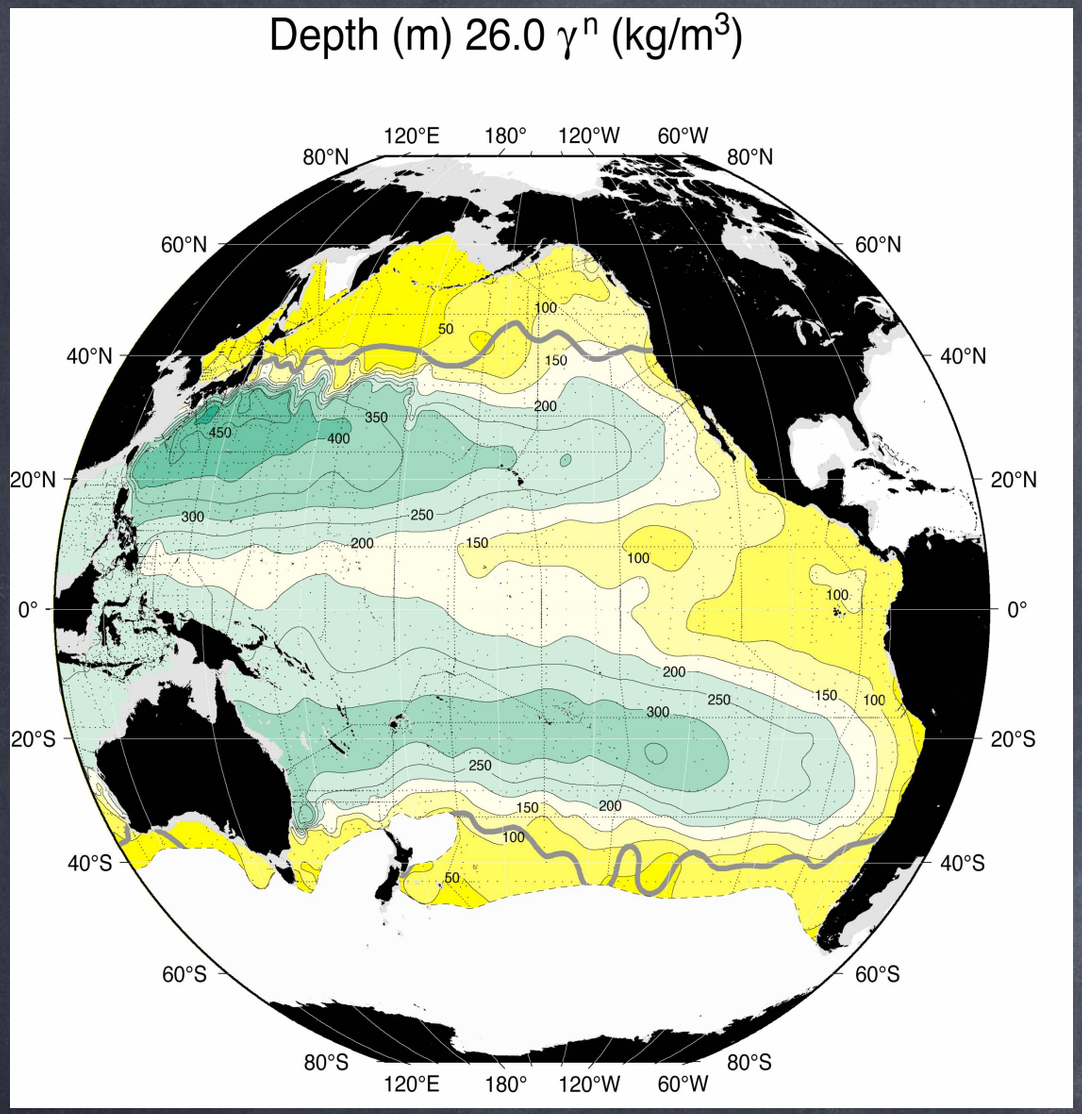


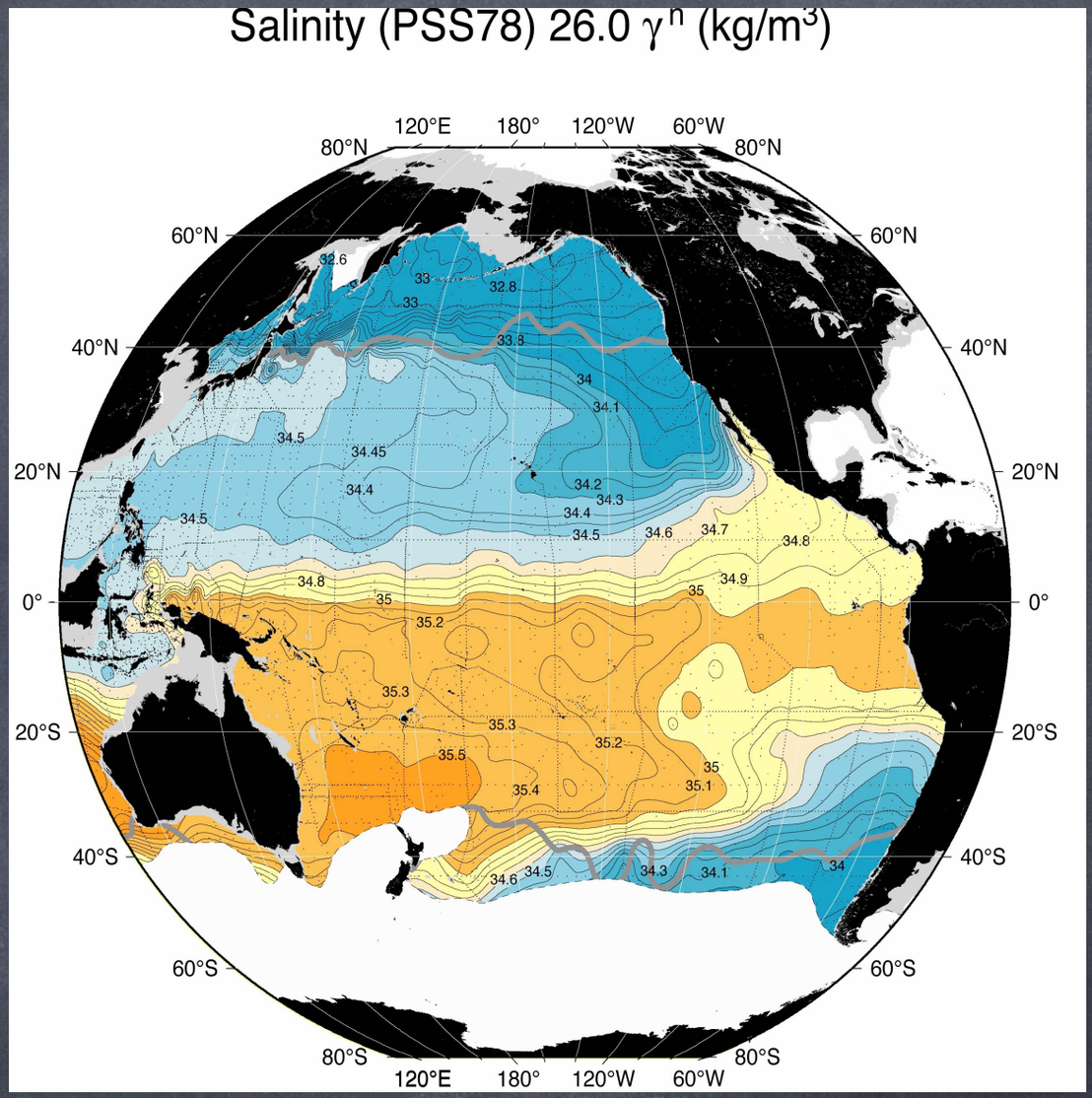
Ventilation observed in anthropogenic tracers

