NAME: _____

SIO 210 Introduction to Physical Oceanography
Mid-term examination
November 2, 2015; 1 hour 20 minutes

Closed book. (100 total points). One sheet of your own notes is allowed. A calculator is allowed. No electronics with communications.

Possibly useful expressions and values
1 Sv = 1 x 10^6 m^3/sec (volume)
f = 1.414 x 10^{-4}/sec * sin (latitude)
1° latitude = 111 km
Ro=f/T
g = 9.8 m/s^2
$\rho c_p T$
ρ = 1025 kg/m^3
c_p = 4000 J/kg°C
1 PW = 10^{15} W
$F \sim \rho V(S_o - S_i)/S_m$
acceleration + advection + Coriolis force = pressure gradient force + gravity + friction

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

1. Which of these equations or terms is NOT part of Newton's Laws as discussed in class?
(a) Hydrostatic balance
(b) Continuity equation
(c) Fick's Law
(d) $\mathbf{a} = \mathbf{F}/\rho$

2. Surface waves
(a) have Rossby number much smaller than 1 (Ro << 1)
(b) have wavelengths on the order of several thousand kilometers
(c) can be generated by earthquakes
(d) are always too shallow to feel the ocean bottom

3. If an ocean measurement is clearly offset from the true value, we say that the measurement is
(a) biased
(b) noisy
(c) aliased
(d) uncorrelated

4. In most regions and averaged over the seasons, the smallest term in the local air-sea heat exchange is
(a) latent heat flux
(b) sensible heat flux
(c) solar radiation
(d) longwave radiation

5. Lagrangian observations
(a) can be made at Scripps pier
(b) can be made on a moored current meter
(c) can be made with surface drifters
(d) are often made from steered autonomous gliders

6. The maximum density of seawater occurs
(a) at lower temperature for higher salinity
(b) at 0°C
(c) at the same temperature as the maximum density of freshwater
(d) at the freezing point of seawater

7. The ratio of the time scale of diffusion to the time scale of a fluid phenomenon is called the
(a) Reynolds number
(b) Rossby number
(c) Aspect ratio

8. Gravitational force is NOT directly associated with (i.e. in the equation for)
(a) surface waves
(b) the horizontal pressure difference that drives ocean circulation
(c) tides
(d) internal waves

9. The thermocline
(a) is created by or affected by vertical diffusion
(b) is always associated with a strong halocline
(c) is formed by advection along constant depth surfaces
(d) is the name given to tilted isotherms

10. Antarctic Bottom Water is
(a) returned to the sea surface through direct upwelling driven by winds
(b) formed by open ocean deep convection in the Antarctic region
(c) formed in just one location along the coast of Antarctica
(d) is formed by brine rejection along the coast of Antarctica

Short answer or calculations (80 points total)
11. (10 points)
One of the momentum equations is given here.
(a) Which momentum equation is this (which direction)?_____

Label each of the terms (viscous, pressure gradient, acceleration, advection)

$$\partial u/\partial t + u\,\partial u/\partial x + v\,\partial u/\partial y + w\,\partial u/\partial z = -(1/\rho)\partial p/\partial x + \partial/\partial x(A_H \partial u/\partial x) + \partial/\partial y(A_H \partial u/\partial y) + \partial/\partial z(A_V \partial u/\partial z)$$

(b) Which term(s) are motivated using Fick's Law?_____

(c) What is Fick's Law?

(d) Why are the horizontal and vertical viscosities expressed as separate symbols? What does this tell you about the assumed source of effective viscosity in this equation?

12. (25 points) (Hendershott)
(a) Explain what is meant by a "deep water" and a "shallow water" surface wave. What is the difference between them?

(b) Distant events in the *deep mid-ocean* energize both deep and shallow water (surface) waves. For the following two events, are the generated waves *deep* or *shallow*?
List the typical period and typical phase speed for each of the two. Use the lists provided.

	Deep or shallow?	Typical period	Typical phase speed
(a) Storm			
(b) Submarine earthquake			

Typical period: 1 sec, 5 sec, 15 sec, many minutes to a fraction of an hour, few hours, 12 hours, 24 hours.

