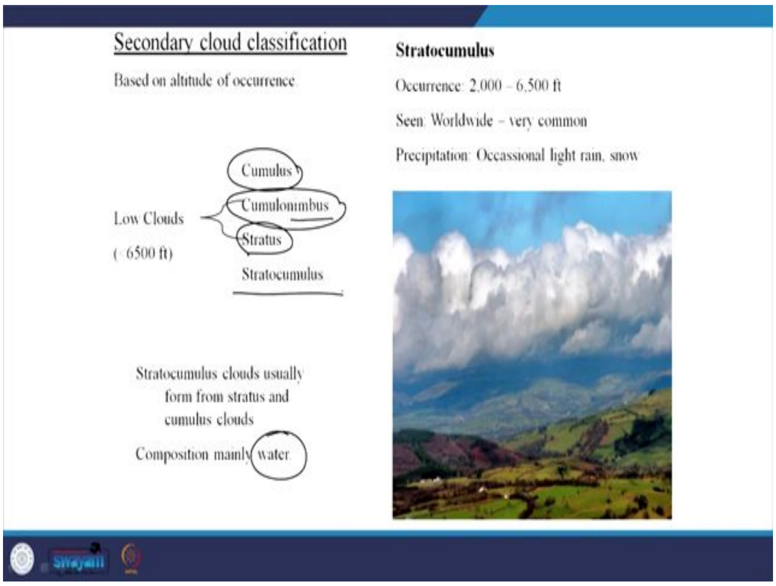
Introduction to Atmospheric and Space Sciences
Prof. M. V. Sunil Krishna
Department of Physics
Indian Institute of Technology, Roorkee

Lecture – 31
Secondary Cloud Classification and Fog

Hello, dear students. So, today, we will continue our discussions on Cloud Morphology. We have seen how clouds form or what is the importance of lifting condensation level in the process of formation of the clouds. We also seen how to identify different types of clouds, how the naming system has come into existence, how the height of a particular cloud and how the shape of a particular cloud are combined to give you the specific name to identify a certain type of a cloud we have seen all this.

Today's class we will try to understand the secondary classification of clouds or the cloud naming system and we will also try to understand the fundamental process by which fog forms or in how many different ways fog can result. We can also understand the formation of cloud droplets, what is the necessary condition for the formation of cloud droplets stuff like that. So, this lecture is the continuation of our understanding of Cloud Morphology, lecture 1 right.

(Refer Slide Time: 01:54)



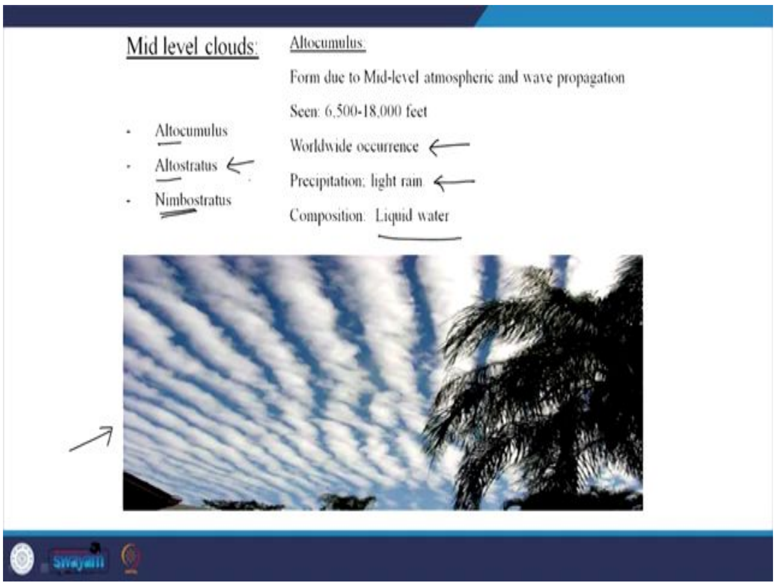
So, secondary classification of clouds is basically based on the altitude of occurrence. So, we have seen the low clouds which lie below 6500 feet that we have cumulus, cumulonimbus, stratus and stratocumulus. We also seen that we associate a particular suffix which is called as the nimbus only for those types of clouds which can result in the formation of reasonable amounts of precipitation right and stratus and stratocumulus.

So, stratocumulus clouds are usually formed from the stratus and cumulus clouds. So, we have seen stratus clouds are the ones which you see as a layered clouds and cumulus clouds are the white puffy clouds that you see are generally called as the cumulus clouds. So, when you combine them you can get to see what is called as the stratocumulus clouds. these are generally found within 2000 to 6500 feet, they are seen everywhere. So, in the earlier class we have seen what are stratus clouds and what are cumulus clouds.

So, in the secondary classification we are able to see that what are the different types of clouds in the low altitudes; that means, below 6500 feet. So, one of that is the stratocumulus cloud. So, it is a very commonly seen type of cloud that you can see anywhere. A precipitation is occasional you do not expect heavy rains if you see this type of cloud in the sky right.

And, they are mainly composed of water. So, that means, that depending on the altitude of occurrence of course, the content is already decided; that means, what can be the primary content I mean is it going to be water or is it going to be ice right.

(Refer Slide Time: 03:22)



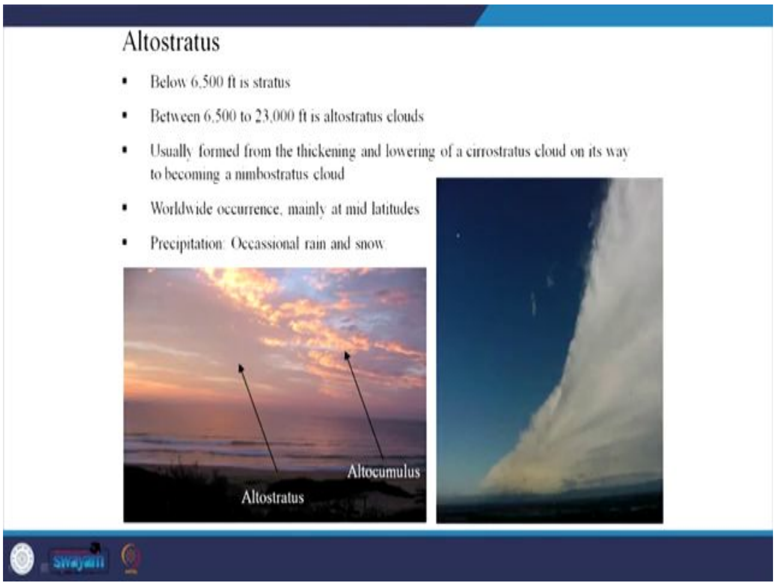
Then, the mid level clouds apart from the low level clouds you have also have the mid level clouds which are altocumulus, altostratus and nimbostratus right. So, here you see alto which indicates the height which are upper altitude regions and nimbostratus nimbo means the moisture content right.

