

SIO 210 Final examination  
Wednesday, December 7, 2011  
3-6 PM

Name: \_\_\_\_\_

Turn off all phones, iPods, etc. and put them away.

This is a closed book exam. You may use one page of notes, both sides, written or typed.  
No books.

You may use a calculator.

Please mark initials or name on each page.

Please hand in your notes page, if you have one, with your exam.

Check which you prefer regarding the return of this exam and other graded materials

\_\_\_\_\_ I will pick up the exam in Nierenberg Hall 310 (after Dec. 14)

\_\_\_\_\_ Return the exam etc to me via campus mail

Mailcode \_\_\_\_\_

There are two parts: Talley (weighted 80% of exam) and Hendershott (weighted 20% of exam)

Talley portion: 100 points

[1-5] 5 Multiple choice 2 points each \_\_\_\_\_/10

[6-14] 9 Short answer various points each \_\_\_\_\_/90

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**Possibly useful expressions and values; you will not need all of these.**

$\rho$ : use  $1025 \text{ kg/m}^3$  for generic calculations unless otherwise instructed

$c_p = 3850 \text{ J/kg}^\circ\text{C}$

$\rho c_p T$

Earth's radius: 6371 km

$1 \text{ PW} = 10^{15} \text{ W} = 10^{15} \text{ J/sec}$

$C = 2\pi R$

$A = \pi R^2$

$A = 4\pi R^2$

$U_{Ek} = \tau / (\rho f)$  (should have had parentheses)

$PV = (\text{relative vorticity} + \text{planetary vorticity}) / \text{height} = (\zeta + f) / H$

$f = 2\Omega \sin(\text{latitude})$

$\Omega = 0.71 \times 10^{-4} / \text{sec}$

$\sin(30^\circ) = 0.5$

$\sin(50^\circ) = 0.77$

$1^\circ \text{ latitude} = 111 \text{ km}$

$1 \text{ Sv} = 1 \times 10^6 \text{ m}^3 / \text{sec}$  (should have included and did not have it here)

acceleration + advection + Coriolis force =

pressure gradient force + gravity + friction

**Multiple choice** (circle the single best answer for each) (2 points each)

1) Circle the statement that is CORRECT:

The Gulf Stream

- (a) is the Deep Western Boundary Current of the North Atlantic
- (b) has maximum speeds of more than 500 cm/sec
- (c) includes waters that come from the South Atlantic
- (d) is forced by upwelling due to Ekman transport due to winds blowing along the east coast of North America

2) Which of the following is NOT a geostrophic flow?

- (a) Deep Western Boundary Current
- (b) Sverdrup transport
- (c) Leeuwin Current
- (d) Langmuir circulation

3) Which of the following is NOT a part of the Antarctic Circumpolar Current?

- (a) Agulhas Current
- (b) Malvinas Current
- (c) Polar Front
- (d) Subantarctic Front

4) Circle the CORRECT statement about the Pacific Ocean:

- (a) the water at the bottom comes from the surface in the Okhotsk Sea
- (b) the water in the northern hemisphere around 1000 m comes from the surface in the Bering Sea
- (c) the water at about 3000 m comes directly from the North Atlantic
- (d) the Central Water in the thermocline comes from the sea surface

5) When seawater reaches the freezing point

- (a) It is less dense than it is at 4°C
- (b) It all sinks to the abyssal ocean because it is so cold
- (c) It forms ice that becomes less salty than the original sea water
- (d) It is 0°C.

**Short answers**

6) The picture on the next page shows the tropical Atlantic Ocean sea surface temperature (SST) (winter NH and winter SH spliced together – please ignore the discontinuity).

(a) Is the equatorial SST HIGH or LOW in the west compared with the east?

If the coupling between the Atlantic Ocean's SST and the atmosphere is the same as in the equatorial Pacific Ocean:

