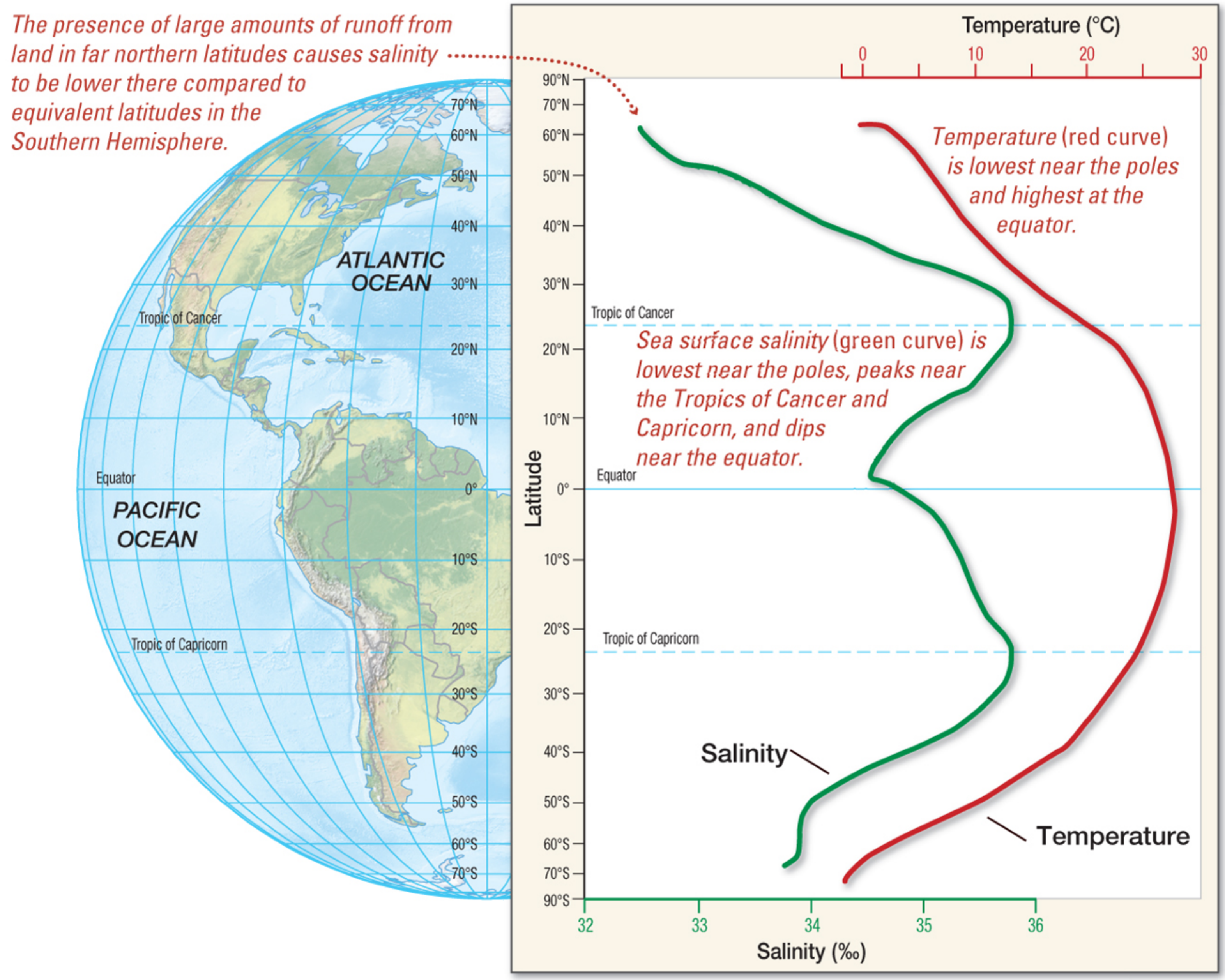
Lecture 11: Density

Density

The ocean is a variable place when it comes to salinity, temperature, and density. These characteristics can vary quite a bit across latitudes, and with ocean depth, and these patterns are super important to how the ocean operates. The way that water mixes, how currents move around, and even how life in the ocean works is influenced by these variations in salinity, temperature, and density.

