SIO 210 Final examination
Wednesday, December 9, 2015
3-6PM Sumner auditorium Name:____________________

Please put your initials or name on each page.

Turn off all phones, iPods, etc. and put them away.
This is a **closed book exam**.
You may use **two pages** of notes, both sides, written or printed.
You may use a non-communicating calculator.

Check which you prefer regarding the return of this exam and other graded materials
______I will pick up the exam in Nierenberg Hall 310 (after Jan. 4)
______Return the exam etc to me via campus mail (or full address)
Mailcode________________________

[1-3] Hendershott	_______________/18
[1-10] 10 Multiple choice 1 point each	_______________/10
[11-17] 7 Problems (Talley)	_______________/80
Total	_______________/98

Hendershott portion

1. (6 points) Here is a list of astronomical events associated with tides.
   A. times when moon is in earth's equatorial plane
   B. times when moon is farthest out of earth's equatorial plane
   C. times when sun is in earth's equatorial plane
   D. times when sun is farthest out of earth's equatorial plane
   E. times of half moon
   F. time of full moon
   G. time of new moon
   H. time of lunar perigee (closest distance to earth)
   I. time of lunar apogee (greatest distance from earth

Answer the following questions using the letters "A" through "I"

(a) which of the above events occurs at the equinoxes, when day and night are very close to the same length? _____C__

(b) the range of lunar tides is least (neap tides) around the time(s) of which events on the above list ? ____E___

(c) the daily inequality in tides is least pronounced around the time(s) of which events on the above list? ___A,C____

(d) the range of lunar tides is greatest (spring tides) around the time(s) of which events on the above list ? ___F, G____

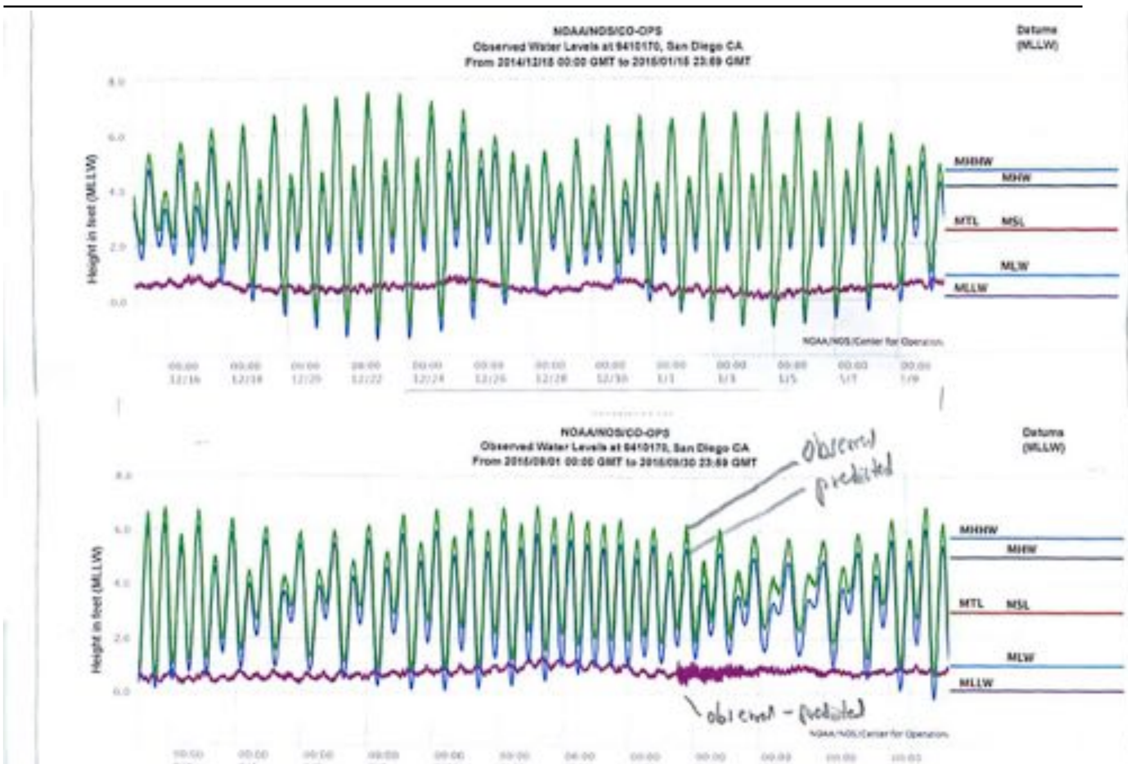
(e) Perigean spring tides require the near coincidence of event ____H______ on the above list with events ______F,G___________ on the above list?

