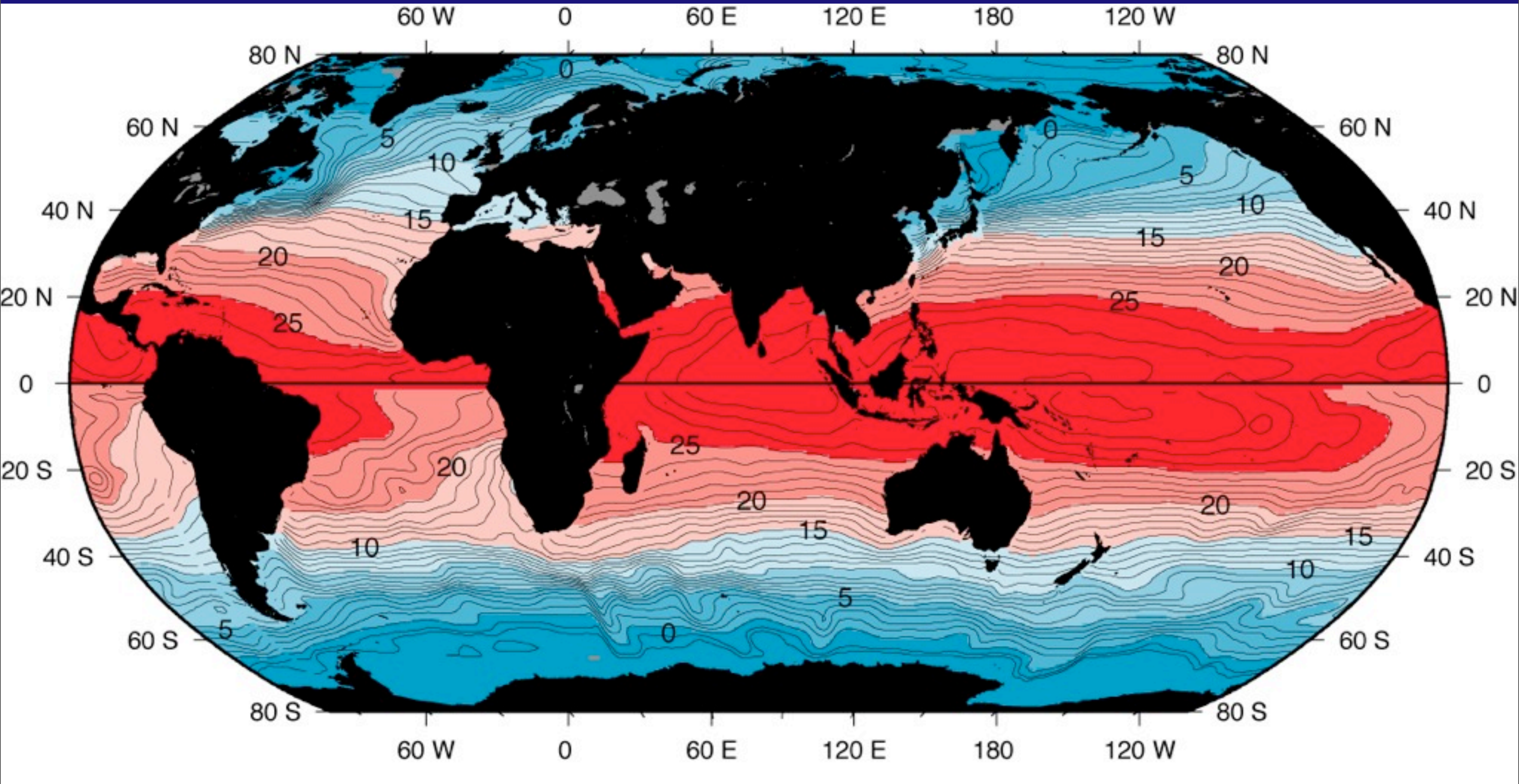
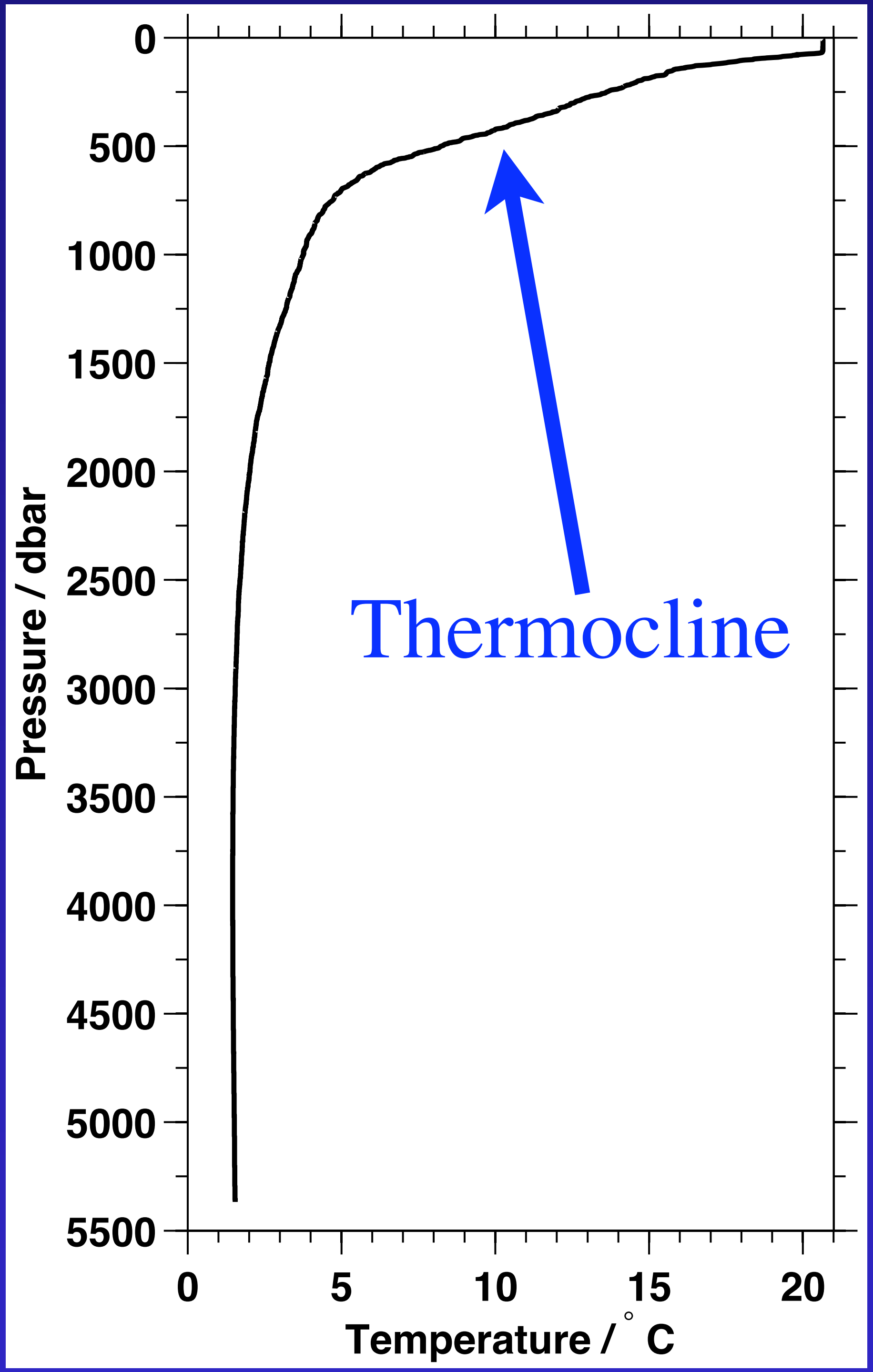
Surface temperature (°C)

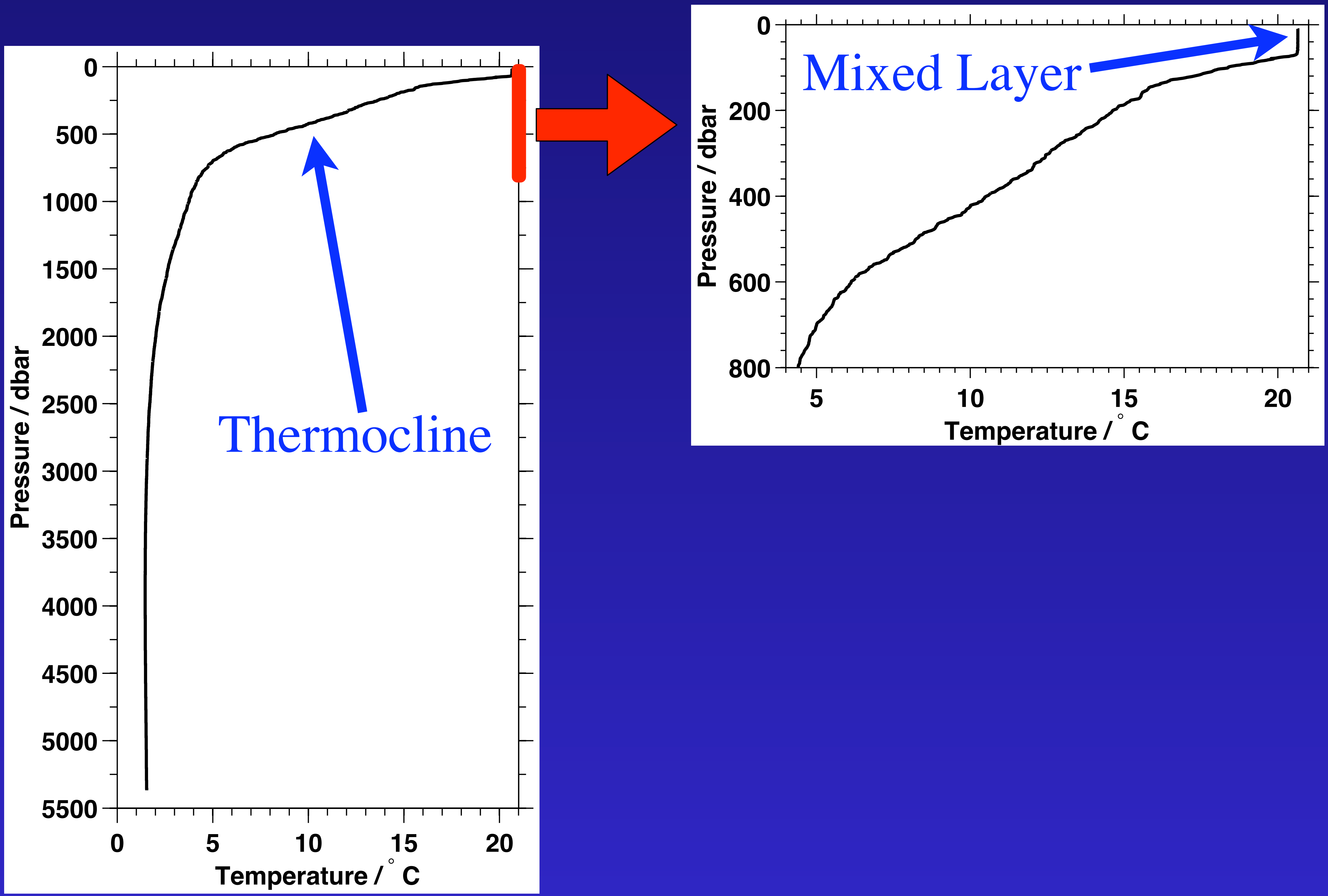


DPO Figure 4.1: Winter data from Levitus and Boyer (1994)

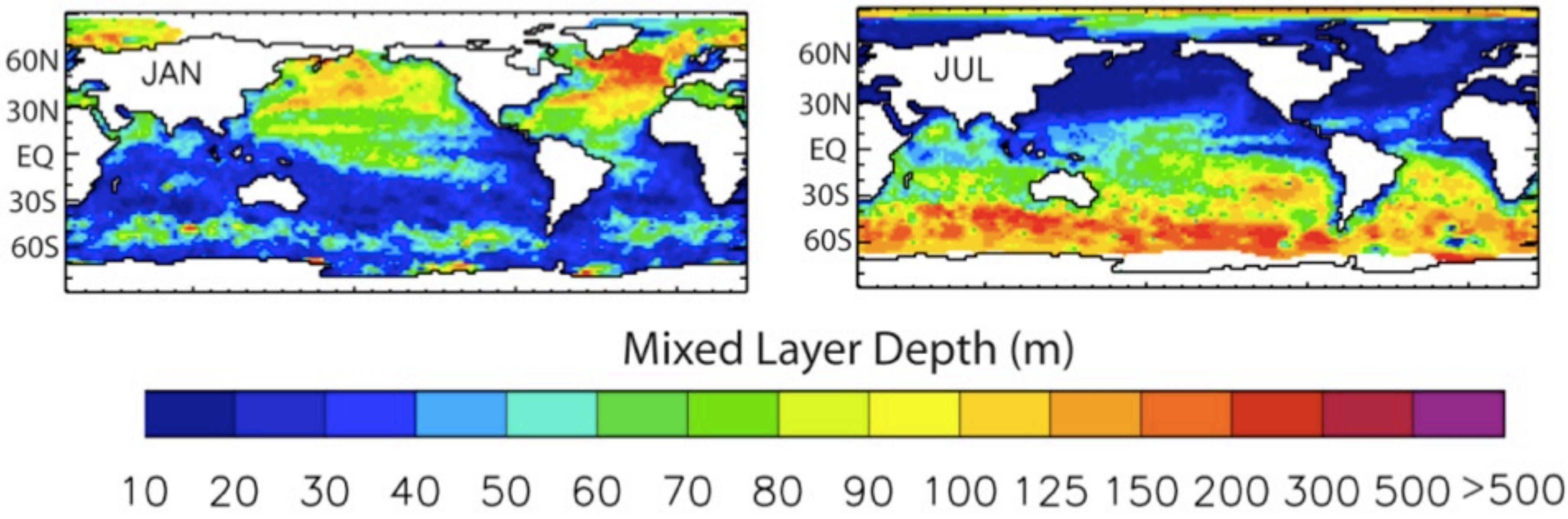
Looking below the surface...



Looking below the surface...



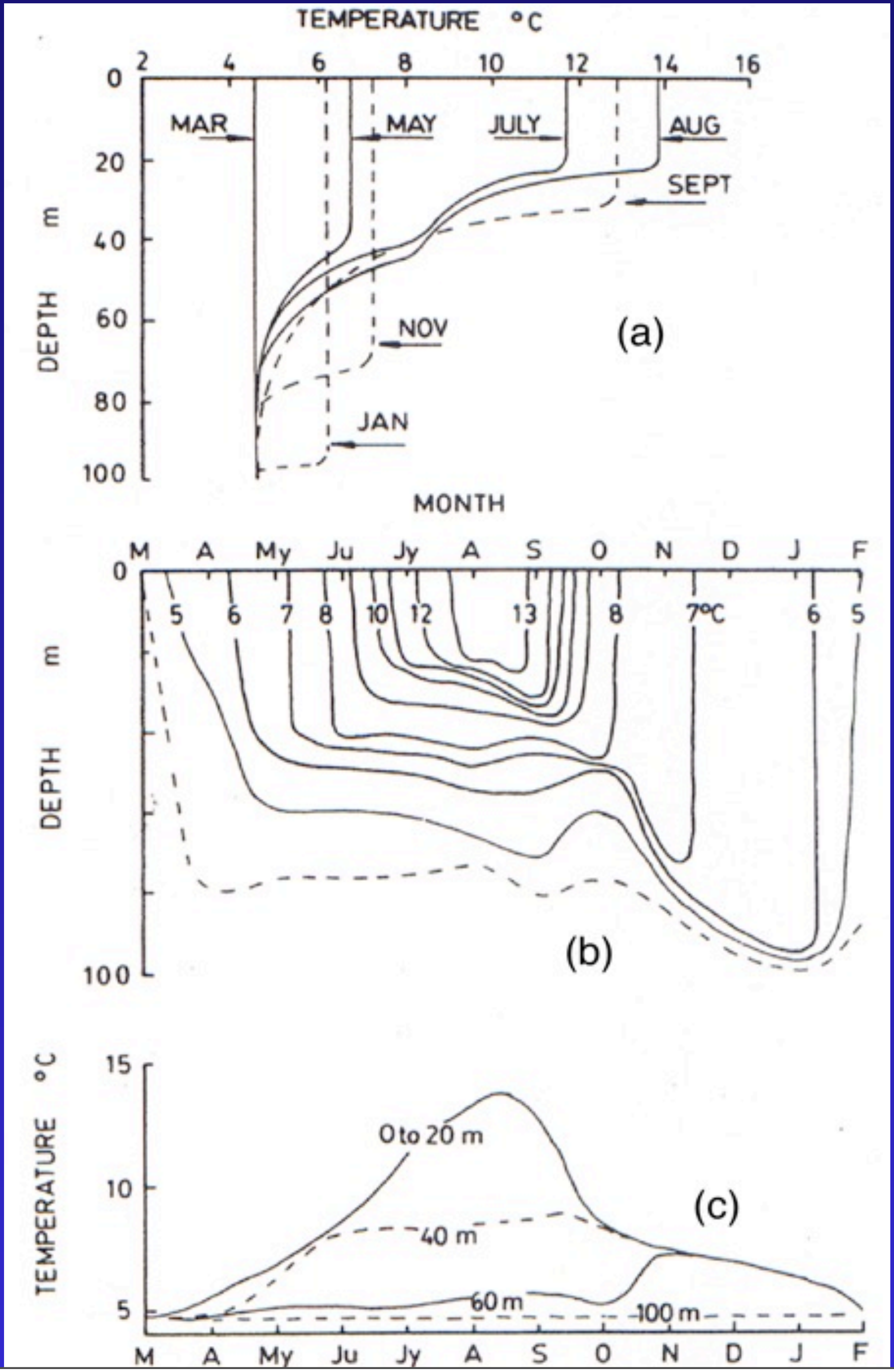
Mixed layer depth in January and July



Using delta T = 0.2°C

deBoyerMontegut et al. (JGR, 2004)

Mixed layer development



Winter development of mixed layer:

