Physical properties of Seawater

Lecture 3

What is salinity and how is it measured?

- Grams of dissolved material in 1 kg of sea water. Dimensionless. But, gases and chlorides lost in drying.
- Most accurately measured using laboratory titration of chloride, S=1.8Cl. Ratio of ions in seawater (largely) constant: 50% chloride, 31% sodium, 8% sulphate…
- Most conveniently measured in situ using conductivity. Error (0.003) caused by variations in non-conducting salts like SiO2. Units "psu". TEOS10 Absolute Salinity uses geographic information to correct to 0.0003.

What is temperature and how is it measured?

- Temperature relates the activity level of molecules. More active = higher T (℃)
- Measured in situ using a thermistor. Loosely wound, strain-free, pure platinum wire with resistance a function of temperature.

What is pressure and how is it measured?

- Depth in ocean measured in situ as pressure (decibar), typically with a quartz transducer
- $p = \int \rho g \, dz \cong \rho g z$, assuming incompressibility
- $p(1\ m) = 1027\ kg\ m^{-3} \times 9.81\ ms^{-2} \cong 1\ dbar$
- 1 Atm = 10 dbar

What is density and how is it measured?

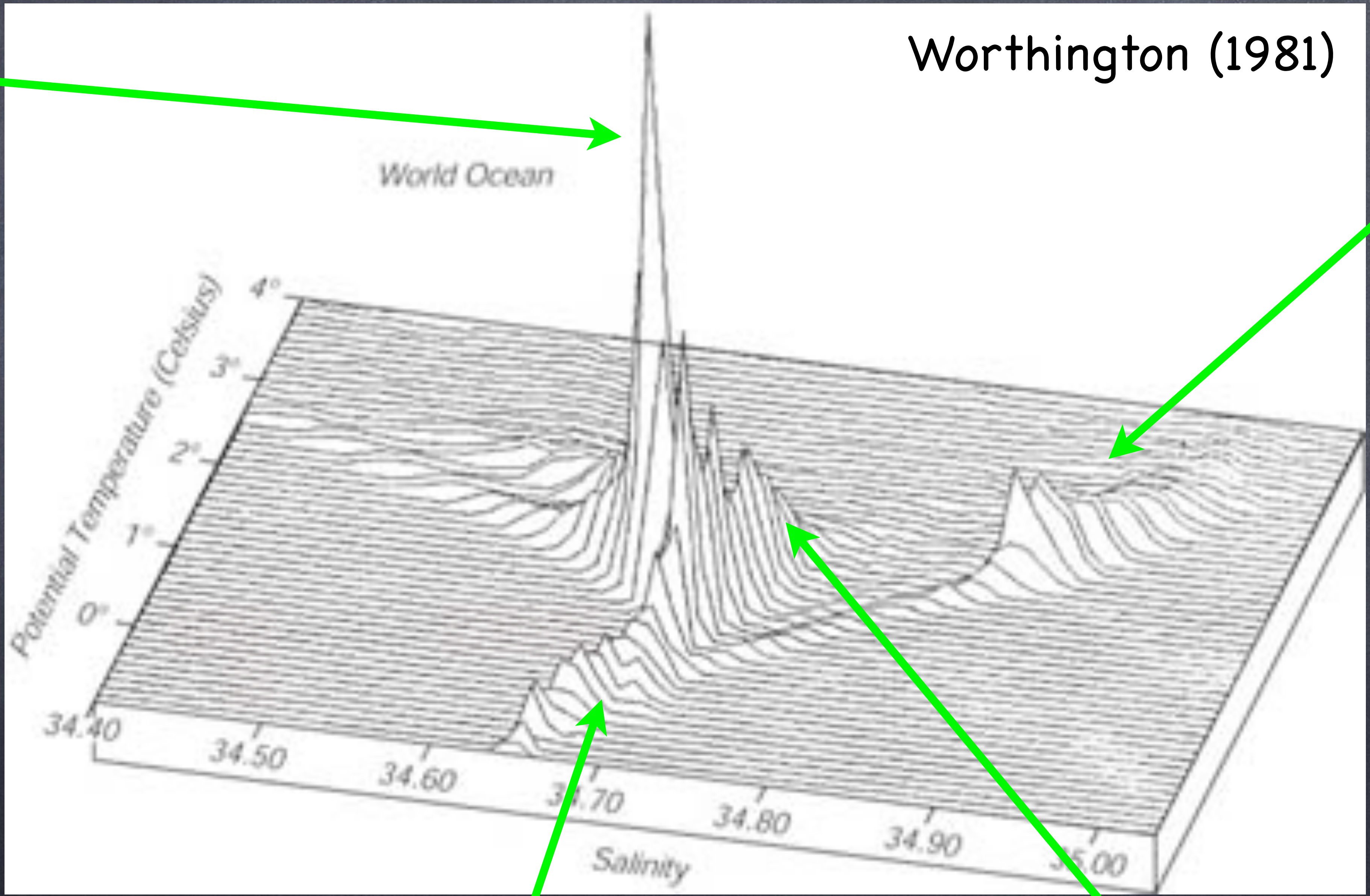
- Density (kg m^{-3}) is **derived** using the equation of state of seawater, an empirical high-order polynomial. 48 terms. TEOS-10.org. (McDougall, Millero et al., 2011).
- Density, rho, is a function of T, S, p. Contours called isopycnals.
- For accuracy, oceanographers use sigma = rho-1000

Means and ranges in the ocean

- Mean
  - S=34.7;
  - T=3.5 ℃;
  - p=4000 dbar;
  - rho=1027 kg m^{-3}
- Range
  - 5 < S < 40;
  - -2 ℃ < T < 30 ℃;
  - 0 dbar < p < 11,000 dbar
  - 1020 kg m^{-3} < rho < 1070 kg m^{-3}

50% water in ocean is deep water!

