NAME: ___________________________________

SIO 210 Introduction to Physical Oceanography
Mid-term examination 11-12:30 PM; Eckart 227
October 31, 2019; 1 hour 20 minutes

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

Possibly useful expressions and values
1 Sv = 1 x 10^6 m^3/sec
$\rho c_p T$
$\rho = 1025$ kg/m^3
$c_p = 4000$ J/kg°C
1 PW = 10^{15} W
$H = \rho\, c_p\, V(T_o - T_i)$

Multiple choice (5 problems, 2 points each, 10 points total)
For each problem, **circle the CORRECT answer**. (There should be **only one**.)

1. For the Gulf Stream (or Kuroshio), the approximate aspect ratio H/L, where H is the height of the phenomenon and L is its length scale, is
(a) 1
(b) 1000
(c) 0.05
(d) 0.00001

2. Salinity in sea ice compared with open ocean salinity (sea ice salinity/ocean salinity) is approximately
(a) 3 psu/30 psu
(b) 40 psu/35 psu
(c) 25 psu/40 psu
(d) 0 psu/30 psu

3. Brunt-Vaisala frequency is high (period is short)
(a) in the surface mixed layer
(b) compared with surface wave frequency
(c) in the abyssal ocean
(d) compared with mesoscale eddy timescales

4. Which of these makes Eulerian observations?
(a) Surface drifter
(b) Moored current meter at the equator
(c) Glider (autonomous underwater vehicle)
(d) Subsurface float in the Argo program

5. Density
(a) Increases with increasing temperature
(b) Increases with decreasing pressure
(c) Increases with increasing salinity
(d) Has units of kg.

Circle the best answer (5 problems, 2 points each, 10 points total)

6. The temperature at the freezing point of water (**increases/decreases**) with increasing salinity.

7. An anticyclone rotates counterclockwise around a (**High/Low**) pressure in the Southern Hemisphere

8. In hydrostatic balance, (**Coriolis force/gravity**) balances the pressure gradient force.

9. Eddy viscosity results from the (**molecular/turbulent**) motion of water.

10. Inertial motion results from a balance between acceleration and (**Coriolis/centrifugal**) force.

Problems (80 points)

11. (15 points)
The momentum equations in a fluid in a rotating reference frame are

x: acceleration + advection + Coriolis = pressure gradient force + viscous forces

y: acceleration + advection + Coriolis = pressure gradient force + viscous forces

z: acceleration + advection = pressure gradient force + gravity + viscous forces

or, written mathematically:

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

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

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

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(a) Which pairs of terms yield geostrophic balance? **(circle and label in the equations above – either word equations or actual equations or both)**

(b) What is the Coriolis force? (**Brief answer**.)

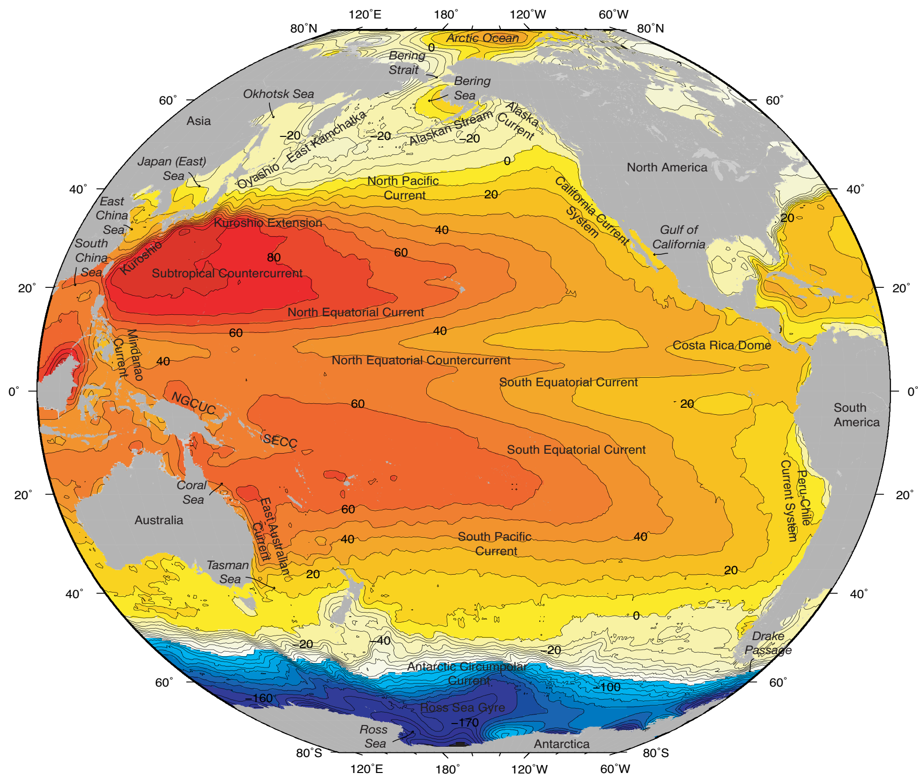
(c) The map shows sea surface height in the Pacific Ocean.

