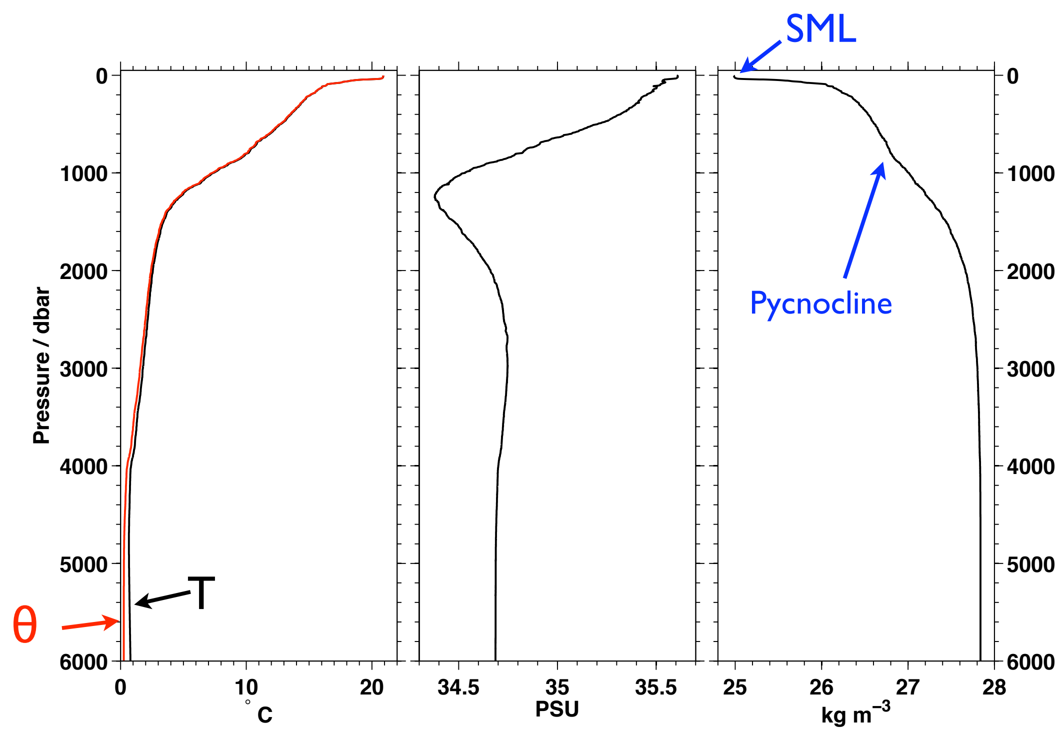
Homework # 3, Due October 14th

1) Below are profiles from a mystery location.



a. Of the two profiles in the left panel, one is temperature and one is potential temperature. Identify which is which.

b. The maximum pressure plotted here is 6000 dbar. It's important to keep in mind the actual depth of the instrument when making these measurements (so you don't smash into the bottom). Using a rough estimate of the average density, what's the maximum depth?

Using the hydrostatic balance, $(\Delta p/\Delta z) = -\rho g$, a pressure of 6000 dbar = 6×10^7 N/m^2, and an approximate average density of 1040 kg/m^3 (actual density is larger than the potential density plotted above), we get $z = p/(\rho g)$ = 5880 meters.

c. In the potential density profile (right panel), label the surface mixed layer and pycnocline. Is the mixed-layer shallow or deep compared to typical values? What time of year might this profile have been taken?

The mixed layer is shallow, this profile was taken in summer.

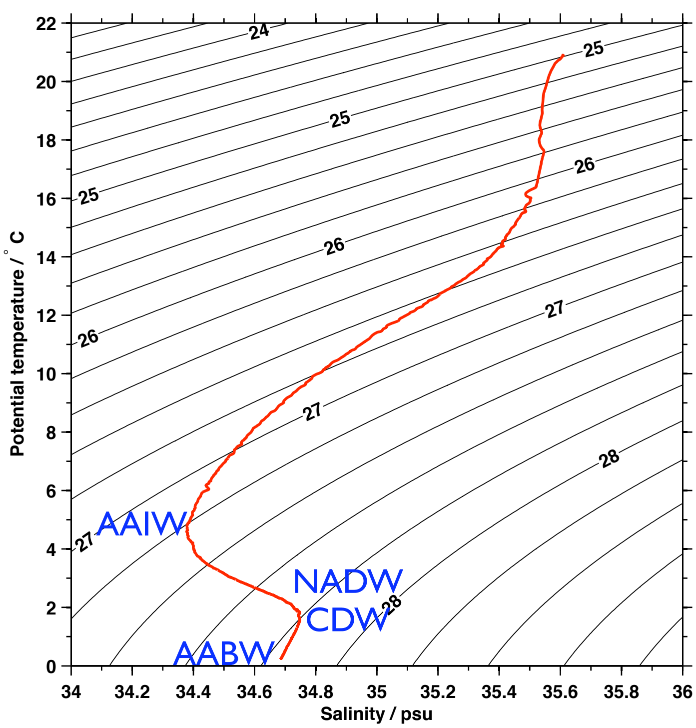
d. In the blank panel (next page) draw a T-S diagram that goes with these profiles.

e. Based on your T-S diagram, discuss in a few sentences what type of water masses are present here, and where they might be coming from.

