SIO 210 Final examination
Wednesday, December 7, 2016
3-6PM Vaughan 100 Name:_____

Please put your initials or name on each page.

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 in Nierenberg Hall 310 (after Jan. 2)
_____Return the exam etc to me via campus mail (or full address)
Mailcode_____
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**Talley portion**

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

$\rho$: use 1025 kg/m$^3$ for generic calculations
$c_p$ = 3850 J/kg°C
$\rho\ c_p\ T$
Freshwater transport ~ $\rho V(S_o - S_i)/S_m$
1 PW = $10^{15}$ W = $10^{15}$ J/sec
Earth's radius: 6371 km
$V_{Ek} = -\tau^{(x)}/(\rho f)$
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
g = 9.8 m/sec$^2$
acceleration + advection + Coriolis force =
pressure gradient force + gravity + friction

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

1) In a region of downward Ekman velocity (Ekman pumping), what direction is the geostrophic general circulation just beneath the Ekman layer? Assume the northern hemisphere: _____

2) Temperature in the atmosphere decreases with height from the surface up to the tropopause. Circle the primary reason(s) for this structure.

a) Wind shear
b) Adiabatic expansion
c) Solar radiation
d) Moisture content

3) Deep Western Boundary Currents

a) flow in the opposite direction to the interior Stommel-Arons predicted flow
b) are found only in the bottom 100 m layer of the ocean
c) carry Antarctic Bottom Water northward in the Pacific Ocean
d) are not geostrophic

4) Which of the following is NOT a characteristic of Pacific Deep Water?

a) Vertical oxygen maximum
b) Vertical dissolved silicate maximum
c) Potential temperature of about 1° to 2° C
d) Vertical delta C14 extremum (large negative values)

5) The meridional heat transport across a coast-to-coast (N. America to Africa) section in the North Atlantic at 24°N is *northward*. Therefore:

a) There is net heat gain north of 24°N
b) The net volume transport of warm water flowing northward is larger than the net volume transport of cold water flowing southward
c) The net northward flow across 24°N has a higher temperature than the net southward flow across 24°N

6) Sverdrup balance, which requires wind, is a simplified way to describe flow in

a) the frictional (viscous), wind-driven surface layer
b) the Canary Current
c) interior of the Agulhas Current's gyre
d) the abyssal Pacific circulation

7) An open patch of ocean in the *Southern* Hemisphere experiences a steady wind blowing eastward (i.e. a westerly wind). What direction is the vertically integrated transport in the surface layer (top 50 to 100 m)?

a) N
b) E
c) S
d) SE

8) Which of the following currents flows predominantly towards the west?

a) Antarctic Circumpolar Current
b) Equatorial Undercurrent
c) South Equatorial Current
d) Florida Current

9) The wind-driven subtropical gyres

a) Are driven by Ekman transport divergence rather than convergence
b) Extend in their entirety to the ocean bottom
c) Have equal strength eastern and western boundary currents
d) Shrink towards the pole with depth