1.3℃ < T < 3.8℃; 34.6 < S < 34.8



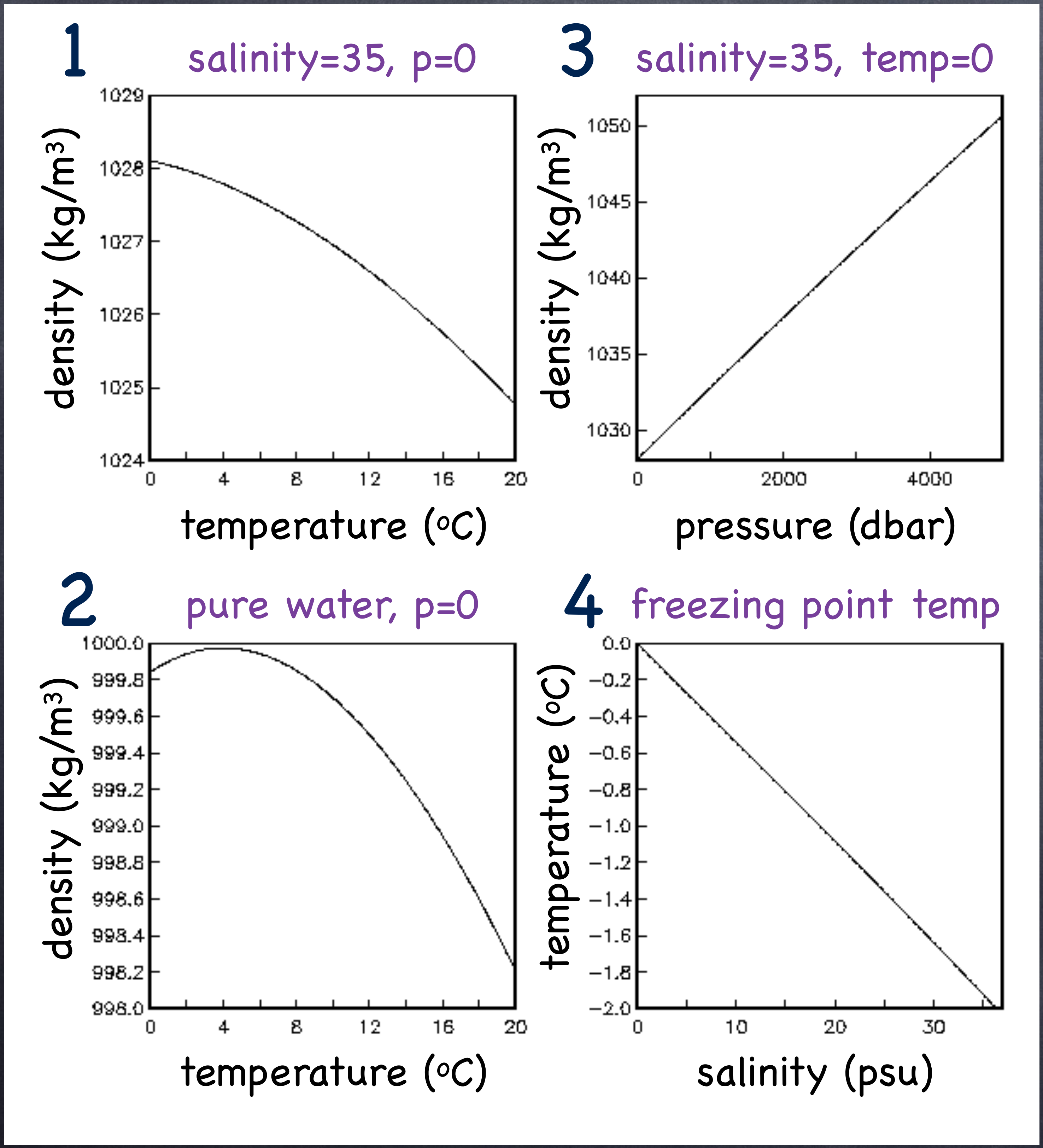
Pacific

Atlantic

Antarctic

Indian

Density, T, and S



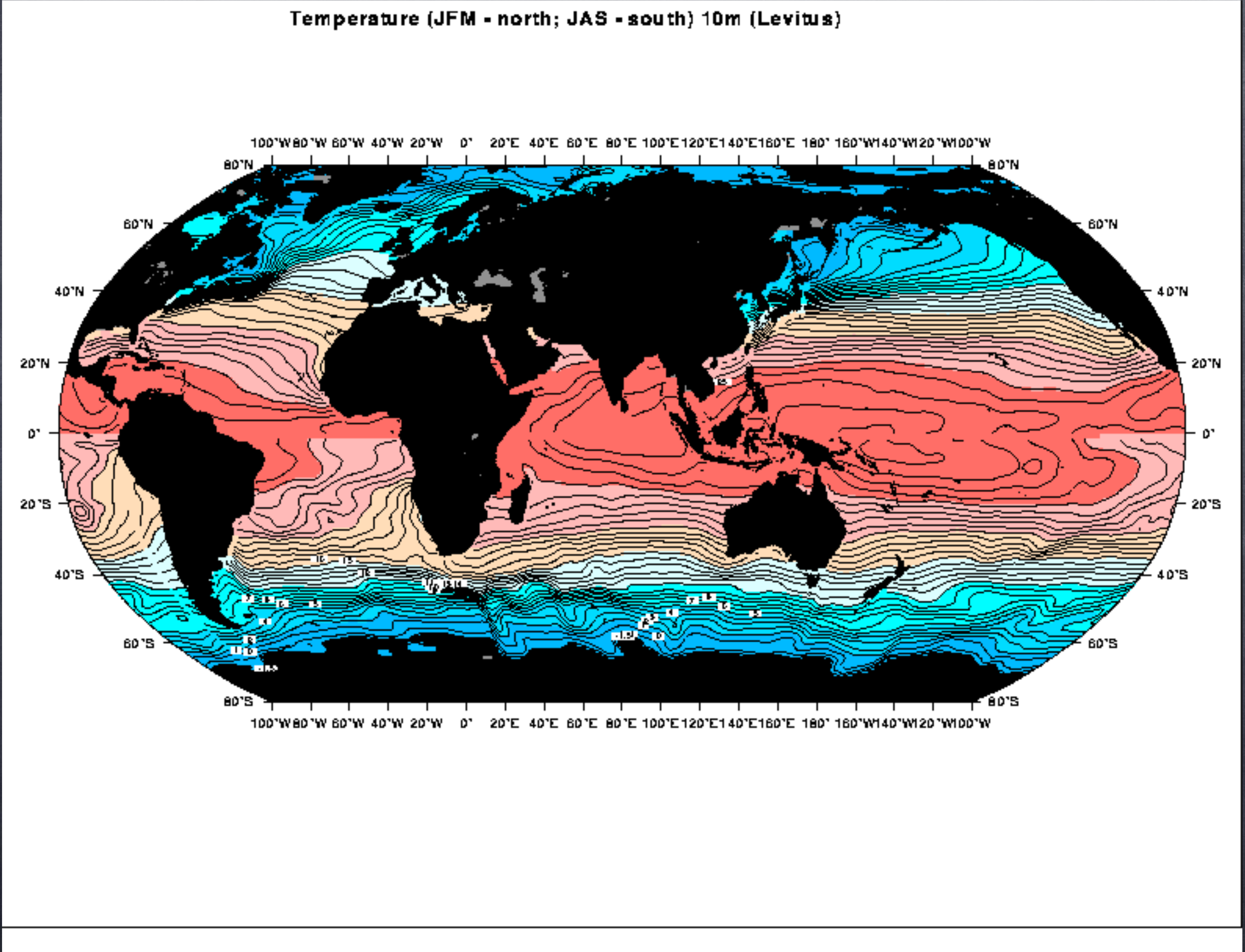
1. seawater densest at freezing point
2. fresh water densest at 4°C
3. under a lot of pressure seawater compresses and gets denser.
4. freezing point of seawater is -2°C. when ice crystals form salt is rejected. Ice crystals rise to the top leaving behind super-cooled briny water

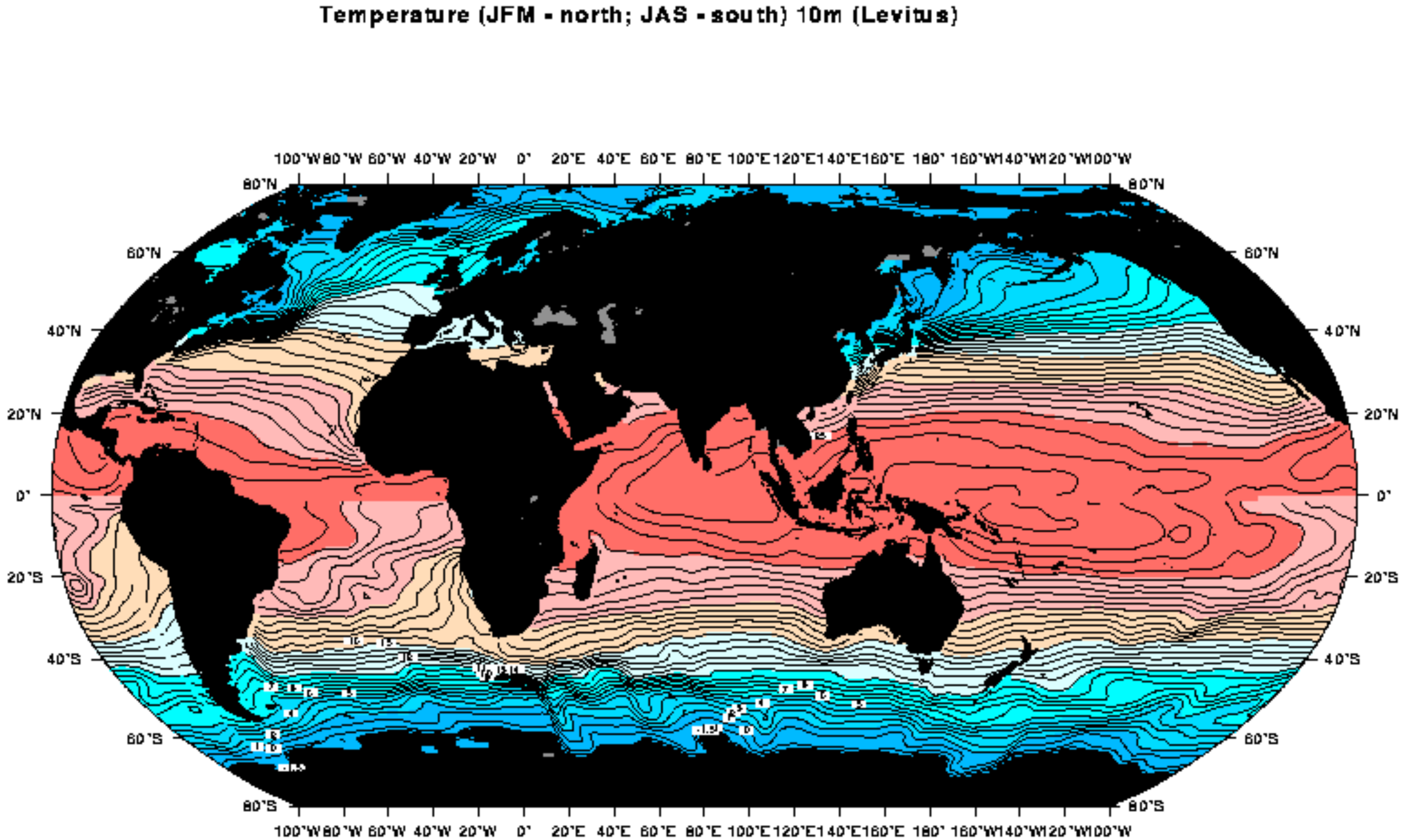
Why are temperature and salinity key to understanding the ocean?

- Changes in T and S lead to changes in DENSITY and density gradients drive ocean currents, overturns, and mixing
- Once away from the ocean surface, water masses can be traced around the globe using their distinctive T/S relationship, revealing the global thermohaline circulation.
- Water masses like to preserve their density, moving along surfaces of constant density, or isopycnals, in the ocean interior.

What can affect the T & S of sea water at the surface of the ocean?

