Introduction to Atmospheric and Space Sciences
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Lecture – 27
Atmospheric Stability and Cloud Formation

Hello dear students. So, in continuation with our discussions on atmospheric thermodynamics. In today's class we will try to understand a very important concept in lower atmospheric physics it is about the Stability of Atmosphere. So, the idea is to introduce the concept of cloud formation how does the clouds form or what are the different types of clouds, what are the conditions in atmosphere that will be conducive for the formation of clouds.

So, before all these things it is very important for us to understand, what is the concept of atmospheric stability. So, how does atmosphere being stable or unstable help in the formation of clouds. So, in today's class we will basically be understanding the Atmospheric Stability and its connection with the Formation of Clouds ok. So, what we will do today is let say, so we will start with the basic idea of saturation or basic idea of vapor pressure.

So, we have already seen that is we have already came across the idea of air parcel. So, air parcel is an imaginary volume of air which is kind of adiabatic in nature; that means, it is not exchanging any matter or its not exchanging any energy with the surroundings and we also see that every air parcel maintains the same amount of pressure as the surroundings.

So, if there is an amount of moisture inside; we have seen that there is a limitation to which the air that is present inside this parcel can carry the amount of moisture. So, it cannot carry any amounts of moisture, but rather the amount of moisture that can be contained in this particular air parcel is limited or is mainly decided by the temperature of this air parcel.

So, if you keep on changing the moisture content; there comes a point where the parcel will be at equilibrium or the parcel will reach saturation. So, at saturation if you say, the saturation has also been explained in terms of with respect to the plane surface of water and we have also seen what is saturation with respect to plane surface of ice. the idea is; , the amount of vapor pressure that is exerted on the liquid surface or on the water surface decides how much amounts ofwater vapor can exist. So, saturation is the point where the evaporation is equal to the condensation.

So, if you consider, if you put water liquid water and air parcel or in a container there is a constant rate of evaporation from the surface of this liquid and there is a constant condensation from the gas phase to the liquid phase.

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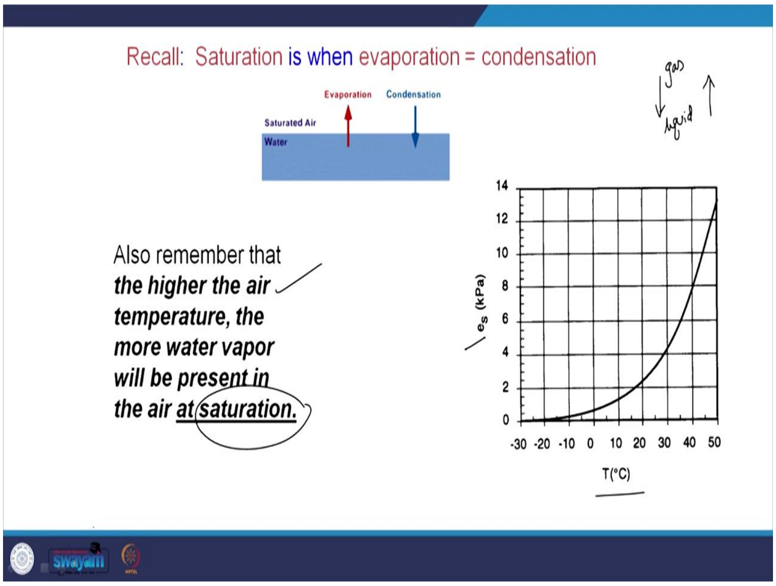

So, there is a condensation which is trying to for a phase transition between the gas to liquid and there is always an evaporation which is the opposite direction. So, these two things are most probably and most of the times they are in equilibrium.

So, the rate at which there is liquid that is trying to become gas is equal to the rate at which the gas is becoming liquid. So, basically, what you see is that even these two rates become equal; we say that the liquid is saturated or the vapor that is there is saturated with respect to plane surface of water. If the water is what you have kept in this particular chamber ok.

So, saturation is when the evaporation is equal to the condensation. Now, what will happen if you increase the water vapor content inside that will lead to the formation of droplets or that will lead to the condensation to prevail and as a result you may see that the on the walls of this container; there will be tiny droplets of water right.

So, basically the idea is; so, what we are trying to do is we are trying to understand the idea of saturation. So, now, saturation you define it as the point when the amount of evaporation is equal to the amount of condensation, but this saturation is not defined just with respect to the amounts of vapor pressures, but we can also define saturation with several other parameters.