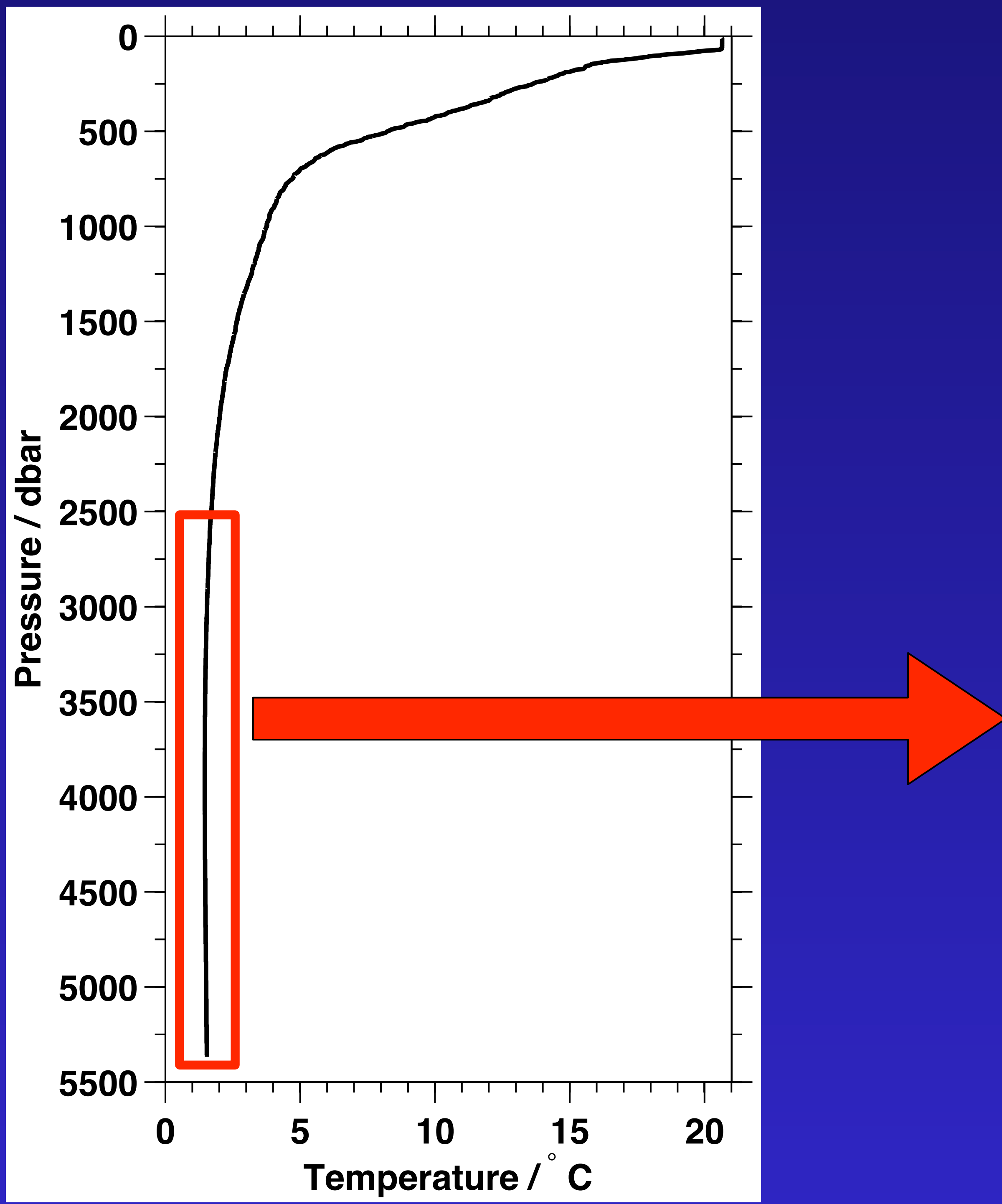
Wind stirring and cooling erode stratification, gradually deepening the mixed layer to maximum depth at the end of winter (Feb. to April depending on location)

Summer restratification:

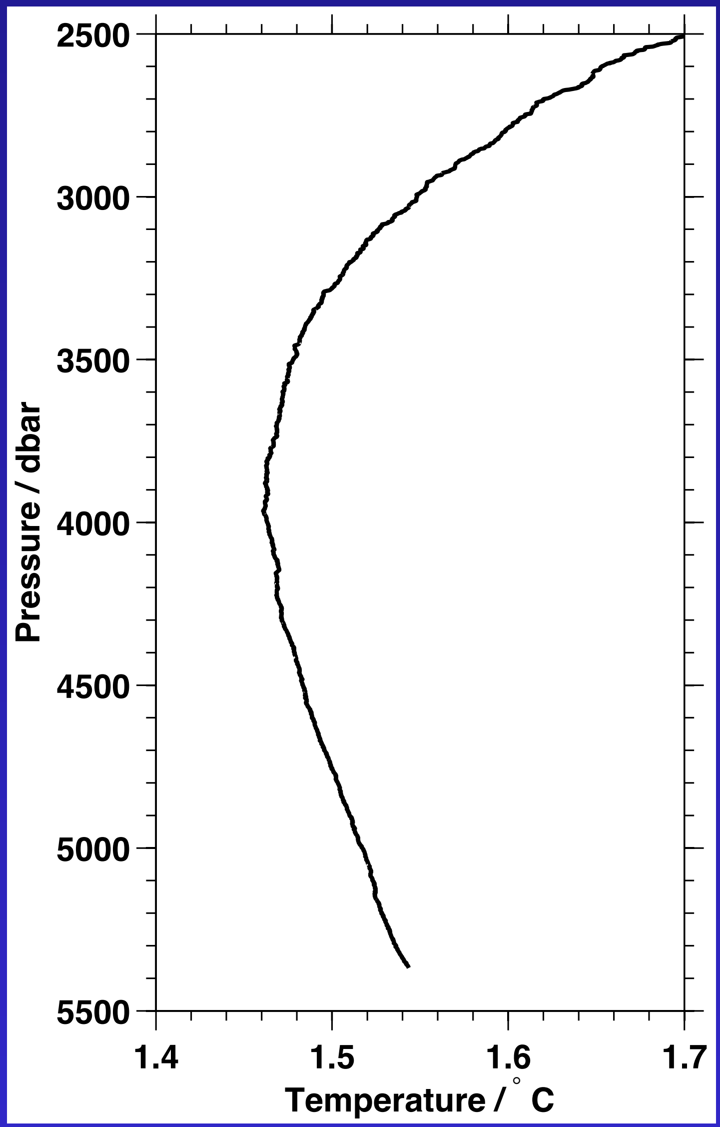
Warming at the top adds stratified layer at surface, usually leaves remnant of winter mixed layer below.

DPO Figure 4.7

Looking below the surface...



Temp increasing with depth, seems unstable...



Potential Temperature

- Seawater slightly compressible. Increase in pressure makes water warmer.

Adiabatic lapse rate: $\Gamma = \frac{\partial T}{\partial p}$

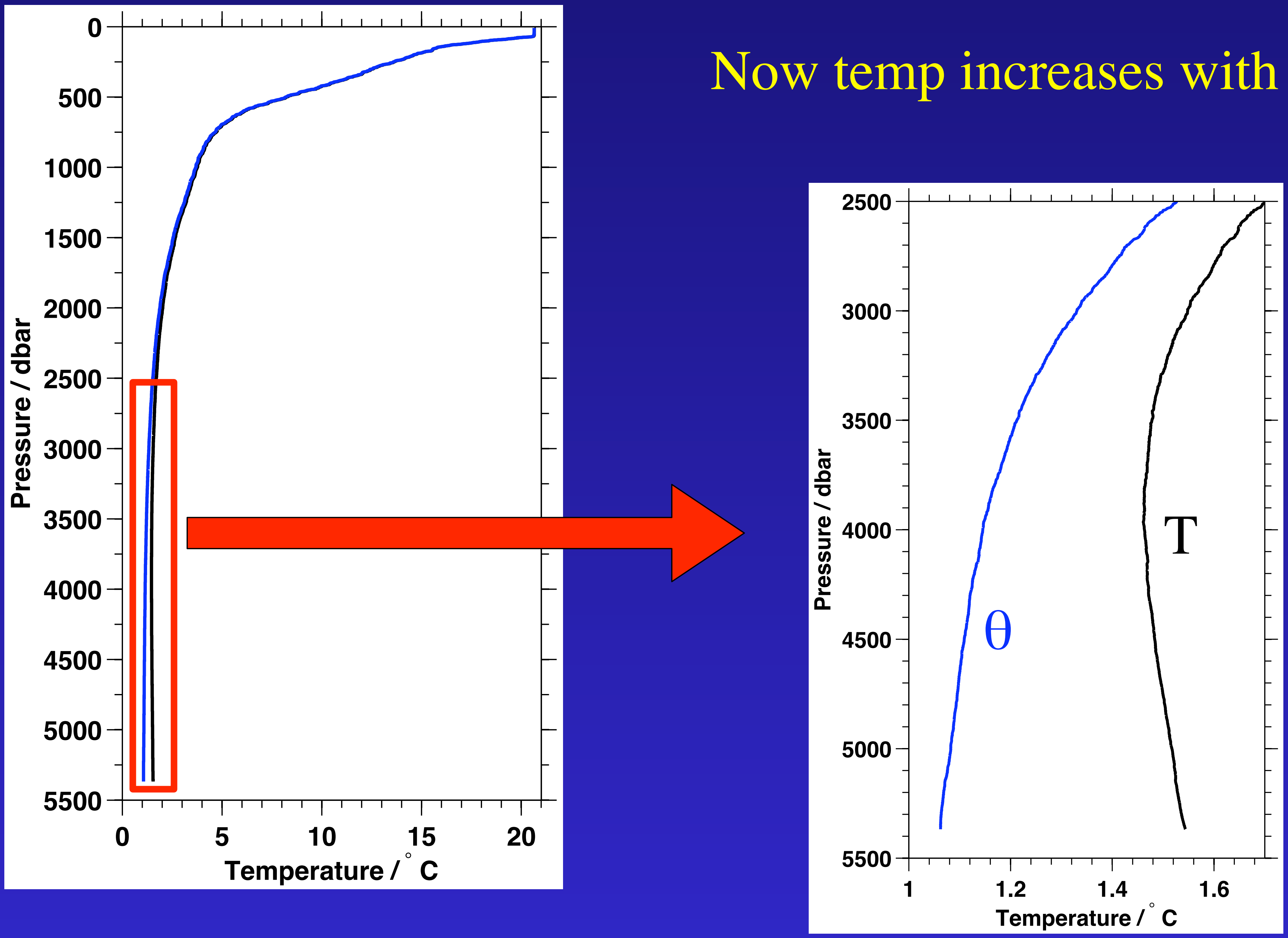
- But we'd like to compare water masses inherent properties (without pressure effect)

- Potential temperature (θ) is what temp a water parcel WOULD have at a given reference level, usually the surface.

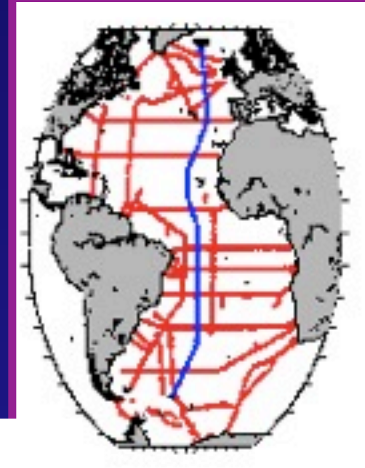
$$\theta = T + \int_p^{p_r} \Gamma(S,T,p)dp$$

