NAME: _____

SIO 210 Introduction to Physical Oceanography
Mid-term examination 11-12:30 PM; Eckart 227
November 1, 2018; 1 hour 20 minutes

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

Possibly useful expressions and values
1 Sv = 1 x 10^6 m^3/sec
1° latitude = 111 km
$2\pi R$
Ro = f/T = f/UL
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
$F \sim \rho V(S_o - S_i)/S_m$

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

1. The volume transport of the Gulf Stream is approximately
(a) 100 m/sec
(b) 100 x 10^6 m^3/sec
(c) 1 Sverdrup
(d) 100 km x 5000 m

2. Which of the following components of the ocean-atmosphere heat flux is always into the ocean (warming the ocean)?
(a) Sensible
(b) Short wave
(c) Latent
(d) Long wave

3. If you sample sea surface height (SSH) once per day for 360 days, and the integral time scale of the SSH is 20 days, the number of degrees of freedom in your estimate of its frequency spectrum is
(a) 1
(b) 360
(c) 20
(d) 18

4. Which of these makes Lagrangian observations?

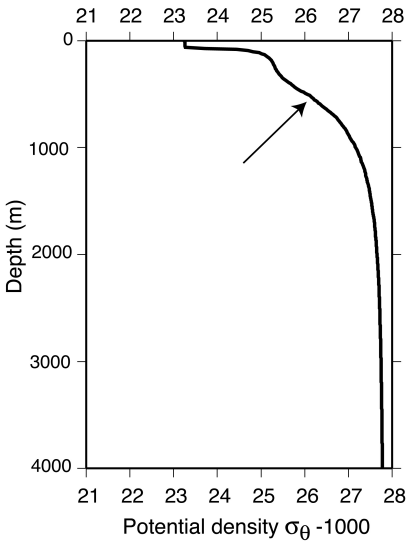
(a) Satellite ocean color sensor
(b) Moored current meter at the equator
(c) Research ship making CTD observations every 100 km between California and Asia
(d) Subsurface float in the Argo program

5. The pressure gradient force
(a) Points towards the center of the Earth
(b) Always results in acceleration of the water
(c) Points from high pressure to low pressure
(d) Is almost always balanced by friction

6. The moon causes semidiurnal tides (period about 12 hr) and diurnal tides (period about 24 hr) in the ocean because the earth rotates on its axis once every 24 hours. If the earth rotated on its axis once every 48 hours, the periods of the lunar tides would be about
(a) 6 and 12 h
(b) 12 and 24 h
(c) 24 and 48 h.

7. In hydrostatic balance
(a) Vertical acceleration is non-zero.
(b) Coriolis force balances the pressure gradient force
(c) Gravity balances the pressure gradient force.
(d) Pressure depends on water velocity.

8. In the vertical profile of density shown in the figure, the arrow points to the
(a) Thermostad
(b) Mode water
(c) Abyssal ocean
(d) Pycnocline



9. In the Mediterranean Sea there is excess evaporation and cooling of waters that flow in from the Atlantic Ocean through the Strait of Gibraltar. These waters then return to the Atlantic Ocean. Flow through the strait is characterized by the following
(a) Potential density of the outflow is less than the potential density of the inflow
(b) Salinity of the inflow is less than the salinity of the outflow
(c) Mass transports into the Mediterranean is less than the mass transport out of the Mediterranean.

10. Sound speed
(a) increases as temperature becomes colder for a fixed pressure
(b) has a minimum at the bottom in the deep ocean (> 4000 m depth)
(c) increases as pressure becomes higher for a fixed temperature

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Short answer or calculations (80 points)

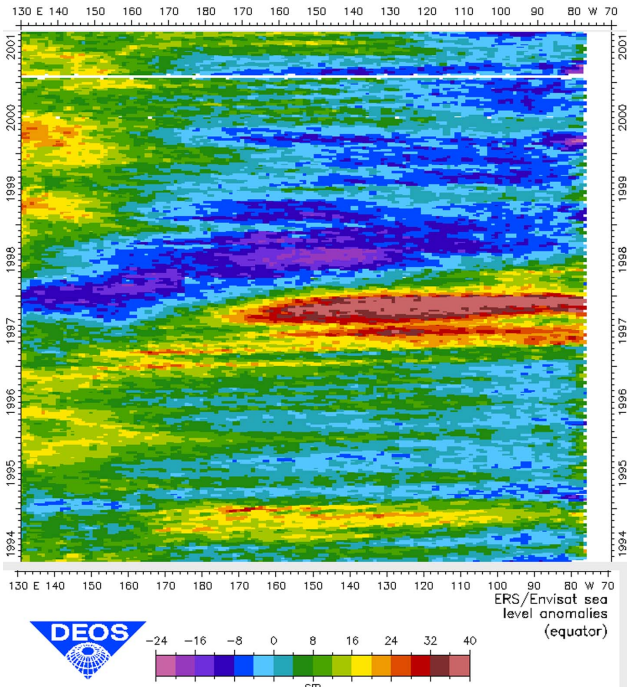
11. (10 points)
The Hovmuller diagram shows observed sea level anomaly at the equator in the Pacific Ocean.
(a) Describe what a Hovmuller diagram is and why it can be useful.

