

SIO 210 Final examination
 Wednesday, December 11, 2013
 2-5 PM 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.

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. 15)

_____ Return the exam etc to me via campus mail (or full address)

Mailcode _____

[1-10] 10 Multiple choice/short 2 points each _____/20

[11] 1 Problem (Hendershott) _____/10

[12-19] 8 Problems (Talley) _____/70

Total _____/100

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

ρ : use 1025 kg/m^3 for generic calculations

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

$\rho c_p T$

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

Earth's radius: 6371 km

$C = 2\pi R$

$A = \pi R^2$

$A = 4\pi R^2$

$U_{Ek} = \tau / (\rho f)$

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

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

$\Omega = 0.73 \times 10^{-4} / \text{sec}$

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

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

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

$1 \text{ Sv} = 1 \times 10^6 \text{ m}^3 / \text{sec}$

acceleration + advection + Coriolis force =

pressure gradient force + gravity + friction

Multiple choice and very short answer (2 points each; 20 points total)
For each multiple choice problem, **circle ONE CORRECT answer**.

1. Upwelling at the ocean's surface creates
 - (a) inertial circles following a strong storm
 - (b) surfacing of abyssal (> 2 km depth) water in the California Current
 - (c) equatorward Ekman transport
 - (d) high nitrate at the surface in the Southern Ocean

2. 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) directly pushes the North Atlantic Current to flow downwind beneath the Westerlies
 - (d) heats the ocean

3. 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

4. The *undercurrent* in the California Current system
 - (a) is forced by offshore Ekman transport
 - (b) carries subpolar water southward
 - (c) sits at about 200 m depth
 - (d) is located offshore of the California Current

5. The atmosphere's Hadley circulation
 - (a) is forced mainly by high surface temperatures in the tropics
 - (b) creates eastward winds at the sea surface
 - (c) includes rising air directly along the equator in the annual mean
 - (d) has sinking air near the north and south poles

6. In the large-scale ocean gyres, the potential vorticity balance in the open ocean (not near the boundaries) is between
 - (a) Coriolis force and stretching
 - (b) Coriolis force change with latitude and stretching
 - (c) Stretching and eddies (relative vorticity)
 - (d) Coriolis force change with latitude and eddies (relative vorticity)

7. 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

8. In the tropical Pacific, the Walker circulation
- (a) weakens during El Nino events
 - (b) strengthens during El Nino events
 - (c) causes the surface water along the equator to flow eastward
 - (d) is associated with excess rainfall near Ecuador and Peru

Very short answer. Problems 9 and 10 are to be answered together.

9. Circle the eastern boundary currents in the following list. There are several (more than one).

(9) circle EBCs	(10) list ocean
East Greenland Current	_____
Canary Current	_____
Peru-Chile Current	_____
Agulhas Current	_____

10. For ALL of the boundary currents in the previous question: list the appropriate ocean basin (South Atlantic, North Atlantic, South Pacific, North Pacific, Indian)



Problems 4 to 15 points each

11. (10 points) (Hendershott)

This is a list of astronomical events associated with tides:

- A. times of half moon
- B. time of full moon
- C. time of new moon
- D. time of lunar perigee
- E. times when moon is in earth's equatorial plane
- F. times when moon is farthest out of earth's equatorial plane
- G. times when the sun is in the earth's equatorial plane
- H. times when sun is farthest out of earth's equatorial plane

Answer the following questions using letters "A" through "H":

(a) Which one of the above events occurs at the equinoxes, that is, the times of year when day and night are the same length? _____

(b) Which one of the above events occurs at the solstices, when the sun is as far north or south in the sky as it will be during the year? _____

(c) Flooding once per day at La Jolla Shores at e.g. the Marine Room due to strong winter storms is particularly common in early January. Which event on the list A through H is this close to in time? _____

(d) Spring tides are most pronounced around the time(s) of which astronomical events on the list A through H? (one or more events) _____

(e) The daily inequality is most pronounced around the time(s) of which astronomical events on the list A through H? (one or more events) _____

12. (6 points)

(a) Sketch the pathway of inertial motion in the Northern Hemisphere. Make sure you have the correct direction.

