SIO 210 Final examination
Wednesday, December 12, 2007
3-6 PM

Name:______________________

This is a closed book exam. 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. 17)

________Return the exam etc to me via campus mail

Mailcode__________________________

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

Talley portion: 70 points
[1-5] Multiple choice 3 points each ________________/15
[6-10] Short answer 5 points each ________________/25
[11-12] Long answer 15 points each ________________ /30

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

1) The wind-driven subtropical gyres
(a) Shrink towards the pole with depth
(b) Extend in their entirety to the ocean bottom
(c) Have equal strength eastern and western boundary currents
(d) Are driven by Ekman transport divergence

2) Potential density computed relative to 4000 dbar
(a) depends on pressure, temperature and salinity
(b) has a range of values for the ocean between 22.0 and 28.0
(c) has flatter contours in the potential temperature-salinity plane than does potential density relative to 0 dbar
(d) has large inversions in the vertical in the deep (> 2000 m) South Atlantic

3) 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

4) The Kuroshio
(a) differs from other subtropical western boundary currents by including a so-called large meander before it separates from the coast
(b) has a transport on the order of 10 Sv
(c) is the western boundary current of the South Pacific
(d) carries subpolar water to the coast of Japan

5) Deep Western Boundary Currents
(a) are found only in the bottom 100 meters of the ocean
(b) are not geostrophic
(c) flow in the opposite direction of the interior Stommel-Arons flow
(d) carry Lower Circumpolar Deep Water northward in the Pacific Ocean

Short answers. (5 points each)

6) Subduction is a process found in the upper ocean in the subtropical gyres.

(a) Name one of the water masses that is associated with subduction
Subtropical Mode Water or Subtropical Underwater or Central Water

(b) Describe how the water mass is detected
STMW: Thickening of isopycnals/isotherms at about 18°C
SUW: Shallow salinity maximum
CW: High vertical density gradients between the upper and intermediate ocean (thermocline/pycnocline)

7) An Equatorial Undercurrent (EUC) is found in the Pacific and Atlantic Oceans.

(a) At approximately what depth is the EUC found in the Pacific?
100-200 m

(b) Describe (3 sentences or less) what drives the EUC.
Westward wind stress pushes surface frictional layer due west along the equator, piling water up at the western boundary. This causes an eastward PGF and creates the EUC. A second reasoning, which we didn't cover in class, is that off-equatorial Ekman transport to the north (south) on the northern (southern) side of the equator, causes equatorial upwelling, which causes isopycnals/isotherms to be pulled upward on either side of the equator. The geostrophic response to this, off the equator, is eastward along-equator flow. This second set of reasonings involves the Coriolis force, which begins to be felt at about ¼ degree from the equator, so a combination of both the non-Coriolis and the Coriolis explanations