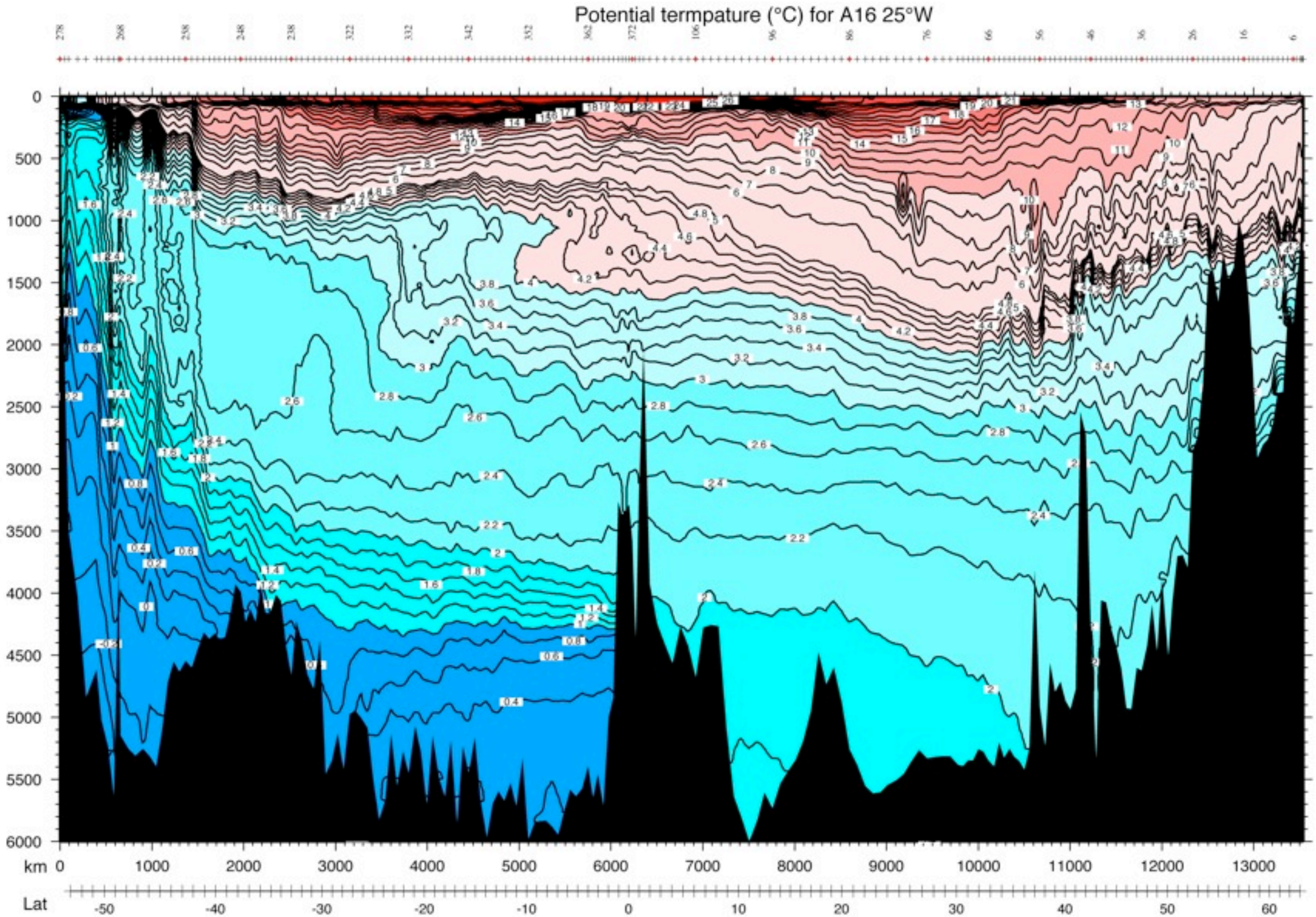
Potential Temperature

Now temp increases with depth

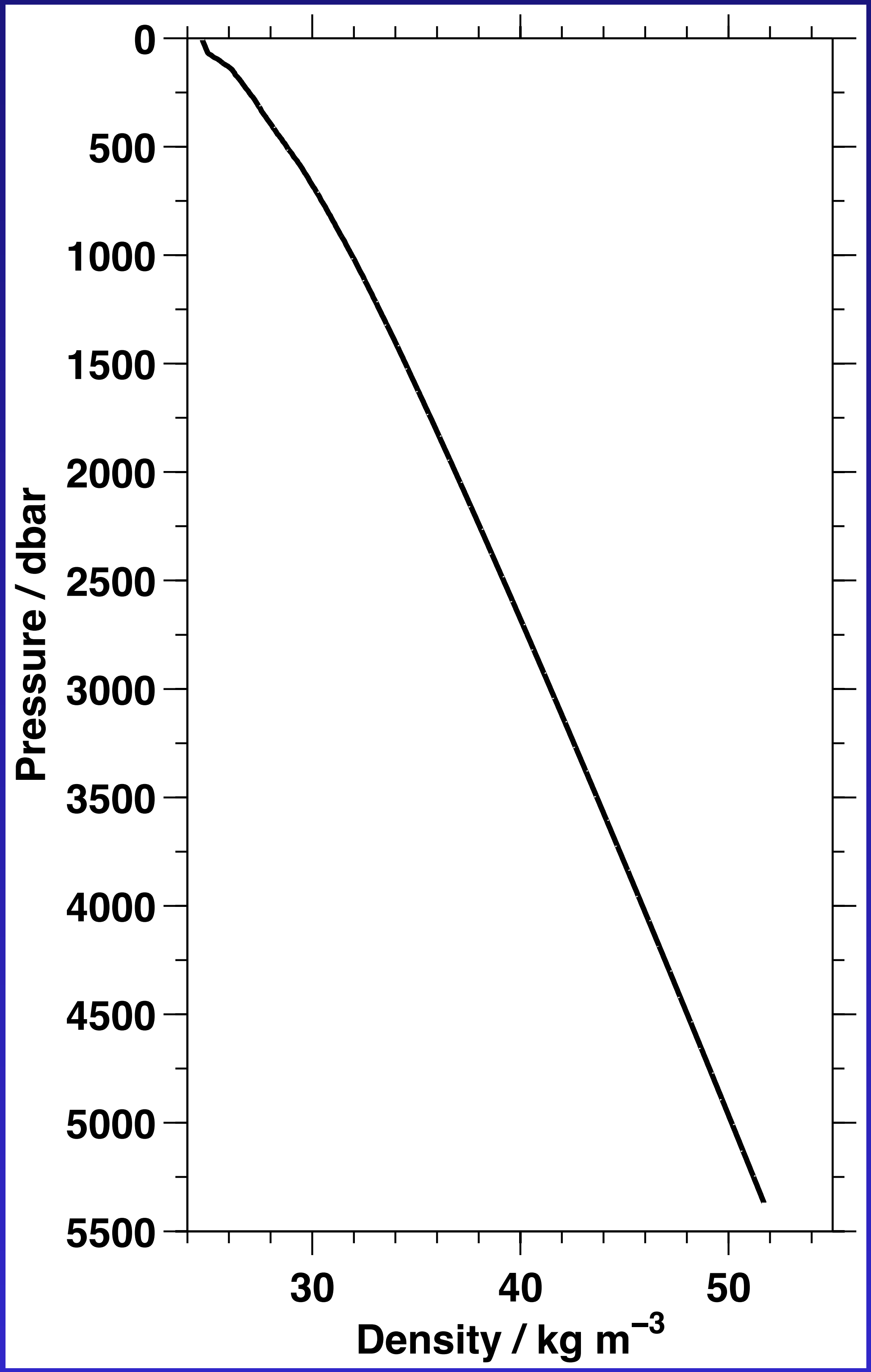


Atlantic potential temperature section



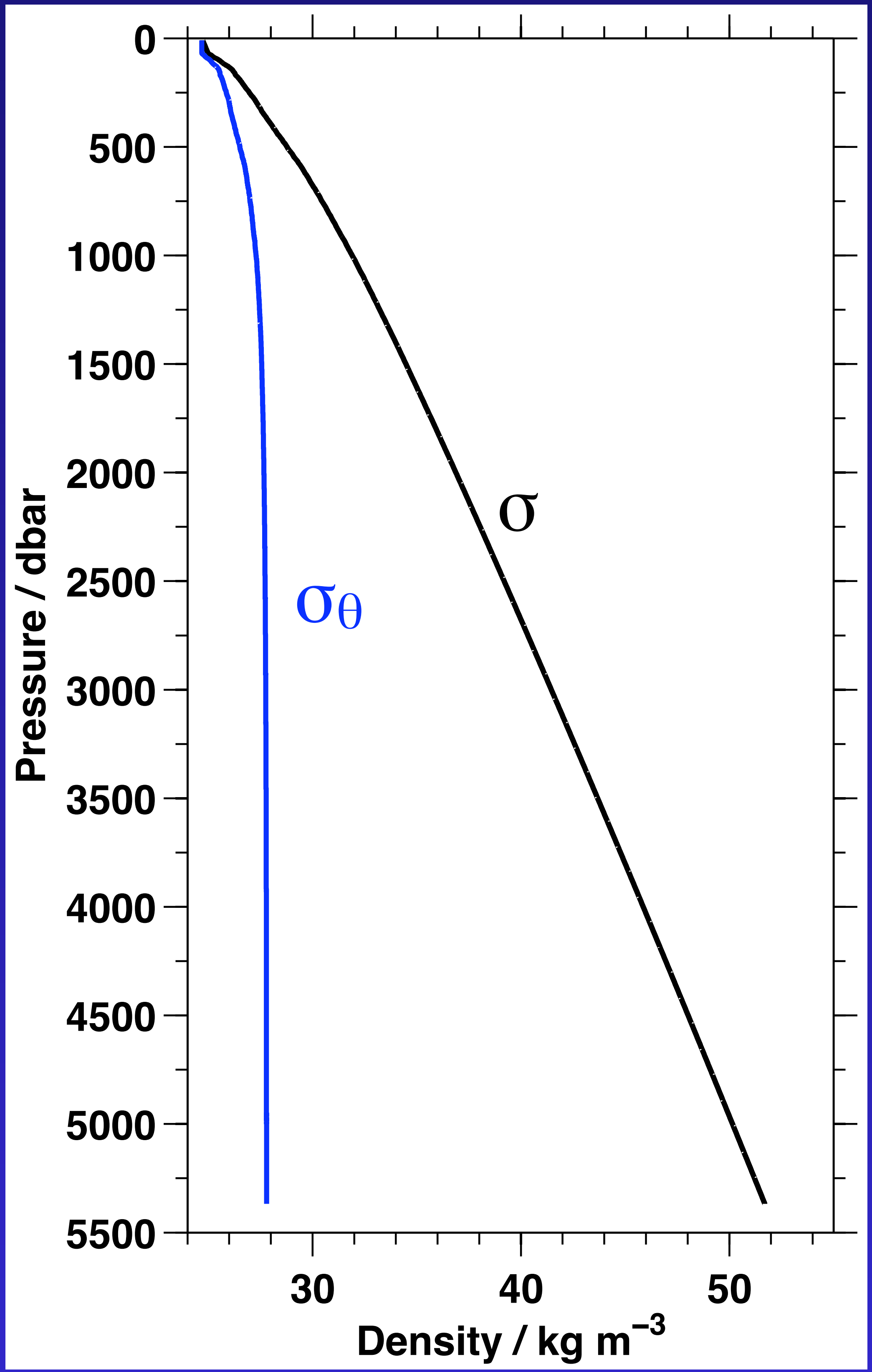


Density and potential density

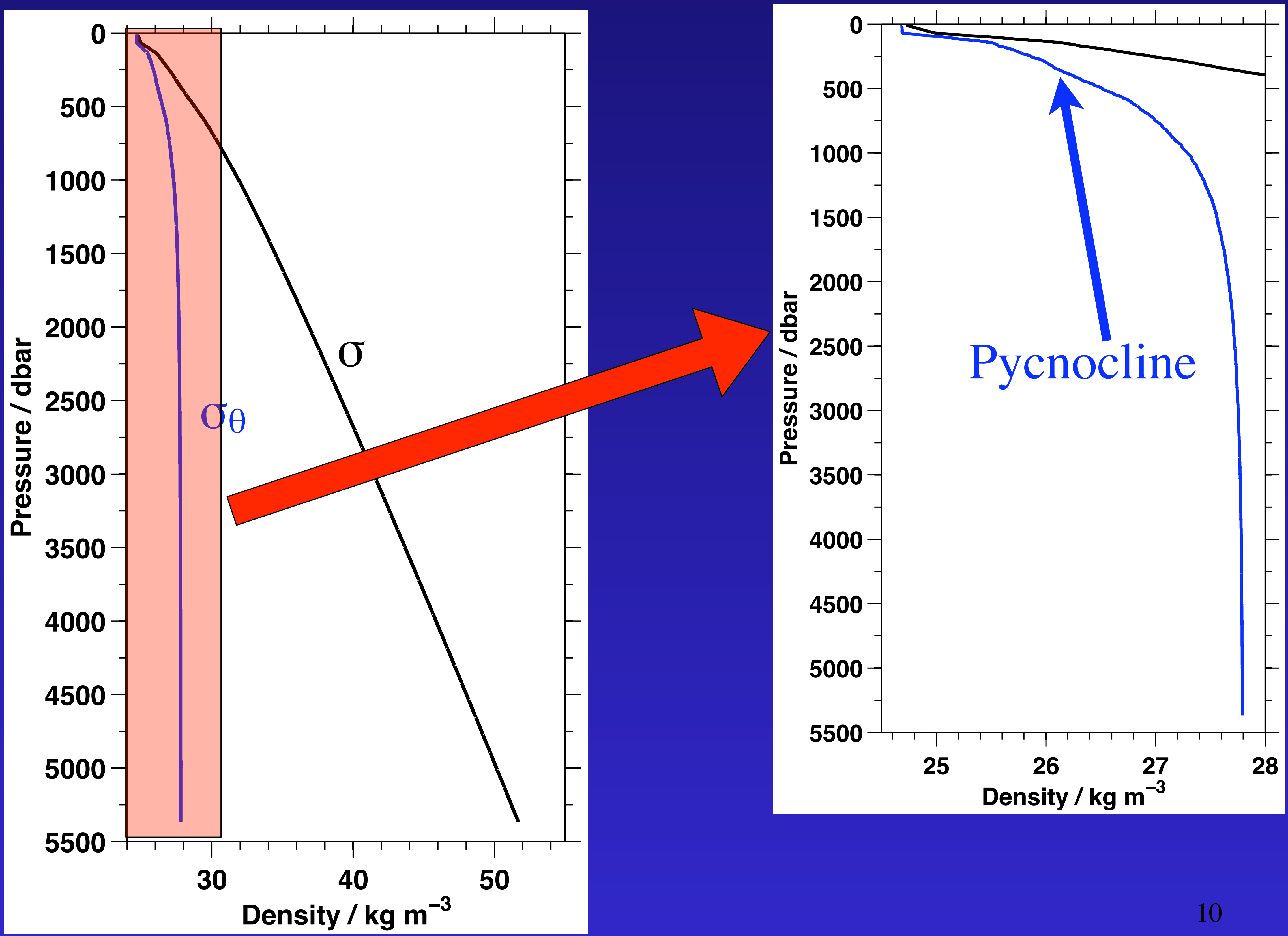


- Pressure exerts primary influence on density.
- Potential density: what density a parcel of water would have if it were adiabatically (without heat exchange with the environment) moved to a reference depth.