Now, so at a particular point there is evaporation that is equal to the condensation, but what generally happens is? the amount of water vapor that can be held by this air parcel is very much dependent on the temperature of the air parcel. So, that means that the higher the air temperature is the more water vapor will be present in air at saturation. So, , no matter whatever the point of saturation is at higher temperatures; the saturation is achieved at larger values of water vapor content inside the air parcel.

So, this curve shows the temperature on the x axis and e_s is the saturation vapor pressure which is given in kilo Pascal. So, what you see is that the saturation vapor pressure increases as you increase the temperature. So, vapor pressure is the amount of pressure that is exerted by the vapor on the liquid surface. If there are more number of vapor molecules; gas molecules, H_2O molecules in the gas the pressure will be more as simple as that right. So, what it means?.

What this curve means is that; if the temperature is more, if you keep on increasing the temperature of this particular container or this particular air parcel the number of water vapor molecules in the air will increase; that means, the air parcel is able to hold more amount of water vapor in it.

So; that means, that technically, so saturation is the point when the rate of evaporation becomes equal to the rate of condensation and this point may also be dependent on the temperature because, as you go on increasing the temperature the more amount of water vapor can be contained by the gas right.

So, then if this quantity the amount of water vapor if it is changing with respect to the temperature, then we have to define a parameter which measures the quantity or which kind of quantifies the amount of water vapor that is present inside the air parcel right.

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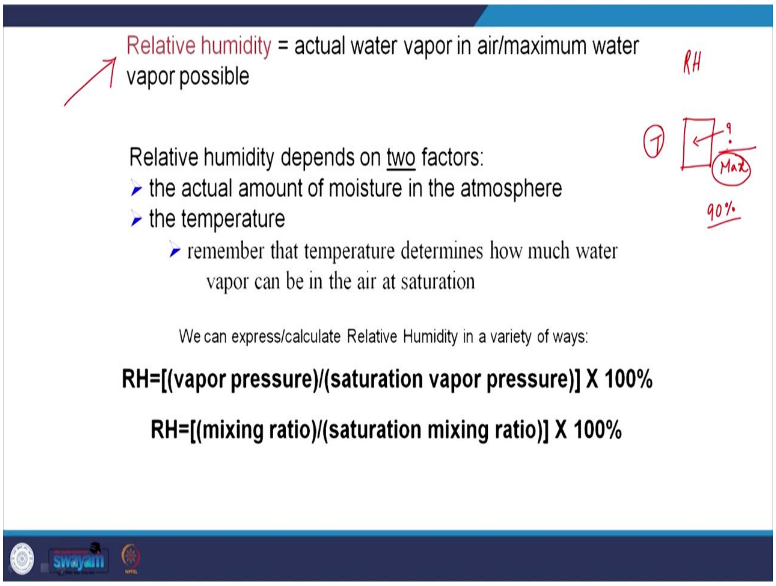

Then we define what is called as the relative humidity. A very important variable in atmospheric physics is what is called as the Relative humidity this is familiarly known as R H. So, relative humidity is the actual water vapor in air with respect to the maximum water vapor that could be contained within this air parcel. so relative humidity let say you consider an air parcel. Now you define the temperature at which this air parcel is present let say you fix this temperature, then at this temperature what is the amount of water vapor that is existing at a particular point of time with respect to the maximum amount of water vapor that this air parcel can contain.

This, the ratio of these two parameters will give you relative humidity. That means, let say if you have 90 percent relative humidity what it means in reality is that the so, there is still a provision of increasing the water vapor content by 10 percent or 15 percent I mean relative humidity can exceed more than 100 percent.

So, the relative humidity is just the ratio of the amount of moisture or amount of water vapor that is contained in this air parcel to the maximum amount that can be put into this air parcel. Now, more importantly the relative humidity now depends on two factors what does it depend? The relative humidity depends on the actual amount of moisture in the atmosphere at any given point of time and it also depends on the temperature. So, why does it depend on the temperature? Because, the denominator the maximum amount of water vapor that can be contained varies with respect to the temperature.

So, as you keep on increasing the temperature; the air gets the tendency to accept more amounts of water vapor into it. So, basically, the actual amount of water vapor that is present in the atmosphere will decide the relative humidity being the factor in the numerator and the temperature which decides the maximum amount by varying the denominator. So, we have to remember that the temperature determines how much water vapor can be held within the air parcel at a particular condition ok.

