SIO 210 Final examination ANSWER KEY
Wednesday, December 8, 2010
3-6 PM

Name:______________________

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

This is an open notes exam. You may use your own class notes. No books.
You may use a 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 Dec. 13)

________Return the exam etc to me via campus mail

Mailcode__________________________

There are two parts: Talley/MacKinnon (weighted 70% of exam) and Hendershott (weighted 30% of exam)

Talley/MacKinnon portion: 100 points
[1-5] 5 Multiple choice 3 points each ________________/15
[6-10] 5 Short answer 9 points each ________________/45
[11-12] 2 Long answer 20 points each ________________ /40

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

Seawater density ρ: use 1025 kg/m^3 for generic calculations unless otherwise instructed
c_p = 3850 J/kg°C
Earth's radius: 6371 km
$A = \pi R^2$
$A = 4\pi R^2$
PV = (relative vorticity + planetary vorticity)/height = $(\zeta + f)/H$
$f = 2\Omega \sin(\text{latitude})$
sin (30°) = 0.5
sin (25°) = 0.42
sin (35°) = 0.57
$\Omega = 0.71 \times 10^{-4}$/sec
1° latitude = 111 km
acceleration + advection + Coriolis force =
pressure gradient force + gravity + friction

Multiple choice (circle the single best answer for each) (3 points each)

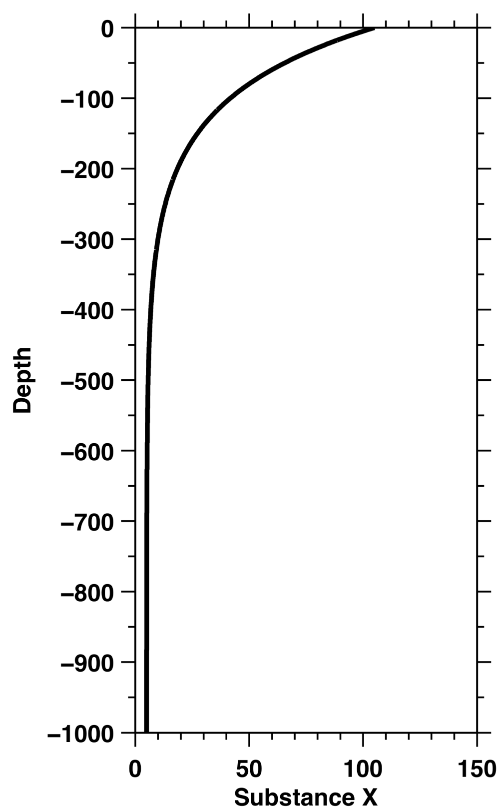
1) The Equatorial Undercurrent
(a) flows westward
(b) is about 1000 meters thick
(c) has a maximum velocity of 100 to 150 cm/sec
(d) is completely in geostrophic balance

2) Climate sometimes involves feedbacks. Which of the following exhibits a positive feedback?
(a) sea ice and air temperature
(b) volcanoes and air temperature
(c) surface salinity and Subtropical Underwater formation

3) Bottom water in the far northern North Atlantic Ocean, around Greenland, comes from
(a) The Red Sea
(b) The Strait of Gibraltar
(c) The Nordic Seas
(d) The Antarctic continental margins

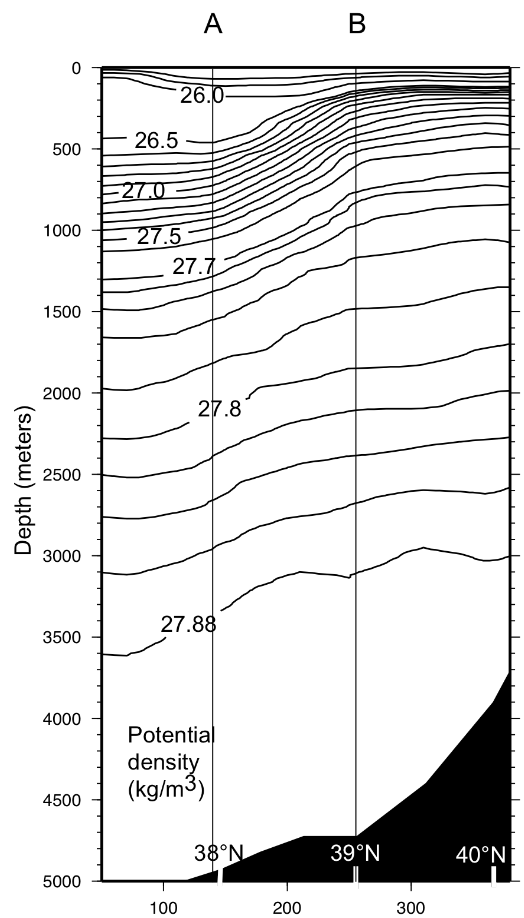
4) A typical period for an internal wave is
(a) about a day
(b) a few seconds
(c) a few weeks