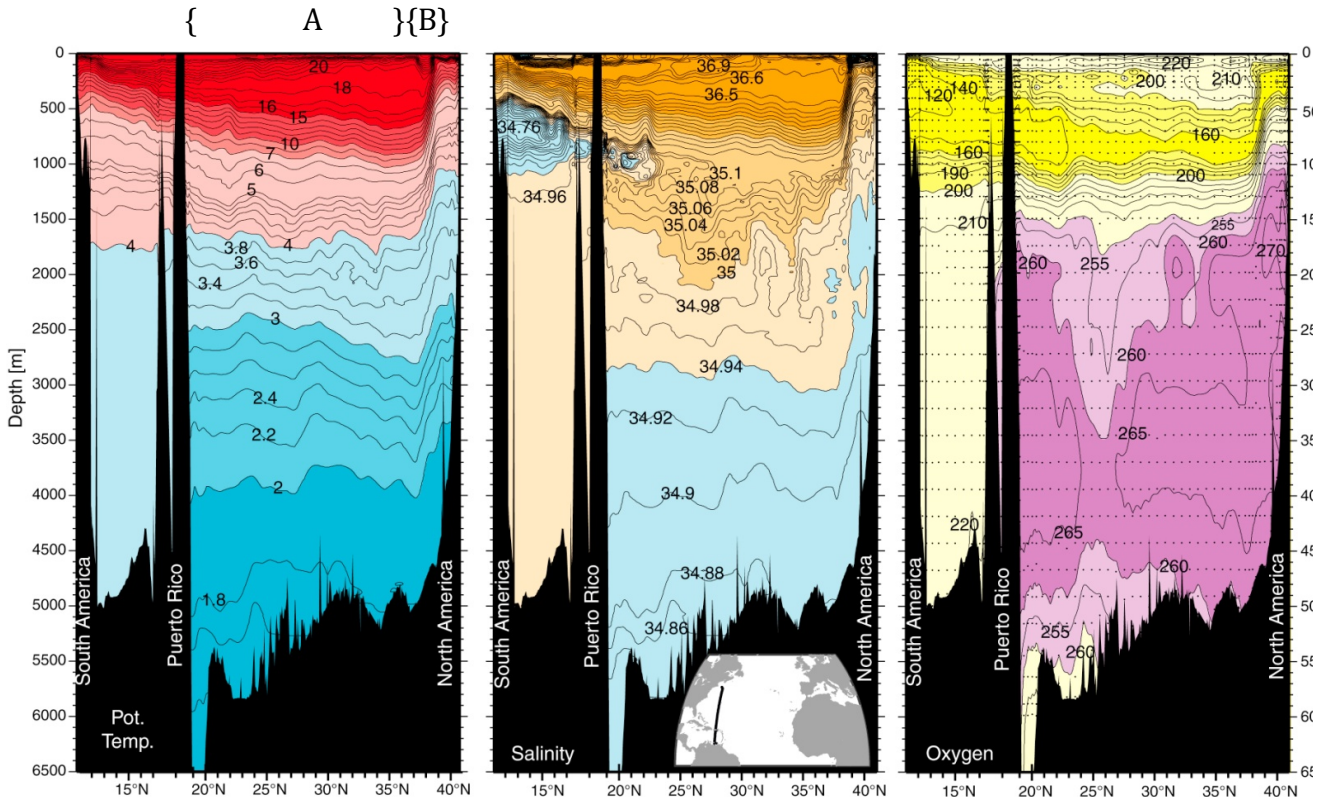
10) The monsoonal winds in the northern Indian Ocean

a) blow from the Himalayan plateau towards the ocean during summer
b) cause the western boundary current, the Somali Current, to reverse
c) drive upwelling along the southeast coast of the Arabian peninsula in winter
d) drive a permanent equatorial undercurrent along the equator

**Problems**

11) (24 points)

(See color version of figure on separate sheet.)




The above figure is along a section from south to north in the subtropical North Atlantic. (A small map showing its location is shown.)

a) Why have we plotted potential temperature in the left panel instead of temperature? In your answer please DEFINE potential temperature.

b) The potential density vertical section looks very much like this potential temperature section. Why?

c) Assume that the circulation represented by this section is in geostrophic balance. Assume that the flow is very weak at the maximum depth of the section and increases upward.

Given THESE VERTICAL sections (and not everything you know about the horizontal circulation of the Atlantic), what can you infer about the direction of the *surface* flow in the bracketed regions labeled A and B?

