Sample answer

EAS4305/6305 **Midterm exam**

Time: 12:00 – 13:15PM, October 25th, 2018
Closed book and **calculator & 1-page (double side) cheat sheet is allowed**

***Write your answers in the blank sheets provided, put page numbers, and when it's finished, staple them together to submit.**

Potentially useful constants and units

1 Sv = 1×10^6 m^3s^{-1}
1 bar = 10^5 Pa = 10^5 Nm^{-2} = 10^5 kg s^{-2} m^{-1}
$g = 9.8$ ms^{-2}
$\rho = 1025$ kgm^{-3}
$c_p = 3{,}900$ $Jkg^{-1}K^{-1}$
R = 6,370 km
$\Omega = 0.7 \times 10^{-4}$ s^{-1}
sin(30°)=0.50
sin(40°)=0.64
sin(50°)=0.77
sin(60°)=0.87

Multiple choice questions (3pts x 10 = 30pts)

1-1 In the southern hemisphere oceans, Antarctic Intermediate Water is typically found in the:
(a) thermostad
(b) mixed layer
(c) dichothermal layer
(d) salinity minimum layer

1-2 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.

1-3 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

1-4 *Surface* wind-driven Ekman circulation in the northern hemisphere is:

(a) directed 45 degree to the right of the wind stress
(b) directed 45 degree to the left of the wind stress
(c) directed 90 degree to the right of the wind stress
(d) directed 90 degree to the left of the wind stress

1-5 Cyclonic flow is

(a) Clockwise
(b) Counter-clockwise
(c) In the same sense as the planetary rotation
(d) In the opposite sense from the planetary rotation

1-6 Below the surface mixed layer, the ocean hardly receives any solar heating, and its circulation is close to *adiabatic*. Which of the following statement is NOT true?

(a) Potential temperature and salinity do not change following the trajectory of the circulation.
(b) Potential temperature and salinity must be constant everywhere along isopcnal surfaces
(c) Water properties are transported along isopycnal surfaces
(d) Isopycnals and isoneutrals both provide useful framework for analyzing the transport of water properties.

1-7 The sense of the atmospheric wind stress over the subtropical ocean is:

(a) cyclonic
(b) anti-cyclonic
(c) clockwise
(d) counterclockwise

1-8 What is the sense of the geostrophic circulation around a low pressure?

(a) cyclonic
(b) anti-cyclonic
(c) clockwise
(d) counterclockwise

1-9 Ekman flow describes the force balance between:

(a) Coriolis and pressure gradient force
(b) Coriolis and gravitational force
(c) Centrifugal force and pressure gradient force
(d) Coriolis and frictional force

1-10 Consider the southern coast of Australia. We can approximate that the coastline is zonal (east-west). Which direction of the wind stress can drive a coastal upwelling there?

(a) Northward
(b) Southward
(c) Eastward
(d) Westward

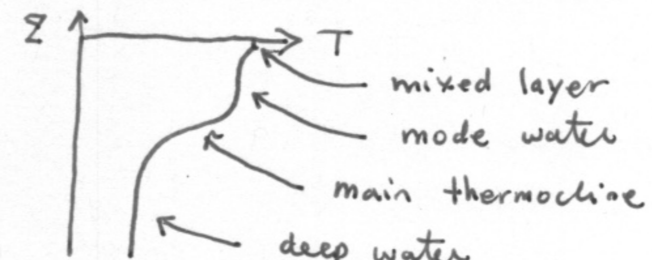
(continue to the next page)

2. Short answer questions (6 pts x 5 = 30 points, answer in ***a few sentences***)

2-1 What is the definition of salinity? What is its unit? What instrument(s) can measure it?

$S = \frac{\text{grams of salt}}{1 \text{ kg of s.w.}}$, psu , CTD instrument or salinometer.

2-2 Draw a typical profile of temperature in subtropical oceans. Define the mixed layer, the mode water, the main thermocline and the deep ocean using your sketch.



2-3 Assume the same magnitude of pressure gradient force. What would happen to the speed of geostrophic current if the planet were spinning twice as fast?

$V_g = \frac{g}{f}\frac{\partial z}{\partial x}$, so if f is twice as large, V_g will be half as strong.

2-4 Coriolis force applies to all moving objects on the rotating planet, but not significantly affect our normal daily activities. Explain the reason we do not feel it, but it dominates the large-scale ocean currents. (hint: what are the Rossby numbers for humans and oceans?)

