SIO 210 Final examination
Wednesday, December 17, 2014
3-6PM Sumner auditorium 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 printed.
You may use a non-communicating calculator.
Please mark initials or name on each page.

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 Jan. 4)
_____Return the exam etc to me via campus mail (or full address)
Mailcode_____

[1-10] 10 Multiple choice/short 1 points each	_____/10
[11-19] 9 Problems (Talley)	_____/90
Hendershott	_____/20
Total	_____/120

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

ρ: use 1025 kg/m^3 for generic calculations
c_p = 3850 J/kg°C
$\rho\ c_p\ T$
1 PW = 10^{15} W = 10^{15} J/sec
Earth's radius: 6371 km
$U_{Ek} = \tau/(\rho f)$
Ro = U/(fL)
$f = 2\Omega \sin(\text{latitude})$
$\Omega = 0.73 \times 10^{-4}$/sec
sin (30°) = 0.5
sin(50°) = 0.77
1° latitude = 111 km
1 Sv = 1x10^6 m^3/sec
acceleration + advection + Coriolis force =
pressure gradient force + gravity + friction

Multiple choice (1 point each; 10 points total)
For each multiple choice problem, **circle ONE CORRECT answer**.

1. The force balance in an Ekman layer is between
(a) acceleration and pressure gradient force
(b) advection and Coriolis force
(c) Coriolis force and vertical diffusion
(d) Coriolis force and horizontal diffusion

2. Brine rejection
(a) creates North Atlantic Deep Water
(b) causes sea ice to become salty
(c) occurs in hydrothermal vents
(d) causes Antarctic shelf water to be denser than Antarctic Surface Water

3. Subducting flow is associated with
(a) High nitrate at the sea surface
(b) Formation of slightly warmed water at deep sea tectonic subduction zones
(c) Central Water
(d) Nordic Sea Overflow Water

4. During the Asian Southwest monsoon
(a) the Somali Current flows northward
(b) the Somali Current flows southward
(c) India has its dry season
(d) the tropical Pacific enters a La Nina phase

5. The Subantarctic Front marks
(a) the northernmost extent of Antarctic shelf water
(b) the southernmost extent of Antarctic Intermediate Water
(c) the northernmost extent of sea ice
(d) the zero of wind stress

6. The northeastward circulation in the northeastern North Atlantic, between the Reykjanes Ridge and Ireland, far to the south of Iceland, is called the
(a) Labrador Current
(b) Azores Current
(c) North Atlantic Current
(d) Norwegian Atlantic Current

7. Seawater compression
(a) is important for geostrophic balance
(b) is important for sound waves
(c) is important for tides
(d) is important for the outflow of fjords

8. The Rossby number is
(a) an indication of existence of a large-scale wave
(b) small when flow is geostrophic
(c) large in an El Nino
(d) an indication of the speed of a tsunami wave

9. The Equatorial Undercurrent
(a) flows from east to west
(b) is driven directly by the frictional wind stress
(c) is one of the strongest currents in terms of speed
(d) extends to the ocean bottom

10. Wind stress acting on the ocean's surface
(a) causes surface flow to the right of the wind in the Southern Hemisphere
(b) causes counter-rotating vertical cells with convergences aligned with the wind
(c) pushes the North Pacific Current to flow downwind beneath the Westerlies
(d) heats the ocean

Very short answer (5 points)
11. Circle the western boundary currents in the following list. There are several (more than one).

circle WBCs	list the ocean for every current including "South" or "North" if appropriate
Leeuwin Current	_____
Gulf Stream	_____
Oyashio Current	_____
Antarctic Circumpolar Current	_____

Problems 10 to 15 points each

12. (10 points)
(a) In the subtropical *South Atlantic*, the meridional heat transport across 30°S is approximately 0.5 PW northward. Much of this transport is associated with the global overturning circulation. Sketch the circulation in a vertical cross-section, and label the northward and southward portions. If there are specific water masses associated with these portions, please include those names. Indicate which part of the circulation is warmer and which part is cooler.