Mark the highest surface height in the North Pacific Ocean.

Mark the lowest surface height in the North Pacific Ocean.

Draw arrows showing the direction of the geostrophic currents between 10°N and 40°N using this distribution of sea surface height.

(d) Explain the direction of these currents that you have marked, relative to the high and low sea surface. You may refer to the equations above.



12. (20 points)

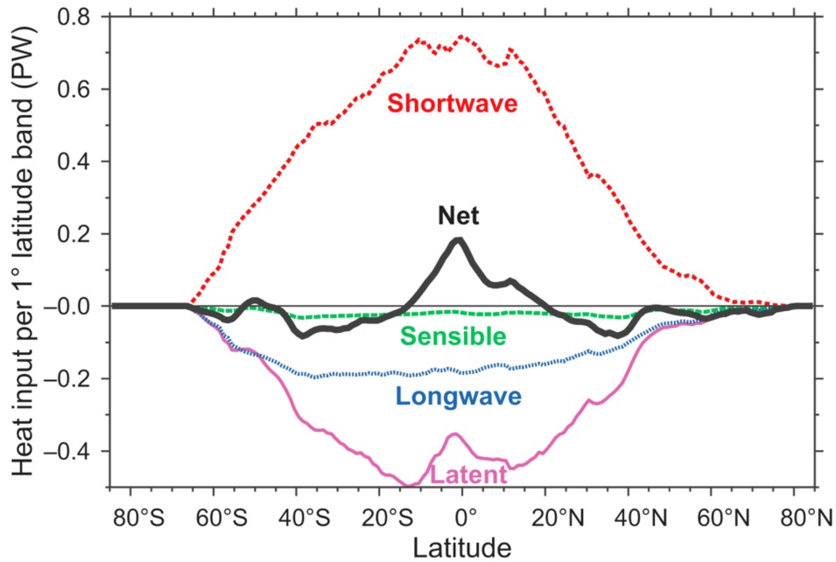
(a) Heat flux at the ocean surface is the sum of **shortwave, longwave, latent** and **sensible** heat fluxes. Which *two* of these are radiative fluxes?

Of these two radiative fluxes, which one results in the ocean losing heat to the atmosphere?

(b) The plot shows the four components of air-sea heat flux and the net flux (sum). They have been zonally averaged around the globe.