Typical phase speed: few cm/sec, 1 or 2 m/sec, 20 m/sec, 200 m/sec, 1500 m/s

(c) For deep water waves, the group speed c_g is half the phase speed c_p. The sum of two nearly identical plane waves with wavenumber k and $k+\Delta k$ consists of a **carrier wave** $\cos(k(x-c_p t))$ of

wavelength $2\pi/k$ that moves at phase speed c_p, and an **envelope** $\cos(\Delta k(x - c_g t))$ of much greater wavelength $2\pi/\Delta k$ that modulates the carrier wave and moves at the group velocity c_g.

Explain, just in words, how this combination of carrier wave and envelope affects the deep water ocean surface waves that we see arriving from a distant storm.

(d) Sketch the locations of the Earth, moon, and sun during a spring tide and during a neap tide.

13. (25 points)
In the Kuroshio region there is a large amount of heat loss from the ocean to the atmosphere, in the annual mean. The attached map shows the surface heat exchange. Negative means the ocean is losing heat, positive means the ocean is gaining heat. (A color version of the map is shown on the last color figure page.)

(a) Explain how the annual mean temperature of water in a region including the Kuroshio has almost no variation even though there is very large annual mean net heat loss in that region.

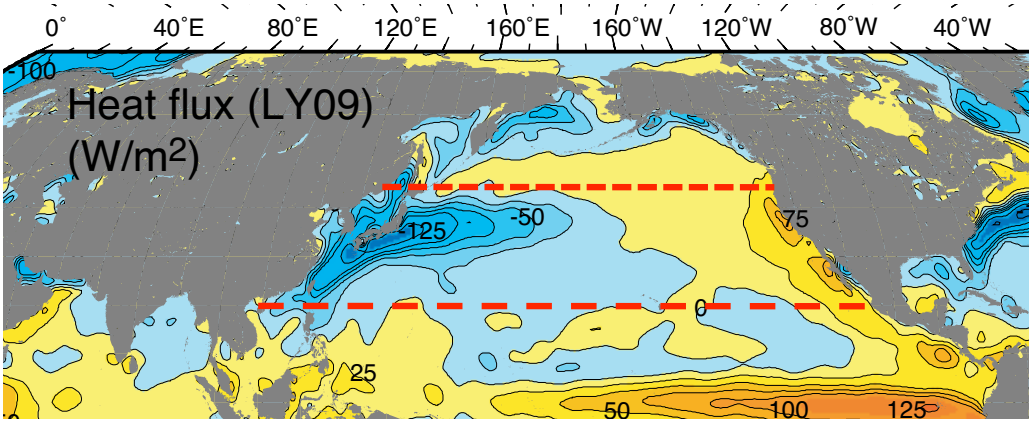
(b) A long-dashed line is drawn at 20°N in the attached figure. Assume that all of the heat exchange in the North Pacific north of 20°N is in the upper ocean (ignoring deep and intermediate waters). Assume that the temperature of Kuroshio water crossing 20°N is 25°C, and that the temperature of gyre water returning southward across 20°N is 18°C. What is the direction of ocean heat transport at 20°N? Why?

(c) Assume that the volume transport of this circulation is 30 Sv. What is the magnitude of the heat transport across 20°N? (Calculation.)

(d) How much heat does the ocean gain or lose north of 20°N based on your answer to (c)? (Assume that there is no leakage through Bering Strait.)

(e) If all of this ocean heat gain/or loss occurs between 20°N and 45°N (see short-dashed line figure), what is the average surface heat loss/gain in that box? To do this, estimate the surface area of the N. Pacific between 20°N and 45°N. (Just assume that it is a rectangle, and give your estimate of distances.)

(f) How does your average from (e) compare with the air-sea heat flux in the map? (small, comparable, large)?



For Problems 14 and 15, refer to the color figures on the last page.

14. (10 points)
The attached page with color figures shows various properties in the Pacific Ocean. The location of the section is in the small map.

(a) On the potential temperature section, circle and label the "Antarctic Bottom Water".

(b) On the oxygen section, also circle the Antarctic Bottom Water.

(c) Water masses are identified through a common formation history. What is the mechanism for formation of Antarctic Bottom Water? _____

(d) Explain how you identified Antarctic Bottom Water and how this relates to its formation mechanism.

15. (10 points)
(a) Define the "thermocline".