Tritium

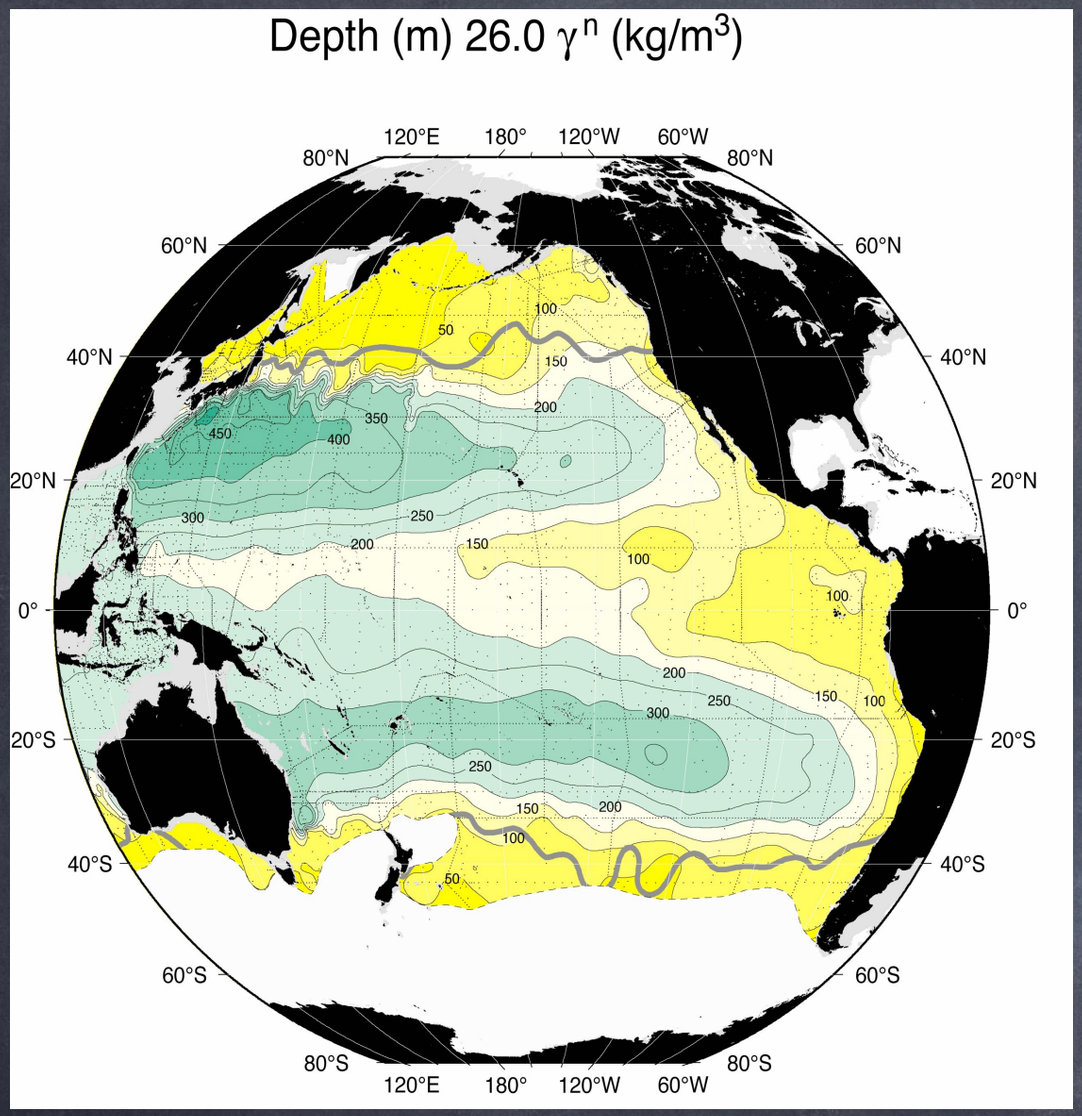


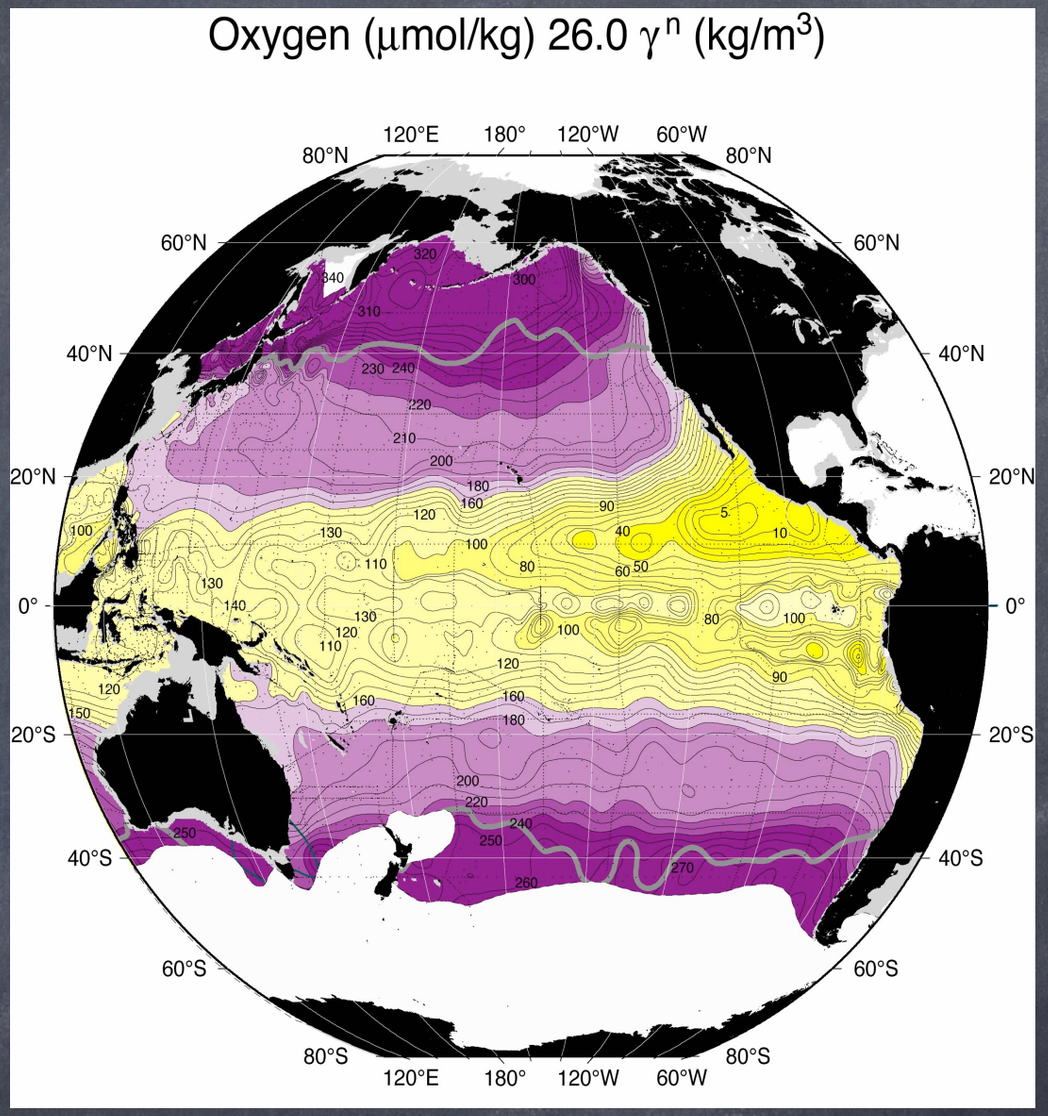
Ventilation: an isentropic process





Ventilation: an isentropic process



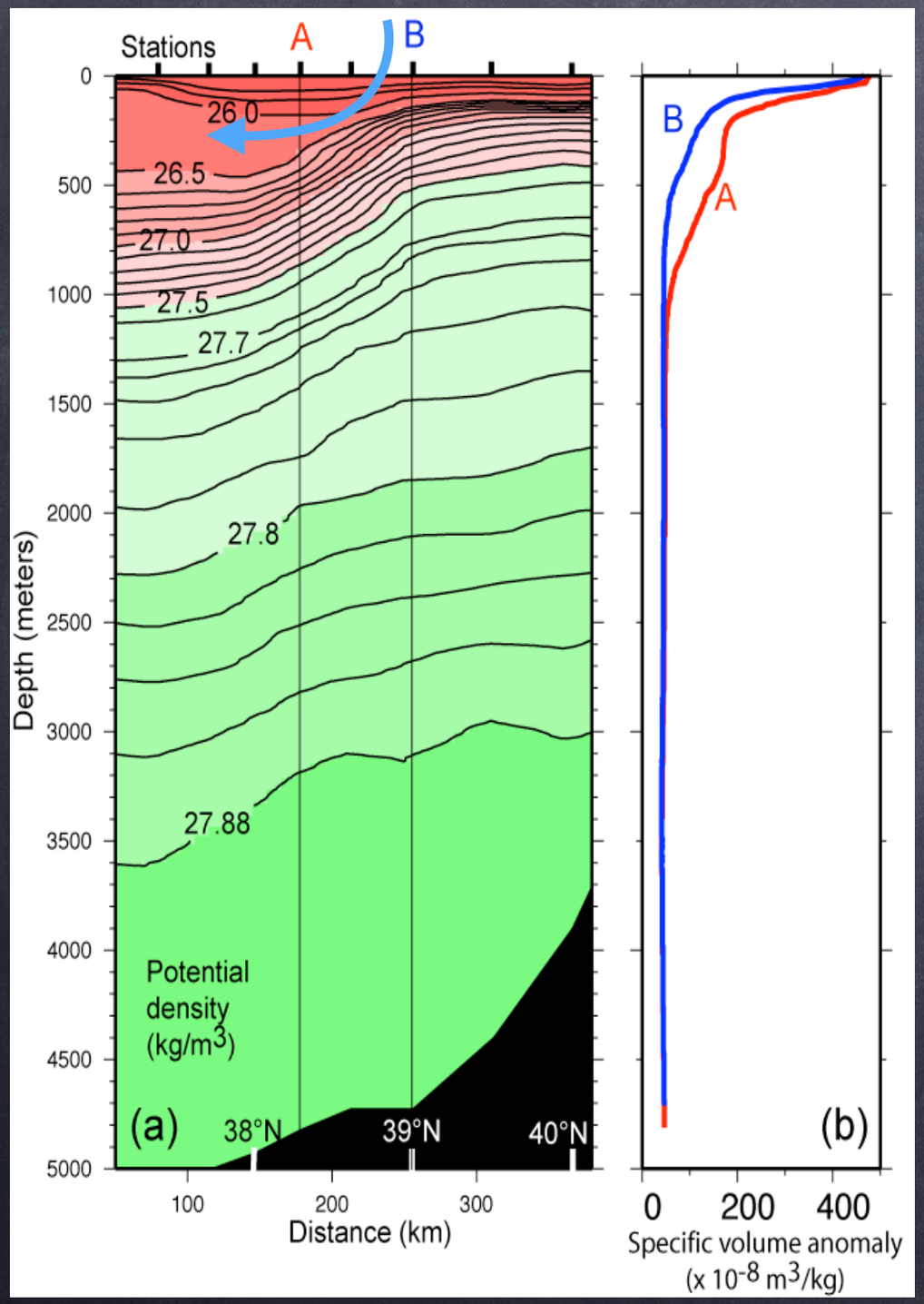


Oxygen is a non-conservative tracer. The general regions of newly ventilated versus older waters can be seen, but the picture is muddied by oxygen utilisation near the eastern boundary.