(f) eclipses of sun or moon never occur at the times(s) of which events on the above list ? ___E____

2. (6 points) The attached figure shows predicted and observed sealevel as well as observed-minus-predicted sealevel at San Diego for two periods: 16 Dec 2014 – 9 Jan 2015 and 1 Sept 2014 – 30 Sept 2014.

VERY BRIEFLY (a few words suffice) explain
a. what happened around 17 Sept 2015?_________________tsunami__________

b. why is the daily inequality so much greater during 6 Dec 2014 – 9 Jan 2015 than during 1 Sept 2014 – 30 Sept? (hint; in your answer, it will be most convenient to refer to the list of astronomical events given in the previous question.
Event D, sun farthest out of earth equatorial plane, "king tides" in el nino coverage



3. (7 points) Here is a list of some of the various kinds of waves that propagate through the ocean and/or solid earth.

A. Capillary (surface tension) waves.
B. Deep Water (wavelength<< depth) surface gravity waves
C. Shallow water (wavelength >> depth) surface gravity waves
D. Seismic S and P waves
E. Acoustic waves

Answer the following questions using the letters "A" through "E"

(a) arrange the above letters in the order: fastest propagating wave first… slowest propagating wave last _E, D, C, B, A_______

(b) The waves that are excited by submarine earthquake to constitute a tsunami are primarily ______C________

(c) The open ocean waves most strongly excited by storm winds are ______B______

(d) The waves that are used to trigger an initial tsunami alert are __D________

(e) The waves whose speed of propagation is very close to $\sqrt{(gD)}$ are _____C______

(f) The waves whose speed of propagation is very close to $\sqrt{(g\lambda/2\pi)}$ are ____B_______

(g) The waves that may make you seasick in a small boat in rough seas are ____B______

Talley portion

Possibly useful expressions and values; you will not need all of these.

ρ: use 1025 kg/m^3 for generic calculations
c_p = 3850 J/kg°C
$\rho\, c_p\, T$
Freshwater transport ~ $\rho V(S_o - S_i)/S_m$
1 PW = 10^{15} W = 10^{15} J/sec
Earth's radius: 6371 km
$V_{Ek} = - \tau^{(x)}/(\rho f)$
Ro = U/(fL)
f = 2Ω sin(latitude)
Ω = 0.73 x 10^{-4}/sec
sin (30°) = 0.5
sin(50°) = 0.77
1° latitude = 111 km
1 Sv = 1x10^6 m^3/sec
g = 9.8 m/sec^2
acceleration + advection + Coriolis force =
pressure gradient force + gravity + friction

Multiple choice (1 point each; 10 points total)
For each multiple choice problem, **circle ONE CORRECT answer**.

1. In the North Atlantic overturning circulation (HAS TWO CORRECT ANSWERS)
   (a) Dense water is principally formed by brine rejection
   (b) Inflowing water from other oceans is principally through Bering Strait
   (c) Heat transport is northward
   (d) Freshwater transport is southward

2. Which of the following subtropical gyre western boundary currents provides a major connection between oceans in the global overturning circulation?
   (a) Brazil Current
   (b) East Australian Current
   (c) Gulf Stream
   (d) Agulhas

3. The restoring force in a Rossby wave, which makes the water return back to an equilibrium location, is
   (a) the variation of Coriolis parameter with latitude
   (b) gravity
   (c) potential vorticity (they might answer this, and I think it's sort of 0.5 points)

(d) the discontinuity in density between the air and the sea

4. As water moves adiabatically (without change of heat energy) from the sea surface to the deep ocean
   (a) its temperature decreases
   (b) it expands
   (c) its temperature increases
   (d) its potential density increases

5. The Labrador Sea Water, which contributes to North Atlantic Deep Water, is
   (a) a layer of high salinity in the North Atlantic
   (b) formed by brine rejection in the Labrador Sea
   (c) a low salinity intermediate water
   (d) formed by deep convection to the ocean bottom in the Labrador Sea

