SIOC 210 Problem Set 3 Answer Key Nov. 14, 2019, due Nov. 21 100 points total

Problems 1 and 2 are very similar to the questions that were distributed on Oct. 24. Since I provided an answer key for that problem set, I have altered the questions somewhat.

1 15

2 25

3 20

4 20

5 10

6 10

1.

## 15 points total

(a)

On the attached potential temperature section, from the North Atlantic at 36°N, indicate the direction of the near-surface flow (upper 100 m) close to the western end of the section, that is, in the Gulf Stream. First note where the Gulf Stream is in this figure (it is not exactly at the boundary).

## 3 points

The Gulf Stream is the very steep plunge of isotherms between 71 and 72W, and it flows northward (into the paper).

Assume it is geostrophic. Explain how you know the direction of the current given the temperature section. Note that this is a VERY narrow feature.

# 4 points

The isotherms slope downward towards the east. The Gulf Stream flows northward at the sea surface, which means that the sea surface height is higher offshore. The sloping isotherms compensate for the surface height slope and, through thermal wind, cause the northward flow to weaken with depth.

## (b)

# 3 points

Sketch the expected sea surface height above this current. (Ignore the large eddies that are east of about 67°W). Sketch would show SSH sloping upward over the same very narrow location as the downward sloping isotherms.

## (c)

Look at the isotherm slopes beneath this surface flow, down to 2000 m depth. Describe what they look like.

## 2 points

## There is almost no change in the slopes down to the bottom.

Sketch the change in the geostrophic current (Gulf Stream) with depth (vertical shear in the geostrophic current), on the vertical section, using our conventional icons for arrows either along the page or in and out of the page.

#### 3 points

Large circle with X at the surface, smaller circles with increasing depth. Source of figure: http://whp-atlas.ucsd.edu/atlantic/a03/sections/printatlas/A03 THETA.jpg



<sup>2.</sup> On the attached Pacific property sections (from DPO 6<sup>th</sup> chapter 4): 25 points

(a) Label the "4 layers" (schematically)

4 points (1 point for each)

Upper layer is the very salty and warm water at the surface. Intermediate layer is the fresh layer beneath this, both N. and S. Pacific Deep layer is best identified by the low oxygen (yellow). Bottom layer is the cold, high oxygen, high salinity water layer extending from southern end of section to the right. (Note that this is the Pacific, where this bottom water is salty. In the Atlantic, it is fresher than the deep water.)

(b) Label the major water masses based on our class examples.

6 points

In the upper layer: Central Water and Subtropical Underwater (or Salinity Maximum Water). In the intermediate layer: AAIW in the south and NPIW in the north (salinity minima) In the deep layer: Pacific Deep Water (low oxygen), and call it either North Atlantic Deep Water or Circumpolar Deep Water in the Antarctic Circumpolar Current (highest salinity) In the bottom layer: Antarctic Bottom Water.

Choose 2 of the water masses from (b).

I'll choose Antarctic Intermediate Water and North Pacific Intermediate Water.

(c) How do you identify each of the two water masses you've chosen?

4 points (2 points for each water mass)

Each is an intermediate depth salinity minimum, AAIW in Southern Hemisphere and NPIW in Northern Hemisphere.

(d) What is the formation history of the two water masses you've chosen? 6 points (3 points for each water mass)

AAIW is formed in the ACC, close to Drake Passage. Low salinity surface water subducts northward beneath subtropical surface waters, forming intermediate salinity minimum. NPIW is formed in the Okhotsk Sea through brine rejection during sea ice formation.

(e) Look up the chlorofluorocarbon section that corresponds to this section. The Pacific hydrographic atlas is located at <u>http://whp-atlas.ucsd.edu/pacific\_index.html</u>. (There are two CFCs: CFC-11 and CFC-12; just use one of them. CFCs in the large area of uniform cyan are below detection limit.) Describe its main features in terms of these water masses and what you know about their age and ventilation history.

The section in this problem is "P16".

5 points

I looked at <u>http://whp-atlas.ucsd.edu/pacific/p16/sections/printatlas/P16\_CFC-11\_final.jpg</u> Simple structure is that it is high in the surrace layer, and unmeasurable (below detection limit) beneath the thermocline in most of the Pacific. The exception is in the ACC, where there are measurable CFC to the ocean bottom south of 55S, with a hint of highest CFCs at the bottom south of the ridge (in the Ross Sea). There is an interesting equatorial structure which suggests perhaps vigorous mixing, or a faster path for ventilated water to the equator than to the tropics on either side.