Mode Waters (pycnostad/thermostad)

- Found within the thermocline, typically 100 to 500 m thick.
- Layer of homogeneous water properties subducted from bottom of thick winter mixed layers, usually associated with a convergent (subtropical/subpolar) front.
- Antarctic Intermediate water is deepest form of mode water

Subtropical Mode Water (Eighteen Degree Water)

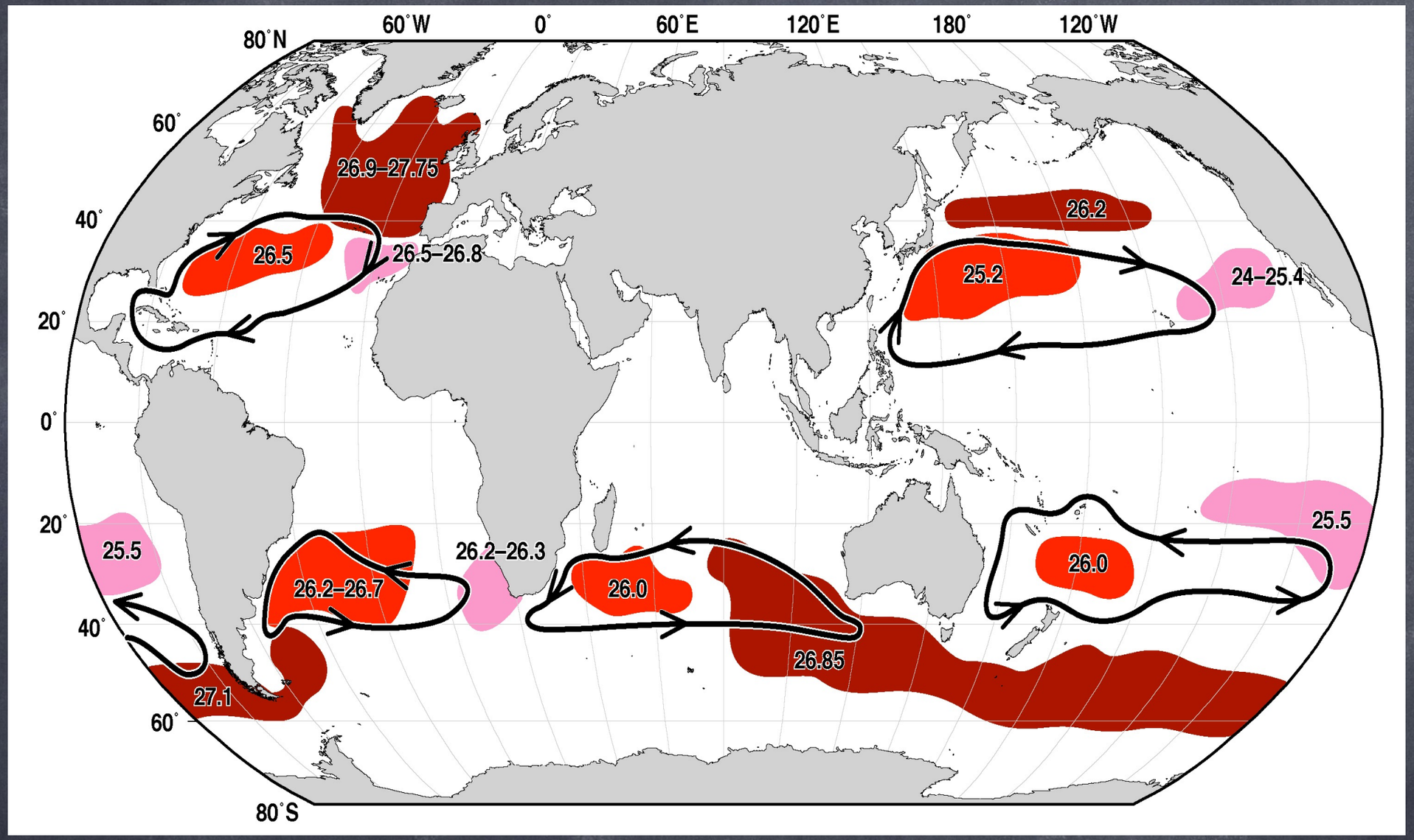


Talley et al Figure 8.21

Meridional section across the Gulf Stream

- Thickening of layer between isopycnals 26 and 26.5
- Forms at surface as a thick mixed layer on the southern flank of the Gulf Stream in late winter.
- Subducts into the interior of the subtropical gyre south of the Gulf Stream along isopycnals.

