Course Name: An Introduction to Climate Dynamics, Variability and Monitoring

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THE OCEAN AND THE CLIMATE

Good morning club and welcome to our continuing lectures on climate dynamics, climate variability and climate monitoring. In today's lecture and in today's week, we will discuss an aspect of climate that we have overlooked so far and that is the oceans and the impact of oceanic circulation systems on the climate. The importance of oceans to the climate is second only to that of the troposphere. 97% of the total surface water on earth is contained in the oceans. Further, it covers 71% of the earth's surface and has an average depth of 3730 meters. The oceans, moreover, unlike the land masses, are connected to each other and the liquid water of the ocean is free to flow from any location within the oceanic system to another location.

And hence, we can think of them as a single world ocean, even though there are localized differences between the various oceans like the Atlantic and the Pacific Ocean as well, which we will touch upon. How does oceans play a role in determining the climate of the planet? Some of the ways are, oceans act as storehouses of heat and chemicals that are absorbed and released on time scales that can vary from seasons to centuries. So, oceans, one of the primary ways it absorbs and releases heat, absorbs and releases chemical to the, to and from the atmosphere and the time scales of this release and absorption can vary from as short as a season within a year to scale of centuries. Particularly, oceans absorb carbon dioxide from the atmosphere and release oxygen to the atmosphere.

Oceans are a net sink of CO_2 and a net source of O_2. The phytoplanktons and other autotrophic marine organisms in the oceans release a lot of oxygen as they photosynthesize and this oxygen is released into the atmosphere. Furthermore the ocean, the water is a good medium in which CO_2 can dissolve and generate carbonic acid. So, a significant amount of atmospheric CO_2 can get dissolved in the ocean waters. In fact, a significant portion of the anthropogenic greenhouse gas emissions have been absorbed by the ocean so far. which of course makes the oceans acidic in nature because it produces carbonic acid with a low pH, but it also helps to mitigate a large part of the global warming effect. If this CO2 had been in the atmosphere rather than being absorbed in the ocean, the warming effect would have been significantly stronger. Thirdly, ocean currents move heat poleward thereby cooling the tropics and warming the extra tropics. So, ocean currents just like the wind circulation system move a significant amount of heat from the equator towards the poles thereby warming the tropics, cooling the tropics and warming the extra tropics, some regions of the world. Evaporation from the oceans is the primary source of water vapor to the atmosphere and hence rainfall and snowfall over the land.

So, again oceans are a primary source of water vapor in the atmosphere and hence the rate of evaporation determines the amount of rainfall one can expect over land, rainfall or snowfall. In this context, to understand how oceanic circulations work, we need to know some basic properties of the sea water relevant to that. Question. The two most important properties that determine the oceanic circulation are the temperature of the water and the salinity of the water. The temperature of the ocean ranges from minus 2 degree centigrade to plus 30 degree centigrade.

So, it is a large range. It is not as large as the range of the land, but it is still a significantly large range. The average temperature of the ocean is 3.6 degree centigrade, which shows that the region where the ocean is quite cold is actually much larger than the region where the oceans are hot and close to 30 degree centigrade. So, in a sense, if you look at the mean temperature of land, atmosphere over the land, which is around 15 degree centigrade, the mean temperature of the oceans is much lower, 3.6 degree centigrade. Oceans are overall significantly colder than the air above the land surface. In terms of temperature, the oceans can be subdivided into three regions with respect to depth from the surface. So, when we are looking at the temperature distribution of the oceans, we can subdivide the ocean into three regions in terms of depth. Just as we subdivided the atmosphere into multiple regions in terms of the temperature gradient, the oceans can also be subdivided like that.

We have a thin well-mixed layer at the top which is stirred by the winds and the waves so efficiently that the temperature and the salinity values are nearly constant with them. This is called the mixed layer or a well-mixed surface layer where vigorous mixing by the winds and the waves keeps the values of temperature and the salinity in this region relatively constant. Because the water is well mixed within this zone, the temperature and the salinity are nearly constant with depth. Beyond the well-mixed layer, as we go deeper, we have what is called the permanent thermocline. This permanent thermocline is a region of rapid temperature change with depth, which lies below the mix layer up to a depth of around 1000 meters below the sea level.

