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

Lecture – 26
Convection of Air and Types of Convection

Hello dear students, so in continuation to our discussions on atmospheric thermodynamics, we have seen what is equivalent potential temperature in the last class. Today we will continue our discussions on parcel lapse rates. So, let us consider an air parcel.

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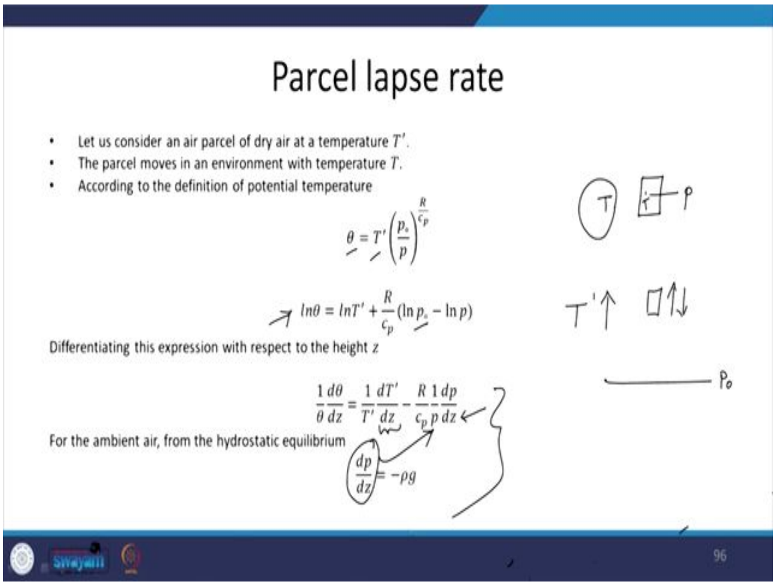

So far, we have considered an air parcel and this air parcel is at the same pressure as the surroundings and the temperature can be anything. I mean the change in the temperature will only decide whether the air parcel is going to rise or sink.

So, let us consider the parcel of dry air at a temperature T prime. So, the temperature inside is considered to be T prime the parcel moves in an environment with a temperature T. So, the temperature outside is taken to be T. So, we have defined the potential temperature to be that particular temperature which an air parcel will eventually reach if it is compressed or expanded to reach the sea surface or the standard pressure right.

So, we can define that the potential temperature with respect to the temperature of the air parcel T prime as this. So, theta is equals to T prime times p naught by p raised to the power

R by Cp right. So, we can take a logarithm of theta, then differentiating with differentiating this expression with respect to z with respect to the height.

So, we are trying to find out how the temperature of the air parcel changes. Let us say how it changes and as the air parcel rises or sinks in comparison to the putting the standard pressure p naught with reference. And let us see how the temperature varies with respect to height and how it connects or how it relates to the dry adiabatic lapse rate or moist adiabatic lapse rate right.

So, we are taken a derivative of ln theta which will be take a logarithmic derivative of this expression. So, it will be 1 by theta d theta by d z is equals to ln T prime is 1 by T prime d T prime by d z. So, this is the lapse rate that I am talking about. So, this lapse rate tells you how the temperature changes inside the air parcel. Subject to the conditions that the air parcel is adiabatic in nature with our assumptions and there is no exchange of heat. At the same time it is at the same pressure with respect to the surroundings.

So, this derivative we will give you R by Cp this p naught being a constant this term will be 0 and minus ln p will be 1 by p d p by d z. So, the derivative is with respect to the height. So for ambient air so that means, with respect to the temperature capital T the hydrostatic equilibrium can be simply d p by d z is equals to minus rho g. So,it tells you how the pressure of the ambience changes with respect to height and how it relates to the gravity right.

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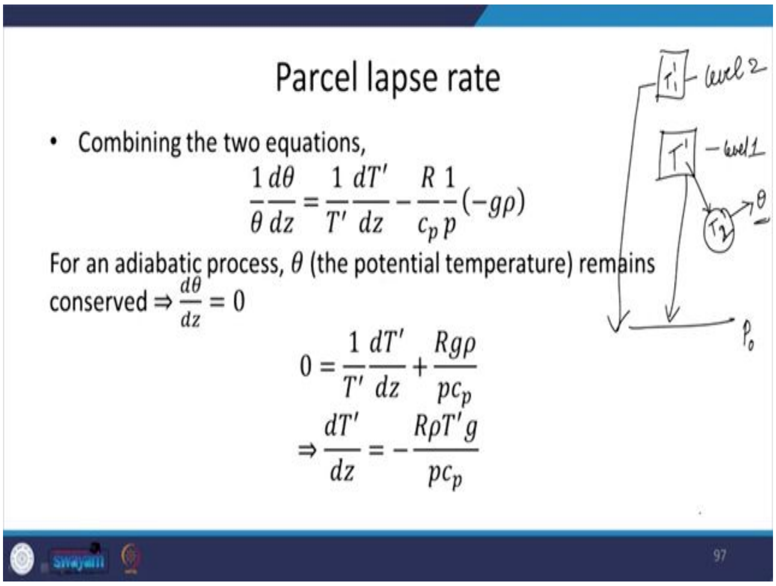