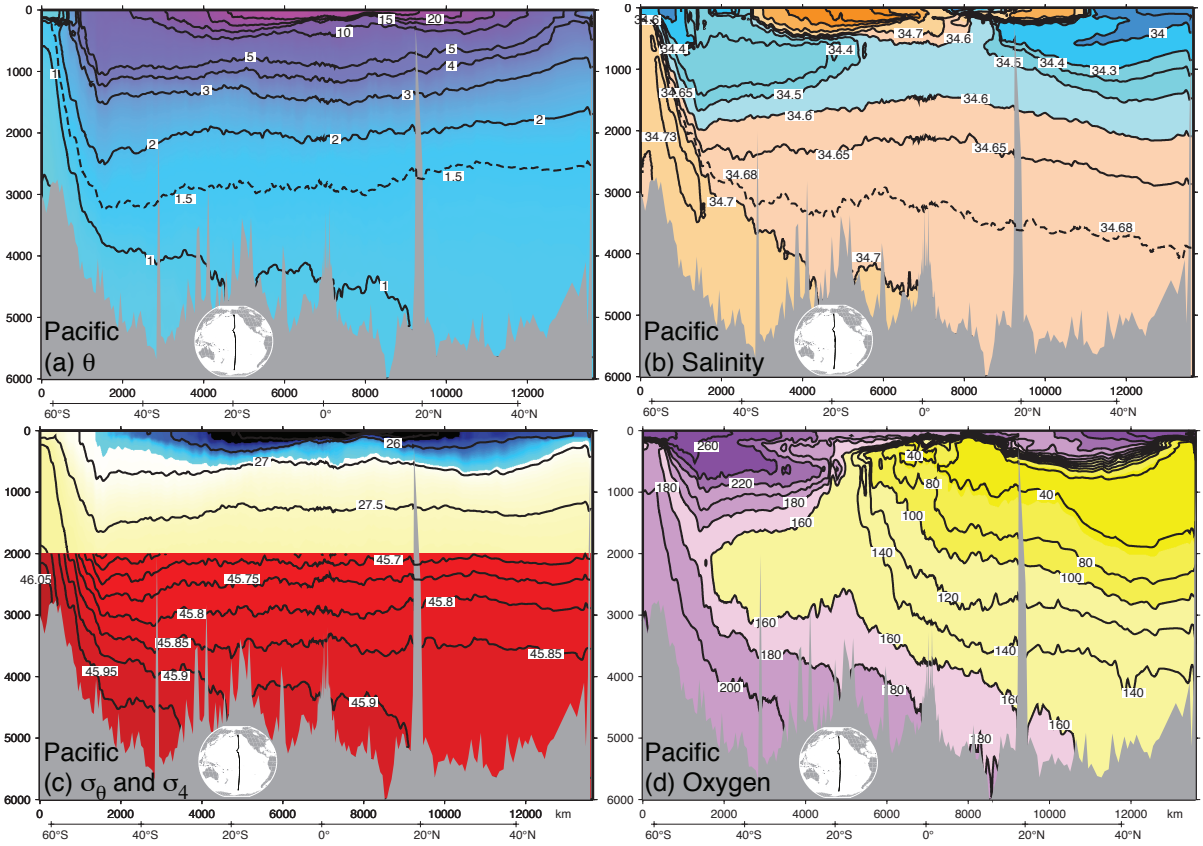
(b) On the color figure (last page), there is a Pacific Ocean potential temperature section. **Circle the main thermocline** of the subtropical Pacific Ocean.

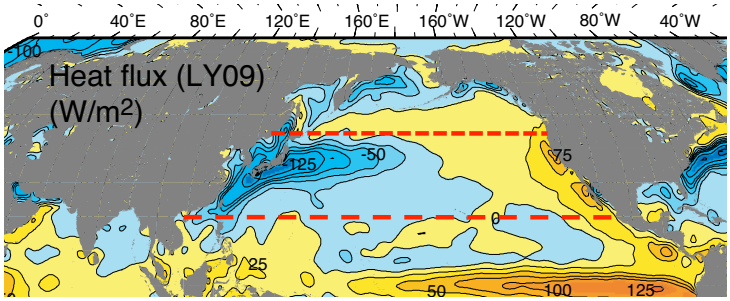
(c) We described two separate mechanisms for producing the main thermocline. Describe one of these mechanisms.

(d) Extra credit (2 points): describe the other of the two mechanisms.

--------End of exam-----

Figure for Problems 14 and 15.





Color version for Problem 13