So, for example, altocumulus they form due to the mid level atmosphere and wave propagation. So, this is how they look like So, they form due to the atmospheric wave propagation. So, waves such as gravity waves or propagating waves will result in the formation of this type of cloud. So, they are seen in the mid level of altitude. So, we cannot say that it is mid altitude rather it is mid range altitude for the clouds formation. So, it is generally results in 6500 to 18000 feet.

So, we have seen less than 6000 as the low level clouds stratocumulus stratus we have seen stratus cumulonimbus right. So, here one more important thing that I have forgot to mention stratus clouds we have also seen the status clouds by the basic shape of the cloud; cumulus cloud we also see and cumulonimbus cloud does not generally confined to one particular height. It spans the entire altitude ranges of the clouds, it is from the lowest of the low to the highest of the high right.

So, this only other type of clouds is the stratocumulus cloud and when you bring in mid heights mid level altitudes we say that the altocumulus is the one. So, which can be seen worldwide you can see it everywhere; precipitation is light rain, it is not so much and they are mainly composed of liquid water right.

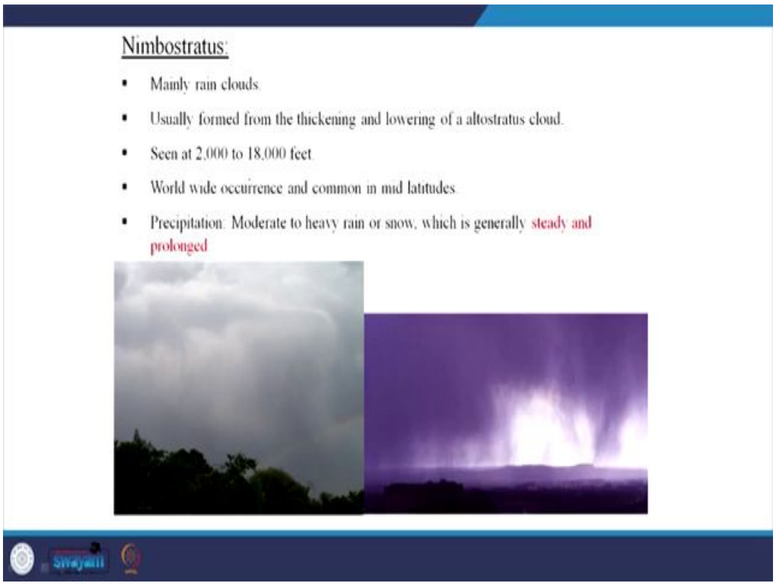
(Refer Slide Time: 06:15)



And, the altostratus – so, the next type of cloud is altostratus; altostratus clouds generally form from 6500 to 23000 feet is altostratus. So, we have seen what is the stratus cloud. Stratus cloud is like a layer which is generally found below 6500 feet if this cloud rises further up by any mechanism this will result into the formation of altostratus clouds.

So, usually they are formed from the thickening and lowering of the cirrostratus cloud on its way to becoming a nimbostratus cloud and they are to be seen everywhere worldwide occurrence you can see them to be occurring everywhere and mainly at the mid latitudes. Mid latitudes are the places where you can find altostratus clouds. A precipitation that you can expect from this type of cloud is occasional rain and snow because they are at high altitudes, you can also expect some amount of snow.

(Refer Slide Time: 06:13)

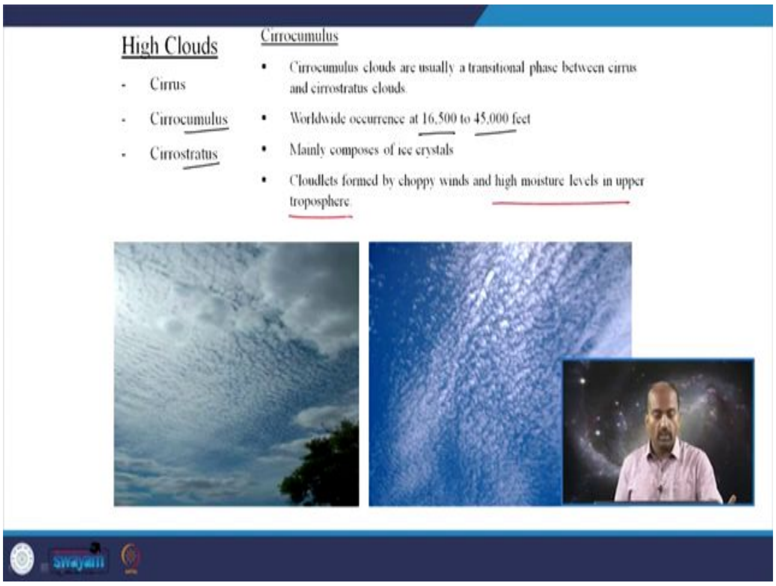


And, nimbostratus cloud which is again a mid level cloud these are the main rain clouds. Apart from the cumulonimbus clouds, nimbostratus clouds are the clouds which bring a reasonable amount of precipitation. Cumulonimbus clouds bring heavy amounts of precipitation, but nimbostratus clouds are the ones which will bring moderate to high amounts of precipitation for most of the latitudes.

