SIOC 210 Final examination **Name:_____**
Wednesday, December 11, 2019
11:30-2:30 PM

Please put your initials or name on each page, especially if you pull pages apart.

Turn off all phones, iPods, etc. and put them away.
This is a **closed book exam**.
You may use **two pages** of notes, both sides, written or printed.
You may use a non-communicating calculator.

Check which you prefer regarding the return of this exam and other graded materials
_____I will pick up the exam (after Jan. 5)
_____Return the exam etc to me via campus mail (or full address)
Mailcode_____

Possibly useful expressions and values; you will not need most of these.
ρ: use 1025 kg/m^3 for generic calculations
c_p = 4000 J/kg°C
$\rho\ c_p\ T$
1 PW = 10^{15} W = 10^{15} J/sec
Earth's radius: 6371 km
$V_{Ek} = -\tau^{(x)}/(\rho f)$
$f = 2\Omega \sin(\text{latitude})$
$\Omega = 0.73 \times 10^{-4}$/sec
U/fL, 1/fT
sin (30°) = 0.5
sin(50°) = 0.77
1° latitude = 111 km
1 Sv = 1x10^6 m^3/sec
g = 9.8 m/sec^2
Force balance (momentum equation):
acceleration + advection + Coriolis force =
pressure gradient force + gravity + friction

Multiple choice or short answer (2 points each; 14 points total)
For each multiple choice problem, **circle ONE CORRECT answer**.

1. The California Current
(a) is driven by Ekman downwelling in the subtropical gyre
(b) is pushed directly downwind by alongshore winds
(c) is a boundary current that reaches the ocean bottom (several kilometers deep)
(d) is driven by upwelling due to offshore Ekman transport

2. The restoring force in a Rossby wave, which makes the water return back to an equilibrium location, is
(a) the variation of Coriolis parameter with latitude
(b) gravity
(c) potential vorticity
(d) the discontinuity in density between the air and the sea

3. The Kuroshio
(a) differs from other subtropical western boundary currents by including a so-called large meander before it separates from the coast
(b) has a transport on the order of 10 Sv
(c) is the western boundary current of the South Pacific
(d) carries subpolar water to the coast of Japan

4. The speed of a shallow water wave
(a) depends on wavelength of the wave
(b) increases as the bottom depth decreases (becomes shallower)
(c) depends on water depth
(d) depends on what caused it, for instance a storm or an underwater earthquake

5. A neap tide occurs
(a) during full moon (brightest)
(b) during new moon (darkest)
(c) when the moon is in the equatorial plane of the Earth
(d) during half moon

6. Which of the following is NOT TRUE about ENSO (El Nino/Southern Oscillation)
(a) Characteristic period is 3-7 years
(b) Decreases the sea surface temperature of the Eastern Tropical Pacific
(c) Is associated with decreases in fisheries catches along the western coast of South America
(d) Alters the zonal structure of the tropical oceanic heat flux to the atmosphere

7. For the global overturning circulation:
(a) Surface sources of deep water in the North Pacific contribute to the global overturning circulation.
(b) The net overturning transport associated with North Atlantic Deep Water formation is approximately 2 Sv.
(c) Inflow to the Nordic Seas occurs through the branches of the North Atlantic Current.
(d) The Sverdrup balance results in Deep Western Boundary Currents.

Problems

8) (10 points) (2,1,1,1,3,2)
The mean wind stress (in N/m^2) in the eastern and central **South** Pacific is shown in the figure.

(a) Indicate on the figure where coastal upwelling is found.
Sketch the direction of the Ekman transport at this location.
What is the name of the current system where this occurs?_____

(b) Mark the regions of the Westerlies and Trades in mid-South Pacific (subtropical region).

(c) Sketch the direction of Ekman transport relative to these Westerlies and Trades.

(d) Is there Ekman CONVERGENCE or DIVERGENCE in this open-ocean region? (Circle answer.)

