NAME: ____________________________________

SIO 210 Introduction to Physical Oceanography
Mid-term examination 2-3:20 PM; Sumner Auditorium
October 31, 2016; 1 hour 20 minutes
Answer Key

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
f = 1.414 x 10^{-4}/sec * sin (latitude)
1° latitude = 111 km
$2\pi R$
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 ~ $\rho V(S_o - S_i)/S_m$
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. The ocean's **mesoscale** has length and time scales of about
(a) 10 m and 1 hour
(b) 1000 km and 1 year
(c) 100 km and 10 years
(d) 100 km and 1 month

2. The in situ temperature of a parcel of water at 3000 m is 2°C. If the parcel is raised adiabatically to the surface its temperature would:
(a) increase
(b) stay the same
(c) decrease
(d) not enough information is given here to answer this question.

3. Salinity of a given sample of seawater
(a) is the ratio of the mass of salt to the mass of seawater
(b) is the ratio of the mass of salt water to the mass of fresh water
(c) is the ratio of the mass of salt to the mass of freshwater

(d) always changes fastest when temperature is also changing

4. If a current meter on a mooring records 10000 measurements over 1 year
(a) the lowest frequency that can be resolved is 1/(1 year)
(b) the lowest frequency that can be resolved is 1/10000
(c) the highest frequency that can be resolved is 1/(1 sec)
(d) the highest frequency that can be resolved is 10000

5. Ocean surface mixed layers
(a) are deepest in regions where the atmospheric convection goes up to the highest altitude
(b) are exactly the same depth as the Ekman layer
(c) are deepest at the end of winter
(d) are deepest on the shortest days of the year (winter solstice)

6. North Atlantic Deep Water has high oxygen in the Atlantic Ocean because
(a) it has a large input of oxygen from the Labrador Sea
(b) it is much younger than the low oxygen tropical waters that sit above it
(c) it has a large input of oxygen from the Mediterranean Sea
(d) phytoplankton deep in the ocean (>1000 m) are creating oxygen

7. In the Northern Hemisphere
(a) Centrifugal force creates spiral eddies
(b) Coriolis force causes water to deflect to the right when it runs into a continental boundary
(c) Coriolis force causes water to circulate counterclockwise around a center of low sea surface height
(d) Centrifugal force causes the ocean to be 21 km deep near the equator.

8. The Hadley circulation in the atmosphere
(a) has descending air at about 30° north and south of the equator
(b) has ascending air in the tropics and descending air at the poles
(c) is associated with the mid-latitude westerly winds at the sea surface
(d) is directly involved in the Bjerknes feedback between the tropical ocean surface and atmosphere

9. Geostrophic currents
(a) always decay with depth
(b) are in balance between pressure gradient force and Coriolis force
(c) include vertical velocities that can be significant
(d) are created right after a storm impulsively pushes the ocean surface

10. The ocean is nearly inviscid, so therefore
(a) wind forcing is transmitted to the ocean through a surface boundary layer that is 1 m thick
(b) inertial currents can last for up to a year
(c) horizontal and vertical eddy viscosity are of the same order of magnitude
(d) effective 'eddy' viscosity due to turbulence takes on the role of actual viscosity

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Short answer or calculations (80 points total)

11. (10 points)
The general expression for a momentum equation in a fluid in a rotating reference frame is

Acceleration + advection + Coriolis force = pressure gradient force + gravity + viscous terms

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

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

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

In the following you can refer to either the ‘word equation’ or the actual equations

(a) Which pair of terms yields geostrophic balance?____________________

(b) Which pair of terms yields hydrostatic balance?____________________

(c) Which pair of terms yields Ekman balance?________________________

(d) What additional pseudo-force due to rotation is hidden in this equation? _________
Which term is it hidden in?_______________________

(e) Which term in this equation does NOT appear in the horizontal (x,y) momentum equations, where the horizontal equations are in a Cartesian plane along the surface of the Earth?________

12. (5 points)
In the tropical atmosphere, along the equator, the wind is driven directly by the sea surface temperature. Explain how this works, using the Pacific Ocean as your example. If it makes your answer easier, provide a sketch.