So, out of these two things the main important thing that we should understand is. So, saturation of course, depends on the rates of evaporation and condensation, but this the rates and the point at which these two things become equal are very much dependent on the temperature. So, there is no necessity that only at a particular value of temperature; the saturation is to be reached. It can be reached at various different values of temperature.

So, now, keeping these two things in mind, so relative humidity can be defined in a more different parameters let say. So, the relative humidity can also be defined as the vapor pressure; defined by the saturation vapor pressure into 100. So, vapor pressure is we have already defined vapor pressure. Now vapor pressure can be defined at any given point of time, not only at the saturation. So, even before reaching the saturation.

Now, let say for example, you just keep a container and you keep water in the at the base of this container immediately when you keep it there is an amount of vapor pressure that is existing inside this gas, inside this chamber. Now, if you allow sufficient amount of time to pass and if you allow saturation to establish, then at this point of time you the vapor pressure that is exerted on the surface of this liquid will be different.

Now, this the ratio of these two things multiplied by a 100 will give you the relative humidity in percentages. Or if you want to talk about mixing ratios; let say, mixing ratio is generally how much amount of the substance is contained in the total mixture. So, mixing ratio can also be used in defining the relative humidity, the parameter of relative humidity. So, the relative humidity can be defined as the mixing ratio by saturation mixing ratio into 100 ok.

So, the relative humidity and saturation mixing ratio, saturation condensation, these parameters are very well connected and we should always keep them in our mind. Now, we also defined another very important parameter or very important temperature which is called as the dew point. So, the dew point is the temperature to which air must be cooled in order to become saturated right.

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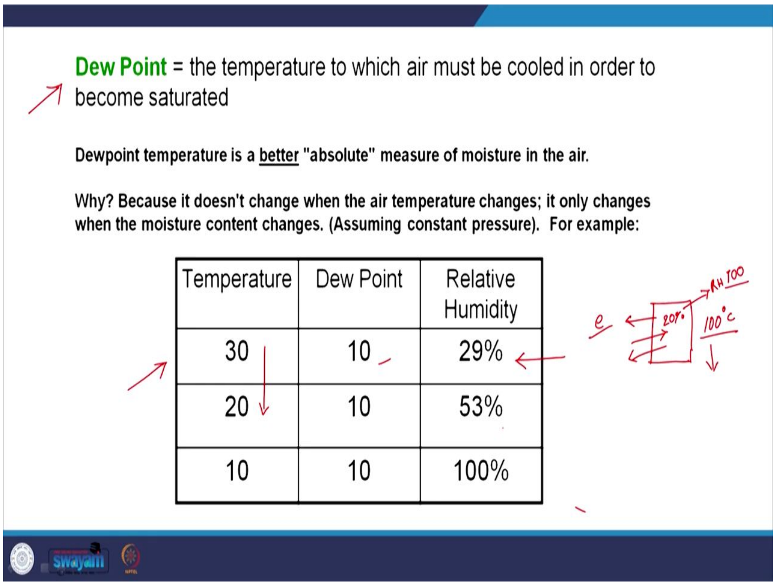

Now, one very important thing that we have been able to establish is that; the amount of water vapor that can be held by the air parcel is of course, dependent on the temperature right. then depending on the amount of water vapor it can be more or less. So, , now depending on the amount of water vapor; we cannot say whether the condition of saturation is reached.

For the saturation to happen the amount of water vapor has to be of some ratio with respect to the total amount of water vapor or maximum amount of water vapor. Now, by changing the temperature; what you can do is within the existing limits by not changing the amount of water vapor just by changing the temperature what you can do is with the existing value, with the existing amount of moisture in the air parcel we can reach saturation right. For example, if you have 20 percent of moisture at a particular temperature.

So, now let say at a very high value of temperature; this 20 percent of moisture is giving you a relative humidity of something let say. Now, if you keep decreasing the temperature, but not changing let say you take an adiabatic air parcel which is not allowing either inward or outward transfer of moisture from the air parcel right. Now you have 20 percent of water vapor within this. Let say that now the temperature is 100 degree Celsius.

Now, if you decrease the temperature; now 20 percent is not sufficient for us to call that the relative humidity is 100 percent it is just. So, relative humidity; that means, the relative humidity is just 20 percent in this case. But, if you decrease the temperature; what will happen? If you decrease the temperature, the vapor pressure will decrease. The vapor pressure; let say e will decrease.