So, this is seen worldwide occurrence you can see it everywhere and most common in mid latitudes that is 30 to 60 degree latitude. So, they are usually formed from the thickening and lowering of altostratus cloud. We have just seen what is altostratus cloud; from the thickening of altostratus cloud we can see the formation of nimbostratus clouds.

So, precipitation that you can expect from this type clouds is moderate to heavy rain or snow which is generally steady and prolonged. So, this type of clouds generally give you a lot of precipitation and this precipitation lasts over a very long period of time right.

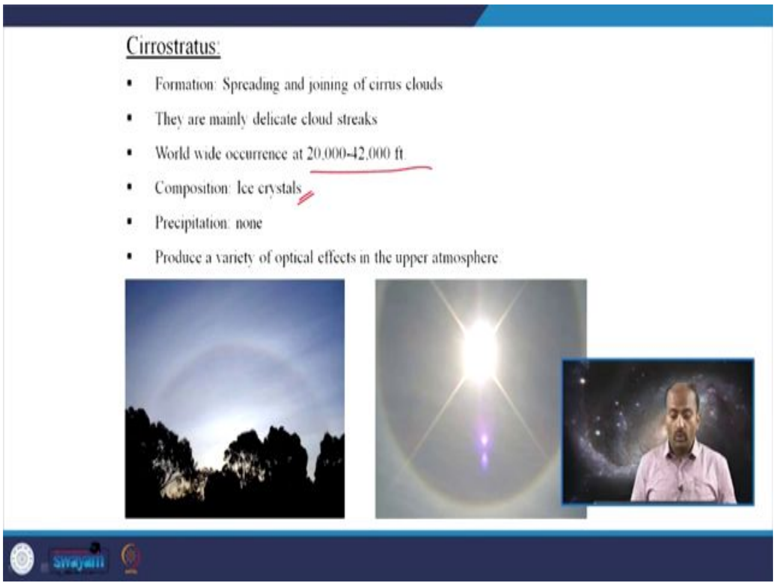
(Refer Slide Time: 07:18)



Then based on the height the third altitude or the level is high clouds which are found in at very high altitudes above let us say 15000 or 16000 feet. So, there are three different types of clouds which can be seen at these heights where they are cirrus, cirrocumulus and cirrostratus. So, in the primary classification again I am telling you in the primary classification we have seen how these names mean a particular type of cloud.

So, for example, cirrocumulus: cirrocumulus clouds are usually a transitional phase between cirrus and cirrostratus clouds. They can be seen everywhere between 16500 to 45000 feet. They are mainly composed of ice crystals. They are at very high altitude, so, it is natural that they are mainly composed of the ice crystals. And, cloudlets formed by choppy winds and high moisture levels in the upper troposphere. So, this will result into this type of process right.

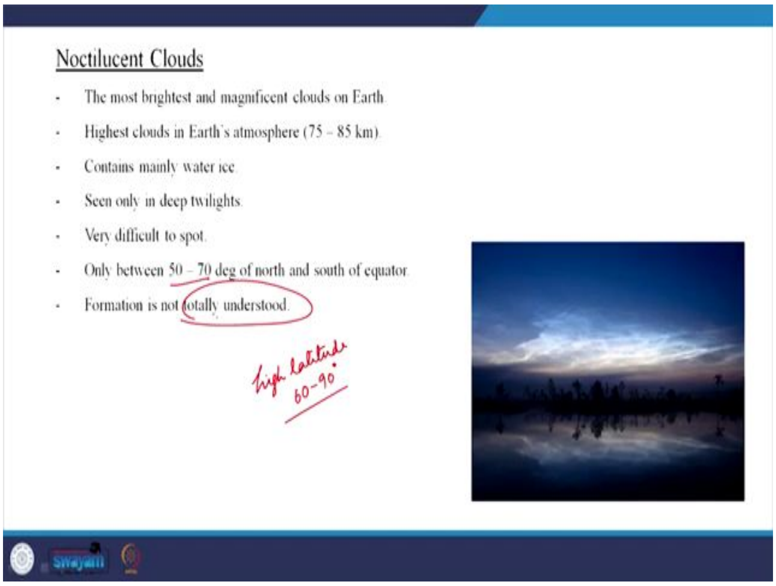
(Refer Slide Time: 08:28)



Now, the other type of high level high lying clouds is cirrostratus. They are formed by spreading and joining of cirrus clouds. They are mainly delicate clouds streaks that you see during the formation of halo or something like that. They are high level clouds; that means, they can be seen worldwide at very high altitudes 20000 to 42000 feet.

Composition is mainly ice crystals that is how it results into this let us say the formation of halo and precipitation is none. Since they are very high altitudes they would not precipitate and even if they precipitate that would never reach the surface. And, produce of very various effects various optical effects in the upper atmosphere such as halo and these things ok.

(Refer Slide Time: 09:15)



Then other important type of cloud which is not relevant for the precipitation or for the moisture or for the phase transitions stuff like that they are called as the noctilucent clouds. They are the most brightest and the magnificent clouds that we can see from the earth. The highest clouds they are not in the altitude ranges that we have defined for identification of clouds or for classification of clouds, they are typically from 75 to 85 or 90 kilometers altitude. There is still a lot of research that is going on to understand the formation and the effects of noctilucent clouds.