(b) How was the information in this diagram collected? (what instrument?) If you don't really know, then make some good guesses and explain your answer.

(c)If the sea level is given by h(x,t), write an expression for the sea level 'anomaly'.

(d) Describe in words the anomaly pattern during 1997 and 1998. What do you see, is it propagating? If so, what is the approximate speed of propagation?

(e) Extra credit: do you know the name of the phenomenon that caused the 1997-1998 anomalies?



12. (20 points)
(a) What is salinity? (brief answer)

(b) What is the approximate range of salinity in the world ocean (not including very near-shore regions affected by local river runoff etc)? _____

The figure is a salinity section from south to north through the length of the Atlantic Ocean.

c) Circle any region of high salinity near the UPPER surface of the ocean. Given an explanation in terms of atmospheric forcing of why salinity is high in the region you've circled.

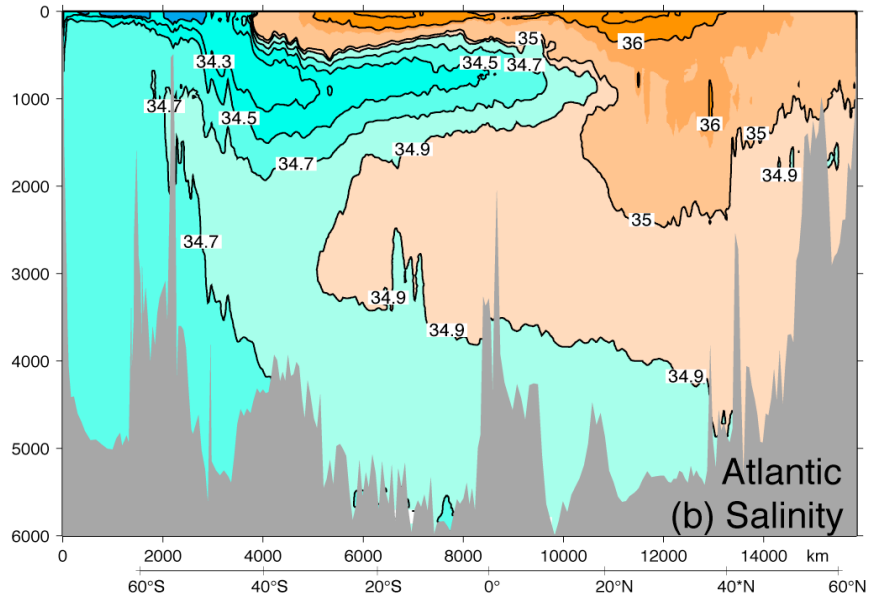
(d) Why is it possible to have high salinity water near the sea surface? (Why doesn't it sink?)

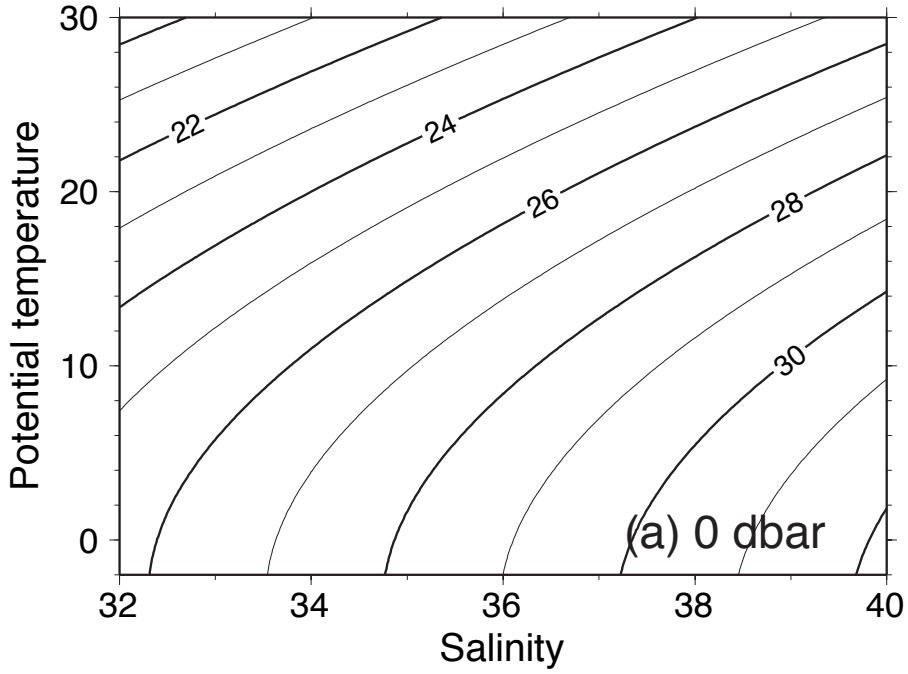
(e) On the blank potential temperature/salinity diagram (on the next age):
(i) mark where your circled high salinity water might be found. Then
(ii) mark a place where a lower salinity BOTTOM water parcel might be found.

