Homework 5: Background
Ocean Water Properties & Stratification

The ocean is a heterogeneous mixture of water types - each with its own temperature, salinity, and density (Figure 5-1).

![Figure 5.1](image)

The density of a particular water type is determined by its own values of temperature and salinity. The density of a water type increases when either its salinity increases and/or its temperature decreases (see Figure 5.2).

When two water types with different densities come together, the more dense water type sinks relative to the less dense water type; and spreads out horizontally into layers. In the process of seeking their appropriate depth, adjacent water types mix with each other to form a whole range of water types with intermediate densities. Water types with intermediate densities occupy layers between those which are more and less dense.
respectively. The resulting suite of water types is called **water mass** because its properties are similar and related through mixing.

![Diagram of Temperature vs. Salinity](image)

**Figure 5.2** the dependence of sea water density on temperature and salinity change

The extensive horizontal layers of waters within a particular water mass and the ocean in general are said to be *stably stratified*; with the more dense water layers underlying the less dense water layers. The greater the difference in densities in two adjacent layers, the less the layers mix. These relations are explored next for temperature, salinity, and density respectively.

### 5-1. OCEAN TEMPERATURE

The sun is the major source of heat energy for the oceans, directly heating the surface layer. Because the incoming solar radiation is more direct and concentrated at the lower latitudes, tropical surface waters are considerably warmer (and less dense) than in much of the world’s oceans. While less extreme, subtropical ocean water properties in the mid-latitudes are similar to those in the tropics. The Figure 5-3 profile of temperature versus depth (typical of that in the tropics and subtropics) shows three distinct temperature zones. The warmer **upper zone** and the colder **lower zone**, which are characterized by gradual declines in the temperature with depth, are separated by the **thermocline** zone, which is characterized by larger changes in temperature with depth.

Tropical ocean temperature profiles exhibit particularly strong thermal stratification all year because the less dense warm surface water contrasts strongly with the continually refreshed deeper cold, denser polar waters.
Figure 5-3. This generic oceanic temperature profile for the tropics and subtropics shows that (a) ocean water temperatures decrease more gradually with increased depth in the warmer upper zone layer and the colder lower zone layers; and (b) ocean water temperatures decrease more strongly with increased depth in the thermocline zone, where the slope of the temperature profile or temperature gradient is largest.

5-2. OCEAN SALINITY

Because there are exceptional amounts of rainfall in the tropical ocean, tropical surface waters tend to be fresher (and less dense) than in many places in the world’s oceans. While less extreme, subtropical ocean water properties in the mid-latitudes are similar to those in the tropics.

Salinity is a measure of the quantity of salts dissolved in specified volume of water – the more salt the denser the water. The salinity units are expressed in parts per thousand (abbreviated PPT or ‰), which means number of grams of dissolved salts in 1000g (= 1 kilogram or 1 kg) of sea water. For example, a sample of seawater with a salinity of 20‰ means that a kilogram of the seawater sample would consist of 20g of salt and 980g of pure water (with S = 0‰). The percentage of salt in this sample is 20g /1000g x 100 or 2%. Of course, this particular seawater sample is 98% pure water.

Since fresher water is less dense than saltier water, the salinity of ocean waters tends to be less near the surface (upper zone in Figure 5-4) than at depth (lower zone). Ocean mixing processes tend to concentrate the salinity changes in the halocline which lies between the upper and lower zones. Typical salinity profiles (Figure 5-4) generally exhibit three distinct zones. The least dense upper zone and most dense lower zone, which are marked by more gradual changes with depth, are separated by a halocline zone in which salinity (and hence density) increases more rapidly with depth. The thickness of the halocline zone varies with the amount of mixing between the upper and lower zones - the greater the mixing, the thicker the halocline zone. Most rapid temporal changes in salinity occur in the upper zone because it is strongly influenced by variability in river flow, rainfall and wind effects. The temporal variability of the salinity is generally much less in the other zones.
Figure 5-4. This generic oceanic salinity profile for the tropics and subtropics shows that (a) ocean water salinities increase more gradually with increased depth in the warmer upper zone layer and the colder lower zone layers; and (b) ocean water salinities increase more strongly with increased depth in the halocline zone, where the slope of the salinity profile or salinity gradient is largest.