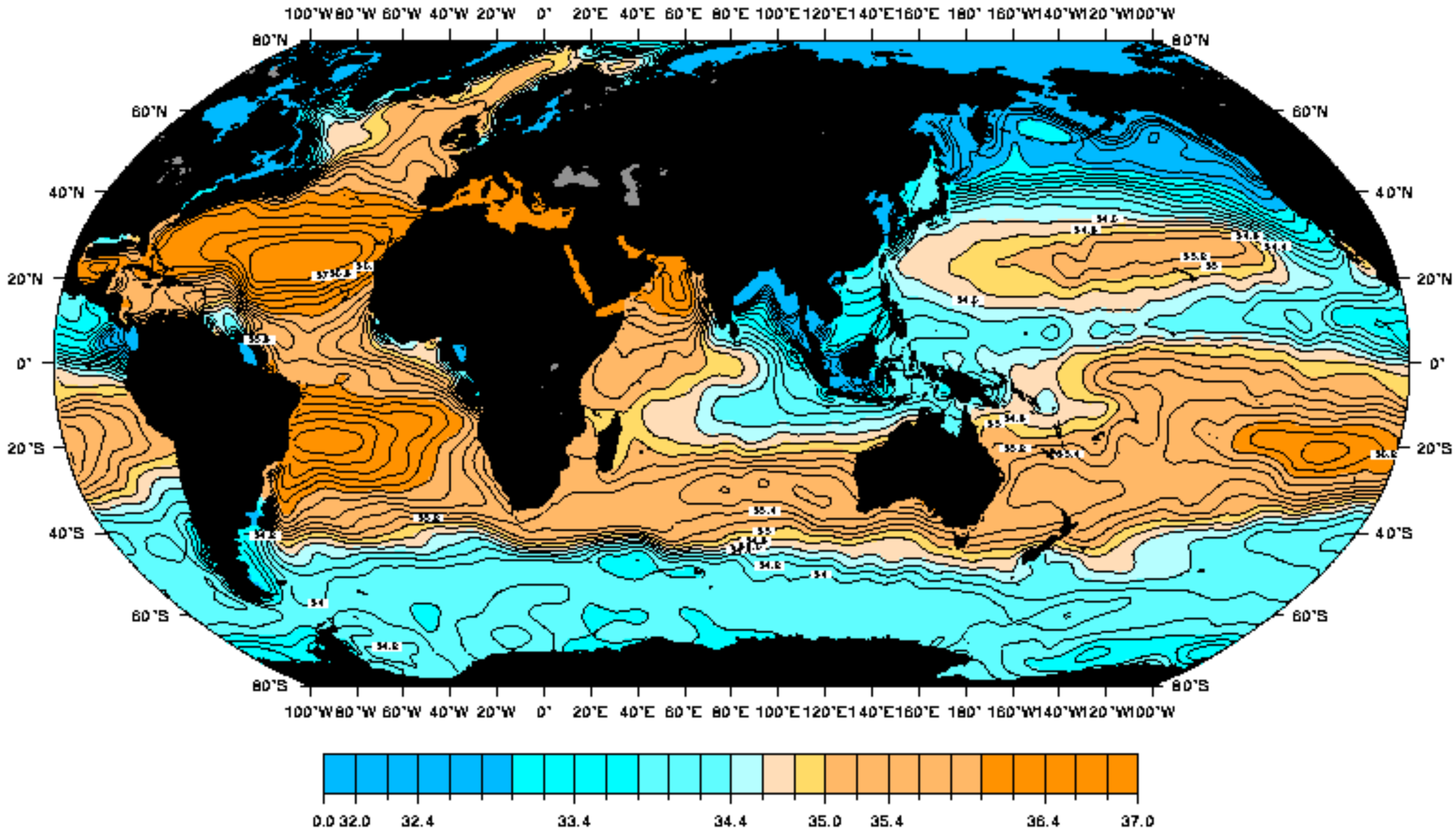
- surface heat fluxes: Incoming solar radiation, outgoing longwave radiation, sensible and latent heat.
- evaporation and precipitation and runoff
- freezing/melting of sea ice
- buoyancy-driven convection
- wind-driven mixing

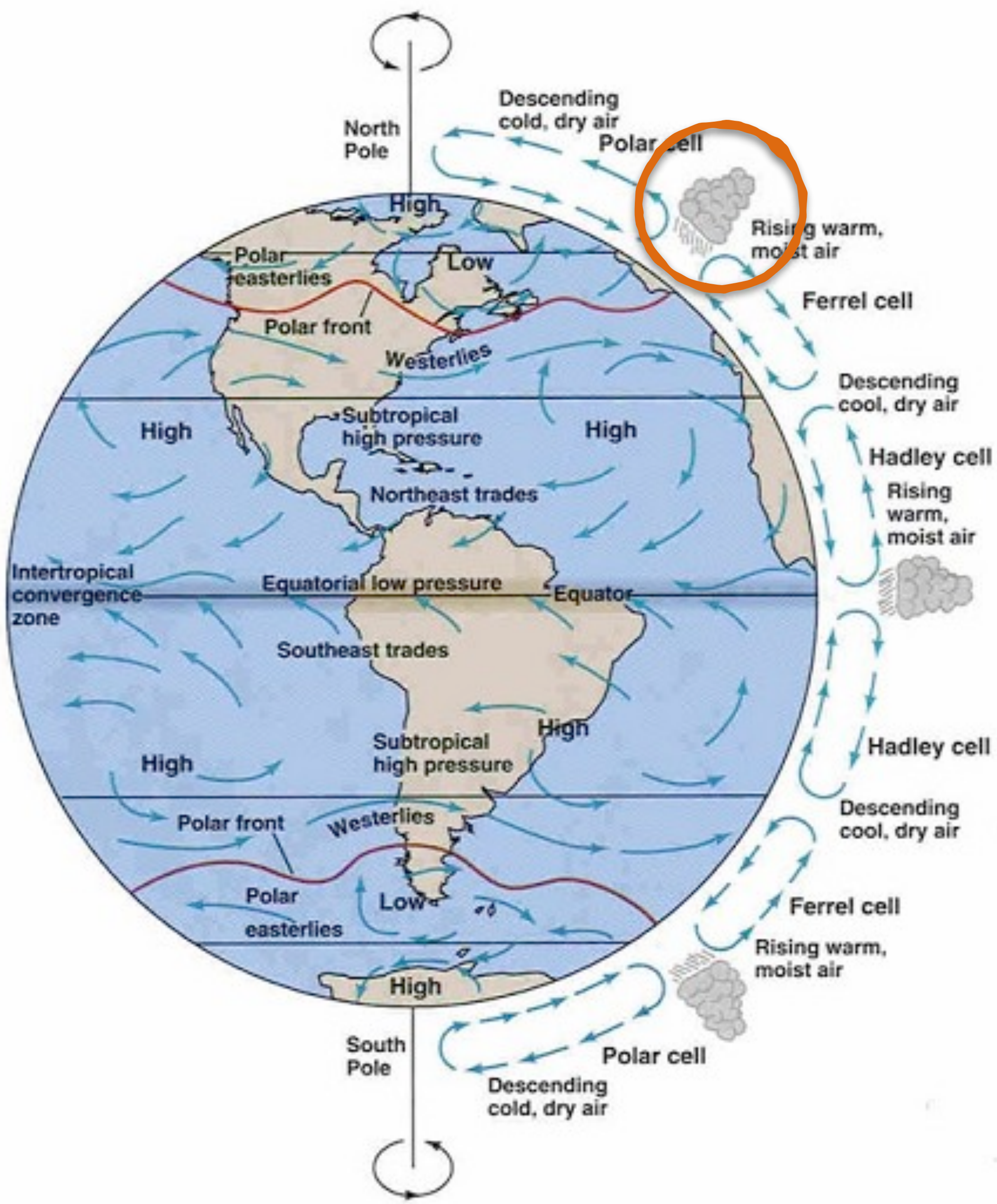

Temperature (JFM - north; JAS - south) 10m (Levitus)
100°W 80°W 60°W 40°W 20°W 0° 20°E 40°E 60°E 80°E 100°E 120°E 140°E 160°E 180° 160°W 140°W 120°W 100°W
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S



Surface temperature is dominated by net heating in the tropics and cooling at higher latitudes. The total range of temperature is from the seawater freezing point (-2ºC) up to about 30ºC.

Salinity at the sea surface (annual mean) (Levitus)