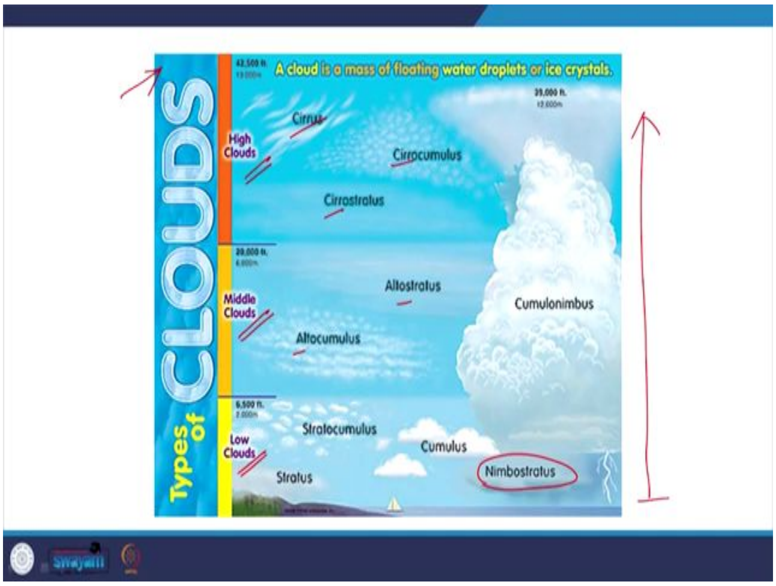
They mainly contains of water ice. they can be seen only in deep twilights; twilight it is a period of time when the sun is below the horizon and still you will find illumination, and they are very difficult to spot. They are very difficult to identify or the sightings are very rare and they occur only between 50 to 70 degrees north and south of the equator.

So, they are the clouds which will form in the high latitudes; high latitudes are generally 60 to 90 degrees right. So, you see the formation is not totally understood. We do not know much or we do not know completely the formation mechanism of this type of clouds, but they are the brightest or they can be easily seen with the brightest and magnificent occurrence right.

So, this kinds of completes the morphology of the cloud formation. I mean, in how many different ways you can identify the cloud looking at the cloud what can you say about its precipitation chance things like that. So, I suppose with this understanding you will be able to just out of the window if you see I suppose you must be able to understand or you must be able to tell what is the name of the specific type of cloud that you see out of your window, right.

Then if you put them all together let us say so, this is how it looks like. So, the cloud is just a mass of floating water droplets or ice crystal; always remember, when cloud is just a mass which has tiny droplets of ice or some ice crystals right. Now, clouds result into the formation of rain only when the droplets inside them grow to sufficiently large sizes and, that means, when the cloud destabilizes when the stability is gone by some mechanism it will result in the formation of rain.

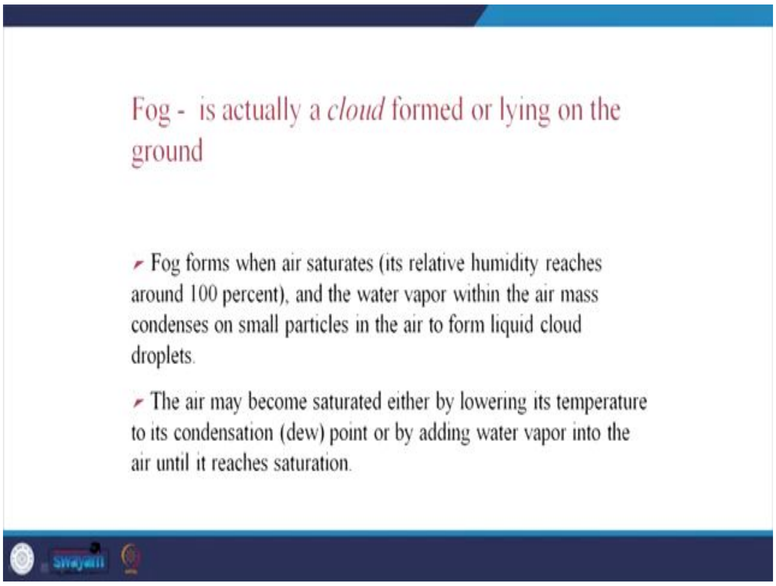
(Refer Slide Time: 12:05)



So, what you see in this figure is that the highest altitude is marked at 42500 feet. So, anything below 6500 feet was named as low clouds and these are the mid clouds and the high clouds. Now, the low clouds are stratus which are layered stratocumulus which are spread; cumulus are the puffy or you know white well defined bordered clouds; nimbostratus is the clouds which will bring precipitation again and cumulonimbus is the cloud which is spread of course, across all the altitude regions of the cloud formation heights and, cumulonimbus clouds is the one which brings heavy amounts of precipitation, wind and so many other things.

And, when you go to the mid level clouds you have altocumulus, altostratus and cumulonimbus of course, and in the high you have cirrostratus you have cirrocumulus and cirrus right. So, this is the summary of all the cloud formation heights various different types of clouds, what is the moisture content that you can expect within these clouds right.

(Refer Slide Time: 13:14)



Then, we will see what is fog. Fog is also a cloud that is formed not on not in the sky rather which lies on the ground. So, fog is not to be named as a not to be understood as a different mechanism rather it is the same it is actually a cloud which has formed on the ground right.

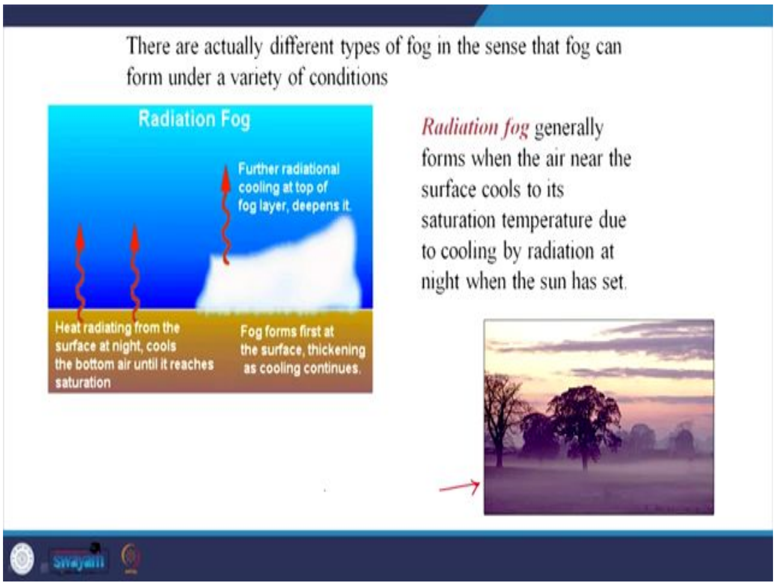
Now, if you look back the basic idea of the cloud is that when you cool an air parcel you are reducing its ability to hold water or you are reducing its ability to contain more amounts of water; that means, you are bringing the saturation point to lower limits. That means, whatever the amount of saturation that it had is now enough to have super saturation case.