6. The surface mixed layer
   (a) is always deeper than the Ekman layer
   (b) is only mixed by the wind
   (c) can be mixed by upwelling deep water
   (d) is sometimes shallower than the euphotic zone layer

7. In the tropical Pacific, the interaction between the winds and sea surface temperature is called the
   (a) Bjerknes feedback
   (b) Kelvin feedback
   (c) Rossby feedback
   (d) Walker feedback

8. The force balance in the "thermal wind" balance is between
   (a) acceleration and temperature
   (b) pressure gradient force and Coriolis force
   (c) Coriolis force and vertical diffusion
   (d) Coriolis force and acceleration

9. Pacific Deep Water (I'll take both of these answers as well – I didn't phrase c the way that I intended to)
   (a) is transported northward away from the Southern Ocean
   (b) is formed from upwelled Antarctic Bottom Water
   (c) upwells all the way to the sea surface within the Pacific Ocean
   (d) has a dense water source in the Bering Sea

10. For water with a given temperature and salinity at the sea surface: when it is moved to high pressure (great depth), its
   (a) sound speed decreases
   (b) salinity increases

(c) potential density σ_θ increases

(d) its temperature increases

Problems

11. (10 points)
Time series observations are made over a limited length of time (record length) and are sampled at discrete times rather than continuously.
(a) The highest frequency that can be determined from these measurements, based on their sampling, is called the (**circle one**)

(i) Nyquist frequency
(ii) Fundamental frequency
(iii) Aliasing frequency

(b) This highest frequency that can be determined is based on (**circle one**)

(i) the length of the record
(ii) the sampling interval

(c) If there are frequencies higher than this highest sampled frequency, they contribute their energy to a lower frequency. We call this (**circle one**)

(i) biasing
(ii) aliasing
(iii) variance

(d) "Degrees of freedom" express the number of independent realizations of a given process or dominant cycle in a given time series. What is the approximate minimum number of degrees of freedom that are useful for our oceanographic data analyses? (**circle one**)

(i) 100
(ii) 2
(iii) 10
(iv) 1000

Suppose we are observing the El Nino Southern Oscillation (ENSO) in the Pacific Ocean. How should design our sampling? Answer the following:

(e) What is the approximate time scale of ENSO? (approximately how much time is between El Nino events?)______3-7 years___________________

(f) What is the approximate minimum time that we should measure ENSO variables to begin to characterize typical ENSO cycles with good statistics? (Use an answer drawn from part d above.) For 10 indepedendent realizations, we should observe it for about 50 years or longer.

12. (12 points) Pressure is related to depth through this equation:

$$0 = - \Delta p/\Delta z - \rho g$$

(a) These two terms are which terms in the momentum equation? (**circle the two correct terms in the following word equation)**

acceleration + advection + Coriolis = PGF + gravitational force + viscosity

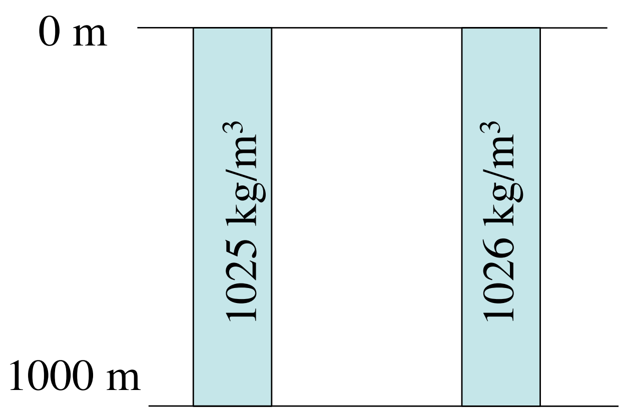
(b) What is the name we give to this relationship between pressure and depth?______hydrostatic balance____________________________________

(c) Calculate the pressure at 1000 m depth using this equation and values of constants from the top of the exam. Use a density of ρ = 1025 kg/m^3 for the left column shown here.

$P = \rho g z = (1025\ kg/m^3)(9.8\ m/sec^2)(1000\ m) = 1.0045 \times 10^7\ kg/(m\ sec^2) = 1.0045 \times 10^7\ N/m^2$

Calculate the same (pressure at 1000 m) for the column of density ρ = 1026 kg/m^3.