Now, if we can use this term into this part right. So, we can combine these two equations 1 by theta so the same expression. So here we have used this we have combined these two expressions. What we will get is 1 by theta d theta by d z is equals to one by T prime d T prime by d z minus R by Cp into 1 by p times minus g rho right.

So, for adiabatic process when we discussed the potential temperature, we were talking about the invariance of few physical quantity. Generally in an adiabatic process d q is 0; that means, heat taken or heat given out is 0 and this will make sure that the potential temperature will remain a constant if the process is adiabatic. That means, if you rise a parcel from one point, say let say level 1 to level 2 let say.

Now, here the most important is that the pressure at the surface or the reference pressure is p naught. Now according to the definition of potential temperature we can say that if the temperature inside is T prime. Now if you bring this air parcels pressure to this p naught, then whatever the temperature T prime that will become T prime to T let say T 1 or T 2 let say.

This T 2 is called as the potential temperature right or you can also say this is T 1 prime the temperature at the level 2 is T 1 prime. Let say even if you bring this air parcels pressure to the surface pressure which is p naught, this temperature will also be theta. That means, as long as there is no heat input or output from this air parcel, the potential temperature will remain a constant that is the basic idea. So, a process which keeps the potential temperature constant is called as the adiabatic process right.

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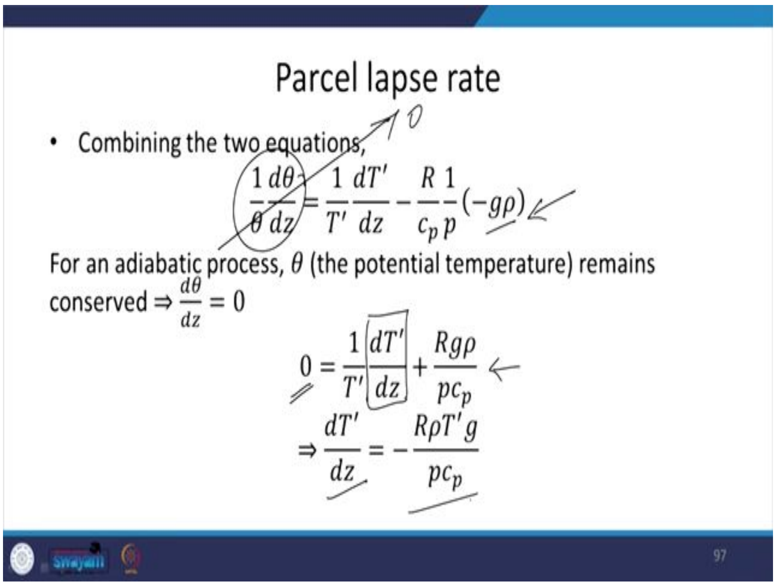

So, in this equation we can take it for granted that when we are talking about parcel lapse rates, that how temperature changes with respect to height. It will be guaranteed that within the parcel the potential temperature will always be kept constant not temperature. But the potential temperature will be kept constant. So, this term straightforward becomes 0 right. So, what you have left with is 1 by T prime d T prime by d z.

So, d T prime by d z is what we want to find out we want to find out we want to understand how temperature changes inside the air parcel. But why is the temperature should change the inside the air parcel that is the question? For starters what we can see is if the air parcel is rising for some reason whatever the stability that permits this rise, if the air parcel is rising in order to keep itself at the same pressure as the ambience the parcel must expand. So, when this expansion happens this expansion has to be at the expense of the internal energy of the air parcel.

So, if the internal energy is taken out automatically the temperature will decrease. So, this is one reason why temperature should decrease in the first place for an air parcel which is assumed to be adiabatic right. Now we are trying to find out how this expression looks like.

So, we have simply substituted this into this, so d T prime by d z is the rate of change of temperature inside the air parcel with respect to height. So, this becomes now 0, so d T prime by d z can simply be written as R rho T prime. So, this is just rearranging this term R rho T prime into g divided by p Cp right. That is what I have we have written carried forward here.