Now, if you keep on decreasing the temperature; there is a point at which with the existing value of moisture itself you can establish the saturation. This particular point to which the air must be cooled so that it can its vapor pressure becomes equal to saturation vapor pressure is called as the dew point.

So, dew point is generally considered as a better or absolute measure of moisture in the air because, in dew point you are not changing the moisture content rather you are just changing the temperature. That means, because it does not change when the air temperature changes because the amount of moisture is not changing. With the same amount of moisture itself you are changing that parameter. So, that it reaches an equilibrium or it reaches the humidity of 100 percent.

So, it only changes when the moisture content changes. So, assuming constant pressure of course, right. For example, when the temperature is 30 degrees. So, that when the temperature is high, the dew point is 10 degrees. I mean; so, for this air parcel to by maintaining the same pressure. So, when you say that you are maintaining the same pressure you are not adding any gas or you are not adding any moisture content.

Now, at this point the relative humidity is just 29 percent. Now, if you decrease the temperature; if you decrease the temperature of this air person the dew point is always a 10 degree Celsius ok. But the humidity relative humidity changes because, by decreasing the temperature you are decreasing the ability of this water ability of this air parcel to hold water. So, as you go on decreasing the temperature at a particular point with the same amount of moisture itself you have reached the saturation right.

So, this is the greatest advantage of using dew point as a measure of let say quantifying the amount of humidity within the air parcel ok. So, the point is when you keep on decreasing the temperature the at a particular point with the same amount of moisture; you reach a relative humidity of 100 percent.

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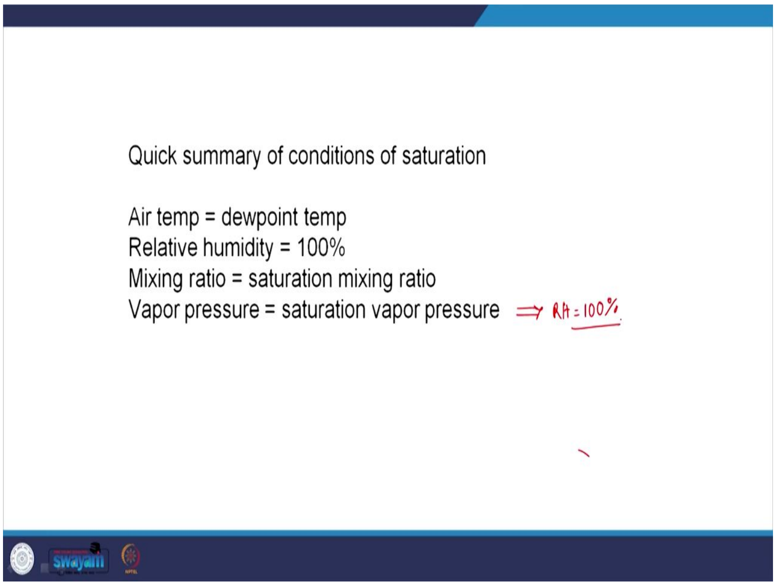

Now, if you recap of the points that we have learned about saturation and various humidity variables is that air temperature when equal to the dew point temperature. We say that the relative humidity is 100 percent. In terms of mixing ratio; when the mixing ratio when the existing mixing ratio of an air parcel becomes equal to the mixing ratio at the saturation or saturation mixing ratio, we also say that their relative humidity is 100 percent.

And we also say that the when the vapor pressure of the air parcel becomes equal to the saturation vapor pressure then also we can say that the relative humidity at in these cases should be 100 percent. So, to define relative humidity, you can define it in terms of temperature you can define it in terms of vapor pressure or you can define it in terms of mixing ratio.

So, relative humidity becoming 100 percent means; the temperature of the air parcel is equal to the dew point temperature. The mixing ratio inside the air parcel is equal to the saturation mixing ratio and vapor pressure inside the air parcel is equal to the saturation vapor pressure. So, these three are the main methods or main criteria using any of which you can say that the relative humidity is achieved to be at 100 percent ok.