$P = \rho g z = (1026\ kg/m^3)(9.8\ m/sec^2)(1000\ m) = 1.0055 \times 10^7\ kg/(m\ sec^2) = 1.0055 \times 10^7\ N/m^2$



Pressure at 1000m:__ 1.0045 x 10^7 N/m^2____1.0055 x 10^7 N/m^2 (or Pa)

(d) Use an arrow to show the direction of the pressure gradient force (PGF) at 1000 m. Points to the left.

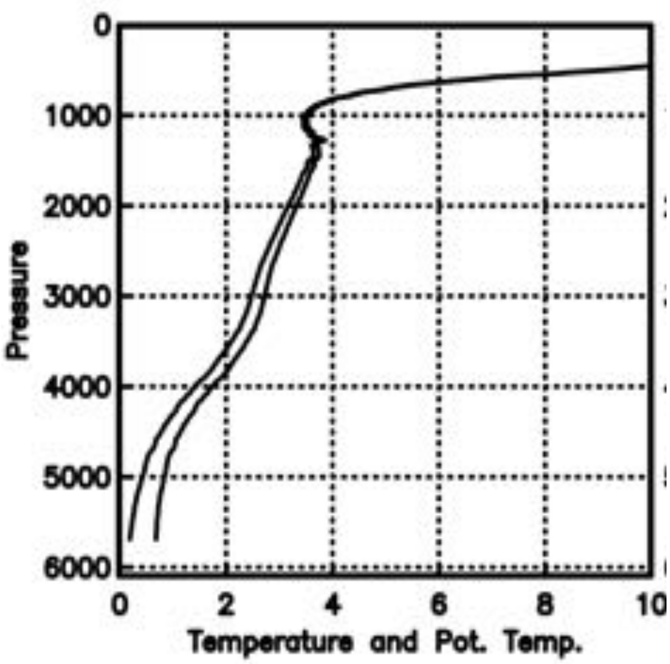
(e) If there is a geostrophic flow due to this density distribution, and this is the northern hemisphere, which is the flow direction at 1000 m? Indicate it on the plot using symbols like these: Points into the paper

⊙ ⊗ →

(f) Assuming the sea surface is *flat*, what is the pressure gradient force at 0 m?___0__
What is the geostrophic flow at the sea surface?_____0 cm/sec_________
(g) What is the name given to the balance that describes how this geostrophic flow varies from 0 to 1000 m?____thermal wind balance_____________________

13. (20 points) (a) Briefly define *potential temperature*.
Potential temperature is the temperature a parcel has when brought from its actual depth/pressure to another reference pressure. We usually define potential temperature as relative to the sea surface. (However, we use potential temperature relative to other pressures especially when calculating potential density relative to pressures other than the sea surface.)

(b) The attached figure shows potential temperature and temperature from a station in the central South Atlantic. On the figure, mark which curve is potential temperature and which is temperature.