So, from the bottom of the mix layer, the mix layer has variable depth as we will see, from the bottom of the mix layer to 1000 meters below the sea surface is a region where the temperature varies rapidly with depth and this is called the region of permanent thermocline. This rapid temperature change is caused by heat transport from the well-mixed layer downward. The well-mixed layer is also where most of the sunlight is being absorbed. So, a lot of heat is being deposited in this well mix layer heating it up. And this heat is slowly transported downwards to primarily conduction processes.

And this is one of the downward moving heat fluxes that determine the temperature gradient. And this is balanced by the slow upward movement of colder water from below. This colder water can move upwards particularly in certain regions because it is less dense than the warm saline water on the mixed net. So cold but fresh water may be less dense than warm but saline water. So if salinity is constant, then warm waters will be less dense than cold waters.

However, if salinity is large, then a warm packet of water with high salinity value can be more dense than a cold packet of fresh water. So cold fresh water from the bottom can move upwards along the 70 degree gradient. The temperature of the bottom of the permanent thermocline is between 4 to 5 degree centigrade at the low and mid latitudes, but around 0 degree centigrade at the poles. So, at the low and the mid latitudes at the bottom of the thermocline, that is 1000 meters below the sea level, the temperature is around 4 to 5 degrees, but at the poles it goes to 0 degree centigrade. Below the permanent thermocline is the deep layer and this deep layer is an almost uniform temperature and salinity values.

So again the temperature does not change significantly or the salinity does not change significantly below 1000 meters, below the bottom of the permanent thermocline. And this happens up to the ocean bottom whose average depth is 3.7 kilometers below the sea level. In the deep layer, the temperature remains relatively uniform and slowly drops from 4 degrees at the base of the thermocline to 2 degrees at the ocean bottom, which is around 4000 meters. So, 4 degrees to 2 degrees, a very slow decline in temperature.

However, at the poles, the temperature of the deep layer remains around 0 degrees centigrade. So, there, there is no temperature gradient near the poles in the deep layer. So, here we are showing the figure of how the temperature change happens, temperature gradient with depth in the oceans, in the first 1500 meter of the oceans at different, different latitudes and in the, and in different seasons. This is the northern hemisphere winter, this is northern hemisphere summer. So, what you can see here is that, so the red is at the equator and the longitude value is also given because there are differences between say Pacific and the Atlantic Ocean, which we will discuss later.

Basically, this is equator and 25 degree west, so it is in the Atlantic Ocean more or less. So, here we can see this is the equatorial temperature gradient of the oceans in the winter months, northern hemisphere winter months and in the northern hemisphere summer months. And you can see in the equatorial region, the mixed layer is quite small. It is a very shallow region at the top, maybe less than 30, 10 to 20, 30 meters. After that you have a steep permanent thermocline going up to 1000 meters where the temperature kind of stabilizes at 4 to 5 degree centigrade.

And here the thermocline kind of ends by around say 700 or 800 meters in the equatorial region. This is the region of the permanent thermocline where the temperature falls rapidly from the hot thin mixed layer of around to at 25 degree centigrade to around 4 to 5 degree centigrade at the end of thermocline which is at 700 meters. Now if you look at the mid-latitudes, this is the mid-latitude here, here you will see there is a significant difference in the mix layer between the winter months and the summer months. In the winter months, you have a colder but much thicker mix layer at around 12 degree centigrade, at 25, at 45 degree north latitude here. Then a thermocline with a less steep gradient starting from say around 200 meters to extending up to say 1000 to 1200 meters, where it reaches again 5 degree or 4 degree centigrade.

In the summer months, the mix layer is more warmer but also thinner. So, the summer month mix layer in the mid latitude looks more like the equatorial mix layer behavior, thin and warm and a steep thermocline, whereas the winter months it is a cold deep mix layer with a less steep thermocline gradient. And this is similar to what you would expect in the high latitudes. So, at 75 degree north if you can see in the winter months you have a thick mixed layer once more which is even colder of course the ocean becomes progressively colder as we move from equator towards the poles and then a less a less steep thermocline that goes from say around 4 degree centigrade, 3 degree centigrade to 0 degree or minus 1 degree centigrade. Whereas in the summer months once again in the poles you have a relatively warm, it is only relatively warm, it is only 4 degree centigrade, but thin mixed layer followed by a relatively steep thermocline going to minus 1 degree centigrade which ends at around 600 meters and then the deep layer starts.

