Ocean Circulation - PART- I: In Class. Must be done in-class, and signed off by your TA before you leave to earn full credit.

Ocean Circulation

Activity 1: The Sverdrup

In our homes, we are used to calculated water volumes in terms of gallons.

The SI unit for volume is the cubic meter ($m^3$): $1 \text{ m}^3 = 264 \text{ US gallons.}$

For household quantities, the liter is often used:

$1 \text{ liter} = .001 \text{ m}^3 = .264 \text{ US gallons (1 US gallon} = 3.8 \text{ liters).}$

1. A flow rate of 2.5 gallons/minute represents an efficient shower head, and is now mandated by law, in a home. How many liters per second come out of an efficient shower head? What is that in cubic meters per second?

2. The Columbia River transports about 4,250 cubic meters of water per second during high flow periods. How many gallons per second flow down the Columbia River?

Basin-scale ocean currents transport truly enormous volumes of water, typically tens of millions of cubic meters per second. As a result, oceanographers use the unit Sverdrup (named after a famous mid 20th century oceanographer).

$1 \text{ Sverdrup} = 1 \text{ million cubic meters per second}$

$1 \text{ Sv} = 10^6 \text{ m}^3/\text{s}$

3. At its maximum, the Gulf Stream (which is an intense current in the western North Atlantic ocean) transports about 150 Sv. As it passes the Florida coast, its transport is about 30 Sv. How many gallons per second is 30 Sv?
4. For comparison, all of the rivers in the world put together are about 1 Sv of flow into the ocean. The Mississippi River is about 20,000 cubic meters per second. How many Sverdrups does the Mississippi account for?

Activity 2A: The Effect of Coriolis

1. Draw a (small) sphere and then draw a line from the South to North Pole. The Earth rotates eastward around this axis. It is called the axis of rotation. Above the sphere, draw an arrow to indicate the direction of rotation. Think about how this explains sunrise and sunset.

2. Draw another sphere and draw yourself standing at the South Pole. When viewed from above your head (so imagine someone is above the South Pole, looking down at you), are you turning clockwise or counter-clockwise?

3. Draw another sphere, but put yourself at the North Pole. When viewed from above your head, do you now appear to be turning clockwise or counter-clockwise?
4. Draw a last sphere, and draw yourself standing at the Equator. Draw the Earth’s axis of rotation, and draw an axis from foot to head through the figure at the Equator. This axis represents a local vertical axis at the point on the Earth that you’ve drawn. When viewed from above your head, are you rotating about this local vertical axis clockwise, counter-clockwise or not rotating at all?

Activity 2B: The Effect of Coriolis—This does NOT need to be completed in section.

5. The Coriolis Effect is directly proportional to the magnitude of the rotation rate about the local vertical axis. Where on the planet is the local rotation rate a positive (i.e., counter-clockwise) maximum, a negative (i.e., clockwise) maximum, and locally zero? If maximum positive is given an arbitrary value of 1, and maximum negative is given an arbitrary value of -1, describe (or draw) a relationship that explains how your Coriolis value changes with latitude. Does the value change with longitude, also? What are the coordinates (latitude and longitude) for maximum positive, maximum negative, and zero Coriolis?
Ocean Circulation: PART- II: Homework (does not need to be done in section)

Activity 3: Dynamic Height maps

It is very difficult to measure ocean currents directly over the enormous scales of the ocean basins, but oceanographers can make use of “geostrophy” to estimate currents. Geostrophy represents a dynamical balance between horizontal pressure gradients and the Coriolis Effect (“Geostrophic Balance”). Due to the planet's rotation, this balance has the result that currents flow parallel to pressure contours, and not down pressure contours as they do in your bathtub. From measurements of temperature and salinity, oceanographers can calculate the ocean density and create maps of dynamic height, which approximately show the shape of the sea surface relative to an imaginary level surface. These maps reveal ocean currents, as long as we're not too near to a coastline (where geostrophy breaks down because the effect of friction becomes really important—this is why it doesn’t work in your bathtub, either).