13. (20 points)
The attached map shows sea surface height (SSH) in the North Pacific Ocean.

(a) Mark the location of highest SSH.

(b) The surface circulation is geostrophic. Using the map, sketch the direction of the circulation with respect to this highest SSH. Please be as precise as possible.

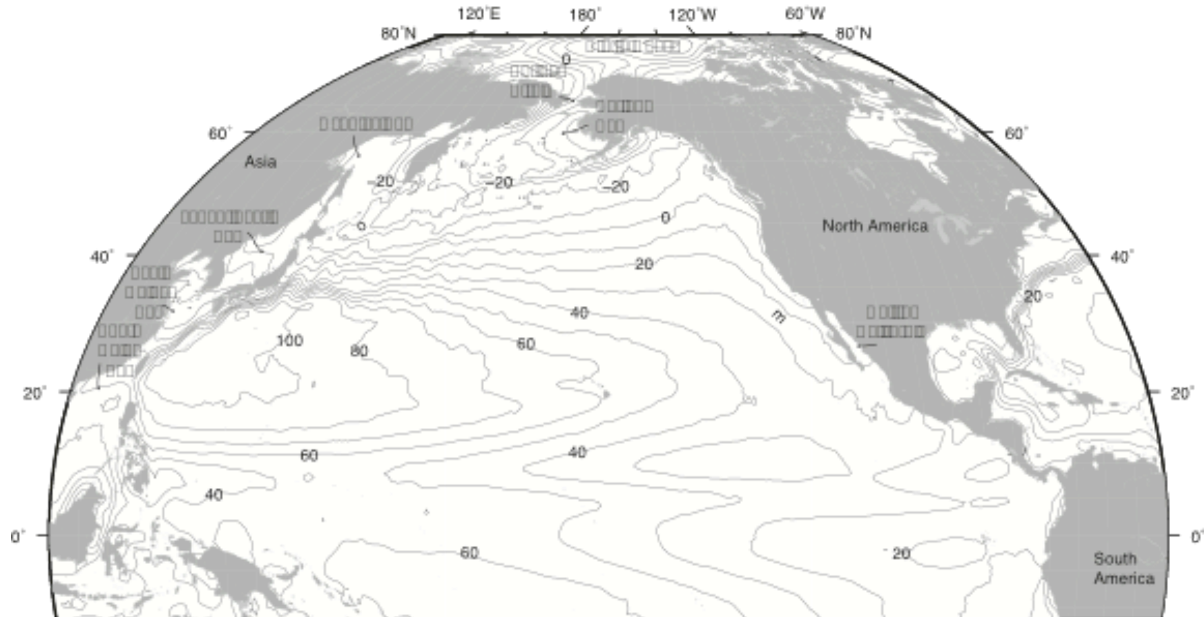
(c) Explain the direction of the circulation in (b).

(d) What is the name of the western boundary current associated with this highest SSH?

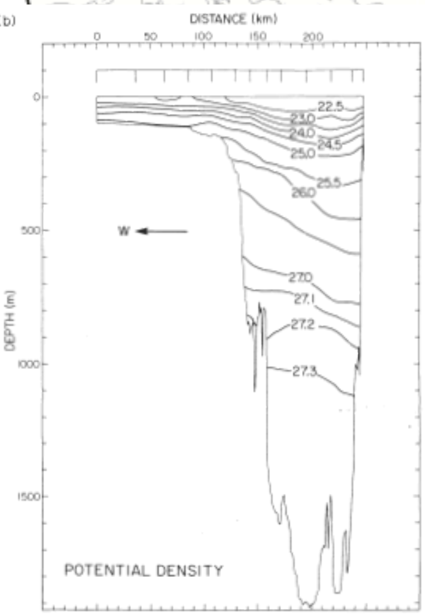
(e) With increasing depth, do you expect the circulation to become WEAKER, STRONGER, STAY THE SAME (circle one)?