{A} _____ and {B} _____
Indicate this direction on the plot.

d) Using your result from c), sketch a smoothed version of the sea surface height above the plot. Explain why you drew this shape.

e) Explain in words how the distribution of isotherms in bracketed area A can lead to a geostrophic velocity difference between the bottom of the section and the top of the section. That is, describe how the thermal wind balance works.

f) Label (Name) the current indicated by bracket B._____

g) In the upper ocean, just to the left (south) of that current, there is a thickening of the isotherms. What is the water mass name of this layer?_____

(h) On the salinity section, there is a layer of low salinity at about 500-1000 m depth in the south. What is the water mass name of this layer?_____

(i) On the oxygen section, there is a layer of high oxygen at about 3500-4000 m. What is the water mass name of this layer?_____

(j) In this same oxygen feature, there is meridional (south-north) variation. What is the name of the current that is responsible for the regions of higher oxygen in this depth range? _____

(l) On all three sections, there is a layer of (low pot. Temp., low salinity, low oxygen) at the bottom. What is the water mass name of this layer?_____

12) (12 points) (2,2,2,3,3)
Compare and contrast eastern and western boundary currents in subtropical gyres in terms of:
(a) magnitude (maximum velocity, order of magnitude of transport)

(b) direction

(c) depth penetration

(d) BRIEFLY describe the process that creates a typical eastern boundary current.

(e) BRIEFLY describe the process that creates a typical western boundary current.

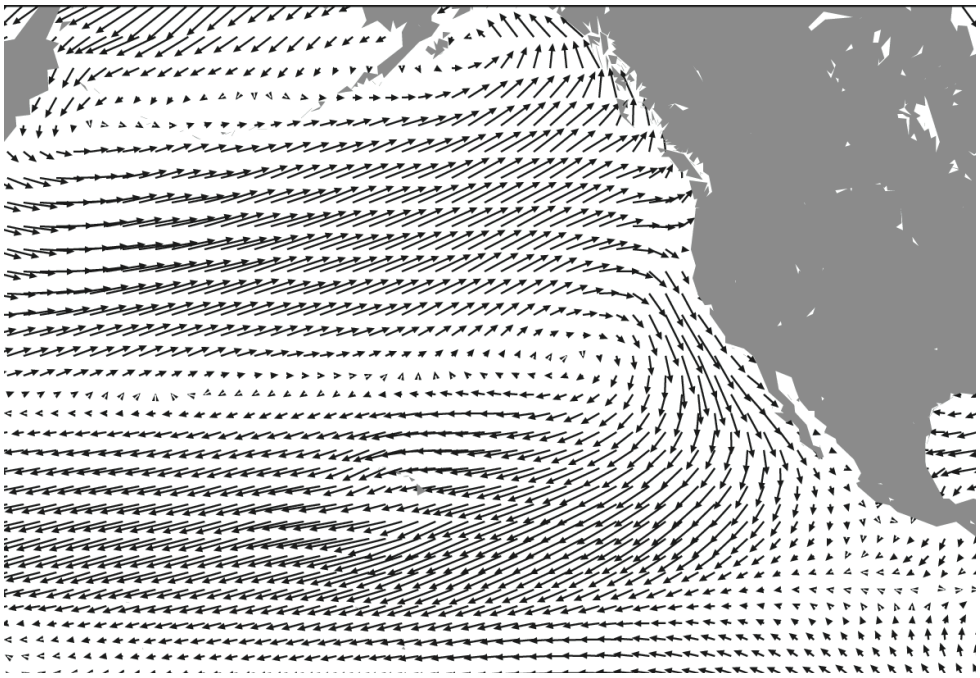
4) (12 points) (3, 2, 3, 4)
The mean wind stress (in $N/m^2$) in the eastern and central North Pacific is shown in the figure (next page).

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. Close to that feature of coastal upwelling, there is also open ocean upwelling. Sketch the Ekman transports that result in this upwelling.

c. Indicate on the figure where large-scale, open ocean upwelling is likely to be found. Sketch the Ekman transports that result in this upwelling. What is the name of this part of the general circulation?_____