At the surface we see warm, salty water, characteristic of low-mid latitudes in all basins and most of the North Atlantic. Beneath that is a fresh water layer that looks like intermediate water, most likely formed in the high P-E (precip - evaporation) region at high latitudes. Many people suggested this layer was related to glacial runoff. However, a positive value of P-E (e.g.lots of rain) is the dominant feature setting low salinity at many if not most sites of intermediate water formation. The minimum salinity is about 34.4. Below that there's a cold, relatively salty layer characteristic of North Atlantic Deep Water (in this case it also happens to include a modified version of NADW known as Circumpolar Deep Water that's formed in the Southern Ocean and exported to intermediate layers in the southern hemisphere). And finally at the bottom the water is slightly fresher and very cold, which is Antarctic Bottom Water.

f. Where do you think this profile might be from? (Chapter 4 of DPO has some helpful T and S sections). Justify your answer with a few sentences.

There are four visible layers (salty, fresh, salty, slightly fresh). In DPO this sort of 4-layer structure is visible in both the South Atlantic (approx 30 S - 10 N) and the Indian Ocean (40S-30S). The surface salinity near 35.5 could be from either place, as could the intermediate water salinity minima near 34.4. However, the third layer (deep water) near 34.7 is a better match with the Indian Ocean. n fact, this profile is from about 57E, 33S in the Indian Ocean.   There were a range of student answers here, with most people guessing either the South Indian or South Atlantic. One important thing to keep in mind with all these sections is that there is also substantial variability in the E/W direction that you can't see from these single sections. Part of the purpose of this question was to point out the difficulty in trying to do such an identification. In reality, there are lots of other measurements (dissolved oxygen or other chemical markers) used to identify water masses.



2) As the earth warms, rising sea-level will threaten many low-lying coastal areas throughout the world. A rise of only a meter may be enough to render many small islands totally uninhabitable. For the following questions you may need to use the following values: $\alpha=3*10^{-4}$ ˚C^{-1}, c_p=4000 J /(kg ˚C) , average ocean surface area = $3.6*10^{14}$ m^3, average density = 1025 kg/m^3.

a. Assuming surface heating is distributed in the top 1000 meters of the ocean, how much "extra" heat flux into the ocean would be required to produce a global sea level rise of 1 meter by 2100?

Let's write down the equations we know that are relevant to this problem.

$$q = \rho\, c_p\, T$$

$$(\Delta\rho / \rho) = -\alpha\Delta T$$

$$(\Delta q / \Delta t) = J / h$$

where q is the heat per volume, T the temperature, J the heat flux, t the time, and h the vertical depth the heating is distributed over. We want to relate heat flux to rise in sea level, so first we can relate heat flux to change in density,

$$\Delta\rho = (-\alpha\ J\ \Delta t) / (h\ c_p)$$

And now we use the conservation of mass to relate the original density to the new density,

$$\rho_1 * h_1 = (\rho_1 + \Delta\rho)*(h_1+\Delta h)$$

Assuming that $(\rho_1 + \Delta\rho) \sim \rho_1$, we put it all together and get,

$$\Delta h = (\alpha\ J\ \Delta t) / (\rho\ c_p)$$

For part a, we want to set Δh = 1m, Δt = 91 years (~2.9e9 s) and solve for J. We get J = 4.7 W/m^2.

b. The actual observed extra heat input over the last decade is approximately 2 W/m^2 (though it is likely to accelerate). What sea level rise would this value produce by 2100?

Here we can use the same equation, but this time we know J=2 and we want h. Plugging in again, we get 0.4 meters.

c. How much glacial ice would need to melt to produce the same sea level rise?

The volume of water needed is 0.4 meters times the surface are, giving 1.4e14 m^3, or 1.4e5 km^3. This is a reasonable rough estimate. To get a more accurate estimate, note that the density of ice is less than that of fresh water (about .92 to 1), so this would give us 1.5e5 km^3 of ice. Note I'm using 1000 as the density of freshwater, not 1025 for seawater.

d. The volume of the Greenland ice sheet is approximately $3 * 10^6$ km^3. Under the more pessimistic warming scenarios, the entire thing could melt. How much would this raise global sea level?

An ice volume of 3e15m^3 gives us a freshwater volume of 2.76e15m^3. Dividing this by the surface area gives about 7.6 meters - very bad news!!