# 3. Dynamics: Ekman layers

# 20 points

The attached figure is wind stress at the sea surface (from Chapter 5).



(a) In the North Pacific, label the Trade Winds and the Westerlies.2 points (1 point for each)Trade Winds are the dark blue region, Westerlies are the red region in the north.

(b) In the N. Pacific, sketch the direction of Ekman transport in the Trade Winds and Westerlies. 4 points (2 points for each)

Ekman transport is northward in the Trades, and southward in the Westerlies.

(c) Also in the N. Pacific, sketch the direction of Ekman transport along the California coast. 2 points

Along CA coast, Ekman transport is offshore (southwestward).

(d) Calculate the meridional Ekman transport at 40°N: use a single estimate of the wind stress from this map to calculate the local Ekman 'transport' in m<sup>2</sup>/sec (so it won't be exact, but please use an exact expression relating Ekman transport to wind stress). Integrate this very approximately across the full width of the N. Pacific to obtain the total Ekman transport in m<sup>3</sup>/sec.

#### 5 points

1 Estimate 0.1 N/m<sup>2</sup> for wind stress. Reasonable range is OK.

1 The expression for Ekman 'transport' at one location is  $V_{ek} = -taux/(f rho)$ At 40°N, f = 2 omega sin(latitude) = (1.414x10<sup>-4</sup> /sec) (0.64) = 0.90 x 10<sup>-4</sup>/sec 1  $V_{ek} = -(0.1 \text{ N/m}^2)/(0.90 \text{ x } 10^{-4}/\text{sec})*(1025 \text{ kg/m}^3)$ Units 1 N = 1kg m/sec<sup>2</sup>  $V_{ek} = -1.08 \text{ m}^2/\text{sec}$ 

1 Width of N. Pacific at 40°N is about 7000 km = 7 x  $10^6$  m. Reasonable range is OK. 1 V<sub>totek</sub> = -(1.08 m<sup>2</sup>/sec)\*(7 x  $10^6$  m) = -7.6x  $10^6$  m<sup>3</sup>/sec = -7.6 Sv (e) Calculate Ekman transport also at 15°N, as in (d). Integrate this very approximately across the full width of the N Pacific.

5 points, same distribution as for (d) Estimate -0.1 N/m<sup>2</sup> for wind stress At 15°N, f = 2 omega sin(latitude) =  $(1.414x10^{-4} / sec) (0.26) = 0.36 \times 10^{-4} / sec$ V<sub>ek</sub> =  $(0.1 N/m^2)/(0.36 \times 10^{-4} / sec)*(1025 kg/m^3)$ Units 1 N = 1kg m/sec<sup>2</sup> V<sub>ek</sub> = 2.7 m<sup>2</sup>/sec

Width of N. Pacific at 15°N is about 15000 km =  $15 \times 10^6$  m. Reasonable range is OK. V<sub>totek</sub> =  $(2.7 \text{ m}^2/\text{sec})^*(15 \times 10^6 \text{ m}) = 40.5 \times 10^6 \text{ m}^3/\text{sec} = 40.5 \text{ Sv}$ 

(f) Write down the terms in the x- momentum equation that are applicable for Ekman transport.

2 points Coriolis and vertical viscosity

4.

## 20 points

Use the wind curl map here and Sverdrup balance to estimate the transport of the Kuroshio at 30°N. Assume that the wind curl is uniform and equals the maximum value of curl at 30°N. Look at the map of Sverdrup transport from lecture or the textbook to compare with your answer.



Steps:

(i) Maximum curl at  $30^{\circ}$ N is about  $1 \times 10^{-7}$  N/m<sup>3</sup> (dark blue in middle).

2 points.

They can use a range of values from 1 to 1.5 since there is no additional contour inside the 1 contour.

(ii) Ekman pumping vertical velocity is  $w_{ek} = k \cdot curl (tau/(f \cdot rho))$ 

3 points

Ignore variation of f and rho in the derivative, so  $w_{ek} = k \cdot curl(tau) / (f \cdot rho)$ 

I realize this is a tricky step and they might not easily find it. Some might have tried to calculate the full derivative.