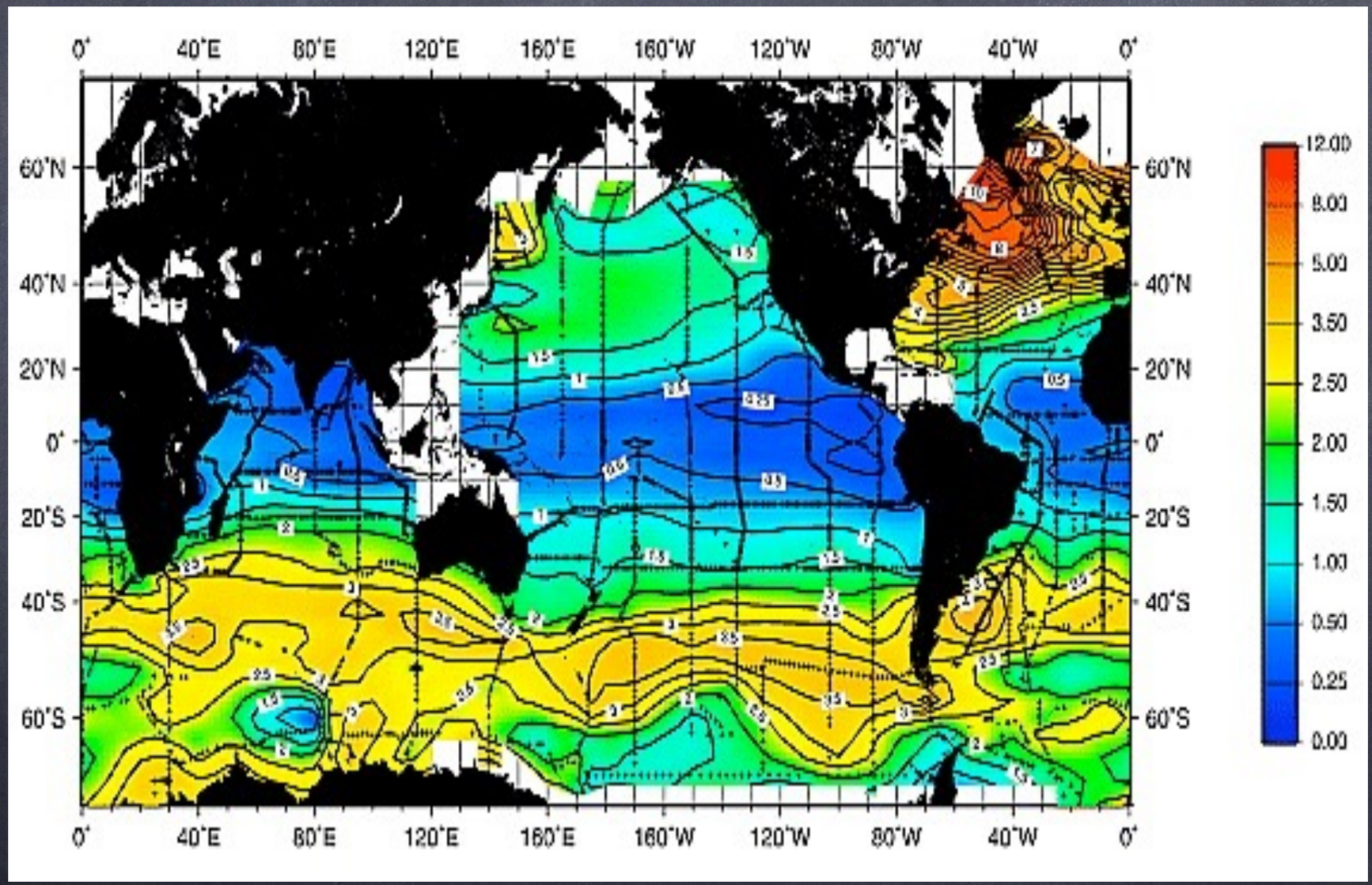
Mode Waters



Location of mode waters 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

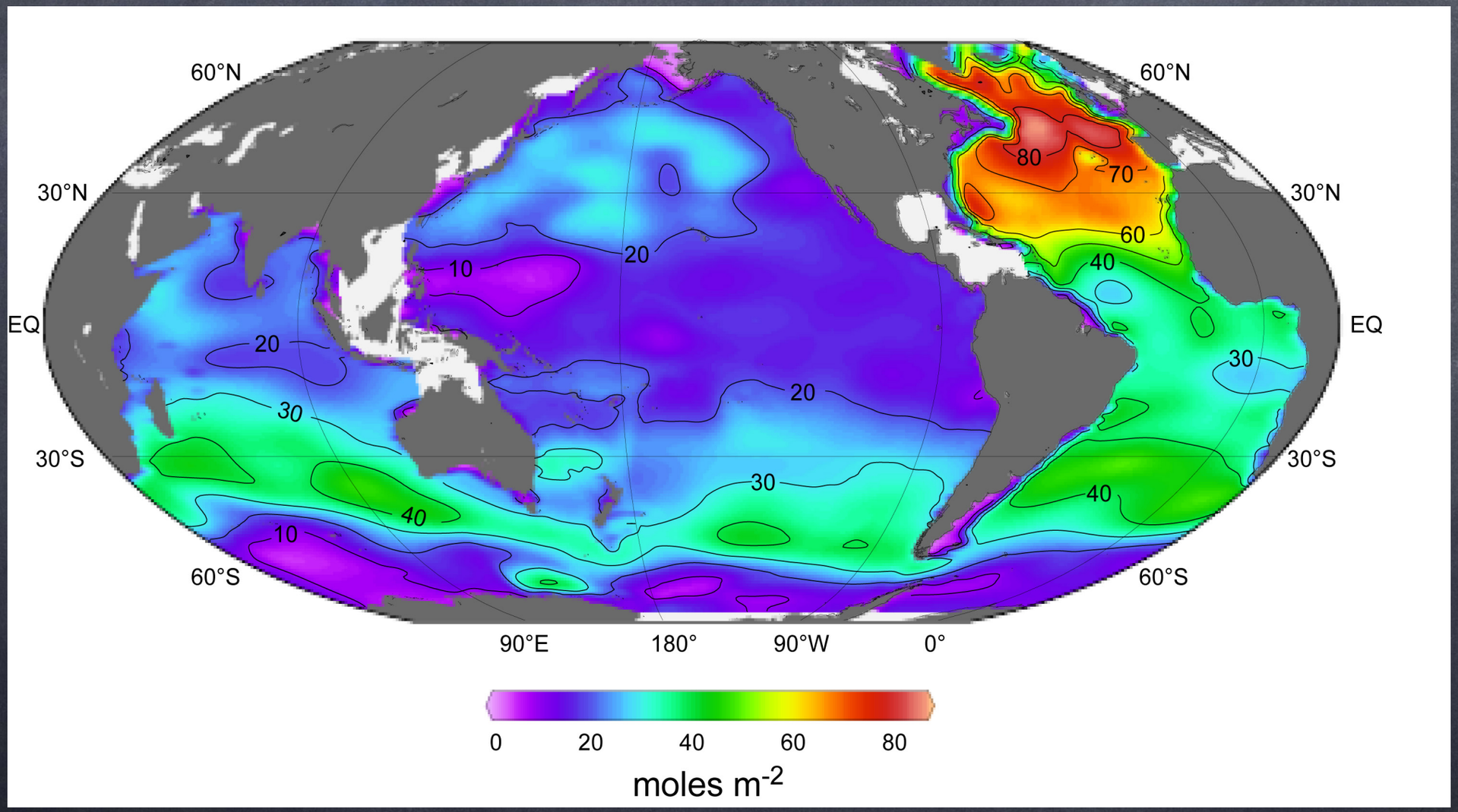
CFC water column inventories



Willey et al. (GRL 2004)

Importance of mode waters for dissolved gas inventories

Anthropogenic CO2 water column inventories

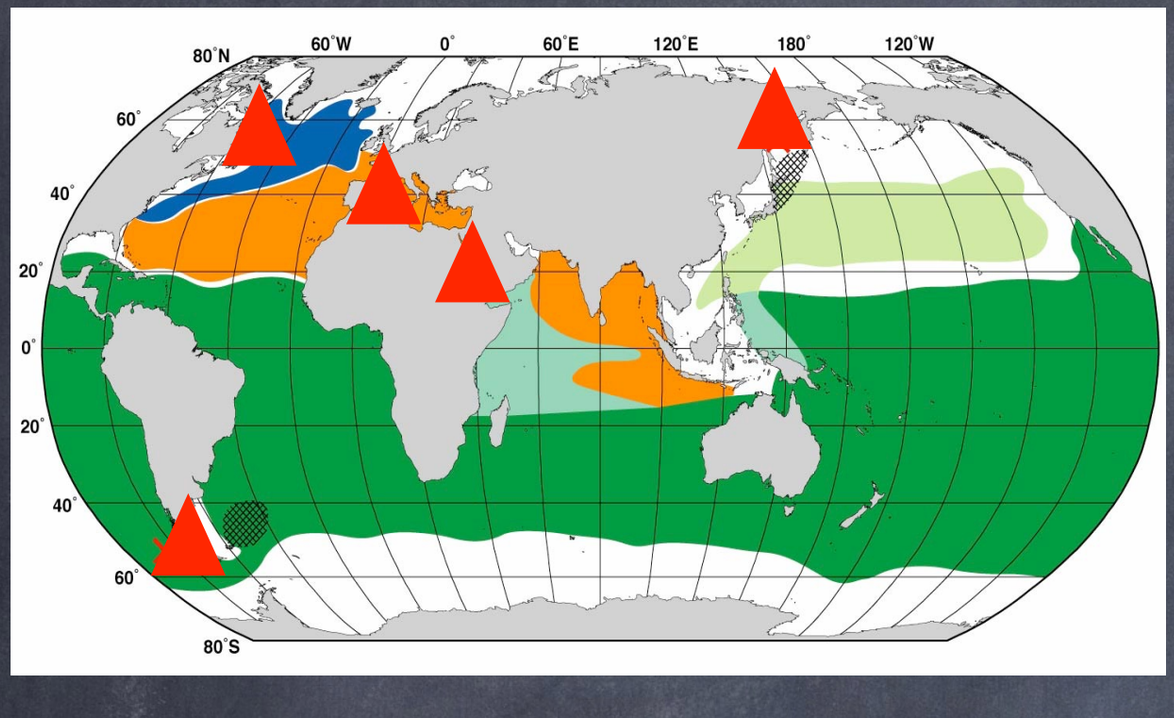


Sabine et al. (Science 2004)

Intermediate, Deep and Abyssal waters

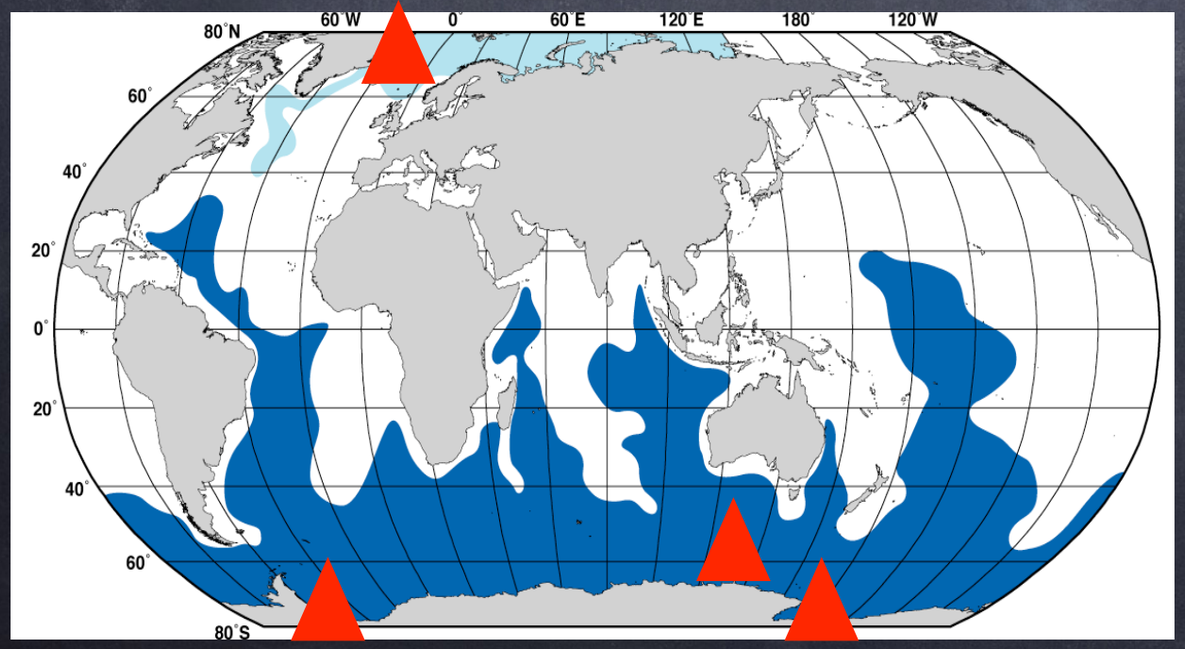
- Dense waters formed over small regions by **convection**
- Formed by extreme cooling and brine rejection at high latitudes or by extreme evaporation at mid and low latitudes (semi-enclosed seas).

Water masses formed by deep convection



Intermediate production sites:

