SIO 210 Introduction to Physical Oceanography
Mid-term examination
November 5, 2012; 50 minutes
Answer key

Closed book; one sheet of your own notes is allowed. 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
$F \sim \rho V(S_o - S_i)/S_m$
acceleration + advection + Coriolis force = pressure gradient force + gravity + friction
heat flux = shortwave radiation + longwave radiation + latent heat flux + sensible heat flux

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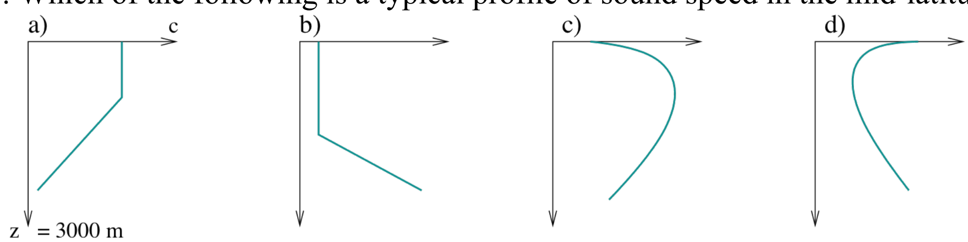
Multiple choice (5 problems, 4 points each, 20 points total)
For each problem, **circle the CORRECT answer**. (There should be only one.)

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



2. If the water column becomes more stratified

(a) The frequency of inertial waves (inertial motions) increases
(b) The minimum frequency for internal waves increases
(c) The maximum frequency for internal waves increases
(d) Surface gravity wave frequencies increase

3. If you take observations every hour for 3 weeks, then

(a) The Nyquist frequency is 1/(3 weeks)
(b) The fundamental frequency is 1/(3 weeks)
(c) Frequencies lower than 1/(3 weeks) are aliased into other frequencies
(d) The decorrelation time scale is 1 hour.

4. To determine the importance of viscosity for the dynamics of a given type of flow, the Rossby number of the flow is

(a) Irrelevant
(b) Small
(c) Large

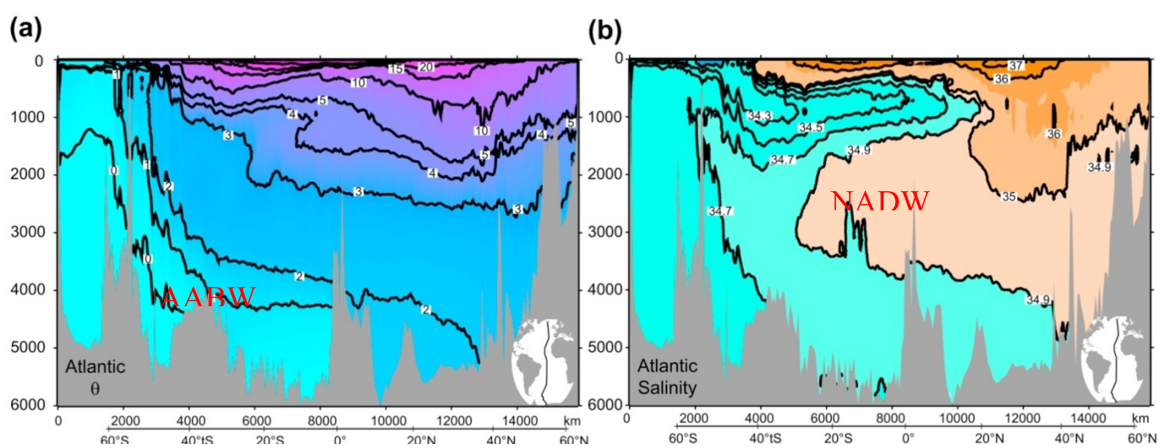
5. The temperature of a parcel of water at the sea surface is 2°C. If the parcel is moved down adiabatically to 2000 m its temperature would:
(a) decrease
(b) stay the same
(c) increase
(d) not enough information is given here to answer this question.

Short answer (3 problems, 50 points total)

6. (15 points) The illustration shows water properties along a meridional section that spans the Atlantic Ocean.
(a) In panel (b) (salinity), label the North Atlantic Deep Water layer.

(b) In panel (a) (potential temperature), label the Antarctic Bottom Water layer.