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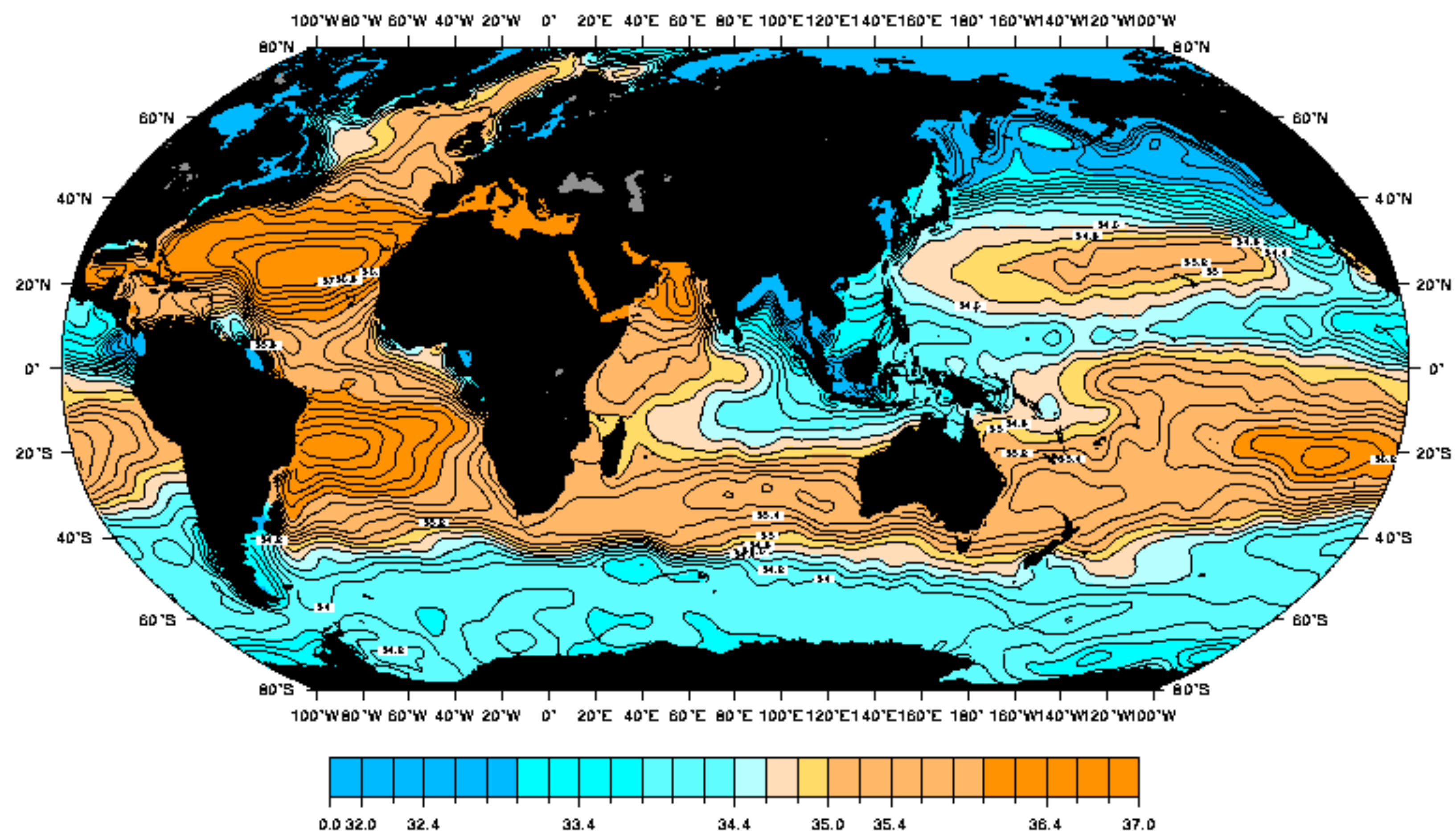
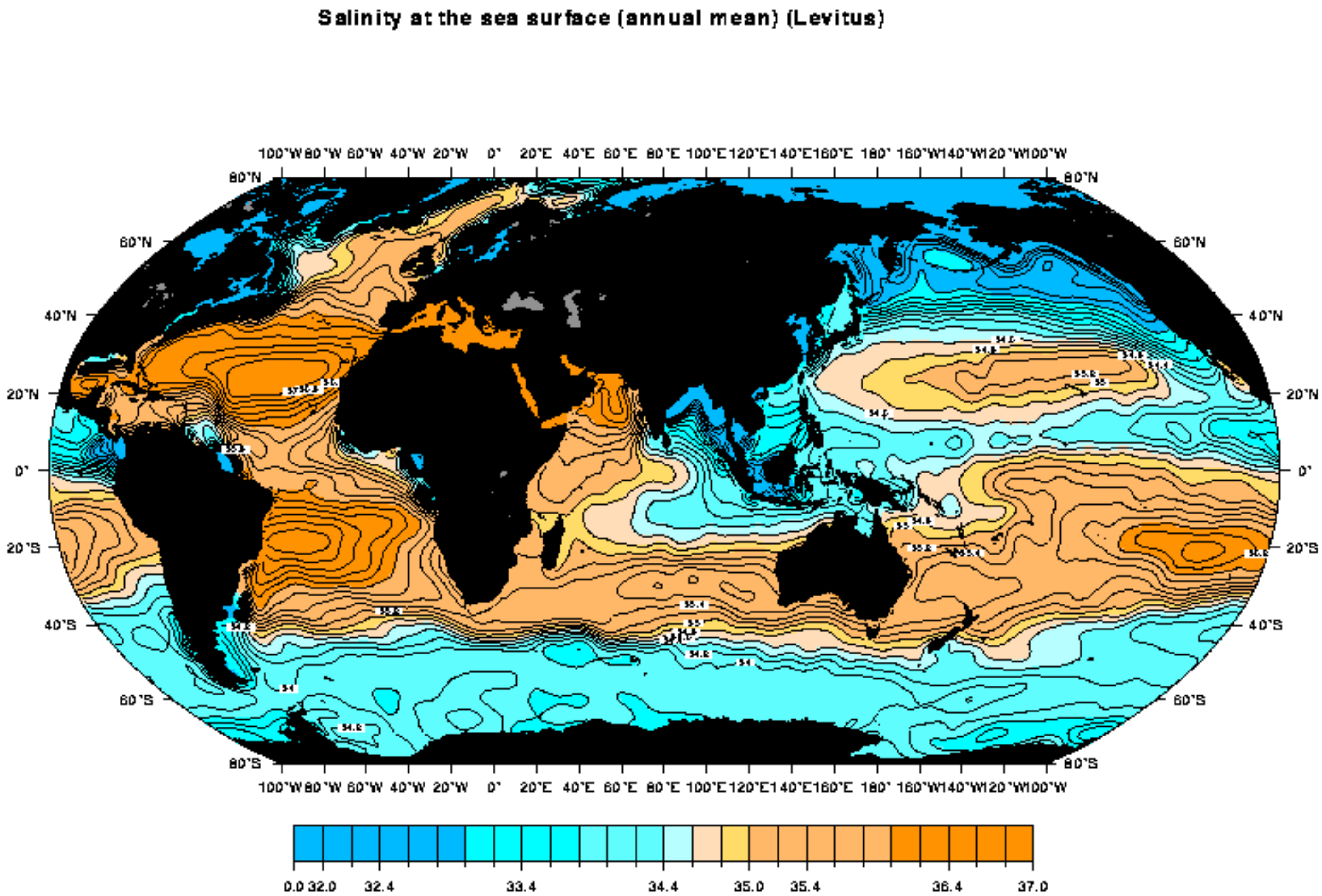
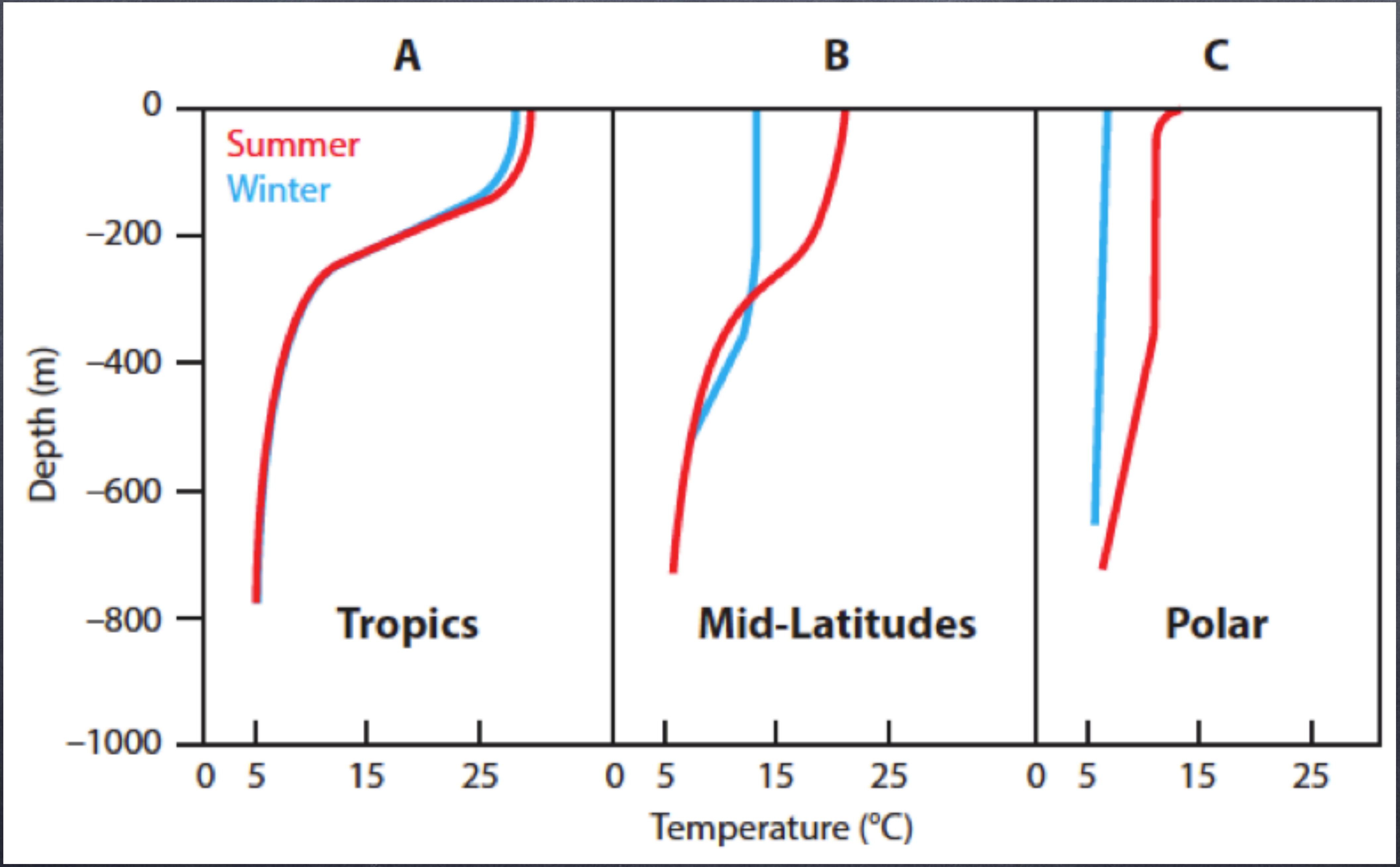