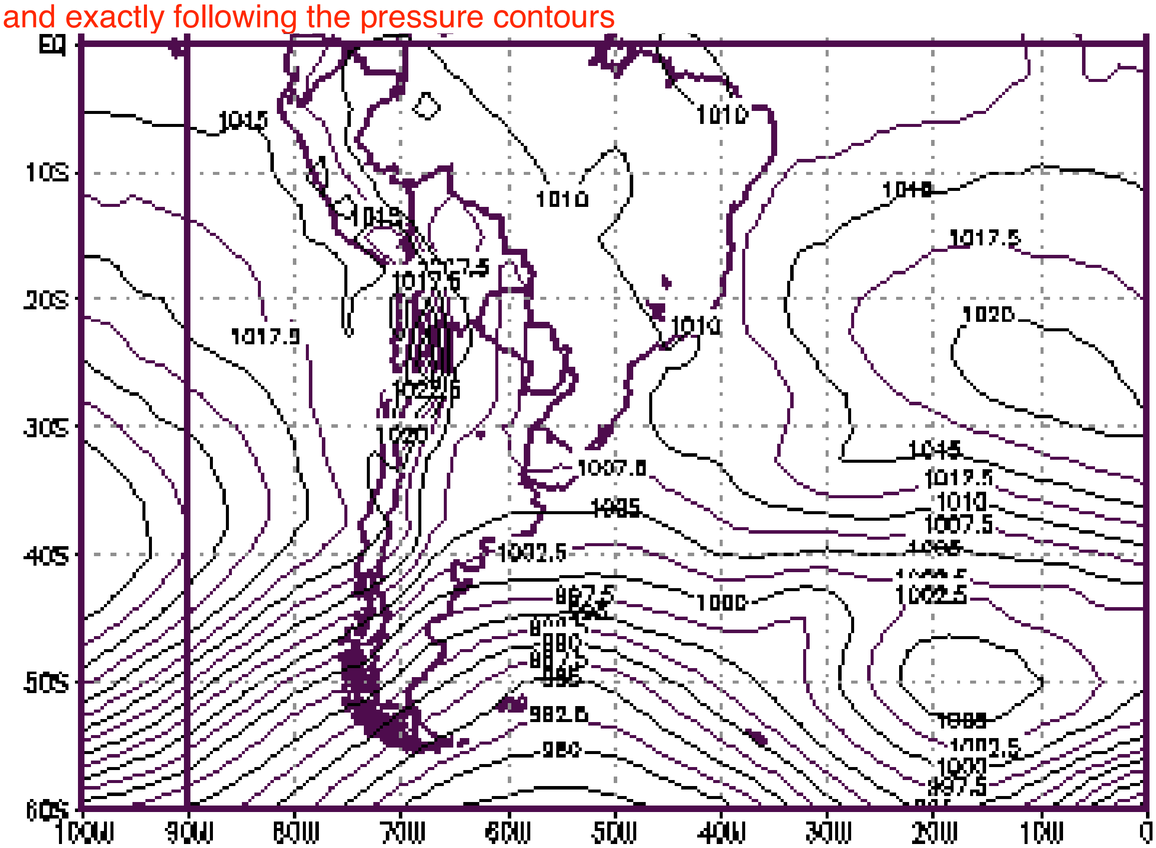
is the full argument for the EUC.

8) On the map provided, there are some high pressure centers. Be careful about what hemisphere this is from is as you answer the following.

(a) Choose ONE of the high pressure centers and indicate (on the map) the direction of the pressure gradient force relative to the high pressure.
There is a high pressure center on the right side and also one on the left side of the map. Direction of PGF is from the high center outward to the low pressure surrounding it.

(b) Indicate (on the map) the direction of the Coriolis force relative to the high pressure.
Coriolis force vector should exactly equal and opposite to the PGF vector.

(c) Indicate (on the map) the direction of the geostrophic wind relative to the high pressure.
Geostrophic wind should be counterclockwise around the high pressure center, and exactly following the pressure contours



Sea Level Pressure (mb) Composite Mean
12/8/07 to 12/9/07

NCEP/NCAR Reanalysis

9) What are the units (in the mks system) of the following? (1 point each)
(a) Mass transport kg/sec

(b) Freshwater transport kg /sec

(c) Heat transport J/sec or W

(d) Oxygen transport moles/sec

(e) Volume transport m^3/sec

10) The trade winds blow from east to west throughout the tropics. Assume that the winds are steady and that they are exactly east-west (no north-south component) as you answer the following.

(a) What is the name of the frictional layer at the surface that is driven directly by the winds (everywhere except on the equator)?
Ekman layer

(b) In the northern hemisphere, what is the direction of the ocean mass transport in this layer?
northward, 90° to the right of the wind

(c) In the southern hemisphere, what is the direction of the mass transport in this layer?
southward 90° to the left of the wind

(d) What is the direction of transport in this layer exactly on the equator?
frictional layer is exactly westward. Some answered that the layer ("Ekman layer") doesn't exist, which is accurate, so I gave full credit for both answers.

