Objectives

In this lab we will investigate how variations in (1) seawater temperature and (2) salinity play a role in establishing vertical circulation of the ocean. We will also examine the details of how evaporation and the formation of ice affect water salinity and density. Then, we will demonstrate that surface water mixing causes a change in density and, therefore, also plays a role in the vertical circulation of the ocean. At the end of this lab, you should be able to:
- distinguish between surface and deep-ocean circulation and their driving forces;
- identify factors that affect seawater density;
- understand how changes in density lead to the development of vertical motions;
- describe how seawater salinity and temperature varies with latitude and depth of the oceans;
- understand the impact that ocean circulation has on climate and understand the basics of how human activity can influence ocean circulation.

Theoretical Background

When compared to the Atmosphere, the structure of the Ocean seems very stable. The ocean is heated by the Sun from above, so the warmest waters are usually at the ocean’s surface (at the top of the water layer), while the coldest and most saline waters are located on the ocean floor (at the bottom of the water layer). Therefore, external forces are required to start the vertical motion of ocean waters.

**Surface** current are driven by the wind and modified by the rotation of the Earth, the presence of shorelines, and some other factors. These currents resemble rivers because they can be either colder or warmer than the surrounding ocean waters and don’t mix with them. Further, surface currents move only the upper several hundred meters of the ocean. The best known example of a surface current is the Gulf Stream which brings warm water from the tropics to the north of Europe. There are more than 50 important currents in five of the Earth’s oceans (the Pacific, Atlantic, Indian, Southern and the Arctic Oceans).

**Deep-ocean** circulation occurs on a much longer time scales than surface currents. It takes around 1000 years for deep water to go around the ocean’s **conveyor belt** (another name for deep-ocean circulation). Deep-ocean is driven by changes in water density due to variations in salinity and temperature; because of this, it is sometimes referred to as Thermohaline circulation (**halinos** means salt in Greek). These density changes are subtle, but very important.

Deep-ocean circulation starts with the production of dense (cold and salty) water at high latitudes, which is a result of the sea-ice formation. This dense water sinks to the bottom of the
ocean, while less dense water replaces it at the surface, as required by conservation of mass principle. The world map with a diagram of Thermohaline circulation is shown in Figure 1.

![Thermohaline Circulation](http://en.wikipedia.org/wiki/Image:Thermohaline_Circulation_2.png, Robert Simmon, NASA. Minor modifications by Robert A. Rohde)

**Figure 1. Diagram of deep-ocean circulation**

**Salinity.** The term *solution* refers to a mixture of one substance, *solute*, that is uniformly distributed within another substance, called *solvent*. A the solute is usually some kind of solid substance, for example sugar or table salt, and the solvent is a liquid, most often pure water.

The density of the solution usually increases as the amount of dissolved solids increases because the total mass increases without a proportional increase in the volume of the solution.

In Oceanography, the salinity describes how much dissolved salts are contained in the ocean water. In these laboratory experiments salinity will be measured as Total Dissolved Solid (TDS). This quantity represents the ratio of the mass of solute $m$ (total amount of salt) to the mass of solvent (pure water) $m_0$:

\[
TDS = \frac{m}{m_0} \text{[‰]},
\]

TDS is usually reported in units of parts per thousand (denoted as ppt or ‰). Sometimes alternative units are used, for example g/L or Practical Salinity Scale units (abbreviated as PSS or PSU). The latter is determined based on conductivity of the water sample and is close in value (but not exactly the same) to the ppt units. Ocean salinity varies between 30 and 40 PSU in different parts of the World Ocean and is higher in the internal seas with little river runoff,
like the Mediterranean, and in subtropical areas with low precipitation and high evaporation (values of salinity are shown as color shading in Figure 1).

The salts in the ocean water are mostly NaCl (sodium chloride or table salt), with small amounts of Magnesium, Potassium, Sulfur, Calcium, Bromine and several other ions. The amount of dissolved salts is almost constant over the oceans, while the amount of solvent (pure water) can vary due to evaporation, precipitation, the formation and melting of ice, and the addition of low-salinity water by continental runoff, as illustrated in Figure 2.

Figure 2. Processes that affect seawater salinity: evaporation and precipitation, sea ice formation, iceberg melting, river runoff.