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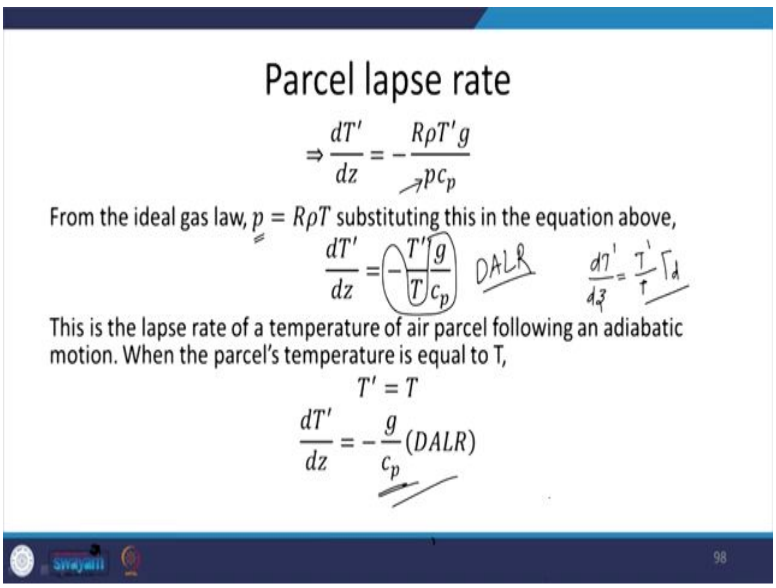

So, from the ideal gas law, so pressure p is R times density times temperature substituting this into this part. So, d T prime by d z is equals to T prime by T into g by Cp right. Now we know that this part g by Cp minus g by Cp is called as the Dry Adiabatic Lapse Rate we have written here already. So, this part so d T prime so to be more precise, d T prime by d T is T prime by T times gamma d.

That means, the rate at which temperature changes inside the air parcel is of course dependent on the dry adiabatic lapse rate, but also on the ratio of temperatures between the air parcel and the surroundings let say the atmosphere is stable with respect to the parcel. That means, the parcels convective moments are not allowed, in that case the temperature inside the air parcel is also equal to the temperature outside the air parcel.

So, their entire stability derivations that we have seen are basically built up on this concept that temperature changes are the ones which will allow the air parcel to rise or sink right. So, we can say that the rate at which the temperature changes inside the air parcel is simply equal to the dry adiabatic lapse rate multiplied by the ratio of the temperatures right.

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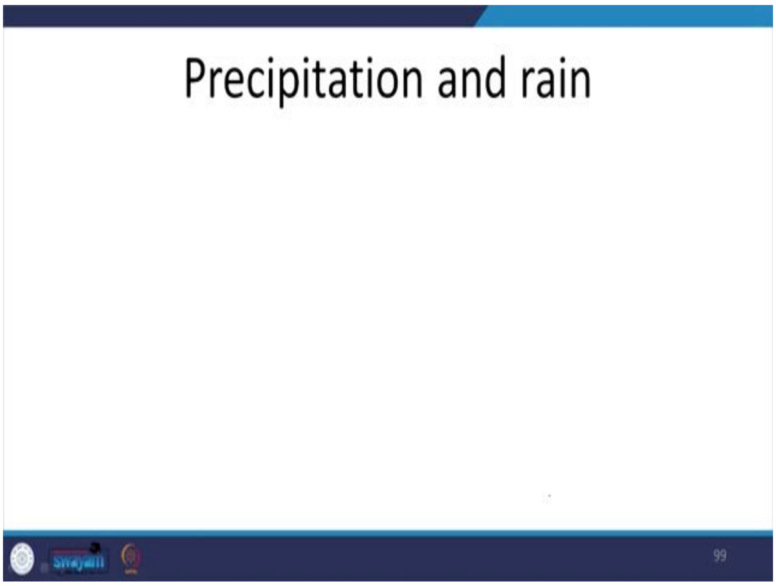

Now, so, we have seen what is the stability, what kind of stability allows an air parcel to rise and why the rise of the air parcel is important ? It is important to understand the concept of condensation, it is important to understand the idea of formation of the clouds various different types of the clouds and so many things right.

So, atmospheric stability we have seen in detail. How we can calculate the frequency of the oscillations which are permitted by the stable atmosphere and when the atmosphere can be called as neutral, when the atmosphere can be called as conditionally stable when the atmosphere can be called as absolutely stable or absolutely unstable. So, having discussed all these things its now appropriate for us to go ahead and discuss the processes of Precipitation and rains.