Long answer or calculation (15 points each)

11) The California Current flows southward along the west coast of the U.S. It is caused by the wind. For this question, consider it as a separate phenomenon from the subtropical gyre.

The California Current is driven by a southward alongshore wind. The wind causes an offshore Ekman transport.
Assume that the total Ekman transport is 1 Sv. (1 Sv = 1×10^6 m^3/sec.)

(a) Explain how the California Current itself arises from this forcing. (short answer)

Wind blows alongshore, causing offshore Ekman transport and upwelling along the coast. This causes the isopycnals to slope upward towards the coast. The geostrophic response to the offshore Ekman transport and the upward-sloping isopycnals is a southward alongshore current, which is the California Current.

(c) Along the coast, there is upwelling in a strip that is about 10 km wide. Assume that it occurs over a 1000 km length of the coast.
Make a reasonable assumption for the thickness of the upwelling layer based on what is causing the upwelling. ________100 to 200_______m

Assuming that the Ekman transport of 1 Sv occurs out of this box, calculate the offshore Ekman velocity (using the transport and dimensions of the box).
Transport through offshore side of box is
(1000 km) x (100 m) x v = 1 Sv = 1×10^6 m^3/sec
so the velocity v = 0.01 m/sec = 1 cm/sec

(d) Calculate the upwelling velocity into the box (using the transport and dimensions of the box).
(1000 km) x (10 km) x w = 1 Sv = 1×10^6 m^3/sec
so the vertical velocity w = 10^{-4} m/sec = 0.01 cm/sec

(e) The upwelled water is around 8°C. This water must become 13°C to join with the offshore waters. The expression for heat in terms of temperature is

$$Q = \rho c_p T$$

Assume that the seawater density is 1020 kg/m3 and the specific heat is 4000 J kg^{-1} K^{-1}

What are the units of heat? This was actually heat content (heat per unit volume), or
[Q] = (kg/m^3) (J kg^{-1} K^{-1})(K) = J/ m^3
Equally valid response is heat itself, units are J.

What is the heat transport into the box from the upwelling?
(1020 kg/m^3)*(4000 J kg^{-1} K^{-1})*8C*1e^6 m^3/sec = 3.3 $\times10^{13}$J/sec
which is actually a temperature transport and not a heat transport. If you added 273.16K to the 13C, then you would get a heat transport. But since all that really matters is the difference between heat transport into and heat transport out of the box, the 273.16 is not important (see next 2 parts of question).

If you computed full Kelvin temperature:
(1020 kg/m^3)*(4000 J kg^{-1} K^{-1})*(281K)*1e^6 m^3/sec = 1.15 $\times10^{15}$J/sec