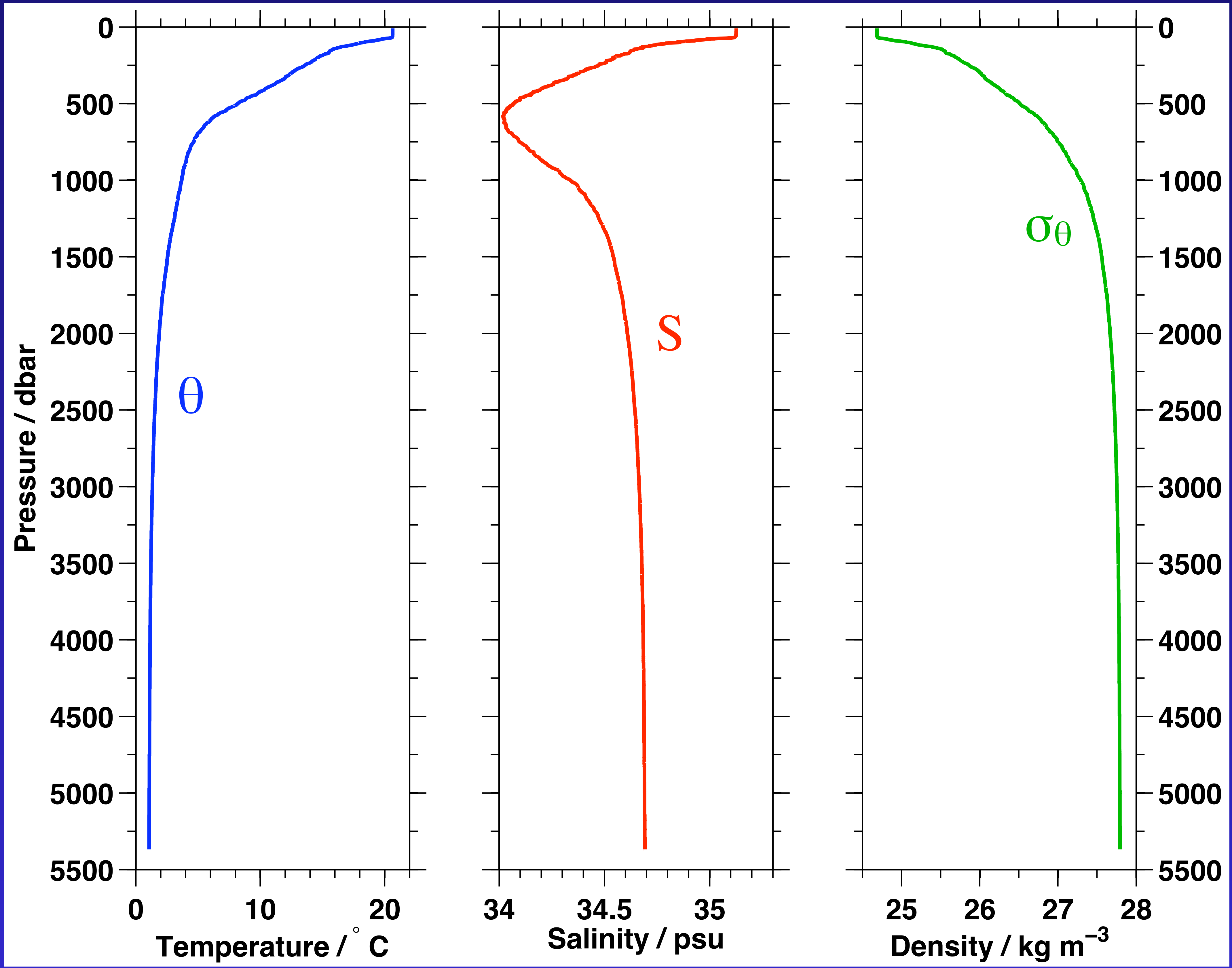
Density and potential density



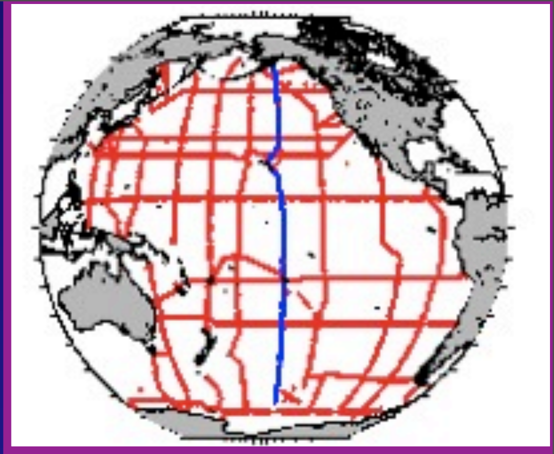
Density and potential density

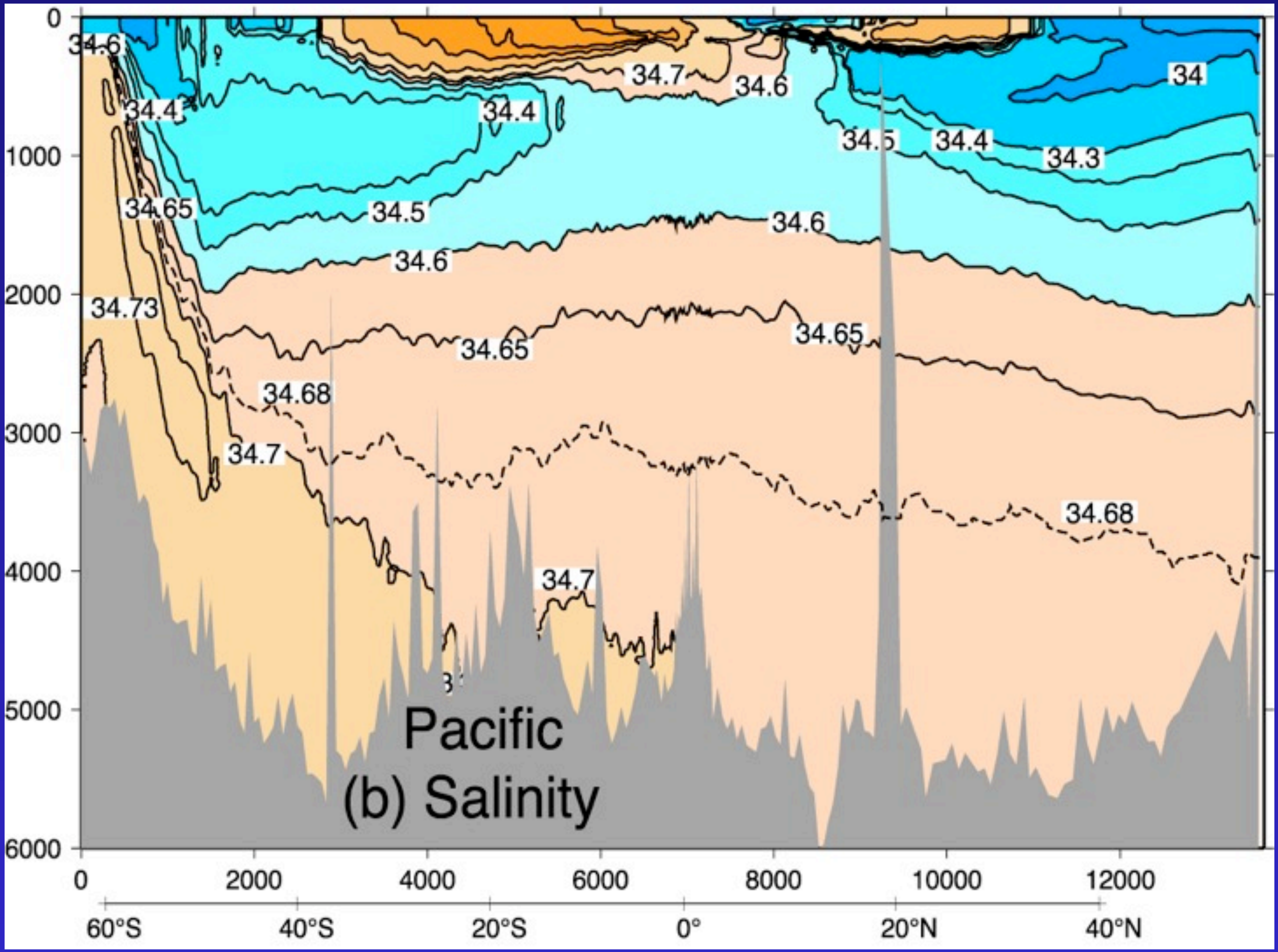


Adding Salinity

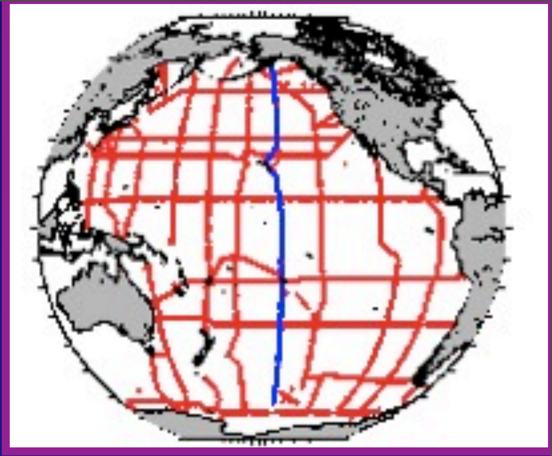


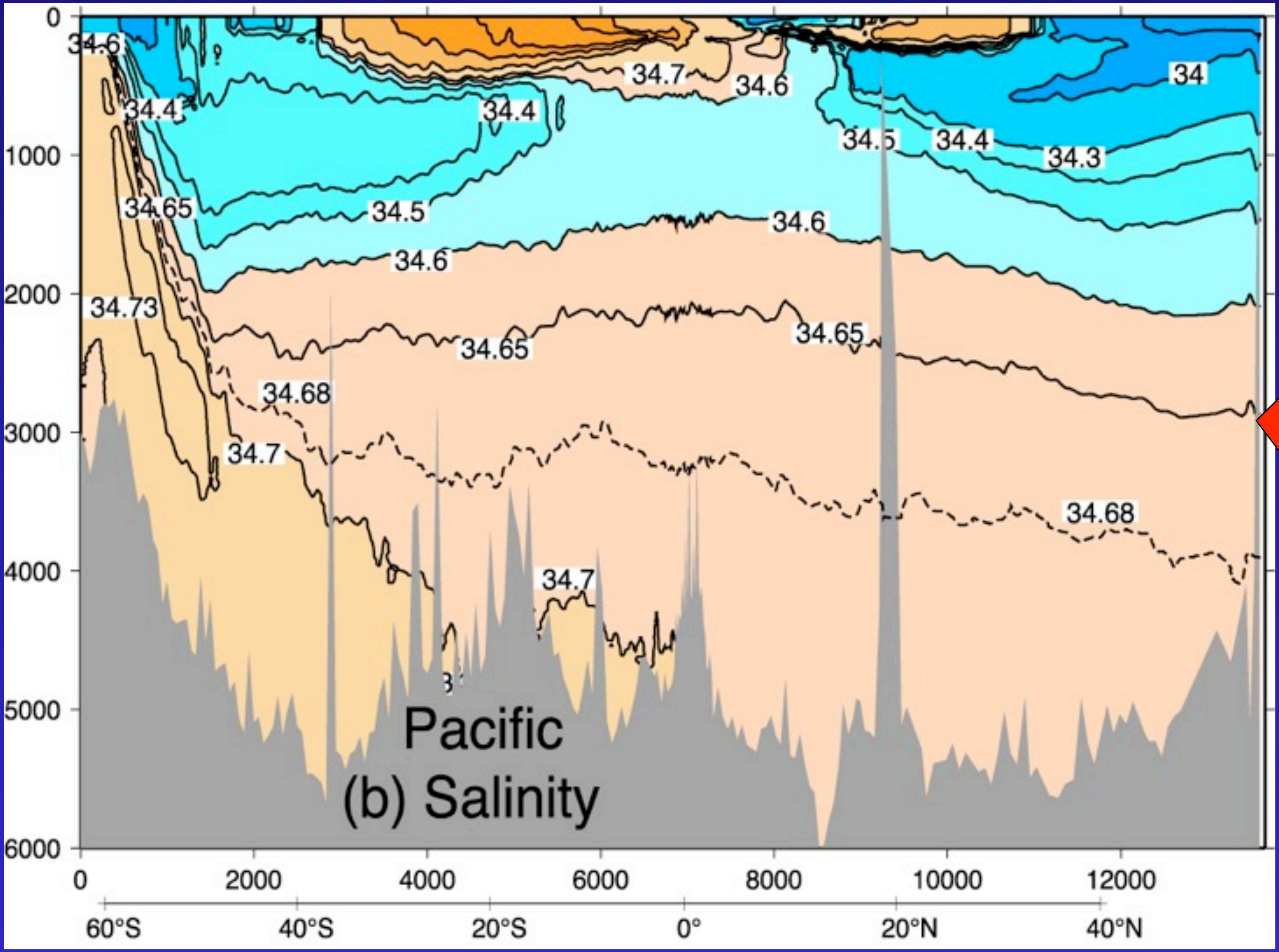
Pacific salinity section

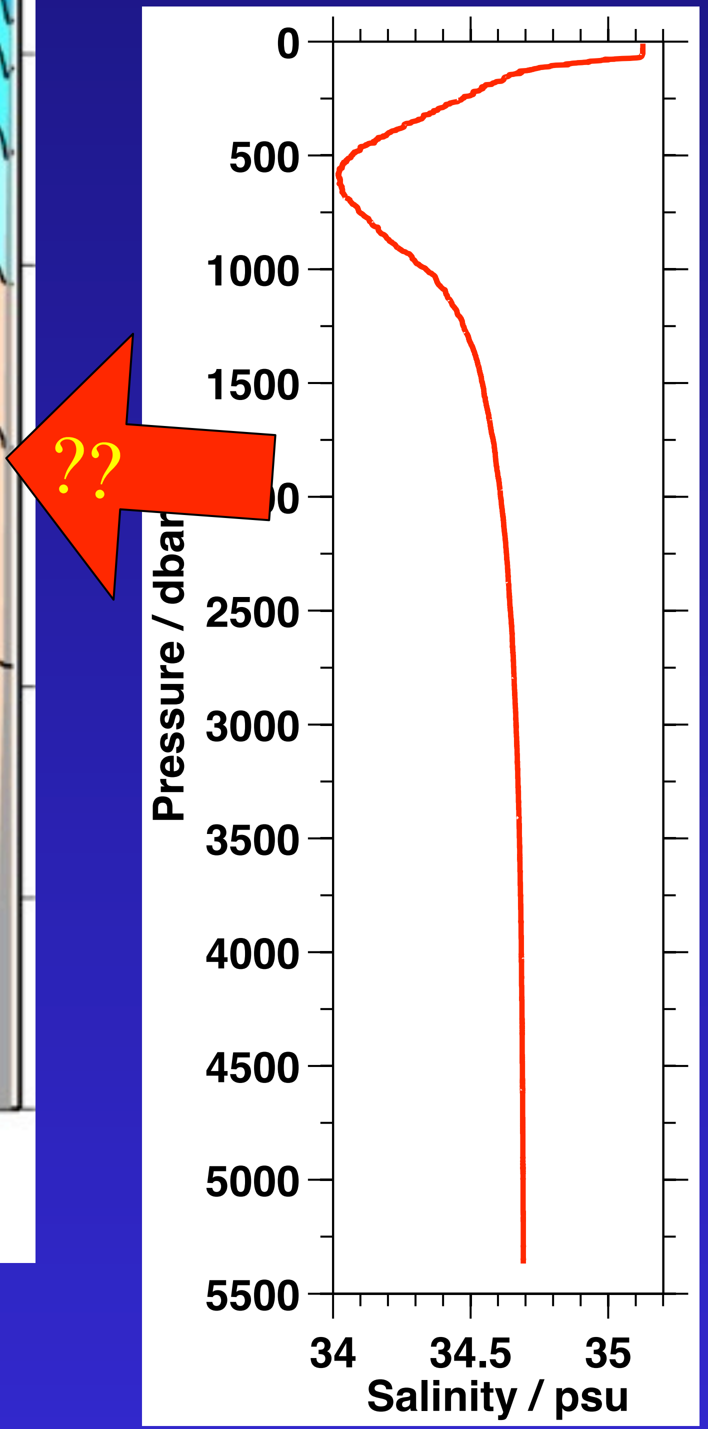




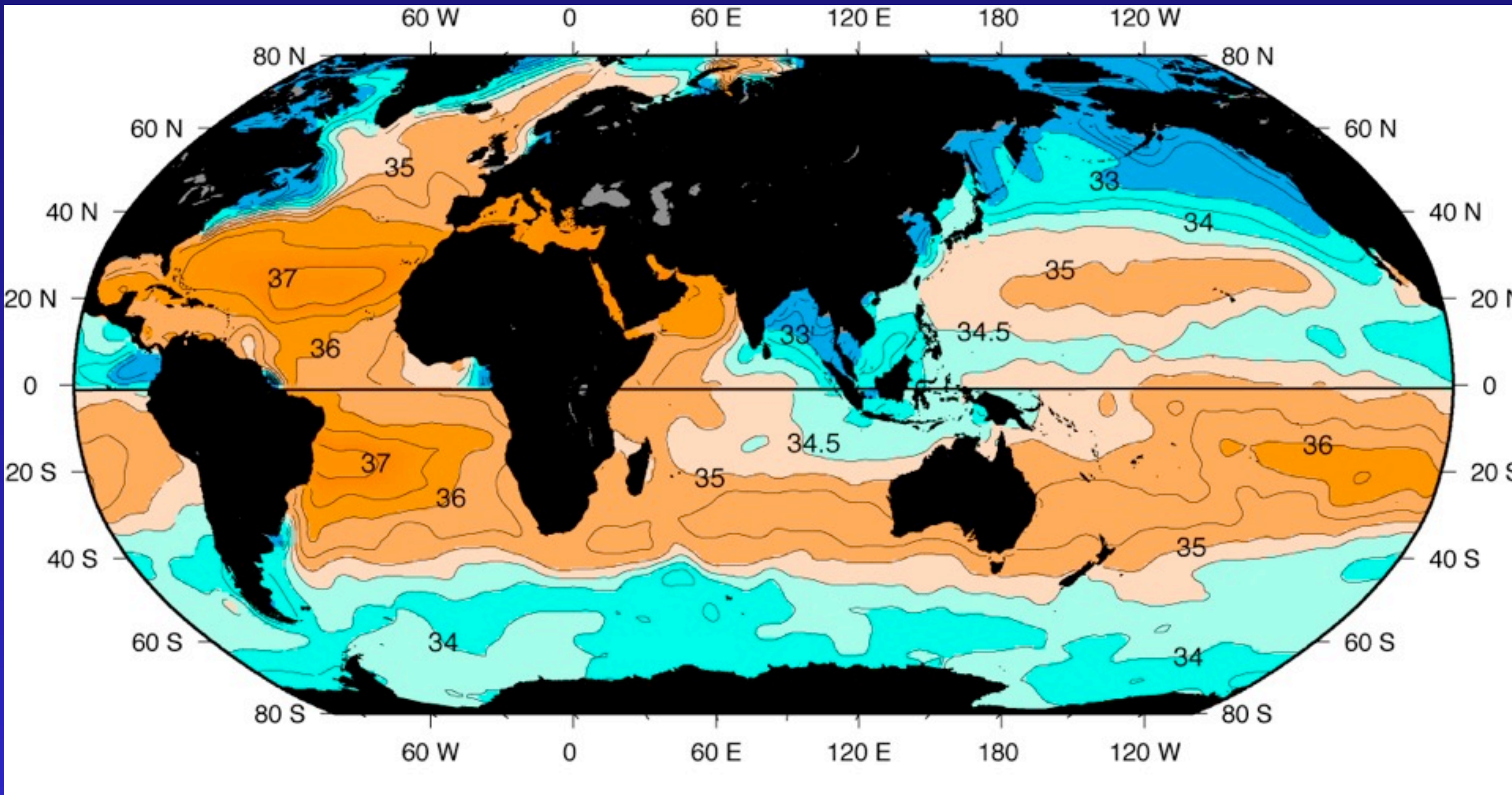
Pacific salinity section



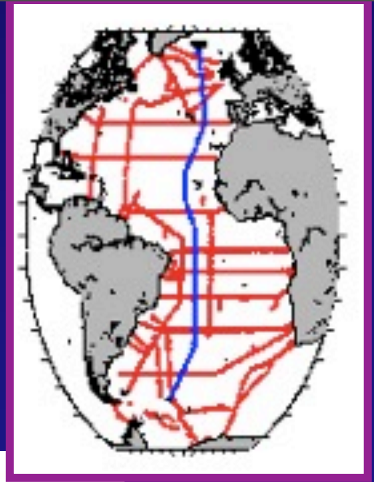


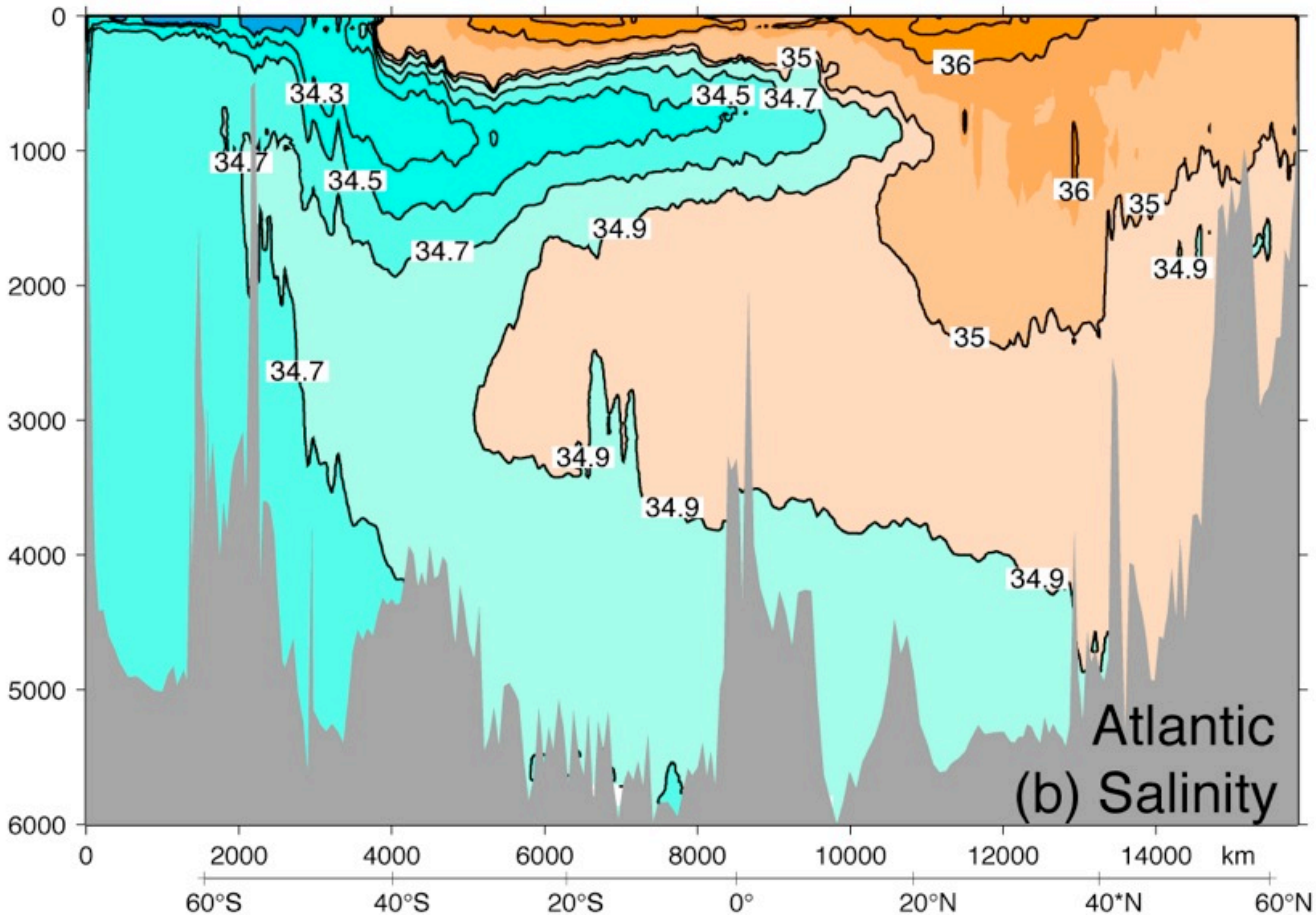


Surface salinity



Atlantic salinity section





Concepts for studying ocean property distributions

- Ventilation (breathing): properties of ocean waters are mostly set initially at the sea surface (heat, freshwater, gas exchange) and modified internally (mixing, biological processes, radioactive decay)

- Water mass
  - Define the water mass based on properties (often a property extremum)
  - Define based on unique, identifiable formation process

- Isentropic (isopycnal) flow and mixing is much easier than diapycnal flow and mixing, so water parcels tend to follow isopycnals as they enter the ocean interior

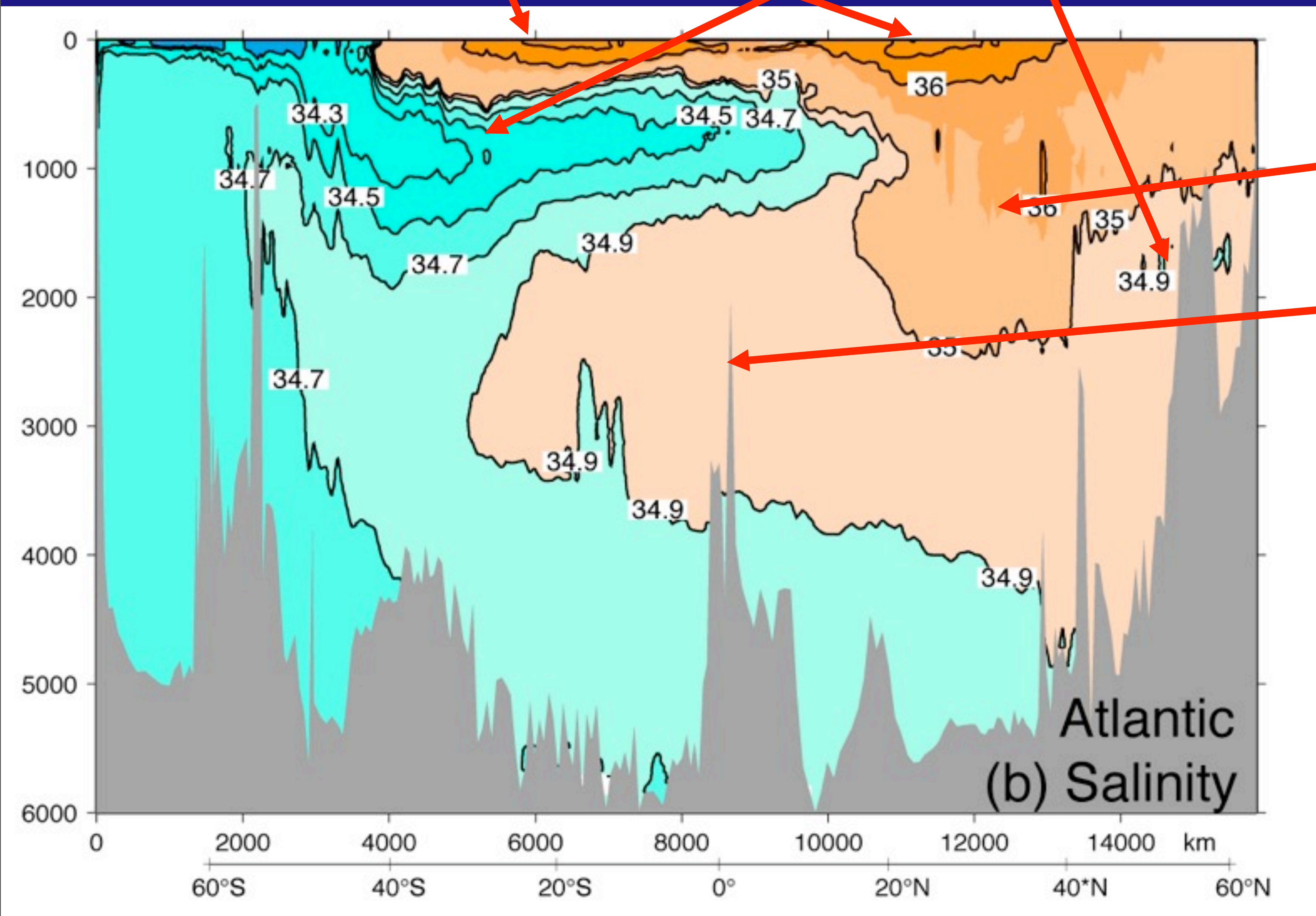
Atlantic salinity section

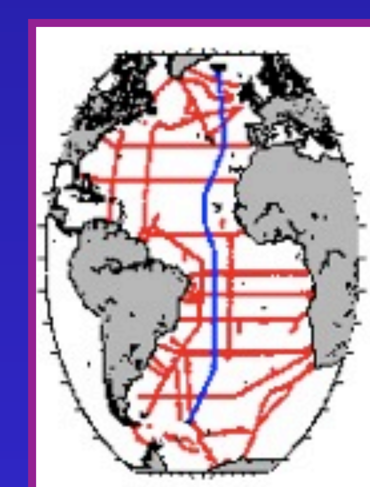
Salinity maximum layers

Salinity minimum layers (Antarctic I.W. and Labrador Sea Water)

Mediterranean Water

North Atlantic Deep Water



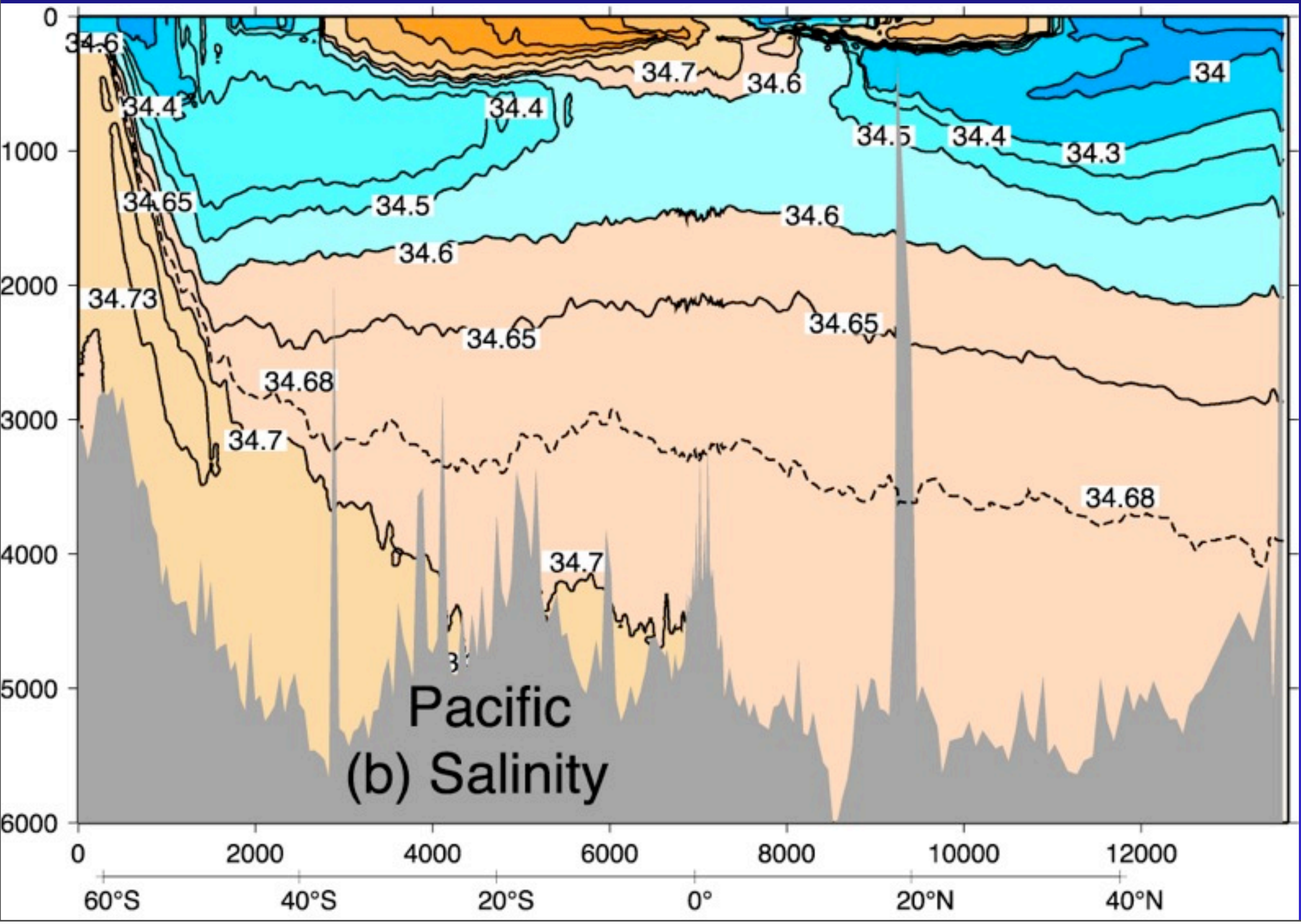


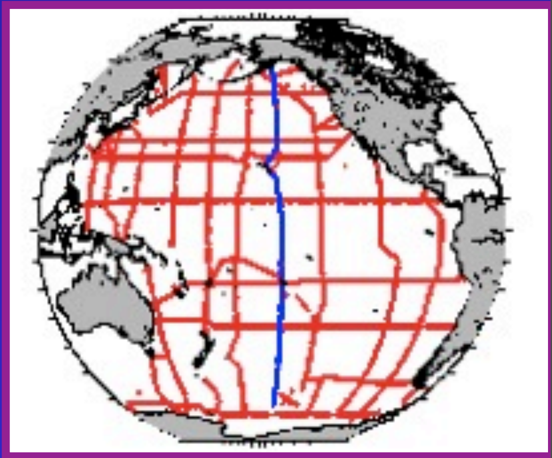
DPO Fig. 4.10

Pacific salinity section

Salinity maximum layers

Salinity minimum layers - intermediate waters (Antarctic and North Pacific I.W.)