(f) On the second attached figure, you see potential density in a vertical section crossing this system that you have sketched. What about the figure tells you where the western boundary current is most likely located?

(g) Explain how you infer the answer to (e) from this figure.


120°E
180°
120°W
60°W
80°N
80°N
60°
60°
Asia
North America
40°
40°
20°
20°
0°
0°
South America
100
80
60
40
20
0
-20

(b)


DISTANCE (km)
DEPTH (m)
W
22.5
23.0
24.0
24.5
25.0
25.5
26.0
27.0
27.1
27.2
27.3
POTENTIAL DENSITY

14. (10 points)

The air-sea exchange of heat is written as a sum of four terms:

Air-sea heat flux = Solar radiation + Longwave radiation + Latent heat flux + Sensible heat flux
$Q_{sfc} = Q_s + Q_b + Q_e + Q_h$

Assume that heat flux is positive if it is heating the ocean. (This is the convention for oceanography).

(a) Which term is always positive? ___________________________

(b) Which two terms are turbulent heat fluxes? ___________________ and __________________

(c) Which term depends on the temperature of the sea surface (and not on the air temperature)?__________________

(d) Which term depends directly on the difference in temperature between the sea surface and the overlying air?_______________

15. (10 points)
The Earth's radius is about 6370 km.

(a) (2) How big is the Earth's circumference (distance around the planet)?

(b) (3) At the equator, how fast is a point on the Earth's surface moving due to rotation?

(c) (2) At the North Pole, how fast is a point on the Earth's surface moving due to rotation?

(d) (3) Why is the Coriolis force stronger at the North Pole than at the equator? (Consider only the part of the Coriolis force that acts on velocities in the local horizontal plane.)

16. (5 points)
Consider a region of the Kuroshio, as in your homework for the heat budget. Assume that air-sea fluxes act only on the upper layer of the Kuroshio, and that the volume transport of that layer is 20 Sv.

(a) If the salinity of water entering the Kuroshio is 34.5 and the salinity exiting the Kuroshio is 34.6, assuming there is no mixing with adjacent water, is there NET EVAPORATION or NET PRECIPITATION along its path?______________

(b) Calculate the total freshwater flux between the ocean and atmosphere between the inflow of water at salinity 34.5 and exit at 34.6.

17. (5 points)
On the attached color sections,
(a) Circle and label the North Atlantic Deep Water
(b) Circle and label the Antarctic Intermediate Water

18. (15 points)
The attached vertical section (yellows/blues) is potential density σ_θ relative to the sea surface in the Atlantic Ocean. Near the equator, at about 3500 to 4000 m depth, there is a vertical inversion in potential density σ_θ. Note also the set of 4 small panels; the lower left panel shows potential density σ_4 relative to 4000 dbar in the red color.

(a) Circle this inversion in the σ_θ section.

(b) Is the water column actually vertically unstable here at 4000 m? Use the small panel of potential density σ_4 relative to 4000 dbar to answer this question.

(c) Use the other small panels of potential temperature and salinity to further explain your answer to (c). That is, use the small panels to find the approximate potential temperature and salinity that is within the density inversion layer.
Potential temperature ~ _____________________.
Salinity ~ ___________.

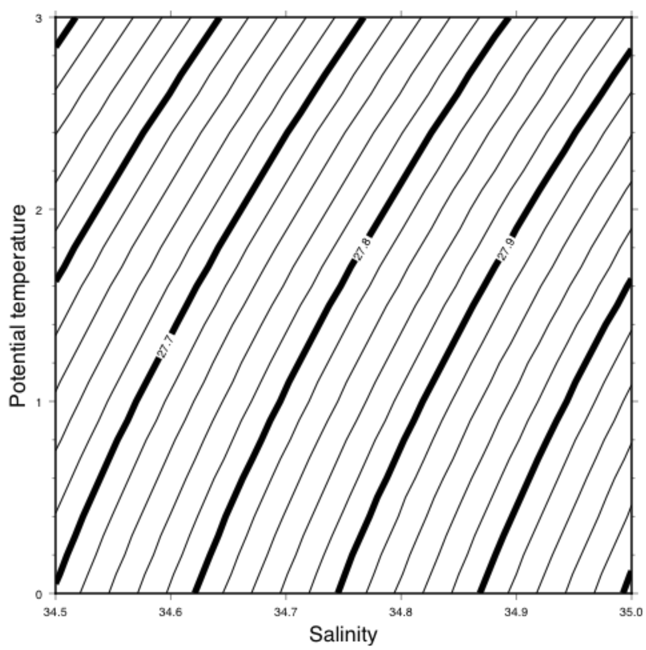
Then approximate the potential temperature and salinity that are just below the inversion layer. (There are not enough contours on the plots to give you precise values, so just choose values relative to the first set within the inversion.)
Potential temperature ~ _____________________.