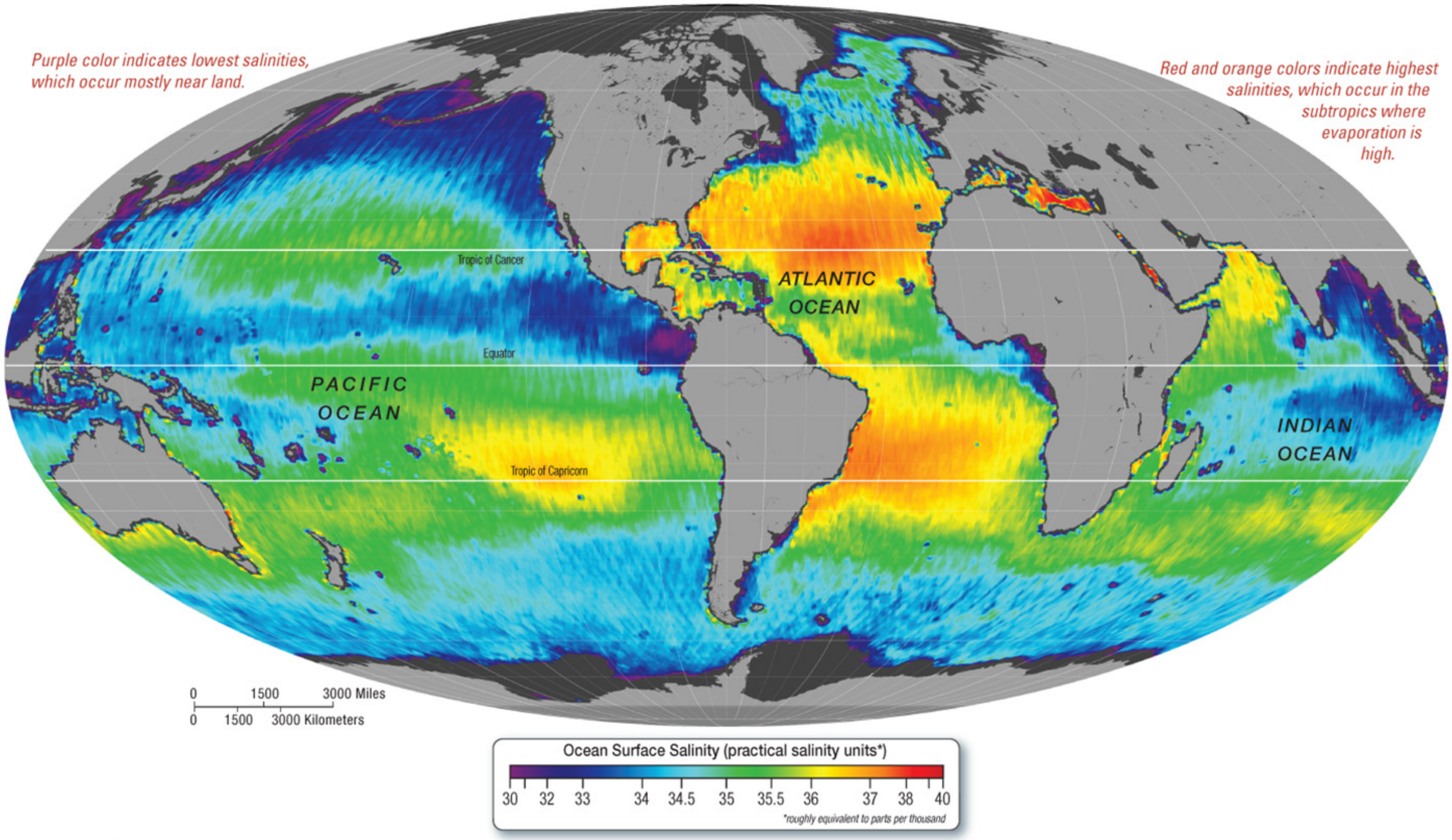
On average, the salinity in the surface of the ocean is 35‰, but this surface salinity varies by latitude. The graph below shows how salinity varies as you go from one pole to the other. Precipitation and runoff from land and melting of icebergs in the northern and southern latitudes (high latitudes) causes surface salinity to tend to be low in those regions. These high latitudes are also cooler, which means less evaporation from the surface, which also helps to keep salinity low.