Between 20°N and 40°N, is the global ocean **gaining** or **losing** heat? (circle one or write it out)

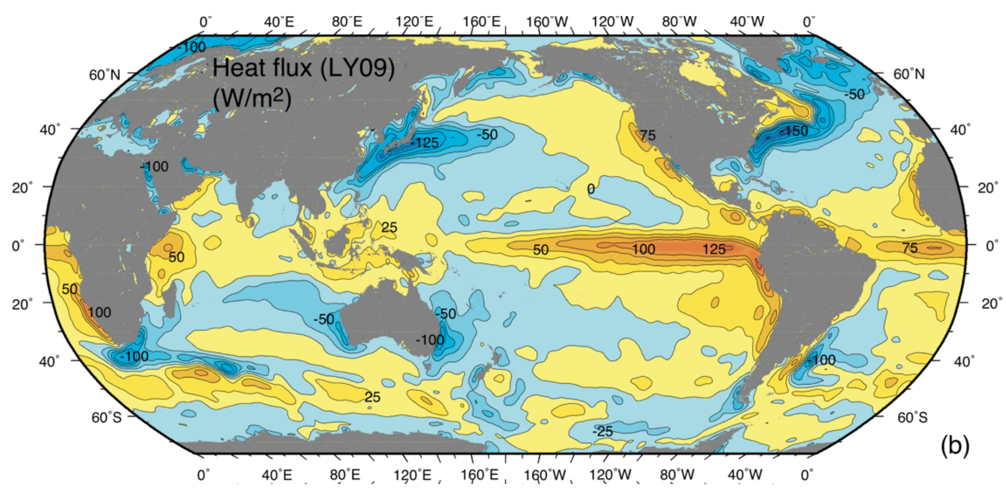
How can you tell from the plot?



(c) Based on this plot, does the global ocean most likely transport heat **northward** or **southward** between the equator and 35°N?
Explain your answer.

(d) On the surface heat flux map, look at the Northern Hemisphere between 20°N and 40°N.

Circle the areas of largest heat exchange.
Which major ocean current in each ocean is located in these areas of the largest air-sea heat exchange?



North Pacific:___________________

North Atlantic:__________________

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e) If the North Pacific heat transport at 24°N is 1 PW, and the volume transport of the Kuroshio is 100 Sv, **calculate the difference in average temperature** between the Kuroshio and the southward interior subtropical gyre flow. (Just a note: you can assume that the deep circulation here carries very little heat since the deep N. Pacific circulation is very weak compared with its upper ocean circulation.)

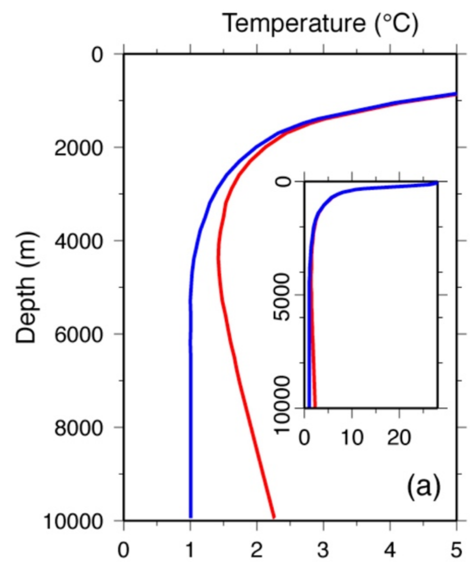
13. (10 points)

(a) The plot shows measured ('in situ') temperature and potential temperature over the Mariana Trench in the Pacific (deepest place in the world ocean).

Label the curves:

measured temperature T

potential temperature θ



(b) How do you know which one is potential temperature? (brief explanation)

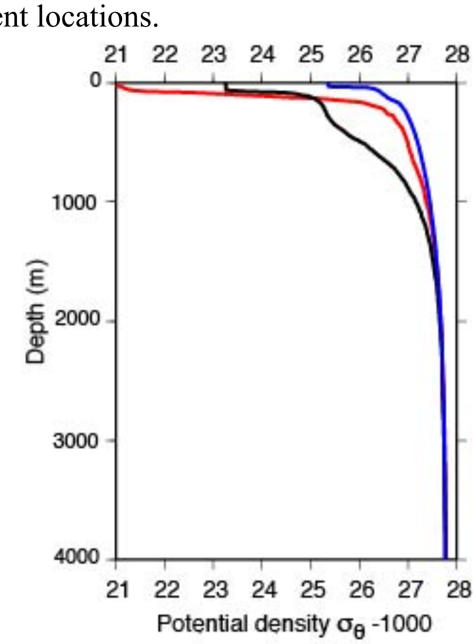
(c) This plot shows potential density in the North Pacific, at 3 different locations.