Salinity ~ ___________.

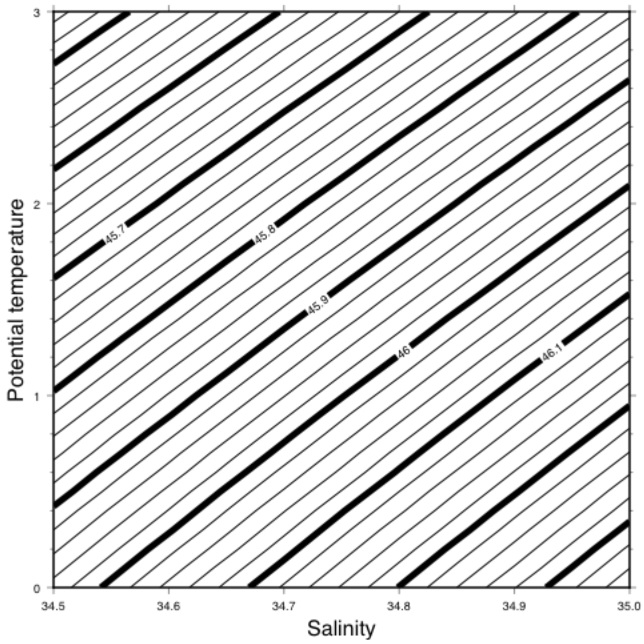
(d) Graph those values on the TWO attached potential temperature/salinity diagrams; one is density relative to σθ and the other is relative to σ4.

(e) Explain what you see or should see in the graphs to explain the density inversion or lack of inversion.

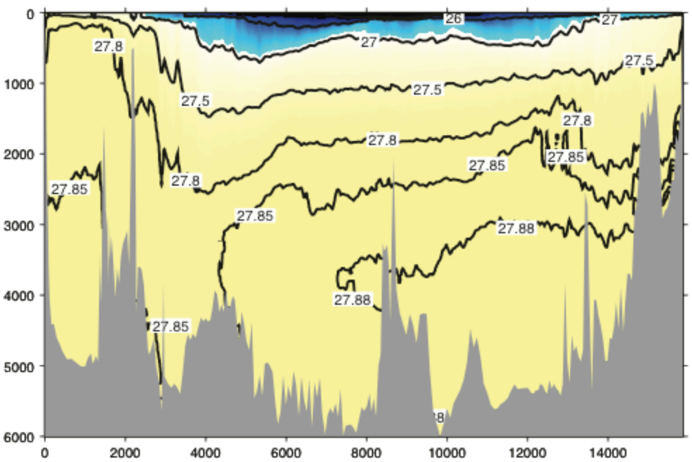
(f) Why don't the contours of potential density σθ and σ4 have the same slope in the potential temperature/salinity diagram? (Explain this in terms of compressibility of sea water.)