Salinity tends to be higher around the tropics (lower latitudes) where there is warm, dry air which increases evaporation and causes surface ocean water there to be higher. Around the tropics of Cancer and Capricorn, there is also little precipitation and runoff that would decrease salinity. These combined circumstances mean that these latitudes are where the marine and continental deserts of the world are found.

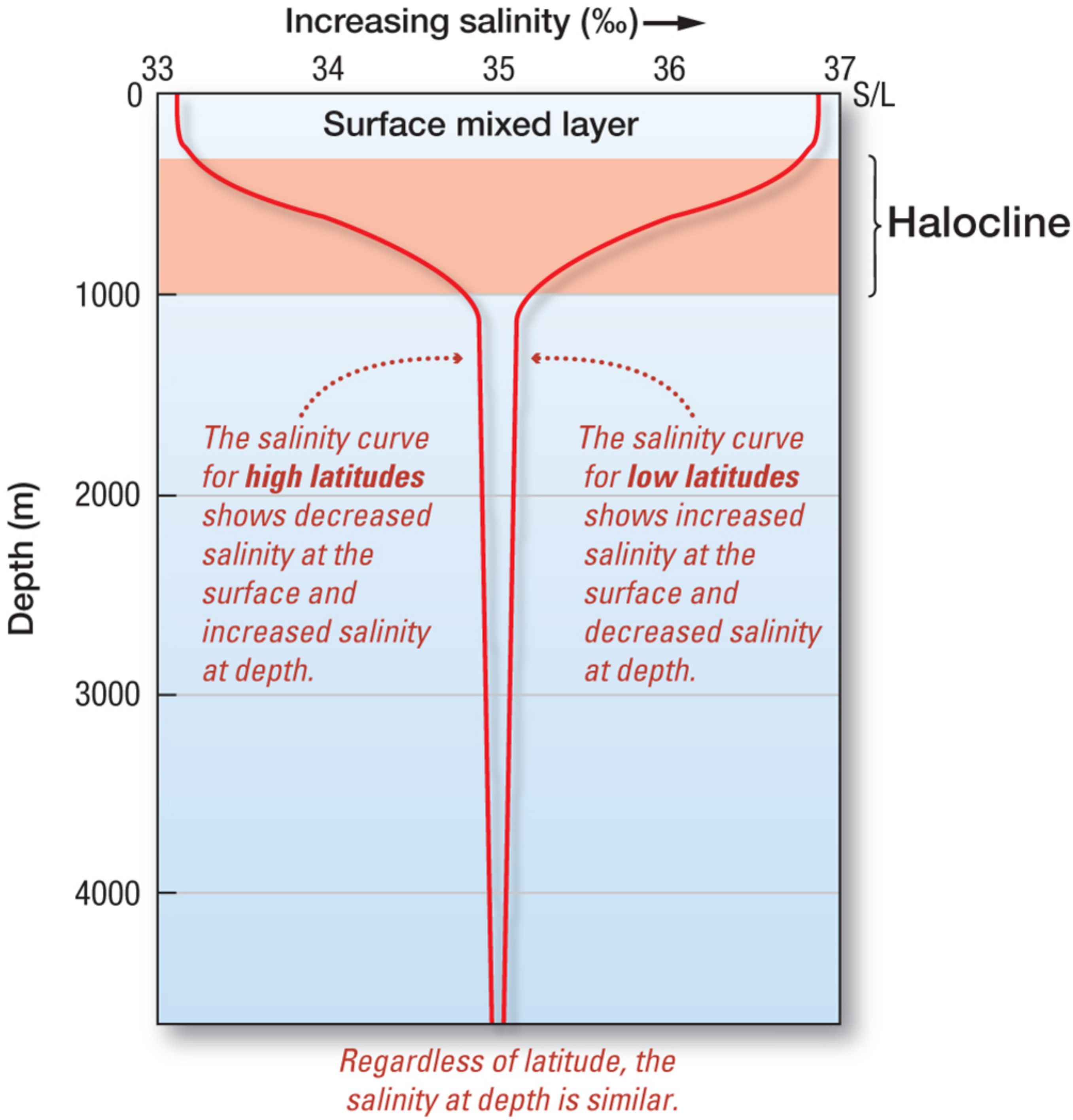


Around the equator, there is both high temperature (which increases evaporation and increases salinity) and high precipitation and runoff (which decreases salinity). You can see in the graph above, that salinity there is lower than the tropics, but not as low at the high latitude regions of the world.

Now, let's look at the map below which shows surface ocean salinity from satellites. What patterns can you see? The bluer colors are low salinity, and the redder colors are higher salinity. Notice the pattern that we discussed above on the graph where high latitudes are lower in salinity, and the tropics are high salinity. You can also see the band of moderately low salinity along the equator. There is also a difference in salinity between the Pacific and Atlantic ocean, with the Atlantic being saltier at the surface than the Pacific. This is because the Atlantic is narrower than the Pacific, so it gets more evaporation due to the continents being closer to one another and creating more evaporation.



Salinity also varies in the ocean by depth. Let's look at how this varies by looking at some data. The graph below shows a salinity profile – in oceanography we call figures that show some sort of data (in this case salinity) from the surface at the top of the graph, to the bottom of the ocean at the bottom of the graph, a profile. A profile is a convenient way to look at how conditions in the ocean change from the surface to the bottom. Back to our salinity profiles below. The red line on the left shows a salinity profile from a high latitude region, and the one on the right shows a low latitude or tropical region. We just talked about how those regions differ in surface salinity – you can see those same trends in this graph. The high latitude profile is lower in salinity at the surface, while the low latitude is higher in surface salinity (review the sections above if you can't think of why this is). In the high latitude profile, as you go deeper in the water column the salinity increases. In the low latitude profile, salinity decreases with depth. Both profiles get to the same ultimate salinity at depth. Another important feature that is shown in this figure is that salinity varies a lot in the very upper part of the ocean, but below about 1000 m depth, there is very little variation in salinity. This is because all of the processes we talked about above happen at the surface, so the things that change salinity (evaporation, precipitation, runoff) are all surface processes that don't change salinity in the deep ocean.