(b) If the circulation transports 10 Sv northward, and returns 10 Sv southward, what is the difference in temperature between the northward and southward parts of the circulation? (*calculate)*

13. (10 points) The potential vorticity for the general circulation (both wind-driven and abyssal) is

$$PV = (\zeta + f)/H$$

(a) Which terms are the relative vorticity _____, planetary vorticity _____, and related to stretching_____? (Fill in the blanks.)

(b) For the abyssal circulation, Stommel-Arons model, which terms in the PV are dominant? Which term(s) are ignored?

(c) For abyssal circulation, explain the external forcing for the flow. (For instance, is it wind, dense water formation, topography, etc.?)

(d) For the abyssal circulation, describe the pattern of horizontal circulation. Assume the ocean has a flat bottom, and that it has vertical sides, including meridional boundaries.

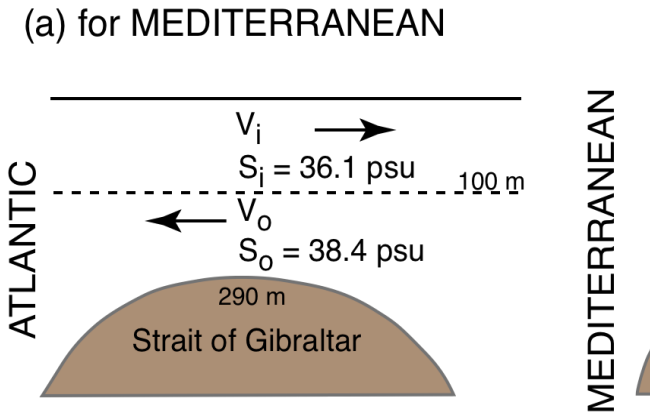
14. (10 points) ENSO is a coupled climate phenomenon in the tropical Pacific that has both regional and global impacts.

(a) The Bjerknes feedback between the ocean and atmosphere maintains the distribution of equatorial winds and ocean circulation. Describe how this feedback works during "normal" or La Nina years.

(b) Describe how the ocean-atmosphere system is different during El Nino years.

c) During an El Nino event, the surface waters along the Peruvian coast become warmer. Why are the Peruvian surface waters usually cold?

15. (10 points) The North Atlantic and the Mediterranean Sea are connected through the narrow Strait of Gibraltar, which has a two layer flow. See the figure. In the Strait, all inflow to the Mediterranean is in the surface layer, and all outflow back to the Atlantic is in the bottom layer.



Assume that the inflow transport and outflow transport are approximately equal. Given:

average inflow salinity is 36.1
average outflow salinity is 38.4
Average exchange volume transport V is 0.7 Sv = 0.7 x 10^6 m^3/sec

(a) (7 points) Freshwater: calculate the net Evaporation – Precipitation – Runoff within the Mediterranean. Use the Average exchange volume transport. Express your answer in Sv (either mass or volume based).

(b) (3 points)
Using your answer to (a), if the inflow volume transport is exactly 0.7 Sv, what is the estimated outflow volume transport? (Note that we assumed they are approximately equal in (a), and now we being more accurate and saying that they are not exactly equal.)

16. (10 points) A map of adjusted steric height, corresponding to geostrophic streamlines, in the Pacific at the sea surface and near the ocean bottom.

(a) On the map, mark the Kuroshio and California Current.