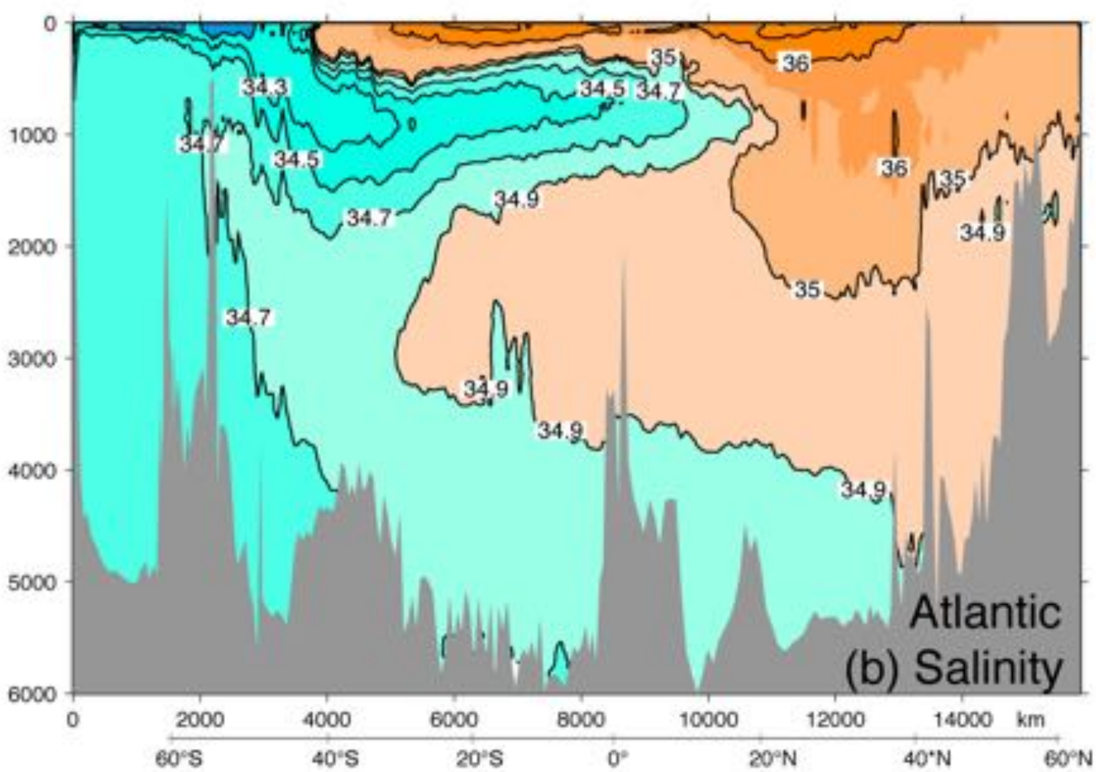
(c) On the same figure, mark the location of the *thermocline*. Briefly ***define*** what the thermocline is. Thermocline is the layer through which temperature changes rapidly. The main thermocline in this profile is between the surface and 1000 m. I can allow answers that also point out that there is a deep thermocline, around 4000-4500 dbar, which is due to the juxtaposition of two different water masses.

(d) On the figure, mark the location of a vertical inversion in temperature and potential temperature. Briefly explain why this vertical minimum in temperature in

the central South Atlantic can be stable (steady, unchanging over time), given that density decreases when temperature increases.
Occurs at 1000-1200 dbar. It is sustained by a similar inversion in salinity, which is related to the Antarctic Intermediate Water.

(e) The attached vertical section of *salinity* from the Atlantic Ocean includes the station used for the temperature-potential temperature plot.
Label these water masses on the salinity section: See plot.

Antarctic Intermediate Water
North Atlantic Deep Water
Antarctic Bottom Water
Mediterranean Overflow Water
Labrador Sea Water



(f) Return to the black and white line plot of temperature/potential temperature profiles in (b). That profile is from about 25°S. *Label the water masses on that plot (the single profile*), from the list of water masses that you just used. See plot.

(g) What is the direction of net volume transport in each water mass at 25°S (CORRECTED), summed zonally across the whole South Atlantic? You may draw arrows or write on the vertical section. You may also do this on the black/white profile. AABW is northward; NADW is southward; AAIW is northward; can even show that thermocline as a whole is northward.

(h) What is the approximate volume transport (a number) for the water mass associated with the part of the temperature profile centered at 3000 m? Why is this information useful? (broad explanation from your own point of view is fine)

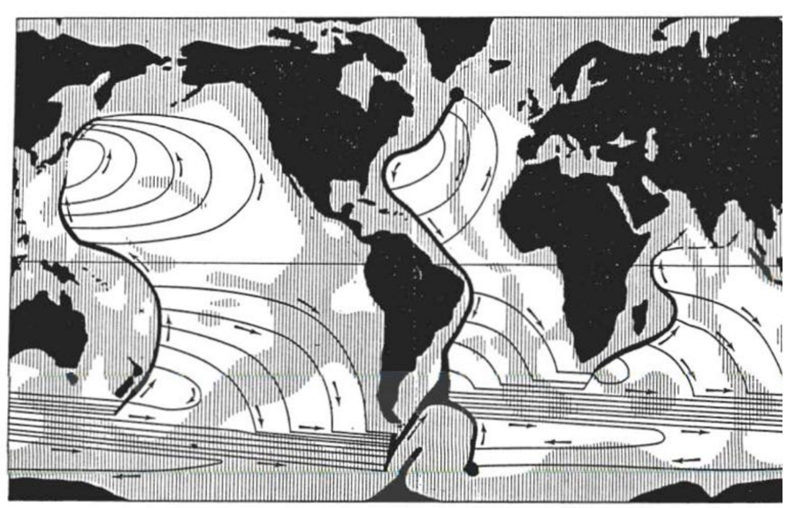
The value we provided in class, and see on Schmitz's overturning circulation with volumes, is 15 to 20 Sv. This is useful because it reflects that large magnitude of overturn that occurs because of dense water formation in the North Atlantic. This pulls surface water (salty, nutrient and carbon-poor, oxygen rich) down to mid-depth and spreads it around the oceans. People can go on and on in whatever direction they wish on this answer; will just check for accuracy.