5) This is a plot showing the concentration of substance "X" as a function of depth. Assuming a homogenous field of turbulent motions at all depths, is vertical diffusion likely to make the concentration of substance X at 200 meters:
(a) increase in time
(b) decrease in time
(c) diffusivity will not alter the shape of this profile



Short answers (8 points each)

6) This is a vertical section of potential density across a major current in the North Atlantic. Assume that the velocity is strongest at the sea surface.



(a) Sketch the approximate sea surface height. Mirror image of something like the 26.5 isopycnal

(b) Indicate the direction of geostrophic flow near the sea surface between stations A and B. Eastward, out of page.

(c) Indicate the direction and relative magnitude of geostrophic flow (compared with the flow at the sea surface) at 1000 m between stations A and B. (Don't calculate, just give an indication.) Decreasing eastward strength with depth (which could reverse to westward). From knowing that this is a Gulf Stream section, you would recognize that the flow is still eastward at about 1000 m, but weaker. The important point is the shear.

7) El Nino Southern Oscillation (ENSO) represents a strong feedback between the ocean and atmosphere.

(a) Describe the equatorial wind system in normal circumstances:

What is its direction? westward

What is the special name for it? Walker circulation, Trade Winds are both acceptable answers

How is it forced? SST difference between western and eastern equatorial Pacific (warm in west, cooler in east)

(b) Describe the wind-driven equatorial current system in the upper 300 to 400 meters depth. In the following, please describe only the currents that are within a few degrees latitude of the equator. You will be describing two currents.

What are their directions? Westward surface flow, eastward jet below the surface

What are the names of the currents? South Equatorial Current, Equatorial Undercurrent

How are they forced? Wind stress/friction for the SEC; west-east pgf set up by westward SEC for the EUC

(c) In what sense are these two systems coupled? Question worded awkwardly. I meant the ocean and atmosphere, and for you to describe the elements of the Bjerknes feedback.

8)