**Temperature.** Temperature is another parameter that determines the density of water, and therefore plays an important role in deep-water circulation. Unlike salinity, temperatures are much easier to measure. Surface water temperature can be determined remotely by satellite (sea surface temperature, or SST) via measuring the amount of infrared radiation emitted by water.

In different parts of the World Ocean temperature of surface water changes more significantly than salinity– it can be lower than 0 °C in polar areas and as warm as +30 °C at the equator. Deep water temperatures are low at all latitudes, and range between 0 °C and +5 °C.

**Online exercises/activities**
Experiment Setup

Using the TDS meter to measure the salinity:

![TDS-meter and probe](image)

Figure 3. TDS-meter and probe. Two stainless steel stripes at the end of the probe are to be completely submerged into the liquid.

To measure the Total Dissolved Solids in ppm or ppt:
1. Rinse the probe with de-ionized or distilled water. Shake the probe carefully to remove the water.
2. Turn the TDS-meter on by pressing the “ON OFF” switch. The screen will show several constants/parameters used for measuring, then all LCD segments will light up for 2 seconds, and then TDS-meter will change to measurement mode.
3. You are now ready for TDS measurements.
4. To measure the salinity of your solution, pour it into a 50 ml beaker, tilt it and carefully immerse the probe. Make sure the two stainless steel stripes at the end of the probe are completely submerged into the solution. Wait for ~30 seconds for the measured value to and the range to stabilize.
5. To switch between TDS and Temperature measurements press “MODE” button.
6. After taking the measurements, turn the TDS-meter off by pressing the “ON OFF” switch and rinse the probe with de-ionized or distilled water.

*Be very careful with the probe. It is fragile!*
*Do not hit the probe against anything to remove the water!*
**Safety precautions**

There are several things to remember in order to stay safe during this lab:
- Handle the glass beakers, thermometers and the TDS-meter probe with care.
- There should be no water spills on the table where the equipment is set up. Clean all spills immediately.
- The electric bulb used in the experiments can get very hot during the operation, so make sure not to touch it.
- Turn off the bulb as soon as you are done with your measurements. Do not leave it on unattended.
- Water used for the experiment in Part 2 can be hot and can cause burns if spilled on the skin. Pour the water from the electric kettle slowly and carefully.
- Check the Styrofoam cups before the experiment – look if they are in good condition with no cracks or holes. If your cups are in poor condition, let the lab instructor know immediately.

**Sequence of Procedures:**

**Part 1: Setting up the experiments for the effects of Evaporation and Ice Formation on Salinity**

1. Record the mass of the clean, dry 200-ml beaker. Pour 100 ml of pure water into the 200-ml beaker. Use the electronic scales to get the exact weight of the water (remember you should subtract the mass of the empty beaker). Record the exact mass of water used in Table 4 on the page 16 of this lab manual. (Note: the water should be deionized or distilled, i.e. should not contain any dissolved solids).
2. Weigh out about 4 grams of salt using the electronic scales. Record the exact mass of salt.
3. Add the salt to the water and stir until the salt is completely dissolved. Calculate the concentration of the salt solution (g/L).
4. Measure the TDS of the prepared solution by using the TDS-meter (refer to page 4 on the TDS measurements). Record the value in Table 4.
5. Pour about half of the solution into the provided Petri dish.
6. Place the lamp ~ 10-15 cm above the Petri dish and turn the lamp on. Record the evaporation start time in Table 4. Come back to check on the condition of the setup in 20-30 minutes. If a noticeable amount of water has evaporated, stop the experiment and proceed to Part 4.
7. Pour the remaining salt solution into a 50-ml beaker. **Note: use only the glass beaker!** You need to use the glass beaker in order to accelerate the heat exchange through the walls, and thus accelerate freezing.
8. Put a label on the beaker and sign it to distinguish from the other team’s beakers.
9. Measure the temperature and TDS using the TDS-meter and record the values in Table 5 on the page 16 of this lab manual.
10. Give the beaker to your lab instructor who will put it into the freezer for about 30 min to one hour. Periodically check the beaker – if thick ice has formed in the surface, stop the experiment and proceed to Part 5.
Part 2: The Effect of Temperature on Water Density

