SIO 210 Introduction to Physical Oceanography
Mid-term examination
October 31, 2011; 50 minutes

Closed book. A calculator is allowed.
(100 total points.)

Possibly useful expressions and values

1 Sv = 1 x 10^6 m^3/sec
g = 9.8 m/s^2
ρ = 1025 kg/m^3
c_p = 4000 J/kg°C
$F \sim \rho V(S_o - S_i)/S_m$
f = 2Ω sin(latitude)
Ω = 0.71 x 10^{-4}/sec
acceleration + advection + Coriolis force = pressure gradient force + gravity + friction

Multiple choice (5 problems, 4 points each, 20 points total)
For each problem, **circle the CORRECT answer**. (There should be only one.)

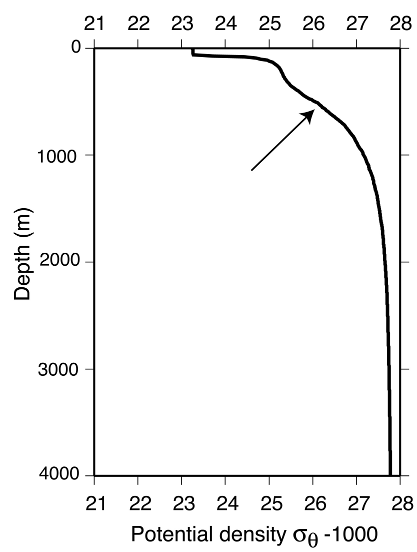
1. In the vertical profile of density shown in the figure, the arrow points to the

(a) Thermostad

(b) Mode water

(c) Abyssal ocean

(d) Pycnocline



2. Which of these makes Lagrangian observations?

(a) Subsurface float in the Argo program

(b) Satellite ocean color sensor

(c) Moored current meter at the equator

(d) Research ship making CTD observations every 100 km along a straight track from California to Asia

3. Which of these equations expresses hydrostatic balance?

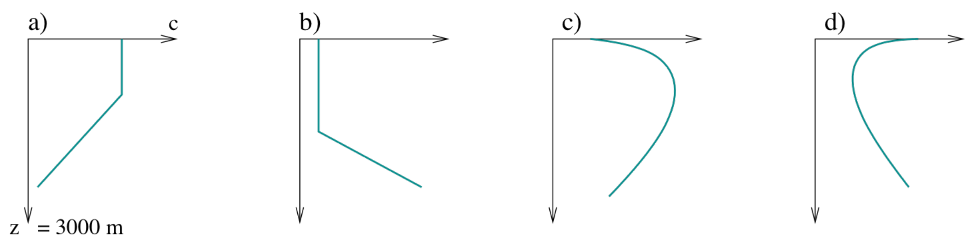
(a) $D\rho/Dt + \rho(\partial u/\partial x + \partial v/\partial y + \partial w/\partial z) = 0$

(b) $0 = -(1/\rho)\partial p/\partial z - g$

(c) $N^2 = -g\,(\partial\rho/\partial z)/\rho_0$

(d) $Dw/Dt = -(1/\rho)\partial p/\partial z - g + \partial/\partial x(A_H \partial w/\partial x) + \partial/\partial y(A_H \partial w/\partial y) + \partial/\partial z(A_V \partial w/\partial z)$

4. Which of the following is a typical profile of sound speed in the mid-latitude ocean? (D)



5. 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 **NOT** characterized by the following

(a) Potential density of the outflow is greater than the potential density of the inflow

(b) Salinity of the inflow is greater than the salinity of the outflow.

(c) Mass transport into the Mediterranean is greater than the mass transport out of the Mediterranean

Short answer (2 problems, 20 points each, 40 points total)
6. Two water parcels (call them "A" and "B") have the same density at the sea surface. Parcel "A" has a *lower* salinity than parcel "B".

(a) At the sea surface, is the temperature of "A" **HIGHER** or **LOWER** than the temperature of "B"? (circle the correct answer)

(b) Is the potential density σ_θ of "A" **HIGHER**, **LOWER**, or **EQUAL** to the potential density σ_θ of "B"? (circle the correct answer).
Explain your answer: Potential density sigma theta IS the density at the sea surface, and it was given that they have the same density

(c) Is the potential density referenced to 4000 dbar of "A" **HIGHER, LOWER**, or **EQUAL** to the potential density reference to 4000 dbar of "B"? (circle the correct answer).
Explain your answer: Because cold water is more compressible, when brought to 4000 dbar, parcel A compresses more than parcel B and it is therefore more dense. Therefore its potential density relative to 4000 dbar is higher than B's.