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



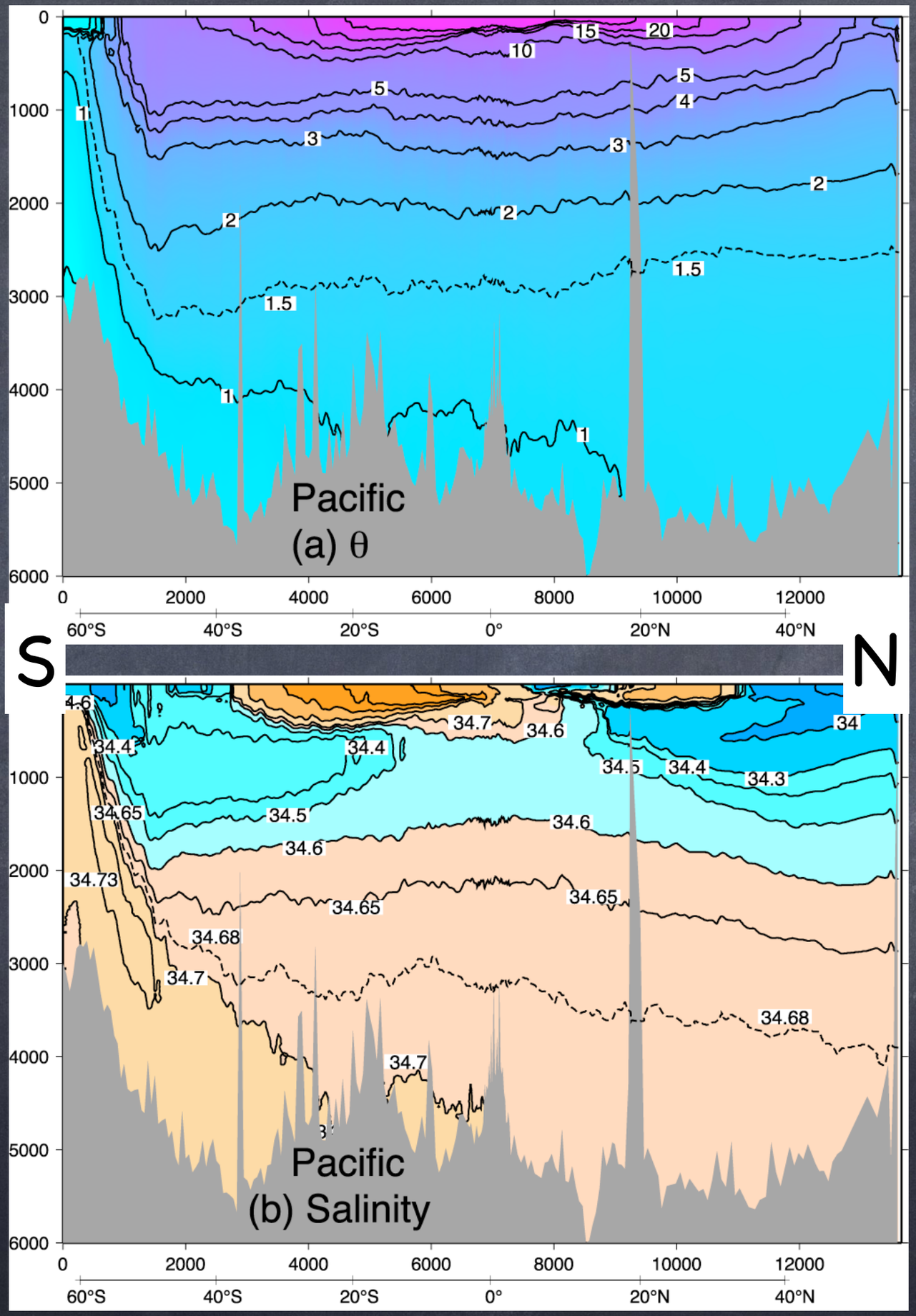
Deep and bottom water production sites

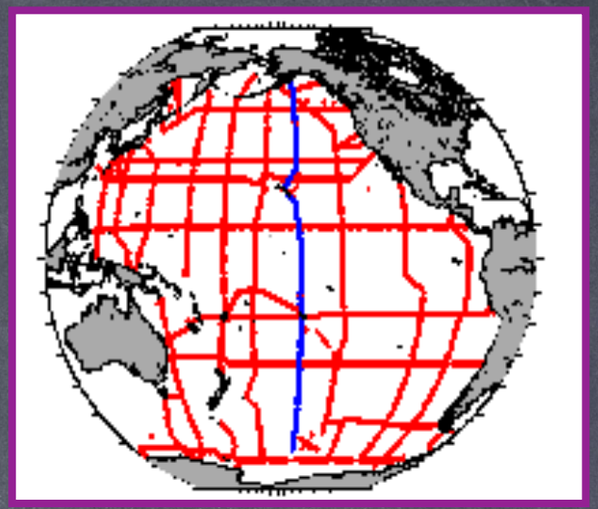
NADW (Norwegian/Greenland Sea, Irminger basin)
CDW = Circumpolar Deep Water
AABW = Antarctic Bottom Water

Pacific

potential temperature (℃)

salinity





thermocline

STUW

AAIW

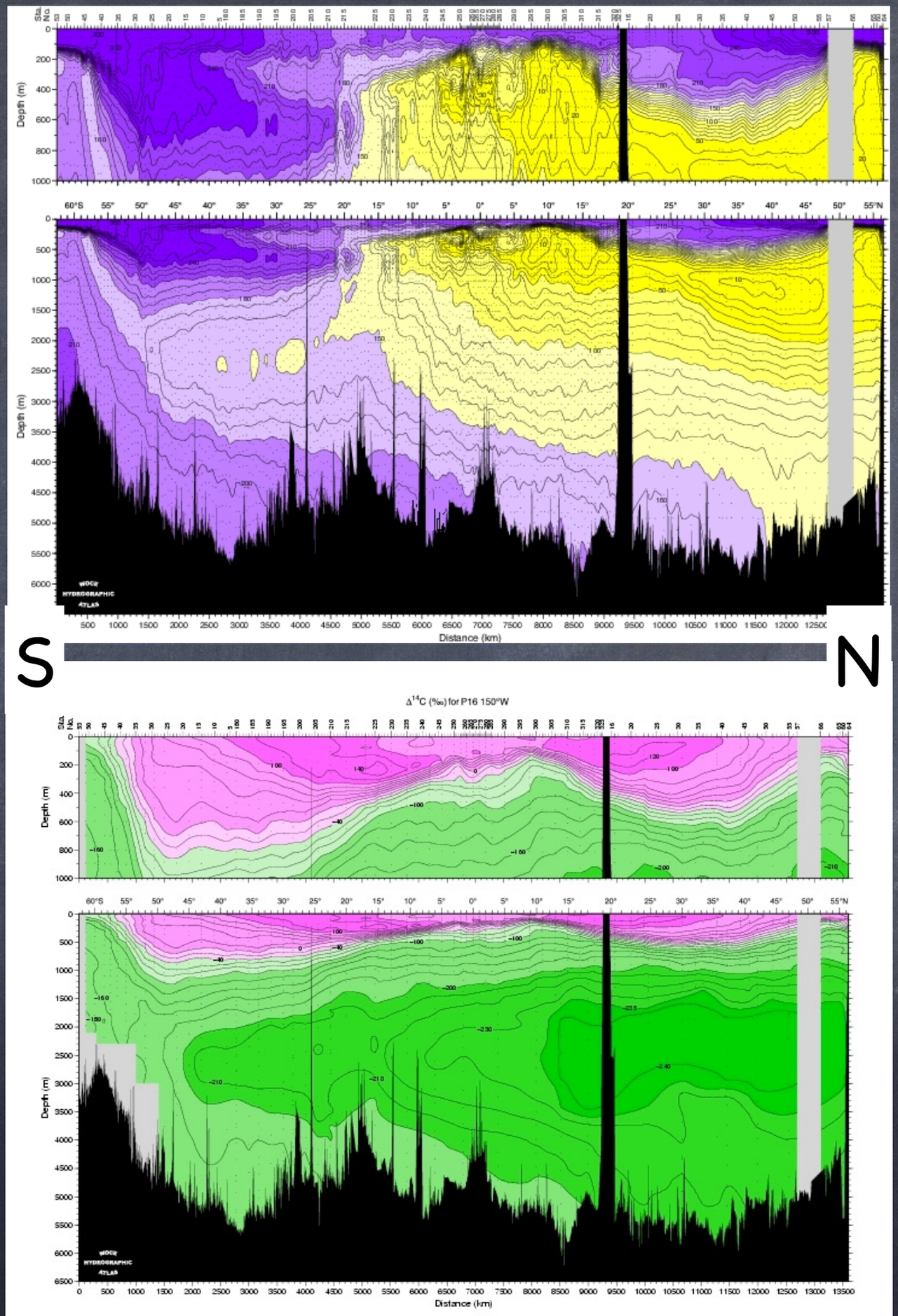
NPIW

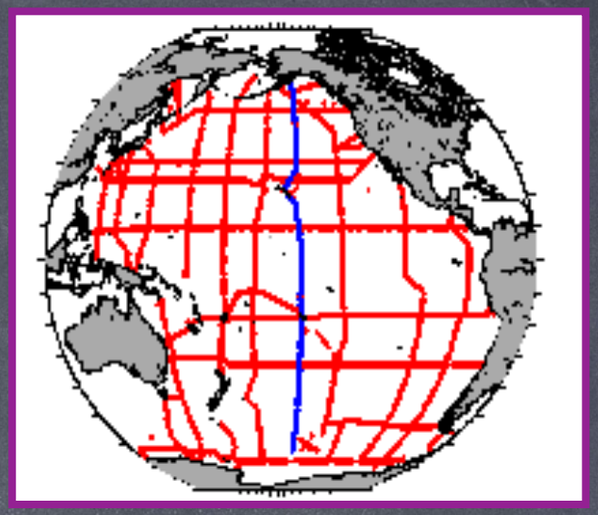
AABW

CDW

Pacific

Oxygen
(μmol/kg)