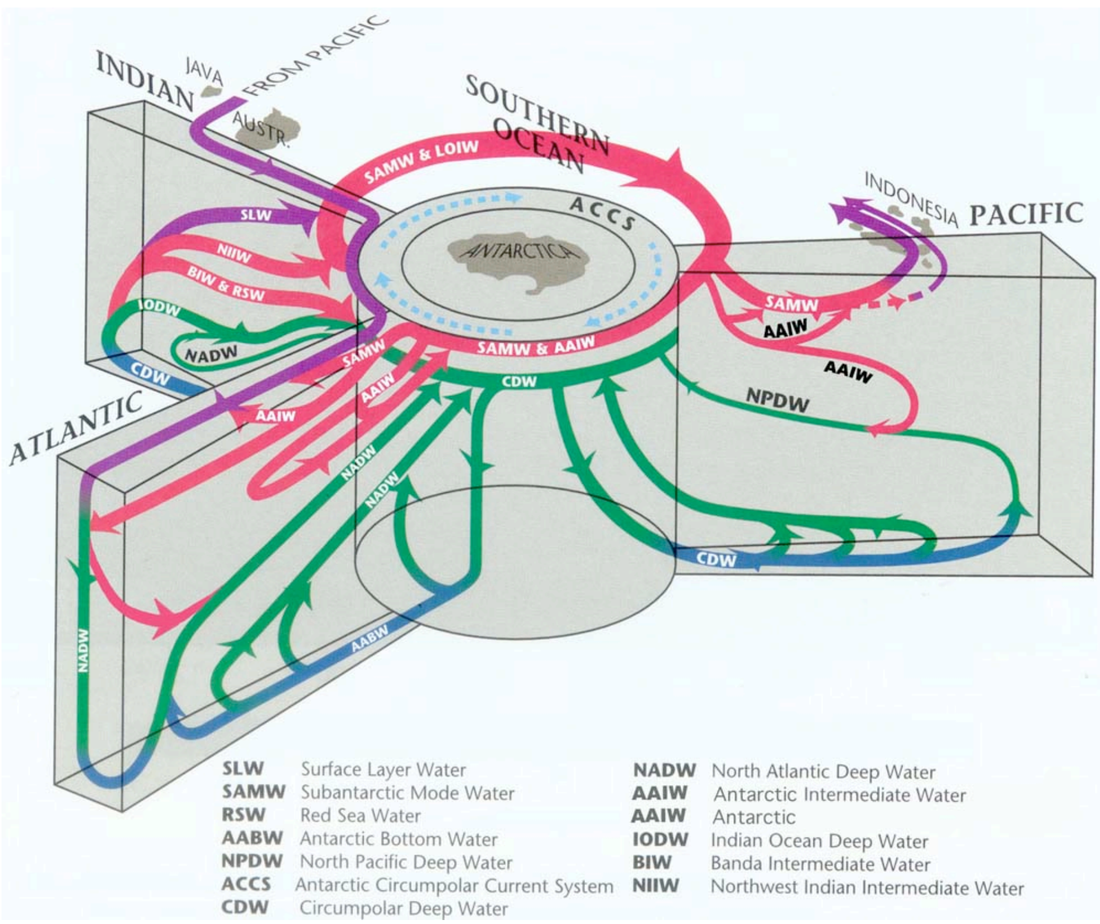
(f) What is the heat transport out of the box at the higher temperature?
(1020 kg/m^3)*(4000 J kg^{-1} K^{-1})*13C*1e^6 m^3/sec = 5.3 x10^{13}J/sec
or if you computed full Kelvin temperature:
(1020 kg/m^3)*(4000 J kg^{-1} K^{-1})*(286K)*1e^6 m^3/sec = 1.17 x10^{15}J/sec

(g) What is the net air-sea heat flux that must occur within the box to create this heating?
5.3 x10^{13}J/sec -3.3 x10^{13}J/sec = 2 x10^{13}J/sec = 2 x10^{13} W is the total heat.
To get heat flux, divide by the surface area of the box Area = 10 km x 1000 km = 10^{10}m^2

Heat flux = 2 x10^{13}W / Area = 2 x10^{3}W/m^2

Calculate the air-sea heat flux for the box (upwelling strip) for conversion of the 8°C water to 13°C water.
Woops – same question, same answer

12) This is an overturning schematic for the global ocean.



(a) On the diagram, there is a purple path at the top. Describe the significance of this pathway in terms of the global overturning circulation. (Describe what waters are involved and what their role is in the overturn.)
This is the return path for surface waters from the deep Pacific and Indian Oceans to the Atlantic Ocean in the global overturning circulation. Upwelling in the Pacific feeds the Indonesian Throughflow, which is joined in the Indian Ocean by upwelling from the deep Indian, then enters Atlantic through the Agulhas and Benguela Current systems and eddies. Then joined by upper ocean upwelling in the Atlantic as it transits to the northern N. Atlantic to produce components of NADW.