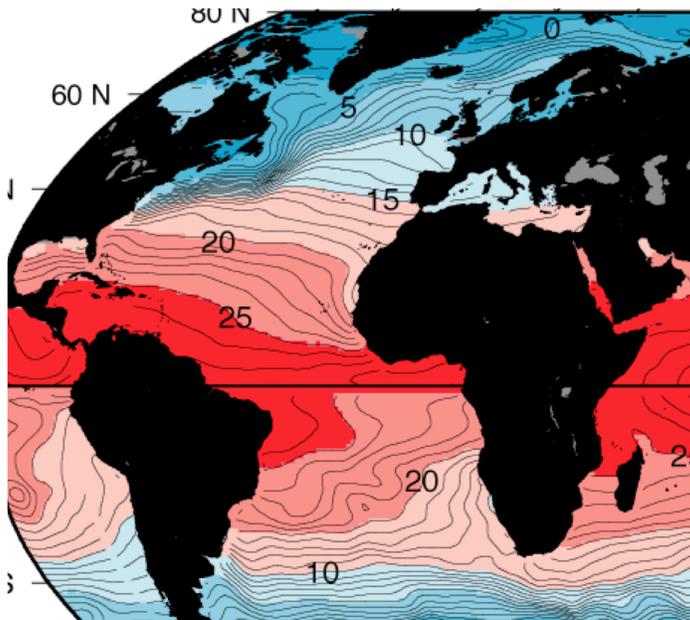
(continued on next page)

(b) SKETCH the direction of the surface winds on the map that would arise from this SST.

(c) MARK on the map, *along the equator*, where you expect the sea surface height (SSH) to be HIGH and where it will be LOW.

(d) What is the direction of the current that will be driven by this difference in sea surface height? \_\_\_\_\_

(e) What is the name of this current? (The names are the same as in the Pacific Ocean.) \_\_\_\_\_



7) Ekman response and transport:

Suppose that the wind blows *northward* along the coast of Washington and Vancouver Island (western coast of North America).

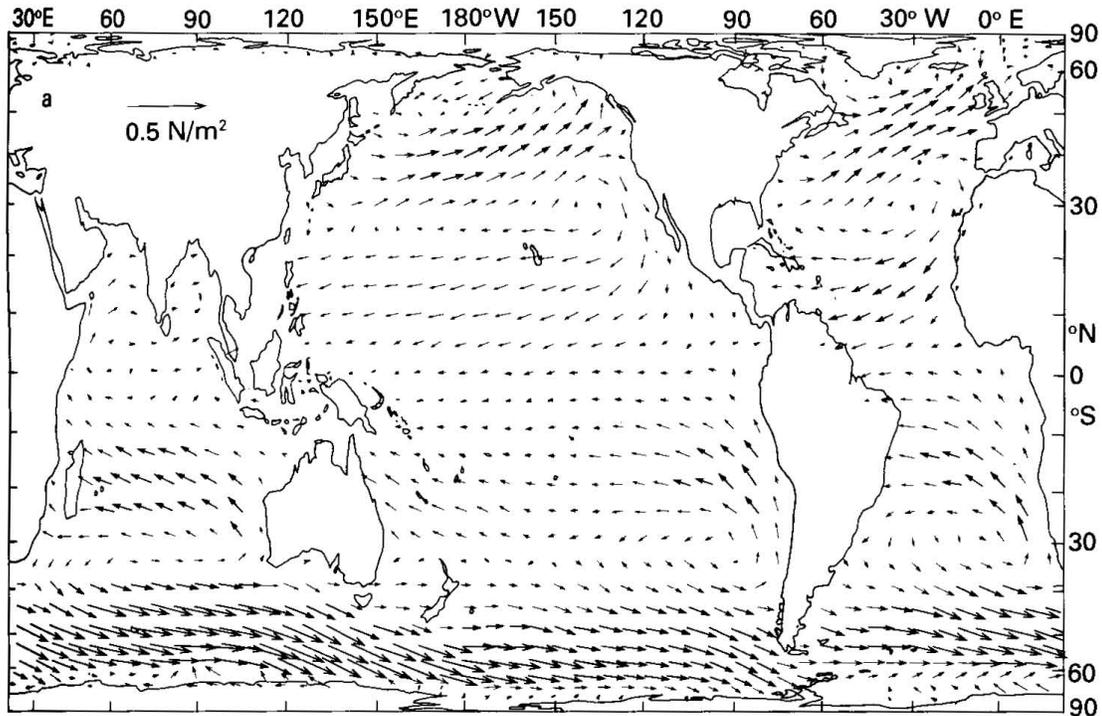
(a) What is the direction of the associated Ekman transport relative to the coast? \_\_\_\_\_

(b) Do you expect upwelling or downwelling along the coast? \_\_\_\_\_

(c) Would you expect to see high surface nutrients along this coastline? (YES or NO)

(d) Contrast this or compare it with the surface nutrients in the open North Pacific along about 50°N. (The map for problem 8 might help you with your answer.)

8) The figure shows annual mean wind stress for the globe.