(b) What is the force balance in an inertial motion? _____ and _____

(c) Explain the direction of the inertial motion in terms of this force balance.

13. (6 points)

The equation of state of seawater relates the seawater density ρ to physical properties of seawater. That is, $\rho = \rho(\text{property i, property ii, property iii})$.

(a) What are the three properties (in any order)?

property i. _____

property ii. _____

property iii. _____

(b) Seawater density dependence on these properties can be expressed as

$$\frac{\partial \rho}{\partial \text{property}}$$

Which property, when placed in this expression, is related to *sound speed*? _____
(actually sound speed is the square root of the inverse of this expression)

(c) Explain why sound speed has this dependence: that is, what is an acoustic wave?

14. (10 points) (a) In the subtropical North Pacific, the meridional heat transport across 24°N is approximately 0.8 PW northward. Almost all of this transport is associated with the subtropical gyre circulation. If the circulation transports 30 Sv northward, and returns 30 Sv southward, what is the difference in temperature between the northward and southward parts of the circulation? (*calculate*)

(b) Sketch the circulation for part (a), and label the northward and southward portions. If there are specific current names associated with these portions, please include those names. Indicate which part of the circulation is warmer and which part is cooler.

(c) In the South Atlantic, the total meridional heat transport at 30°S is approximately 0.3 PW northwards. 30°S is across the center of the subtropical gyre. Explain why the South Atlantic's meridional transport is northwards, including insight from parts a and b.

15. (10 points)

(a) If 20 Sv of NADW is formed in the far northern North Atlantic and adjacent seas, and rises uniformly over the entire ocean, *calculate* the average vertical velocity of the upwelling.

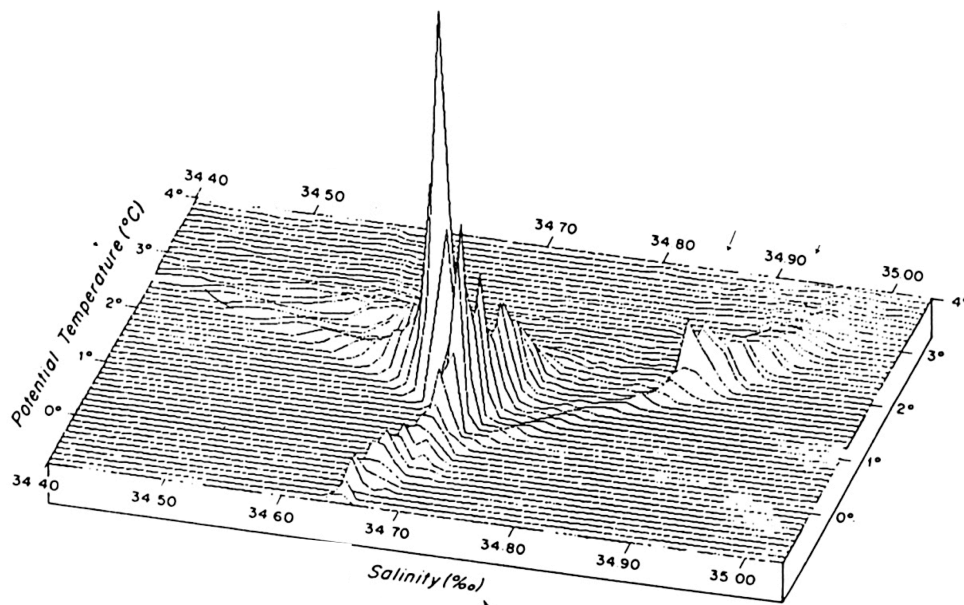
(Assume that the oceans cover 70% of Earth's surface and, for simplicity, assume the ocean is flat bottomed and is all very deep, with no shelves, etc.)

(b) From the simplified Stommel-Arons theory of abyssal circulation, what direction is the deep circulation associated with (a) in the North Atlantic, if you assume that the ocean has a flat bottom? (use words and/or a sketch)

16. (4 points) The figure shows the amount of water in each potential temperature-salinity grid box for the deep World Ocean (potential temperature $< 4^{\circ}\text{C}$).