So, we will cover a lot of discussion on the clouds, how the clouds are formed how many different types of clouds exist all these things. But after that we will have to understand what is the process of precipitation and how does rain form. So now so far in our understanding whatever the convective processes or any other process which could lift the air to a particular height which is called as the lifting condensation level will be responsible for the creation of clouds.

So, today we will touch upon the basics of something like that and then we will see how we can mathematically understand the precipitation process and what kind of effects are important to decide the rate of precipitation and things like that right.

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So, let say if you just look at the various different types of clouds, you will always notice that there are some clouds which will be vertically developed. That means, their vertical extent the top of the cloud is at a very great height and you will always see that many times.

Like 90 percent of the times you will see that clouds are not vertically developed rather they are suspended in at 8 to 10 kilometers altitude with not much vertical development right. And it is also to be noticed that whenever you have large accumulation of vertically developed clouds which are also called as the cumulonimbus clouds, the chances of rain or any other natural precipitation process are very likely right.

So, what are the primary means of convection. let say the by the means of convection, I am just trying to understand how a bubble can travel from the surface towards the higher altitudes. Because it's movement is against the gravity.

So, by all means we always take it for granted that the atmosphere is in hydrostatic equilibrium, which means the vertical pressure gradient force is always balanced by the gravitational pull. So, as long as this balance is held, the parcel or the any bubble should not rise into this kind right.

So, there are four different ways in which this can be achieved one is Surface heating surface gets heated up, the air near the surface is low becomes low intensity. So, it naturally has a tendency to rise right. So, topographic lifting is when the air encounters a land mass which is building up on an elevation. So, the air will travel across the elevation and it will reach the higher altitudes allowing condensation to happen.

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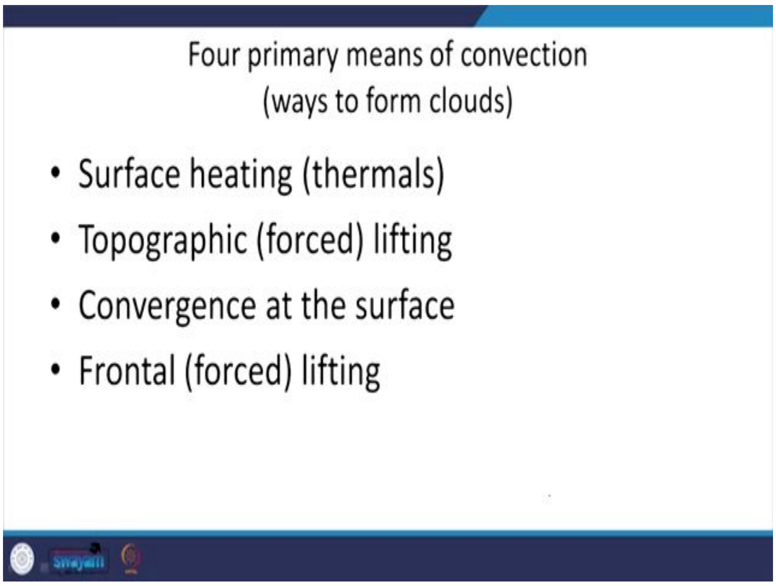

Convergence at the surface is when air directed in different directions converge to a point and this convergence makes a situation in which air can only rise upwards. But not in any other direction we will be called as convergence at the surface or force lifting or frontal lifting is also a mechanism in which two different fronts of let say the cold air mass which is less likely to occupy the lower altitudes or near the surface. If warm air which travels from some other parts or geographically some other regions travels towards this cold surface, then it is naturally this cold surface will make the uplift of the wormier resulting in the vertical moment of the air right.

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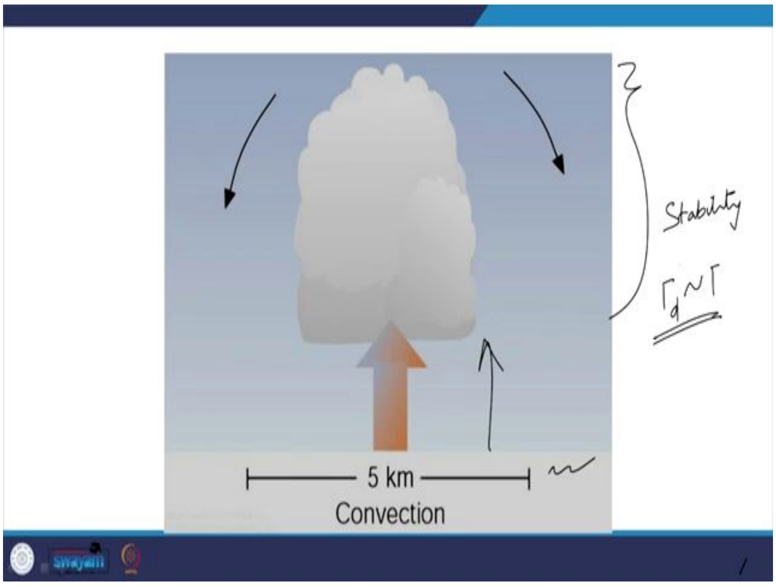