(iii) Sverdrup transport is V = (1/beta)\* f \* w<sub>ek</sub> = (1/beta) \* curl(tau)/rho
(the Coriolis f cancels, so just need to calculate beta)
3 points for expression for Sverdrup transport; it's OK to calculate the pieces with f still in them
(see next lines), and more elegant and simpler to realize that f cancels out.

(iv) beta = 2 omega cos (30)/ $R_{earth}$  = (1.414x10<sup>-4</sup> /sec) (0.87)/(6.371x10<sup>6</sup> m) = 0.19 x 10<sup>-10</sup>/m sec 3 points for reasonable value of beta, including correct units.

[If you calculate the Ekman pumping first, here is a value for it:  $w_{ek} = (1 \times 10^{-7} \text{ N/m}^3)/(0.71 \times 10^{-4}/\text{sec})(1025 \text{ kg/m}^3) = 1.4 \times 10^{-6} \text{ m/sec}]$ 

 $V = (1/0.19 \times 10^{-10} / \text{m sec}) * ((1 \times 10^{-7} \text{ N/m}^3)/1025 \text{ kg/m}^3) = 5 \text{ m}^2/\text{sec}]$ 

(v) For total Sverdrup transport southward across 30°N, multiply this by the ocean width of about 10,000 km =  $1 \times 10^7$  m

3 points for choosing reasonable width and understanding that this step is just multiplying (iv) by this width.

(vi)  $V_{totSv} = 5 \times 10^7 \text{ m}^3/\text{sec} = 50 \times 10^6 \text{ m}^3/\text{sec} = 50 \text{ Sv}$ 3 points for the answer, including correct units (1 point).

(viii) This is very similar to the maximum transport shown at the western boundary in the Sverdrup transport map.

3 points for comparison with Sverdrup transport at western boundary at 30N shown on the map.

5. Waves and Tides10 points (2 points per part)

Very long swells generated by a distant storm are observed in the open ocean, which is assumed to be very deep (about 5000 m). Their period is T seconds.

- a. What is the formula for (deep water) surface wave speed c in terms of wavelength L? (This is the phase speed.) c = sqrt(g\*L/2pi)
- b. Rewrite this: what is the wavelength L in terms of wave period T?

C = L/TSubstitute and get T = sqrt(2 pi L / g)

- c. Evaluate the wavelength L if the period T = 20 sec and g = 9.8 m/s<sup>2</sup>. Rewrite again: L =g  $T^2/(2 \text{ pi}) = (9.8 \text{ m/s}^2)(20 \text{ sec})^2/(2 \text{ pi}) = 31.2 \text{ m/sec} = 623 \text{ m}$
- d. Calculate the speed of these waves. Rewrite again:  $c = (gT)/(2 pi) = (9.8 m/s^2)(20 sec)/(2 pi) = 31.2 m/sec$

As these waves pass by, water parcels at the surface carry out circular orbits (forward at the crest, then downward, backward at the trough, then upward).

e. If the wave height (from crest to trough) of these waves is H, what is the diameter D of the orbit? D = H

6. Short answer questions about tides: circle correct answer and draw a diagram to explain. 10 points: 2 points for right answer, 3 points for diagram for each portion

a. Spring tides (times of large semidiurnal tidal range) occur twice a month

- A. when the moon is in the earth's equatorial plane,
- B. when the moon is out of the earth's equatorial plane,
- C. at full or new moon,
- D. at the quarter moons,
- E. at lunar perigee.

Draw a diagram to illustrate your answer.

Here is the diagram from class, which should also include the moon being on the opposite side of earth, lined up with the sun.



b. The daily inequality (elevation difference between a high tide and its immediate successor) vanishes for lunar tides

- A. when the moon is in the earth's equatorial plane,
- B. when the moon is out of the earth's equatorial plane,
- C. at full or new moon,
- C. at the quarter moons,
- D. at lunar perigee.

Draw a diagram to illustrate your answer.

Here is the diagram from class that illustrates the daily inequality, which arises from the moon being out of the earth's equatorial plane. Therefore, when it is IN the plane, there is no inequality.

