1. (a) Explain briefly what potential temperature ($\theta$) is. Temperature when a water parcel is moved adiabatically to a reference pressure, which can be 0 dbar or any other chosen pressure.

(b) The plots show temperature (T) and potential temperature ($\theta$) profiles at two different locations in the North Pacific. Potential temperature here is calculated relative to a reference pressure at the sea surface. On each plot, indicate which curve is temperature and which is potential temperature. T is the warmer of the two curves on both plots.

(c) On the plots above, indicate where the thermocline is found. High density gradient between surface layer and about 600-800m (right and left plots).

(d) On the plots above, indicate where there is a thermostad. Low density gradient in left plot at about 300-400 m.

(e) Potential temperature can also be calculated relative to other reference pressures. On the plots above, sketch the potential temperature relative to 4000 dbar. (This can be referred to as $\theta_4$) What is your reasoning? Matching T at 4000, increasingly higher towards sea surface.
(f) Construct a very simple "vertical section" from these two profiles. That is, in the following box, make a vertical section of potential temperature. (Be careful about unjustified contouring – you have only TWO profiles to work with.) Draw straight line contours of T between the profiles, matching the temperatures seen in the plots above; easiest to read off depth for a given T from profiles and then draw on diagram.

2. Estimate the non-dimensional aspect ratio (height/length) and Rossby number for the following phenomena:

(a) Surface gravity wave \( H/L \sim 1\text{m}/1\text{m} = O(1); \ R \sim 1\text{day}/1\text{sec} >> 1 \)
(b) Thermohaline circulation \( H/L \sim 5\text{km}/10,000 \text{ km} << 1; \ R \sim 1\text{ day}/\text{decades} << 1 \)
(c) Gulf Stream \( H/L \sim 5\text{ km}/100\text{km} \text{ or } 5\text{km}/1000\text{ km} \) (cross-stream or along-stream); \( R \sim 1\text{ day}/\text{decades} << 1 \)
(d) For which of these will the earth's rotation be an important factor, based on the estimated size of the non-dimensional parameters? Important when \( R << 1 \), so for (b) and (c)

3. Assume you have a column of water 100 m thick. Its initial salinity is 35. 2 cm of water are evaporated from the column. What is the final salinity? You can work this out with volumes, but in the end it is the same as simply looking at the proportion of dilution that is changed by shortening the column. Answer: \( 35(99.98/100) = 34.993 \)

4. The attached figure (next page) is a salinity section from south to north through the length of the Atlantic Ocean.
(a) Circle any region of high salinity near the upper surface of the ocean. Give an explanation in terms of atmospheric forcing for why salinity is high in the region you've circled. I might pick 20-30N. High evaporation due to descending dry air in the high pressure zone in the atmosphere.
(b) Why is it possible to have high salinity water near the sea surface? (why doesn't it sink?) Because stability in these regions is controlled by temperature, which is high at the sea surface.
(c) On the blank potential temperature/salinity diagram, mark where your circled high salinity water might be found. (Use the companion potential temperature section from the lecture or from Chapter 4 of DPO – Fig. 4.11 – to find a reasonable potential temperature.) What is the approximate potential density relative to the sea surface of this water parcel? I chose S 37 psu, Theta 20°C, so pot. dens. about 26 kg/m³.

(d) North of about 40°N at the ocean bottom, the water comes from the Nordic Seas (north of Iceland). As in (c), find a reasonable potential temperature of this bottom water from the companion potential temperature section. Plot it on the potential temperature/salinity diagram. What is the approximate potential density of this water? (relative to the sea surface) I used S 34.9 psu, 2°C, so pot. dens. about 28.0 kg/m³.

(e) At the same latitude there is a high salinity layer at about 1000 m depth. This comes from the Mediterranean Sea but has mixed to a lower salinity at this location west of the Strait of Gibraltar. If this layer started out at 13°C and at exactly the same potential density as the bottom water in (d), what was its salinity at the Strait of Gibraltar? About 37 psu.

(f) On the potential temperature/salinity diagram, sketch the contours of potential density $\sigma_4$ relative to 4000 dbar. Contours should be flatter than those relative to 0 dbar. I sketched them (badly using Acrobat).

(g) Now consider the two parcels of water from (d, e). Would they have the same potential density $\sigma_4$ relative to 4000 dbar? No Which one is denser relative to 4000 dbar? The colder, fresher parcel is denser. Does this help to explain anything about their relative position in the actual water column in the salinity section? Even though the 2 parcels enter over their respective sills at about the same density, when they sink into the N. Atlantic, the colder, fresher parcel compresses more and sinks much farther down as it is denser relative to deeper pressures.