So, this is the convection this convection is very simple. So, because of the heating of the surface air will rise right. Now, here we always remember the vertical development of the cloud is subject only to the stability of the atmosphere. That means, how the dry adiabatic lapse rate compares with respect to the environment lapse rate. So, this is the relation between these two lapse rates will only decide how the air will rise.

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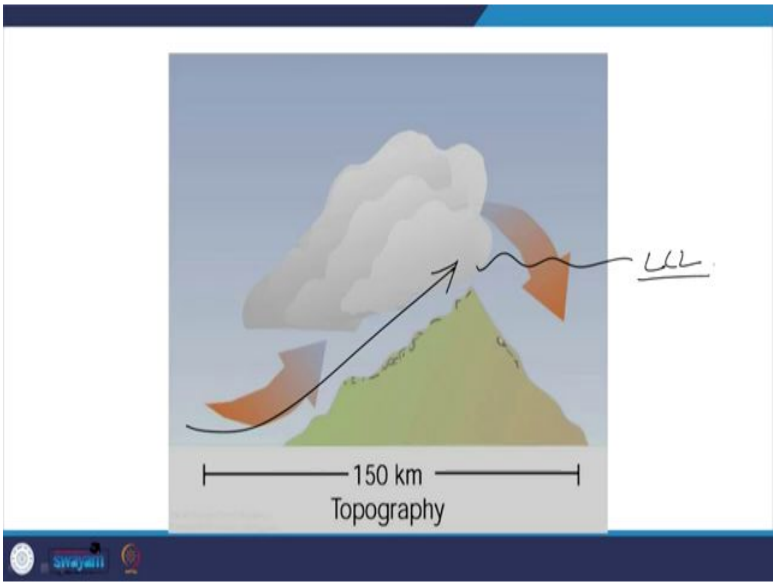

So, this is the topographic lifting when the air is traveling like this. So, it has to travel across this topography. So, it will naturally rise somewhere at this point if your LCL is existing, then it will lead to the formation of clouds that is it right and this is the convergence of air.

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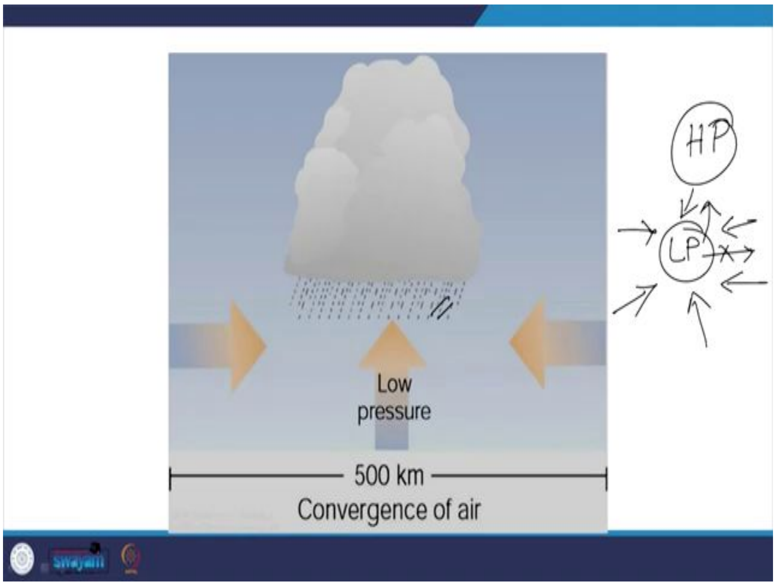

So, air is converging into this low pressure region. So, it is naturally a low pressure region if there is high pressure, air is bound to travel like this and if that air is traveling from all directions into this low pressure region. Air cannot go anywhere I mean, so air can never go from a low pressure to high pressure system, so this is forbidden. So, the air has a natural way of rising towards the higher altitudes and forming the clouds.

