SIO 210 Introduction to Physical Oceanography
Mid-term examination ANSWER KEY
November 4, 2013; 50 minutes

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 (volume) or 1 Sv = 1 x 10^9 kg/sec (mass)

g = 9.8 m/s^2

ρ = 1025 kg/m^3

c_p = 4000 J/kg°C

E-P-R ~ F ~ $\rho V(S_o - S_i)/S_m$

acceleration + advection + Coriolis force = pressure gradient force + gravity + friction

Hendershott portion (38 points)

Multiple choice

For each problem, **circle the CORRECT answer**. (There should be only one.)

1. (8 points)

A record of, for example, sea level, is digitized and played back as an audio file.
If a listener hears one clearly defined note or pitch, as opposed to random or "white" noise, the spectrum of the record

(a) has no distinct peaks
(b) has one sharp and distinct peak
(c) has a number of sharp and distinct peaks.

If a listener hears no clearly defined pitch but simply random noise, the spectrum of the record

(a) has no distinct peaks
(b) has one sharp and distinct peak
(c) has a number of sharp and distinct peaks.

2. (8 points)

When waves are arriving at a coastal location from a powerful but distant storm (as in "Waves Across the Pacific"), the spectrum of sea level taken from an hour or so of sea level record generally has just one pronounced peak for wave periods between about 20 sec and 10 sec, and as records continue to be taken over a day or two, that peak

(a) shifts towards higher frequencies
(b) shifts toward lower frequencies
(c) does not shift appreciably.

This corresponds to the fact that as you watch the waves come in over a day or so, the period of waves arriving from a distant storm gradually

(a) decreases
(b) increases
(c) hardly changes at all.

3. (22 points: 2 for each answer)
Compare ocean surface waves from a distant storm and a distant submarine earthquake.

From which source have waves arriving at an observing station been strongly influenced by intervening seafloor topography?

a. earthquake, b. storm, c. both, d. neither.

From which source are waves observed to arrive at a distant observing station soonest after the generating event provided the sources are equidistant from the observing station?

a. earthquake, b. storm, c. both, d. neither.

From which source may waves approaching the coast in principle be strongly refracted by offshore submarine topography?

a. earthquake, b. storm, c. both, d. neither.

From which source are the waves at sea, before reaching the shore, generally of greatest amplitude?

a. earthquake, b. storm, c. both, d. neither.

From which source are the waves arriving at the shore always of greatest amplitude?

a. earthquake, b. storm, c. both, d. neither.

From which source are the waves arriving at the shore sometimes of amplitude exceeding many meters?

a.earthquake, b. storm, c. both, d. neither.

From which source are the waves that generate rip currents?

a. earthquake, b. storm, c. both, d. neither.

From which source are the waves that generate along-shore currents that carry sand along Southern California beaches?

a. earthquake, b. storm, c. both, d. neither.

From which source do ocean surface waves travel outward at several hundred meters per second?

a. earthquake, b. storm, c. both, d. neither.

From which source do ocean surface waves travel outward at speeds of several tens of meters per second?

a. earthquake, b. storm, c. both, d. neither.

From which source to ocean surface waves travel outward at about 1500 m/s?

a. earthquake, b. storm, c. both, d. neither.

Talley portion (62 points)

Multiple choice (6 problems, 2 points each, 12 points total)
For each problem, **circle the CORRECT answer**. (There should be only one.)

4. A **Lagrangian measurement**
(a) follows the water
(b) is made from a ship
(c) is made from a mooring
(d) is made using a satellite

5. The non-dimensional **aspect ratio** is of order 1 (not small or large) for
(a) Atlantic meridional overturning circulation
(b) tsunami wave
(c) Flow through the Bering Strait
(d) internal waves

6. **Hydrostatic balance** describes the force balance between:
(a) acceleration and pressure gradient force
(b) Coriolis and gravitational force
(c) gravitational force and pressure gradient force
(d) advection and diffusion

7. Of the terms that contribute to air-sea heat flux, which one is *most likely* to be **both positive and negative** (reducing or increasing seawater density):
(a) latent heat flux
(b) solar radiation
(c) longwave radiation
(d) sensible heat flux