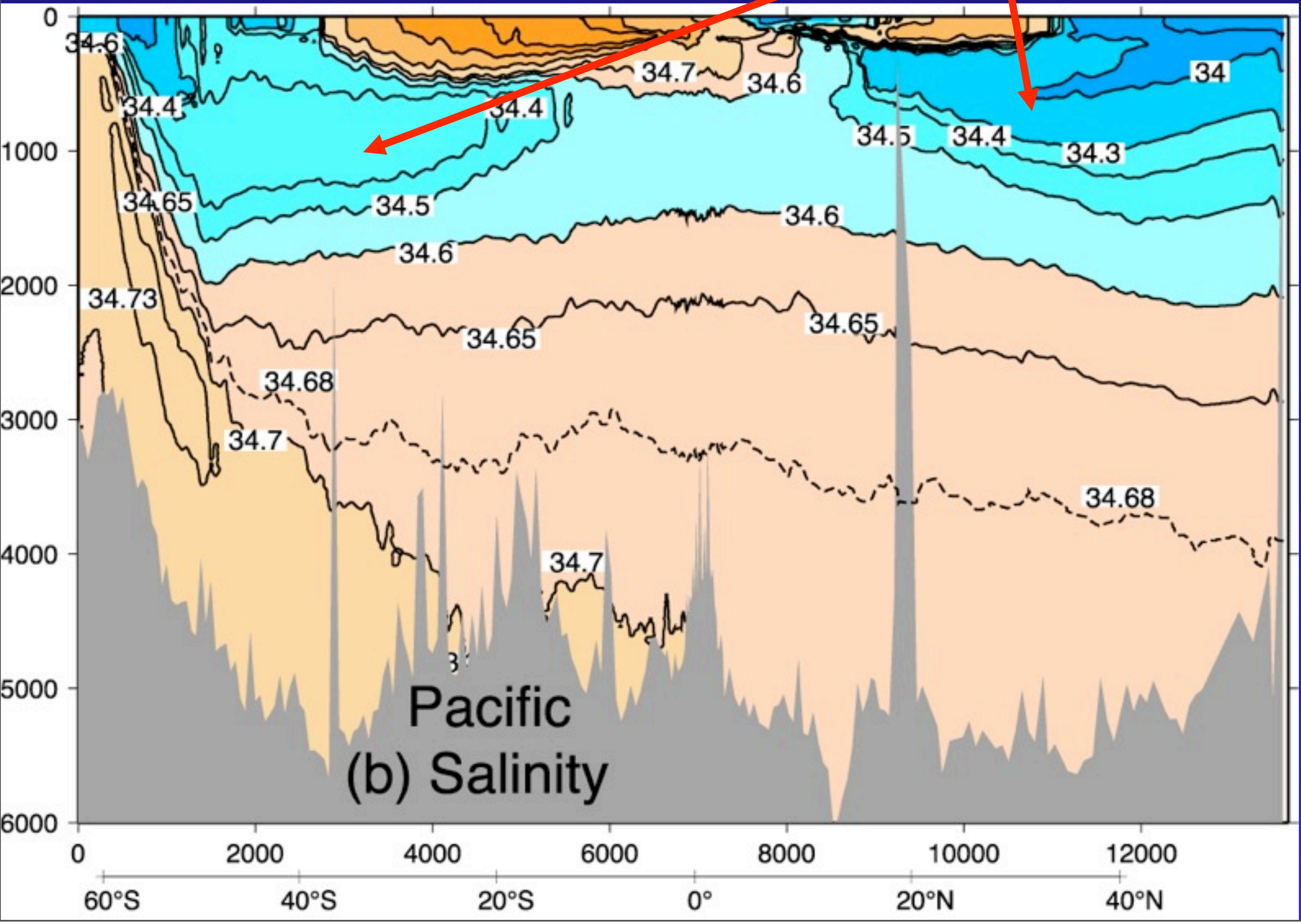


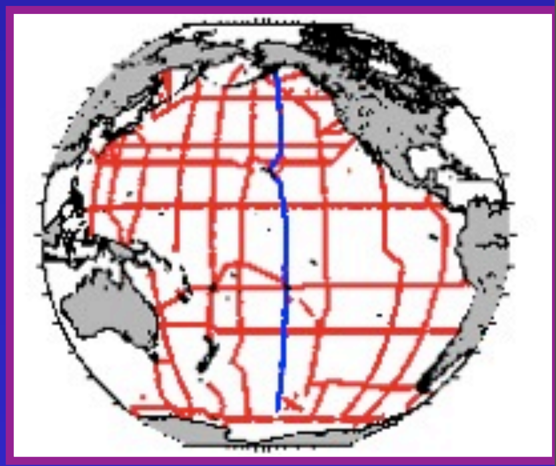
DPO Fig. 4.11

Pacific salinity section

Salinity maximum layers

Salinity minimum layers - intermediate waters (Antarctic and North Pacific I.W.)



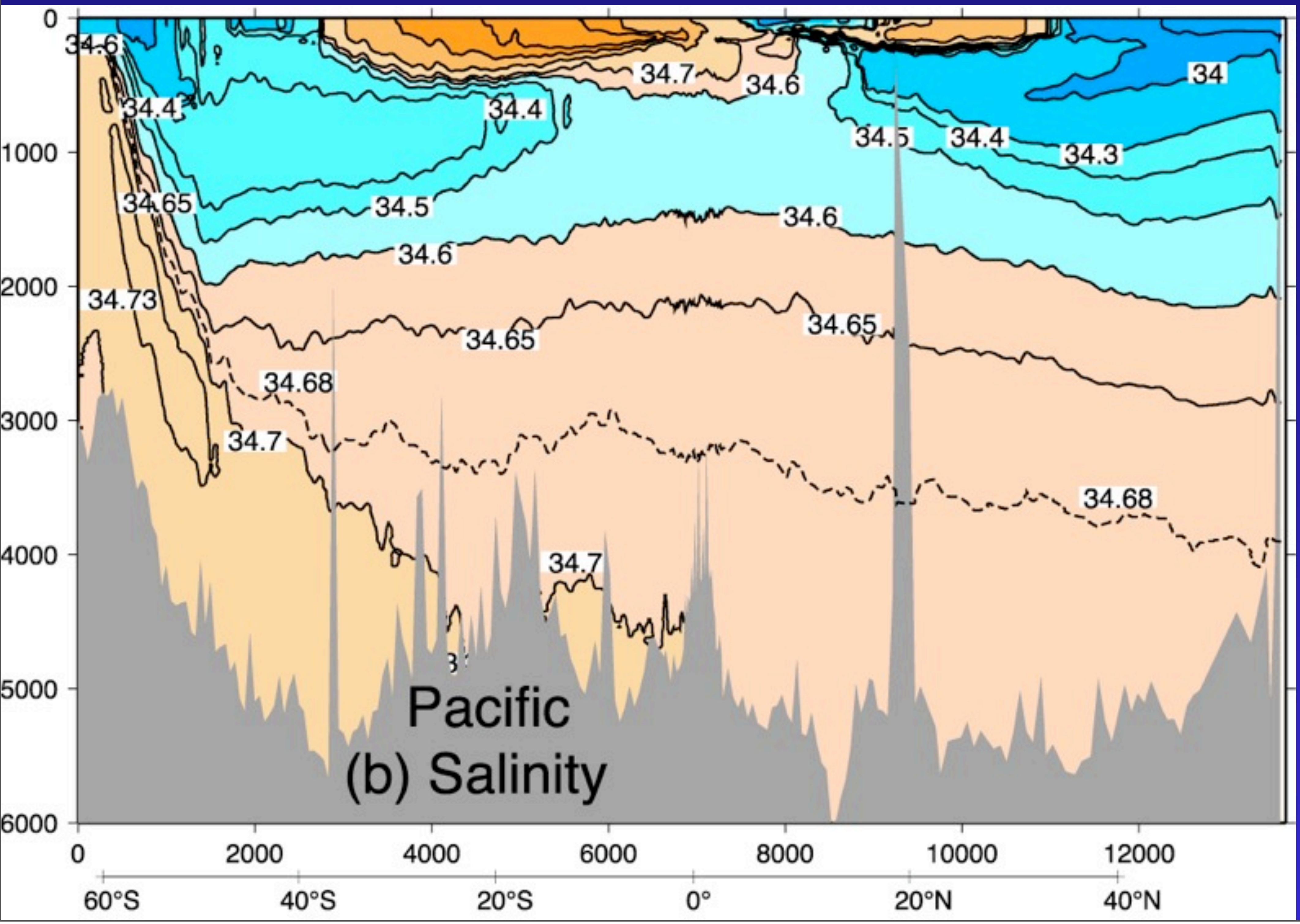


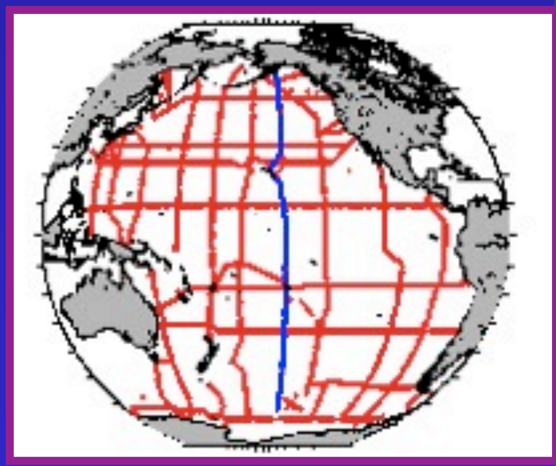
DPO Fig. 4.11

Pacific salinity section

Salinity maximum layers

Salinity minimum layers - intermediate waters (Antarctic and North Pacific I.W.)



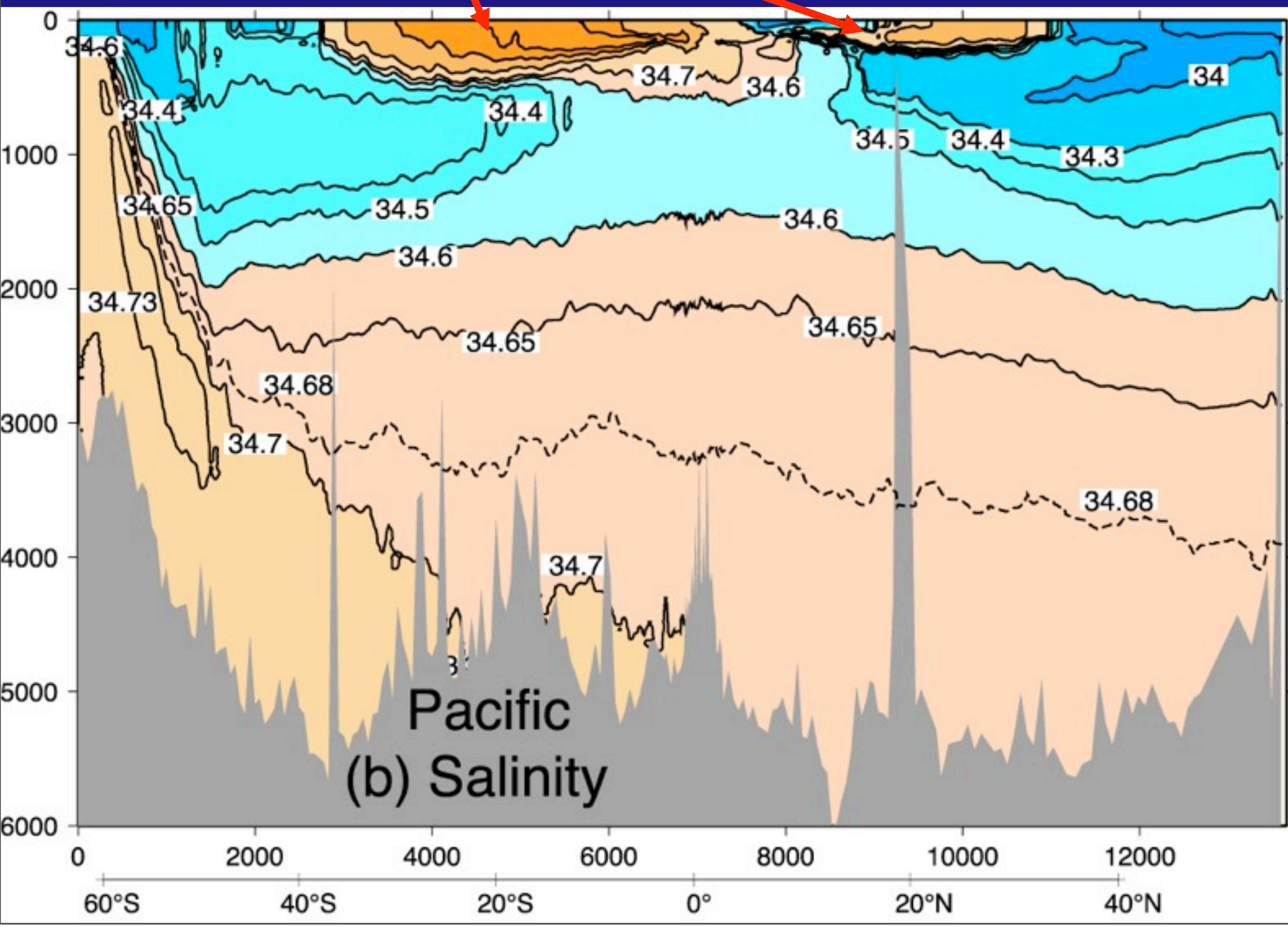


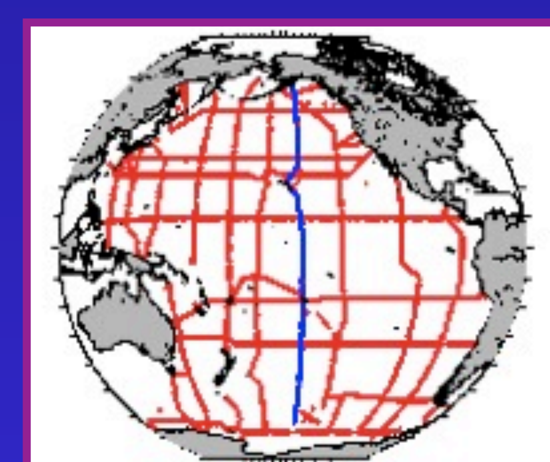
DPO Fig. 4.11

Pacific salinity section

Salinity maximum layers

Salinity minimum layers - intermediate waters (Antarctic and North Pacific I.W.)