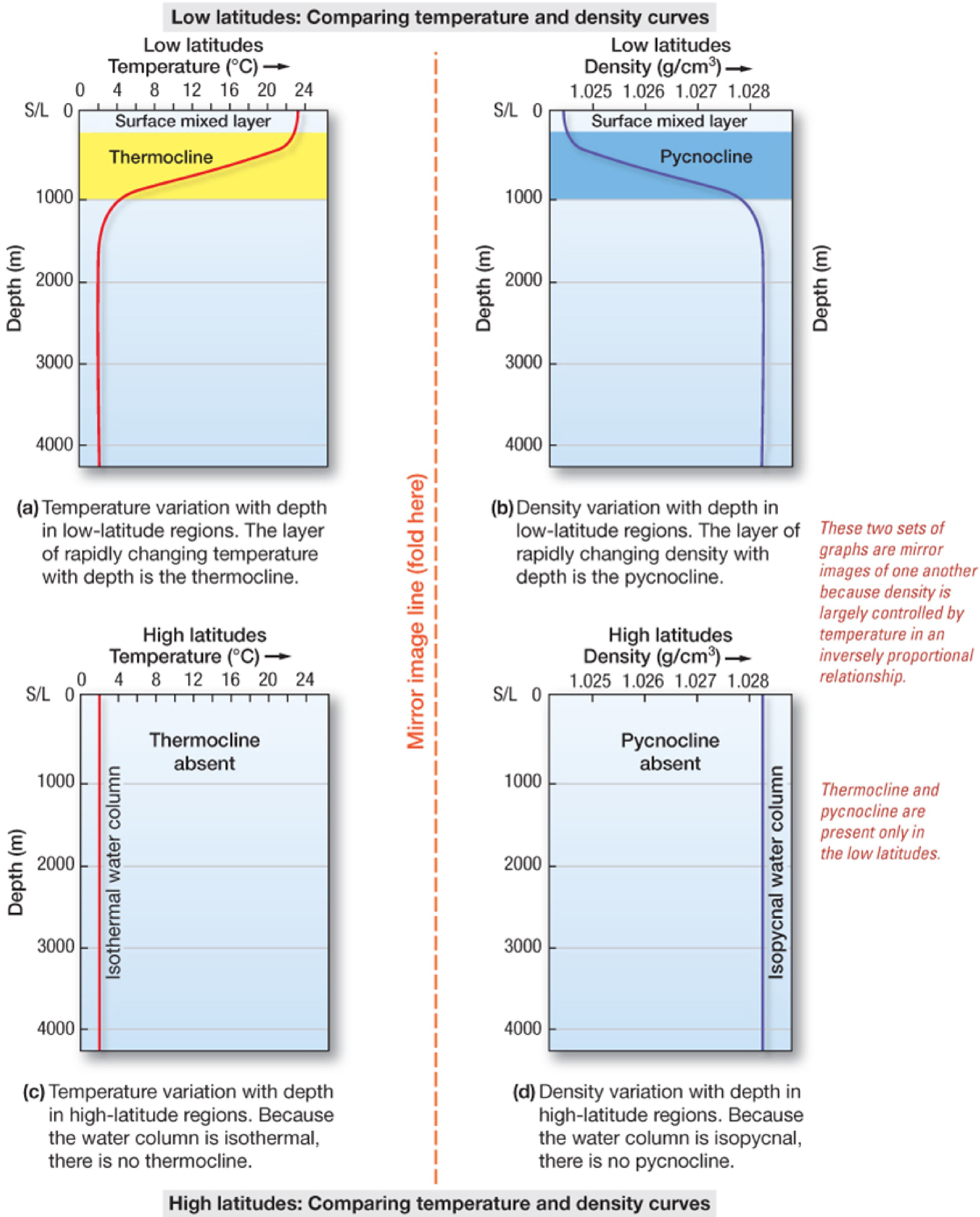
The region of the ocean where the salinity changes very rapidly (in the figure above, it is the part of the ocean where the red line goes rapidly to the left or right) is known as the halocline. Halo means salt, and cline means slope. The halocline is important because it is the layer of the ocean that separates water of different salinity in both high and low latitude regions of the ocean. You already know that salinity changes the density of seawater (if that isn't familiar, review the previous lectures), so the halocline is important in separating layers of salinity and density.

Remember that at 4°C the density of pure water is 1.000 g/cm^3. When we dissolve substances in water, the density increases. We have talked about how the salinity can change around the global ocean – that means that the amount and types of things dissolved in the seawater changes too. In the open ocean, seawater density averages between 1.022 to 1.030 g/cm^3. This means that on average, the open ocean is 2 to 3% more dense than pure water. Unlike pure water, seawater continues to increase in density until it freezes at -1.9°C (can you recall what happens to the density of pure freshwater as it gets close to freezing?). At it's freezing point, seawater also decreases density, in much the same way as pure water, so sea ice (solid water) also floats.

Density is a very important characteristic of water because it determines how water masses will move past one another. As an example, if you were to add open ocean seawater with a density of 1.030 g/cm^3 to pure freshwater, the seawater would slide below (sink) the freshwater, creating a deep current.

We have already discussed the concept of density and layers when we talked about the Earth's crust. The same layering happens in the ocean with low density water on the surface, and higher density water below. The highest density water in the ocean is generally found in the deepest ocean depths. Seawater density can be affected by salinity, temperature, and pressure and how these interact are important to how the ocean works. As temperature increases, density decreases due to thermal expansion. This is known as an inverse relationship – as one goes up the other goes down. Salinity does the opposite: as salinity increases, density also increases because of the increase in dissolved material in the water (this is known as a direct relationship). As pressure increases, density increases due to compression. Only salinity and temperature matter to the density of surface water. Pressure alters water density only in places of high pressure like the deep ocean trenches. Even so, the deepest parts of the ocean are only 5% higher density that the surface despite the very intense pressures in the deep ocean. This is because water is a relatively incompressible fluid. So pressure doesn't matter much to seawater density, but the other two matter quite a bit so we are going to focus on those. Can you think of what combination of temperature and salinity make the most dense water?