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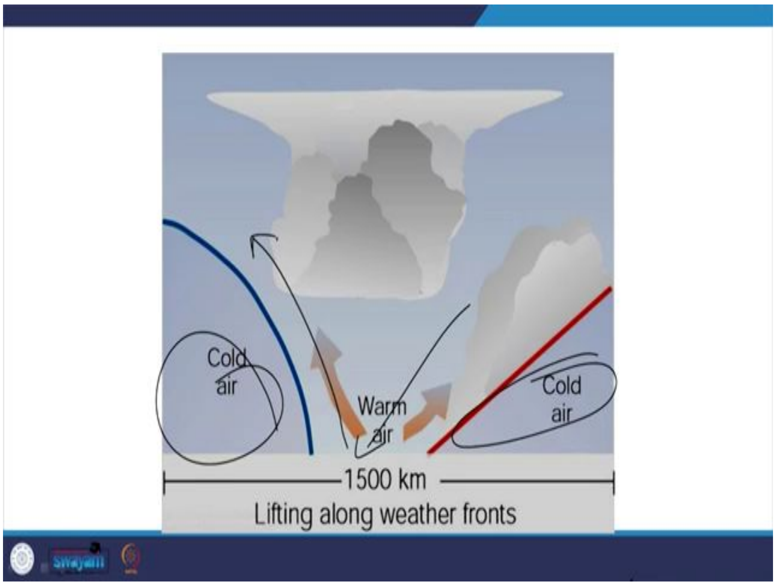

And lifting along the weather front, so like I said cold air will occupy the lower altitudes, if warm air comes from some other region. So, this cold air will create the lift for this warm air to rise to higher altitudes.

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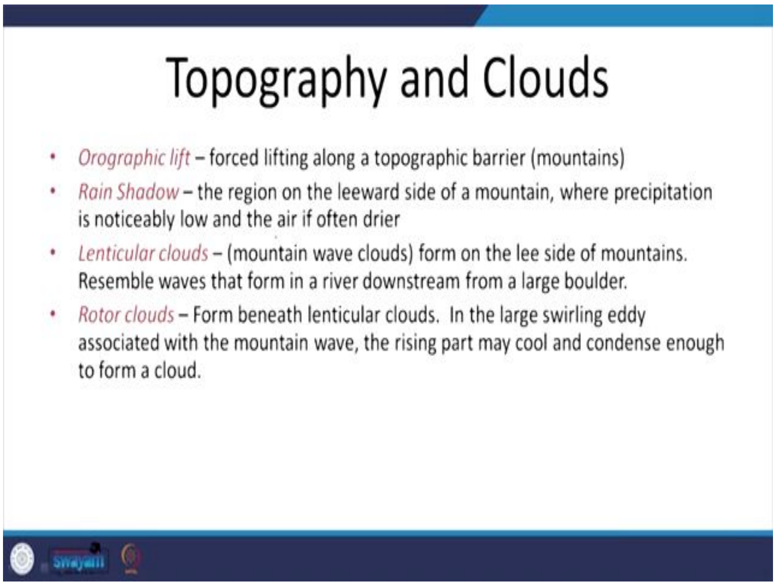

So, let say topography is more important in the sense it creates more amount of let say cloud cover, orographic lifting, force the lifting along the topographic barrier mountains. It also creates a rain shadow at the region on the leeward side of the mountain where precipitation is noticeably low and the air is often dry air.

Lenticular clouds are the ones which mountain wave clouds from the lee side of the mountains, they also resemble that form in a river downstream from a large boulder. So, this is various effects of the topographic clouds ok.

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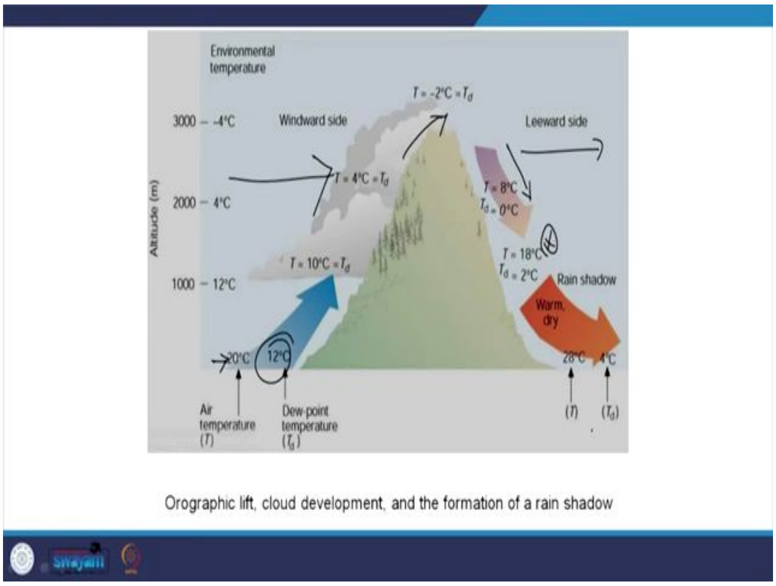

