Lecture 10: Salinity

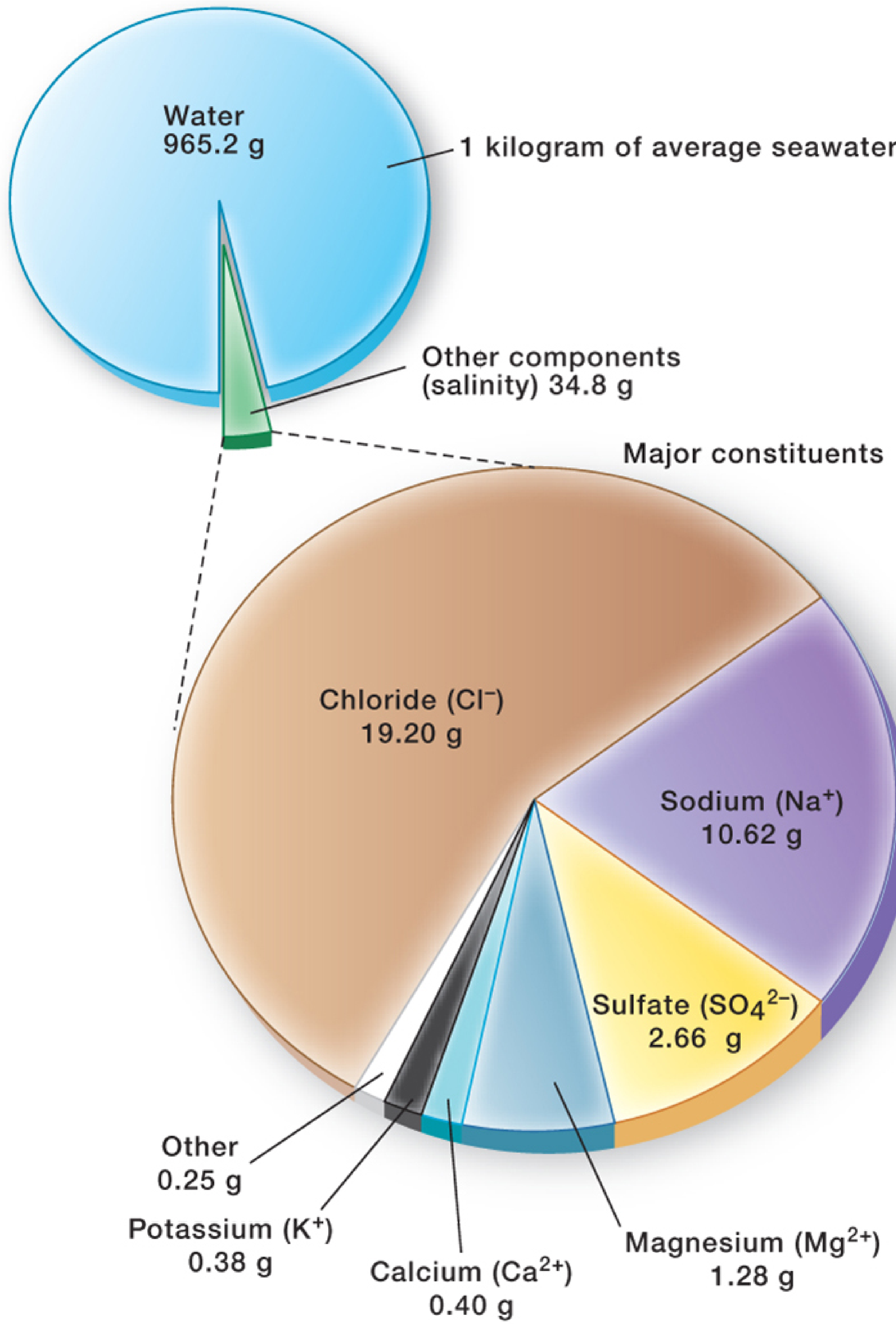
Salt in the Sea

We have all been in the ocean, and we know it is very salty. You also can't drink it. If you are marooned on a life raft, and you don't have freshwater on board, then you are likely to die of thirst before anything else. The salt is made from many dissolved substances but we often tend to only think of sodium chloride ($NaCl$), table salt. Fun fact: the oceans contain enough salt to cover the entire planet with a layer more than 150 meters thick.

