

SIO 210 Final examination
Wednesday, December 12, 2011
3-6 PM

Corrections noted during exam are in red.

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. 19)

_____ Return the exam etc to me via campus mail

Mailcode _____

Talley portion: 100 points

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

[6-14] 6 Problems: various points each _____/90

Hendershott portion: 17 questions, 2 points each _____/34

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

ρ : use 1025 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 PW = 10^{15} W = 10^{15} J/sec

$C = 2\pi R$

$A = \pi R^2$

$A = 4\pi R^2$

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

PV = (relative vorticity + planetary vorticity)/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° latitude = 111 km

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

acceleration + advection + Coriolis force =

pressure gradient force + gravity + friction

Multiple choice (circle the single best answer for each) or **Very Short Answer** (2 points each)

1) In an Ekman layer

- (a) The surface velocity is *always* oriented 45° to the right of the wind stress
- (b) The transport is proportional to the Coriolis parameter f
- (c) The transport can be 90° to the left of the wind stress
- (d) The force balance is between pressure gradient force and viscous stress

2) If (cold, fresh) Nordic Seas Overflow Water (NSOW) and (warmer, saltier) Mediterranean Overflow Water (MOW) have the *same* potential density relative to 0 dbar (σ_θ) at their 500 m-depth sills where they plunge down into the North Atlantic, then

- (a) NSOW has higher potential density relative to 4000 dbar (σ_4) than MOW
- (b) NSOW will have a different potential density relative to 0 dbar (σ_θ) than MOW after they both plunge to 2000 m depth (assuming no mixing)
- (c) After plunging down into the North Atlantic, NSOW would equilibrate and spread at the same depth as MOW
- (d) NSOW would equilibrate above the MOW because it is fresher

3) In a fluid that behaves according to Fick's Law

- (a) Temperature changes are caused by evaporation
- (b) Temperature will change if it varies linearly with distance
- (c) Diffusion of temperature is proportional to pressure
- (d) Diffusion of temperature is accomplished by random motions of molecules or turbulent structures

4) The Intertropical Convergence Zone is

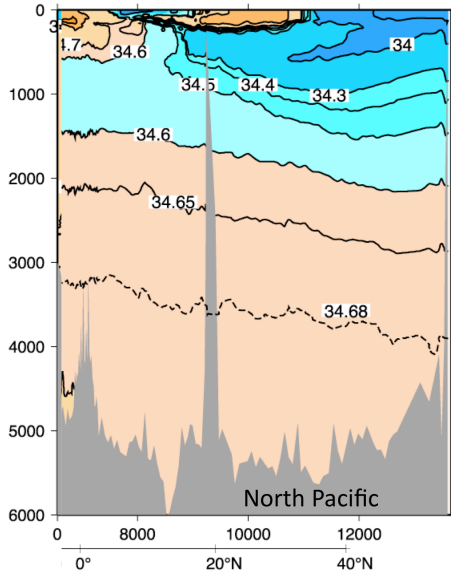
- (a) The rising limb of the Walker circulation
- (b) Located exactly on the equator
- (c) The rising limb of the Hadley circulation
- (d) Located at the maximum Ekman transport convergence in the subtropics

5) In geostrophic flow, the force balance is between _____ and _____ (which two terms)

Problems

6) (10 points)

In the subtropical North Pacific there is a vertical salinity minimum at about 500 m depth (see figure).



- (a) What is the water mass name for this salinity minimum? _____
- (b) Where does the low salinity water in the salinity minimum come from?
- (c) What process creates this low salinity water? (there might be multiple steps in the answer, so describe at least one part, preferably the original source)
- (d) In the same figure there is higher salinity water at depth. Where does this come from?

7) (12 points)

- (a) In the equatorial Pacific, which direction do the prevailing (zonal) winds normally blow? _____
- (b) What are these winds called? _____
- (c) What direction is the surface ocean velocity along the equator beneath these winds?

(d) Describe the Bjerknes feedback between these winds and the sea surface temperature distribution along the equator. (You can sketch it if it helps your description.)

(e) What is the major climate phenomenon called that is associated with this feedback? _____

(f) If the normal zonal winds are interrupted, in fact, if they are suddenly set to 0 (no wind), what surface current might you expect to see immediately after the winds turn off? (Contrast with your answer to (c).) Why?

8) (12 points)

Start with a completely motionless **upper ocean (100 to 200 m layer)**, which is stratified (temperature warmest at the top and decreasing linearly with depth). Assume there is no air-sea flux of heat or freshwater (no buoyancy forcing). If we suddenly turn on a strong wind, describe **BOTH motion and stratification**:

(a) within the first few seconds to minutes

(b) within 10s of minutes to an hour

(c) after a day

(d) at “steady state” after many weeks or months have passed (assume no time dependence to the wind).