(a) Label the portions that are in the Atlantic, Pacific, and Southern Oceans. (Mark on the figure.)

(b) Explain how you can tell the difference between the Atlantic and Pacific waters in this plot.



17. (4 points)

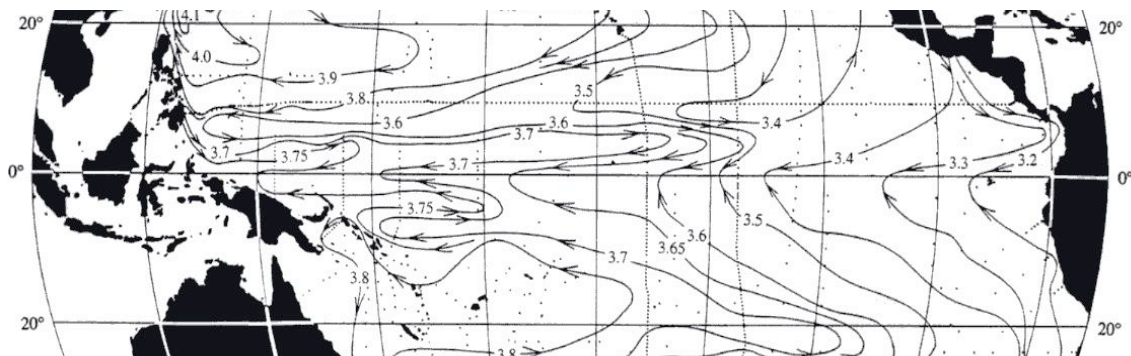
(a) The Pacific surface steric height and inferred direction of circulation is shown in the figure (from Reid, 1997). Label the:

North Equatorial Current

North Equatorial Countercurrent

South Equatorial Current

(b) Is the equatorial surface current geostrophic? If not, what is the force balance for this surface current (top 50 meters of the ocean)?



18. (15 points)

The attached color figures show (i) oxygen on the neutral density surface $\gamma^N = 28.10 \text{ kg/m}^3$, (ii) the depth of the neutral density surface surface $\gamma^N = 28.10 \text{ kg/m}^3$, and (iii) oxygen at 3500 m depth, and in the Pacific and Atlantic. NOTE: the color scales are DIFFERENT in the two panels. (Yellow-purple break is $160 \mu\text{mol/kg}$ in both Pacific maps but $244 \mu\text{mol/kg}$ and $225 \mu\text{mol/kg}$ in Atlantic neutral density and 3500 m maps.)

(a) Explain the oxygen pattern on the isoneutral surface in the Atlantic in terms of water mass formation and circulation that affect this isoneutral surface:

(i) What water masses dominate the Atlantic map?

(ii) Choose one of these water masses and explain where and how it is formed.

(iii) What circulation of those water masses is implied by the oxygen pattern?

(b) Explain the oxygen pattern on the isoneutral surface in the Pacific in terms of water mass formation and circulation that affect this isoneutral surface:

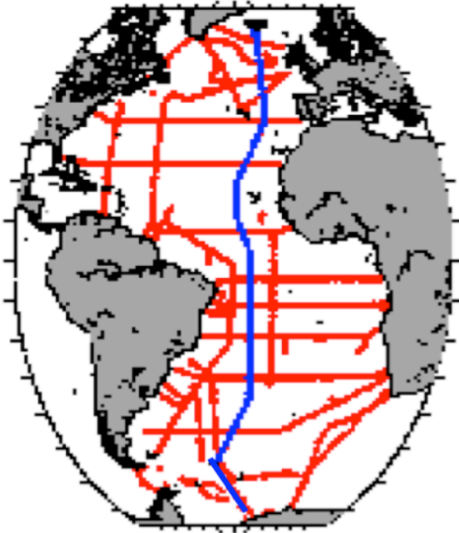
(i) What water masses dominate the Pacific map?

(ii) What circulation of those water masses is implied by the oxygen pattern?