What is salinity?

Salinity is the total amount of solid material dissolved in water. This typically doesn't include dissolved gases or organic molecules. Salinity is the ratio of the mass of dissolved substances to the mass of the water sample. The salinity of the ocean is typically around 3.5%, about 220 times saltier than freshwater. A salinity of 3.5% means it contains 96.5% pure water and 3.5% dissolved material by mass. Salinity is usually measured in parts per thousand (sometimes called ppt) or ‰, so 3.5% equals 35‰. Converting between percent (per cent is a measure of how many things per hundred) and parts per thousand (how many things per thousand) simply involves moving the decimal point one place to the right.

Ocean salinity contains several elements, which includes chlorine, sodium, sulfate, magnesium, calcium and potassium. These elements account for 99% of the dissolved solids. There are over 80 other chemicals for that remaining <1% of mass of dissolved solids in seawater.



Measuring salinity

The earliest methods were pretty straightforward. You would carefully evaporate a precisely weighed sample of seawater, and then you would weigh the salts that remain after all the water had been evaporated. This is a time consuming method, and it is not very precise.

There is another method, which was established by William Dittmar and was used to measure countless samples on the Challenger Expedition. This approach relies on the Law of Constant Proportions, which states that the major dissolved constituents responsible for salinity occur in the exact same proportions, regardless of the absolute salinity. Since seawater has a constant composition of chemicals, if you can measure one you can estimate them all. Chloride (Cl^-) is the constituent in highest abundance and it is the easiest to measure. The amount of chloride in a sample is known as its chlorinity. Chloride ions account for 55.04% of the dissolved solids in the water. The conversion from chloride to total salinity is:

Salinity = 1.80655 X chlorinity (‰)

Today, salinity can be measured very accurately using in instrument called a salinometer. These instruments work by measuring the amount of electrical current that a sample of water can transmit, known as the conductivity of a sample. The amount of electricity water can conduct increases with increasing salinity because the number of charged particles increases with salinity (recall the previous lecture about how water's polarity allows it to dissolve salts and consider how this relates to conductivity). Chloride ions in water can be measured very precisely - to the nearest ten-thousandth of a part per thousand. There is a special place where the sea water is very constant in its salinity, Wormly, England. Water from Wormly is sealed into glass ampules and shipped throughout the world to be used to calibrate salinometer. That ensures that oceanographers around the world are all using the same precision to measure salinity no matter where they are working.

Salinity and the Properties of Water

Salt water is made up of mostly (96.5%) pure water, so many of it's properties are the same as pure water. For example, saltwater is transparent, just like pure water. However, adding salt to pure water changes some of its properties in important ways. It changes the temperature of state changes, it alters density, and changes pH.

Dissolved substances can change how water changes state (solid to gas, etc). This is why salting roads causes the ice to melt faster. Adding salt will lower the freezing point, and salt will increase the boiling point. Dissolved salt in water moves the freezing point from 0°C to -1.9°C, and increases the boiling point from 100°C to 100.6°C.

Higher salinity water is also denser than freshwater; the density of normal sea water goes from 1.000 g/cm^3 to 1.028 g/cm^3. Ever notice that it is easier to float in the ocean than in a lake? It is because the water in the ocean (salty water) is more dense than freshwater! This concept of density is one that is going to come up in a number of places (and already has) so take note! Adding dissolved solids to water increases the density because the volume doesn't change, but the amount of 'stuff' in that volume does (and you already know that density is the mass per unit volume), so the density goes up. The density change from 1.0 g/cm^3 to 1.028 g/cm^3 may not seem like a lot, but it actually makes a pretty big difference in how the water works. For example, an egg will float in seawater, but sink in freshwater. Don't believe me – try it yourself at home.

Finally, the addition of dissolved salts in water causes the pH to change from 7 which is neutral, to 8.1 which is slightly basic. More about pH later.