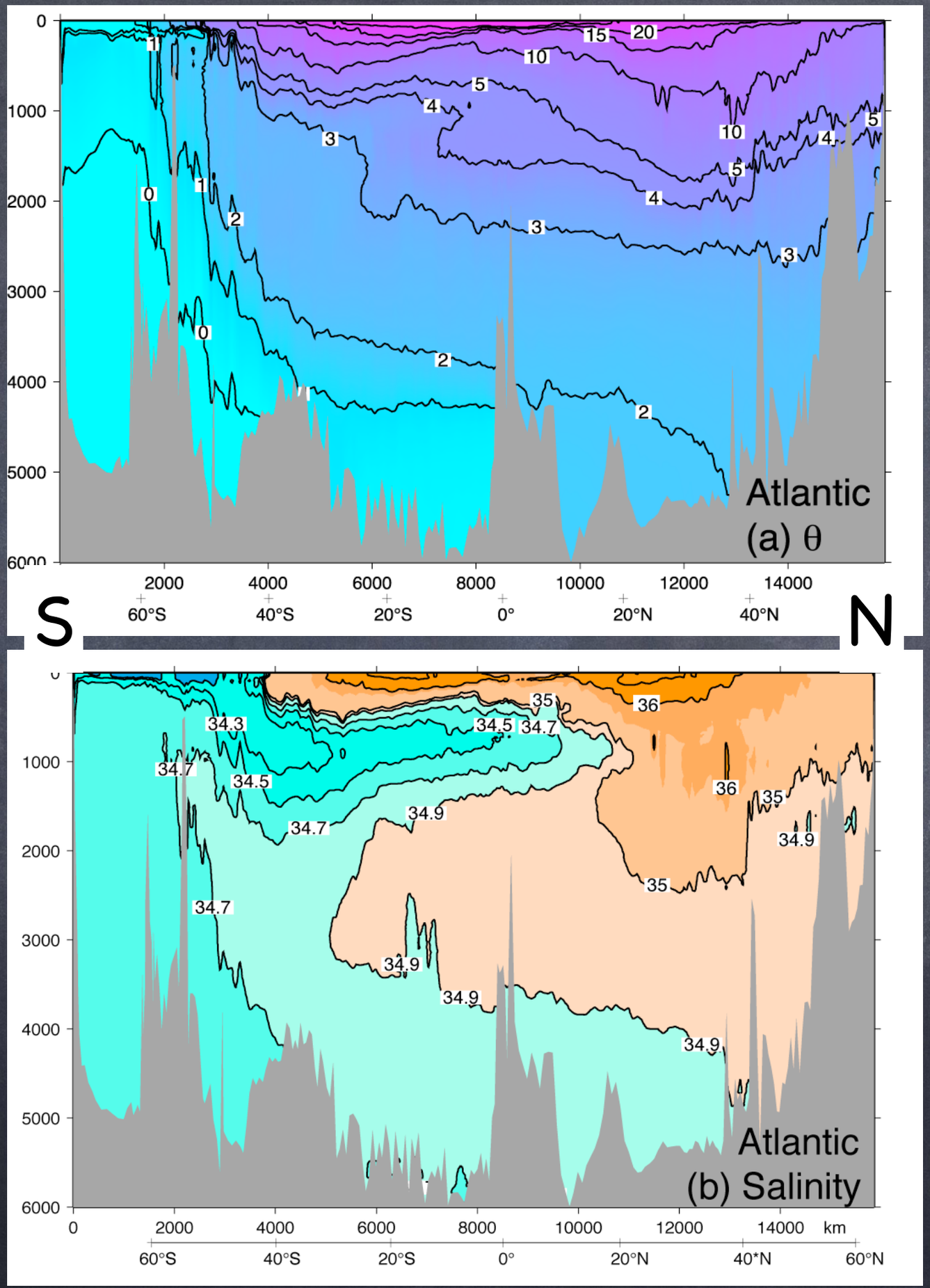


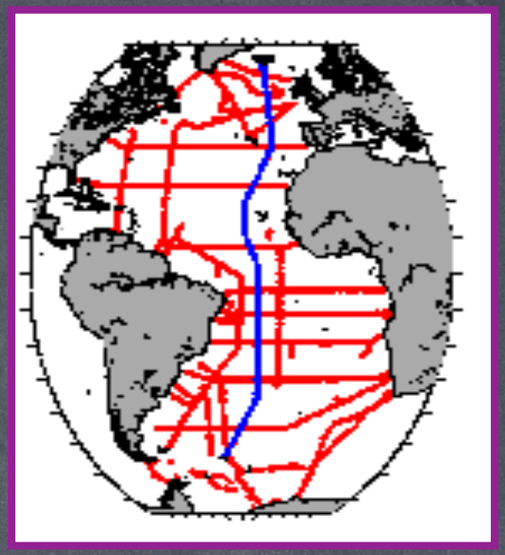
thermocline
STUW
AAIW
NPIW
AABW
CDW

Carbon 14
(‰)

Atlantic

potential temperature (°C)