Temperature has the biggest influence on seawater density because it has the biggest variation. Let's focus on temperature and density for a bit. The graph below shows a temperature profile (remember what a profile is?) on the left and a density profile on the right. The top two graphs show profiles that would be typical for a low latitude region, with warm, low density seawater on the surface. Recall what a halocline is – there is a similar feature shown here that is called the thermocline (thermos meaning temperature) where there is a rapid change in temperature with depth. In low latitude regions, the sun warms the surface of the water, but the energy from the sun only penetrates the upper layers (recall how much heat water can hold, and how much energy it takes to change the temperature of water). In the open ocean, below the thermocline at about a depth of 1000 m, the temperature of the ocean remains relatively constant. The density of the seawater, shown on the right, follows the opposite pattern as the temperature profile – recall that these two properties are inversely related. The density in low latitudes is low at the surface, then increases through the pycnocline (pycno meaning density) to about 1000 m, below which it remains relatively constant. The two lower figures show temperature and density profiles for high latitude regions where surface temperatures are low, and do not differ much from deeper water. What does that mean for density? It also remains relatively constant from the surface to depth in high latitude regions.



(a) Temperature variation with depth in low-latitude regions. The layer of rapidly changing temperature with depth is the thermocline.

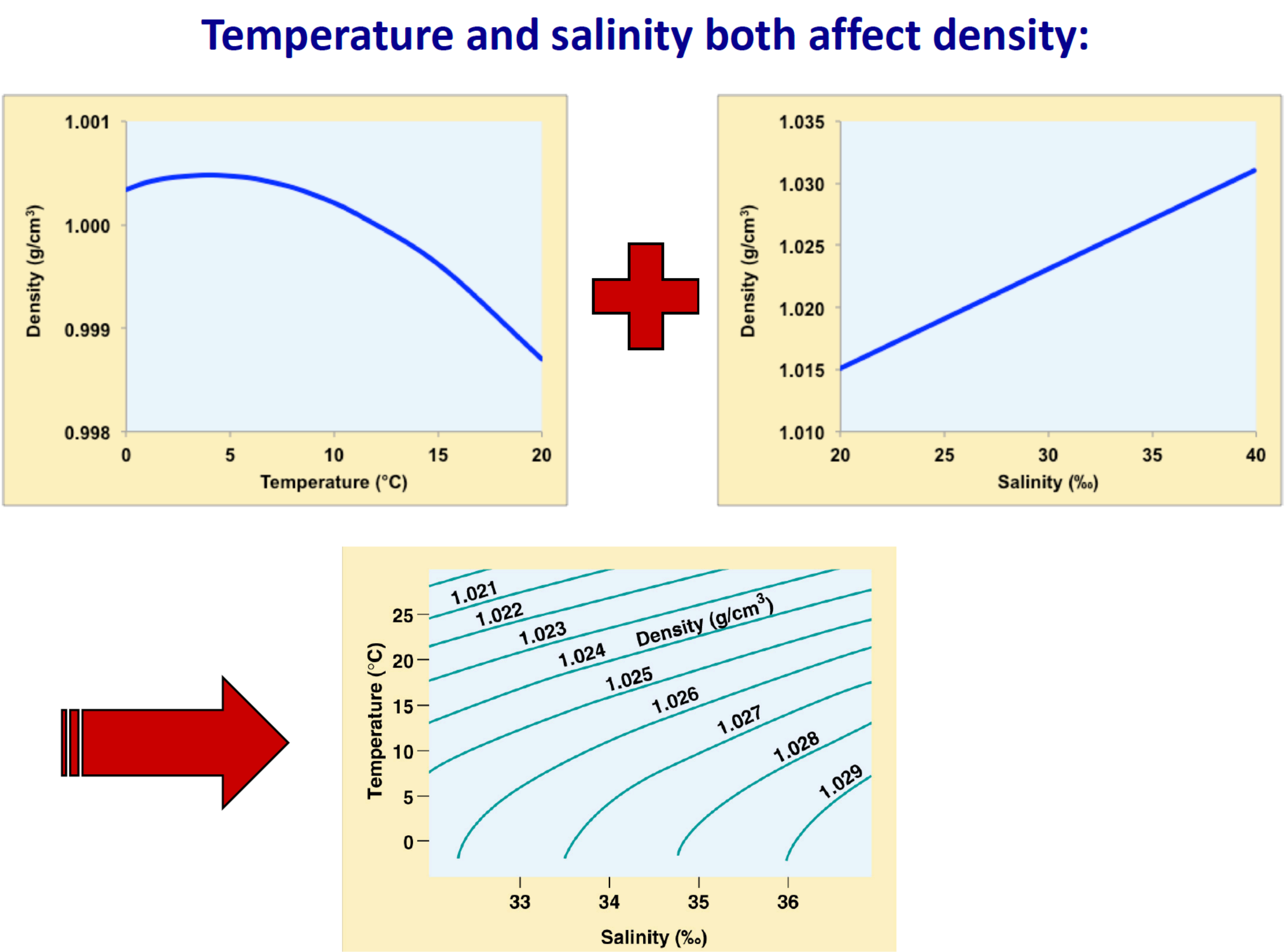
(b) Density variation with depth in low-latitude regions. The layer of rapidly changing density with depth is the pycnocline.