Does Salinity Vary in the Oceans?

In the open ocean, salinity varies from 33 to 38. In coastal areas the variability can be even larger. If you go to the Baltic sea you will find salinity values of around 10, whereas a place like the Red Sea can have a salinity of 42. Water with a salinity below that of the open ocean is often referred to as brackish, whereas water with higher salinity than the open ocean is called hypersaline. The Great Salt Lake in northern Utah is 280 salinity units and is extremely hypersaline, and getting more saline as **water diversions for agriculture and megadroughts are shrinking the lake** (https://www.nytimes.com/2022/06/07/climate/salt-lake-city-climate-disaster.html) .

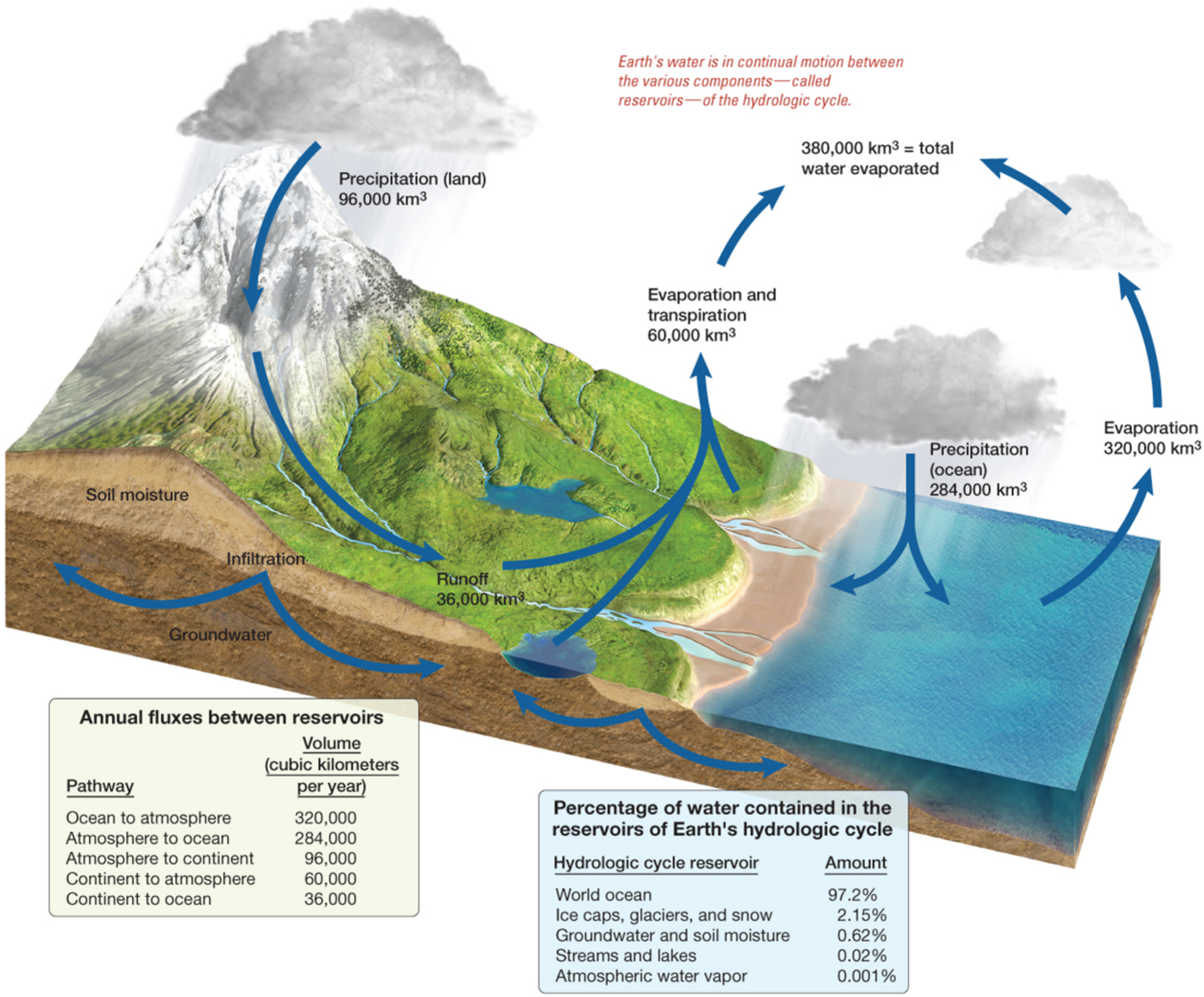
Let's talk about what causes these variations in salinity in the ocean?