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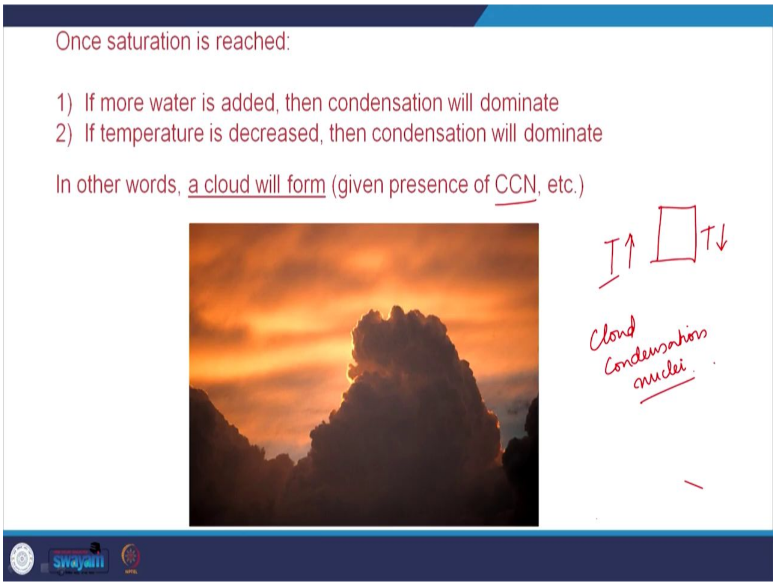

Then, so now, the thing is by this mechanism; decreasing the temperature you are reaching saturation or by increasing the amount of moisture content inside the air parcel you are reaching saturation right. Or by changing the mixing ratio also you are also reaching the saturation right. Now, what is the point of discussing the saturation as such?

Because saturation is the point beyond which either you decrease the temperature or beyond which you increase the moisture, you try to increase the moisture content; the system will not accept any further addition of moisture into the parcel. That means, the system then develops a tendency to throw away the extra amount of moisture which is above this saturation values right.

So, that is why once the saturation is reached if more water is added; that means, if you are trying to add more moisture content into the air parcel, this will lead to the process of condensation. And to what is the role of condensation? Condensation will develop tiny droplets of water on the let say on the surface or it will be thrown out right.

Now, what is the other way of going beyond saturation? Going beyond saturation see, if you increase the temperature you are just allowing the air parcel to accept more amount of moisture right. So, if you increase the temperature; you are deviating away from the saturation, but if you want to go towards the saturation the easiest way is to decrease the temperature.

So, the point is; if you want to reach saturation let say, i by having more amount of moisture in this parcel, you can increase the temperature. The point is if you want to reach saturation by adding more amount of water vapor into the air parcel you have to increase the temperature by increasing the temperature, you are increasing the ability of the air parcel to hold more moisture.

Now, if you do not want to add any more moisture rather you want to attain saturation with existing amount of moisture itself, then you have to decrease the temperature. So, these two conditions they work one method requires more amount of moisture to be physically added to the air parcel, another method do not require physical addition of moisture rather it requires decrease of temperature right. Both of these cases will allow the air parcel to become saturated or supersaturated.

Once the super saturation is reached, it will throw out the extra amount of moisture beyond saturation outside and this happens by the means of condensation and condensation will release some amount of latent that is a different story right. Now, so basically, so it will lead towards the condensation and the vapor when condenses to form tiny droplets in the atmosphere is generally called as the phenomenon of clouds or the phenomena of cloud formation itself. So, what is a cloud? Cloud is a collection of tiny particles of water or ice which have condensed from the gas right.

Now one more important thing is that; for the formation of droplets the saturation has to be several times larger than 100 percent. So, what it means is that? If you want cloud nuclei or if you want the cloud droplets to form out of moisture, you will need particles these particles will act as the platform over which condensation will happen and this particles are generally called as the cloud condensation nucleus CCN is cloud condensation nuclei right.

Now, so clouds will only form when there is saturation that is reached and when there are n th number of cloud condensation nuclei present in the atmosphere right. So, why are we discussing this? We have seen the methods by which you can reach saturation, now we are seeing what will happen once you reach saturation right.