7. Of the following terms, state which pair forms the primary balance for each of the following approximations.

Terms:

Pressure Gradient Force
Temporal change in velocity (acceleration)
Coriolis "force"
Gravity
Tidal Potential
Centrifugal Force

(a) Hydrostatic Balance: _______PGF______________ and ________gravity_____________

(b) Surface Waves: _______accel.____________ and _______gravity______________

(c) Inertial Oscillations: ______accel._______________ and ___Coriolis force_____________

(d) Geostrophic balance: ______PGF_____________ and ______Coriolis force_______

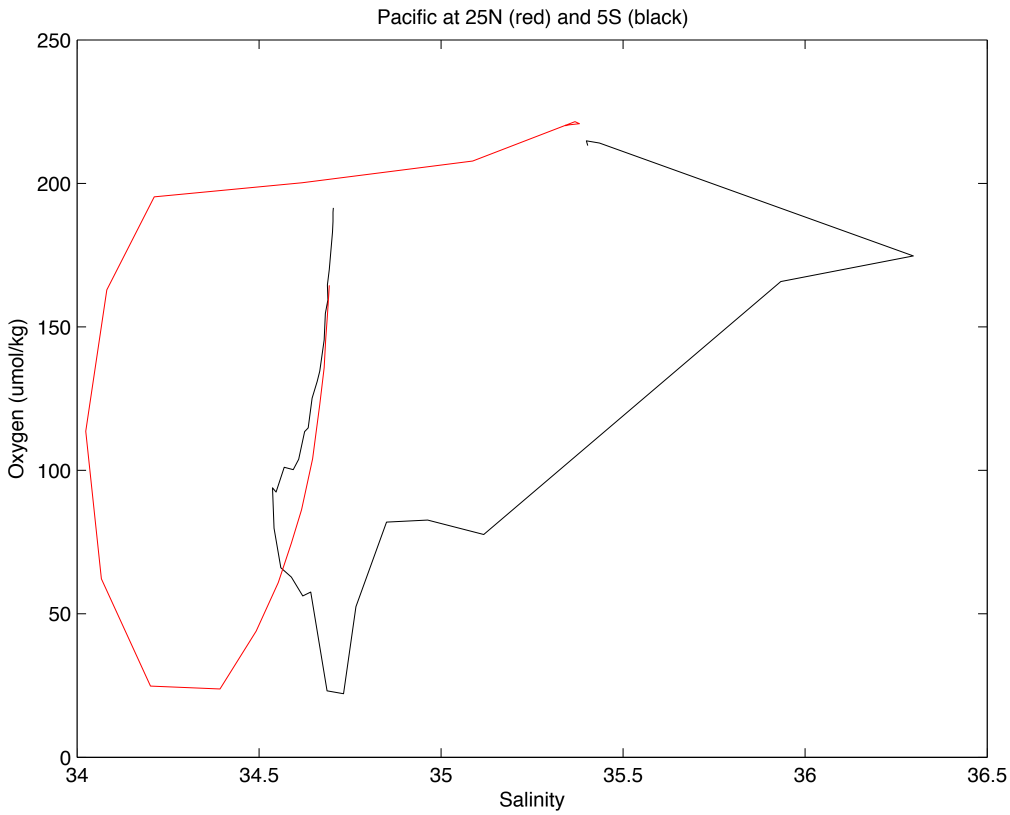
Longer problem (1 problem: 40 points total)
8. Geostrophic flow, transport, net heat transport, throw in names, scaling

(SEE COLOR FIGURES AT BACK OF EXAM.)
The attached meridional sections are from the Pacific Ocean, at about 150°W. Their location is shown on the small inset map.
Label them as salinity and oxygen correctly.

(a) Indicate on the sections the location of the Shallow Salinity Maximum Water (also known as Subtropical Underwater). What external forcing (outside of the ocean) creates the high salinity in these maxima? SSMs are the high salinity features near the top of the salinity section. Created by excess evaporation in midlatitudes, due to atmospheric highs (descending dry air in the Hadley circulation).

(b) Contrast the two regions: around 5°S and around 25°N. On the attached axes, sketch the oxygen vs. salinity relation in these two regions.

Here is a plot from actual data at 5S and 25N.



(c) What is the physical process that creates these salinity maxima within the ocean? If you don't know the answer precisely, then what physical process is responsible for creating the stratification in this overall layer of the ocean? Stratification is due to warming at surface and the balance of local E-P. The process I was looking for is "subduction", which moves the highest salinity surface waters from the highest evaporation regions beneath slightly fresher surface waters, which creates the subsurface maximum.

(d) Why is the water column vertically stable in the presence of subsurface salinity maxima? Because temperature contributes to density as well, and the water is warmest at the sea surface.