So, what we see in all of these cases is two things. Equatorial mix layer is always very warm and shallow followed by a very steep thermocline. In the summer, you have a shallow mix layer in mid latitudes as well as in the high latitudes. So, the temperature of this mix layer progressively decreases and so the thermocline steepness also progressively decreases. In winter months, both in the mid-latitudes and in the high-latitudes, the mix layer is colder but much deeper, followed by a significantly less steep thermocline.

below the 1000 meters or 700 meter depth where the thermocline ends, the ocean temperature is around 4 to 5 degrees for the equators and the mid-latitudes, but it is around minus 1 degree centigrade for the high latitudes. So, these points have been noted here. So, you can just go over this in this description here. Now sea leather, sea water is slightly compressible for the high pressures found in deep ocean. So, even though liquid is considered incompressible substance, because of the very high pressures at the near the bottom of the deep ocean, there is a slight compressibility effect.

This compressibility effect by itself will change the density and temperature of seawater with depth. So, in order to properly assess the density data, we have to negate this compressibility effect of seawater with pressure. So, we define something called potential temperature and potential density profiles of seawater with depth. What is the potential temperature and potential density? Potential temperature and potential density are the temperature and density values a parcel of seawater at a given depth Z will have if that parcel is adiabatically, so there is no heat transfer with that surrounding, adiabatically brought to a chosen reference pressure, usually 1 bar from its original pressure at the depth of Z. So you take a mass of seawater at a certain depth Z, which is at a certain pressure.

You now bring this mass of seawater adiabatically from that high pressure at the depth to the one bar pressure which is typical of the surface and see what its density and salinity is after it has been brought in that fashion. That density and salinity is the potential density and potential temperature, sorry not salinity, potential temperature and potential density of that seawater. So, this helps if every seawater is contour is plotted in terms of potential values rather than the actual values that the impact of compressibility with increasing pressure and depth can be taken out of the equation and hence the actual depth profile density profiles can be compared, temperature profiles and density profiles. So apart from the temperature, which has a strong impact on the density of seawater, salinity is the next most important property of seawater. Salinity is defined as the number of grams of dissolved salt that is present per kg of seawater.

So if you take 1 kg of seawater, the number of grams of dissolved salt that is present in that 1 kg is the salinity. Salinity in open oceans range from 33 grams per kg to 38 grams per kg. So, the difference is not that much, 33 grams per kg to 38 grams per kg with an average salinity being 34.7 grams per kg. The average value is 34.7, it varies from 33 to 38. salinity is also expressed as parts per thousand. So this is grams is 1000 of a kg, right.

So, this is 34.7 parts per 1000, okay. So, that is how, just as in the percentage is parts per 100, here we can define it as parts per 1000 and its symbol is this symbol here. So, instead of a 1 0 at the bottom, just like in a percentage sign, you have two 0s at the bottom, which shows its parts per 1000 parts of sea water. So, average salinity of seawater is 34.7 parts per 1000. We can also separate out the salinity of seawater in terms of its composition.

How many grams of individual ions are present in seawater? So, if you have a salinity of 35 parts per 1000, based on this table, Fluoride is 19.7 grams or 19.4 gram parts per

1000, sodium is 10.8 parts per 1000 and these two together is around 31, 31 point some parts per 1000. So, most of the salinity of seawater is coming from sodium ions and fluoride ions.

Apart from this, we have also small but significant amount of sulfur ions, magnesium ions, followed by calcium ions, potassium ions, bicarbonate ions, etc. Very small amounts of bromide, strontium, boron and fluoride may also be present. So, most of it is sodium chloride salt which is over 31, the rest is say magnesium ions, calcium ions and other metal ions. More saline sea water is denser than less saline sea water at the same temperature. So, salinity induced density differences are a major driver of density driven oceanic circulation, especially in the deep oceans and at high latitudes where the temperature changes are small.

So, in the regions of the ocean where there is not much temperature change, there salinity density differences are the main driver of movement of seawater and hence corresponding oceanic circulation. This is happening primarily in the deep oceans where the temperature differences are small as we saw as well as in the oceans of the high latitudes where also the temperature differences are relatively small. So, there salinity gradients are a very, have a very important role in determining the oceanic circulation overturning process. Salinity varies with latitude as well as with depth. In the subtropical latitudes, so 10 degrees to 30 degrees, surface salinity is high as evaporation exceeds precipitation.