The salinity in the open ocean varies from about 33 to 37 ‰. However, in the coastal ocean near, where fresh water from rivers is most prevalent, salinities tend to range from that of fresh water (S ~ 0‰) to about 32‰. Salinities are also low in regions where there is considerable ice melt and/or large amounts of rain fall. Conversely in confined seas, such as the Dead Sea, the salinities may range as high as 72‰ - because the fresh water part of the water evaporates and is not replaced rapidly.

5-3. DENSITY AND WATER STRATIFICATION

The variability in the density of sea water is controlled principally by the variability in the temperature; and to some extent by the variability in its salinity. Because seawater density increases with increasing salinity the Figure 5-5 profile looks like the salinity profile in Figure 5-4 – and consistent with our typical temperature profile in Figure 5-3.

The Figure 5-4 density profile three zones consistent with those of the tropical and subtropical temperature and salinity profiles above. The high vertical density gradient zone in this case is called the pycnocline zone. The corresponding generic profiles in the polar regions look rather different as discussed next.

Polar ocean water property distributions are unique. Polar surface (and deep) waters are much colder (and more dense) than tropical waters because they are (1) warmed less by a less direct and less concentrated incoming solar radiation, as well as (2) cooled by cold winds off the continents. Thus very cold, dense surface water forms leading to repeated episodes of sinking of cold water (ocean convection). The mixing associated with the convective mixing produces a water mass with the nearly the same temperature and thus isothermal. This massive deep water mass fills the deep ocean basin everywhere. These processes are reflected in the temperature versus depth graphs or temperature profiles that are presented next.
Figure 5-5. This generic oceanic density profile for the tropics and subtropics shows that (a) ocean water densities increase more gradually with increased depth in the warmer upper zone layer and the colder lower zone layers; and (b) ocean water densities increase more strongly with increased depth in the pycnocline zone, where the slope of the density profile or density gradient is largest.

These observations are summarized in the Figure 5-6 vertical section of density stratification extending from the northern polar ocean (left) to southern polar ocean through their respective temperate and tropical regions. The surface zone is seen to extend downward to a maximum depth of about 100 meter at latitudes of about 30° north (30°N) or south (30°S) of the equator. This zone contains only 2% of the ocean volume and is well mixed by winds, waves and currents. Much of the oceanic biology in the ocean occurs within the surface zone. In the tropics, surface waters are less dense because of the intense solar heating plus the large rainfalls there (lower salinity) and. In the subtropics in the regions of 30°N and 30° S, the very warm surface waters are less dense than the waters below, despite increased evaporation and higher salinity. In the temperate region, surface waters are less dense despite being relatively cool, because of increased precipitation (rainfall, snow, etc.). In the polar regions, surface and deep zone waters have nearly the same density.

Figure 5-6. A schematic of the latitudinal variation of basic ocean stratification along an ocean section from the north polar ocean (left) to the south (right).
The *pycnocline zone* in Figure 5-6 is characterized by rapidly increasing water density with depth because of changes in temperature or salinity. It is thickest (>1.7 km) in the tropics and thins moving poleward. Its base curves upwards and extends to the surface at about 45° north and south latitude, depending on the season. The pycnocline is virtually non-existent in the polar oceans.

The *deep zone* Figure 5-6 is extremely cold water and increases in density with depth because of increasing pressure and declining temperature. It contains over 80% of all ocean water, is homogeneous and extremely stable. The water of the deep zone extends from the base of the pycnocline to the ocean bottom. In polar and subpolar areas, where no pycnocline exists, waters of the deep zone extend to the surface.