(c) Where is this isoneutral surface the shallowest on these maps? Why is it shallowest there? (Explain in terms of the large-scale external forcing in the region where it is shallowest.)

19. (15 points) The last color figure (last page of exam) is a section of neutral density through the center of the North Atlantic, at about 20°W.

For your information, here is a section location map (dark central section from Iceland to Antarctica). Please answer this question by labeling the NEUTRAL DENSITY SECTION and not this small map.



Assume that neutral density and potential density provide similar information about geostrophic shear. (We did not discuss this equivalence in class.)

While you are answering parts (a) through (d), leave enough space about the section for the answer to part (e).

(a) Locate the Antarctic Circumpolar Current on the neutral density section and mark it.

(b) Locate the Weddell Gyre on the neutral density section and mark it.

(c) Locate the South Atlantic's subtropical gyre on the neutral density section and mark it.

(d) Locate the North Atlantic Current on the neutral density section and mark it.

(e) The above circulations are all surface-intensified circulations. Along the top of the 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.

(f) At the southern end of the section (left side of plot), 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?

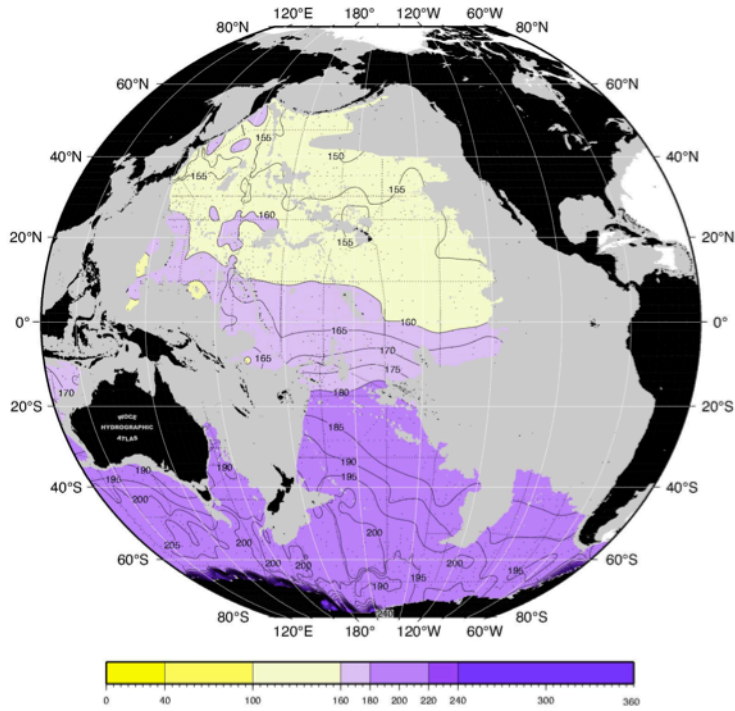
(g) For the Antarctic Circumpolar Current (part a), please indicate on the section the direction and magnitude of the current at the surface and then down through the water column to the bottom.

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

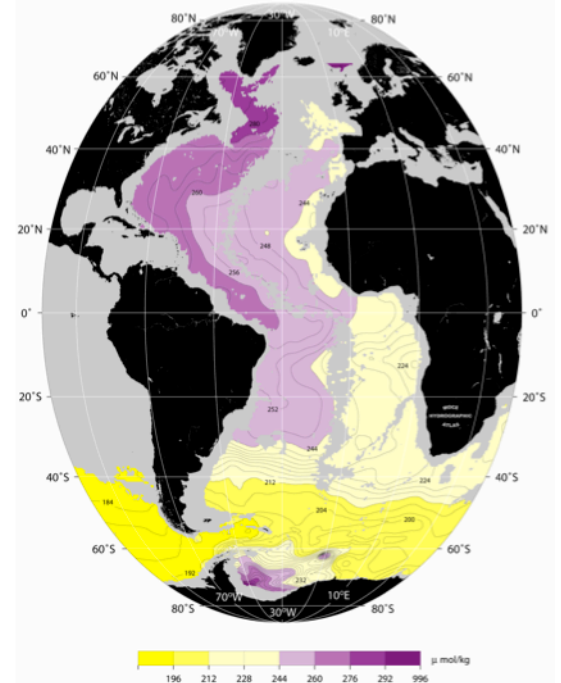


For Question 18.