Procedure:
1. Fill the tank with ~11-12 cm of room temperature water. Measure the temperature of the water and record it in the Table 1 below.
2. Prepare ice water by adding ice to a beaker with tap water.
3. Fill a Styrofoam cup half-full with the ice water. Add green food coloring and stir until it reaches a dark shade of green (~5-10 drops). Record the temperature and color of the ice water in Table 1.
4. Fill another Styrofoam cup half-full with hot water (~65-75°C). Add red food coloring and stir until it reaches a dark shade of red (~5-10 drops). Record the temperature and color of hot water in Table 1.
5. Draw some colored ice water into the syringe. Place the tip of the tubing just beneath the surface of the water in the tank and slowly add the cold water to the tank. Record your observations.
6. Again, draw some ice water into the syringe. Place the tip of the tubing near the bottom of the tank and slowly add the cold water to the tank. Record your observations.
7. Rinse out the syringe with tap water. You will need to do this each time you change solutions (colors).
8. Repeat steps 5 and 6 with the colored hot water.
9. **Do not stir up the tank.** Observe distribution of colors and write down your observations.
10. Carefully empty the tank and rinse it out with tap water.

Figure 4. Setup for the experiment Part 2.
Table 1.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature, °C</th>
<th>Color</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Added to top of the tank</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Added to bottom of the tank</td>
</tr>
<tr>
<td>Tank water</td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Ice water</td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Hot water</td>
<td></td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

Questions:

**Question 1.** Describe what you observed in your experiment after you added colored ice water to the top of the tank. (2 pts).

**Question 2.** Describe what you observed in your experiment after you added colored ice water to the bottom of the tank. (2 pts).

**Question 3.** Describe what you observed in your experiment after you added colored hot water to the top of the tank. (2 pts).

**Question 4.** Describe what you observed in your experiment after you added colored hot water to the bottom of the tank. (2 pts).
Question 5. Explain, why was the colored water moving in your experiment? (2 pts).

Question 6. What basic physical concepts and principles were driving the motion of the water in your experiment? (2 pts).

Question 7. How does temperature affect the density of the water? (2 pts).

Question 8. Think about surface water temperatures and densities at the equator and at the polar areas. Where do you expect to find sinking and where - rising motions? (2 pts).

Part 3: The Effect of Salinity on Water Density

Procedure:
1. Fill the tank with ~11-12 cm of room temperature water.
2. Fill a 100 ml beaker with ~ 95 ml of room temperature water.
3. Weigh out 4 grams of table salt (NaCl). Record the exact mass of the salt in Table 2.
4. Add the salt to the water and stir until the salt is completely dissolved.
5. Determine the density of the prepared salt solution by measuring its mass and exact volume.
   a. Pour the solution into a 100 ml graduated cylinder. Measure and record (in Table 2) the exact volume by looking at the bottom of the meniscus when the meniscus is at eye level.
   b. Record the mass of the clean, dry 100-ml beaker. Pour the solution into the beaker and record the exact mass of solution in Table 2. Don’t forget to subtract the mass of the empty beaker.
   c. Calculate the density of the solution. Remember that density is a measure of the mass per unit volume, g/cm³.
6. Measure the salinity of the prepared solution by using the conductivity/TDS meter. Refer to page 4 on the TDS measurements. Record the value in Table 2.
7. Add green food coloring to the solution while stirring, until it reaches a dark shade of green. Record the color in Table 2.
8. Prepare a saturated salt solution. Start with a 100-ml beaker of room temperature tap water and slowly add table salt. Stir the table salt into the water, and continue stirring and adding salt until no more will enter the solution.
9. Add red food coloring to your saturated salt solution.
10. Measure the density and salinity of the saturated solution. Refer to steps 5-6 above. Record your data in Table 2.
11. Fill the syringe with ~30 ml of the 4g salt solution. Place the tip of the tubing just beneath the surface of the water in the tank and slowly add the salt solution to the tank. Record your observations in Table 2.
12. Rinse out the syringe and then refill it with ~30 ml of the saturated salt solution. Place the tip of the tubing just beneath the surface of the water in the aquarium and slowly add the salt solution to the tank. Record your observations in Table 2.
13. Observe the movement of the water. Keep observing until all the water movements stop completely.
14. Measure the TDS (total dissolved solid) at the water surface, and then at 2 cm, 4 cm, 6 cm, and 8 cm below the surface by using the conductivity/TDS meter. Record your results in Table 3. Your TA will provide instructions on how to use meter. Rinse the TDS probe with clean water after taking your measurements. Be careful with the probe. Do not shake the probe to remove the water!