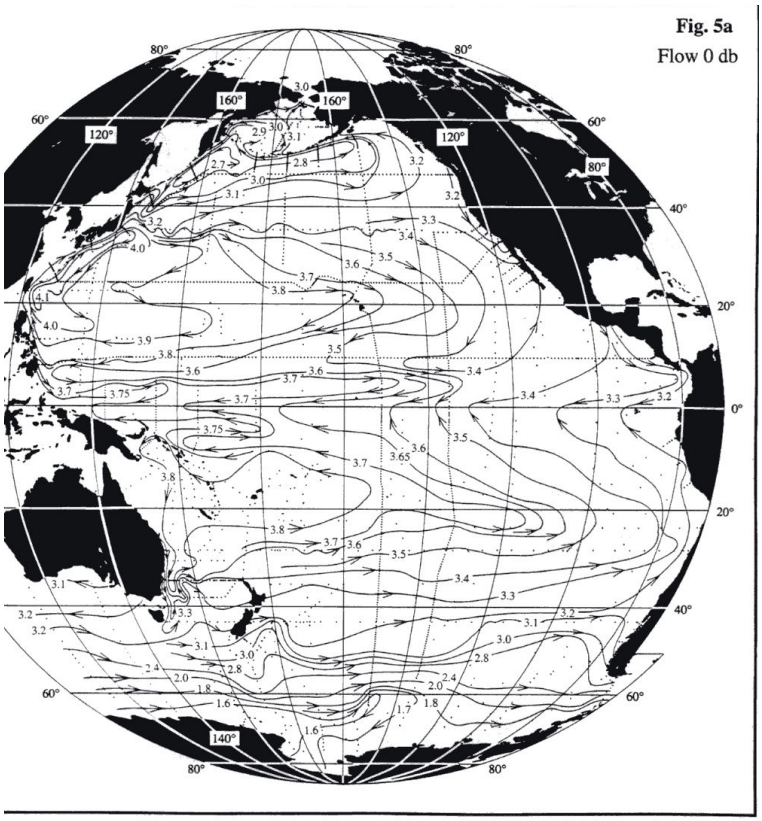
(b) Mark the high and low pressure regions associated with the Kuroshio and its associated large-scale circulation (gyre).

(c) Are these circulations associated with anticyclonic or cyclonic flow? Explain the direction of the flow in this current system relative to the highs and lows.

(d) What is the approximate steric height difference across the Kuroshio?

(e) What is the approximate steric height difference across the California Current?

(f) Estimate the *relative strength* of the surface current in the Kuroshio and in the California Current. Do not calculate the absolute velocities, just the relative sizes.



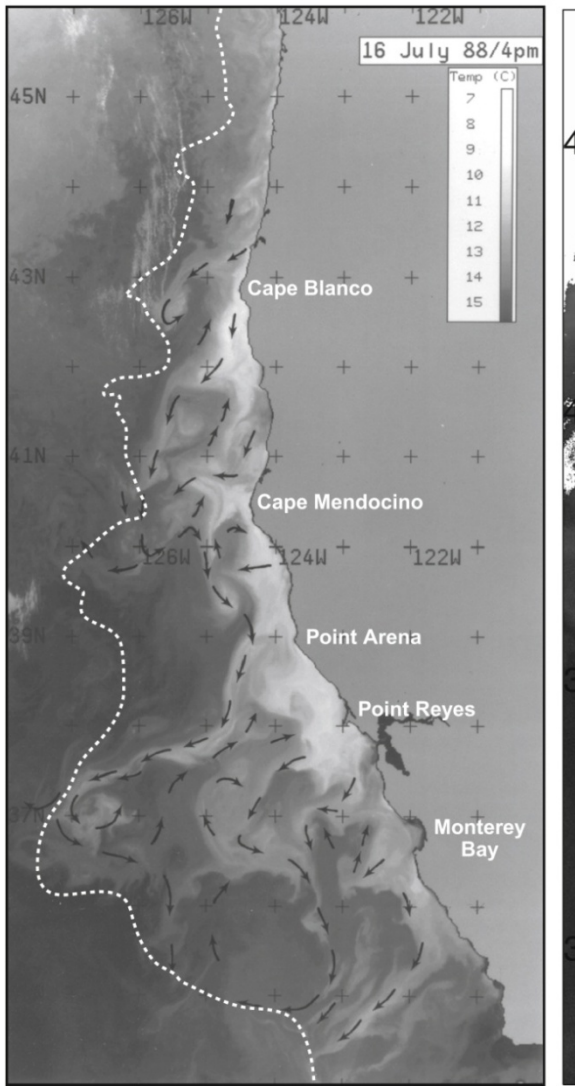
17. (10 points) The satellite image shows surface temperature on a particular day, in shades of gray, along the coast of California and Oregon. Surface currents are also shown (small arrows).

(a) Explain in the simplest terms why there is cold water along the coast. Draw the direction of the wind as part of your explanation.

(b) What is the name of this circulation system? What direction is the overall surface current, at the largest scale?