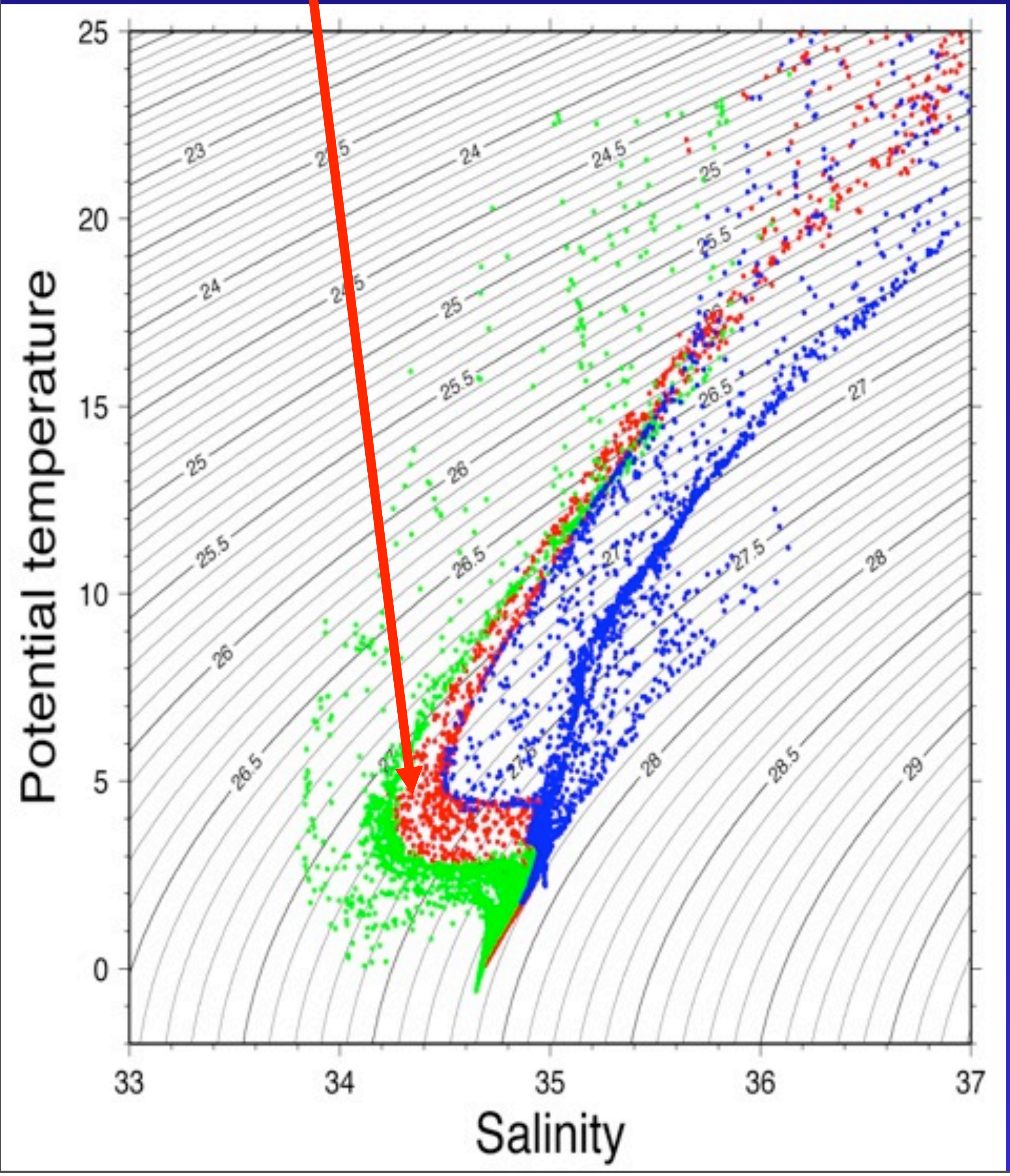


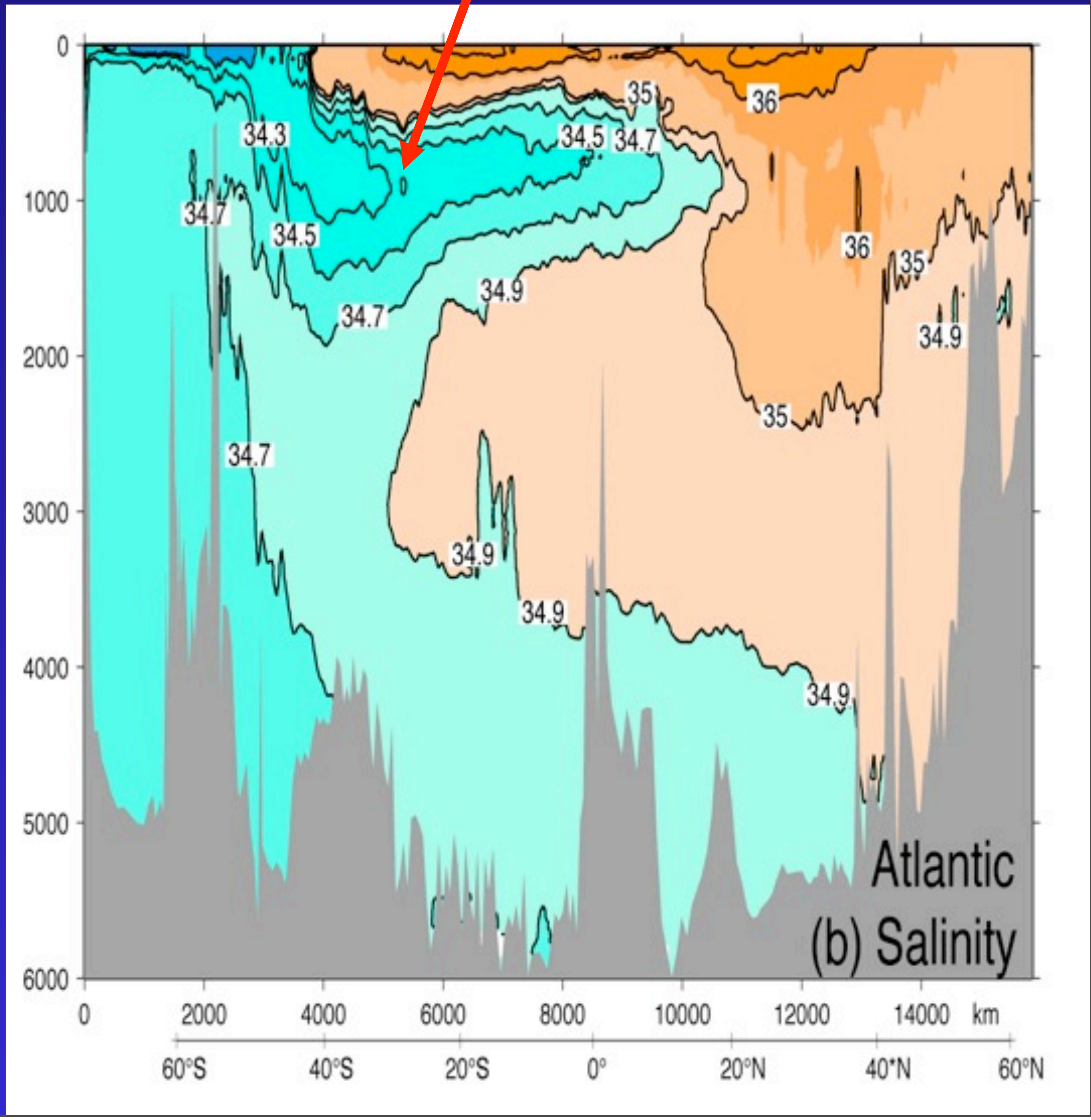


DPO Fig. 4.11

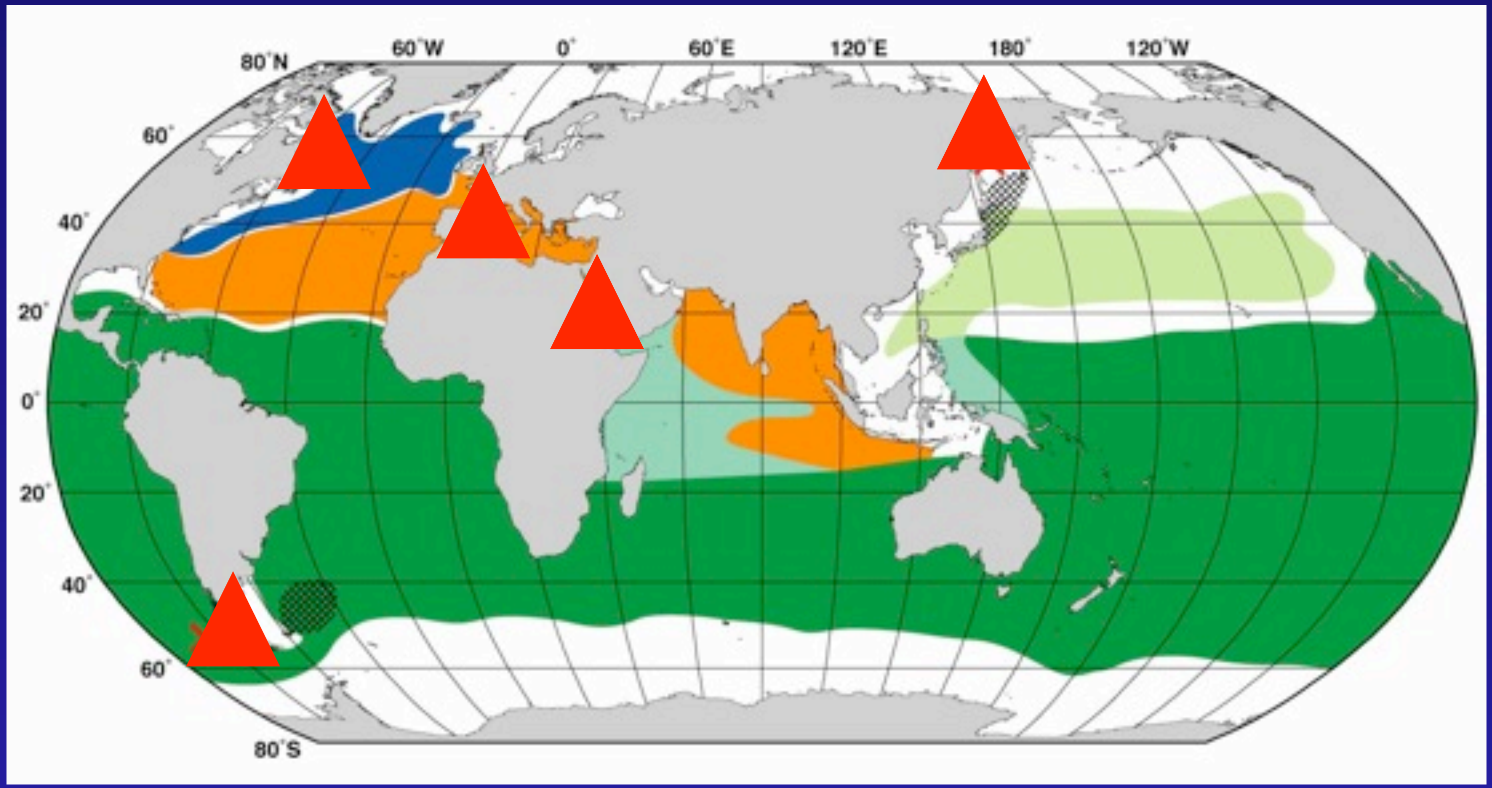
Water mass

Example: Antarctic Intermediate Water - (a) low salinity layer, (b) originating in surface mixed layers near Antarctic Circumpolar Current





Intermediate water masses



Intermediate water production sites

- **Labrador Sea Water: salinity minimum, deep convection in Labrador Sea**
- **Mediterranean Overflow Water: salinity maximum, evaporation and cooling in Mediterranean Sea, overflow**
- **Antarctic Intermediate Water: salinity minimum, medium convection in Drake Passage region**
- **Red Sea Overflow Water: salinity maximum, evaporation in Red Sea, overflow**
- **North Pacific Intermediate Water (Okhotsk Sea): salinity minimum, brine rejection in the Okhotsk Sea**

Potential temperature-salinity at 25°W

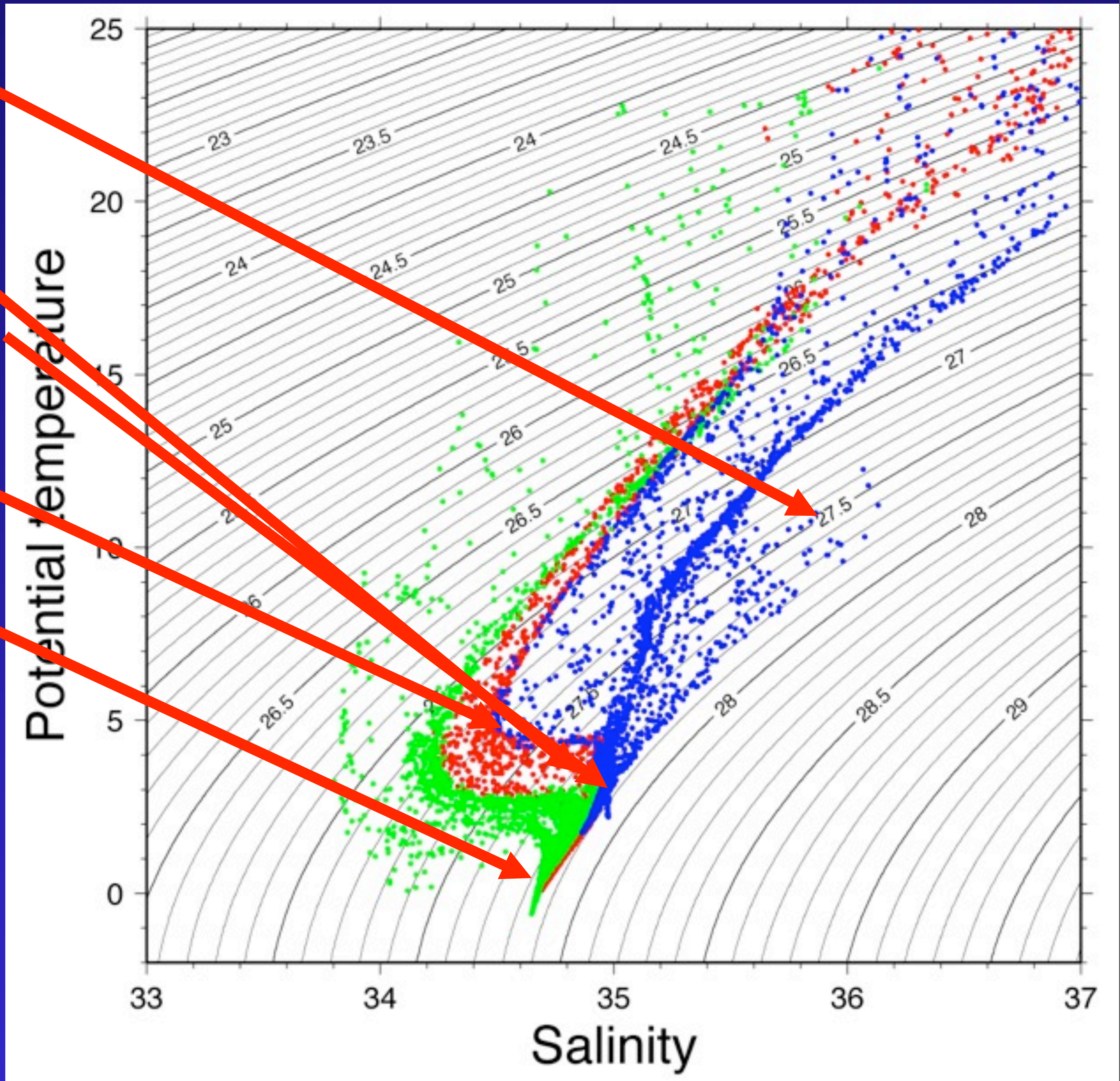
Mediterreanean Overflow Water

Labrador Sea Water

North Atlantic Deep Water

Antarctic Intermediate Water

Antarctic Bottom Water

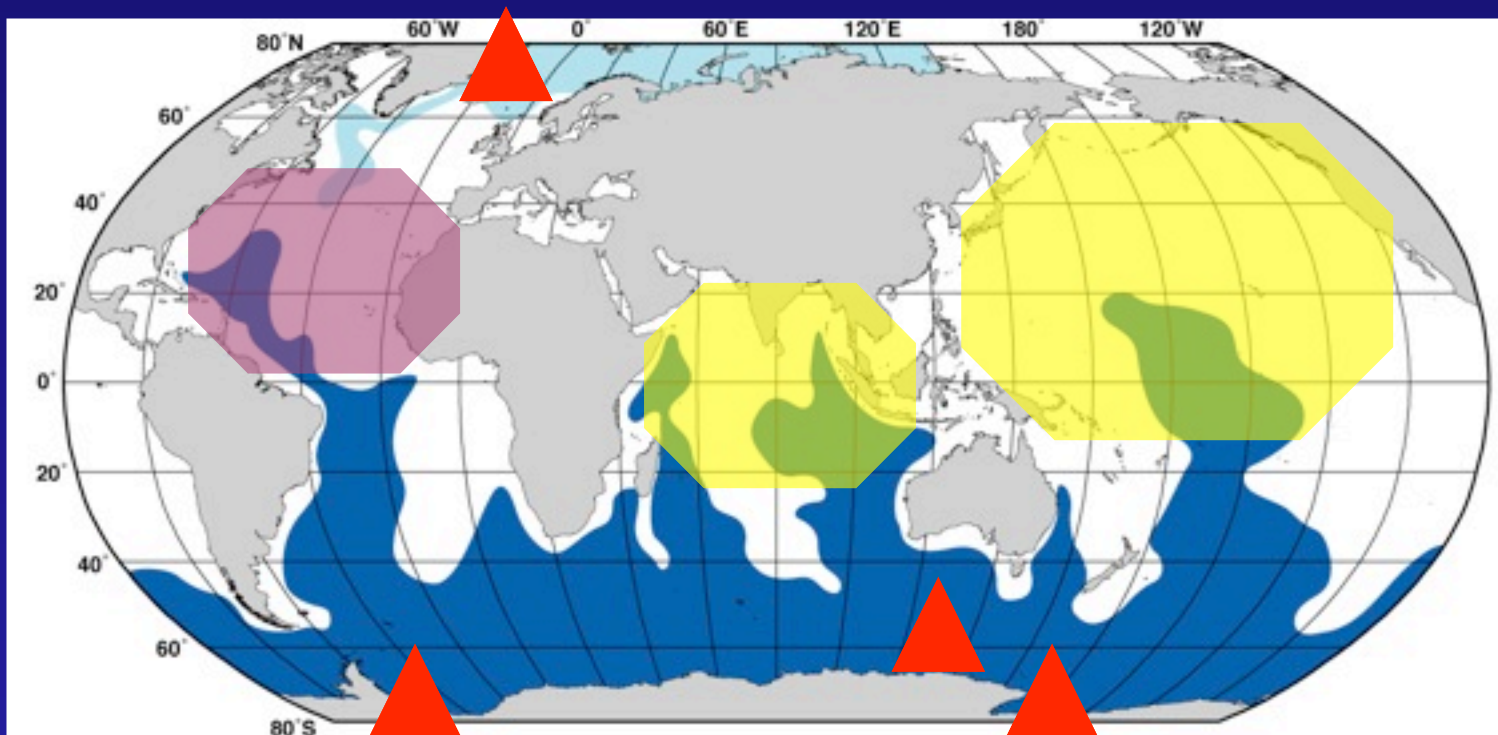


Blue: N. Atlantic > 15°N

Red: 15°S-15°N

Green: S. Atlantic < 15°S

Deep and bottom water



Deep and bottom water production sites

- Nordic Seas Overflow Water (contributor to North Atlantic Deep Water): high oxygen; deep convection in the Greenland Sea, overflow
- Antarctic Bottom Water: very cold, high oxygen; brine rejection along coast of Antarctica
- North Atlantic Deep Water: high salinity, high oxygen; mixture of NSOW, LSW and MOW
- Indian and Pacific Deep Waters: low oxygen, high nutrients; slow upwelling and slow deep mixing of inflowing NADW and AABW

Global deep water potential temperature-salinity Worthington, 1982

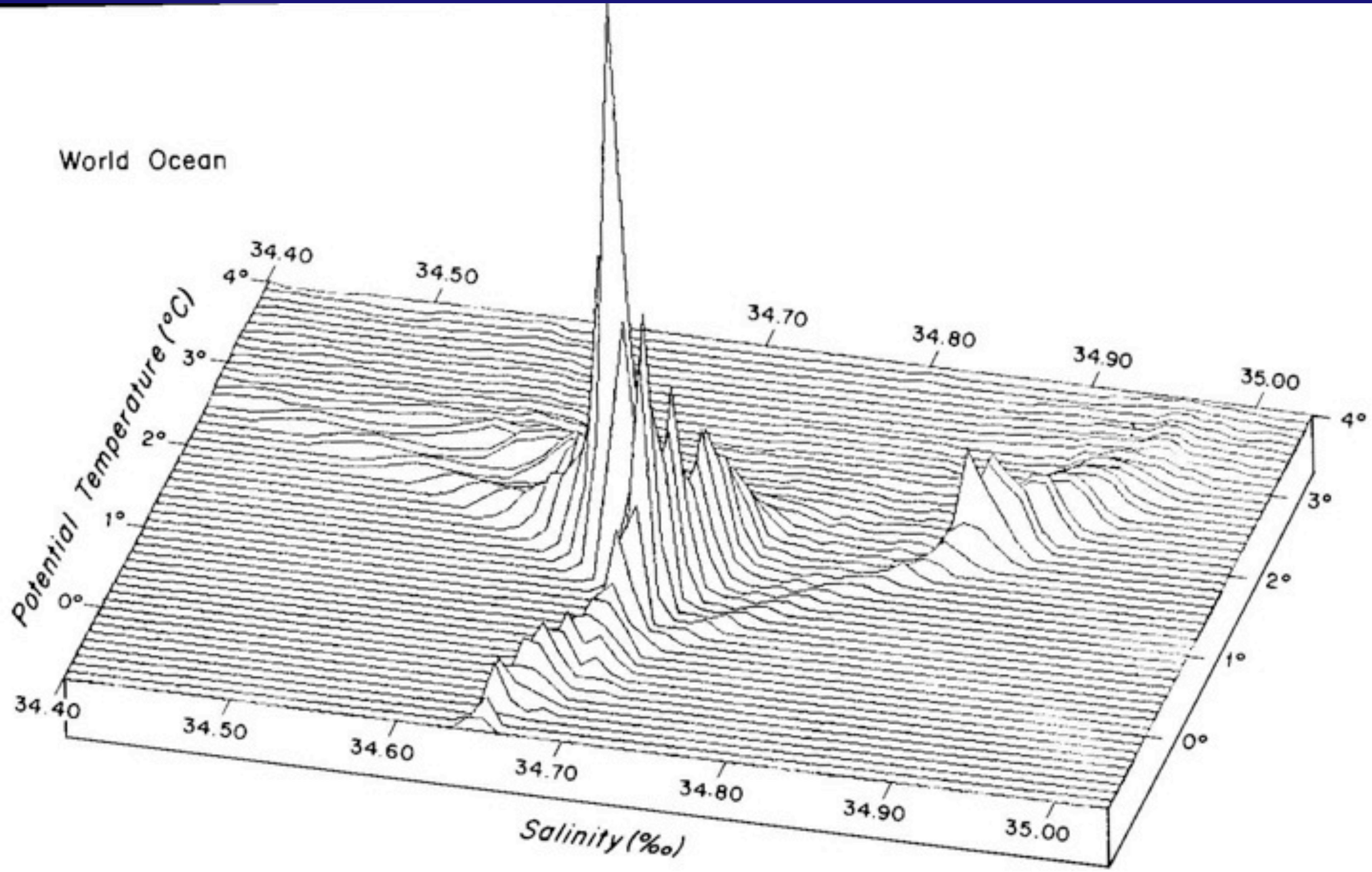


Figure 2.2 Simulated three-dimensional *T-S* diagram of the water masses of the world ocean. Apparent elevation is proportional to volume. Elevation of highest peak corresponds to 26.0×10^6 km³ per bivariate class 0.1°C × 0.01‰.