(e) Suppose that the source water for the Salinity Maximum in the North Pacific is 34.5 psu and that the salinity shown on the meridional section is representative of the entire Salinity

Maximum layer. If the total formation rate of this water mass is 4 Sv, calculate the net freshwater flux across the sea surface, in Sverdrups.

Formula from top of exam: $F \sim \rho V(S_o - S_i)/S_m$

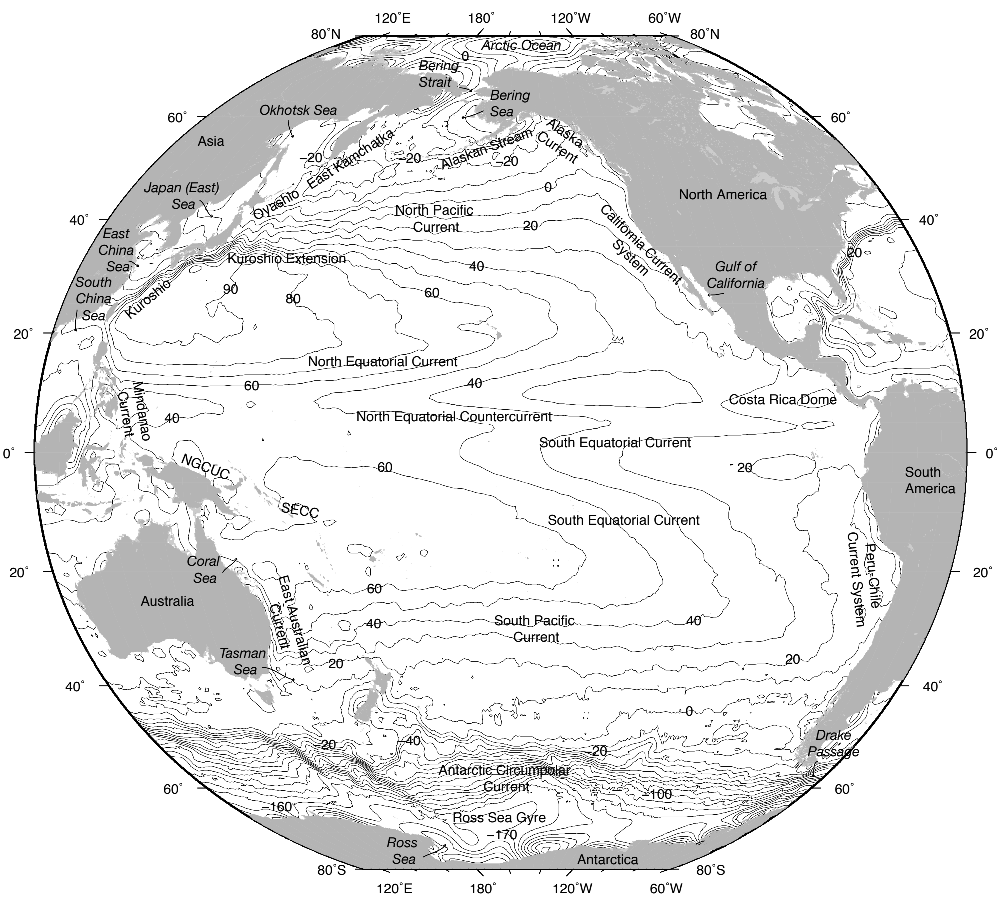
The formation rate V = 4 Sv. The density is about 1025 kg/m3 (see top of exam). Source water salinity is 34.5 (given in problem). SSM salinity is about 35 (from section), or more. Using 35, and a mean salinity of 34.7, the freshwater flux $F = (1025\ \text{kg/m}^3)\ (4 \times 10^6\ \text{m}^3/\text{sec})\ (35-34.5)/34.7 = 59 \times 10^6\ \text{kg/s} = 0.059 \times 10^9\ \text{kg/s} \Rightarrow 0.059\ \text{Sv}$