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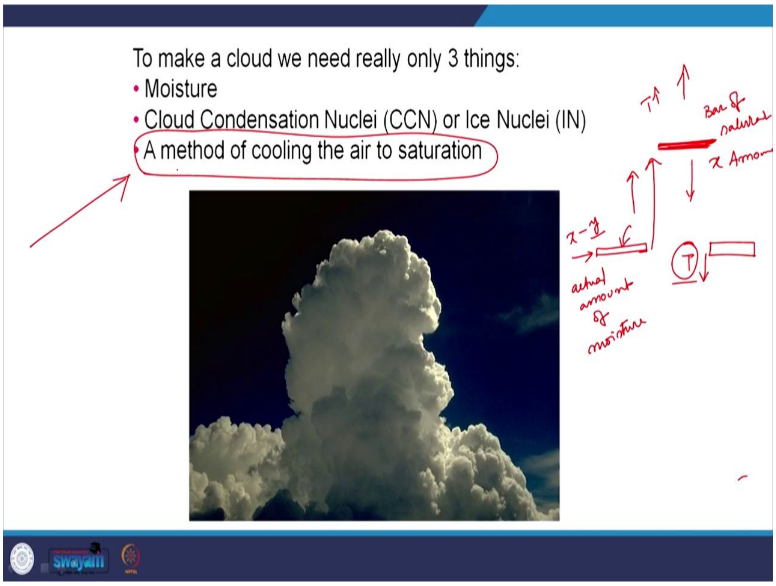

So, now in summary to make a cloud we really need three things. We need moisture of course, we need cloud condensation nuclei and we need a method of cooling the air to saturation. So that means, that like I said by not physically moving moisture into the air parcel with whatever the moisture content that is available in the air parcel; the only way to reach saturation is by decreasing its temperature right.

So, what you are doing is the bar of saturation is here right. So, now, if you the bar of saturation says; at least this much amount of let say x amount of moisture is needed for the saturation let say x amount of moisture is needed for reaching saturation. So, this is the bar of saturation this is what is called as the bar of saturation right.

Now what you can do is; either you rise the amount of moisture from here to here right or you bring this, . So, at any given point of time this is the actual amount of actual amount of vapor pressure or actual amount of moisture simply speaking when the actual amount of moisture becomes equal to the saturation moisture. You can simply say that you have reach the saturation right.

Now, the bar of saturation is held at this position only by the virtue of its temperature. So, if the temperature is very high, this bar will go even further. The easiest way to put it is x grams of water vapor can be held in this air parcel at a particular value of temperature. Now, at the same value of temperature, you do not have x amount of x grams of water molecules inside this air parcel rather you have only let say x minus let say few units x minus y units of water molecules inside.

Now, what you can do is either you rise you keep putting water vapor physically and you rise this to here or what you can do is if you decrease the temperature, this the amount of moisture that is present the amount of moisture that can be present in this air parcel comes down. What you are doing is by decreasing the temperature; you are just bringing the amount of water vapor that can be held by the air parcel to the level that the amount of moisture that is actually present in the air parcel right.

So, now , like this slide says to make a cloud or to allow condensation to happen, you need to three important things. One; when the saturation is reached the excess amount of moisture will try to condense and for this condensation to happen, you need particles, tiny particles which are called as cloud condensation nuclei.

You physically need this I mean; these particles are supposed to be existing at let say 5 to 10 kilometers altitude and only on the top of these particles cloud condensation will happen the droplets will form invariably this is a must condition. Then, now you need a method by which you can decrease the temperature of the air parcel right.

So, you are simply decreasing the temperature. So, decreasing the temperature of the air parcel is the main method by which clouds are formed. So, clouds I mean; moisture is there of course, and cloud condensation nuclei are very much present everywhere in the atmosphere tiny particles like we have seen in the beginning or introductory classes itself that the atmosphere also allows tiny suspended particles to be existing in it right.

So that means, that with the only method or the only process by which clouds form is by rising an air parcel or by rising an air parcel to an altitude which is very low in temperature or by decreasing the temperature of the air parcel. Now, the formation of cloud is mainly dependent on this particular aspect in which you rise the air parcel to an altitude where the temperature is very very less or you decrease the temperature of this air parcel right.