(e) Sketch the direction of the Sverdrup transport in the same region as you marked in (c) and (d).
Explain very briefly the dynamics that result in this direction for the Sverdrup transport.

(f) What is the name of the western boundary current is associated with (e)? _____
Mark its approximate location on the map.

9) (10 points) (1, 2,1, 1, 1, 2, 2)
The attached map of surface geostrophic streamfunction from Reid is meant to assist you with a visual map where you can mark some of your answers. The wind map in problem 8 should also be useful.

(a) During "normal" years in the tropical Pacific, which direction do the large-scale winds blow?_____ What do we usually call these winds?_____

(b) What is the distribution of atmospheric pressure at the sea surface in the tropics which drives these winds? That is, where is the pressure high and where is it low?

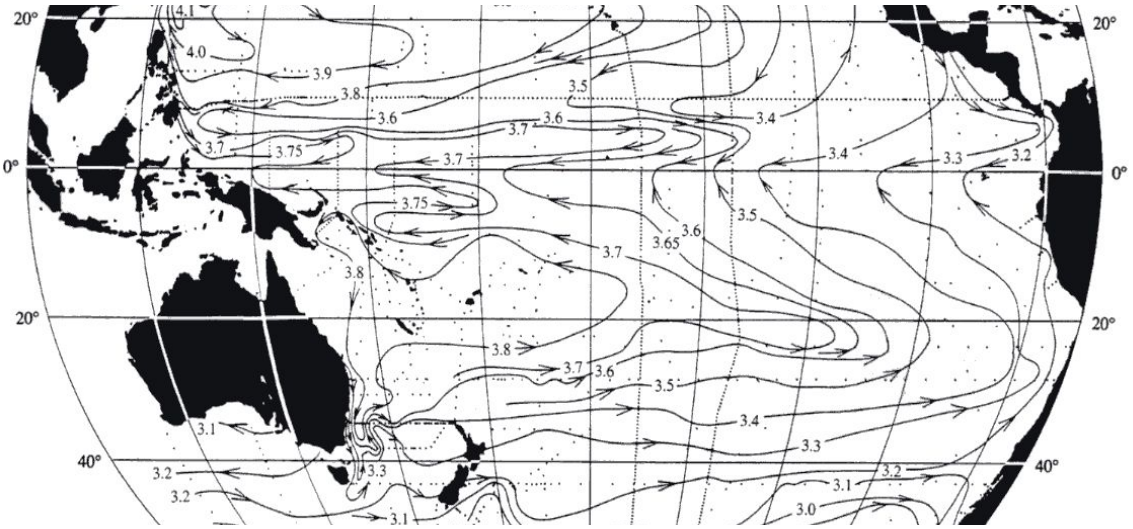
(c) In the region of low surface atmospheric pressure, is it RAINY or DRY? (Circle answer.)

(d) What direction is surface velocity at the equator in a normal year?_____

(e) Is the surface velocity at the equator geostrophic? YES or NO

(f) What are the depth, direction and typical speed of the Equatorial Undercurrent?

