NAME: _____

SIO 210 Introduction to Physical Oceanography
Mid-term examination
November 3, 2014; 1 hour 20 minutes

Closed book; one sheet of your own notes is allowed. A calculator is allowed.
(100 total points.)

Possibly useful expressions and values

1 Sv = 1 x 10^6 m^3/sec (volume) or 1 Sv = 1 x 10^9 kg/sec (mass)
$f = 1.414 \times 10^{-4}$/sec * sin (latitude)
$\delta = H/L$
$g = 9.8$ m/s^2
$\rho = 1025$ kg/m^3
$c_p = 4000$ J/kg°C
$F \sim \rho V(S_o - S_i)/S_m$
acceleration + advection + Coriolis force = pressure gradient force + gravity + friction

Multiple choice (10 problems, 2 points each, 20 points total)
For each problem, **circle the CORRECT answer**. (There should be **only one**.)

1. The Northern Hemisphere ocean's **inertial response** to a strong pulse of wind
(a) makes the water circle to the right (clockwise)
(b) creates a strong pressure gradient downwind
(c) results in a frictional spiral of the water to the right of the wind
(d) makes the water circle cyclonically

2. If surface waves are sampled once a week by a satellite altimeter, then
(a) their frequency is lower than the **Nyquist frequency**
(b) their frequency is higher than the **Nyquist frequency**
(c) the **fundamental period** is 1 week
(d) the **fundamental period** is 1 minute

3. **Antarctic Intermediate Water** is characterized by
(a) very cold water, close to freezing
(b) a mid-depth salinity maximum extending southward
(c) a mid-depth salinity minimum extending northward
(d) low oxygen

4. An **Eulerian measurement**
(a) follows the water
(b) is the same as a Lagrangian measurement
(c) is made from a mooring
(d) is made using a float

5. Assuming we are in seawater with a salinity of 33 (psu): At its **freezing point**, seawater is
(a) more compressible than seawater at 4°C
(b) at a lower density than seawater at 4°C
(c) 0°C

6. The **Hadley circulation** has
(a) a very strong response to seasonally-changing temperatures over Asia
(b) low surface pressure at 30°N
(c) sinking air near the equator
(d) westerly winds at the top of the troposphere

7. **Potential temperature** in the ocean
(a) always decreases downward
(b) is uniform in very deep trenches with single sources of seawater
(c) at 1000 m depth is higher than the locally measured temperature
(d) results from the mechanical compression of molecules

8. **Geostrophic balance** describes the force balance between:
(a) acceleration and pressure gradient force
(b) advection and diffusion
(c) gravitational force and pressure gradient force
(d) Coriolis and pressure gradient force

9. Of these terms that contribute to air-sea heat flux, which is most directly related to planetary boundary layer turbulence? (that is, turbulence in the atmosphere layer just above the ocean)
(a) latent heat flux
(b) solar radiation
(c) longwave radiation

10. Centrifugal force
(a) caused the Earth to bulge outward at the poles by 21 km compared with the equator
(b) causes the Indian Ocean region to be 200 m deeper than the nearby continents
(c) is pointed away from the Earth's rotation axis
(d) is important in geostrophic flow

Short answer or calculations (80 points total)

11. (10 points)
(a) What is the name for the following force/momentum balance? (short answer)

0 = pressure gradient force + gravity force

(b) Is this balance in (a) from the x, y, or z momentum equation? _____

(c) If we write (a) out in differential form, it becomes

$0 = -\Delta p/\Delta z - \rho g$

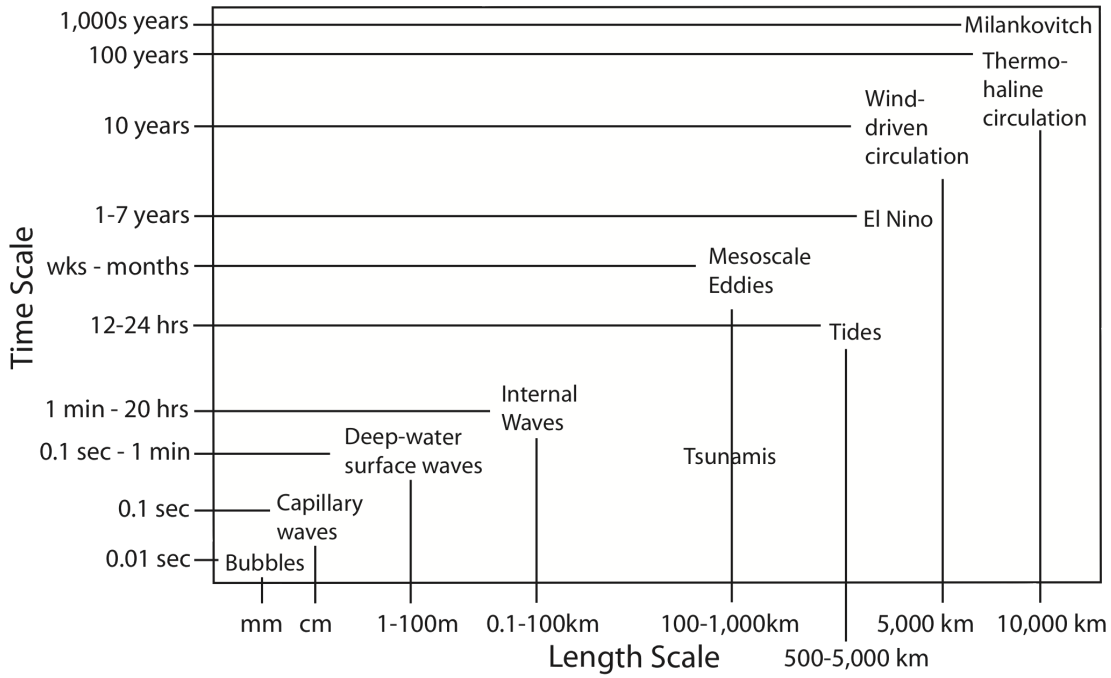
If the water column density is 1025 kg/m^3, calculate the pressure at 100 m depth. You should express it in mks units. ("mks" means "meters-kilograms-seconds")

