1. The plot shows isopycnals in a western boundary current in the NORTHERN hemisphere. Assume that we know that the flow is geostrophic and strongest at the sea surface.
   (a) Sketch the sea surface height, and indicate roughly how large the variation in surface height would be for a current such as the Gulf Stream.
   (b) Indicate by arrows, arrow heads or arrow tails, the direction and magnitude of geostrophic flow at the sea surface and at a greater depth.
   (c) If the Coriolis force were zero, but the sea surface height distribution were as you drew in (b), which direction would the surface water flow?
   (d) Calculate the total mass above 900 m (bottom of plot) at BOTH the left side and right side of plot (at the vertical dashed lines), assuming: \( \rho_1 = 1025 \text{ kg/m}^3 \), \( \rho_2 = 1026 \text{ kg/m}^3 \), \( \rho_3 = 1027 \text{ kg/m}^3 \), and that the bottom layer has density \( \rho_4 = 1028 \text{ kg/m}^3 \) WITHOUT the extra sea surface height from (a).
   (e) Now do the same calculation including the extra sea surface height from (a).
   (f) Calculate the horizontal pressure gradient at the sea surface (just below the extra sea surface height from (a)). Assume that the distance between the 2 stations is 100 km.
   (g) Use hydrostatic balance and your answers from d and e to calculate the pressure at 900 m at each station (left and right), including the extra sea surface height from (a). Then calculate the horizontal pressure gradient at 900 m, also assuming a distance of 100 km between the stations.
   (h) Use the geostrophic balance to calculate the geostrophic flow at 0 m (sea surface) and at 900 m. Assume a latitude of 30°N.
2. List each of the subtropical gyre western boundary currents (5 oceans). For each of these western boundary currents, provide the following information (use the textbook):

a. Name of WBC system
b. Region where it arises (approximate latitude band)
c. Location of its separation point from the western boundary
d. Approximate maximum transport
e. An aspect of that particular current that makes it unique compared with the other western boundary currents on your list.
f. Estimate of the maximum annual mean heat loss (air-sea flux in W/m²)
g. Which of the WBCs have large heat losses (2 of them) and which have smaller ones (3)? Can you come up with a hypothesis to account for the difference between these two groups?

3. Suppose that the most of the water transported from the Indian Ocean to the South Atlantic is in Agulhas rings.

a. Where and how do Agulhas rings form?
b. Calculate the volume of the upper layer (0-500 m) of an Agulhas ring if its diameter is 300 km. Assume the rings are cylindrical for simplicity.
c. If nine (9) Agulhas rings are produced each year that enter the Atlantic, calculate the total warm water volume transport associated with these rings.
d. Describe the role of this inter-basin transport in the global overturning circulation: where does water from the Indian Ocean go in the Atlantic? How does it return to the Indian Ocean? (In a simplified mean sense.)


a. Choose one of the newly-ventilated (locally-formed) water masses that contribute to NADW.__________________________
   What local process creates this water mass?__________________________

b. Indicate on the map (surface circulation) the location of formation of this water mass.
c. What is the surface source of this water mass?

d. Indicate on the map the location and direction of the Deep Western Boundary Current that carries NADW.

e. What is the approximate net formation rate (overturning rate) of NADW as a whole? (You can give a range of values or an order of magnitude.)

f. The return of this new deep water to the upper ocean requires upwelling. If the upwelling occurs in all regions of the deep ocean, estimate the vertical velocity of the upwelling. You can refine your estimate by assuming that the deep ocean occupies about 60% of the earth's surface.

g. In order for there to be upwelling from the deep ocean to the upper ocean, there must be a widely distributed process that converts deep water to upper ocean water. What is this process? ________________________________

In brief, what might control the rate of this specific physical process?