(c) What is the principal mechanism that creates Antarctic Bottom Water from less dense water?
______brine rejection (along coast of Antarctica)__________________



7. (15 points) Richardson (1985) used all available velocity observations (surface drifters, acoustically-tracked floats, current meters) to produce an averaged velocity structure of the Gulf Stream Extension south of Newfoundland, which is far to the east of the location where the Gulf Stream leaves the U.S. coast at Cape Hatteras.

Richardson's result was that the surface current is 900 km wide and has a maximum eastward velocity of 28 cm/sec. The instantaneous Gulf Stream is about 100 km wide with a maximum velocity of about 100 cm/sec.

(a) Why is there a discrepancy between the averaged and instantaneous values of current width and current velocity? Interpreting "Gulf Stream" as "Gulf Stream Extension", because the current meanders and is time-variable, the time average will be broader and weaker than the instantaneous, meandering (eddying) current. If you interpreted "Gulf Stream" as the current along the N. American coast and answered in terms of down stream changes in its instantaneous structure, I gave you quite a few points.

(b) What is a surface drifter? What does it measure? Instrument made up of a surface buoy and a subsurface drogue. Follows the water, so it is a Lagrangian instrument that provides velocity measurements at the depth of the drogue. It can also be instrumented to measure air temp, SST, air pressure, SSSalinity, etc.

(c) If the surface velocity in the Gulf Stream is related to the ocean's pressure distribution, can you think of a more modern method than Richardson's three to calculate the instantaneous surface velocity? Some good answers include: satellite altimetry (sea surface height), PIES array with bottom pressure instruments, Argo CTD profiling to provide density profiles and geostrophic velocity field.

8. (20 points) Consider the heat transport through a zonal section across the Atlantic Ocean. Assume that the ocean is 5,000 km wide. Assume that 20 Sv of water flow *northward* at 20°C in a layer that is 1,000 m thick. Assume that 20 Sv of water flow *southward* beneath this at 2°C in a layer that is 2,000 m thick.

(a) What is the direction of heat transport? (5 points) northward

(b) What is its magnitude? (If you don't have a calculator, use very simplified values for density and specific heat, and estimate the magnitude.) (15 points)
Note that you don't need the layer thickness or area, since the total volume transport is already given, as 20 Sv. The simplest approach is thus
Heat transport = $(\rho\ c_p\ T\ V)_{northward} - (\rho\ c_p\ T\ V)_{southward} = \rho\ c_p\ \Delta T\ V =$
$(1025\ kg/m^3)(4000\ J/kg°C)(20°C - 2°C)(20 \times 10^6\ m^3/sec) = 1.476 \times 10^{15}\ J/sec = 1.476 \times 10^{15} W$

Longer problem (1 problem: 30 points total)

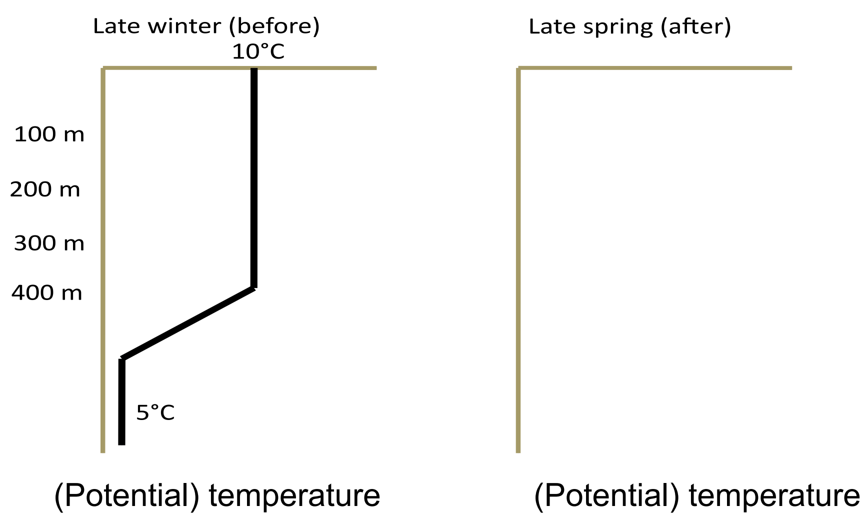
9. Suppose it is late spring. The surface air temperature is 20°C and the sea surface temperature is 10°C. This is also the temperature of the well-mixed surface layer (see figure below). There is a light wind.