(c) The synoptic temperature and current distribution is more complicated than this simplest description. Explain in simple terms why this is so.

(a)



(b)

18. (15 points) The attached color figures are zonal sections of various properties (potential temperature, salinity, oxygen, CFC-11) across the North Atlantic, at 24°N. The map of the section is inserted on the CFC-11 figure.

Neutral density sections at 24°N (left) and 36°N (right) are also attached. Some density features are clearer at 36°N because there is no island near the western boundary.

(a) Locate and mark the Gulf Stream on the 36°N neutral density section.

(b) Locate and mark the Canary Current on the 24°N neutral density section.

(c) Locate and mark the southward flow of the North Atlantic's subtropical gyre on both neutral density sections.

(d) The above circulations are all surface-intensified circulations. Along the top of the 36°N neutral density section, sketch a smoothed version of the sea surface height that is associated with these circulations. Make sure that your sketch corresponds with a smoothed version of the neutral density section. Make sure that your sketch shows the regions that have high and low surface height.

(e) At the left side of the 36°N section, explain the direction of the circulation in terms of the sea surface height that you have just sketched. That is, given the sea surface height, what direction does the circulation go? Why?

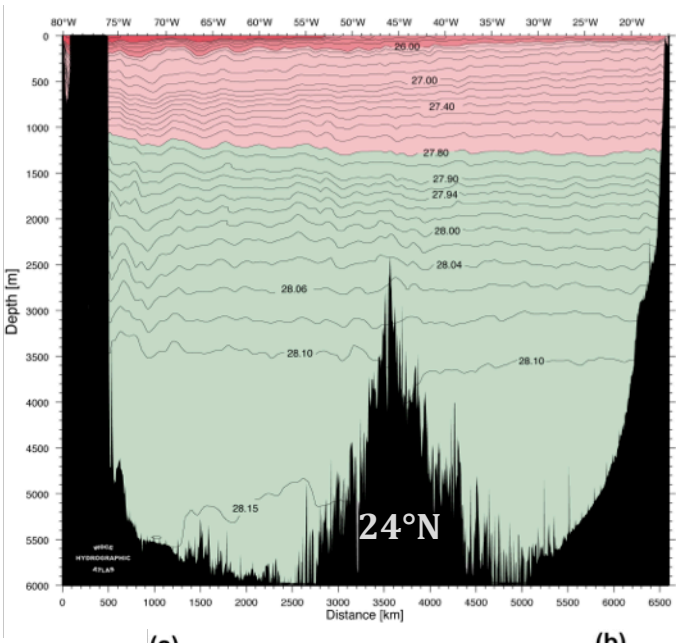
(f) On the same 36°N section, please indicate on the section the direction and magnitude of the current at the surface and then down through the water column to the bottom.

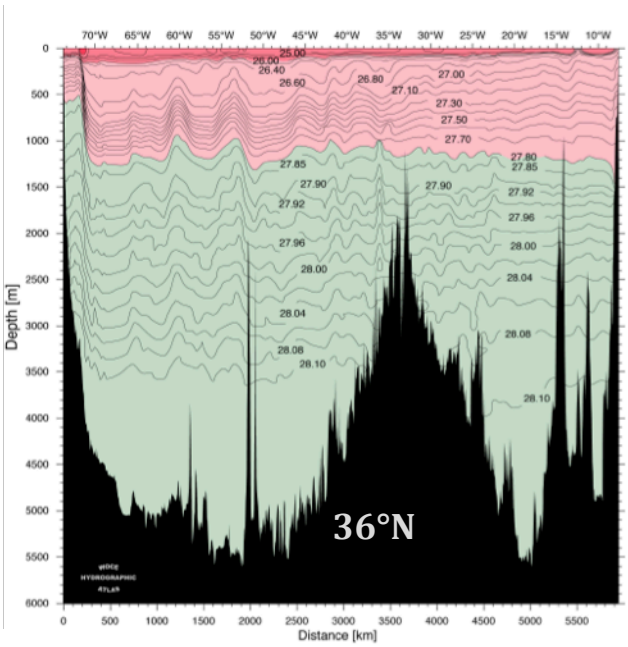
Use symbols like these to show direction, and vary the size of the symbols to show magnitude.