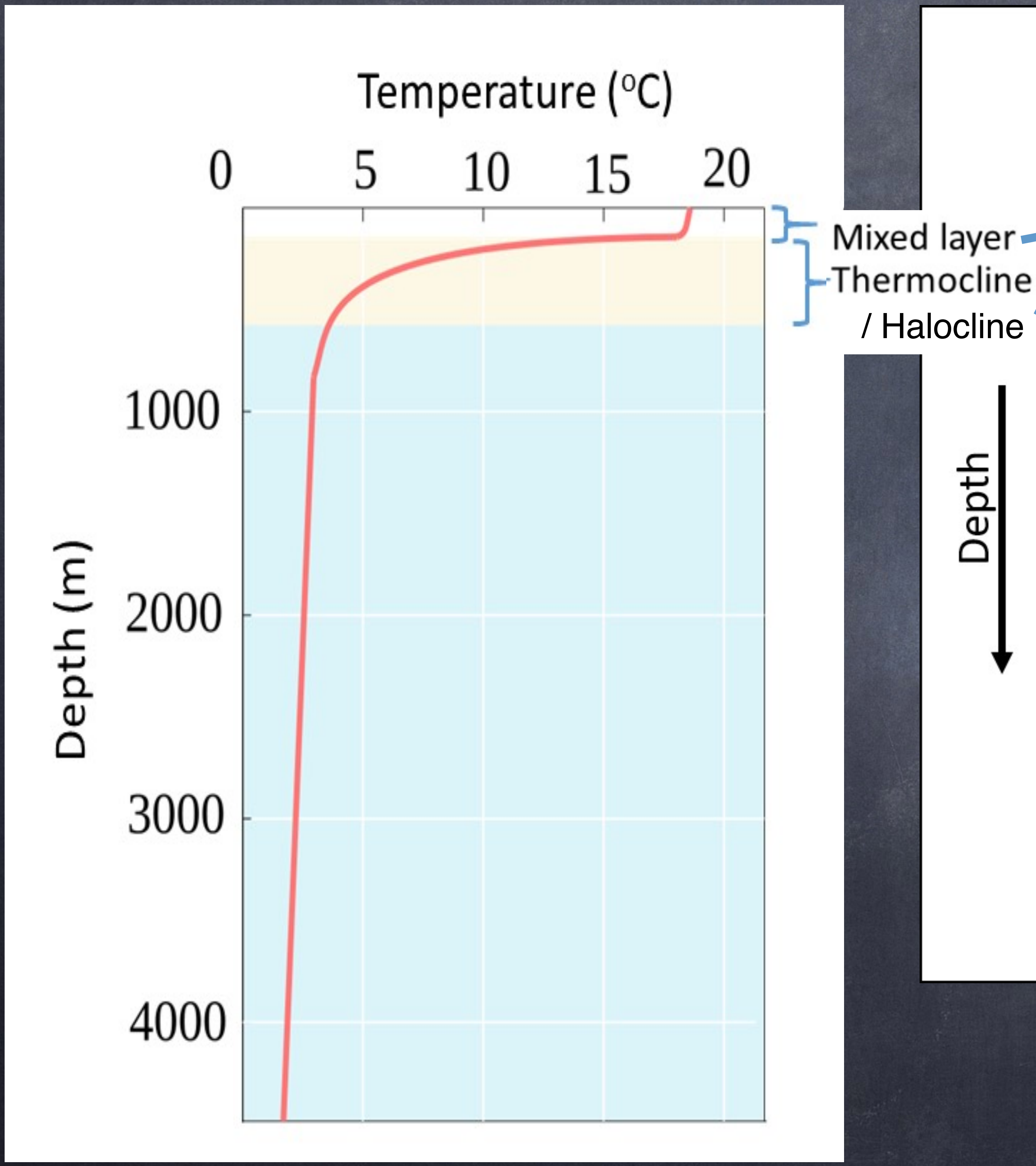


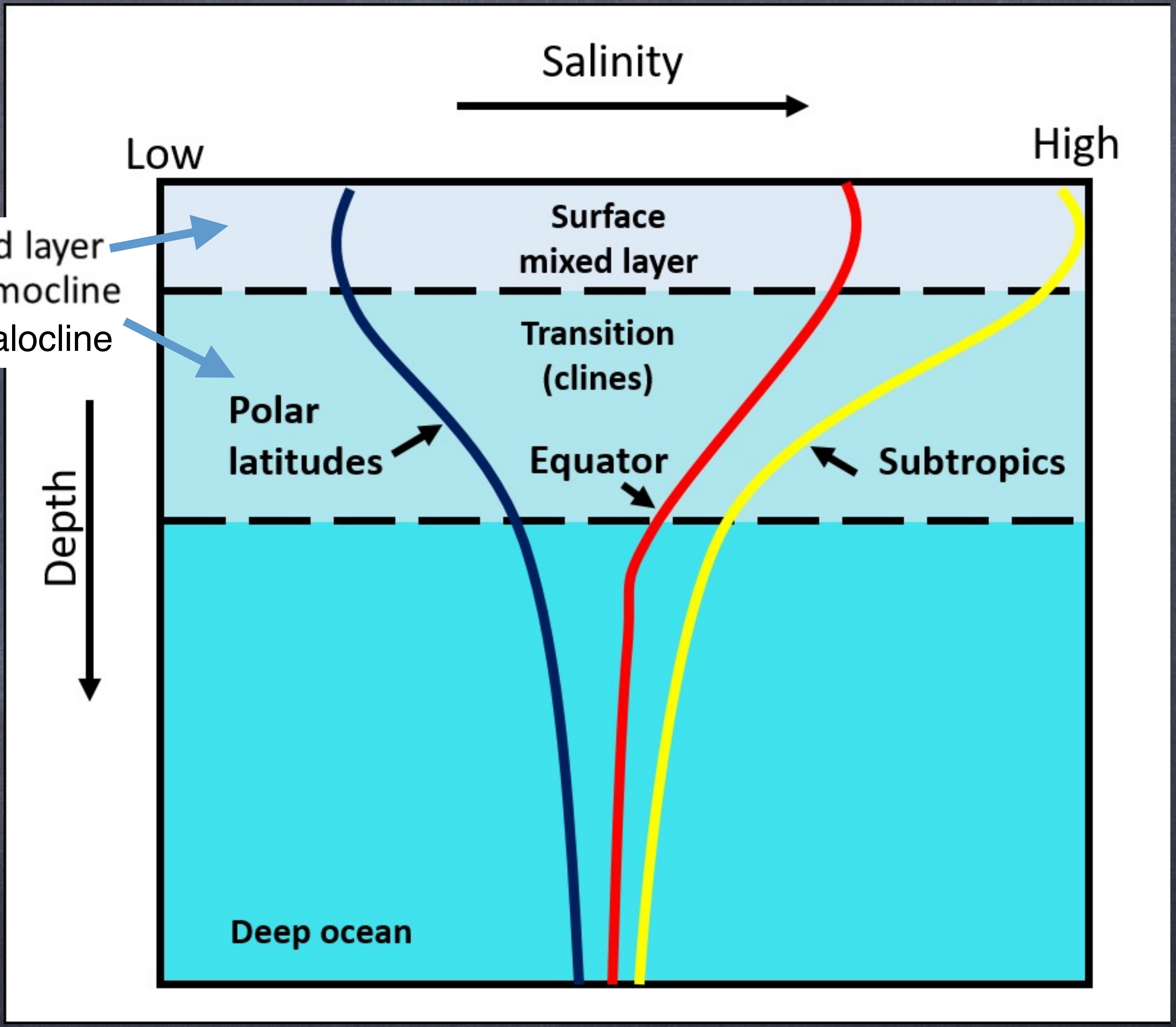
Surface salinity is dominated by net evaporation in the subtropical regions, and net precipitation/runoff at higher latitudes and in the tropics. Range in open ocean is 31 to 38.