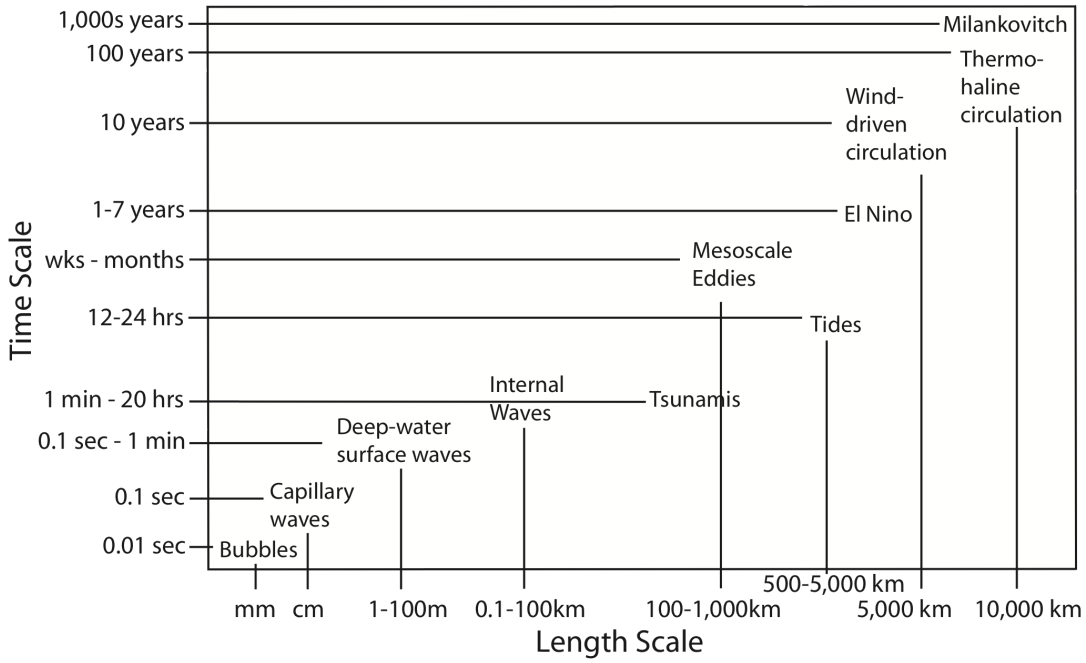
(g) During an El Nino event, does the surface pressure in northern Australia increase or decrease compared with the surface pressure in the central Pacific?



10) (5 points) (2, 1, 2)
(a) Which phenomena in this next diagram are affected by Coriolis force? You can simply circle parts of the diagram and label.

(b) If you compute a Rossby number for these phenomena, which ones have small Rossby number and which ones have large Rossby number?

(c) What is the Rossby number? (Give an expression for it, and explain what it is in words and why it matters.)



11) (10 points) (2, 3, 1, 1, 1, 2)
(a) Define potential temperature.

(b) For a parcel of water at 3000 m, is its potential temperature HIGHER or LOWER than its measured temperature? (Assume that potential temperature is computed relative to the sea surface.) (Circle the correct answer)

Explain why.

(c) Is the freezing point of seawater HIGHER or LOWER than the freezing point of freshwater? (Circle the correct answer)

(d) What is the approximate freezing point of seawater? (in °C)

(e) Is sea ice formed from seawater FRESHER or SALTIER than the seawater? (Circle the correct answer)

(f) How does your answer to (e) relate to the formation of Antarctic Bottom Water along the continental shelves of Antarctica?

12) (6 points) (1,1,1,1,2)
We quantify the amount of water and properties moving through the ocean using transports. Calculate the approximate **volume transport** of a simplified Gulf Stream.

(a) What is the typical surface speed of the Gulf Stream?

(b) What is the typical bottom speed of the Gulf Stream?

(c) What is the typical width across the Gulf Stream?

(d) What is the typical depth of ocean in the Gulf Stream?

(e) Use these quantities, from a, b, c, d and calculate the volume transport of the Gulf Stream. Assume that the velocity of the Gulf Stream is the average of the surface and bottom speed. (Is this likely an overestimate or underestimate?)

13) (9 points) (1,1,1, 2,4)
Oxygen is an important tracer of water masses. It is subject to physical, chemical and biological processes.

(a) What process creates highest oxygen content?