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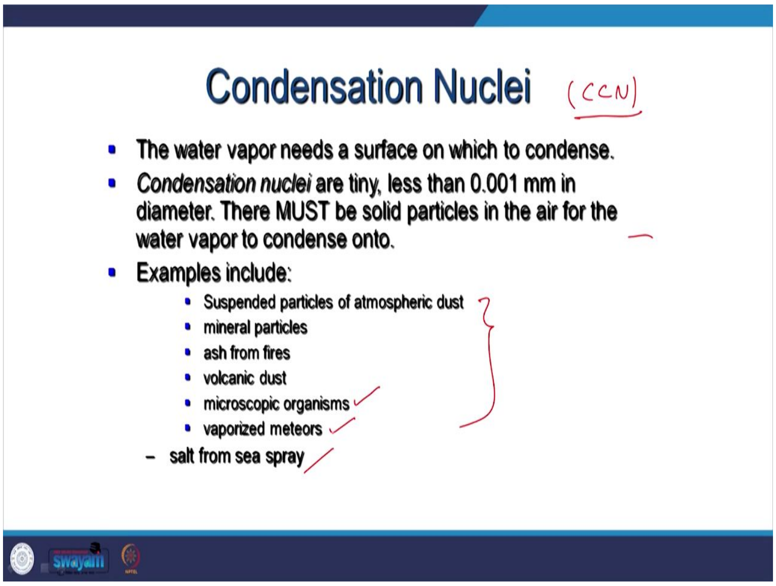

Now, let us talk about the condensation nuclei. So, what are these condensation nucleus. So, this these are called as cloud condensation nuclei. The water vapor needs a surface on which it can condense. So, that means that; when the relative humidity reaches 100 or tries to become over than 100. It needs some particles over which it can condense.

The condensation nuclei are very small, very tiny which are very very small in the sense their diameter is typically of the order of few tens of micrometer. And there must be this particles must be solid particles in the air which are suspended in the atmosphere and there can be many different types of condensation nuclei. So, the one, so, let say suspended particles of atmospheric dust mineral particles, ashes ash from the fires and volcanoes volcanic dust microscopic organisms as well and vaporized meteors.

So, meteors when they enter the atmosphere they will burn up and they will create a lot of ash and the presence of metallic species in the atmosphere. All these things conserved as condensation nuclei. So, the that their roll is just to act as a platform over which tiny droplets of clouds can form and the one more example could be the salt that is sprayed into the atmosphere from the tides of from the oceanic waves right.

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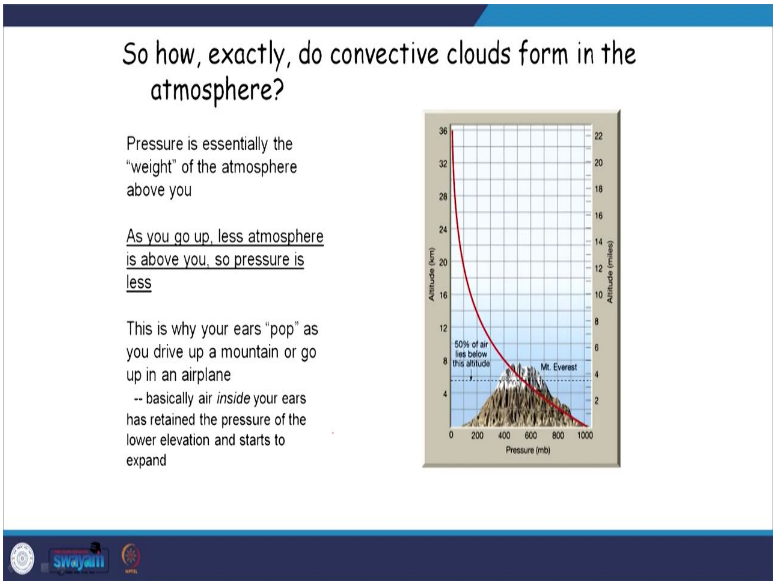

Now, so now, let see what are the what is the main method in which you can actually form clouds ok. We have learned few aspects about saturation. What are the variables which can be used to define saturation in terms of mixing ratio, in terms of vapor pressure or in terms of the amount of moisture content that is available right.

And if you have understood the concept of relative humidity, how it can be used to define saturation and what is the role of temperature in defining the conditions favorable for saturation then we went on to discuss what will happen once you reach saturation.

So, everything is going towards understanding the formation of the clouds or the physical process which will be followed in the formation of clouds. Now, at the end we have realized that for the formation of clouds we need three important things there we need moisture of course, which condenses and forms a cloud and we need a solid surface over which this the moisture can be condensed and thirdly and the most importantly of all the three things.

We need a mechanism by which we can decrease the temperature of the air parcel. So, that it allows condensation to happen. Now, in the next class what we will try to understand is, we will try to understand what are the different ways in which you can rise in air parcel or what are the different ways in which you can decrease the temperature of this air parcel. That will be the topic of discussion in the next lecture.

Thank you.