T, S, rho of sea water with depth in the ocean

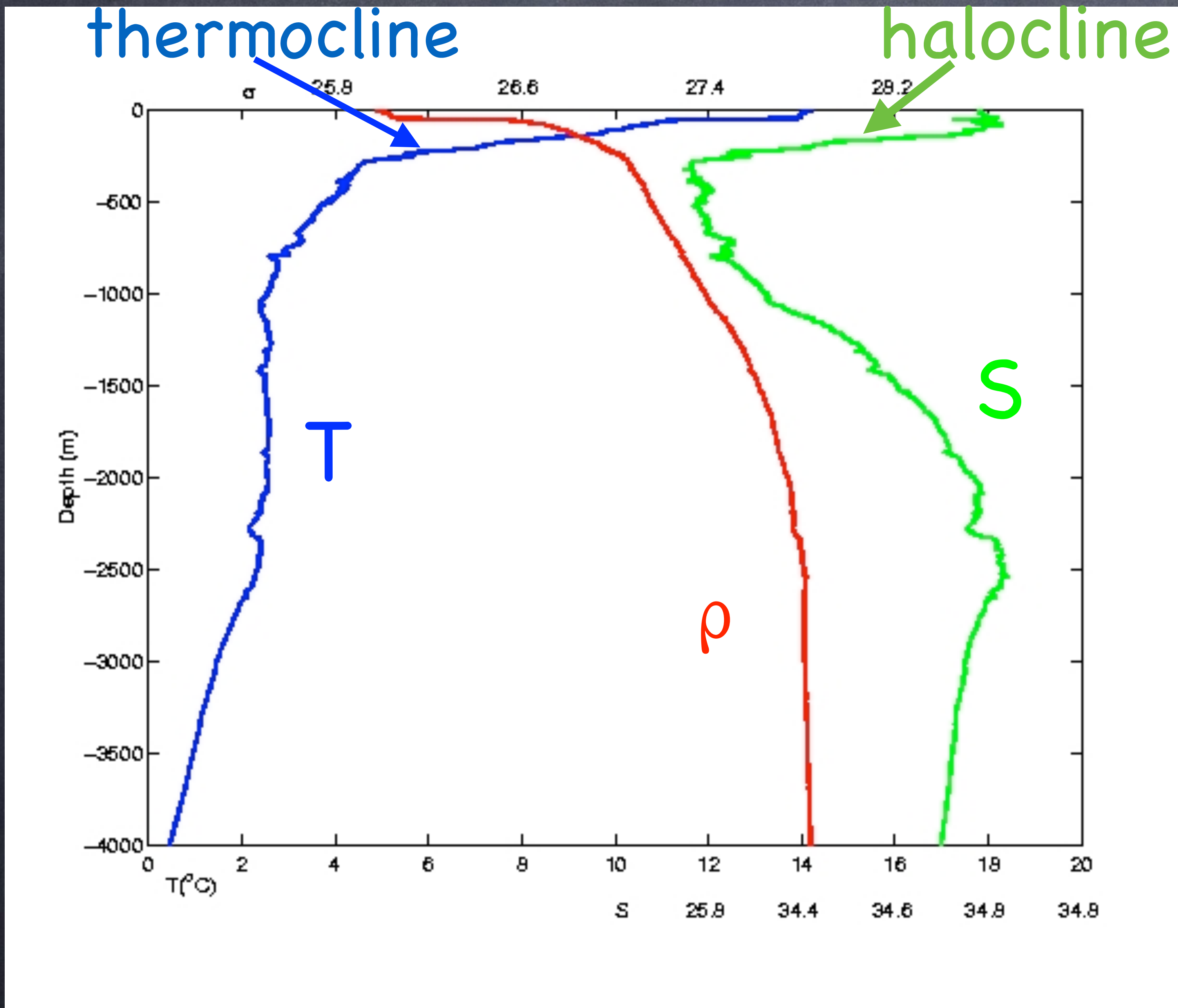


T, S, rho of sea water with depth in the ocean

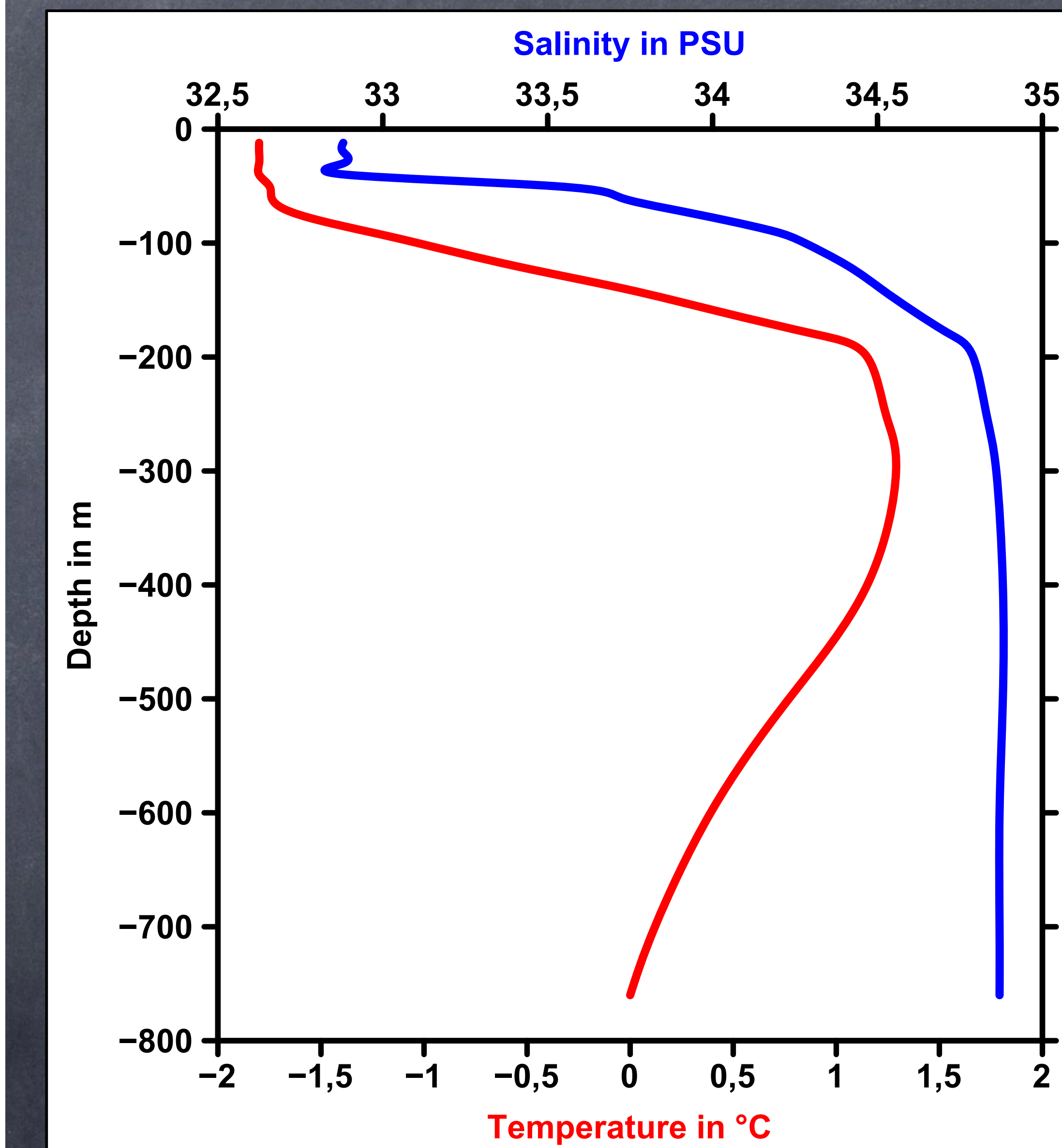




T, S, rho of sea water with depth in the ocean

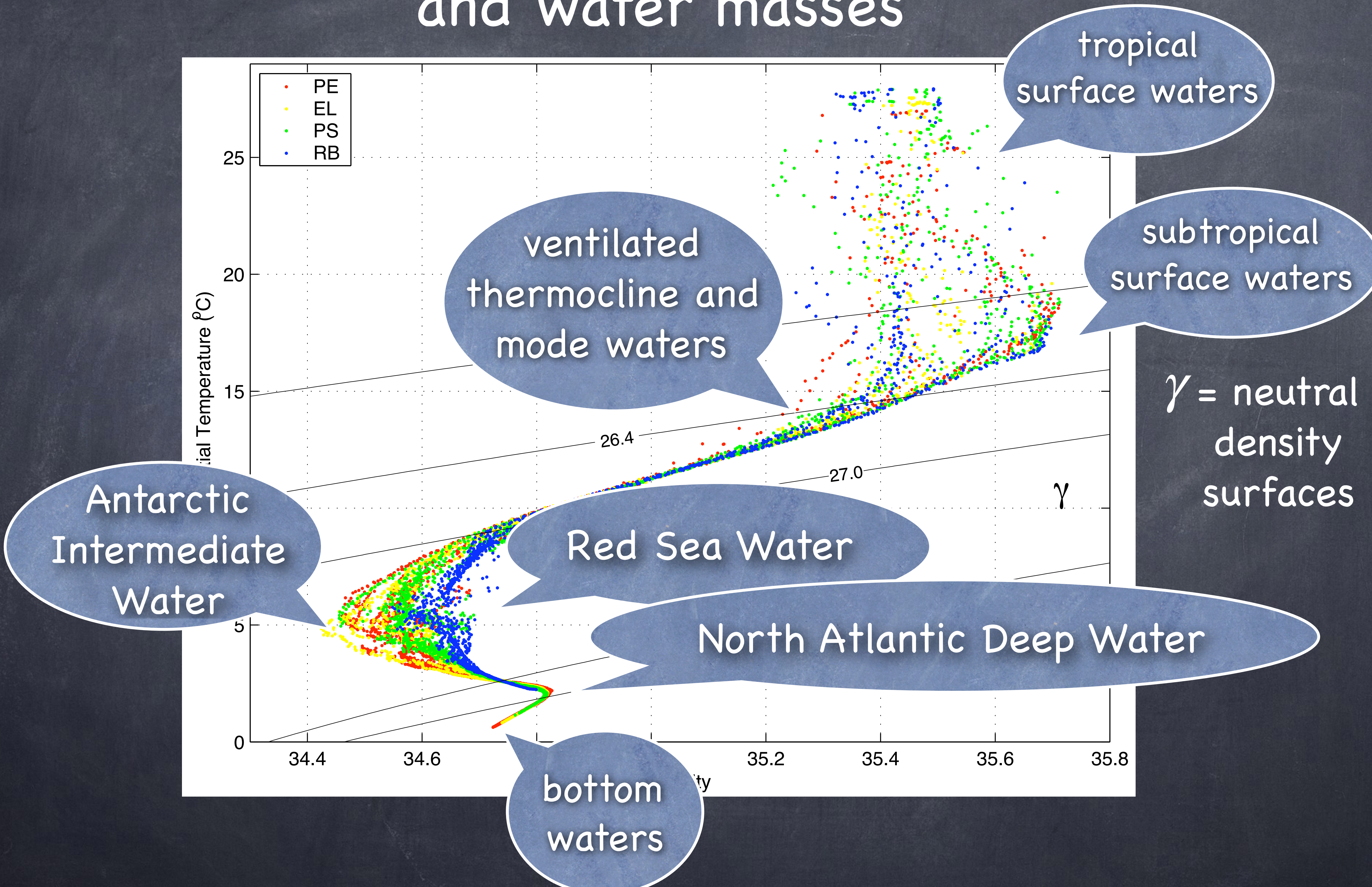


mid-latitude summer



polar winter

Example of a T/S (or T-S) diagram and water masses



γ = neutral density surfaces

Potential Temperature, Θ

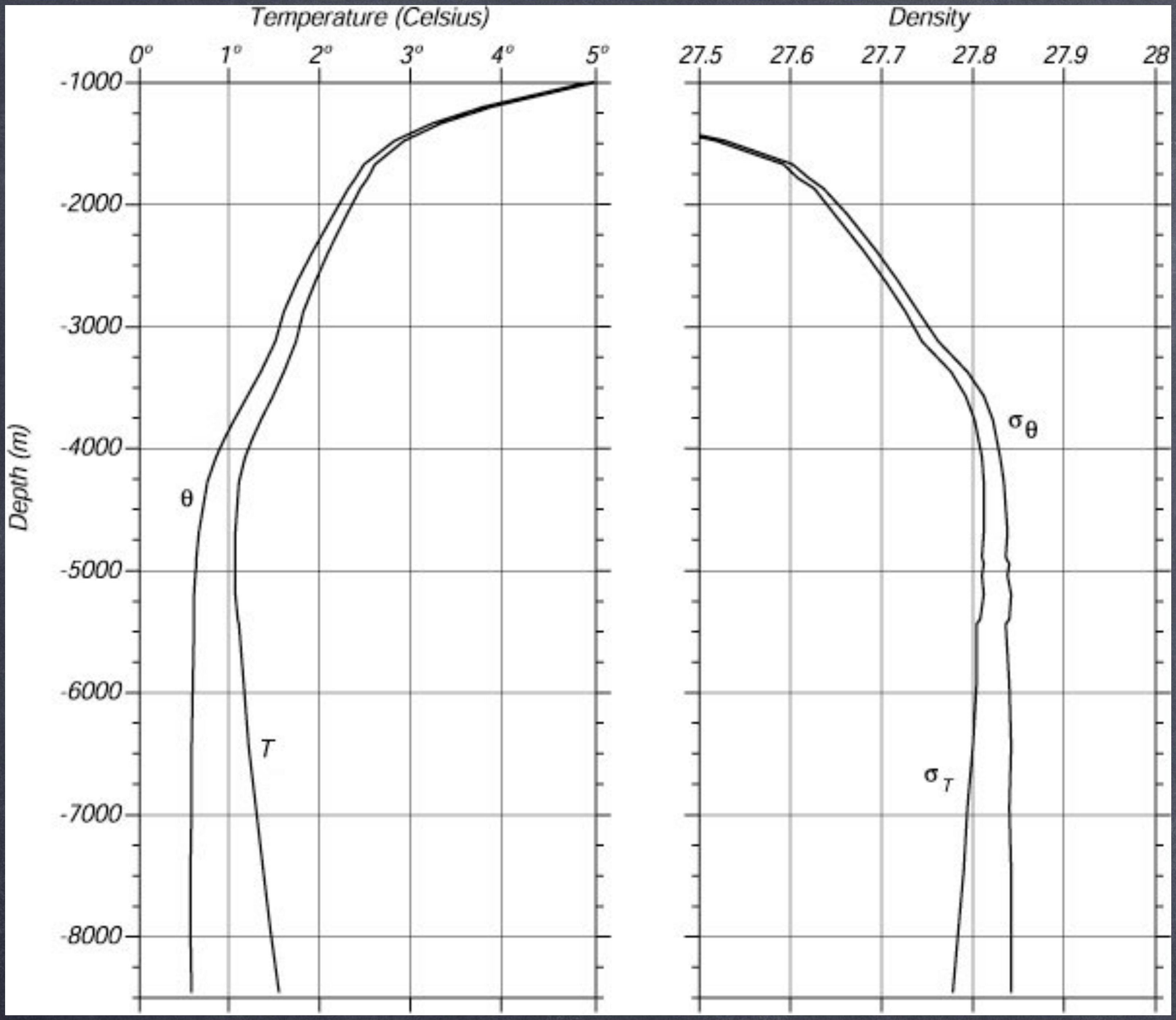
- A parcel of water moving from one pressure to another will be **compressed** or **expanded**
- When compressed adiabatically (without exchange of heat with surroundings) the parcel's temperature will increase. When expanded, its temperature will decrease.
- But, this T change does not represent a true change in energy, or heat content, of the fluid parcel
- To compare, or trace, parcels at different pressures we need to remove the effect of adiabatic contraction or expansion, called "Lapse Rate"

Potential Density, σ_θ

- A parcel of water moving from one pressure to another will be **compressed** or **expanded**, changing its density.