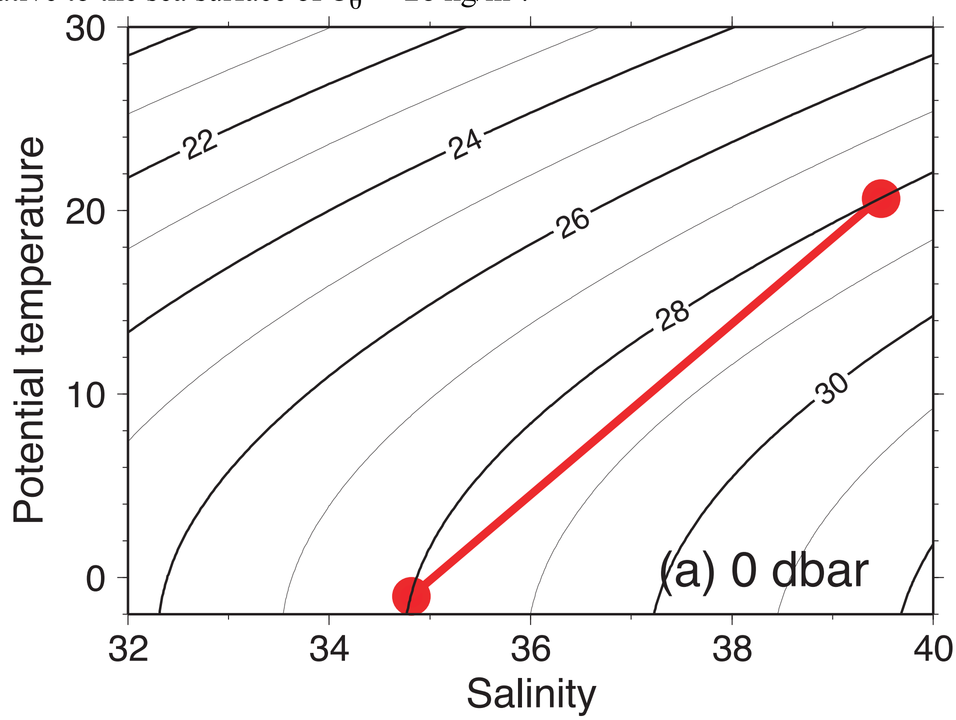
8. In order to properly sample a phenomenon at one location that has a seasonal time scale (cycle), which one of these choices is the most optimal:
(a) Observe every day for one year
(b) Observe for 100 years (badly phrased – needed a frequency of observation, so I accepted this answer)
(c) Have at least 1 degree of freedom
(d) Observe once a week for 10 years

9. 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

Short answer or calculation (4 problems, 50 points total)

10. (10 points)
Water that spills over the deep strait* exiting the Red Sea in the northwestern Indian Ocean is extremely salty and relatively warm. (*Bab el Mandeb) This "Red Sea Water" is very similar to Mediterranean Overflow Water that exits the Strait of Gibraltar, as it is saltier and cooler than the inflow from the Indian Ocean.

Suppose the Red Sea Water is compared with colder, fresher deep water that is coming from the deep Antarctic into the Indian Ocean. Suppose that both of these waters have the SAME density relative to the sea surface of $\sigma_\theta = 28$ kg/m^3.



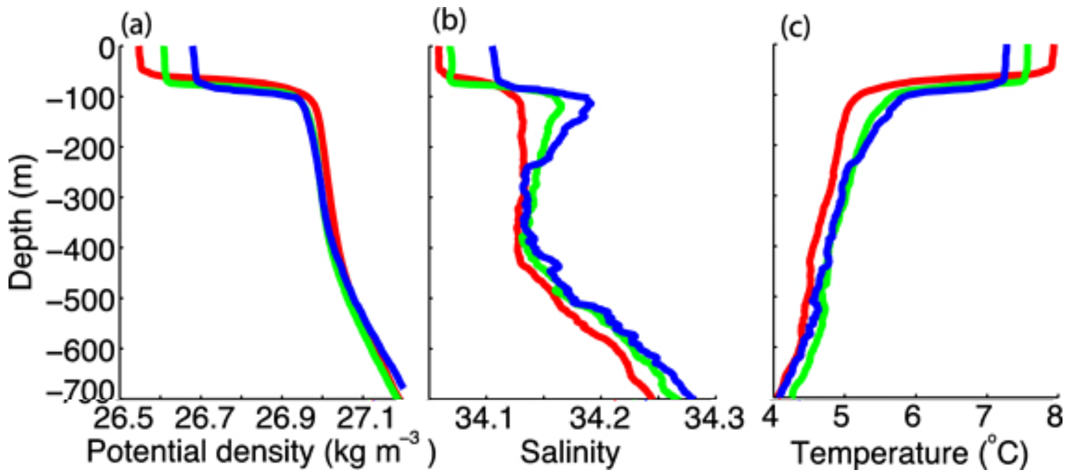
(a) (2 points) On this θ-S diagram, mark which of the two parcels (big filled circles) best represents Red Sea Water (RSW), and which represents Antarctic Bottom Water (AABW).
Upper right is RSW and lower left is AABW.