Orographic lift, cloud development, and the formation of a rain shadow

So, if you see this example you will realize that the dew point temperature for this conditions is 12 degree Celsius. So, at the surface the temperature is 20 degree Celsius, if it rises when it reaches that particular minus 12 degree Celsius.when the temperature reaches this automatically at the dew point condensation is bound to happen and it will be the formation of clouds.

So, now further uplift will only result in the formation of rain and what will happen is this is the windward side from which the wind is coming and the leeward side is the other side. So, automatically when it tries to sink the this is the main aspect that you must have learnt already in your earlier classes is that. On this side on the leeward side the way air is warmed I mean it has to travel down and in the process it will get warmer and generally this place will be devoid of any rain ok.

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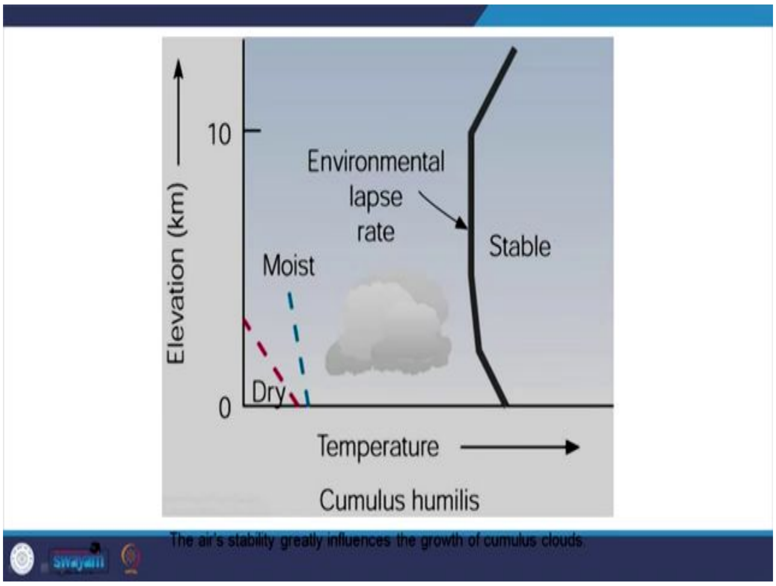

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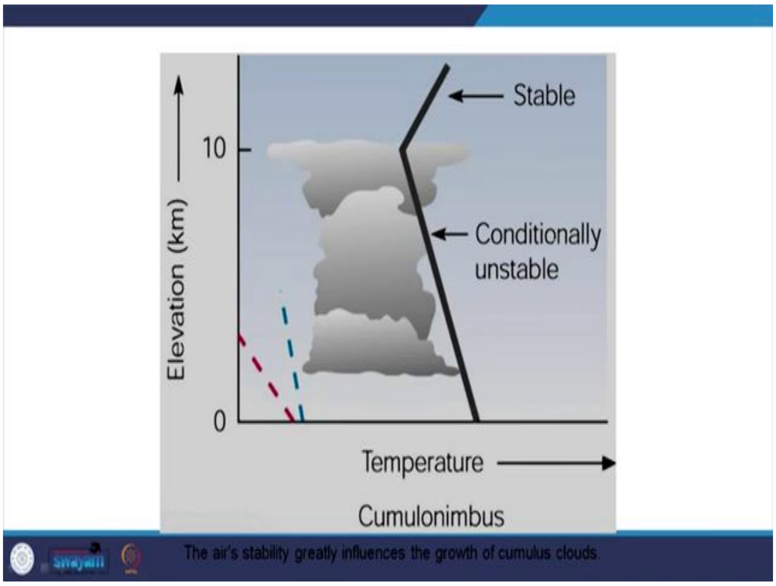