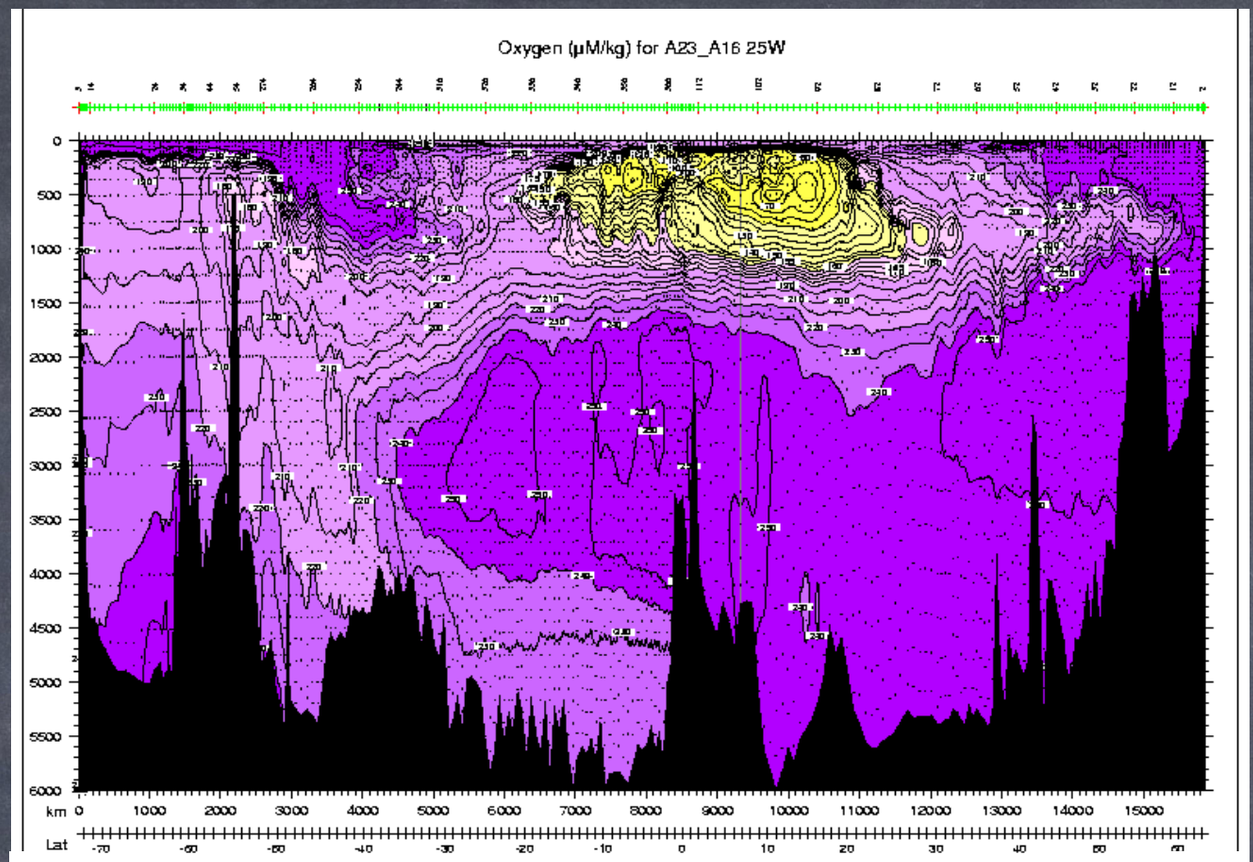


salinity

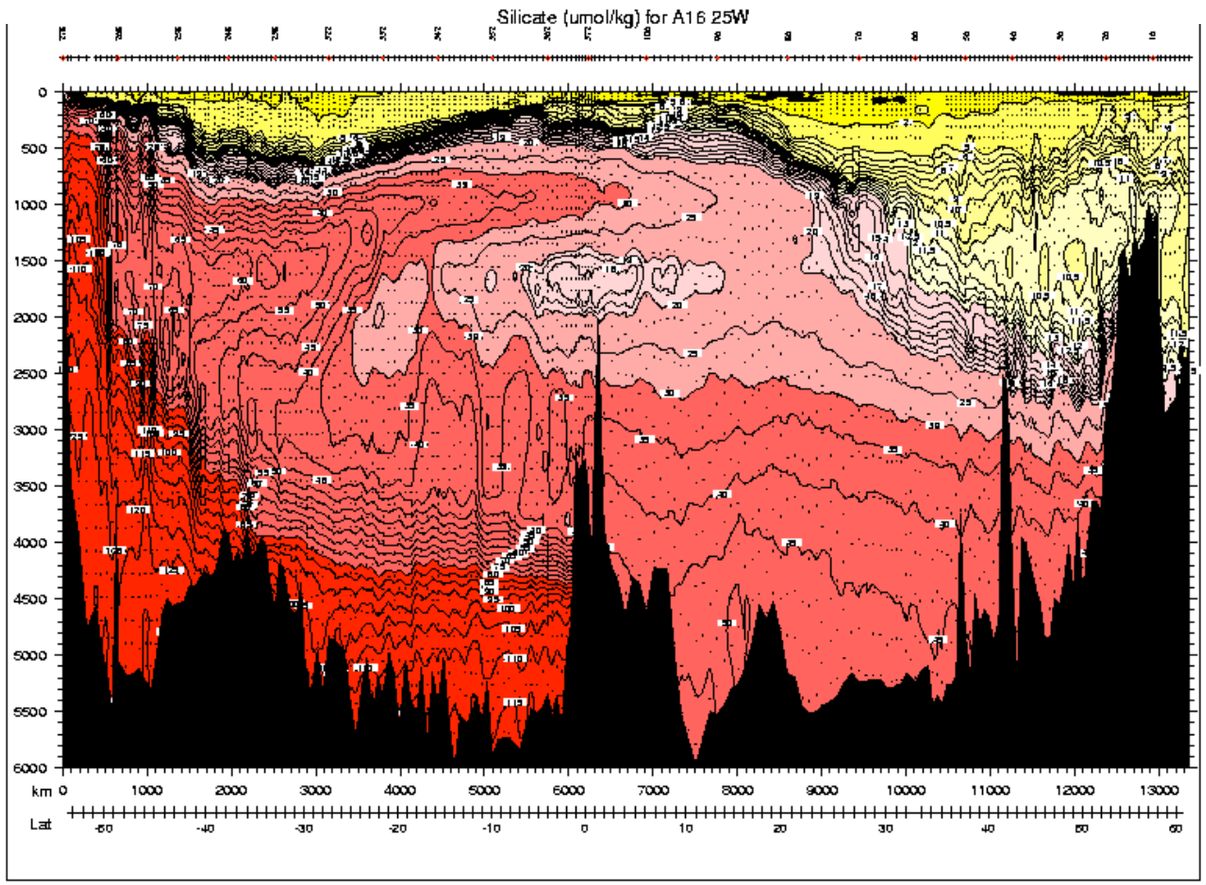
STUW
MW
AAIW
NADW
AABW

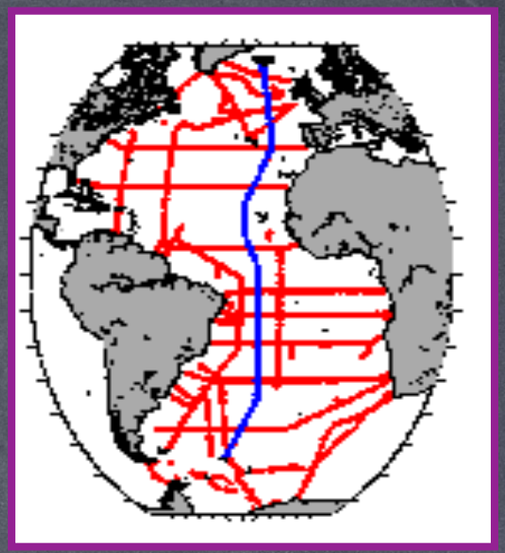
Atlantic

Oxygen (μmol/kg)



S N





STUW

MW

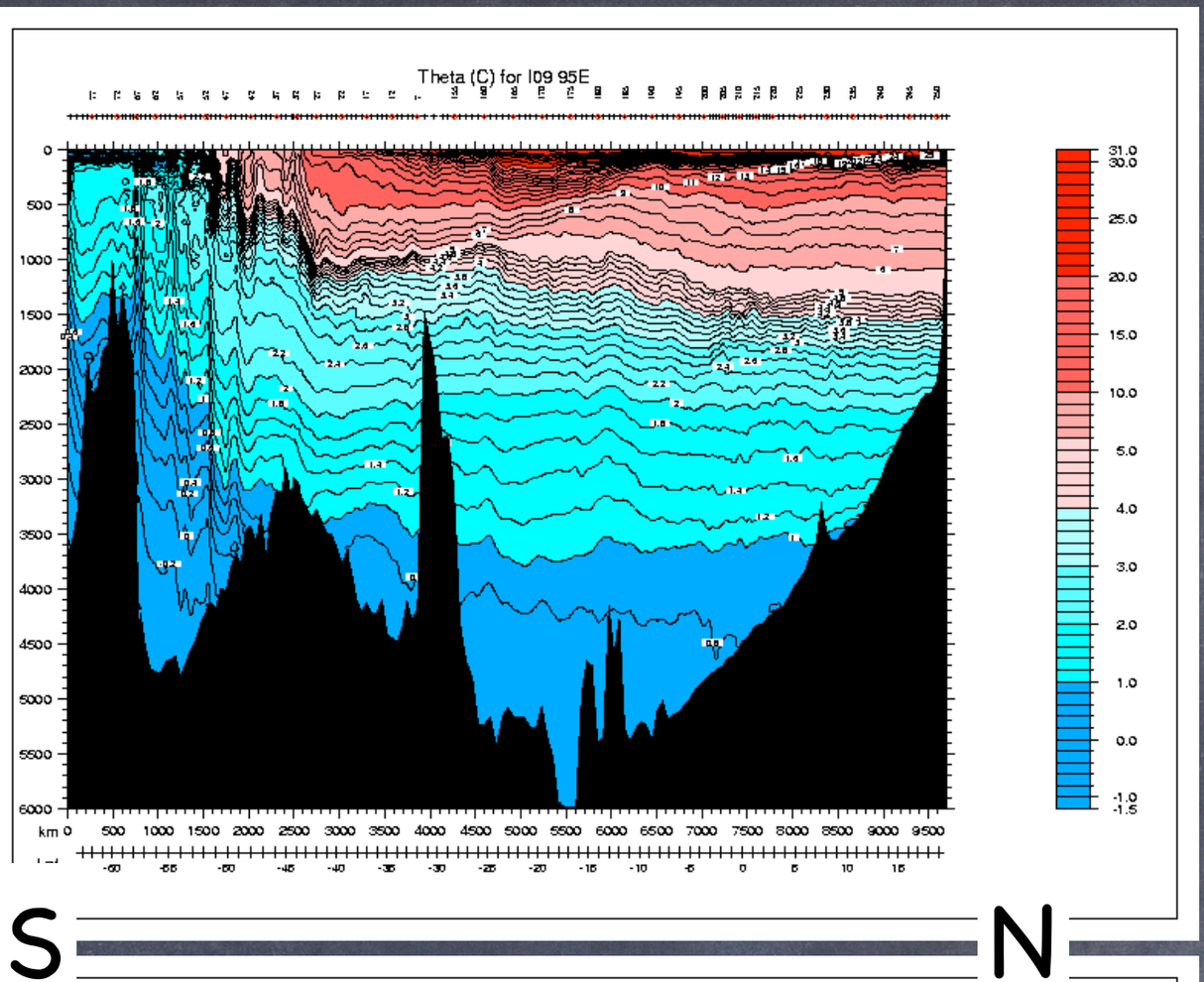
AAIW

NADW

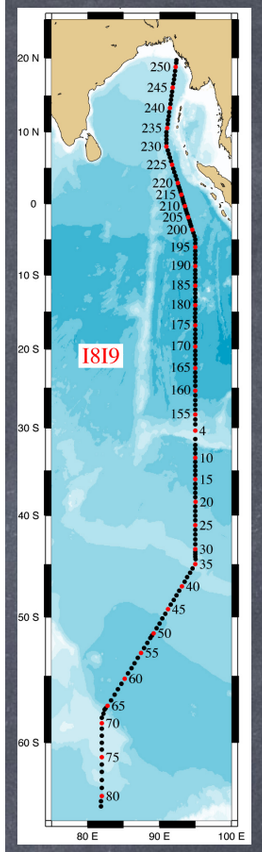
AABW

Indian

potential temperature (°C)

