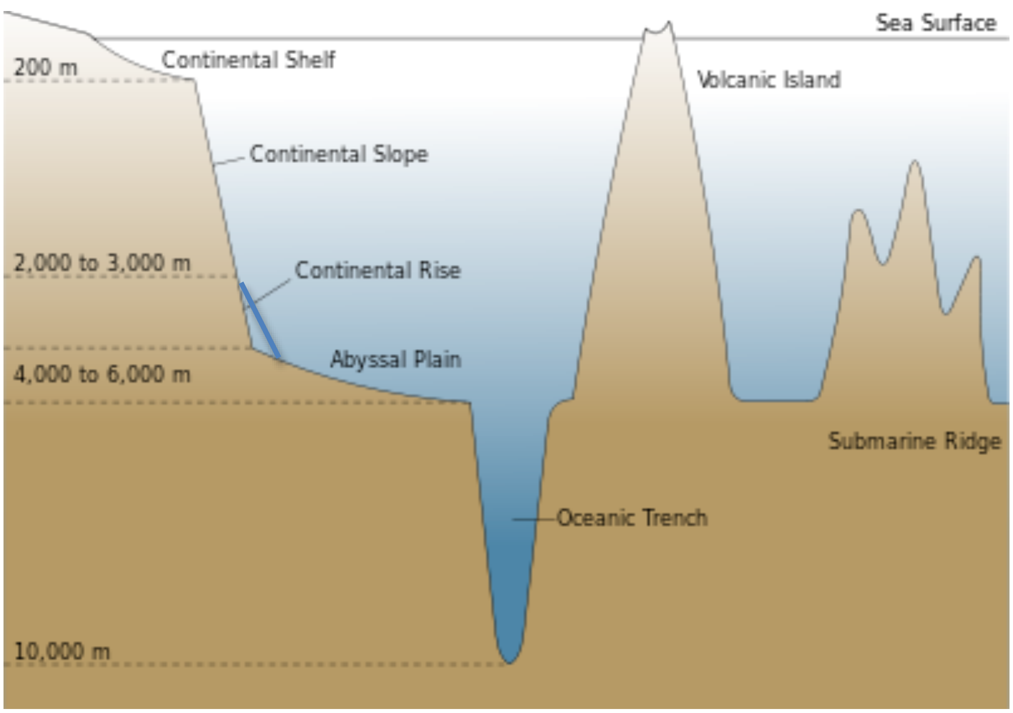
ATOC 5051: Introduction to Physical Oceanography
HW #1: Given Sep 2; Due Sep 16, 2014 Answerkey

Note: you may use any "reliable" resources (peer-reviewed journal articles, books, official websites such as NOAA website, etc.) – in addition to the class materials - to complete this homework. Please list the extra-references (if you have used any) at the end of your homework.

1. Ocean basin and climate (30pts)

1a) Draw a schematic diagram showing the common features of ocean basins; specify the percentage (in volume) that each part roughly occupies. (5pts)
Although each ocean basin varies in its location and size, all oceans have common features. They have continental shelf (7.4% of the ocean volume), continental slope, continental rise (slope+rise 15.9%), and abyssal plain (76.7%) with ridges and trenches. See schematic diagram below.



Schematic diagram showing the common features of ocean basins.

1b) In which ocean is the thermohaline circulation strong? (2pts)
Discuss its basin geometry (including the area, zonal and meridional extent, mean depth) (3pts);
Provide a reason for why you think this ocean favors the thermohaline circulation. (2pts)
The Atlantic. The Atlantic Ocean has a total meridional extent: It extends from the Arctic to Antarctic. Its zonal largest extent, however, spans little more than 8300km from the Gulf of Mexico to the coast of northwest Africa. It has the largest number of adjacent seas. With all its adjacent seas, Atlantic Ocean covers 106 $\times 10^6$ km^2. Its mean depth is 3300m.

The full North-South extent of the Atlantic allows the ocean to extend farther north, where it is cold enough to produce heavier surface water than the subsurface water and thus cause convection and deep-water formation. In addition, sea-ice formation ejects salt, which increases surface salinity and therefore density. This also favors deepwater formation, which is important for thermohaline circulation.