There are processes that decrease seawater salinity. Rain and runoff from rivers adds freshwater locally and decreases salinity. Now, consider why the water falling as rain and in rivers is fresh instead of salty. The water in the atmosphere is a vapor (recall those states of matter we talked about), and it condenses to fall as liquid rain. When it vaporizes to move into the atmosphere, it leaves behind the dissolved solids (salts), so when it condenses and falls as rain, it no longer has salts in it.

About ¾ of the world's rain falls in the ocean. Most of the rain over land runs off to the ocean in rivers and steams. Icebergs also break off from ice sheets and drift out to sea. As those icebergs move out to sea they melt, and release water. The icebergs can be big, some are the size of New Jersey! On a global scale as we melt the ice caps, the ocean salinity will decrease.

There are also processes that increase salinity. You can increase salinity by essentially taking water out of the ocean. This is accomplished by evaporation, where the water moves to the atmosphere leaving behind the salt in the ocean. Also, when sea ice is formed, as the ice is forming the salinity is slowly leached out (through channels in the ice, called brine channels).

This process of moving water between land, the atmosphere, and the oceans is known as the hydrologic cycle. The figure below shows the hydrologic cycle and the tables included show how much water moves between the various reservoirs and how much water is in each component. Despite the fluxes, most of the water on earth, over 97%, is in the oceans. Watch **this NOAA video** (https://oceantoday.noaa.gov/watercycle/) to see an animation of how the hydrologic cycle works to move water around the Earth.



Seawater salinity is a function of dissolved components in seawater. While salinity in the ocean is relatively constant, the components that make up salinity do change over time. Stream runoff is the primary method by which dissolved substances are added to the ocean. The chemistry or dissolved components in streams is different than the dissolved components in seawater. Streams carry more bicarbonate, whereas oceans carry more chloride. How can it be, if streams are contributing dissolved components to the ocean, yet the two end up with different compositions? The answer is residence time! Residence time is the average length of time a substance stays in the ocean. Long residence times lead to higher concentrations in the ocean over time. Sodium has a residence time of about 260 million years, while aluminum has a residence time only 100 years. These differences in residence time means that there is more sodium in the ocean than aluminum.

If residence times are high, does this mean that the ocean is getting saltier over time? No, research suggests that the salinity in the ocean has remained relatively constant. This happens because chemicals are added at the rate that they dissipated or lost. In this way, the salinity in the ocean is in what is called a steady state.

If material is added from streams, and the ocean is in a ‘steady state’, then how are materials removed from the ocean? A major mechanism is sea spray is released to the atmosphere via breaking waves, then blown by wind to land. Recent studies suggest 3.3 billion metric tons of salt enters the atmosphere each year! The salt in sea spray can also be deposited into the sediments, or it can be adsorbed into clay. Another way that dissolved salts can be removed from seawater is through hydrothermal vents. Recall the previous lecture about those, and how they magnesium and sulfate are deposited into the sea floor as mineral deposits. The chemical exchange occurring between the ocean water and the crust is important to the components of salt in the ocean.

Dissolved chemicals like calcium, sulfate, sodium, and silicon can also be taken up by organisms in the ocean to form structures like shells. When those organisms die (or poop) the chemicals that they took up from the ocean water can be deposited on the sea floor (recall the previous lecture about biogenic ocean sediments!). Chemicals in ocean water can also be removed from the ocean when portions of the ocean are isolated and those volumes of water dissolve away leaving salt behind (called evaporites). Chemicals dissolved in ocean water can also be adsorbed onto sinking particles like clays, and deposited to the bottom of the ocean.