Focus on the Southern Ocean, along about 50°S. In this region:

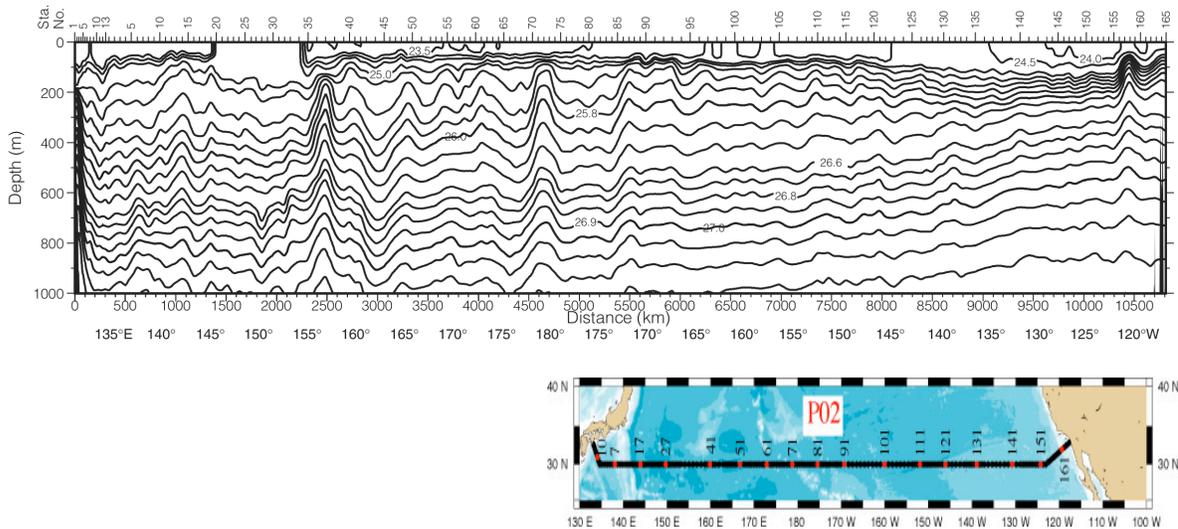
(a) Indicate the direction of Ekman transport on the map in the Southern Ocean region

(b) Calculate the local Ekman transport ( $\text{m}^2/\text{sec}$ ), choosing a typical wind stress from the map. (Assume that the wind stress you pick is appropriate for all longitudes.)

(c) Calculate the total Ekman volume transport ( $\text{m}^3/\text{sec}$ ) at 50°S based on your answer to (b). (The radius of Earth at this latitude is 4,880 km.)

(d) Where is the source of the water in the Southern Ocean that feeds this Ekman transport?

9) The potential density section shown here is from the North Pacific at 24°N. The small map shows its location. Assume that all flows mentioned in this question are geostrophic.



- (a) Indicate where the meridional flow of the subtropical gyre is, based on the 26.6 kg/m<sup>3</sup> contour, and indicate the direction of this gyre flow on the potential density section.
- (b) Indicate PRECISELY where the Kuroshio is on the section, BASED on the potential density contours, and indicate the DIRECTION of the Kuroshio on the potential density section.
- (c) Indicate where the California Current is on the potential density section, and indicate the direction of this current on the potential density section.
- (d) Just above the top of the section, sketch the sea surface height that you would expect to find based on the previous 3 answers. Please ignore the very vigorous mesoscale eddy field. Please be careful to indicate the locations of the above currents as precisely as possible in your sketch.

EXPLAIN why you drew the sea surface height this way.

10) The flows described in the previous problem are forced by the wind. Briefly answer the following questions associated with each of these flows.

(a) What is the relationship between the wind stress and the meridional flow of the gyre? (What is the name of the balance that produces this flow and how is it generated by the wind?)

(b) What is the relationship between the wind stress and the Kuroshio as depicted on this section? (Ignore inertial dynamics that might create a very strong Kuroshio.)

(c) What is the relationship between the wind stress and the California Current?

11) Atlantic overturning circulation.

Deep water is produced in the northern North Atlantic and its marginal seas and flows southward through the tropics and South Atlantic.