14. (5 points)The attached map is a very idealized schematic of the *abyssal circulation* from Stommel. It assumes a flat bottomed ocean, with very localized sources of water for this abyssal layer.

Look at the *South Pacific* on this map. Explain the flow direction on this map in the South Pacific. Why do the arrows point the direction they do? Include potential vorticity in your explanation.

In the South Pacific, the small arrows in most of the basin point eastwards and southwards. In the DWBC they point northwards. Within the basin, the southwards (poleward) flow is the solution to the model – broad upwelling of the dense layer over a flat bottom, leads to stretching, leads to increase in absolute value of f, leads to poleward flow, as a result of potential vorticity conservation.

The direction of the DWBC is such as to satisfy continuity, to feed these interior flows that result from the upwelling, and whose magnitude is dependent on that upwelling rate. The DWBC is on the western boundary, as are all narrow boundary currents that exist to satisfy continuity, and then are located such as to satisfy energy and vorticity balances.



15. (8 points) On the map shown here (next page for color) of sea tropical Pacific surface temperature (SST) and winds, which represents "normal conditions",

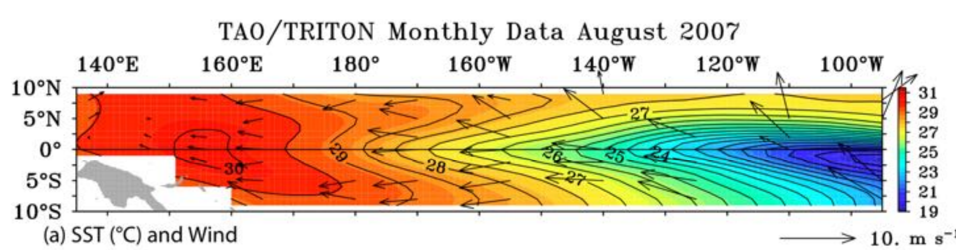
(a) Mark the *warm pool* and the *cold tongue*. Warm pool is in west (e.g. 28-30°C water) and cold tongue is in east (< 25°C)

(b) Explain why there is a cold tongue. Short answer: upwelling. Longer answer: trade winds on the equator drive westward surface flow. This results in upwelling in the east and downwelling in the west. It also results in shoaling the thermocline in the east which brings cold water closer to the sea surface. Longest answer: These two plus the poleward Ekman transport (away from the equator) at all longitudes, due to the trade winds. This createst equatorial upwelling, but because there is a warm pool in the east and shallow thermocline in the west, the upwelling brings cold water to the surface only in the east.

(c) What is the name of the atmospheric circulation (wind pattern) is associated with the forcing due to this SST pattern? _____Walker circulation, also fine to add Hadley circulation________________

(d) Explain how this atmospheric circulation arises from this SST pattern. Cold SST in east and warm SST in west cause rising air in the west and sinking air in the east. These are connected by easterly surface winds (and also be westerly winds aloft).

(e) Explain how this SST pattern arises from that atmospheric circulation. I have included this answer in part (b).



16. (10 points) In the next color image of surface temperature from satellite data, red is high SST and blue/purple-pink is low SST.

(a) What ocean is this?_____North Atlantic (accept "Atlantic" also)__________

(b) Mark the western boundary current (WBC). What is its name?___Gulf Stream____

(c) What direction does this WBC flow? Northward Mark the direction on the map.