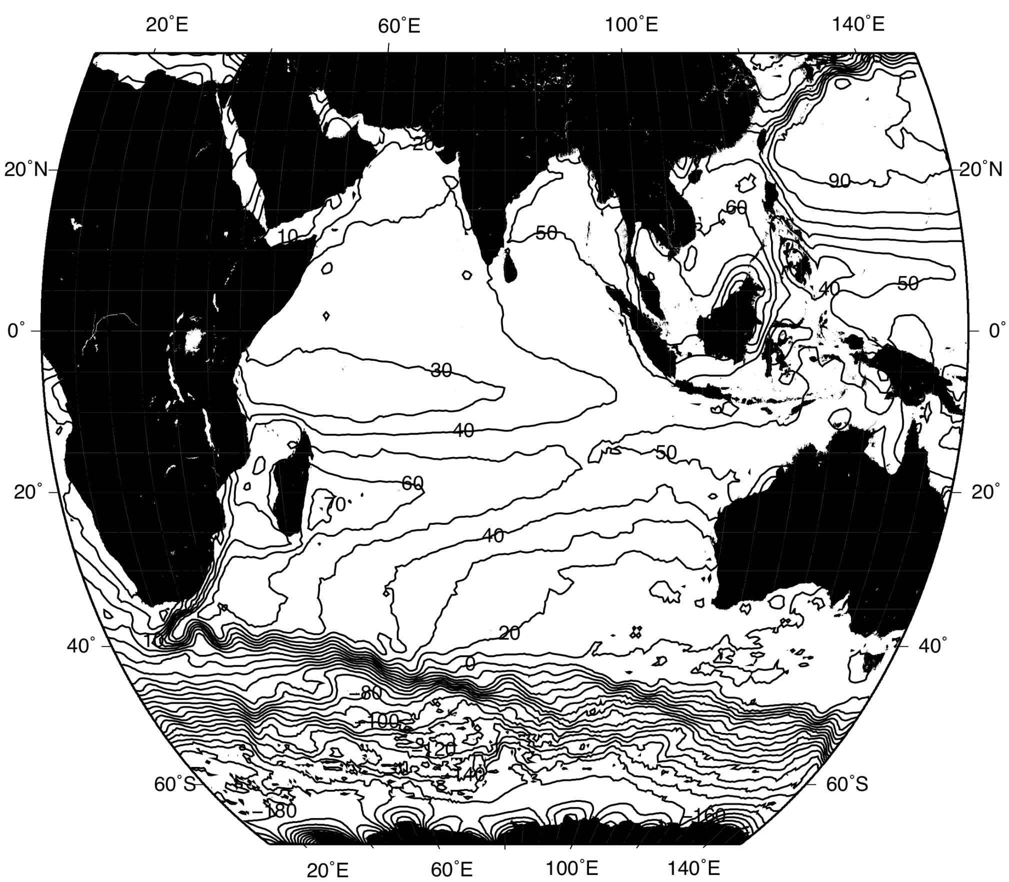
(a) The map below is sea surface height (in centimeters). Label the **Agulhas Current**, the **Indonesian Throughflow,** and the **Antarctic Circumpolar Current – you all got this right.**

(b) On the map, indicate the direction of flow in the Agulhas Current and in the Antarctic Circumpolar Current. Agulhas – southwestward. ACC - eastward

(c) What is the approximate volume transport of the Indonesian Throughflow? (anything in the right range is fine) ______10-15 Sv (1 Sv = 1×10^6 m^3/s)

(d) Suppose this volume transport enters the Indian Ocean at an average temperature of 15°C and leaves the Indian Ocean at an average temperature of 13°C. How much surface (air-sea) heat flux is required within the Indian Ocean for this temperature change? Question worded poorly – I just wanted the total heat loss, but if you did more, that was fine. Using 10 Sv for this answer (you could choose other values):

$\Delta Q = \rho c_p V \Delta T = (1025\ kg/m3)(3850\ J/kg°C)(10 \times 10^6\ m^3/s)(15°C – 13°C) = 7.89 \times 10^{13}$ J/s $= 7.89 \times 10^{13}$ W



9) Suppose the Greenland ice cap melted completely and all of its water entered the ocean. Suppose the volume of water in the ice cap is 3×10^6 km^3. Also suppose that the ocean covers 70% of the earth's surface.

(a) How much would average sea level rise (in meters)?
Sea level rise = volume/area = 3×10^6 km^3/($4\pi R^2$)0.7 = 3×10^6 km^3/[(4π)(6371 km)^{2}0.7] = 0.0084 km = 8.4 m

(b) Suppose the water mixes completely with the ocean. Assume that the ocean is 5000 m deep. If the average salinity of the ocean is 35 psu, what would its new average salinity be?
Since the ice is fresh and since the surface area does not change, the salinity changes in proportion just to the amount of height added.
$S_{new} = S_{old}(H_{old}/H_{new})$ = 35 psu (5000 m / 5008.4 m) = 34.95 psu