**Table 2 [5 points]**

<table>
<thead>
<tr>
<th>4g salt solution</th>
<th>saturated salt solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of salt, g</td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td></td>
</tr>
</tbody>
</table>

**Density and salinity determination:**

<table>
<thead>
<tr>
<th>Volume of solution, cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of solution, g</td>
</tr>
<tr>
<td>Density, g/cm³</td>
</tr>
<tr>
<td>Salinity (TDS-meter) ppt</td>
</tr>
</tbody>
</table>

**Observations (when solution was added to the tank)**

**Table 3 [5 points]**

<table>
<thead>
<tr>
<th>Depth, cm</th>
<th>TDS, ppt</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (surface)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>
Questions:

Question 9. Based on what you have observed in your experiment, how does the density of the 4g salt solution differ from the pure water density? (2 pts).

Question 10. Based on what you have observed in your experiment, how does the density of the saturated saline water differ from the density of the 4g salt solution? (2 pts).

Question 11. Where did saturated saline water end up at the very end of the experiment? (2 pts).

Part 4: The Effect of Evaporation on Salinity

Procedure (continued from page 5):

1. Rinse and dry a 50-ml beaker. Pour the solution from the Petri dish into the 50ml beaker. Record the evaporation stop time in Table 4. Rinse the Petri dish.
2. Give the solution some time to cool down to room temperature if it’s hot. Measure the TDS of the solution using the conductivity/TDS meter. Record the value in Table 4.

Questions:

Question 12. What can be inferred from your experiment about the effect of evaporation on the salinity of the water? (2 pts).
Question 13. Where does the salt go during the process of evaporation? (2 pts).

Question 14. Compare the salinity of rainwater and ocean water. (2 pts).

Question 15. In some location, where evaporation/precipitation balance have changed so evaporation is now higher than precipitation, will the salinity of the ocean increase or decrease? (2 pts).

Question 16. Given that the salinity of ocean water is highest at the surface in the tropics, what can be inferred about the evaporation in tropics? (2 pts).

Question 17. Besides increasing the salinity, in what other way does the evaporation effect the solution? (2 pts).
Part 5: The Effect of Ice Formation on Salinity

Procedure:

1. Remove your salt solution from the freezer (at this point it should have stayed in the freezer for at least 30 minutes). Break the surface layer of ice and decant the liquid into a clean 50ml beaker. **Let the solution warm up to room temperature.**
2. Measure the temperature of the liquid. Next, measure the salinity by placing the TDS probe inside the beaker. Record the values in Table 5 on page 16.
3. **Carefully rinse the TDS probe and all the glassware used in your experiments.**

Questions:

**Question 18.** What can be inferred from your experiment about the effect of ice formation on the salinity of the water? (2 pts).

**Question 19.** Where does the salt go during the process of ice formation? (2 pts).

**Question 20.** How does formation of surface ice in the Arctic and Antarctic oceans contribute to deep-ocean circulation? (2 pts).

**Question 21.** If global warming were to increase the temperature of the Earth such that Greenland glaciers would melt, how would this affect deep-ocean circulation? (2 pts).
Part 6: Temperature-Salinity Diagram, Surface Water Mixing


Procedure:

1. Examine the Temperature-Salinity (T-S) Diagram shown in Figure 5 below. Temperature is plotted along the vertical axis in degrees Celsius. Salinity is measured along the horizontal axis in parts per thousand (‰) or numerically-equal Practical Salinity Units (PSU). Seawater density (g/cm³) is shown on the diagram by curved lines of constant density. The value of each curved line appears immediately above each line. Note that temperature and salinity together govern the density of seawater.

2. On the T-S Diagram, each seawater sample is plotted as a dot at the point determined by its temperature and salinity. Find the temperature and the salinity for two surface seawater samples labeled “A” and “B”, and record these values in Table 6.

3. The density of seawater samples must be determined to several decimal places in order to detect significant differences. Read from the T-S Diagram the densities for the two surface seawater samples labeled “A” and “B” to the fourth decimal place. Record these values in Table 6. Note that their densities are the same, even though their temperatures and salinities are different.