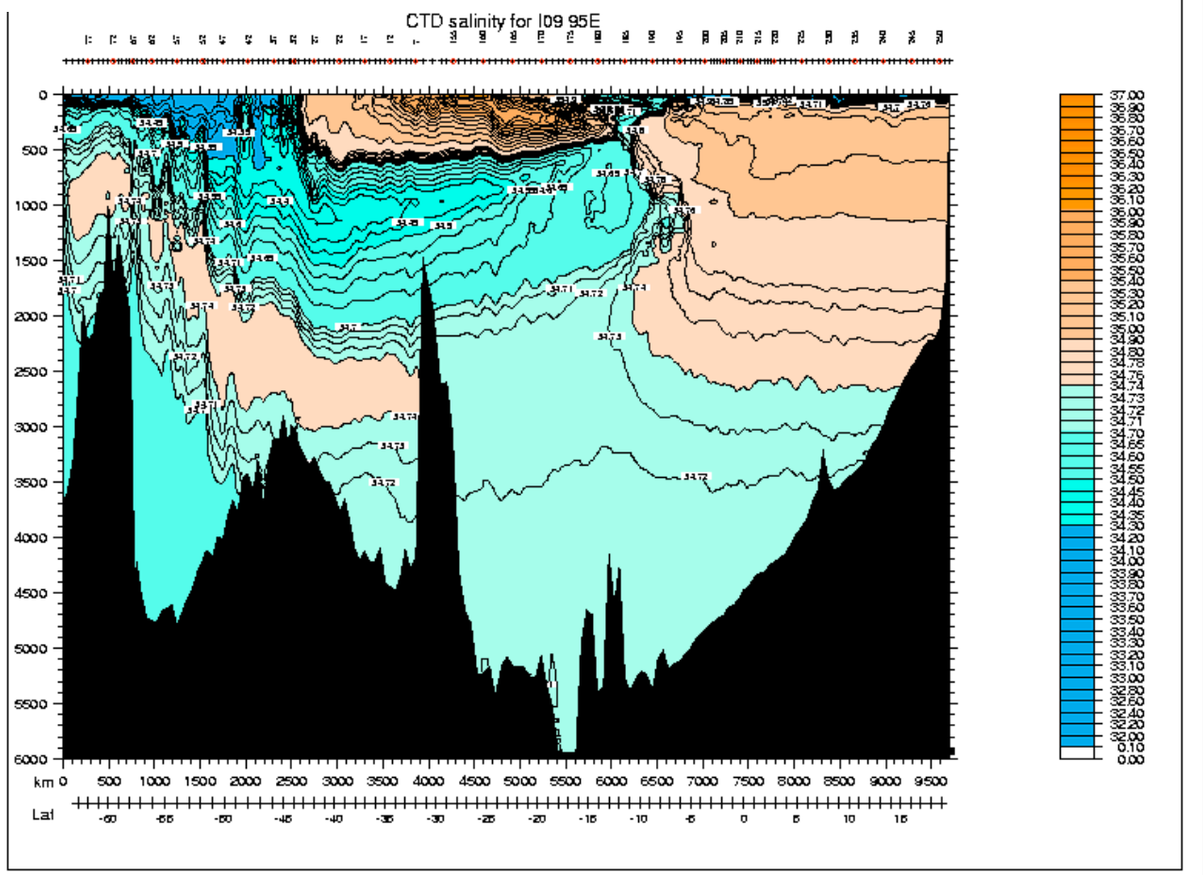


S N



STSW
RSW
ITF
AAIW

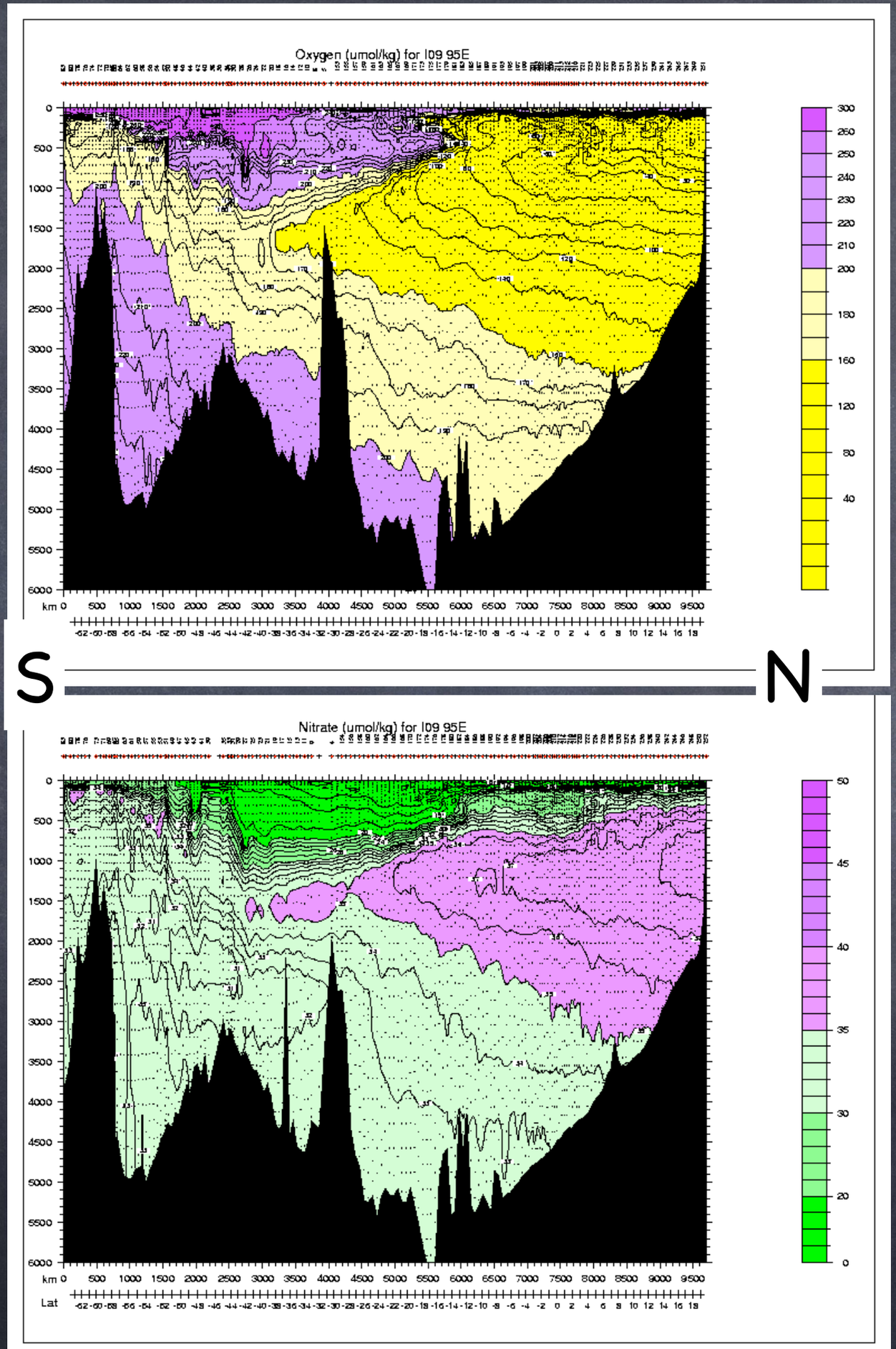
salinity

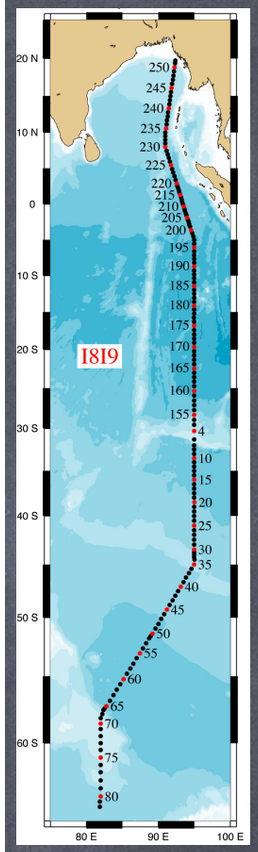


CDW
NIDW
AABW

Indian

Oxygen
(μmol/kg)





STSW
RSW
ITF
AAIW
CDW
NIDW
AABW

Nitrate
(μmol/kg)

On line resources for Ocean Property Distributions

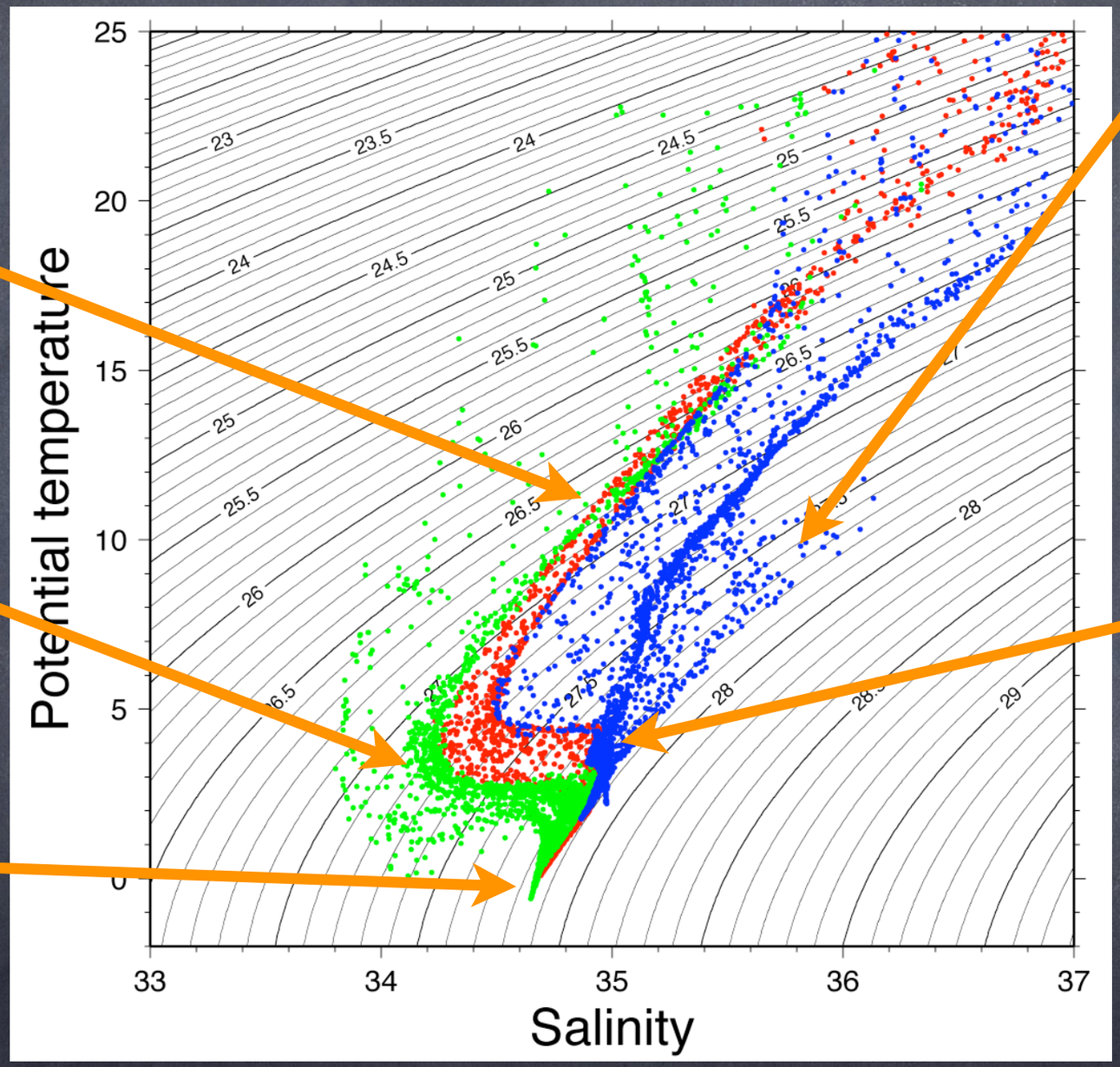
- WOCE Atlases: http://woceatlas.ucsd.edu
- Java Ocean Atlas: http:// joa.ucsd.edu
- Ocean Data View: https://odv.awi.de

Water masses gradually merge/mix as they spread over great distances

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 masses mix along straight lines on T/S diagram