- Potential density, σ_θ is the density of a fluid parcel that has been moved adiabatically to a reference pressure.
- But, compressibility is dependent on T (and S). e.g. cold water is more compressible than warm.
- To minimize the non-linear effect of thermal expansion and saline contraction on compressibility, we must choose a nearby reference: σ_1 = 1000 dbar, σ_2, σ_3,...

Neutral Density, γ

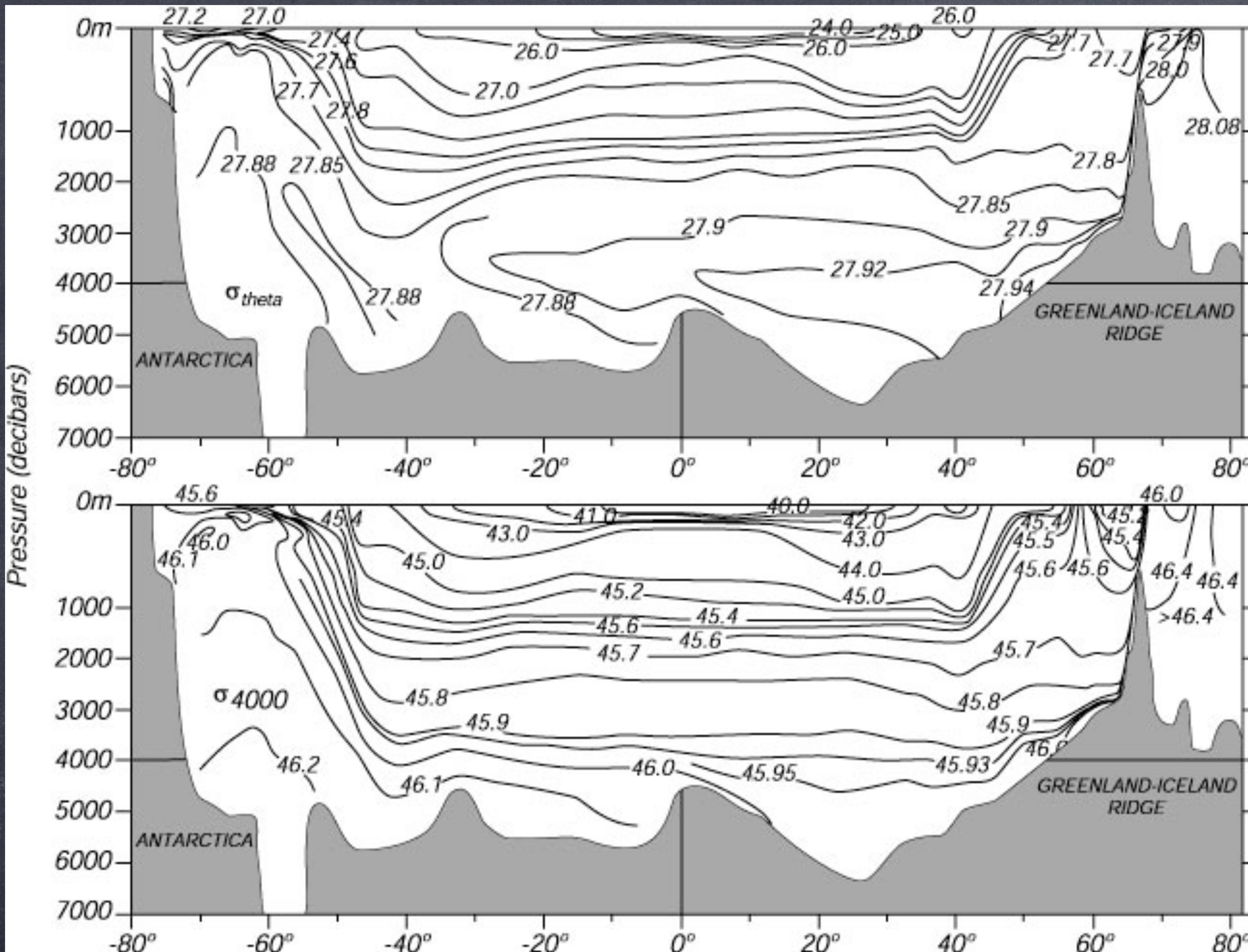
- If water moves with no exchange of heat or salt, it must be moving on an isentropic, or neutral, surface.
- A neutral surface can be approximated as a constant potential density referenced to a local pressure.
- Jackett and McDougall (1997) developed these neutral surfaces and they available as a look-up table
- $$\gamma = f(S,T,p,lon,lat)$$



Temperature and potential temperature

Density and potential density

Potential temperature and potential density = T and ρ with effects of pressure removed.



Density versus depth, Western Atlantic. Upper: σθ, showing an apparent density inversion below 3,000 m. Lower: σ4 showing continuous increase in density with depth. Depth scale changes at 1000 m depth. From Lynn and Reid (1968).