(f) The contours in the diagram are 'potential density' relative to the sea surface, which we call either $\sigma\theta$ or σ_0. What are the potential densities $\sigma\theta$ of the two parcels you marked in (e)?

(g) On this potential temperature/salinity diagram, sketch the contours of potential density σ_4 relative to 4000 dbar. This will not be exact. I am looking for the relative slope of your σ_4 contours compared with σ_0

(h) The difference in contouring for potential density $\sigma\theta$ and potential density σ_4 occurs (mostly) because the compressibility of seawater depends on temperature. Describe this dependence and how it leads to the different slopes of $\sigma\theta$ and σ_4.


0
1000
2000
3000
4000
5000
6000
35
36
34.3
34.5
34.7
34.7
34.5
34.7
34.9
36
35
34.9
35
34.7
34.9
34.9
34.9
Atlantic
(b) Salinity
0
2000
4000
6000
8000
10000
12000
14000
km
60°S
40°S
20°S
0°
20°N
40°N
60°N


30
20
10
0
Potential temperature
22
24
26
28
30
(a) 0 dbar
32
34
36
38
40
Salinity

13. (12 points)
The molecular diffusivity of temperature is
$\kappa_T = 0.0014$ cm^2/sec = 1.4×10^{-3} cm^2/sec = 1.4×10^{-7} m^2/sec

(a) Using just this diffusivity, estimate the time scale for molecular diffusion over a length of 1 km.

Horizontal eddy diffusivity can be
$A_T = 1 \times 10^5$ cm^2/sec

(b) Estimate the time scale for eddy diffusion of temperature over a length of 1 km. (Be careful about units.)

(c) If the property being diffused is salt, are the molecular and eddy diffusivities the same as for temperature? Answer for each of the two (molecular and eddy).

(d) What processes might contribute to the horizontal eddy diffusivity?

14. (12 points)
A wave is characterized by a wavelength and period.

(a) Sketch a wave in spatial coordinates (x) and show the wavelength λ. Label the crest and trough.

(b) Sketch a wave in time coordinates (t) and show the period T. How is the period measured at a given location?

(c) What is the expression for frequency f in terms of the period T?

(d) What is a typical wavelength for a wind wave? (surface gravity wave driven by wind)

(e) In water depth of H = 100 m, using your answer for (d), which dispersion relation does your wave obey:

$c^2 = (gH)$ or $c^2 = (g\lambda/(2\pi)$?

(f) Based on your answer to (e), is your wave a deep water wave or a shallow water wave?_____

15. (10 points)
The momentum equations in a fluid in a non-rotating reference frame are

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

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

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

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

(a) Which pair of terms yields hydrostatic balance?_(circle and label)_____

(b) Circle the advective terms in the x momentum equation. Describe in words how one of these terms works (what is the process for changing momentum using this term).

c) Circle and label the viscous terms in the y momentum equation. Describe briefly how these terms work (what is the process for changing momentum using this term).

16. (16 points)
On the attached color sections,

(a) Circle and label the North Atlantic Deep Water (NADW)
(b) What property (ies) did you use to identify the NADW?

(c) Circle and label the Antarctic Intermediate Water (AAIW)

(d) What property (ies) did you use to identify the AAIW?

(e) Circle and label the Mediterranean Water (MedW)

(f) What property (ies) did you use to identify the MedW?

(g) On the potential temperature section, at about 10-15°S, there is an inversion in temperature. Circle this inversion. If density depended only on temperature, there would be a density inversion here as well. Is it possible to have a density inversion in the ocean at this space/time scale?_____
Explain how this situation can be stable over hundreds of years.