Pacific Deep Water

Antarctic Bottom Water

Indian Deep Water

North Atlantic Deep Water

Global deep water potential temperature-salinity

Worthington, 1982

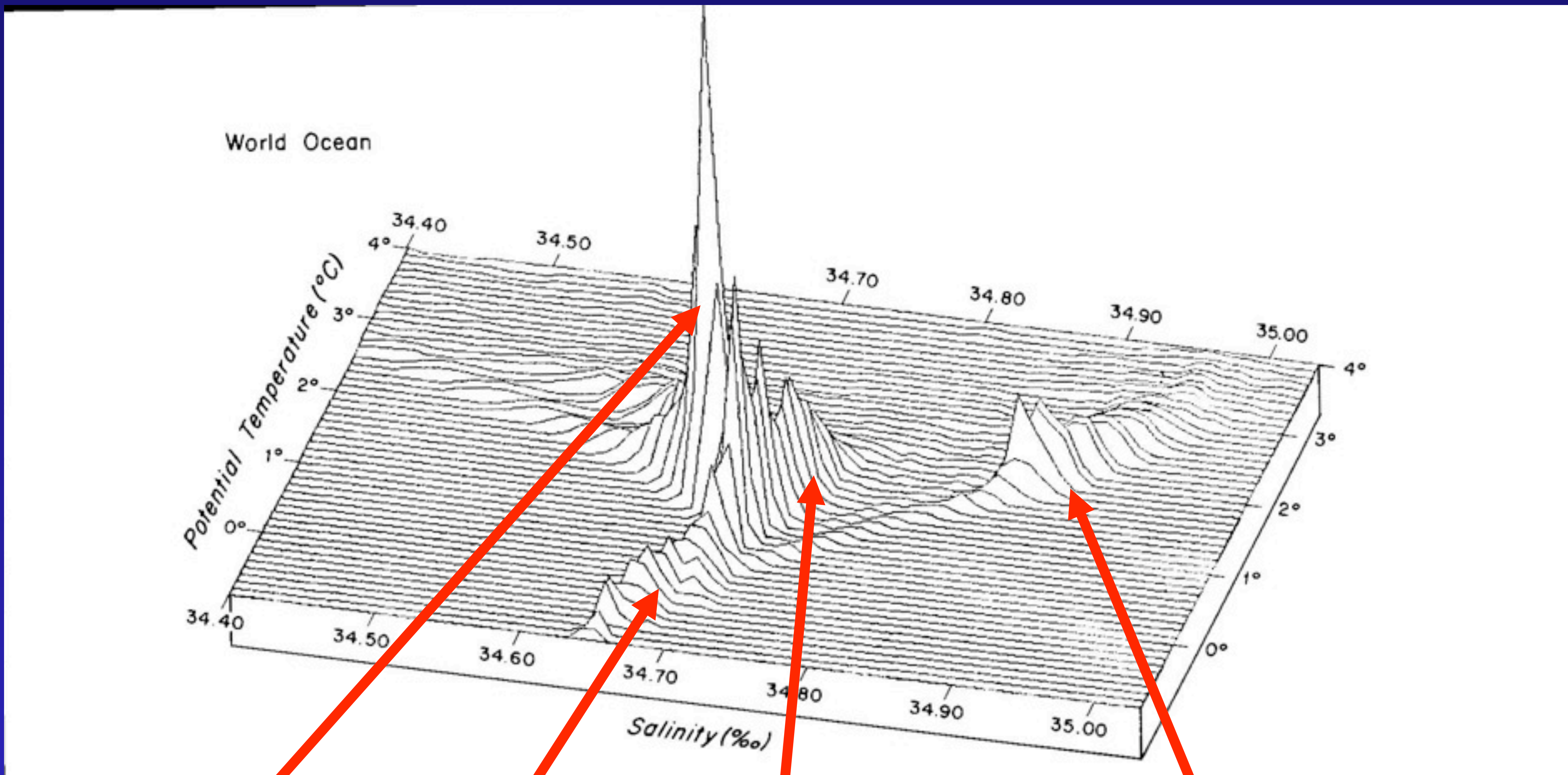


Figure 2.2 Simulated three-dimensional T-S diagram of the water masses of the world ocean. Apparent elevation is proportional to volume. Elevation of highest peak corresponds to 26.0 × 10^6 km^3 per bivariate class 0.1°C × 0.01‰.