9) (12 points)

Eastern boundary currents

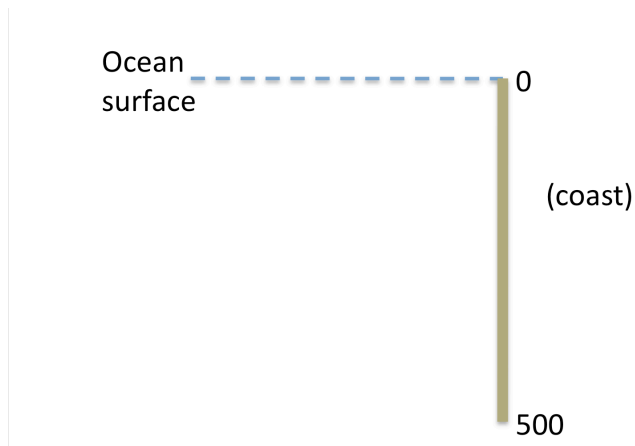
(a) In a “typical”, idealized eastern boundary current upwelling system, which direction do the winds blow? _____

(b) In this idealized EBC system, which direction is the flow that is directly forced by the wind? _____

(c) In this idealized EBC system, which direction is the surface geostrophic flow? _____

(d) In this idealized EBC system, what direction is the flow at about 200 m depth along the coastline? _____

(e) Sketch the sea surface height and isopycnals (isotherms) within the upper 500 m along a section perpendicular to the coast, taking into account your answers to all of the above, using the axes given here.



10) (14 points)

The Indonesian Throughflow (ITF) is a net flow of approximately 10 Sv from the Pacific to the Indian Ocean through the Indonesian archipelago. Because of the topography of the archipelago, much of the flow is shallower than 650 m. Once it enters the Indian Ocean, it flows south and exits.

(a) The ITF flows westward across the Indian Ocean as part of the South Equatorial Current. Suppose that it consists of nearly unaltered Pacific water. Given what you know about the salinity of the Pacific and Indian Oceans, how might you identify the ITF water within the Indian Ocean?

(b) The excess volume transport due to the ITF exits the Indian Ocean within the Agulhas Current. Approximately what percent of the total Agulhas transport is due to the ITF? (Use the information you gathered for the problem set; if you don't remember the number, estimate its magnitude.)

(c) For the Agulhas' subtropical gyre alone, without the ITF, the volume transport northward must equal the southward volume transport in the Agulhas. If the sea surface height at the Australian coast is SSH_{aust} , what is the sea surface height at the African coast SSH_{Africa} (without the ITF)? Assume that all flows are geostrophic and for simplicity that the ocean has uniform density. **Just write a few sentences about what you'd expect, no calculation. Use the diagram to sketch your answer if helpful.**



(d) Now add the ITF transport to the Agulhas. How will this change the relative sea surface height at Australia and Africa?

11) (12 points)

If 20 Sv of North Atlantic Deep Water (NADW) upwells in the Southern Ocean and is cooled to become Antarctic Bottom Water (AABW):

(a) How much heat must be lost at the sea surface? Assume that NADW is 2°C and, to simplify the calculation, that AABW is -1°C.

(b) Which process in the Southern Ocean, other than direct cooling, is very important for forming very dense AABW?

(c) Where does the process (b) preferentially occur in order to make the very densest AABW?

12) (18 points)

The Northern Hemisphere has two subpolar gyres. Assume that their forcing can be described by Sverdrup balance.

(a) Describe the sign of Ekman vertical velocity that occurs in the subpolar gyres.

(b) In terms of surface nutrients or ocean color, what is a signature of this Ekman vertical velocity?

(c) What is the direction of the geostrophic flow throughout the gyre (not at the boundaries) that results from this Ekman vertical velocity? _____

Explain why in terms of potential vorticity conservation.

(d) Where should the boundary currents be found that are associated with these subpolar gyres? _____

(e) Why is a boundary current required dynamically?

(f) Both of the Northern Hemisphere subpolar gyres have rather complicated boundary currents. Identify (name) at least one of the parts of the boundary current that you described in (d).

_____ (one gyre)
and _____ (other gyre)

(g) What is overall type of circulation in the subpolar gyres? CYCLONIC or ANTICYCLONIC (circle one)

(h) In the Southern Hemisphere, name at least one gyre that has the same type of circulation as you circled in (g). _____

Waves and Tides (Hendershott)

1. Waves that are generated by large mid-ocean storms cross the ocean at a speed of about

- a. 7-8 Km/sec, b. 1500 m/sec, c. 200 m/sec,
- d. 10 to 30 m/sec.

2. The first ocean waves of a tsunami cross the open ocean at a speed of about

- a. 7-8 Km/sec, b. 1500 m/sec, c. 200 m/sec,
- d. 10 to 30 m/sec.

3. Seismic waves, upon which our ability to issue an initial tsunami warning relies, travel at about

- a. 7-8 Km/sec, b. 1500 m/sec, c. 200 m/sec,
- d. 10 to 30 m/sec.