So, when the super saturation happens when you exceed the saturation limit it immediately results in the formation of condensation and condensation requires some amount of nuclei are on which the droplets will form, when the droplets form you see a cloud that is it. So, when the moisture condenses you will see a cloud. When the moisture condenses it will also release some amount of latent heat into the parcel that is a different thing right.

Fog generally forms when air saturates when it is relative humidity reaches around nearly 100 percent, and the water vapor within the air mass condenses or small particles in the air to form the cloud droplets. The water vapor condenses on the small particles and results in the formation of cloud droplet. the air may become saturated either, we have also seen the air may become saturated either by lowering its temperature to the condensation point or by adding more amount of moisture physically you can do both of them.

But, generally adding more moisture is not themechanism that works generally when the air parcel rises it is temperature is decreased because it is within the top of pause right. So, you are decreasing the temperature and you are bringing the point of saturation to a lower level of moisture content right.

(Refer Slide Time: 15:32)

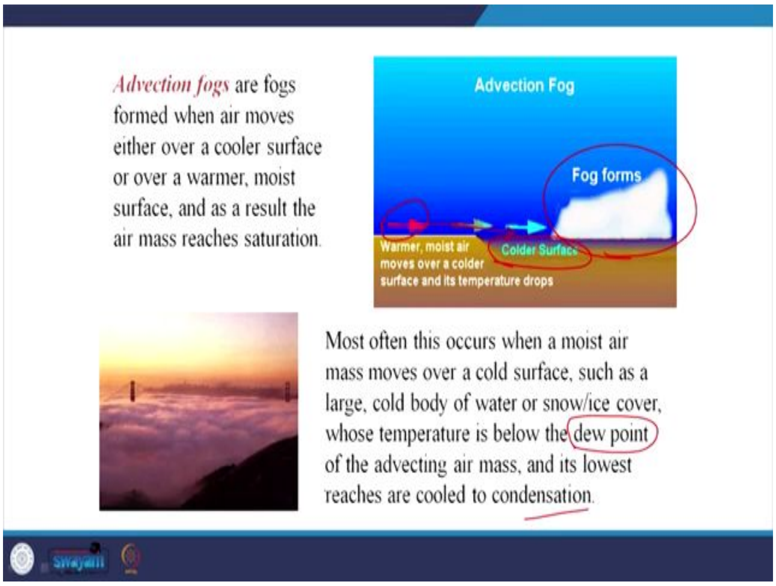


So, what you see here so, there are actually different types of fogs that you see that you must have encountered in the sense that, fog can form under a variety of conditions ok. Generally what happen heat radiating from the surface at nights cools the bottom air until it reaches saturation right, further radiation cooling at the top of fog layer deep in sit. So, generally during the winter season the ground is cooled to a very low temperature.

Now, if there is an amount of heat that is just above the surface or above the ground now when the ground cools to a very low temperature obviously, the air that is in contact with the ground also cools down. So, when it is cooling down obviously, the same mechanism repeats itself; when it is cooling down it leads to the condensation and condensation leads results in the formation of tiny droplets of water. the collection of these tiny droplets of water is the fog in this case, not the cloud we call it as fog because it is nearer to the ground right.

So, fog forms first at the surface, thickening as cooling continues. So, as this cooling process continues the fog thickens. This type of cloud that is formed due to the radiation; radiation is called as the radiation fog generally forms when the air near the surface cools to its surface saturation temperature due to the cooling by radiation at night when the sun has set ok. So, you must have seen this type of cloud, this type of fog near at the surface of near the ground but it's thickening happens as it radiates more and more amount of heat out right.

(Refer Slide Time: 17:19)



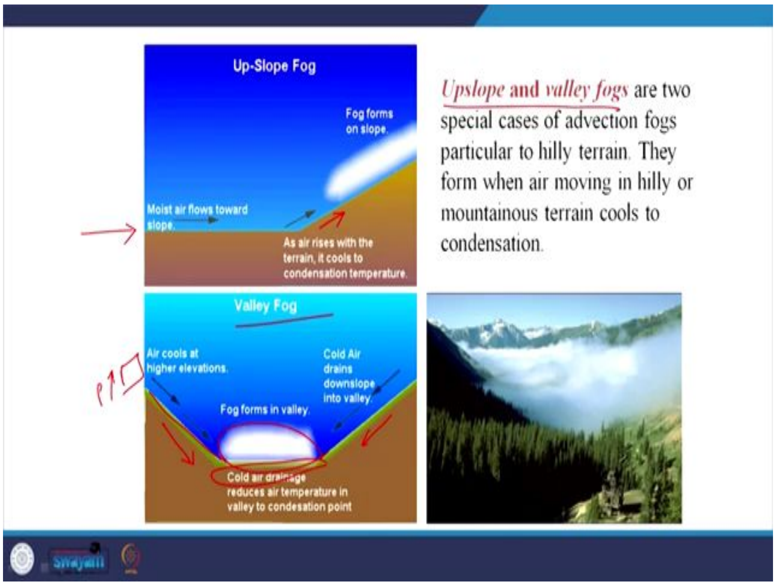
The other type of fog is called as the advection fog. Advection fogs are the ones which are formed when air moves either over a cooler surface of or over a warm moist surface and as a result the air mass reaches saturation. So, if you see this figure what is happening is the air is moving in this direction. So, air is at this point air is warmer means it has the it has more ability to hold moisture.

So, warm and moist air moves over a cooler surface and its temperature drops. So, it is suddenly encountering a surface which is cool in nature. So, suddenly the temperature of this air mass decreases. When the temperature of this air mass decreases suddenly it reaches saturation when this air is moving so, advection fog is generally formed at a point which is not cool rather due to the moment the fog is formed here right.

So, most often this occurs when moist air mass moves over a cold surface such as a large cold body of water or snow or ice cover whose temperature is below the dew point. So, the dew point is always the criteria for the condensation to happen or of the advecting air mass dew point of the advecting air mass and it is lowest reaches are cooled to condensation. That means the lowest reaches which are in contact with the cold surface will get to the point of condensation and result in the formation of clouds or in this case we call them as fog right.