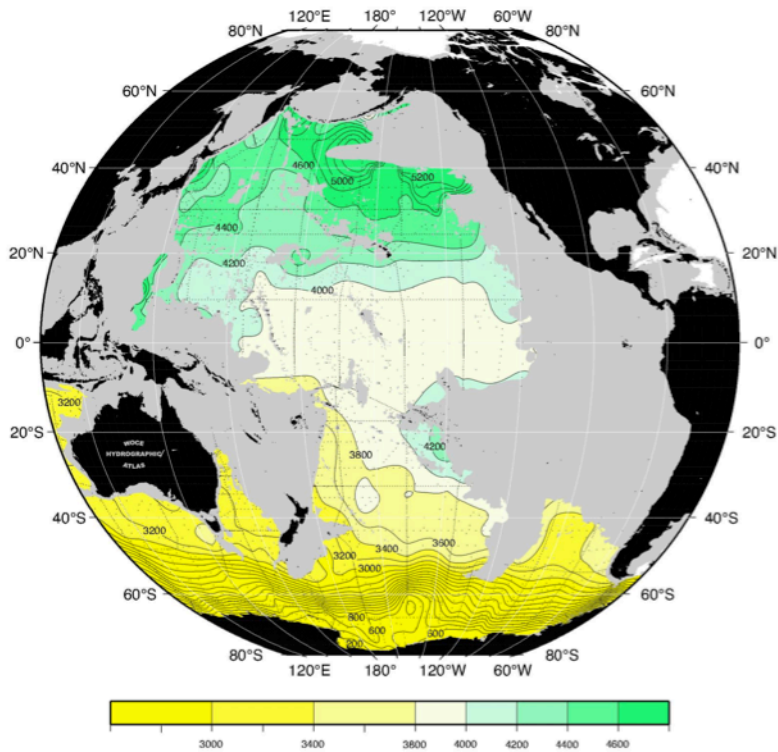
Oxygen ($\mu\text{mol/kg}$) $28.10 \gamma^n$ (kg/m^3)



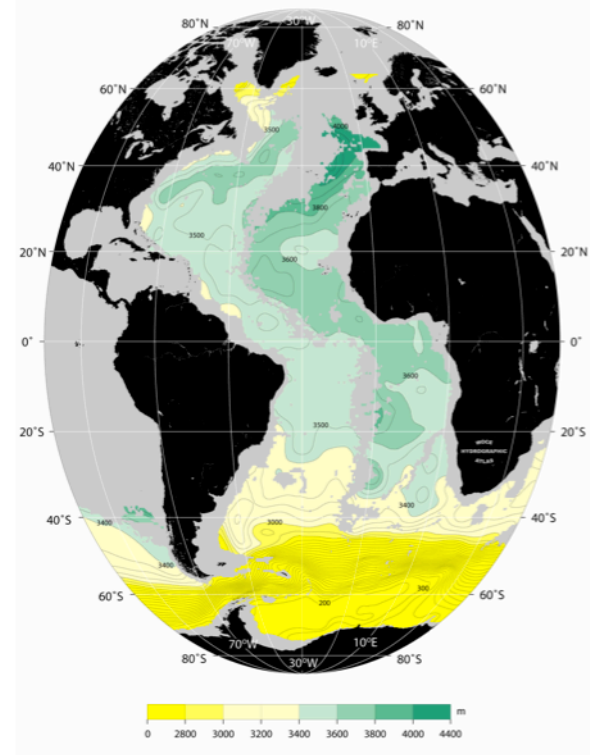
Oxygen on the Neutral Surface $\gamma^n=28.10$



Depth (m) $28.10 \gamma^n$ (kg/m^3)



Depth of the Neutral Surface $\gamma^n=28.10$



For Question 19.