(c) Temperature variation with depth in high-latitude regions. Because the water column is isothermal, there is no thermocline.

(d) Density variation with depth in high-latitude regions. Because the water column is isopycnal, there is no pycnocline.

Let's talk a bit more about these haloclines, thermoclines, and pycnoclines – they are important to ocean processes. Have you ever dove into a lake to go swimming and you can feel the water is colder down below the surface – if you have, you have dove through a thermocline! In places where a pycnocline is established, the density differences between the layers of water make it very stable and thus there is very little mixing among the two layers. You can think of this like your salad dressing – when you put vinegar and oil together and let them sit for a while, the two densities of fluids will separate. Think about which one sits on top of the other. The difference in density of seawater can be determined by the combination of temperature and salinity differences, and greater the density difference, the stronger the separation of water masses.

Below are three graphs – the top two are ones we have already discussed. They show how density (on the y-axis) changes with changes in temperature (on the left) and salinity (on the right). Temperature and salinity can both change together in the ocean and can interact in how they change density. The graph on the bottom – called a TS diagram (TS stands for temperature and salinity). The TS diagram is actually a 3 dimensional graph that shows how density (shown with the lines that have numbers on them) changes with varying combinations of temperature (the y-axis) and salinity (the x-axis). In this graph, you find warmer, fresher water in the top left, and colder, saltier water in the bottom right. Which one is more dense? What about the density of water that is 33‰ salinity and 10°C? You can use the TS diagram to look it up – just find the point on the graph where 10°C crosses 33‰. The density is about 1.025 g/cm^3. Think about the locations on the TS diagram – where would you expect high latitude water conditions to sit on this graph? What about low latitude water masses?



The ocean is made up of three water masses based on density. There is the mixed surface layer which is found above the thermocline. The water in the surface mixed layer is relatively uniform because it is mixed by surface currents, waves and tides. The thermocline and pycnocline are found in a water mass called the upper water. The upper water layer is well developed in the low and middle latitudes in the world's oceans (consider why this is the case). A water mass called deep water is found below the thermocline/pycnocline and extends to the ocean floor. In high latitudes the water column is relatively uniform (with the exception of hot summer days when the sun warms the surface to create a warm layer). This uniform water column is called isothermal or isopycnal (iso meaning same).

We will get around to talking about how density plays a role in ocean currents later – but you could start thinking about how density might be important in ocean currents now that you know a bit more about how it varies.