(d) What is the approximate width (a number!) of the WBC? (This is our general guideline for WBCs; there are no dimensions shown on the map.)_______about 100 to 200 km width______________

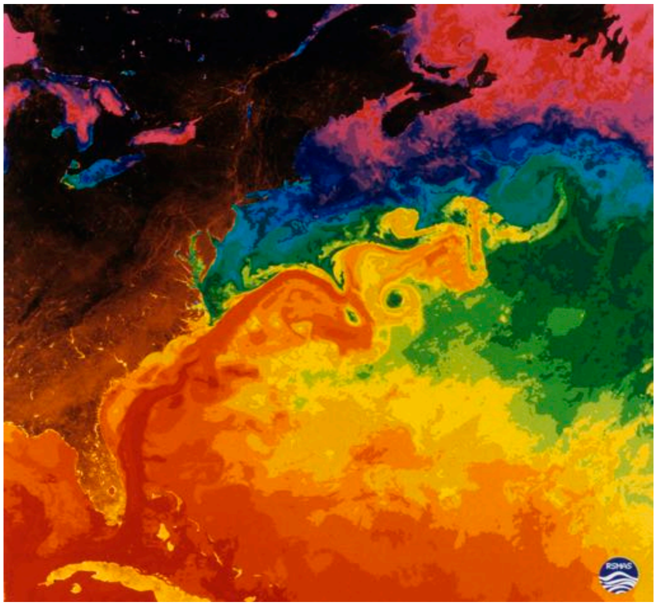
(e) Mark the separation point of this WBC. At Cape Hatteras

(f) Mark the recirculation region for this WBC. Where the cool water is found along southern side of the Gulf Stream, resulting from southwestward flow

(g) Briefly describe the temperature structure of the WBC, and *why* it changes along the direction of flow of the WBC. The surface temperature of the Gulf Stream is highest at the southern end of the graphic, where it originates in the warmest subtropical waters. As it moves northward, it advects this warm signal northward. As it advects this warm water northwards, it loses heat to the atmosphere. What we usually say is that this is due to the very cold, dry continental winds that blow in winter from North America across the Gulf Stream. It is also losing heat simply because the overall surface air temperature to the north is cold and there is a lack of equilibrium between the surface temperature and air temperature. (Very long answer: there is a preferred difference in temperature, with SST higher than SSA, which is required by the Earth's radiation balance, and which results in sensible heat loss almost everywhere in the ocean.)

(h) Briefly describe the background temperature structure (other than the WBC) and why it has this overall structure

In the background we have warm water to the south and cool water to the north. This is because the planet is heated in the tropics and cooled at the poles. The atmosphere and ocean both show this overall pattern very strongly. Advection by ocean circulation produces additional structure, like this Gulf Stream example. Some of you might have also described the mesoscale eddy field and even the submesoscale eddy field, which produce the noise in the SST.



17. (15 points) For the attached map of sea surface height:
(a) Are the red regions areas of HIGH surface height or LOW surface height?
__HIGH_______

(b) Mark the *five* subtropical gyres with an "STG" (Mark the highs at mid-latitudes)

(c) In the North Pacific, indicate the direction of geostrophic flow in the subtropical gyre (mark it on the map with arrows). (clockwise around the high)

(d) Mark the Antarctic Circumpolar Current (tightly packed east-west contours between yellows and blues at southern side of map)

(e)Explain the direction of flow of the Antarctic Circumpolar Current, based on the sea surface height distribution that is shown in the map. (high to the north, low to the south, PFG is southward, geostrophic flow is eastward)

(f)Show the direction of the prevailing winds in the Southern Hemisphere. (mark the easterly trades and the westerlies. Can also mark the easterlies at very southern end of map along Antarctic coastline.) This question should have requested just the zonal winds.

(g)Based on the winds, show the direction of the surface layer flow directly forced by the winds. Describe WHY - what is this surface layer flow called? Draw in the Ekman transport to the left of the SH winds. Explain that viscous response is the Ekman layer at right angles to the wind, to the left in the SH.

(h)Based on this surface flow, show where the Southern Ocean upwelling regions are. Having shown maximum westerlies aroud 45-50S, and easterlies or weaker westerlies to the south of this, the upwelling region is south of these maximum westerlies.

(i) In the South Pacific subtropical gyre, mark the direction of the flow in response to your answer for (f, g). What is this flow and why does it go the direction you show? Mark the counterclockwise gyre, with velocities exactly along the contours that are shown. This flow is geostrophic, follows contours of SSH, and in the SH must be counterclockwise around a high.