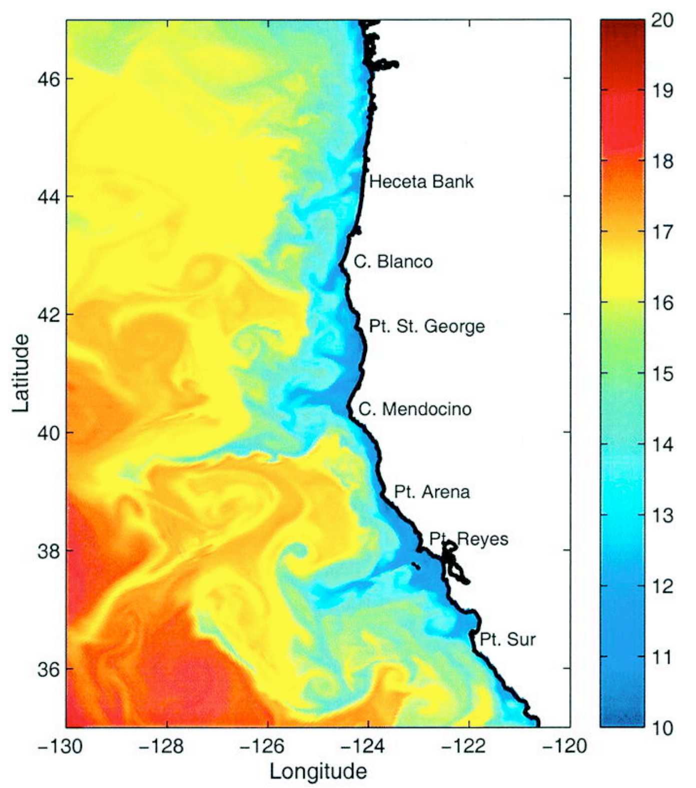
10) Below is a plot of sea-surface temperature along the California coast. A color version is included on the attached sheet. Note both the large-scale on/offshore gradient and the presence of many smaller-scale eddying motions.

(a) What direction of wind stress leads to cold water at the coast? Southward along the coast

(b) Where would you expect to find higher surface nutrients and higher biological productivity? Why? In the regions of cold water near the coast, because the low temperature indicates upwelling. Upwelled water is higher in nutrients, which enhances productivity.

(c) Consider the effective diffusivity from the many eddies present. Will they tend to move heat towards or away from the coast?

Toward the coast: diffusion is down gradient in general, so heat would be moved from high to low. Eddies accomplish this, assuming that the effective diffusivity due to the eddies is uniform.



Long answer or calculation (20 points each)

11) On the next page there is a set of vertical sections from Antarctica to Tasmania (Australia). A color version is shown on the separate sheet; the station locations are shown on the small map on that sheet.

(a) For the following water masses:

- List a characteristic feature that you are using to identify it
- Locate it on one of the vertical sections

Antarctic Intermediate Water_____low salinity_____________

Antarctic Surface Water ____cold, fresh near –surface water_____________________

Lower Circumpolar Deep Water/North Atlantic Deep Water___high salinity deep water