1c) List the names of the major World's oceans; (2pts)
Write down the name of the largest (in area) ocean basin (1pt);
Discuss its basin geometry (3pts);
What major climate mode of variability is this basin associated with, and why? (4pts).

The world's oceans are the Pacific, Atlantic, Indian and Arctic Oceans.
The Pacific Ocean is the largest in size. .

In the tropics, it spans a zonal distance of 20,000 km from Malacca strait to Panama. Its meridional extent between Bering Strait and Antarctic is over 15,000 km. With all its adjacent seas it covers 178×10^6 km^2. Its mean depth is 4270m.

The Pacific Ocean's vast basin size and large zonal extent facilitate air-sea coupling because most region of the ocean is away from the continents; air-sea interaction is the key mechanism for generating the coupled climate variability mode – El Niño and the Southern Oscillation (ENSO).

1d) India and Bangladesh are often plagued by monsoon flood/drought during boreal summer.
Briefly discuss the general features of Indian summer monsoon winds (at the surface) and monsoon rainfall (2pts);
How does the Indian Ocean geographic location and basin geometry contribute to the monsoon formation? (2pts)

The Indian Ocean's northern boundary is located in the tropics. Strong land/ocean heating contrast facilitates the monsoons. During northern summer, land is heated up quicker than the ocean because land has much smaller heat capacity than the ocean. As a result, land is much warmer and its atmosphere is hotter and lighter than that over the ocean. Surface pressure over land is lower than that at the ocean surface. This creates a pressure gradient force that directs from the ocean to land (from high to low), causing the southwest monsoon. As the winds move from ocean to land, it subjects to Coriolis force, which acts to turn the winds toward the right in northern hemisphere. These winds are often referred to as Southwest Monsoon (the winds blow FROM the southwest) or Summer Monsoon, and bring moisture from the Indian Ocean to land, causing surface mass and moisture convergence and therefore producing strong monsoon rainfall – primarily from June to September. [Note: Diabatic heating of the Tibetan plateau is also important for Indian/Asian summer monsoon, and ENSO, etc. can affect monsoon rainfall.]

1e. Discuss the connections of the Arctic Ocean with other World's oceans; (2pts)
Discuss how the Arctic-Atlantic exchange of water/sea ice may affect climate. (2pts)
The Arctic Ocean is connected to the North Pacific Ocean via the narrow and shallow Bering Strait, and to the North Atlantic Ocean via a 1700km wide opening from Greenland across to Iceland, the Faroe Islands and Scotland. Minor openings to the North Atlantic exist through the Canadian Archipelago.

The Arctic Ocean exports fresher water and sea ice to the Atlantic, and the warmer, saltier Atlantic water can enter the Arctic via subsurface.
Sea ice melting/freezing can affect the water property (salinity). The export of Arctic sea ice and fresher water into the North Atlantic can affect the stratification and thus deepwater formation in the Atlantic Ocean, which in turn may influence global thermohaline circulation. On the other hand, the warmer Atlantic water can enter the Arctic, which may affect Arctic sea ice formation and export, and therefore may affect the deepwater formation and thermohaline circulation.
[Note: Sea ice itself may affect albeido and ocean-atmosphere heat flux, which in turn may affect stratification via changing temperature and salinity. This may also affect the thermohaline circulation. – This part is not required.]

2. Observational methods (40 pts)

2a) Assume that you are a physical oceanographer and get funded for two weeks ship time (you can spend two week in the ocean) to investigate the near surface and subsurface temperature and salinity distributions near the Gulf Stream region.

What types of instrument(s) will you bring to the cruise, and how do they measure the temperature and salinity? [Provide detailed discussions for the measurements using your instrument(s).] (10pts)
I would like to bring a CTD, which measures Conductivity, Temperature, and Depth (actually pressure). Temperature is measured using a thermistor mounted close to the conductivity sensor.
Conductivity of seawater depends strongly on temperature, somewhat less strongly on salinity, and very weakly on pressure. If the temperature is measured, then conductivity can be used to determine salinity.
In a CTD, a unit consisting of conductivity (either inductive or capacitance cells to measure conductivity), temperature (thermistor to measure temperature), and pressure sensors is lowered through the water on the end of an electrical conductor cable, which transmits the information to indicating and recording units on board ship. The digital transmitting units have claimed accuracies of 0.005 (conductivity accuracy expressed as equivalent salinity accuracy), 0.005K and 0.15% of full-scale depth. From conductivity, T, and depth, we obtain salinity with depth.