So, what I mean is air mass which is traveling from which is going from one point other point some point it may encounter a very cold surface such as water or ice suddenly it becomes cool there it saturates and results in the formation of a cloud.

(Refer Slide Time: 19:14)



The other type of clouds are the upslope and valley fogs are two special cases of advection fog particularly to a hilly terrain. They form when air moving in hilly or mountain terrain cools to condensation. So, let us say , upslope fog let us say moist air hot and moist air is traveling from this direction. So, as it travels towards a hilly or terrain which gives the advantage of height.

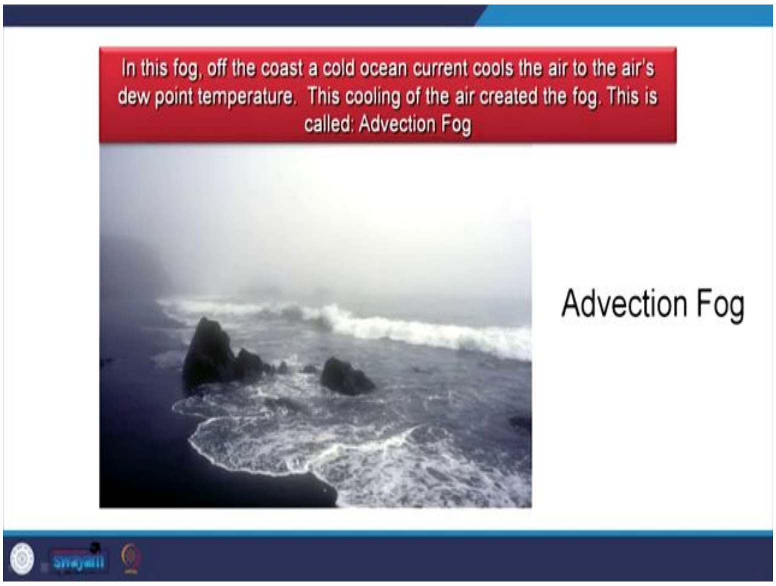
As the air rises now the air is moist it has not reached the saturation, but when it travels across the slope it is height is increased right it is lifted of course, as it rises with the terrain it cools to condensation temperature. So, as it is lifted in may its temperature is of course, cooled and at some point it can form a cloud, but this happens across the terrain. I mean, it is not a mechanism where you are lifting the air parcel and this air parcel that has been lifted goes to your height and then forms a cloud rather this cooling happens as it is lifted across the terrain.

So, that is why you call them as the upslope fog. And, the valley fog is another type of fog as you see in this picture. So, here air cools at higher elevations you know as it cools the density increases of course, the density increases. So, density increases. So, it has the natural tendency to occupy low altitudes right. So, then this elevation also supports this as it cools at higher elevations it cools and it condenses near the valley whereby you see at a particular type of cloud which is called as the valley fog.

So, cold air drainage reduces the air temperature in the valley to condensation point ok. So, the cold air is draining across the valley to a low a point where it condenses and forms what is called as the valley fog. So, how many different types of fog that we have seen? We have seen a radiation fog you know it generally the radiation that is lost creates certain type of cooling mechanism or which fog has resulted.

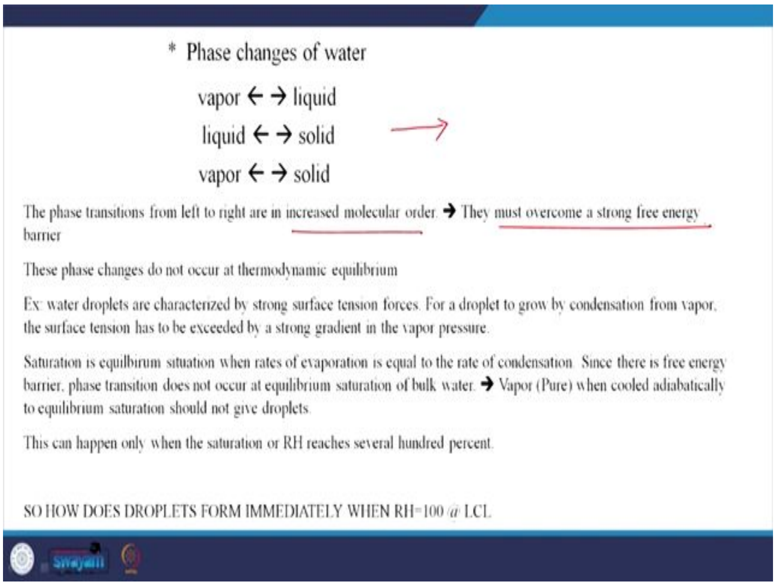
Then we have seen advection fog. Advection fog is the one in which forms due to air advecting from one point to another point within that following the same process; that means, air mass moving from one point another point in between it encountering the condensation. You have also what is called as the upslope fog and the valley fog right.

(Refer Slide Time: 21:57)



Then, so, this is another type of cloud advection fog in this fog, off the coast a cold ocean current cools the air to it is dew point temperature allowing condensation to happen. This cooling of air created this fog let us say this is the picture that you see. So, this fog is just because of the cold current ocean current which saturates the air that is above the ocean right.

(Refer Slide Time: 22:25)



Now, if you look at the basic mechanism of the cloud condensation what you can understand based on or elementary understanding of the phase transitions. Now, in the atmosphere we can always see water to be existing you know it is three different phases – water, liquid water, ice crystals and the vapor water vapor right. Now, if you look at the phase transitions vapor to liquid or liquid to vapor liquid to solid or solid to liquid vapor to solid or solid to vapor.

The phase transitions from the left to right that you see you have all the phase transitions listed here the phase transitions from the left to right are the ones which result in the increased molecular order. That means, if you take a vapor and if liquid arises from this vapor; that means, vapor transforms it is phase to liquid then; that means, that it has resulted in increased molecular order. That means, that for the increased molecular order they must overcome a strong free energy barrier naturally right.