(b) (3 points)
Assume that there is NO mixing.
When the Red Sea Water moves down the continental shelf and into the deep ocean, will it be **denser than** or **lighter than** or the **same density** as the AABW? ____lighter____________

(c) (5 points)
Explain your answer to (b). You are encouraged to sketch on the figure to help with your explanation. With no mixing, RSW conserves its potential temperature and salinity. At higher

pressure, because it is warmer than AABW, it will compress less than AABW and therefore its density will be lower. (Consider drawing sigma 4 contours on the plot to illustrate.)

11. (10 points)
The figure shows observed summertime vertical profiles of potential temperature (right), salinity (center) and potential density (left). (There are 3 profiles in each panel – this is not important.)



(a) (2 points) Label the mixed layer(s). well-mixed surface layer (to about 80 m)

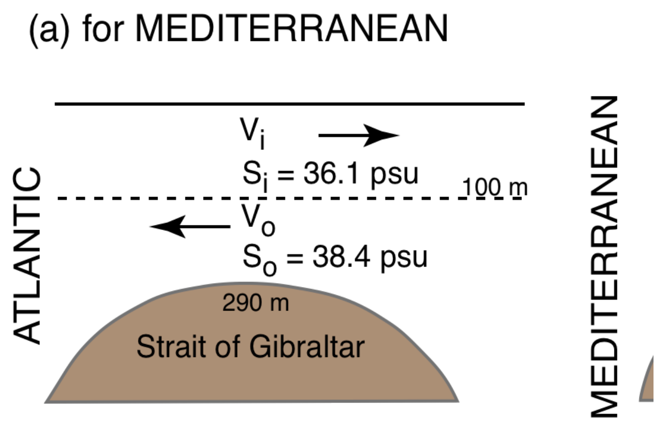
(b) (2 points) Label the pycnocline(s) and the thermocline. Fast change in density and temperature at about 80-90 m.

(c) (2 points) Label the pycnostad and the thermostad. Less stratified layer from about 100 m to about 400 m (between the sharp near-surface pycnocline and the weaker deep pycnocline).

(d) (1 point) Label the salinity minimum. Two acceptable answers: the low surface salinity layer or the S min at about 250-400 m.

(e) (3 points)
These are summertime profiles. On the potential density profile, *sketch* what you think the profile looked like at the end of winter before these measurements. Assume that this is a region of high ocean heat loss in winter. Explain.
1. Surface mixed layer will be denser than the summer mixed layer, so (1 point) you must show that it is denser.
2. Surface mixed layer is well mixed down to the existing summer pycnocline OR all the way through the pycnostad. (2 points) If you showed it as mixing to some intermediate depth and with density lower than the pycnostad, there would have been a double pycnostad in the summer profiles.

12. (15 points)
The North Atlantic and the Mediterranean Sea are connected through the narrow Strait of Gibraltar, which has a two layer flow. See the figure. In the Strait, all inflow to the Mediterranean is in the surface layer, and all outflow back to the Atlantic is in the bottom layer. (If you don't have a calculator, show how to set up the problem and estimate the answer.)