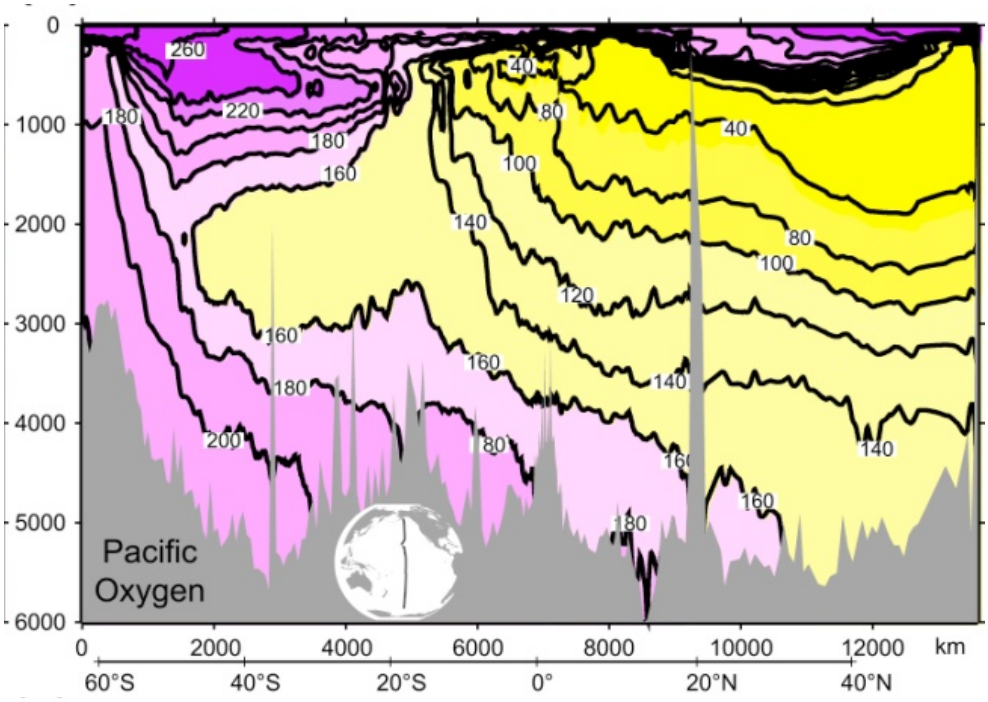
(b) What process creates lowest oxygen content?

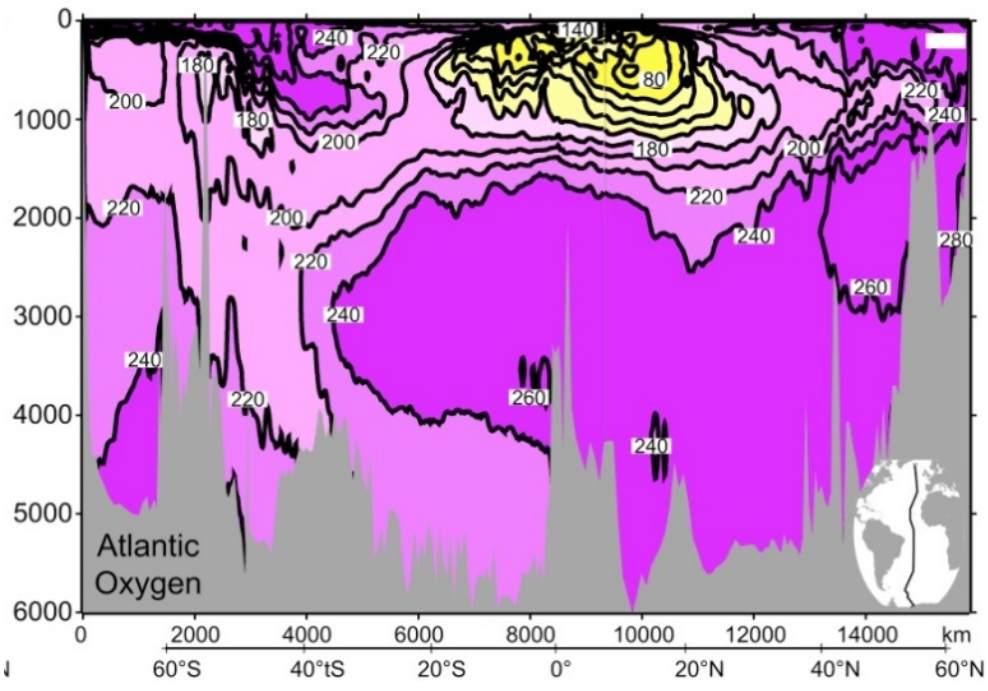
(c) If oxygen is completely saturated (100%), is its concentration in μmol/kg HIGHER or LOWER where the water temperature is highest? (circle one)

(d) The plots are oxygen (μmol/kg) sections in the Pacific and Atlantic.
Mark the Pacific Deep Water (PDW).
Mark the North Atlantic Deep Water (NADW).