Rossby number (R_o) is $\frac{U}{fL}$. and if it is much smaller than 1, Coriolis is important. For ocean, $f = 10^{-4} (s^{-1})$, $U \sim 10^{-2} (m/s)$, $L \sim 10^{6} (m)$, $R_{ocn} = 10^{-4} \ll 1$. For a walking person, $f = 10^{-4} (s^{-1})$, $U \sim 10^{-1} (m/s)$, $L \sim 1 (m)$ $R_{human} = 10^{3} \gg 1$.

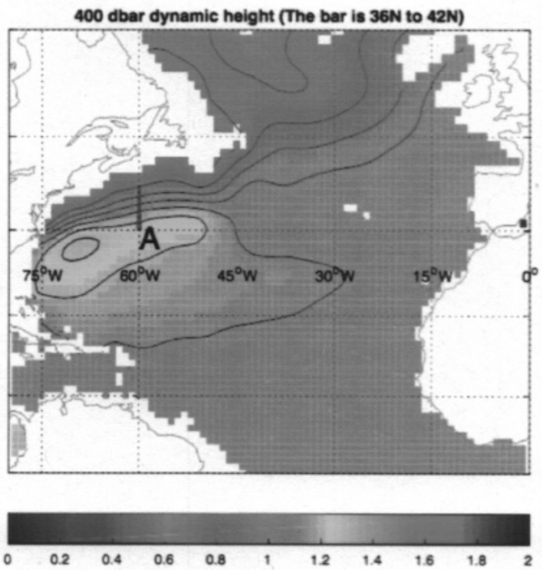
2-5 Explain the reason the Coriolis effect "vanishes" along the equator.

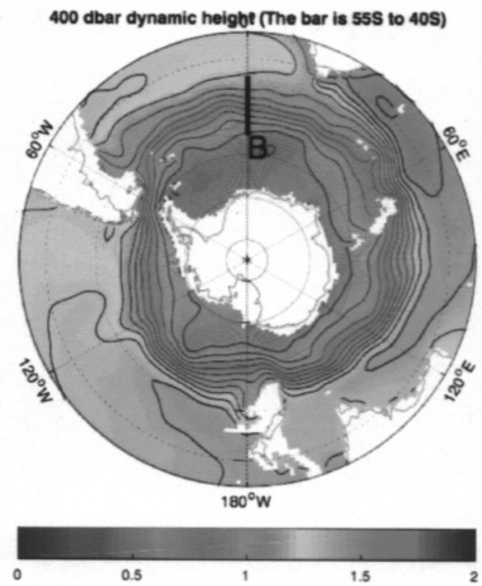
The Earth's rotation vector is perpendicular to the local gravity. Therefore Coriolis effect vanishes in the horizontal force balance.

Or simply $f = 2\Omega \sin\phi = \emptyset$.

3. Long answer question (40 pts)

3-1 Dynamic height and thermal wind The maps below are dynamic height anomaly at 400 dbar level based on the World Ocean Atlas with the 2,000 dbar reference level. Contour interval is set to 0.1m, and the color scale is in the units of m.

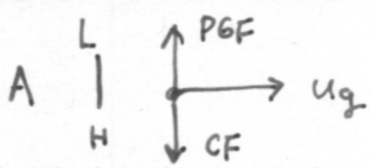




(a, 4 pts). Write the formula for zonal and meridional geostrophic velocity in pressure coordinate.

$$\begin{cases} -f v_g = -g \dfrac{\partial Z}{\partial x} \\ f u_g = -g \dfrac{\partial Z}{\partial y} \end{cases}$$

(b, 4 pts). At the section A, (marked by the east-west line), estimate the direction of the pressure gradient force, Coriolis force, and the geostrophic circulation.



(c, 4 pts). Calculate the speed of the geostrophic current relative to the 2,000 dbar reference level at the section A. The meridional extent of the bar is 36°N to 42°N. Show your calculation.

$u_g = \dfrac{g}{f}\dfrac{\Delta Z}{\Delta Y}$

We have $g = 9.8\ m/s^2$

$f \sim 2\Omega \sin 40° = 2 \times 0.7 \times 10^{-4} (s^{-1}) \cdot 0.64$

$= 10^{-4} (s^{-1})$

$\Delta Z = 0.4 (m)$

$\Delta Y = 6 \times 10^5 (m)$

$u_g = 0.07\ m/s$

(e, 4 pts). At the section B, (marked by the north-south line), estimate the direction of the pressure gradient force, Coriolis force, and the geostrophic circulation.