Assume that the inflow transport and outflow transport are approximately equal.
Given:

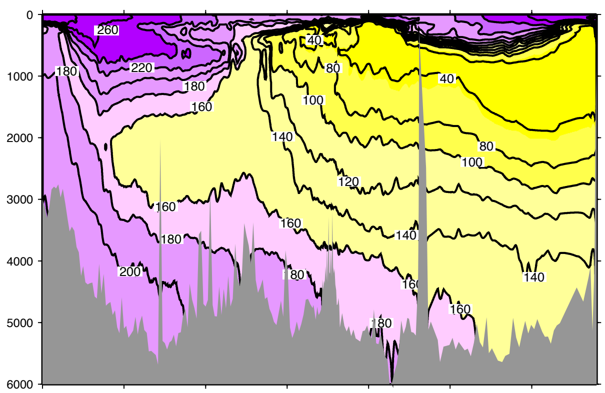
average inflow salinity is 36.1
average outflow salinity is 38.4
Exchange volume transport $V \sim V_o \sim V_i$ is 0.7 Sv = $0.7 \times 10^6\ m^3/sec$

(a) (7 points)
Freshwater: **calculate** the net Evaporation – Precipitation – Runoff within the Mediterranean. Express your answer in Sv (either mass or volume based).
Use expression $F \sim \rho V(S_o - S_i)/S_m$ and the units 1 Sv = 1×10^9 kg/sec given at top of exam.
Using a calculator, we get
$F = (1025\ kg/m^3)(0.7 \times 10^6\ m^3/sec)(38.4-36.1)/(37.25) =$
where I've already found the average salinity $S_m = (38.4 + 36.1)/2$.

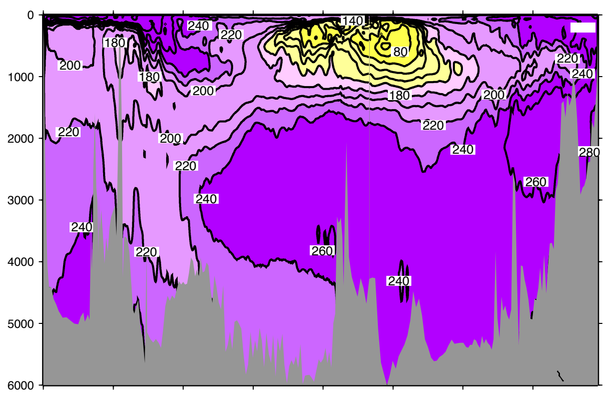
Evaluating: $F = 0.043 \times 10^9$ kg/sec $\sim 0.043 \times 10^6\ m^3/sec$
(b) Using your answer to (a), if the inflow volume transport is exactly 0.7 Sv, what is the estimated outflow volume transport? (Note that we assumed they are approximately equal in (a).)
It will be 0.043 Sv less = 0.7 – 0.043 = 0.657 Sv
(c) (5 points)
The outflowing saline Mediterranean water from the Strait of Gibraltar does not remain at the sill depth. Describe briefly where it goes and how it influences the water mass distribution of the North Atlantic. It sinks partway down into the North Atlantic, mixing turbulently with waters it passes through, and creates a high salinity intermediate layer (Mediterranean Overflow Water) in the North Atlantic. This ultimately joins the NADW as it flows out of the Atlantic. The MOW provides some of the high salinity signature of the NADW.

13. (15 points) Deep waters of the world ocean have a range of ages. Here are two oxygen sections, one from the Pacific and one from the Atlantic. The color scales are the same. Purple is high oxygen concentration and yellow is low oxygen concentration (in µmol/kg).

Pacific



Atlantic



(a) (2 points)
Label the Pacific section and the Atlantic section.

(b) (4 points)
How did you know which is the Atlantic and which is the Pacific? (Explain answer to (a), very briefly.) Pacific has old deep water and Atlantic has young deep water, so Pacific oxygen is low and Atlantic oxygen is high.

(c) (3 points)
On the two sections, mark the location(s) of the

Antarctic Bottom Water (marked at bottom, southern end of both sections)
Pacific Deep Water (marked in the yellow, low oxygen deep layer in the Pacific)
North Atlantic Deep Water (in the purple, high oxygen deep layer in the Atlantic)

(d) (2 points)
Where on these sections might you find water whose carbon-14 ($\Delta^{14}C$) age is almost 2000 years? (mark the approximate region) where you marked PDW, particularly around 3000 m depth in the North Pacific.

(e) (4 points)
Oxygen is a non-conservative tracer. Explain briefly what:

sets the oxygen concentration and what
changes the oxygen concentration

Oxygen enters ocean through air-sea gas exchange, and is also produced by photosynthesis. The surface layer is approximately (but not exactly, depending on location) 100% saturated in oxygen. The actual concentration then depends on this saturation and also on the water temperature.

Oxygen is changed within the ocean both through photosynthesis (minor except in some limited regions), and mainly decreased through respiration, mainly by bacteria.