(e) Using these oxygen plots, explain how deep water formation differs between the North Atlantic and North Pacific. That is,

What is the process of deep water formation in each ocean?
How does that lead to its characteristic oxygen values?



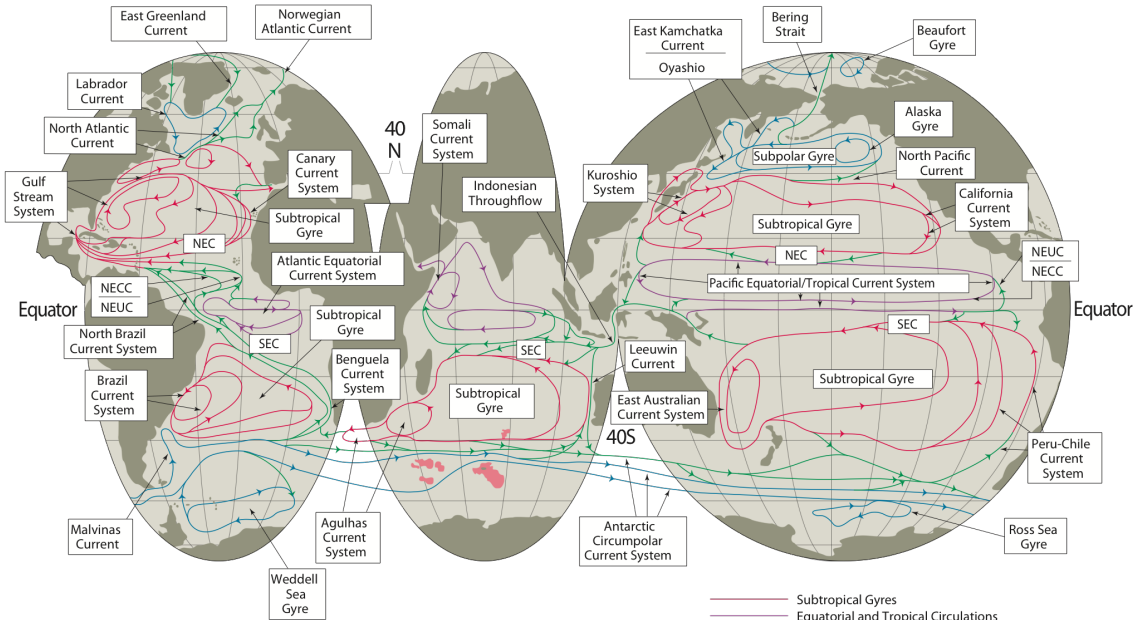


14) (8 points) (2,2,4)

(a) On this schematic map of surface geostrophic circulation, which large-scale circulation features are anticyclonic?
Circle one in each of the five ocean basins (N Pacific, S Pacific, N Atlantic, S Atlantic, Indian).

(b) Choose one of your anticyclonic features: relative to that feature, where is the sea surface high and where is it low?

(c) Explain your answer to (b): what is the force balance in a geostrophic flow?
What does this tell you about where the surface height is high and low?



15) (10 points) (5, 2, 1, 1, 1)
The figure shows potential temperature along a vertical section in the Pacific Ocean (see small map).

(a) Describe and explain the overall structure:
Why the observed distribution of cold and warm water?

Why the tilting isotherms and what do they indicate?

Differences between the South and North Pacific?

(b) Where is the thermocline in this figure? Indicate it on the figure.