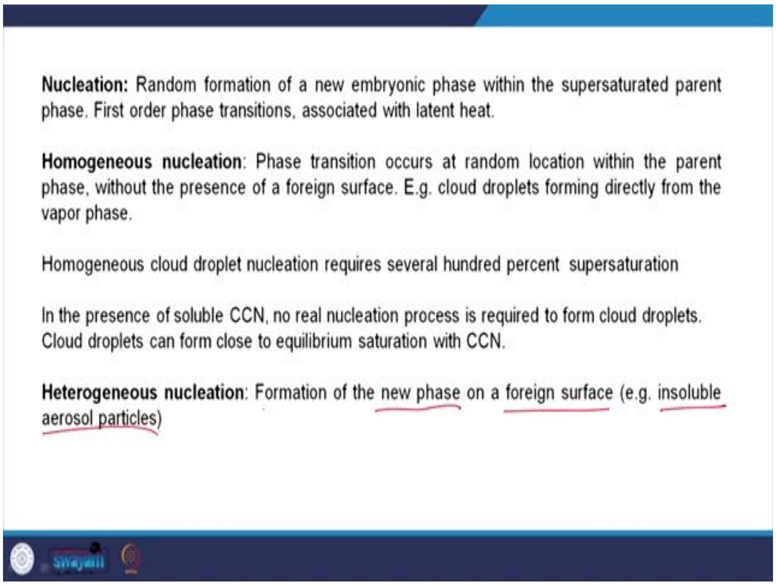
These phase changes do not occur at thermodynamic equilibrium for example, water droplets are characterized with strong surface tension forces. For a droplet to grow by condensation from vapor the surface tension has to be exceeded by a strong gradient in the vapor pressure. So, as the droplet grows it has to grow at the expense that there has to be gradient in the vapor pressure.

Now, saturation is equilibrium saturation when the rates of evaporation are equal to the rates of condensation. If you consider the droplet, if a molecule has to escape this droplet it has to cross the surface tension barrier. So, saturation is some equilibrium point when the rate of evaporation is equal to the rate of condensation. Now, since there is a free energy barrier phase transition does not occur at the equilibrium saturation of bulk water right.

Vapor the pure phase when cooled adiabatically to equilibrium saturation should not give droplets. Purest phase of vapor without any impurities or without the presence of any foreign nuclei which can absorb water will never result into the formation of droplets even when the relative humidity reaches 100 percent. I mean the formation of droplets can only happen if the relative humidity reaches several hundred percent right.but we have seen that the how does the droplets form immediately when the relative humidity reaches just 100 percent at the lifting condensation level right. So, the point is if you have purest phase; that means, no impurities in that particular phase you will not encounter the droplet formation even if the relative humidity is 100 percent. That means the vapor, the gas or let us say the vapor is entirely water vapor then you cannot expect water droplets to form the vapor phase right.

Then the question is how do we expect droplets how do we actually see the droplets to form immediately when the relative humidity has reached 100 percent. where does this happen? This happens at the lifting condensation level right.

(Refer Slide Time: 26:01)



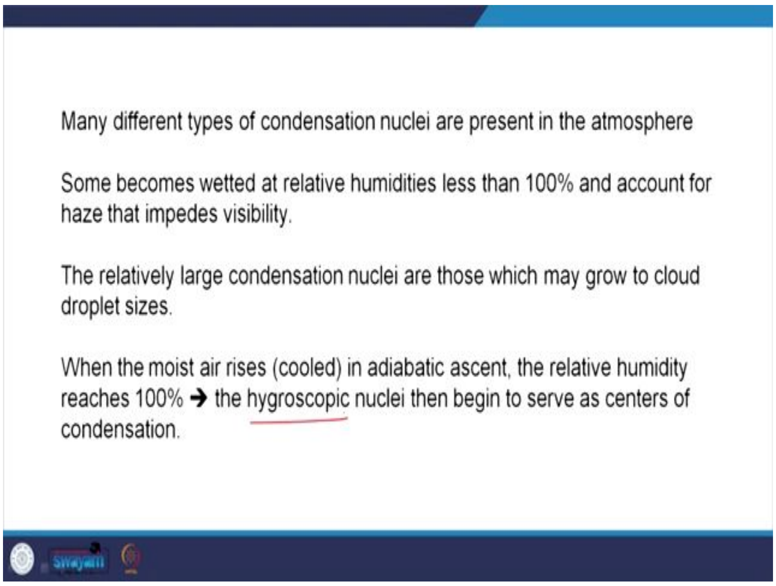
So, the process in which droplets form out of the vapor is called as the nucleation right. So, random formation of new embryonic phase within the supersaturated parent phase is called as the nucleation. Again, the random formation of a new embryonic phase within the supersaturated parent phase is called as a nucleation. This is generally a first order phase transition and always associated with a latent heat; that means heat it is given out or heat is taken.

That homogeneous nucleation is one process is a type of nucleation. Homogeneous nucleation is the one with without the add of the foreign nuclei or foreign phase. Phase transitions that occur at random at random locations within the parent phase without the presence of a foreign surface, example the cloud droplets forming directly from the vapor phase directly from the vapor phase without the add of any other foreign substance.

Homogeneous cloud droplet nucleation require several hundred percent super saturation. So, generally we always take it to the point of hundred percent then we expect saturation then we expect saturation and then we expect transition, then the droplets right. So, in the presence of soluble cloud condensation nuclei no real nucleation process is required to form cloud droplets and cloud droplets can form close to equilibrium saturation with the help of cloud condensation nuclei. This process is called as the heterogeneous nucleation.

So, which is the formation of new phase, new phase is the liquid phase here on a foreign surface which are insoluble aerosol particles right.