How can you obtain density profiles from your measurements? (3pts)
From the temperature and salinity profiles that I measured, I can calculate density at each depth/pressure level (and thus obtain a profile) using the equation of state below as an example.

At 1 standard atmosphere,

$$\rho(S,t,0) = \rho_w + S(0.824493 - 4.0899\times10^{-3}t + 7.6438\times10^{-5}t^2$$
$$-8.2467\times10^{-7}t^3 + 5.3875\times10^{-9}t^4)$$
$$+S^{3/2}(-5.72466\times10^{-3} + 1.0227\times10^{-4}t$$
$$-1.6546\times10^{-6}t^2) + 4.8314\times10^{-4}S^2.$$

ρ_w is the density of pure water with salinity=0.

2b) On the same cruise, you also want to obtain vertical current profiles (currents as a function of depth). Discuss the methods that you can use for obtaining the current profiles. (12pts)

I would bring an ADCP. The ADCP on board a ship measures currents relative to a moving ship. It sends out an acoustic pulse, which is then reflected back to the ship by particles in the water (such as plankton). The Doppler shift of the returned signal makes it possible to compute the ship's speed relative to the water. There are generally several beams at angles to each other--usually 3-4 beams to determine both speed and direction. Using a 4-element sensor head, an ADCP is capable of resolving both speed and direction of the water movements relative to the sensor. ADCP is originated as Doppler speed logs for ships - to measure the speed of the ship through the water. With very precise information from navigation about the ship's speed, heading, and motion, the ship's motion relative to the earth can be subtracted and the speed of the water measured. By controlling the acoustic beams, ADCP can measure currents at different depths. [Note: WOCE used 150kHz, 75kHZ. ADCP Accuracy: 1-a few cm/s, within 10%. Now in coastal region, some used 1200kHZ ADCP: Accuracy 0.9 cm/s or larger.]

I can also infer geostrophic component relative to the reference depth, using the T,S,P measured above and equation of state to calculate density. Then use geostrophic method to calculate the component current.

2c) What is SOFAR channel, and how is it formed? (5pts)
Provide an example for the use of SOFAR channel to observe ocean currents. (2pts)

Sound speed is a function of temperature and pressure (also salinity to some degree): the higher the temperature, the higher the speed; the higher the pressure, the higher the speed. In most areas of the ocean (tropics, subtropics and mid-latitude), the warm water at the surface and the high pressure at the bottom produce a sound speed profile which is maximum at the surface and bottom, with a minimum in between. This sound speed minimum (near surface at high latitudes to over 1000m in mid- and low-latitudes) is referred to as the SOFAR (SOund Fixing And Ranging) channel, within which sound waves are trapped due to refraction and thus can propagate for a long distance.

Subsurface floats (e.g., SOFAR floats, RAFOS floats) measure subsurface currents within the SOFAR channel. SOFAR floats are sound sources and are tracked by moored receivers, and RAFOS floats receive sound from moored sound sources.

2d. Assume the mixed layer depth is 20 m everywhere in the ocean.
Write down the light attenuation law (2pts);
For clear open ocean water where the light attenuation coefficient $k = 0.02m^{-1}$, what is the percentage of light left at the bottom of the mixed layer? (3pts)
For turbid coastal water where $k = 2m^{-1}$, what is the percentage of light left at the mixed layer bottom? (3pts)

The light attenuation law is: $I_z = I_0 exp(-kz)$,

where I_0 is the ``shortwave radiation'' at the surface, and I_z is the shortwave radiation at depth z, and k is the vertical attenuation coefficient of the water.

For clear ocean water with hm=20m and $k = 0.02m^{-1}$,

$I_z=I_0$ x exp(-0.02*20)=0.67 x I_0=67% I_0

So 67% of light is left at the 20m mixed layer bottom.

For cloudy coastal water with

For hm=20m and $k = 2m^{-1}$,
$I_z=I_0$ x exp(-2*20)=0% I_0

So almost no light is left at the 20m mixed layer bottom.