4. If samples of the same density are brought together, they tend to mix. The temperature and salinity of the resulting mixture are somewhere between the temperatures and salinities of the original waters prior to mixing. On the T-S Diagram, draw a straight line between the points representing samples “A” and “B”. Any possible mixture of these seawater samples, including sample “C”, would be represented by a point falling somewhere on the straight line, connecting A and B.

5. Find and record in Table 6 the temperature and salinity of a water sample “C” that would result if equal volumes of samples “A” and “B” were mixed together. (Hint: Mixing one liter of 10°C water with one liter of 30°C water produces two liters of water at 20°C).

6. Plot the new sample “C” on the T-S Diagram.
Figure 5. Temperature-Salinity diagram. Your graph on this figure will be worth **5 points**.

**Questions:**

**Question 22.** According to the T-S Diagram, the density of sample “C” is (choose one from the following and circle the letter that best corresponds to your answer) (2 pts):

A. $1.0265 \text{ g/cm}^3$
B. $1.02675 \text{ g/cm}^3$.
C. $1.02725 \text{ g/cm}^3$.
D. $1.0275 \text{ g/cm}^3$.
E. $1.02775 \text{ g/cm}^3$.
F. $1.0280 \text{ g/cm}^3$.
G. $1.02825 \text{ g/cm}^3$. 
Question 23. Comparison of the seawater densities recorded in Table 6 shows that the density of sample “C” is (choose one from the following and circle the letter that best corresponds to your answer) (2 pts):

A. Less than the density of samples “A” and “B” prior to mixing.
B. Equal to the density of samples “A” and “B” prior to mixing.
C. Greater than the density of samples “A” and “B” prior to mixing.

Question 24. Regardless of the relative volumes of seawater samples “A” and “B” mixed together, the T-S Diagram shows the resulting mixture will always be (choose one from the following and circle the letter that best corresponds to your answer) (2 pts):

A. Denser than either “A” or “B”.
B. Less dense than either “A” or “B”.

Question 25. Any resulting mixture of these original samples will (choose one from the following and circle the letter that best corresponds to your answer ) (2 pts):

A. Remain at the ocean surface.
B. Sink.

Question 26. This investigation shows that mixing surface seawaters of the same density, but different temperatures and salinities, produces seawater of (choose one from the following and circle the letter that best corresponds to your answer ) (2 pts):

A. Greater density.
B. Equal density.
C. Lesser density.
Part 7: Mixing at the strait of Gibraltar

Procedure:
The Strait of Gibraltar, where the Mediterranean Sea and the Atlantic Ocean meet, is a place where different masses of water are forced to mix due to the mechanical mixing (Figure 6). For the provided temperatures and salinities in Table 7, determine the densities of the Atlantic and Mediterranean waters, and the density of the waters that would form as the result of mixing the Mediterranean and Atlantic waters. Use the Temperature-Salinity Diagram and record the obtained densities in Table 7.

Questions:

**Question 27.** Predict what would happen to water that moves from the Mediterranean Sea into the Atlantic Ocean. (2 pts):
Table 4 (5 points)

<table>
<thead>
<tr>
<th>Volume of water (L)</th>
<th>Mass of salt (g)</th>
<th>Concentration of solution (g/L)</th>
<th>TDS before evaporation (‰)</th>
<th>Evaporation Start Time</th>
<th>Evaporation Stop Time</th>
<th>TDS after evaporation (‰)</th>
</tr>
</thead>
</table>

Table 5 (4 points)

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>TDS (Salinity) (‰)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td></td>
</tr>
<tr>
<td>Step 4</td>
<td></td>
</tr>
</tbody>
</table>

Table 6 (3 points)

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Salinity (‰)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7 (3 points)

<table>
<thead>
<tr>
<th>Sample temperature (°C)</th>
<th>Sample salinity (‰)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mediterranean side</td>
<td>15</td>
<td>34.89</td>
</tr>
<tr>
<td>Atlantic Side</td>
<td>5</td>
<td>34.15</td>
</tr>
<tr>
<td>Mixture</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions on the lab

1. Based on what you learned in this lab, draw a diagram that depicts ocean water salinity change with depth in the polar areas of Atlantic Ocean, where the surface ice formation is taking place (3 pts.)

2. On the same diagram, add a graph that depicts ocean water salinity change with depth in the subtropics. Label your graphs. (3 pts.)