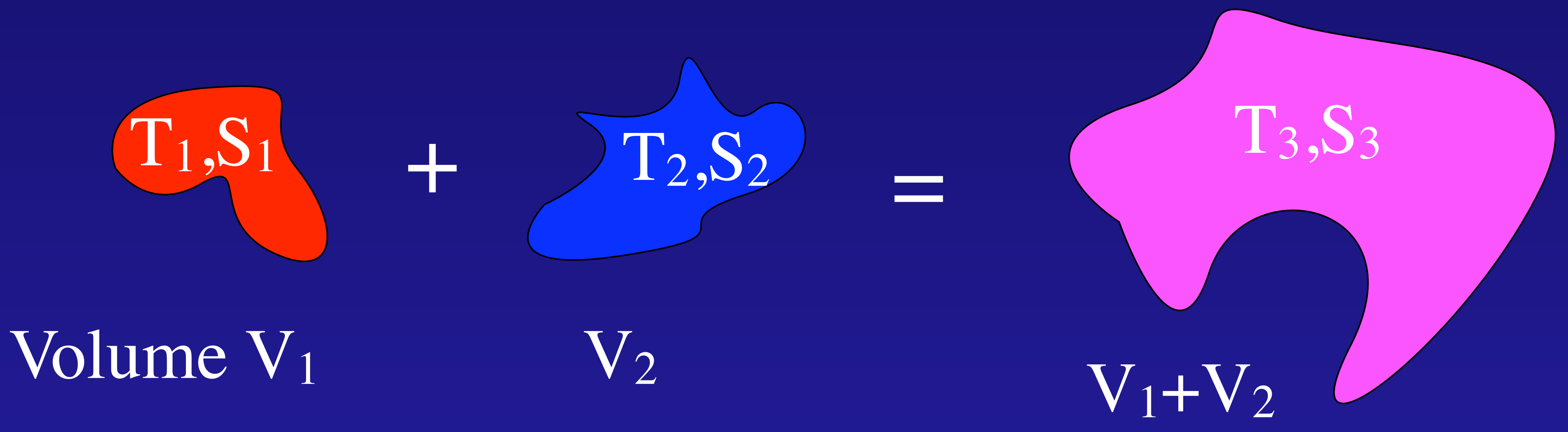
Pacific Deep Water

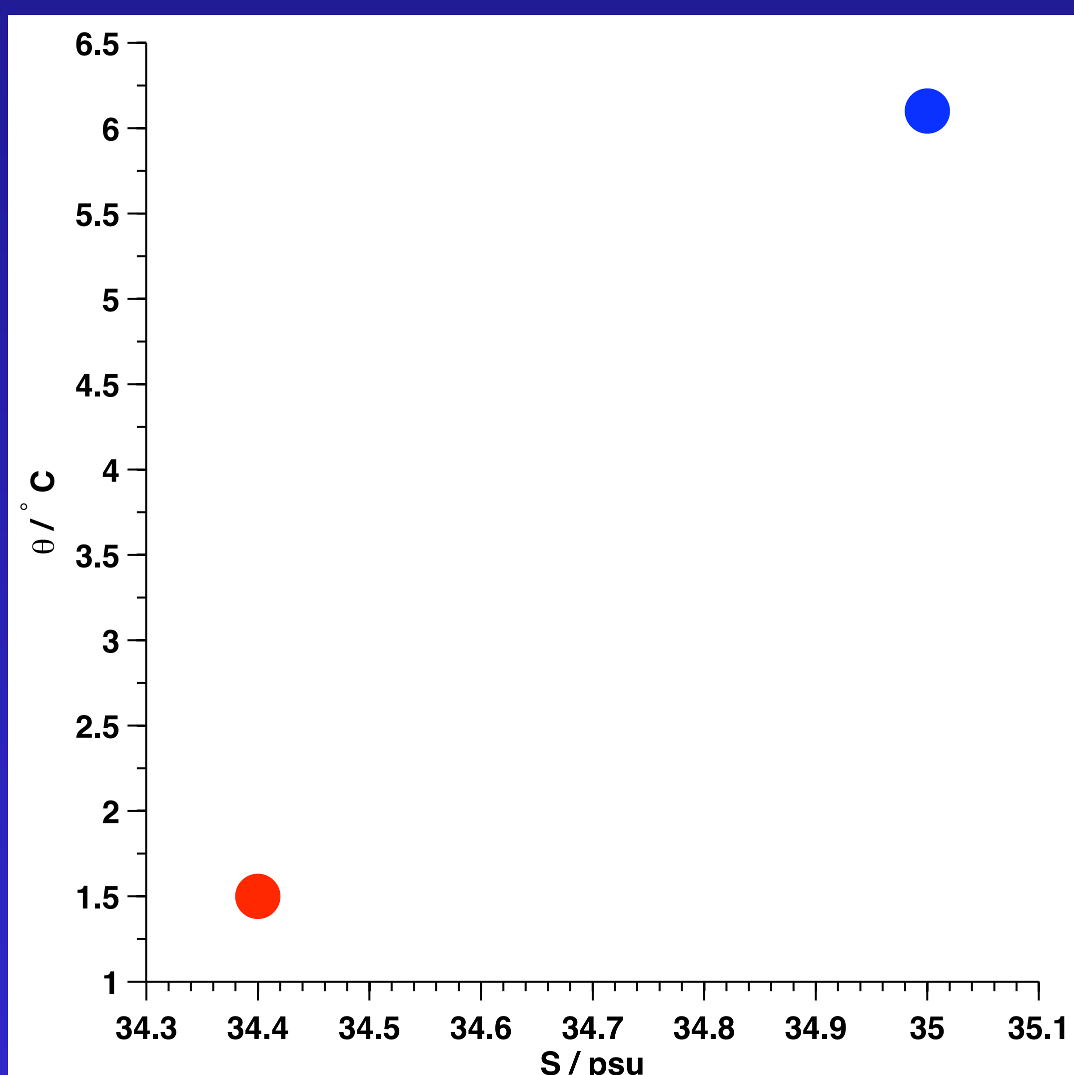
Antarctic Bottom Water

Indian Deep Water

North Atlantic Deep Water

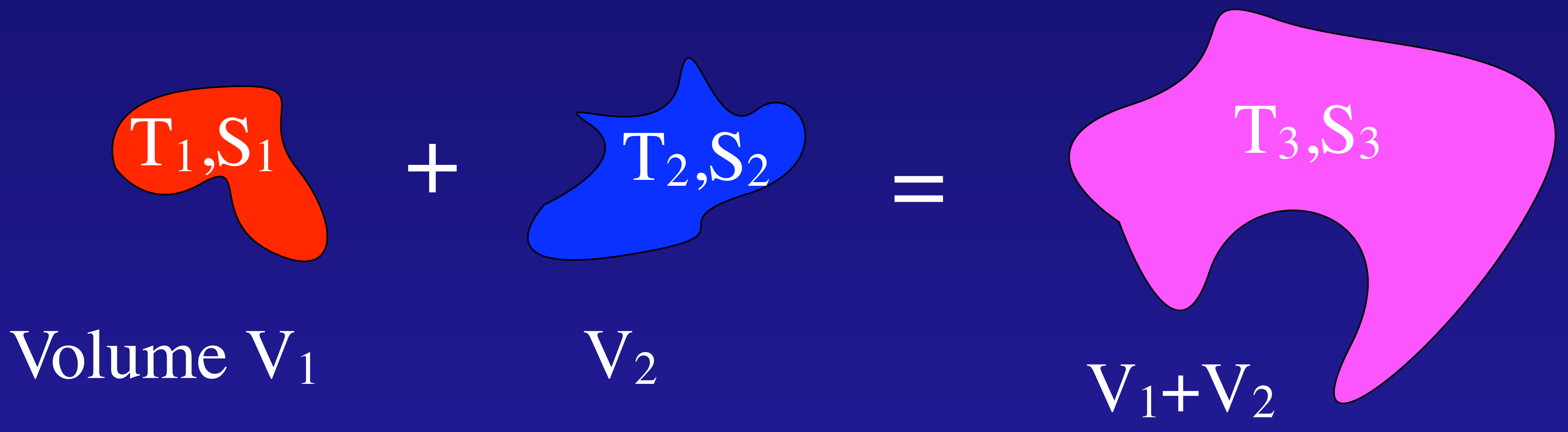
Mixing water masses

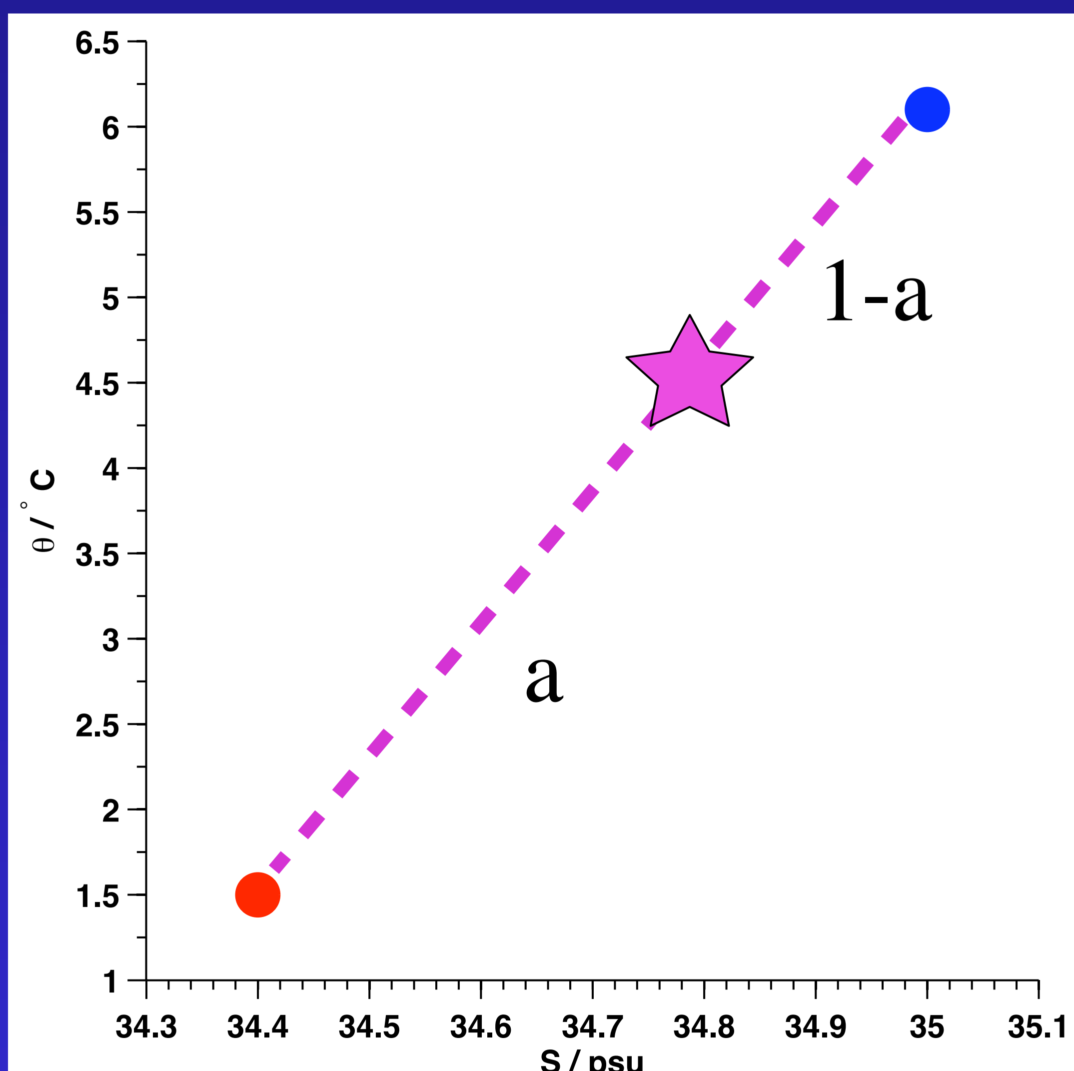




Let $a = V_2/(V_1+V_2)$

Mixing water masses





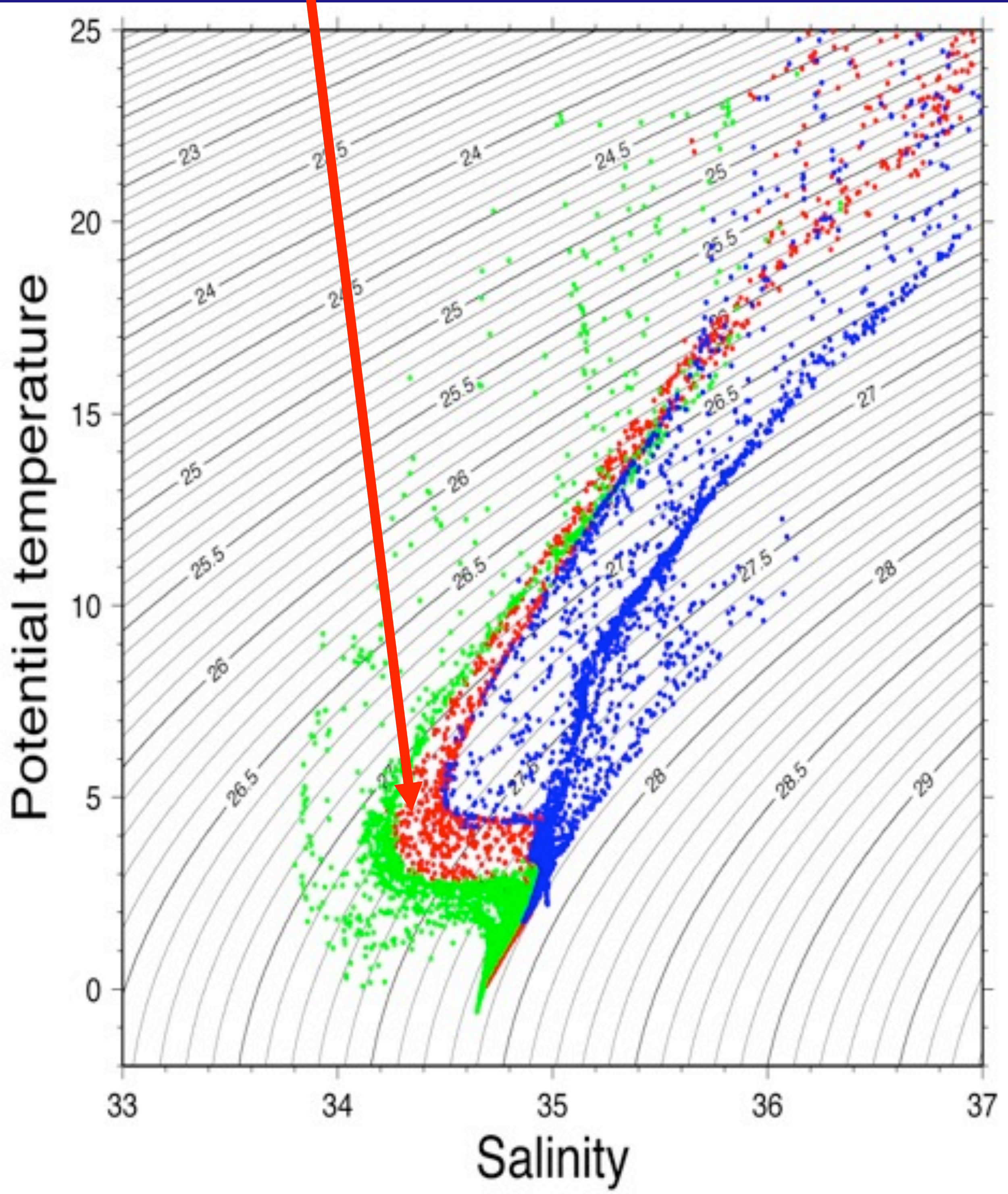
Let $a = V_2/(V_1+V_2)$

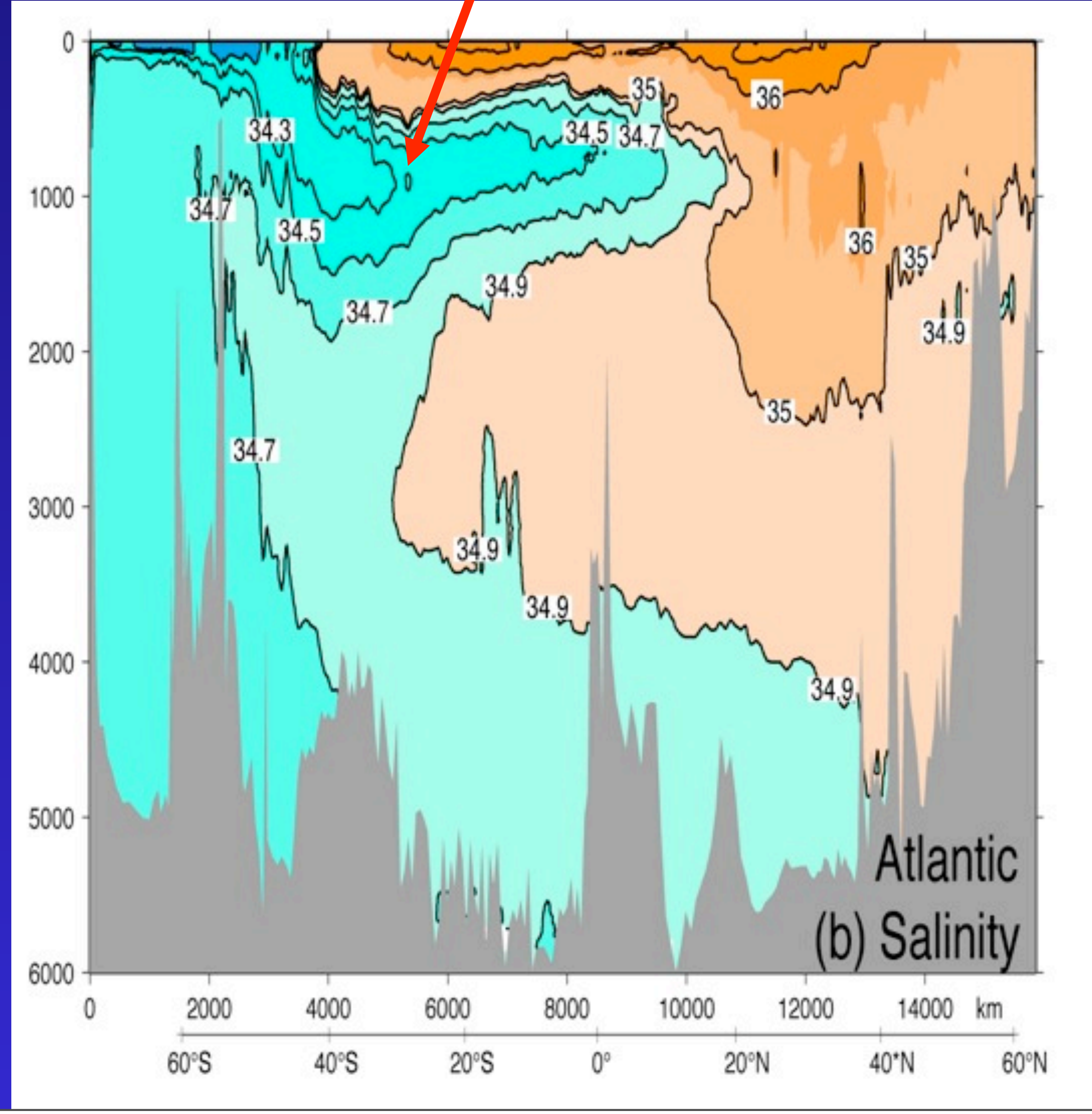
$$T_3 = (1-a) * T_1 + a * T_2$$

$$S_3 = (1-a) * S_1 + a * S_2$$

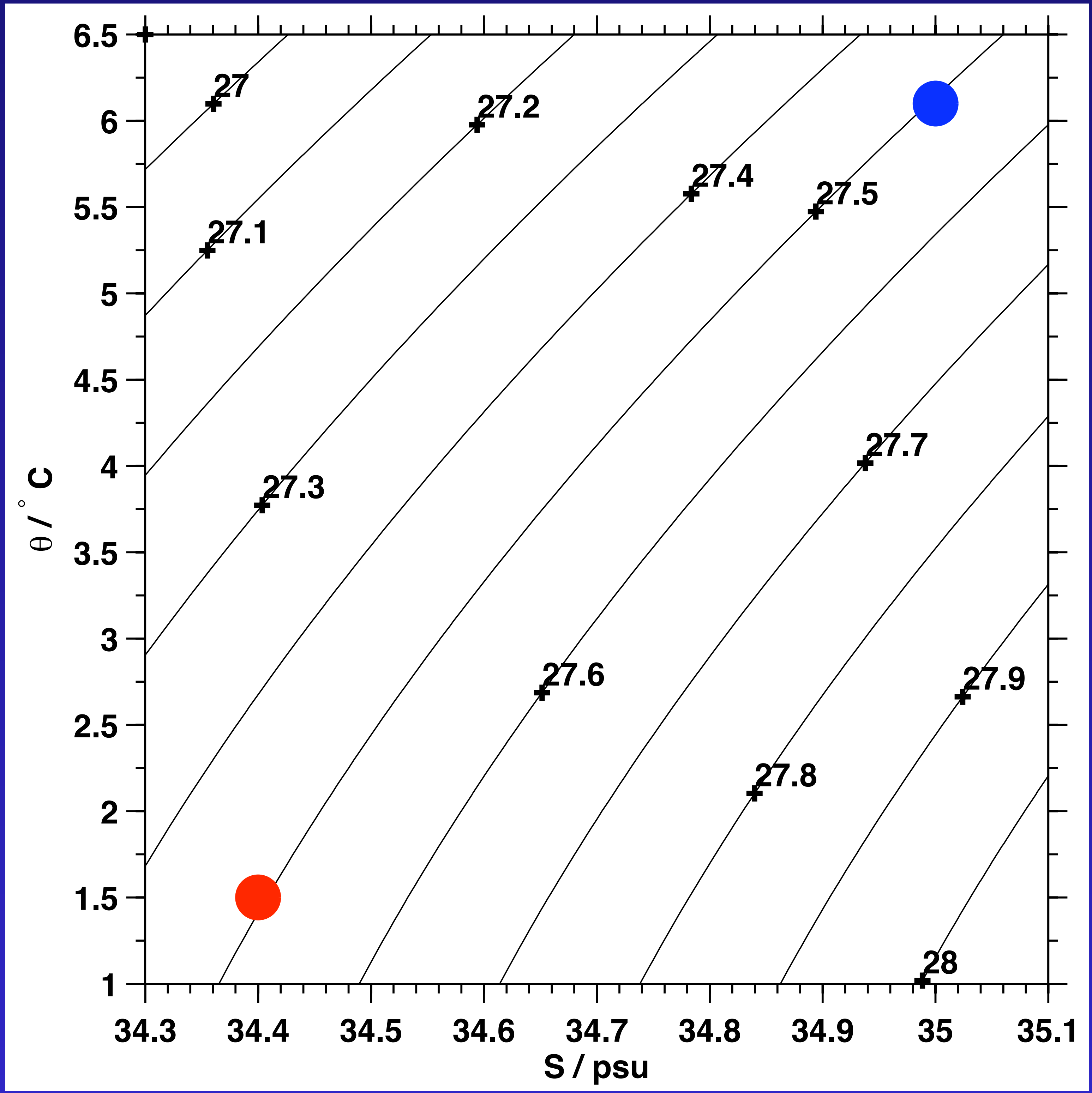
Water mass

Example: Antarctic Intermediate Water - (a) low salinity layer, (b) originating in surface mixed layers near Antarctic Circumpolar Current

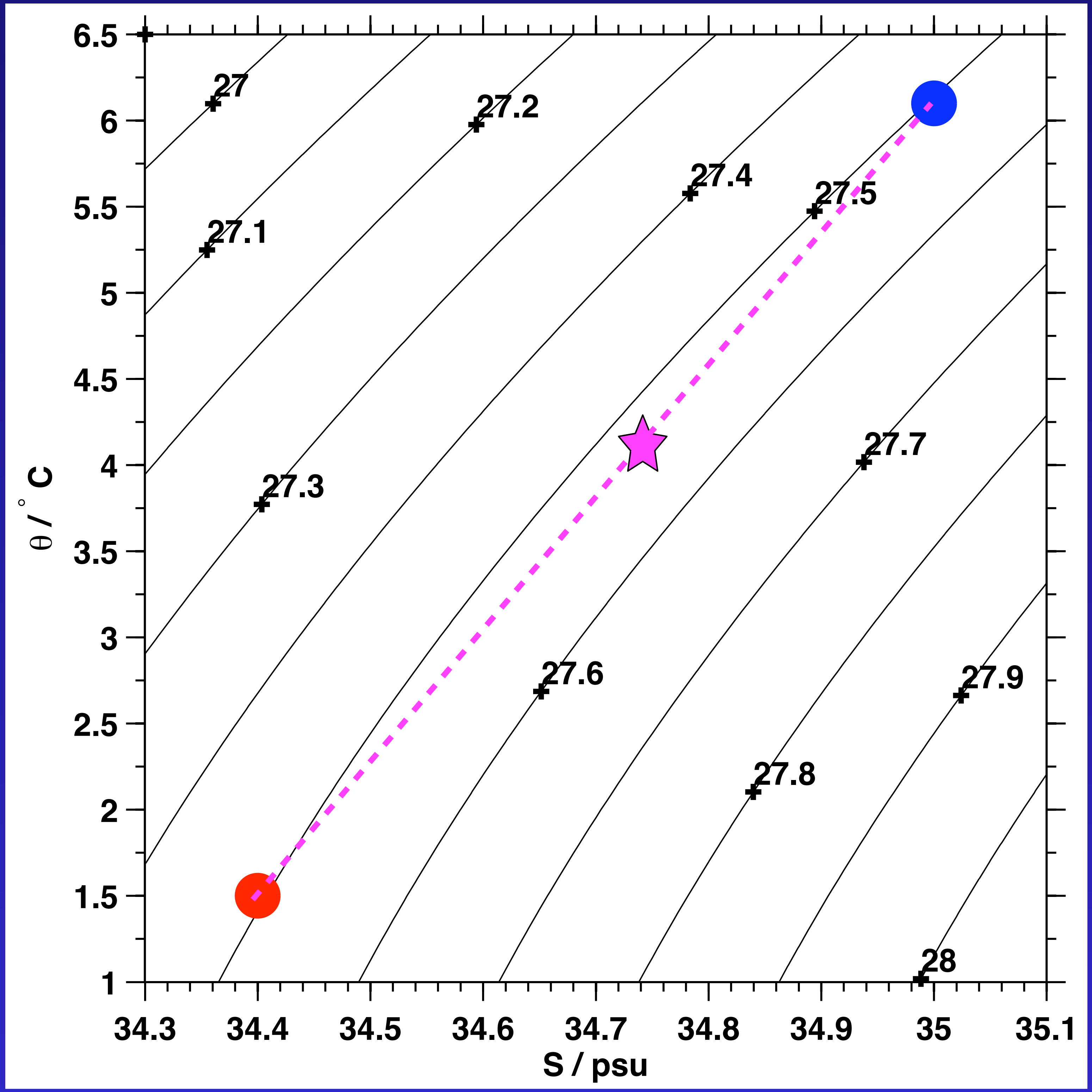




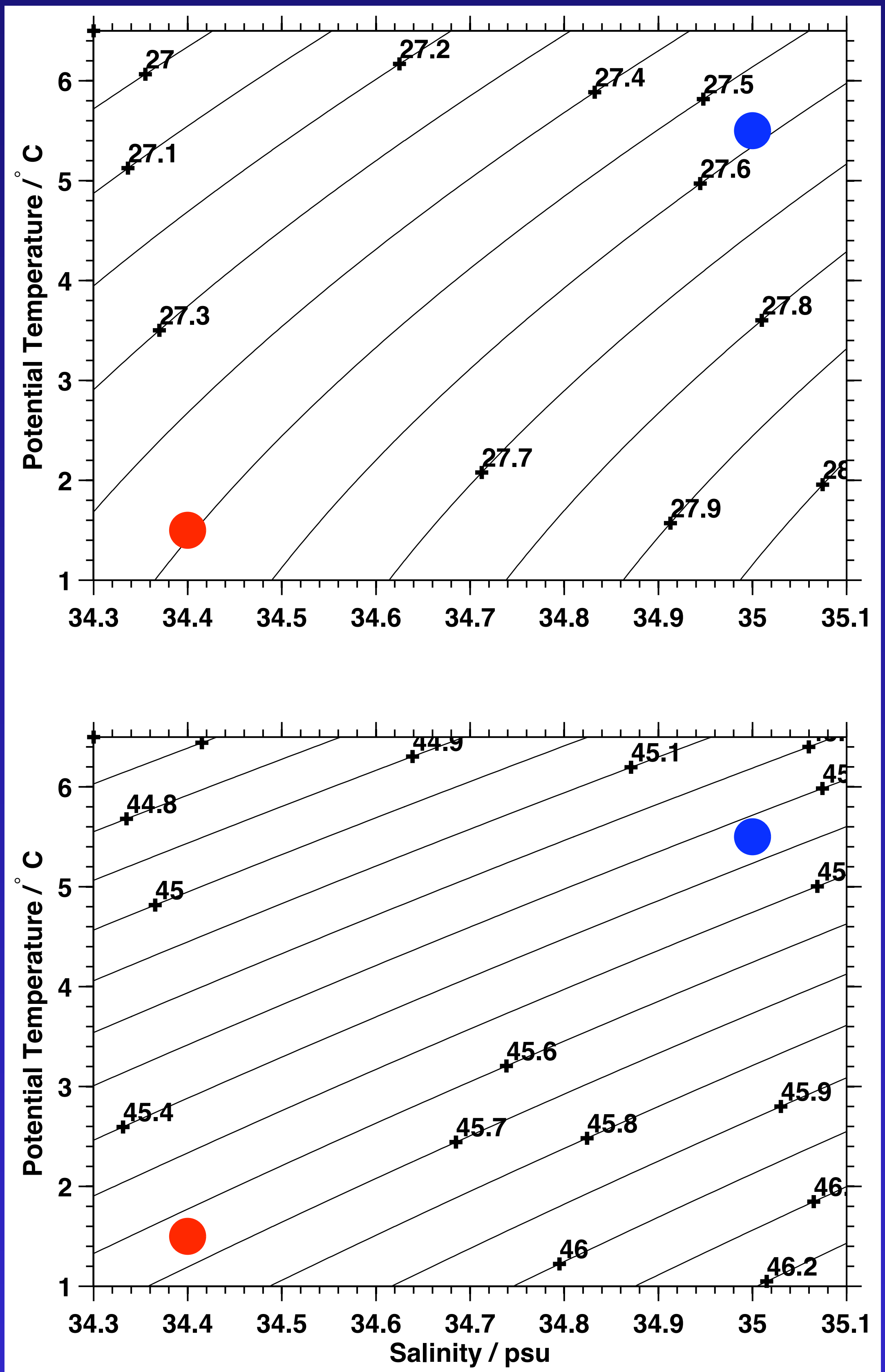
Peculiarities of the equation of state I: Cabbeling



Peculiarities of the equation of state I: Cabbeling



Peculiarities of the equation of state II: Thermobaricity



At 0 dbar: warm salty blob denser

At 4000 dbar: warm salty blob lighter!!