(b) On the diagram, there are many pathways labeled with water mass names. In class we did not necessarily talk about all of these, or use exactly the same terms (particularly in the Indian Ocean).
Most of the class picked either NADW, PDW, CDW or AAIW. Only doing NADW here, although it is the most complex.
Nevertheless, pick one water mass.___NADW________________________

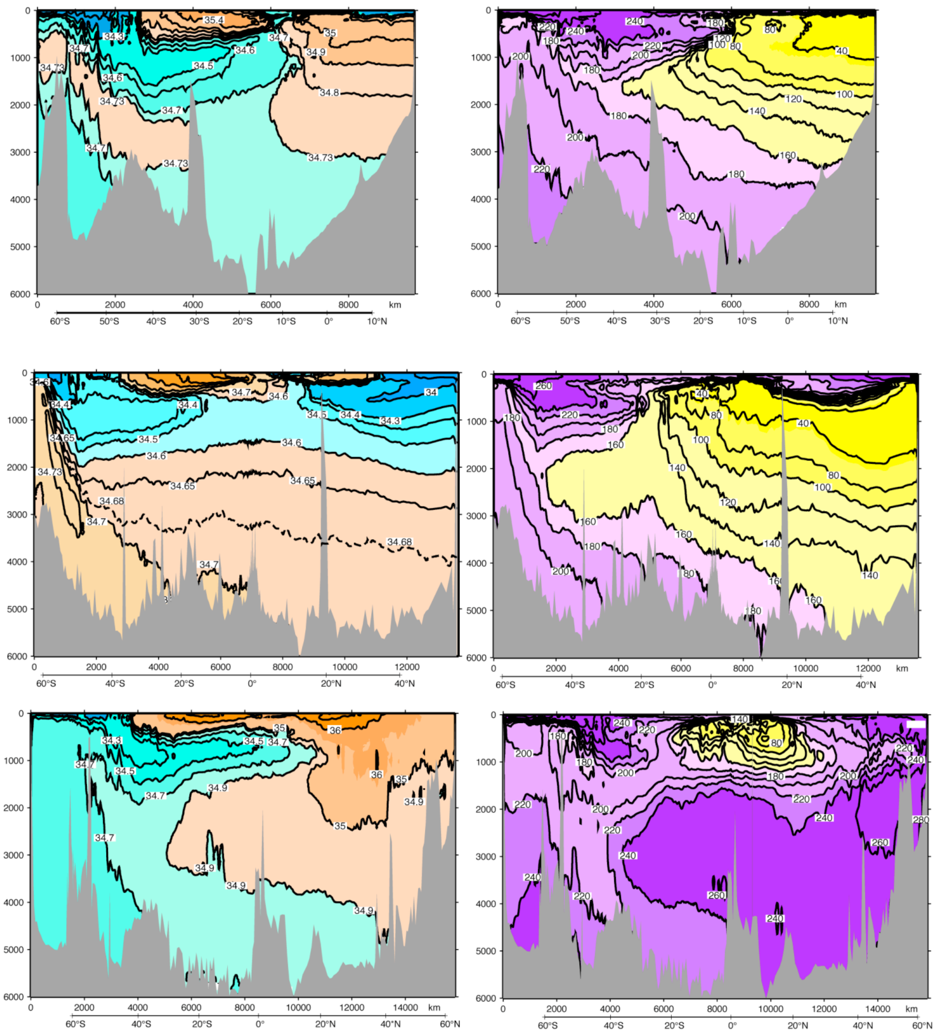
Describe how this water mass is recognized (what tracer or tracers are used to identify it). high salinity, high oxygen, low nutrients

(c) How is your chosen water mass formed?
Deep convection driven by heat loss in the Labrador, Nordic and Mediterranean Seas, joined by entrained AAIW and AABW. Please note that brine rejection is NOT an integral part of this process. These water masses are saline because the N. Atlantic is a net evaporative basin compared with the Pacific.