3. Geostrophic method (15pts)

With the global measurements from ARGO floats, provide a detailed discussion regarding how to calculate the global, geostrophic current maps using "geostrophic method".

ARGO floats provide global measurements of temperature and salinity profiles in the upper 2000m. Gridded ARGO products are available. In order to calculate geostrophic currents, we use the temperature and salinity profiles at two grid points, taking the east-west direction as an example.

The ``geostrophic method" is an indirect way to measure oceanic currents. It calculates the geostrophic current component that is perpendicular to the line connecting a two station pair. The theoretical basis for the geostropic method is that in the ocean interior (away from the surface, bottom, and side boundaries), large-scale ocean circulation obeys geostrophy, which is a balance between pressure gradient force and Coriolis force.

Step 1: Use observed T,S, P derive density ρ and thus $\alpha = \frac{1}{\rho}$ at stations A and B;

Step 2: Calculate Φ from $P(r)$ to $P(z)$ by integrating

$$\Phi = \int_{p(r)}^{p(z)} \alpha dp$$;

Step 3: Calculate geostrophic current

$$V(z) = V(r) + \frac{1}{f}\frac{\partial \Phi}{\partial x} = V(r) + \frac{1}{f}\frac{\Phi_B - \Phi_A}{\Delta x}.$$

We choose 2000m as the level of no motion, where $V(r) = 0$.

4. Observed ocean circulation (15pts).

Alaskan current and stream C
East Kamchatka C

4a. Draw a schematic diagram showing the major ocean gyres of the North Pacific Ocean (north of the equator), and the current systems associated with them (6pts).

Oyashio SPG

STG: NEC, Kuroshio, NPC, California C
SPG: NPC, Alaskan current and stream, East Kamchatka current, Oyashio

Kuroshio NP California C

STG

4b) Draw a schematic diagram showing the equatorial current system (major equatorial currents) of the Pacific Ocean. (4pts)

NEC

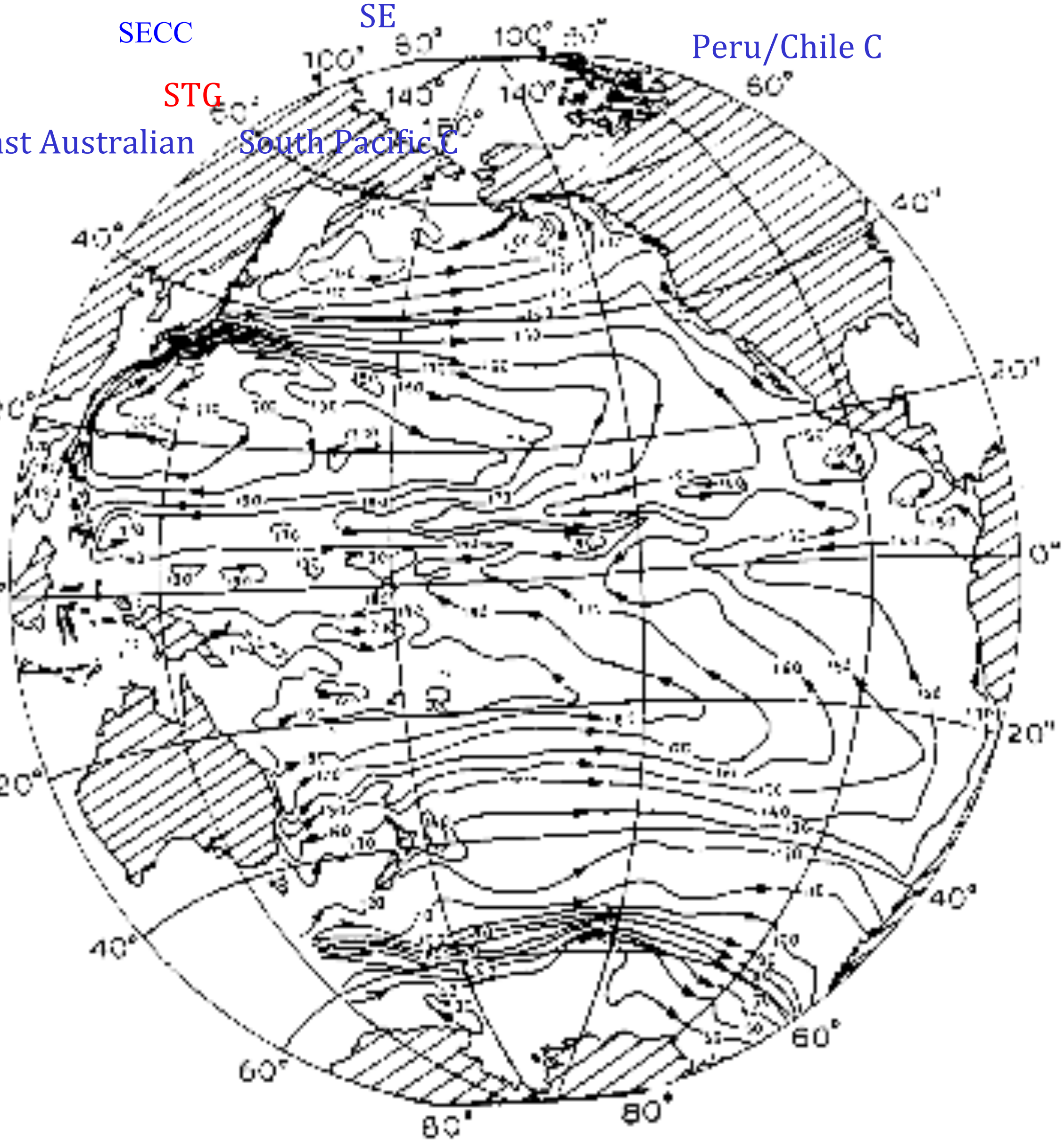
South EQ Current (SEC), North EQ current (NEC), North EQ Counter Current (NECC) or ECC. There is also a South Equatorial Counter Current (SECC) that exists around 2S-5S in the western Pacific basin.