Subantarctic Mode Water thickening of isotherms and isopycnals near surface

Antarctic Bottom Water_______________cold, dense, near bottom water_____

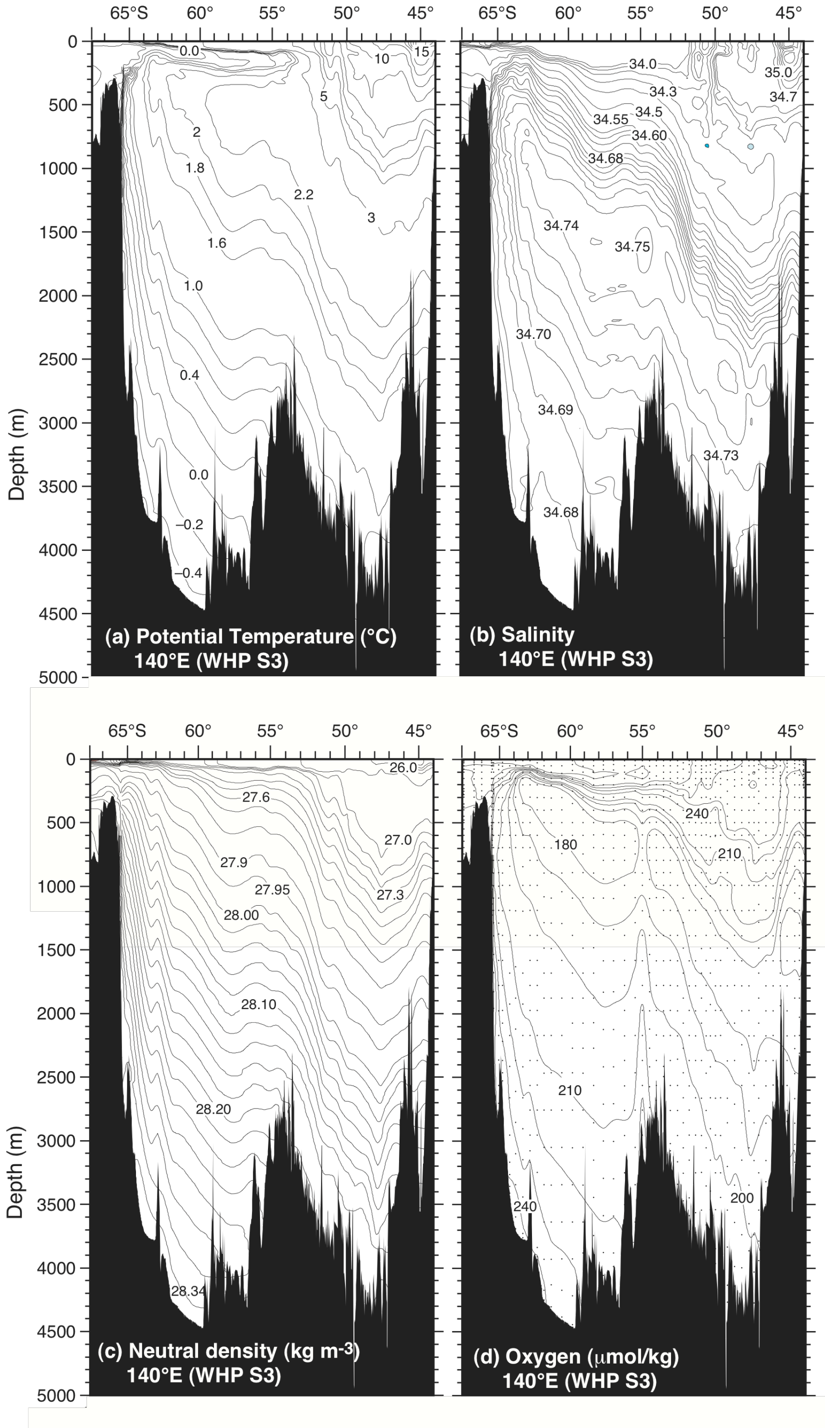
(b) On the vertical section of neutral density, mark the location of the Antarctic Circumpolar Current. How did you identify it? Sloping isotherms and isopycnals over broad latitude range and from top to bottom.

(c) Mark the location of the Subantarctic Front on any (or all) of the vertical sections. Show the direction of flow on the section. Eastward flow
How did you identify the front? Steeply sloping isotherms/isopycnals and onset of AAIW salinitiy minimum north of the front.

(d) Assuming that the circulation is strongest at the sea surface, show the direction of flow as a function of depth in the Subantarctic Front. Eastward at surface, decreasing to weaker eastward with depth.

(e) At the southern end of the section (left side), there is very cold water (near the freezing point) at the sea surface. Explain how this can be vertically stable – why doesn't it sink? It is also very fresh. This layer is covered with sea ice in winter; when ice melts in summer, it leaves behind a very fresh surface layer.

(f) At the bottom on the southern side of the section, there is similarly very cold water. Why did this water sink? Please include ice in your explanation even though it isn't quite at the freezing point. This was near-surface water associated with sea ice production in the winter. Brine rejection from the sea ice increased the salinity of this surface water and allowed it to become dense enough to sink.



65°S
60°
55°
50°
45°
Depth (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
(a) Potential Temperature (°C)
140°E (WHP S3)
0.0
10
15
5
2
1.8
2.2
3
1.6
1.0
0.4
0.0
−0.2
−0.4
(b) Salinity
140°E (WHP S3)
34.0
35.0
34.3
34.7
34.5
34.55
34.60
34.68
34.74
34.75
34.70
34.69
34.73
34.68
(c) Neutral density (kg m-3)
140°E (WHP S3)
26.0
27.6
27.0
27.9
27.95
27.3
28.00
28.10
28.20
28.34
(d) Oxygen (μmol/kg)
140°E (WHP S3)
240
180
210
210
240
200