Potential density must be referenced to a nearby density surface. Best to use neutral density.

Stability and Buoyancy Frequency

$$Stability, E = -\frac{1}{\rho}\frac{d\rho}{dz} \qquad Buoyancy\ Freq., N^2 = -\frac{g}{\rho}\frac{d\rho}{dz}$$

- Buoyancy force is the difference between the density of the water parcel and the surrounding fluid

$$a = \frac{F}{m} = \frac{V\partial\rho g}{V\rho}$$

$$\frac{\partial^2 z}{\partial t^2} = \frac{g}{\rho}\frac{\partial\rho}{\partial z}\partial z \quad take\ initial\ z = 0$$

$$\frac{\partial^2 z}{\partial t^2} + N^2 z = 0,\ where\ N^2 = -\frac{g}{\rho}\frac{\partial\rho}{\partial z} = gE$$

$$Harmonic\ with\ solution\ z(t) = sin(Nt)$$

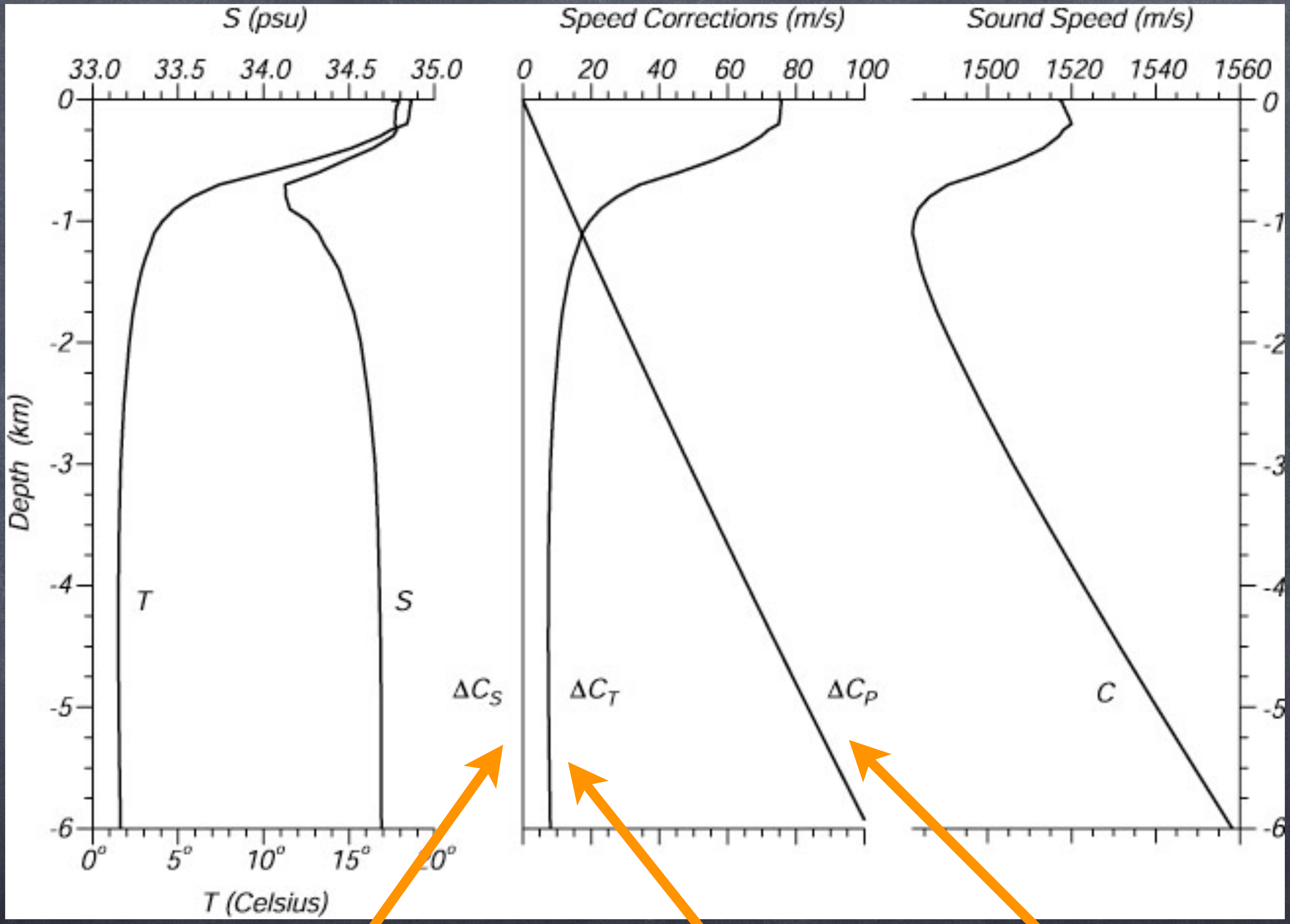
Stability and Buoyancy Frequency

$$Stability, E = -\frac{1}{\rho}\frac{d\rho}{dz} \qquad Buoyancy\ Freq., N^2 = -\frac{g}{\rho}\frac{d\rho}{dz}$$

- E and N^2 are positive for stable stratification, negative for unstable
- A water parcel is more stable if the local density gradient is large
- Water parcels oscillate at frequency N^2 in stably stratified fluids. Period is minutes in thermocline and hours in deep ocean

Effect of p,T, and S on sound speed.

Sound is a compression wave that travels 5X faster through water than air



effect of S on sound speed

effect of T on sound speed

effect of p on sound speed

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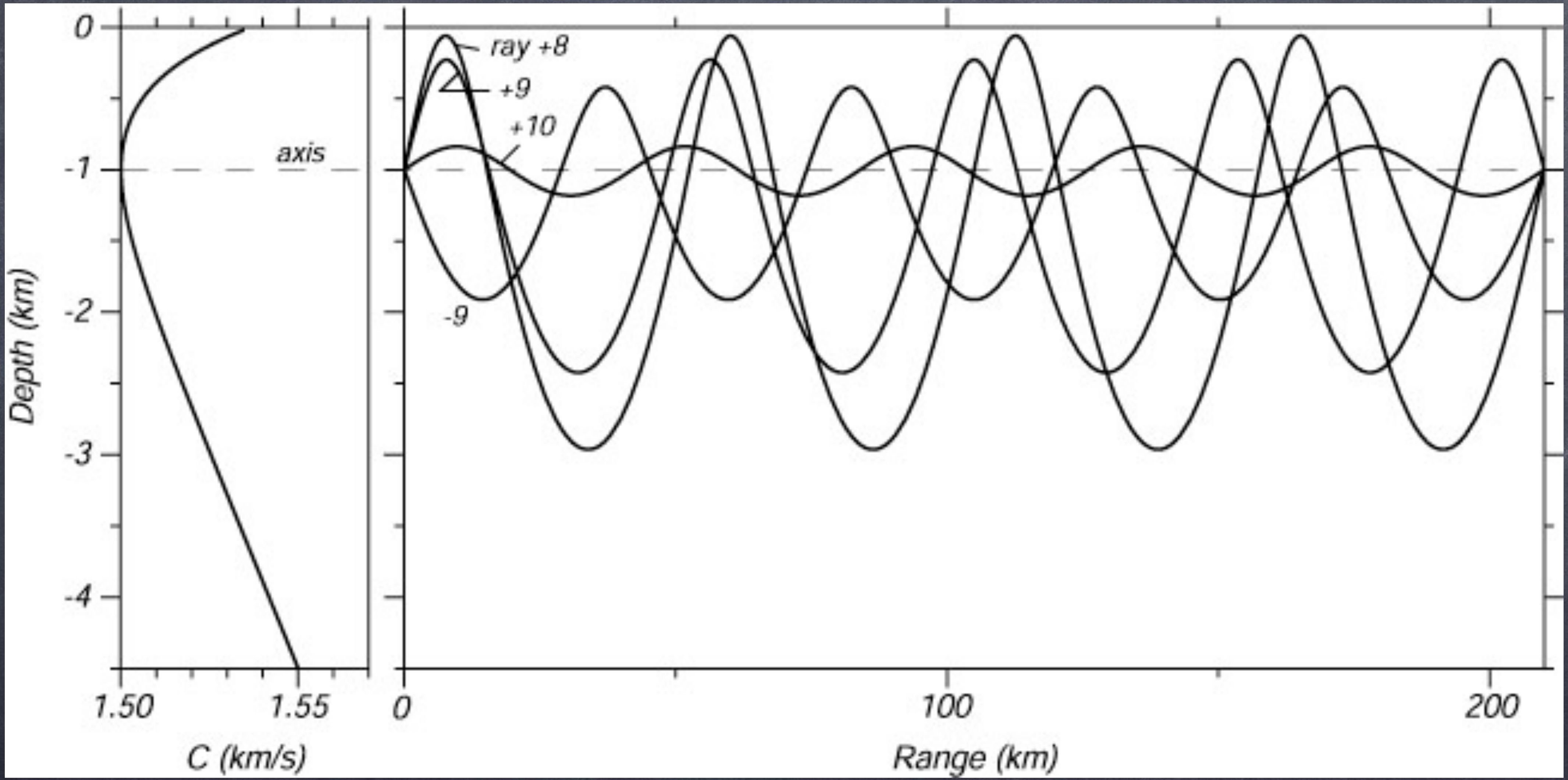
Ray paths of sound in the ocean for a source near the axis of the sound channel. Munk et al. (1995).



Rays are bent (or attracted) towards sound speed minimum = SOFAR channel