(d) What about the formation process for your water mass produces the identifier that you gave in (b)? High salinity due to generally high evaporation, high O2 due to recent formation age, low nutrients for the same reason.

(e) To assist with your description, here are oxygen and salinity sections from the Atlantic, Pacific and Indian Oceans.

Label the Pacific, Atlantic and Indian sections.
Label which are oxygen and which are salinity.



Salinity to left, oxygen to right, Indian, Pacific, Atlantic from top to bottom

(f) On the sections, MARK where your water mass occurs. If it occurs in all three oceans, then label it in all three. Your water mass might not be identified by salinity or oxygen. If that is the case, then indicate generally where your water mass occurs relative to the oxygen and salinity features.

NADW marked as high salinity – large orange water mass in center of Atlantic section, remnant orange high salinities at southern ends of Pacific and Indian.
NADW marked as high oxygen – large purple water mass in center of Atlantic.

(g) Using the schematic at the top of the question and the sections, describe the evolution of either salinity or oxygen along the pathway of the water mass. Does it become fresher or saltier? How does its oxygen change?

NADW becomes fresher as it leaves the North Atlantic due to mixing with overlying fresher AAIW and underlying fresher AABW/CDW. As it enters the Indian and Pacific Oceans, the same mixing continues to freshen the salinity maximum.
NADW oxygen also decreases along the same path, mainly due to aging

(bacterial respiration that reduces oxygen).

SIO 210 FINAl EXAm QUESTIONS FALL 2007 NAME=

____KEY______________________

1.Short answer questions about waves, for each mark or give the most nearly correct answer

a. Waves generated by large mid-ocean storms cross the ocean at a speed of about
   a. several Km/sec, b. 1500 m/sec, c. 200 m/sec,
   *d. 10 to 30 m/sec.

b. The first ocean waves of a tsunami cross the open ocean at a speed of about
   a. several Km/sec, b. 1500 m/sec, *c. 200 m/sec,
   d. 10 to 30 m/sec.

c. Seismic waves, upon which our ability to issue a tsunami warning relies, travel at about
   *a. several Km/sec, b. 1500 m/sec, c. 200 m/sec,
   d. 10 to 30 m/sec.

d. The mid-ocean stable platform FLIP scarcely moves up & down as ocean swell pass by, but as the waves of a tsunami pass by
   *a. FLIP moves vertically with the tsunami waves,
   b. FLIP moves vertically with a much smaller amplitude than the tsunami waves,
   c. FLIP moves vertically with a much larger amplitude than the tsunami waves.

e. At the coast, the vertical motion of the sea surface associated with a major tsunami is generally
   *a. much greater than, b. much smaller than, c. about the same as that associated with wind generated waves.

f. In the open ocean, the vertical motion of the sea surface associated with a major tsunami is generally
   a. much greater than, *b. much smaller than, c. about the same as that associated with wind generated waves.

g. A typical tsunami at a port consists of
   a. An initial rise in sealevel followed by no further unusual sealevel variability.

b. An initial fall in sealevel followed by no further unusual sealevel variability.
c. Either an initial rise or an initial fall in sealevel followed by no further unusual sealevel variability.
d. Either an initial rise or an initial fall in sealevel followed by unusual sealevel variability lasting for weeks.
*e. Either an initial rise or an initial fall in sealevel followed by unusual sealevel variability lasting for many hours.

h. The seismic wave based tsunami warning system can accurately predict
a. the initial arrival time and the initial amplitude of a tsunami,
*b. the initial arrival time but not the initial amplitude of a tsunami,
c. the initial amplitude but not the initial arrival time of a tsunami,
d. the entire sealevel history of the tsunami.

i. The leading crest of the Sumatra tsunami of 2004 advanced into the Indian Ocean (mean depth D_Indian ~ 2000 m) and into the Strait of Mallaca (mean depth D_Mallaca ~ 100 m). What is the ratio of speed of advance in the Indian ocean to that in the Strait of Mallaca, c_Indian/c_Mallaca? Answer both with a formula and a number.

c_Indian/c_Mallaca = sqrt(D_Indian/_Mallaca) =sqrt(20) ~ 4.5

j. If a tsunami alert is issued for La Jolla, you should
a. go to the shore to watch the big waves come in,
*b. go to the top of Mt. Soledad,
c. pay no attention.