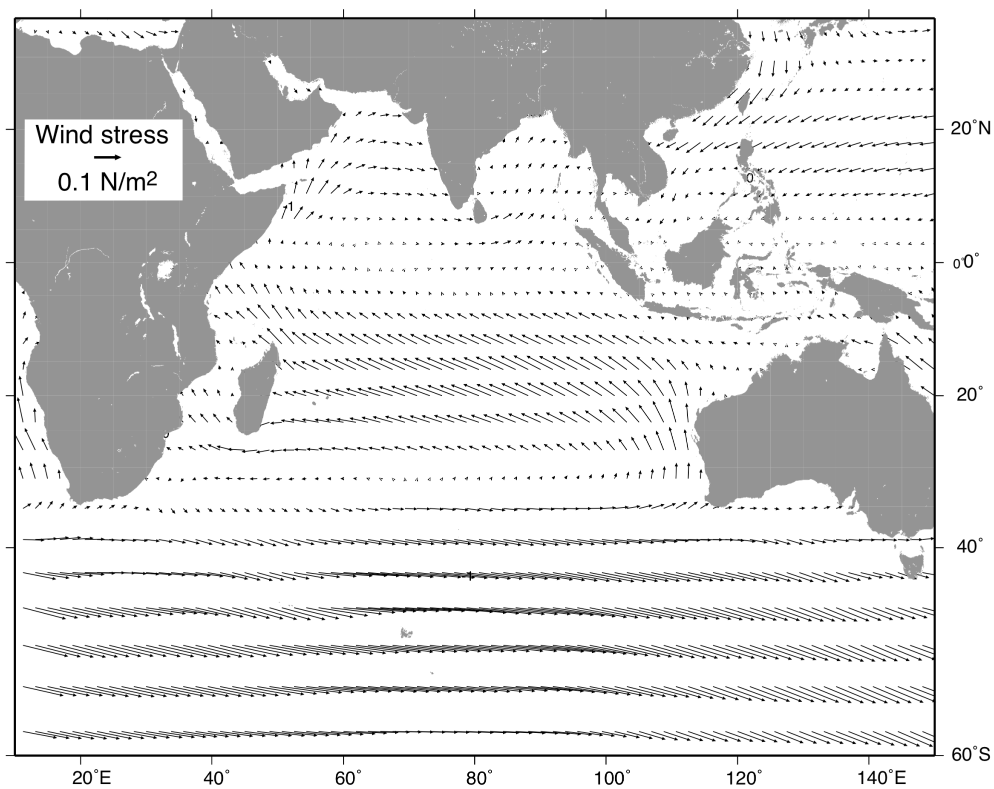
12) Return to Indian Ocean (from problem 7)

Below is a map of the annual mean wind stress for the Indian Ocean.

(a) Mark the location of the westerly winds.

Mark the location of the trade winds in the southern hemisphere.

(b) Mark the location where the winds are dominated by the Asian monsoon in the Northern Hemisphere. Is the Indian Ocean's annual mean (shown here) dominated by the Southwest Monsoon or the Northeast Monsoon? ____________________



(c) For each of these **three** wind regimes (westerlies, trades and monsoonal), indicate the direction of Ekman transport on the map.

(d) In the Southern Hemisphere, between 20°S and about 50°S, is there Ekman downwelling or Ekman upwelling? ______________________
How do you know?

(e) Which direction should the general circulation flow between 20°S and 50°S, where you indicated the Ekman up or downwelling?

What is the dynamical reason for this direction of flow?

(f) Suppose the magnitude of the Ekman downwelling or upwelling at 30°S, in the center of this region, is

$$w_E = 1 \times 10^{-6} \text{ m/sec}$$

If this velocity is applied for 1 year, how much would a water column be "stretched" or "squashed" in that year? (in meters)

(g) Using potential vorticity conservation, estimate the change in latitude that would result from this "stretching" or "squashing". Assume that the stretching affects only the top 500 m layer of the ocean. Assume that relative vorticity is negligible. (You might find much useful information in the expressions at the top of the exam; you can just interpolate if needed.)