### 5-4. WATER PROPERTY MEASUREMENTS

Historically ocean temperature and salinity were measured by arrays of Nansen bottles with thermometers. A typical deep ocean cast (Figure 5-6) would consist of the deployment of up to 30 bottles on a steel winch cable; from which measurements of temperatures with accuracies to within 0.01°C and salinities with accuracies to within 0.01‰ could be obtained at *discrete depths*. The modern oceanographic instrument used to measure *continuous distributions* of conductivity, temperature and salinity versus depth is called a CTD. The electronic CTD instruments are able to measure temperatures and salinities with accuracies to within 0.001°C and 0.001 ‰, respectively.

![Figure 5-7](image)

Figure 5-7 A historic oceanographic survey of water properties consisting of a set of stations (5 in this case). At each station, the ship stops and lowers a steel wire to which are attached an array of Nansen bottles that capture water salinity samples and thermometers that measure temperature (at 14 depths at station NH-105 above). Scientists now use a single electronic CTD instrument to make highly accurate profile measurements of temperature and salinity.

### 5-5. TEMPERATURE CONVERSIONS: CELSIUS - FAHRENHEIT
The Fahrenheit temperature scale was developed by Gabriel Daniel Fahrenheit in Holland in 1724. (The so-called "English temperature scale has nothing to do with England or an Englishman.) The exact origin of the scale is uncertain and several different stories exist. One is that he placed zero degrees Fahrenheit at the lowest temperature he measured during the winter of 1708-1709 and 100° as the temperature of his body. He then divided the scale into 12 divisions and each of these into eight units. On the Fahrenheit scale, fresh water freezes at 32°F and boils at 212°F.

The Celsius temperature scale was developed by Anders Celsius in Sweden in 1742. He used the freezing point of fresh water as 0°C and the boiling point of fresh water as 100°C. Because the temperature difference between the two reference points is 100 units, the scale was initially called centigrade (centi = 100; grade = unit). Because it is based on a multiple of 10, this scale is considered part of the metric system.

Conversion between single degrees Fahrenheit and Celsius is very simple: 1°C = 1.8°F and 1°F = 0.56°C. When converting temperatures between the two scales, however, it must be remembered that 0°C is equal to 32°F. This means that when converting to Fahrenheit from Celsius, it is necessary to add 32°. Similarly, when converting Fahrenheit to Celsius, you must first subtract 32°.

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°F = (°C \times 1.8) + 32 \quad \text{or} \quad °F = \frac{9}{5}°C + 32
\]

\[
°C = (°F - 32) \times 0.56 \quad \text{or} \quad °C = \frac{5}{9}(°F - 32)
\]
HW5 - Exercises  
Ocean Water Properties & Stratification

EXERCISE 1. TEMPERATURE CONVERSIONS

1. Convert each of the following into the temperature of the other system.
   
   1°C = ______°F  
   27°C = ______°F  
   -10°C = ______°F  
   1°F= ______°C  
   31°F = ______°C  
   -25°F= ______°C

2. Convert each of the following into the temperature of the other system. 
   - A change of 05°C = ______°F
   - A change of 30°F = ______°C

3. At what temperature would thermometers using the Fahrenheit or Celsius scale both read the same number of degrees? _____________
EXERCISE 2. TEMPERATURE PROFILES

The figure below lists the data obtained during an oceanographic cruise from the UMass Dartmouth’s School of Marine Science and Technology (SMAST) to the edge of the continental shelf. During that cruise measurements were made at 6 offshore stations NH05- NH105 along an ocean transect.

On the single graph provided plot the temperature versus depth data from the upper 100m for each of 6 sets of data.

Figure 5-8 Temperature data from six station across the continental margin at (where possible) standard depths of 0m, 50m, 100m, 250m, 500m, 750m, 1000m, 1500m, 2000m, and 3000m respectively.
EXERCISE 3. TEMPERATURE SECTION

Now draw in the 3°C, 4°C, 5°C, 6°C, 10°C, 15°C, 20°C, and 25°C contours (or isotherms) for these temperature data.