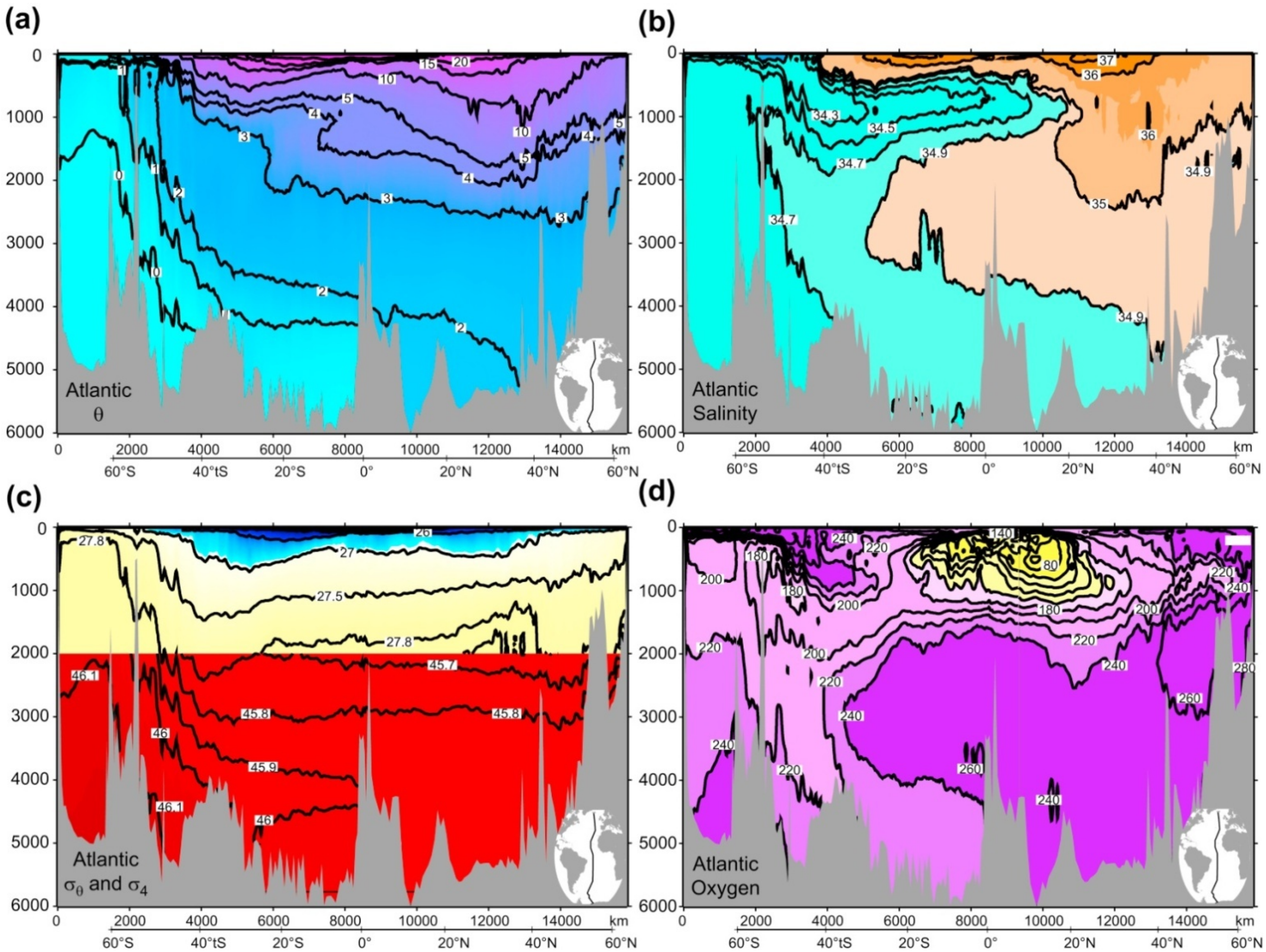


(a) 0 dbar (σθ)



(b) 4000 dbar (σ4)


0
1000
2000
3000
4000
5000
6000
0
2000
4000
6000
8000
10000
12000
14000
26
27
27.5
27.8
27.85
27.88


(a)
(b)
(c)
(d)
Atlantic
θ
Atlantic
Salinity
Atlantic
σ_θ and σ_4
Atlantic
Oxygen
km
60°S
40°tS
20°S
0°
20°N
40°N
60°N