Take a look at the dynamic height map attached to this lab. The units are in m²/s², but if you divide the numbers by 10 m/s², you get approximately the height of the sea surface in meters relative to some level. This (dynamic height divided by gravity, which is approximately 10 m/s²) is also called steric height. Steric height is simply the height relative to an imaginary constant layer, where the water is higher than the imaginary layer because of heating of the water; the heating makes the molecules expand relative to unheated water (so it gets “higher”). What is important in this figure is not the absolute heights, but relative heights. The average sea level can change without significantly modifying the ocean currents, but relative changes in the altitude of a "hill" or "valley" in the sea surface will significantly alter ocean currents. Arrows have been added to the contours to indicate the direction of flow that this map indicates.

Currents have the greatest magnitude where contours are closest together (which indicates the “hills” of water are steeper). In the North Pacific, the North Atlantic, and the Southern Ocean, you’ll find contours that are closely spaced together.

1. Circle and label the California Current, the Gulf Stream, and the Antarctic Circumpolar current on this map. You may want to review Chapter 9 if you aren’t sure where these are.

In each of the ocean basins and in each hemisphere, you'll find a "subtropical gyre", an enormous, basin-scale rotating structure between about 20° and 40° North or South latitude. Subtropical gyres rotate clockwise in the northern hemisphere and counter-clockwise in the southern hemisphere.

2. Circle and identify 4 subtropical gyres on the map.

3. Are these subtropical gyres hills or valleys in the ocean sea surface? About how “big” are they, in meters?
4. Are the hills or valleys found in the center of the ocean basins, near the western edge, or near the eastern edge of the ocean basin?

5. In the southern hemisphere, do the arrows point clockwise around hills or counter-clockwise?

6. In the northern hemisphere, do the arrows point clockwise around hills or counter-clockwise?

7. Why is the rotation different in these two hemispheres? What do you think would happen if the Earth did NOT rotate?

8. Suppose you're on a ship in the North Pacific, and you're interested in seeing this variation in sea surface height. Draw a line on the map from the center of the subtropical gyre in the North Pacific to the center of the "sub-polar" gyre off Alaska. How many meters change in sea surface would you experience en route (i.e. what is the scale of the height variation across the basin)?

9. Is it uphill or down hill?

10. Relative to the ship, roughly what direction is the water moving beneath you at the beginning, middle, and end of your transect (line)?

11. Suppose this ship track covers 5000 km. What is the average slope (slope = rise/run) of the sea surface? Slopes of this (tiny) magnitude in the ocean surface actually indicate that currents beneath transport volumes of water more than a thousand times greater than that flowing down the Mississippi.
Activity 4: Thermal mass of the oceans and atmosphere

YOU MUST WORK INDEPENDENTLY on this activity.

Show your work.

1. Given that the volume of the oceans is $1.5 \times 10^{18}$ m$^3$ and the density is 1024 kg/m$^3$, what is the mass of the oceans in kg?

2. Given that the specific heat of seawater is 4000 Joules/(kg°C) [in other words, it takes 4000 Joules of energy to raise 1 kg of seawater 1°C], how many Joules (SI unit of energy) does it take to raise the temperature of the entire ocean by 1°C?

3. A similar calculation can be done for a simplified atmosphere, given that the mass of the atmosphere is $5.1 \times 10^{18}$ kg and that the specific heat of dry air is 1000 Joule/(kg°C). How many Joules does it take to raise the temperature of the atmosphere by 1°C? What percent of the energy required to raise the ocean by 1°C does this represent?

4. Does the ocean store more heat than the atmosphere? How many times more?

5. If the ocean climate were not changing, the heat fluxes into and out of the ocean would be equal (flux simply means a rate—so heat flux means a rate of heat gain or loss for an arbitrary area, during an arbitrary time). Let’s suppose that these fluxes are slightly out of balance and that, of the 342 W/m$^2$ (1 Watt = 1 Joule/s) that reaches the upper atmosphere, 4 W/m$^2$ (about 1%) contributes to warming the oceans. If a heat flux of 4 W/m$^2$ covered the $3.6 \times 10^{14}$ m$^2$ ocean surface and contributed only to a change in temperature (not latent heat), how many years would it take to raise the average temperature of the oceans 1°C?
Figure 1. Dynamic height (m$^2$/s$^2$) or steric height multiplied by gravity, for the world ocean at 0 m relative to 2000 m. Arrows indicate the direction of the implied movement of water. (Divide contour values by 10 to obtain approximate steric height in m.) From Levitus (1982) as drawn in Tomczak & Godfrey (2002).