So, between 30 degrees and 10 degrees, so 10 degree north to 30 degree north, 10 degree south to 30 degree south, the subtropical oceans are relatively warm and dry and hence there is a lot of evaporation from the oceanic surface causing high salinities in the mixed layer. So, in the subtropical latitudes you have very high levels of surface salinity. In contrast, at high latitudes, surface salinity is lower as precipitation exceeds evaporation. So, in high latitude seas, so say beyond 60 degrees or something, you will have oceans whose surface are much fresher because you have a lot of precipitation and because it is cold, not that much evaporation. So, you have high surface salinity near the subtropical oceans and low surface salinity near the high latitude ocean.

Salinity profile of the deep layer is nearly constant and is almost identical to surface salinity values found in the high latitudes as. deep layer salinity, so below 1000 meters is more or less constant and is almost the same value of salinity as the surface salinity values of high latitude oceans. Why is that? Because as we will see most of the deep layer ocean water is coming from sinking water that is sinking at the high latitude ocean. Because water at the high latitude oceans is sinking and providing the main source of deep water in the oceans. Hence, the deep water salinity values are very similar to the high latitude surface salinity values.

Subtropical oceans show large salinity gradients in the thermocline region. So in the subtropical oceans there is a large salinity gradient in the thermocline region as we would expect because salinity values are low in the deep waters which is coming from the high latitude ocean surfaces whereas salinity values of the mixed layer in the subtropical oceans is very high. So, there is a high salinity at the top and low salinity at the bottom of the subtropical ocean. So, a steep salinity gradient exists in the thermocline region for the subtropical oceans. Of course, in the deep, in the high latitude oceans there is no significant salinity gradient because the deep layer and the surface layers mix because of the sinking of the surface layer waters.

Also, there are differences in salinity between the various oceans. So, the Atlantic Ocean is markedly saltier compared to the more open Pacific Ocean as the former is surrounded by continents with large salt runoff from the land. So, the Atlantic Ocean is a more closed ocean with a large amount of runoff from the land. And this runoff is the main source of salt in the ocean. Land erosion and land runoff based salt is always coming into the oceans.

Because the Atlantic Ocean is surrounded by land, it is more closed ocean, its salinity is higher than that of the more open Pacific Ocean. So, here we see the salinity gradients. This is the average salinity gradient. So, in the equator, the salinity at the surface is actually lower because equator gets a lot of precipitation even in the oceans. So, the surface salinity is low, lower than what is happening in the subtropical ocean.

So, the subtropical ocean 25 degree north, you have the highest salinity in all the ocean. It is around 37 parts per 1000. Equator is lower and similar to mid-latitude values of salinity which is around say 35.6, so 35.8 parts per 1000. After the equator, after the mixed layer, you have a steep gradient of salinity between the mixed layer and the, in the thermocline region where the salinity falls very quickly. Here, in the equatorial region especially, you can have salinity values which are lower than the D portion.

So, it can go down to below 34.5 watt per hour. In the high, in the mid latitudes and in the subtropical ocean, salinity gradients, in the subtropical ocean the salinity gradient is highest, in the mid latitude because of the lower salinity values at the, of the mixed layer the salinity gradient is less steep. And in the deep ocean the salinity is more or less constant from the top to the bottom. Most of the salinity gradients converge to 35 parts

per 1000 in the deep ocean region. In the Atlantic Ocean, the salinity values are typically higher, both in the subtropical oceans, where it is going above 37, whereas in the Pacific it is below, it is 36.

So, these values are Atlantic Ocean values. This is Atlantic versus Pacific. The blue is the Pacific, the red is the Atlantic. So, in the subtropical Atlantic Ocean, mix there is significantly saltier than subtropical Pacific Ocean. As a result, the thermal gradients are also less steep in the Pacific Ocean compared to the Atlantic Ocean. This is true also in the In the mid-latitudes, the salinity of the mixed layer in the Atlantic Ocean remains reasonably high at around 35.8 parts per thousand, whereas in the Pacific Ocean, the mixed layer is significantly fresher than the deep layer. It is around 33 parts per thousand because the Pacific Ocean mid-latitudes gives a lot of precipitation, there is where it will run off. So, as a result, the salinity gradient between the mid-layer and the deep layer is inverted. Salinity is increasing with depth in the mid-latitudes of the pacific ocean.

These kinds of variations needs to be taken into account. And of course, the deep layer of the pacific ocean also has lower salinity than the deep layer of the Atlantic ocean. So, we will stop here. We will continue our discussion of salinity and temperature and its impact on the density of the sea water with depth at various altitudes in the next class. Thank you for listening.