2. Short answer questions about tides, for each mark the most nearly correct answer.

a. Spring tides (times of large semidiurnal tidal range) occur twice a 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 quarter moons,
e. at lunar perigee.

b. The daily inequality (elevation difference between a high tide and its immediate successor) vanishes for lunar tides

*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 quarter moons,
e. at lunar perigee.

c. 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)

d. The tidal range at times when lunar perigee and full/new moon occur together
*a. is unusually large,
b. is unusually small,
c. is nothing special.

e. Spring tides
*a. may occur near the times of an eclipse of the sun or of the moon,
b. never occur near the times of an eclipse,
c. ONLY occur at the times of an eclipse.

f. Neap tides
a. occur near the times of an eclipse of the sun or of the moon,
*b. never occur near the times of an eclipse,
c. ONLY occur at the times of an eclipse.

g. 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 the there would be one high water about every
a. 6 hrs, b. 9 hrs, c. 12 hrs,
*d. 18 hrs, e. 36 hrs

3. Quantitative question about waves. Very long swells generated by a distant storm are observed in the open ocean. Their period is T seconds. What is their wavelength L? Hint; this requires you to remember the formula c=sqrt(gL/(2*pi) for wavespeed c and the general relationship c=L/T to get a formula for wavelength in terms of wave period. Write that formula

L= g(T^2)/ (2*pi) formula

and approximately evaluate the result numerically assuming T=20 s and g=10 m/s2.

L= 2000/pi meters numerical result (may be in terms of pi)

What is the numerical speed of these waves?

c=100/pi meters/sec numerical result (may be in terms of pi)

As these waves pass by, water parcels at the surface carry out circular orbits (forward at the crest, then downward, backward at the trough, then upward). If the waveheight (from crest to trough) of these waves is H, what is the diameter D of the orbit?

D=H formula

What is the average speed s with which water particles traverse the orbit?

s=pi*H/T formula

Numerically evaluate the result for waves of period T=20 s and height H=10 m

s=pi/2 meters/sec numerical result (may be in terms of pi)

4. A More difficult question about tides. Question 2g above, envisages a situation in which the earth rotates about its axis once every 36 h rather than once every 24 but otherwise no detail of the astronomy or of the shape of the ocean floor or of the coasts is changed. Question 2a asks if the dominant period of the tide would change and, if so, what would it be. Now think more deeply about this situation and answer the following questions.

a. Would the spatial distribution and/or amplitude of the tide generating force change? Explain your answer in a short paragraph on page at end of exam.

Spatial distribution/amplitde of tide generating forces do not depend on earth's rate of rotation, they will not change. Simple way to think about this is that, since orbit of moon and of center of earth does not change, then centrifugal force at center of earth does not change, lunar gravity does not change,

b. Would the spatial distribution and/or amplitude of actual the ocean tide and/orof ocean tidal currents change? To answer fully, you may need to think back in the course about dynamical matters that were discussed in connection with ocean currents. Explain your answer in a short paragraph on page at end of exam. I am looking as much for clearly expressed thought as I am for a single correct answer, so please think before you write. Partial credit allowed.

Important ideas.

Tide generating forces do not change shape, just period,
so maybe no change in ocean tide except period
Coriolis force is smaller, so expect change.
But time variation is also smaller, by exactly same amount,
so maybe no change after all.
Time for gravity waves to cross basin largely unchanged
(except for Coriolis effects), but period is different,
so may expect different shape of response.