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

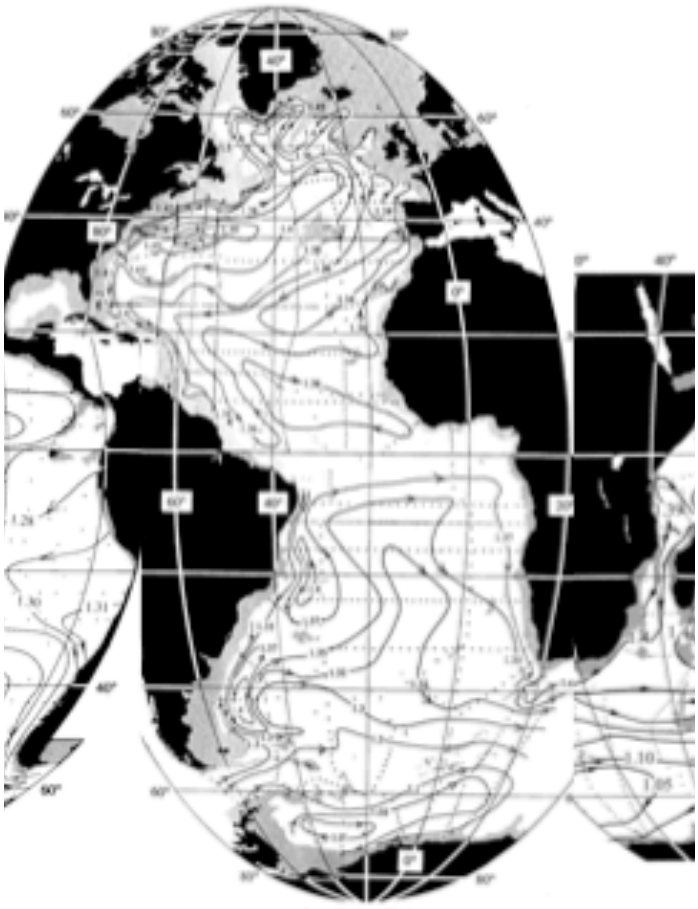


13) (16 points) (2, 2, 1, 1,1,2,3,2,2)
North Atlantic Deep Water is formed from various water masses in the North Atlantic.

a. Choose **one** of the newly-ventilated (locally-formed) water masses that contribute to NADW._____
What local process creates this water mass?_____

b. What characteristic property (or properties) would you use to identify your water mass? (If it's helpful to refer back to previous problem with color sections, feel free.)

c. Indicate on the map (2000 dbar circulation) the location of formation of this water mass.



*Streamfunction at 2000 dbar (adjusted steric height in meters, plus a constant value)*

d. What are the sources of water from outside the Atlantic that feed into the NADW formation? There are 3. List at least 2 of them (names of water masses and/or where they come from physically)
i)_____
ii)_____
[ EXTRA iii)_____ ]

e. Indicate on the map the location and direction of the Deep Western Boundary Current that carries NADW.

f. What is the approximate net formation rate (overturning rate in units of Sverdrups) of NADW as a whole? (You can give a range of values or an order of magnitude.)

g. If the temperature of the surface water feeding the Atlantic overturn averages 17 °C and the deep water formed in the overturn averages 2°C, use the overturning volume transport from your answer (g) and calculate the net heat transport associated with the overturn.

h. Which direction (north, south, east, west) is the net heat transport associated with the Atlantic Meridional Overturning Circulation that includes the NADW and your surface source of water? Indicate this on the map.

i. In order for there to be upwelling from the deep ocean to the upper ocean, there must be a process that converts deep water to upper ocean water. List at least one process_____

Discuss what might control this specific physical process.

**Hendershott portion**

14) (10 points) (3,1,1,2,3)
During certain times, the earth, moon and sun are aligned to produce **very high tides**.
a) Sketch the alignment of the moon and sun relative to the earth at such a time.

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

c) What is the name given to the anomalously low tide?_____

d) What is the typical period for the anomalous high tide? (That is, what is the time 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.

15)(6 points)
Some typical wave speeds in the ocean are

a. a few cm/sec
b. a few cm/s to about one m/s
c. a few m/s to several tens of m/s
d. about 200 m/s.
e. about 1500 m/s
f. several km/s.

Write in the label of the speed that best matches each of the following waves.

i. capillary waves___
ii. seismic waves___
iii. wind generated waves___
iv. ocean sound waves___
v. tsunami___
vi. ocean internal waves___