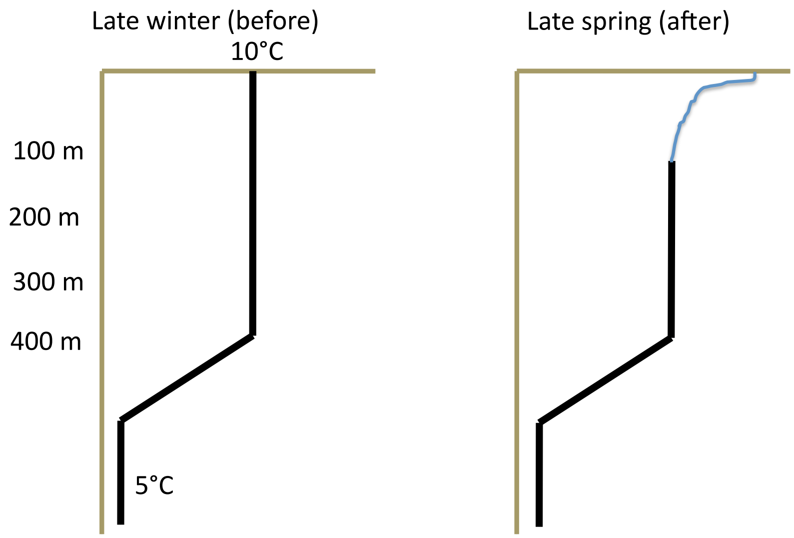
(a) Which heat flux component is directly proportional to this temperature difference? __Sensible heat flux____ (name)
(b) What sign is this component of the heat flux? (Assume that a positive heat flux warms the ocean and negative heat flux cools the ocean.)_____positive__________ (short answer)
(c) Over what approximate depth (meters, tens or hundreds of meters) does this heat flux component change the ocean temperature? Can you explain why? Meters. The heat is exchanged just in the very surface layer, and with a light wind blowing there will be a slight amount of mixing

(d) Which other component of the heat flux warms the ocean? __shortwave radiation___(name)
(e) Over what approximate depth (centimeters, meters, tens or hundreds of meters) does this heat flux component change the ocean temperature? Can you explain why?
About a hundred meters: solar radiation penetrates well into the ocean – the light creates the "euphotic" zone, and it also deposits heat. Thus heating can penetrate well below the sea surface in the absence of any mixing.

(f) Assume that you start with a uniform and thick mixed layer remaining from the end of winter (left panel). Sketch on the CENTER panel the vertical profile of temperature after these 2 sources of warming have continued for a few days. (Assume the spring heat loss terms are very small and that there is almost NO vertical mixing in the spring.)

(Note: This is not a quantitative sketch as you have no equations from which to infer the actual change in temperature. However, make sure that you show the vertical structure of the temperature change.)





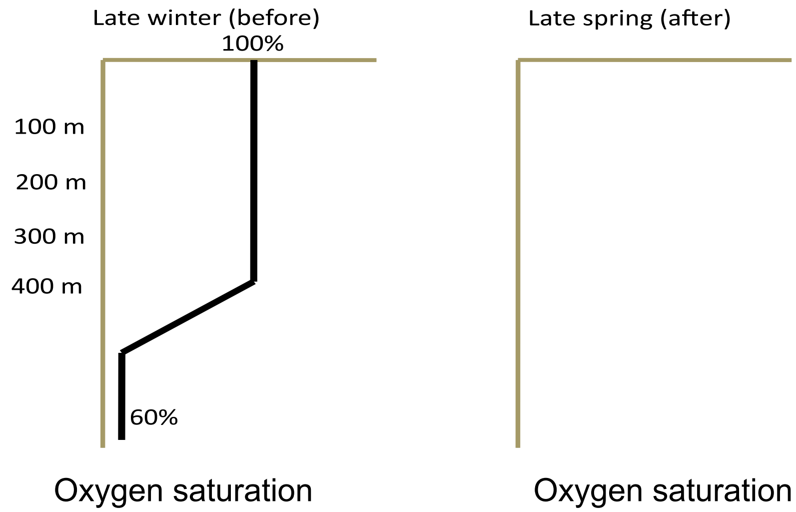
This is a rough attempt using the scribble tool in powerpoint. Salient points: structure is untouched below the heating zone, heating has 2 or 3 parts: exponential dropoff to about 100 m due to shortwave, higher heating very close to surface due to sensible, and possibly very thin mixed layer due to light wind mixing.