Label an example of each of the following:

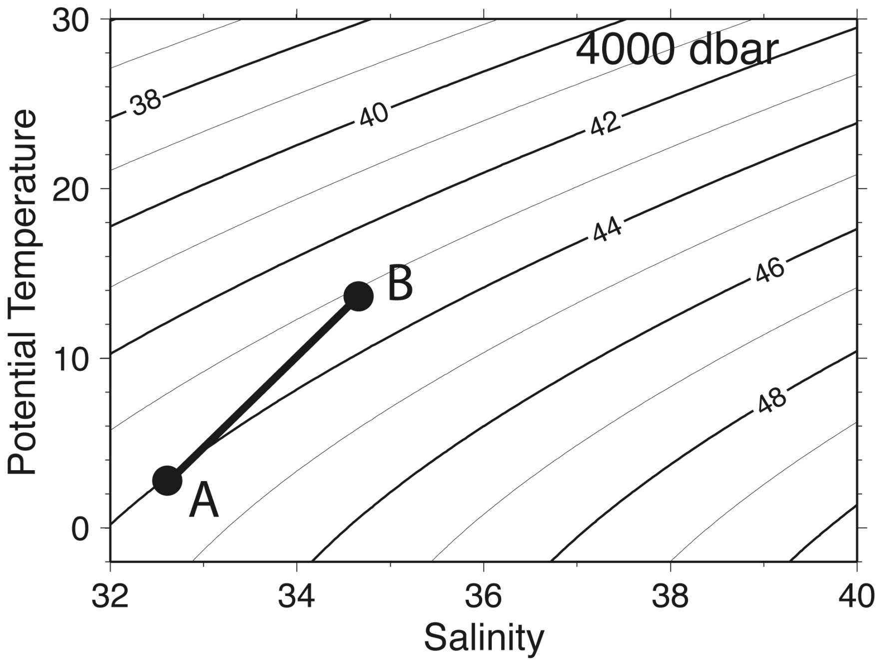
Mixed Layer

Pycnocline

Pycnostad



14. (20 points)
The plot shows contours of potential density σ_4 relative to 4000 dbar.



(a) What are the *approximate* potential temperature, salinity, and potential density σ_4 of A and B?

A: ___________________________________
Potential temperature, salinity, density

B: ___________________________________
Potential temperature, salinity, density

(b) Is colder water **more compressible** or **less compressible** than warmer water? (circle one)

Which parcel is more compressible? **A** or **B**?

(c) Suppose these two parcels, A and B, are brought to the sea surface **adiabatically**. What does it mean to move the water adiabatically? (What is conserved?)

(d) At the sea surface, is the density difference between A and B likely to be **GREATER** or **LESSER** than it is at 4000 dbar? Explain your answer in terms of dependence of sea water compressibility on temperature.

(e) **On the plot**, sketch the orientation of contours of potential density relative to 0 dbar, σ_0. (This is very schematic, but should include the proper orientation relative to the contours that are shown.) Explain the orientation of the contours based on your answer to (d).

15. (15 points)

Water masses: On the attached potential temperature and salinity sections:

(a) Label the "4 layers" (upper, intermediate, deep, abyssal)

(b) Label these two major water masses on the figures:

North Atlantic Deep Water (NADW)
Antarctic Bottom Water (AABW)

(c) How did you locate AABW using these two property sections? (short answer)

(d) How is AABW formed? How does its formation process create the property characteristics that allow you to identify AABW on the sections?