(a) What is the overall name of this water mass, especially after it reaches the tropics and South Atlantic? \_\_\_\_\_

(b) Name one location in the northern North Atlantic where *part* of this deep water is formed. (There is more than one answer – please pick just one.)  
\_\_\_\_\_

(c) What is the formation process in the location you just listed? \_\_\_\_\_

(d) What is the name of the part of the deep water that you just described in b and c?  
\_\_\_\_\_

(e) How is this part of the deep water recognized in comparison with other parts of the deep water? (What property and what about that property assists you in recognizing that portion?) \_\_\_\_\_

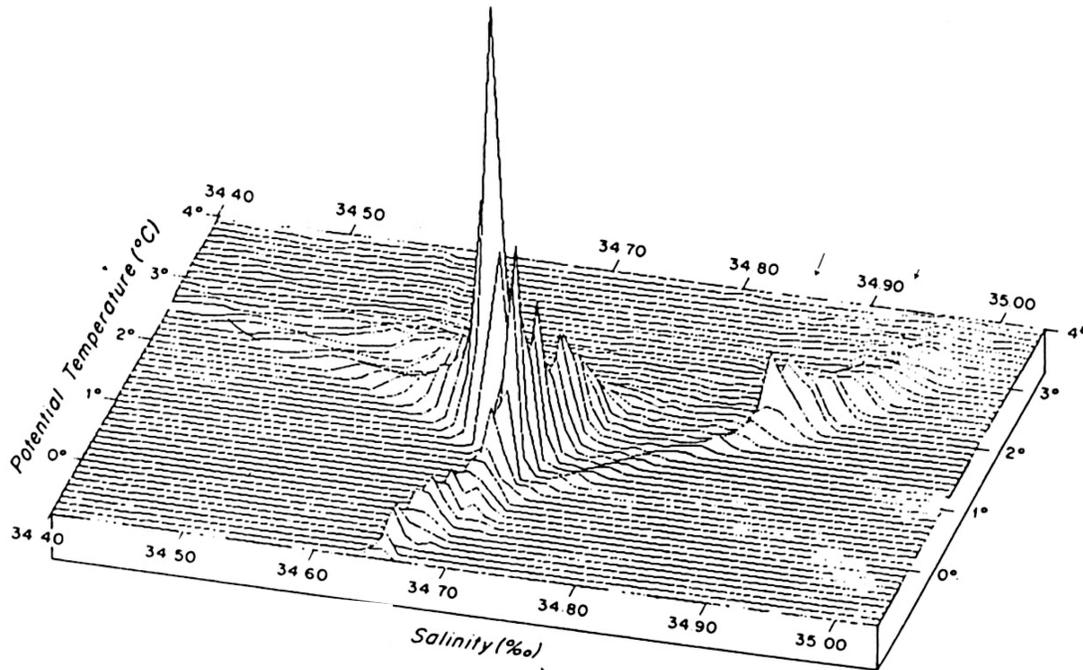
12) Quantifying Atlantic overturning circulation heat transports.

Following up on the previous question: suppose that 20 Sv of deep water is formed. If all of the inflow to the North Atlantic that feeds that deep water formation is in the thermocline (an oversimplification), at an average temperature of 15°C, and if the average temperature of the outflow of deep water is 2°C:

(a) Calculate the net meridional heat transport associated with this water mass formation. (Assume for simplicity that the specific heat and density of the inflow and outflow do not change.)

(b) If this heat transport is associated with Atlantic air-sea heat exchange between 50°N and 70°N, assuming a width of the Atlantic of 3,000 km, what is the average heat flux across the sea surface in this whole region?

13) A volumetric potential temperature-salinity diagram for the global ocean is shown here. Note that it shows only water colder than 4°C. No units are given for the vertical axis (which is volume), but the units of volume are m<sup>3</sup>.



(a) Label the portion of this plot that is associated with the Atlantic Ocean. Explain how you know which part is the Atlantic.

(b) Label the portion of the plot that is associated with the Pacific Ocean. Explain how

you know which part is the Pacific.

(c) Label the portion of the plot that is associated with the Southern Ocean. Explain how you know which part is the Southern Ocean.

(d) Indicate roughly on the plot the isopycnal contours (you do not need to include numbers). Label which are HIGH density and which are LOW density.

(e) For a given potential temperature of, say,  $2^{\circ}\text{C}$ , is the Pacific water LESS DENSE or MORE DENSE than the Atlantic water?

14) A sea surface height map is shown here. The units are centimeters.

(a) Assume that the flow is geostrophic (except at the equator), and indicate as precisely as possible the direction of the geostrophic flow on this map. You don't need to show it at all locations – make sure to provide enough information in the subpolar and subtropical N. Pacific, in the subtropical S. Pacific, and in the Southern Ocean so that I know that you know the answer.

(b) This surface height map was based on thousands of surface drifter measurements. Explain what a surface drifter measures.

(c) Can you come up with an explanation for how the surface drifter measurements can be used to construct this sea surface height map?