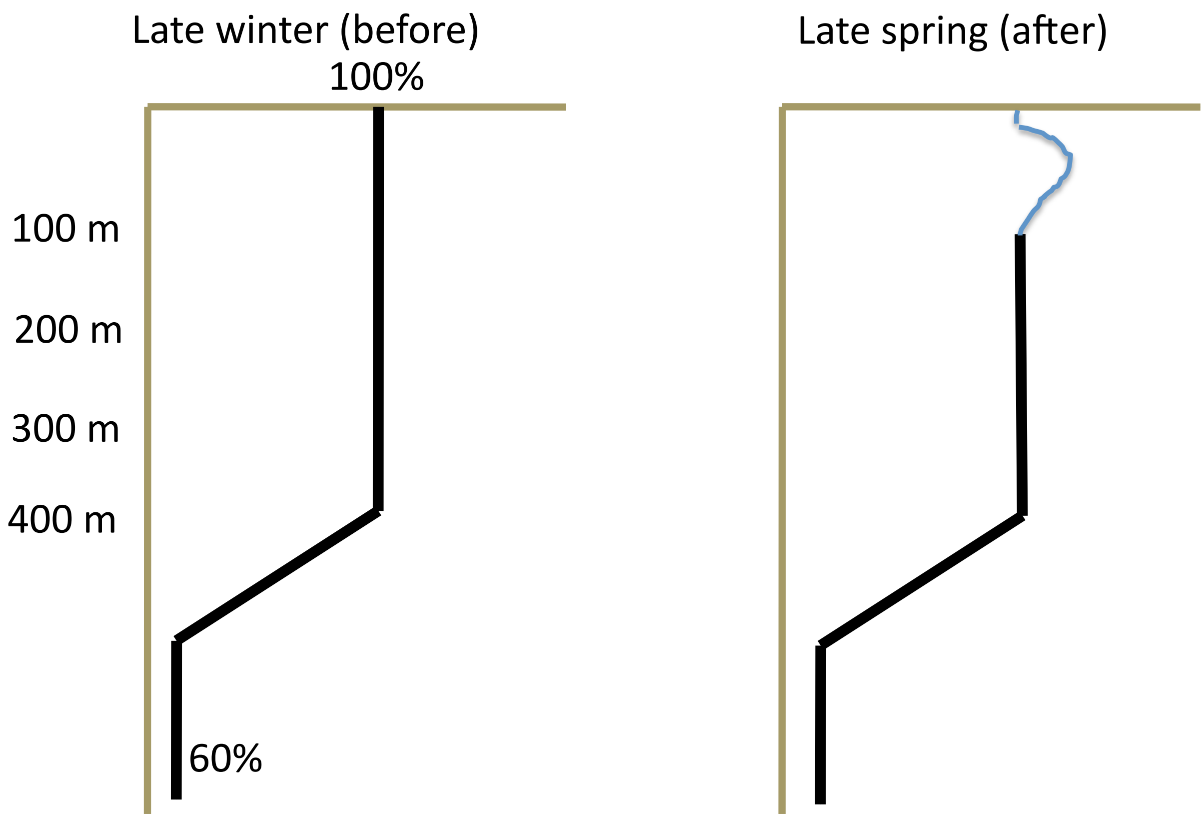
(g) The water column contains dissolved oxygen. Before the warming (left panel temperature structure), the surface mixed layer was 100% saturated in oxygen. After the warming, does the *percent saturation* of oxygen

DECREASE or INCREASE? (circle one)

Explain your answer. As the water warms, the full winter mixed layer becomes isolated from the sea surface by the thin cap of warmest, lightest water. Where the remnant winter mixed lyaer is warmed by shortwave radiation, its oxygen cannot escape, and so the oxygen content remains the same (in the absence of biology). Thus the oxygen saturation increases (to supersaturation).

(h) On the RIGHT panel, sketch the oxygen saturation profile you might expect to see with the warming you sketched for the center profile. Be careful about how you treat the sea surface point. (Again, assume that there is almost no vertical mixing (no formation of a mixed layer) in the late spring.)





This is a similarly rough attempt - the surface saturation should be 100%. It increases below where the water is warmed but not mixing, and then is untouched below the heating (in the absence of biology).