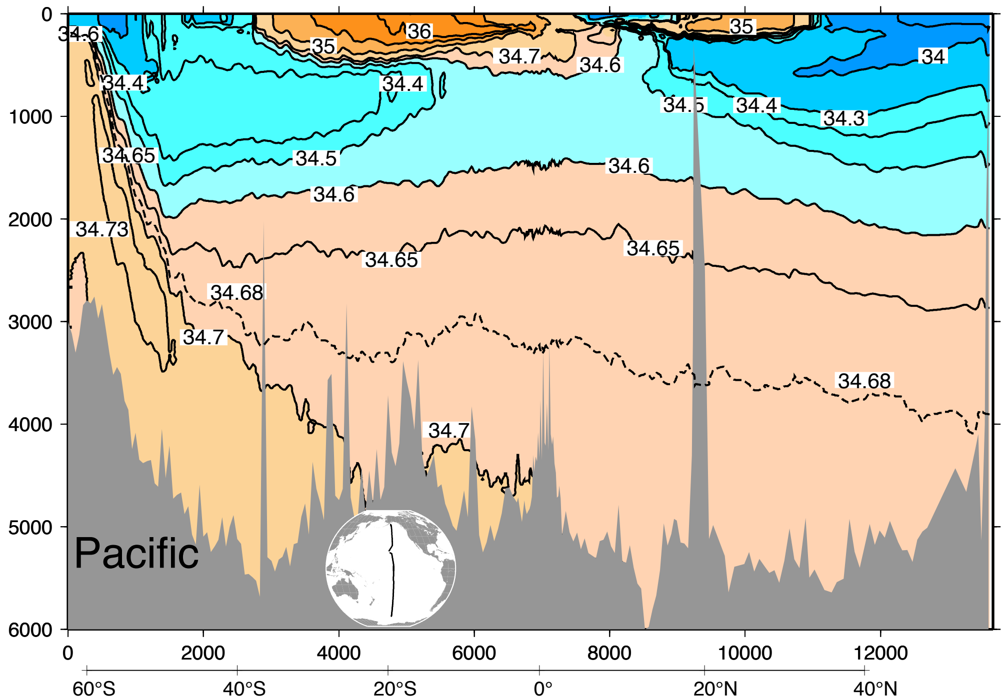
(f) The attached map shows the surface steric height (dynamic height) of the Pacific Ocean. Indicate on the map the region of the Salinity Maximum water in the North Pacific from the previous parts of the question.

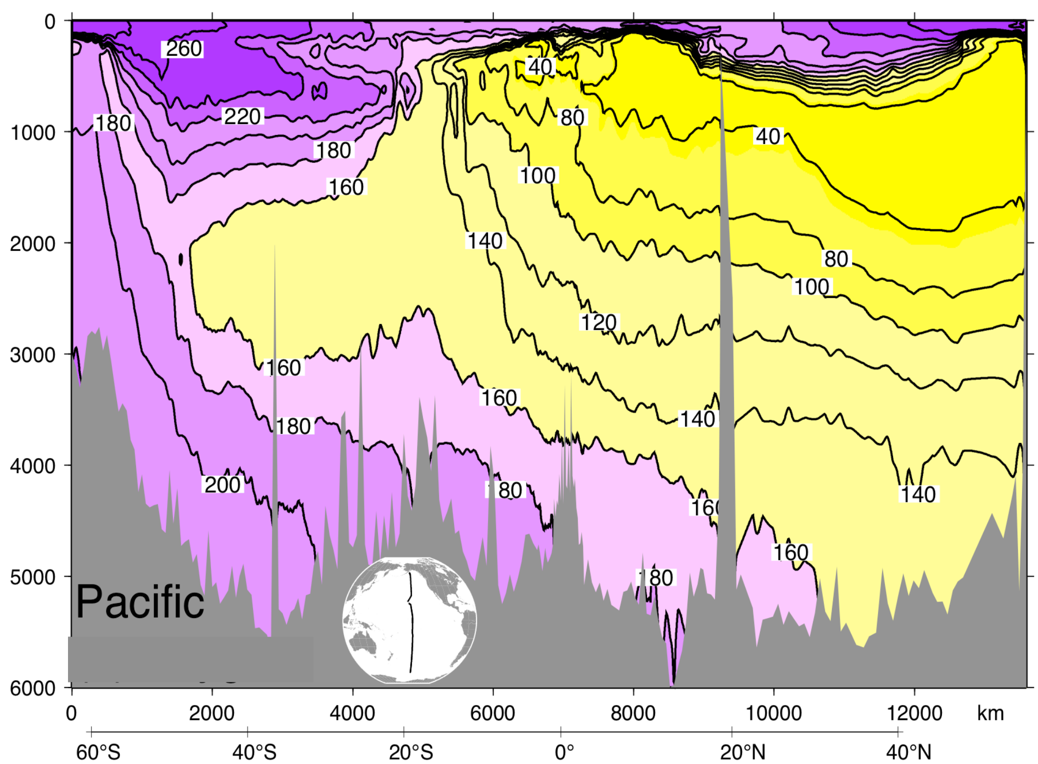
Mark area in subtropics. (I can't easily mark it in this solution set.)

Indicate the direction of flow in the gyre where this water mass is found. (Assume that the circulation is geostrophic.)

Draw arrows along the contours of constant height, NH subtropical gyre is clockwise and the SH subtropical gyre is counterclockwise.







(For problem 8)