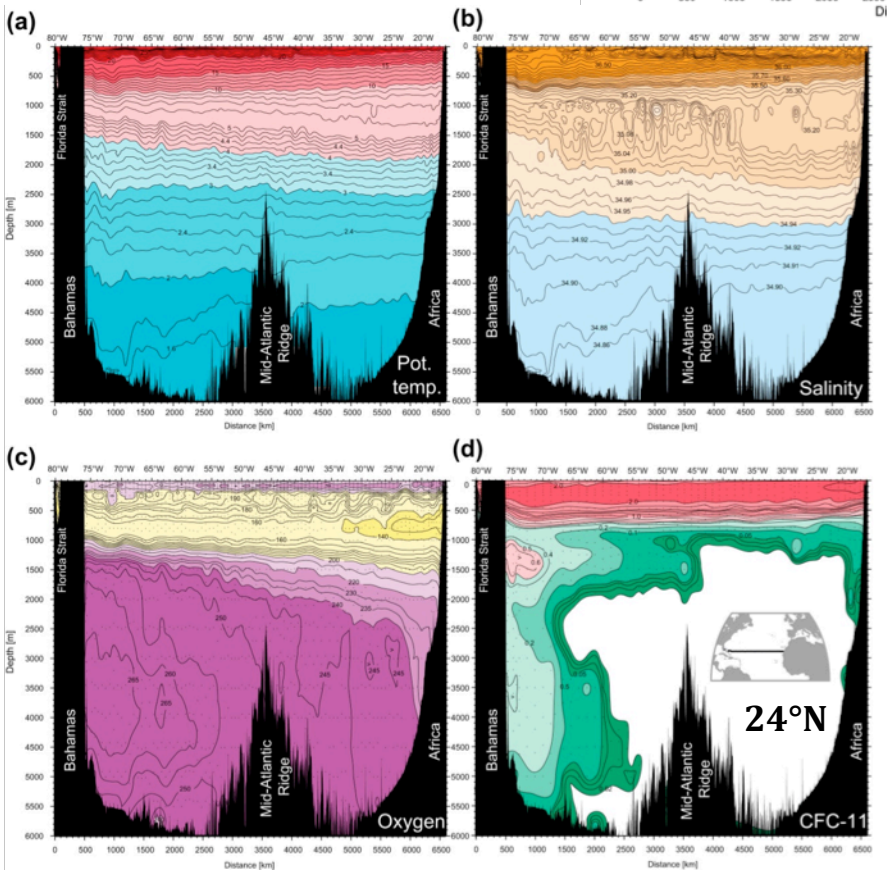
(g) On the colored 24°N property plots, use the properties to identify and mark the following water masses:

(i) Mediterranean Water
(ii) Antarctic Bottom Water
(iii) Nordic Seas Overflow Water
(iv) Subtropical Mode Water

(h) For the Nordic Seas Overflow Water: what properties did you use to identify the water mass? Why do they have the particular signals you use for identification? That is, what is the source of NSOW and how does it reach this latitude?


24°N
Depth [m]
Distance [km]


36°N
Depth [m]
Distance [km]


(a)
(b)
(c)
(d)
Florida Strait
Bahamas
Mid-Atlantic Ridge
Africa
Pot. temp.
Salinity
Oxygen
CFC-11
24°N
Depth [m]
Distance [km]

19. (10 points) Consider the attached map of the global overturning circulation.

(a) What water masses (names) are formed in the highest latitude regions in both hemispheres? Label the water masses on the map, in the North Atlantic, North Pacific, Ross Sea and Weddell Sea.

(b) The blue curves in the Atlantic, Indian and Pacific connect to green, orange and orange, respectively.
What water mass is depicted by the blue curve (name)?_____
What water mass is depicted by the green curve (name)?_____
What water mass is depicted by the orange curve in the south Pacific Ocean?_____

(c) Describe the process that occurs when the blue curves connect to the green and orange curves. What happens to the density of the sea water during the connection? How does this occur?