4. When oriented vertically the ship FLIP scarcely moves up & down as ocean swell pass by, in large part because

- a. FLIP is cylindrical so that friction between water and FLIP motions is negligible,
- b. The bottom of FLIP is not nearly as deep as the wavelength of most surface ocean swell,
- c. The bottom of FLIP is at a depth that is equal to or greater than the wavelength of most ocean surface swell.

5. At the coast, the vertical (up and down) motion of the sea surface associated with a major tsunami may be
- much greater than,
 - much smaller than,
 - about the same as that associated with wind generated waves.
6. In the open ocean, the vertical (up and down) motion of the sea surface associated with wind generated waves is generally
- much greater than,
 - much smaller than,
 - about the same as that associated with a major tsunami.
7. A typical tsunami at a port consists of
- An initial rise in sealevel followed by no further unusual sealevel variation.
 - An initial fall in sealevel followed by no further unusual sealevel variation.
 - Either an initial rise or an initial fall in sealevel followed by no further unusual sealevel variation.
 - Either an initial rise or an initial fall in sealevel followed by unusual sealevel variation lasting for weeks.
 - Either an initial rise or an initial fall in sealevel followed by unusual sealevel variation lasting for many hours.
8. The tsunami warning system that is based on seismic waves can accurately predict
- the initial arrival time and the initial amplitude of a tsunami,
 - the initial arrival time but not the initial amplitude of a tsunami,
 - the initial amplitude but not the initial arrival time of a tsunami,
 - the entire sealevel history of the tsunami.
9. For waves whose wavelength L is short compared with the ocean depth, the paths of fluid parcels
- circles whose radius at the surface is the crest-to-trough wave height and whose radius decreases rapidly below the surface,
 - ellipses whose shape does not change appreciably from the surface to the ocean bottom,
 - circles whose diameter at the surface is the crest-to-trough wave height and whose diameter decreases rapidly below the surface,
 - ellipses whose width does not change appreciably from the surface to the ocean bottom but whose height decreases to zero at the ocean bottom.
 - ellipses whose height does not change appreciably from the surface to the ocean bottom but whose width decreases to zero at the ocean bottom.
10. For waves whose wavelength L is long compared with the ocean depth, the paths of fluid parcels at the surface are

- a. circles whose radius at the surface is the crest-to-trough wave height and whose radius decreases rapidly below the surface,
- b. ellipses whose shape does not change appreciably from the surface to the ocean bottom,
- c. circles whose diameter at the surface is the crest-to-trough wave height and whose diameter decreases rapidly below the surface,
- d. ellipses whose width does not change appreciably from the surface to the ocean bottom but whose height decreases to zero at the ocean bottom.
- e. ellipses whose height does not change appreciably from the surface to the ocean bottom but whose width decreases to zero at the ocean bottom.

11. The leading crest of the Sumatra tsunami of 2004 advanced into the Indian Ocean (mean depth ~ 2000 m) faster than into the Strait of Mallaca (mean depth ~ 100 m). What is the ratio of speed of advance in the Indian ocean to that in the Strait of Mallaca?

- a. $100/2000$
 - b. $\sqrt{2000/100}$
 - c. $\sqrt{100/2000}$
 - d. $2000/100$
12. If a tsunami alert is issued for La Jolla, you should, for your safety,
- a. go to the shore to watch the big waves come in,
 - b. go to the top of Mt. Soledad,
 - c. pay no attention.
13. Neap tides (times of smallest semidiurnal tidal range) occur twice a synodic month
- a. when the moon is in the earth's equatorial plane,
 - b. when the moon is out of the earth's equatorial plane,
 - c. at full or new moon,
 - d. at the half moons,
 - e. at lunar perigee.
14. The daily inequality (elevation difference between a high tide and its immediate successor) is greatest for lunar tides
- a. when the moon is in the earth's equatorial plane,
 - b. when the moon is farthest out of the earth's equatorial plane,
 - c. at full or new moon,
 - d. at the half moons,
 - e. at lunar perigee.

15. Above you thought about the daily inequality for lunar tides. There is also a daily inequality associated with solar tides. When is it greatest?

- a. At the solstices (when the difference between the length of daytime and the length of nighttime is greatest)
- b. at the equinoxes (when day and night are nearly the same length)

16. The semidiurnal tidal range at times when lunar perigee (when the moon in its elliptical orbit is closest to the earth) and full/new moon occur together

- a. is unusually large,
- b. is unusually small,
- c. is neither unusually large nor unusually small.

17. The earth rotates on its axis once every 24 hours, and the strongest tides are semidiurnal (one high water about every 12 hrs). If the earth rotated on its axis once every 36 hours but the orbital motions of earth and moon were not changed, then at most locations there would be one high water about every

- a. 6 hrs,
- b. 9 hrs,
- c. 12 hrs,
- d. 18 hrs,
- e. 36 hrs.