ECC

SECC SE Peru/Chile C

STG

East Australian South Pacific C



4c) Name the current that prevails the Southern Ocean and circulates the globe. (1pt)
Antarctic Circumpolar Current (ACC).

4d. Figure 1 shows 100dbar currents measured by geostrophic method in the North Atlantic. The subpolar Gyre in this figure is much weaker than the directly measured currents at the same depth. Please explain why. (4pts)

In the North Atlantic, currents below 700dbar have significant amplitudes due to the active deepwater formation and mixing. Consequently, current shear is weak. Since geostrophic current (based on geostrophic method) at 100db relative to 700db essentially measures current “shear” between the two levels, we cannot see the SPG circulation. The assumption of level of no motion at 700db is invalid. Additionally, interaction with the Arctic Ocean also obscures the SPG.

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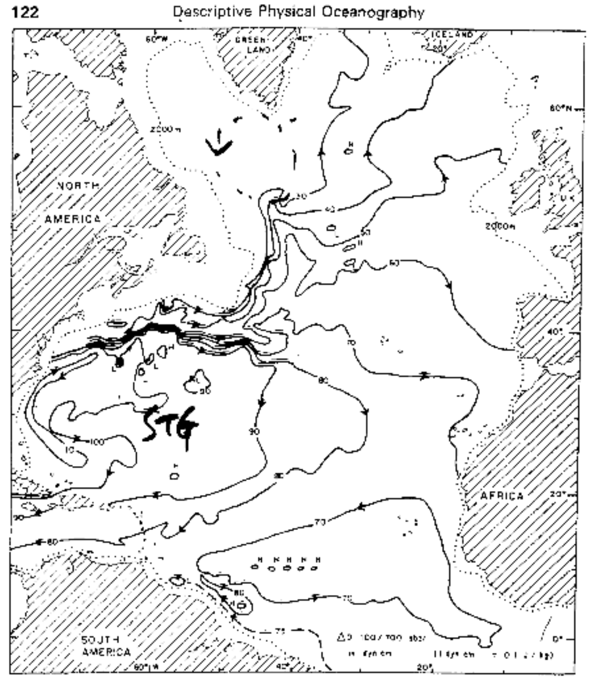

FIG. 6.7. Dynamic topography of 100-dbar surface relative to 700-dbar surface ($\Delta D = 100/700$ dbar) in dyn cm. Atlantic Ocean.