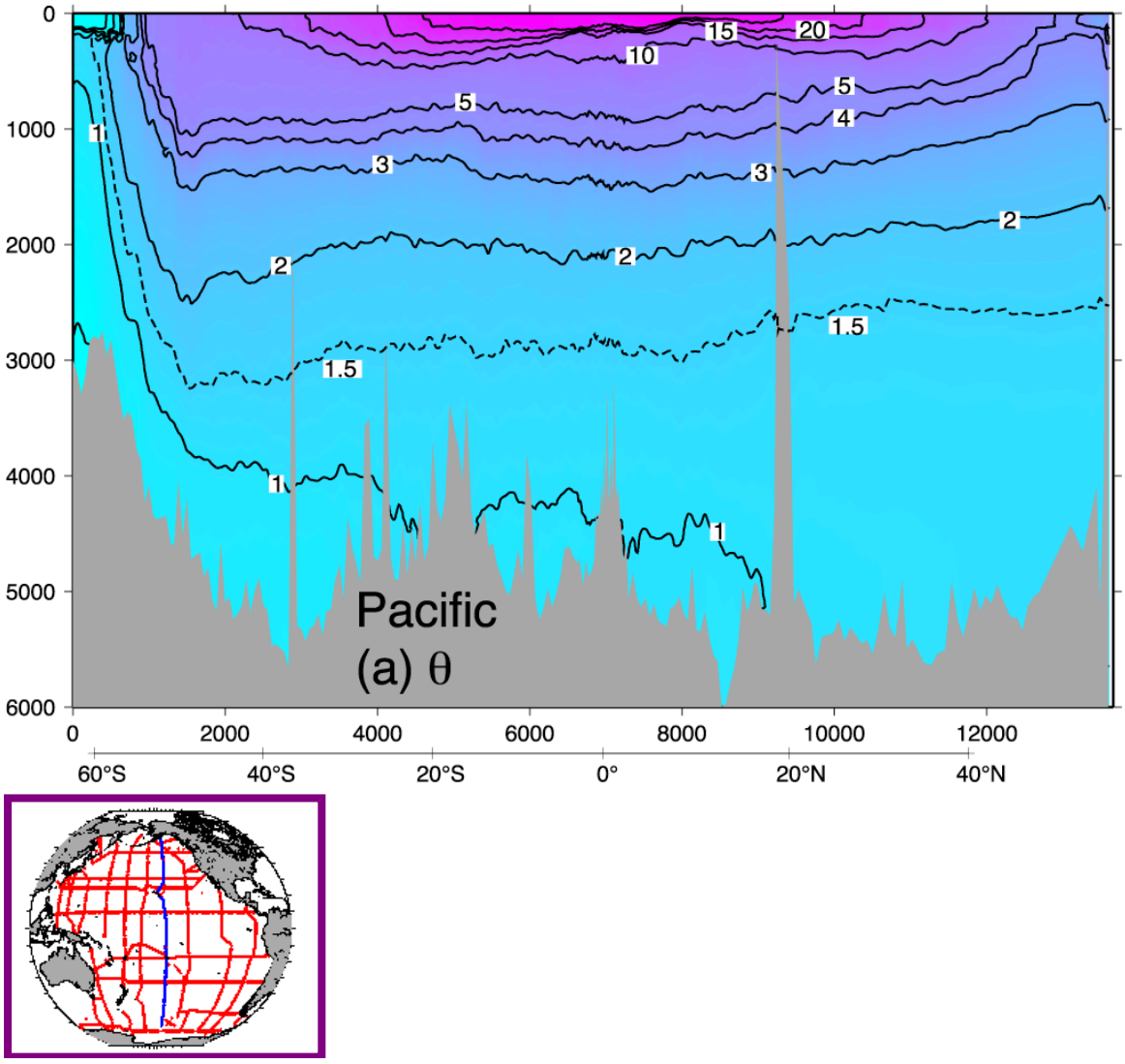
(c) Assuming that density looks mostly like this temperature distribution, use the sloping isotherms to

Identify the location of the current with the strongest vertical shear (geostrophic velocity). MARK it on the section.