Extra credit:
What speed does this translate to in cm/sec or m/sec?

The Indian Ocean is about 5,000 km wide at this latitude. If this same north-south velocity applies at all longitudes across the Indian Ocean, what is the total meridional transport, again assuming a layer that is 500 m thick?

SIO 210 Final exam Hendershott portion   NAME____________________

1. In the space provided, enter the letter of the speed that most nearly corresponds to each of the waves listed below:

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

_____ seismic waves
_____ ocean swell generated by winds
_____ capillary waves
_____ acoustic waves in the ocean
_____ tsunami waves

2. The most energetic waves radiated away from a submarine earthquake have wavelength

a. much greater than   OR   b. much less than

the depth of the open ocean. (circle correct answer)

3. The most energetic waves radiated away from a major midocean storm have wavelength

a. much greater than   OR   b. much less than

the depth of the open ocean. (circle correct answer)

4. Long swell waves (periods of roughly 12 to 20 sec) come in groups because

a. the storm that generated them consists of many individual strong wind events, each one generating a wave group,

OR

b. the fact that long swell travel faster than short swell causes waves arriving at a distant coast to be energetic only over a narrow range of periods, these very similar waves then randomly interfere constructively and destructively to form groups.

5. Long swell waves (periods of roughly 12 to 20 sec) are

a. deep water		b. shallow water		(circle one)

waves in the open ocean but become

a. deep water		b. shallow water		(circle one)

waves when they approach the coast. This

a. is why wave crests generally tend to become more parallel to the coast as the waves enter shallow water near the coast

b. is why wave crests generally tend to become more perpendicular to the coast as the waves enter shallow water near the coast

c. has nothing to do with wave orientation

(circle one)

6. Here is a list of astronomical/orbital features for the earth-moon-sun

a. full moon, new moon

b. half moon

c. lunar perigee

d. moon crosses the earth's equatorial plane

e. moon at maximal angular distance from earth;s equatorial plane

d. sun crosses the earth's equatorial plane

e. sun at maximal angular distance from earth's equatorial plane

Match each with one of the following features of ocean tides

_____maximal daily inequality occurring twice per month

_____spring tides

_____perigean spring tides

_____ maximal daily inequality occurring twice per year

_____ neap tides

7. The tide at most ports may be analyzed into a few perfectly harmonic constituents as listed below

M2 semidiurnal lunar tide, period 1/2 lunar day or about 12.42 h.
S2 semidiurnal solar tide, period 1/2 solar day or exactly 12 h.
N2 elliptical lunar tide, period about 12.64 h
K2 solar elliptical semidiurnal tide, period about 11.97 h
K1 luni-solar declinational diurnal tide, period about 23.39 h,
O1 lunar declinational diurnal tide, period about 25.8 h
P1 solar declinational diurnal tide, period about 24.066

Your knowledge of the various orbital and astronomical features that result in certain features of the tide (e.g. occurrence of full/new moon, ellipticity of moon's orbit, ellipticity of earth's orbit, motion of tide generating bodies out of earth's equatorial plane) will enable you to recognize the constituents that answer the following questions:

a. _____ and _____ interfere to produce solar diurnal tides that vanish twice per month.

b. _____ and _____ interfere to produce lunar diurnal tides that vanish twice per month.

c. _____ and _____ interfere to produce the spring-neap cycle

d. _____ and _____interfere to produce high lunar semidiurnal tides at lunar perigee.

e. _____ and _____interfere to produce high solar semidiurnal tides at solar perihelion (note that this was NOT discussed in class but it is the solar analogue of (d).

In answering these questions you will NOT need to do any calculations with the periods of the individual constituents, they are listed only as a memory aid.

8. In class we emphasized the most important tidal features; one was the occurrence of lunar perigean spring tides. Solar perihelion spring tides also occur but they are not a very important feature of observed tides because

a. the mass of the sun is so much greater than the mass of the moon,

b. the sun is much further from the earth than is the moon,

c. the earth's orbit around the sun is much more circular than the moon's orbit around the earth,

d. the plane of the earth's orbit around the sun makes a much small angle with the earth's equatorial plane than does the plane of the moon's orbit around the earth.