12. (10 points)
A tsunami is a surface wave forced by an under-sea earthquake. A tsunami propagates like a normal surface wave, but it feels the deep ocean bottom. We have not studied them yet, but they are listed on the graph of length/time scales attached. In the following, compare the space and time scales of a tsunami with mesoscale eddies.

(a) What is the approximate ratio of the rotation time of the Earth to the time scale of a tsunami? Is it much smaller or larger than 1?

(b) What is the approximate ratio of the rotation time of the Earth to the time scale of a mesoscale eddy? Is it much smaller or larger than 1?

(c) Which of the two (tsunami or mesoscale eddy) is most likely to be affected by Coriolis force? Why? (use your answers to (a) and (b).)



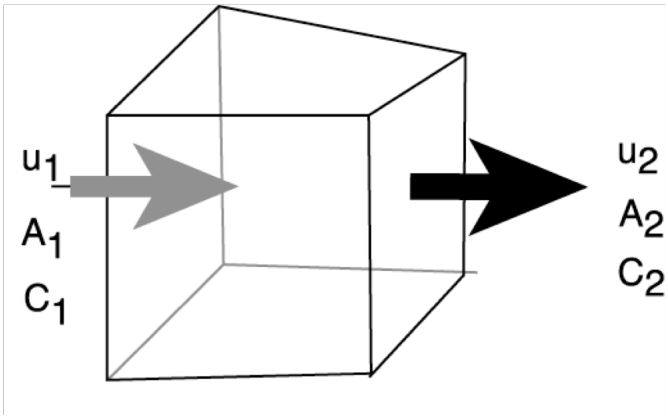
13. (10 points)
Consider the concentration in a volume of the ocean of a conservative tracer (call it chlorofluorocarbon or CFC). The units of concentration are (moles tracer)/(kg seawater), that is, moles/kg.

(a) What is the difference between a conservative and a non-conservative *tracer* ?

(b) Is it possible for the concentration of a tracer within a volume of water to change while the mass in the volume does not change? YES or NO (circle one)

Explain.

14. (25 points)
Consider the volume in the figure. There is flow into the left side of the volume and flow out of the right side of the volume. The inflow has velocity u_1. The outflow has velocity u_2. The area of the inflow is A_1 and the area of the outflow is A_2. Assume *there is no flow through any other side of the box*. Assume that the top surface of the box is the sea surface and that heat can be exchanged with the atmosphere across this surface.



u_1 = 0.1 m/sec
A_1 = width x height = 10 km x 10 meters
T_1 = 15°C
$\rho \sim 1025$ kg/m^3

u_2 = ???
A_2 = width x height = 10 km x 100 m
T_2 = 10°C
$\rho \sim 1025$ kg/m^3

(a) What is the mass transport through the left side? (side "1")

(b) Calculate u_2 using the given values. (To keep this simple, assume the density is the same through both faces; the small difference does not matter for this problem.)

(c) Calculate the difference in heat transport between the left side and right side. Again assume a density of 1025 kg/m^3 and specific heat as given in the "useful values".

(d) Is heat gained or lost through the top surface of the box?

(e) Calculate the total rate of air-sea heat flux for the box (over the whole box).

(f) If the distance between sides 1 and 2 is 1000 km, calculate the average net heating in W/m^2 for the box.

15. (10 points)
The attached page with two color figures shows the Atlantic potential temperature (meridional section) and the potential temperature versus salinity relation for the same data set. The location of the section is in the small map.

(a) On the potential temperature – salinity diagram, circle and label the "Central Water", also known as the "thermocline water".

(b) On the potential temperature section, also circle the Central Water. The Northern Hemisphere and Southern Hemisphere Central Waters can be considered to be separate.

(c) Water masses are identified through a common formation history. What is a mechanism for formation of Central Water? (There may be more than one theory; as long as you explain one, you will get credit.) _____

16. (15 points)
Consider again the potential temperature section (attached color figures). There are several regions where there is a vertical potential temperature inversion.

(a) Circle one of the potential temperature inversions on the vertical section.

(b) Locate the temperature inversion on the θ-S (potential temperature-salinity) diagram, being sure to have the same corresponding potential temperature and general latitude range.

(c) Explain how there can be a potential temperature inversion that is stable over many years, even though density usually depends strongly on temperature.

(d) EXTRA 3 points. For your potential temperature inversion: explain how it arose – what is the mechanism that results in there being an inversion?

Color figures used for both Problems 15 and 16

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