(f, 4 pts). Calculate the speed of the geostrophic current relative to the 2,000 dbar reference level at the section B. The meridional extent of the bar is 55°S to 40°S. Show your calculation.

$$u_g = \frac{g}{f}\frac{\Delta Z}{\Delta Y}$$

$g = 9.8 \, \frac{m}{s^2}$

$f = 2\Omega \sin 50^\circ = 2 \times 0.7 \times 10^{-4} (s^{-1}) \cdot 0.77$

$= 1.12 \cdot 10^{-4} (s^{-1})$

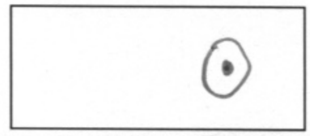
$\Delta Z = 0.7 \, (m)$

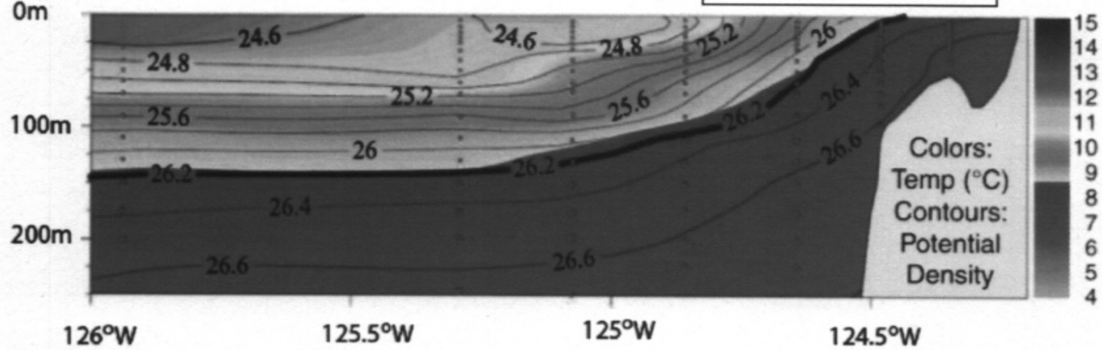
$\Delta Y = 1.5 \times 10^6 (m)$

$u_g = 0.04 \, (m/s)$

3-2 (5pts x 4 = 20pts for 4305; 3 pts x 4 = 12 pts for 6305)

California Current The diagram below shows the zonal (east-west) transect off the coast of California. Solid contours are potential density and the color shading is temperature. It implies the coastal upwelling of relatively cold thermocline water along the California coast. This coastal cooling is driven by the wind-driven Ekman upwelling.



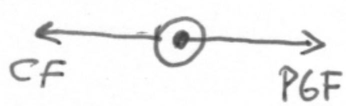


(a) What would be the direction of the atmospheric wind that can cause this upwelling? Draw your answers in the box below. Briefly explain your answer.

Easten boundary upwelling requires southward wind to drive westward Ekman transport, causing the coastal upwelling.

(b) Next, consider the geostrophic current that is in thermal wind balance with this density structure. As a first step, sketch the sea surface height as a function of longitude.

(c) Consider the zonal (east-west) force balance that supports geostrophic currents. What is the dominant balance of forces near the surface? What are the directions of those forces?



(d) Which direction is the geostrophic flow at the surface (east, west, north or south)?

Southward, as shown above.

3-3 (8 pts; extra credit for 4305)

Pacific Ocean Water Masses

The figures below show the hydrographic structure of the central Pacific.

(a) (4 pts) Identify two out of four major water masses as indicated by the circles (#1=yellow, #2=red, #3=blue and #4=grey). For the chosen two water masses, describe their regions of formation, and the formation mechanisms.

#1 Subtropical Mode Water, Kuroshio Extension, Winter mixing

#2 North Pacific Intermediate Water, Okhotsk Sea, Brine Rejection

#3 Antarctic Intermediate Water, Drake Passage, Winter mixing

#4 Pacific Deep Water, mixture of NADW and AABW.

(b) (4 pts) Sketch a T-S diagram with contours of potential density (σθ). Locate each water mass (#1-4) on the T-S diagram.