What is this current called?_____

Which direction does this current flow? _____

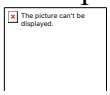
MARK it on the section using our symbols for current direction.



16) (6 points) (2, 1, 2, 1)
A wave is characterized by its wavelength and its frequency.
(a) For surface gravity waves that we observe from the beach here in La Jolla, what is a typical wavelength? _____What is a typical frequency?_____

(b) If the water depth is 4000 m, and you have a surface gravity wave with the wavelength you just specified in (a), is that wave a
DEEP WATER wave or a SHALLOW WATER wave? (Circle correct answer)

(c) Which of these two expressions is the phase speed of a SHALLOW WATER wave? c is phase speed, g is gravity, H is depth, and k is wavenumber.

or


(Circle correct answer)

(d) In either of these surface gravity waves (deep or shallow), what is the restoring force for the wave? That is, when the water is disturbed, what force causes the disturbance to change?

17) (8 points) (2,1,1,1,3)
During particular times that occur regularly, the earth, moon and sun are aligned to produce **anomalously (high) high tides**.

(a) Sketch the alignment of the moon and sun relative to the earth at such a time.

(b) What are these 'particular times'?

(c) What is the name given to this anomalously high tide?_____

(d) What is the typical period for the anomalous high tide? (That is, what is the time interval between anomalously high tides?)

(e) The semi-diurnal tide has high tide twice a day. Why are these two high tides usually not the same height?

That is, explain why there is a diurnal inequality in the tide. You may use your sketch in (a) to assist, or make a new drawing.

18) (10 points) (2, 2, 2, 4)
This figure is our schematic of the global overturning circulation.

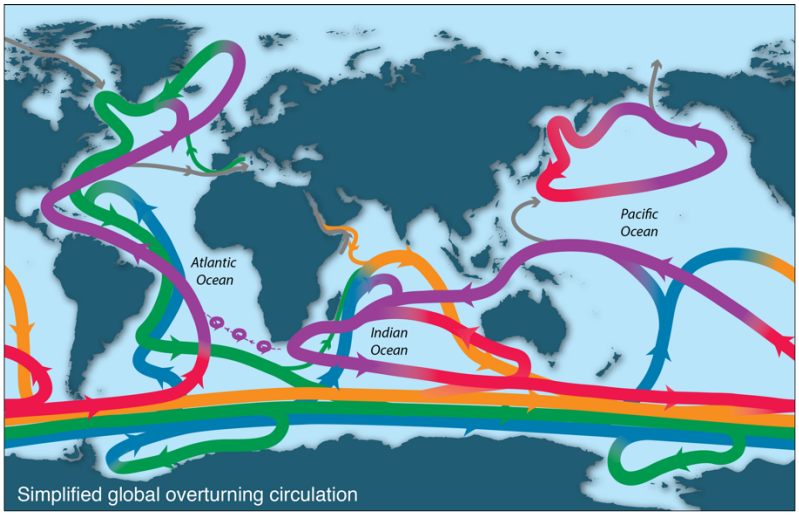
Look at the overturn in the North Atlantic, called the AMOC (Atlantic Meridional Overturning Circulation).

(a) What are the input sources of water from the South Atlantic for this overturn? Circle these sources on the diagram.

Identify them by their water mass names.

(b) Where do these source waters transform to components of North Atlantic Deep Water (NADW)? _____
Circle these locations.

(c) What are the water mass names of these components of NADW in (b), if different from NADW?



Suppose that the net mass transport involved in the AMOC at 24°N is 20 x 10^9 kg/sec (or a volume transport of 20 Sv).

(d) Assume that the inflow is all at one temperature T_{in} and that the outflow is all at one temperature T_{out}. If the net heat transport associated with the overturning is 1 PW = 1x 10^{15} W (W = Watt), what is the temperature difference (T_{in} - T_{out}) ?
(A sketch may help your thinking about this).