(Refer Slide Time: 27:48)

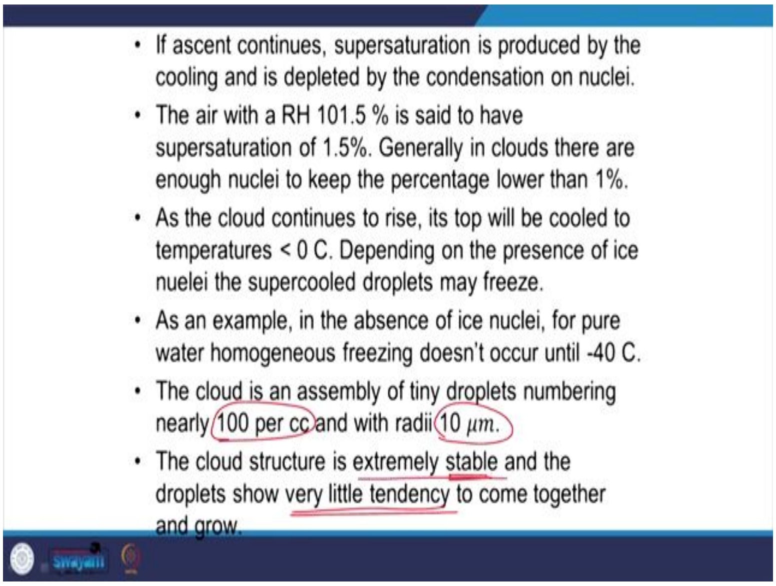


Now, So, many different types of cloud condensation nuclei are present in the atmosphere they are always there right. Some becomes wetted I mean they at relative humidity is less than 100 percent and account for haze that impedes visibility right. So, below the dew point itself sometimes many times during the winter these particle absorbs the water vapor and results in the formation of tiny droplets which we generally called as the haze which really impedes visibility right.

The relatively larger condensation nuclei are those which may grow to cloud droplets. So, cloud droplets are small of course, but when the cloud droplet grows beyond a particular size you call them as the rain droplets that is the different story right. So, when the moist air rises by any force and lifting mechanism in an adiabatic ascent the relative humidity reaches 100 percent and the hygroscopic nuclei then begin to serve as the centers of condensation.

What is hygroscopic? Hygroscopic is the nature to attract water or to get dissolved in water; hygroscopic nuclei then begins to serve as the centers of condensation right.

(Refer Slide Time: 29:12)



Now, if the ascent continues as it is the super saturation is produced by the cooling and these depleted by the condensation on nuclei right. The air with a relative humidity of nearly let us say 101.5 percent is said to have a super saturation of 1.5 percent generally in the clouds there are enough nuclei to keep there are enough nuclei to keep this percentages lower than 1 percent. So, the cloud droplet or the cloud condensation nuclei would not even allow a relative humidity of 101 or 102 percent.

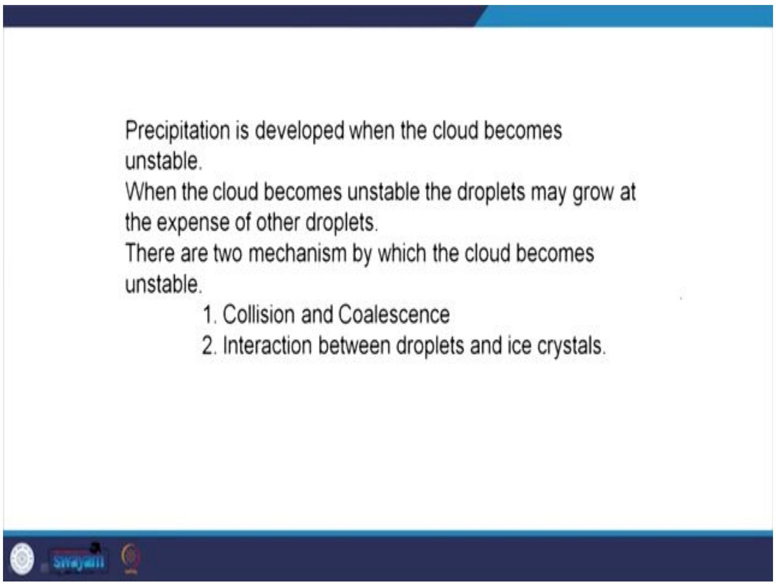
So, they will always keep the relative humidity or the excess some are the super saturation percentage lower than 1 percent. As the cloud continues to rise it is top will be cooled to temperatures below 0 degree Celsius because we have seen in troposphere how much is the lapse rate and starting from let us say 28 or 20 degree Celsius on the ground the temperature reduces to 0 degrees sooner.

So, depending on the presence of ice nuclei the super cooled droplets may freeze because if the temperatures are below the freezing point the vapor will transform there will be a phase transition from vapor to solid phase resulting in the formation of ice crystals. So, as an example in the absence of ice nuclei for pure water homogeneous freezing does not occur until minus 40 degrees. So, that is a difference.

So, if you are rising just at 0 degrees Celsius, vapor will become ice crystals with the help of ice nuclei. If you do not have ice nuclei the temperature should at least go up till minus 40 degrees Celsius. So, the cloud is an assembly of tiny droplets from numbering nearly 100 per cc cubic centimeter and with the approximate radius of 10 micrometers right.

Then the cloud structure the vertical structure of the cloud is extremely stable and the droplets show very little tendency to come together and grow. So, given this density the number of cloud droplets within the cloud and with this radius, we say that the cloud is structure is extremely stable and the droplets show very little tendency to come together and grow.

(Refer Slide Time: 31:41)



So, if you want to destabilize so, precipitation is developed. So, now one important point that you should understand is that the cloud structure is extremely stable it would not allow the droplets; droplets naturally do not have the tendency to come together and grow ok. So, precipitation is developed when the cloud becomes unstable, only.

When the cloud becomes unstable like I said the precipitation is developed when the cloud becomes unstable the droplets may grow at the expense of other droplets. There are two mechanisms by which the cloud becomes unstable. They are, collision and coalescence one mechanism or interaction with droplets and ice crystals right. So, this is the these are the mechanisms by which the cloud will eventually result in the formation of precipitation right.

So, we will learn about these two mechanisms and how we can quantify the rates at which these two mechanisms will work towards the formation of cloud and many other things in the subsequent classes ok.

Thank you.