Now, so, the air stability is what influences the formation of rain

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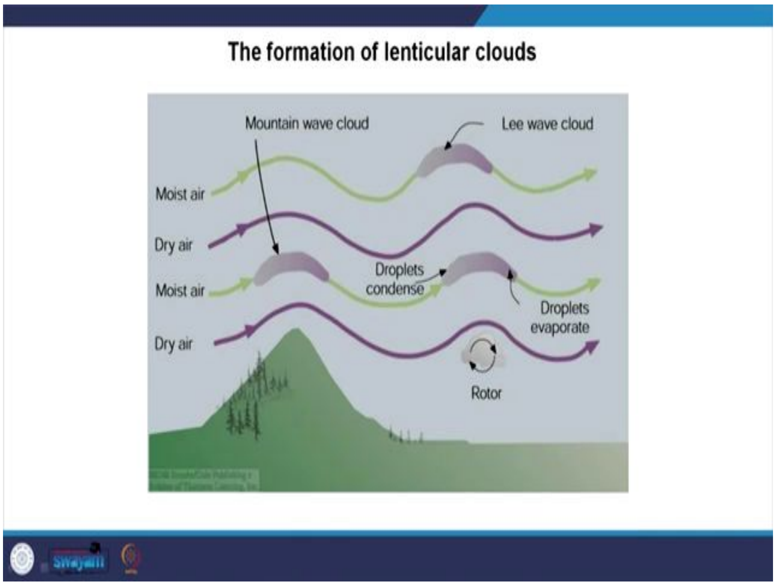

So, these aspects we have already covered right.

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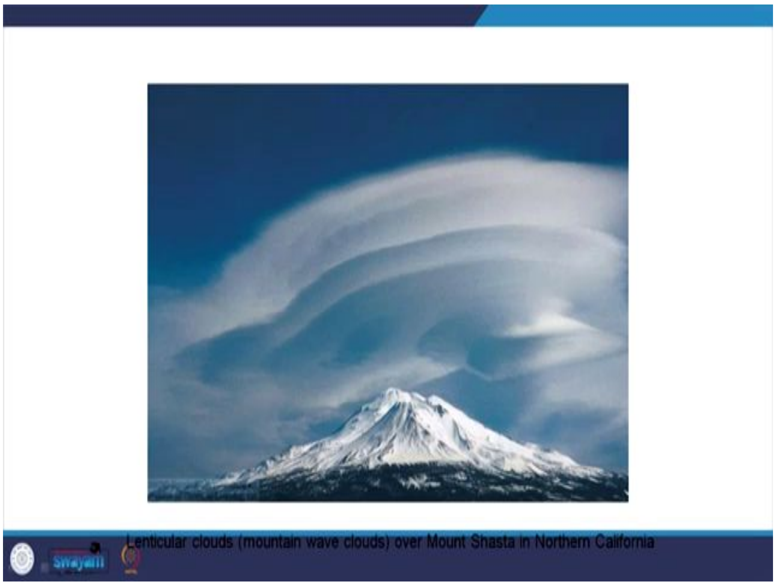

So, now once the condensation happens inside the cloud.

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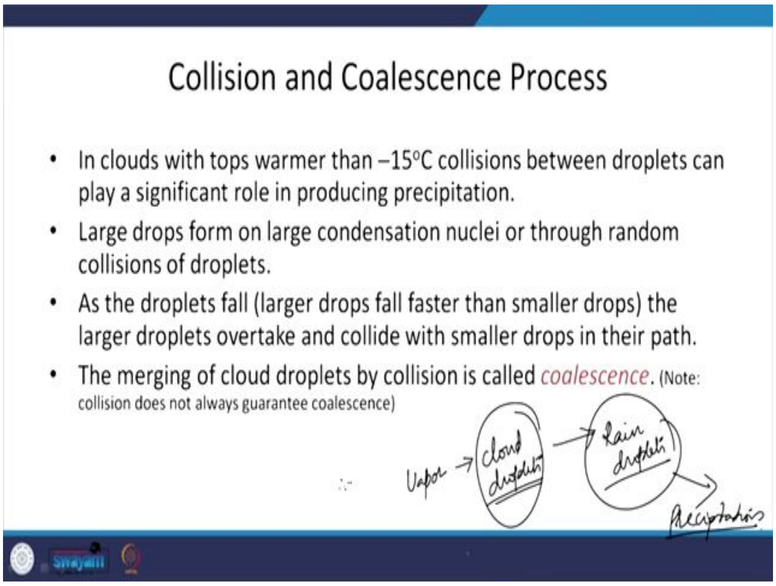

So, we have to understand the process between let say. So, the vapor condenses to form the cloud droplets, the cloud droplets are very small in size and if the cloud droplets grow to a substantial size, where gravity can start acting on them. Then they are going to be called as the rain droplets and once the rain droplets are developed inside the cloud the cloud becomes unstable and this will result into the precipitation this will result in the precipitation.

So, in the clouds whose tops are warmer than minus 15 degrees Celsius, collisions between the droplets collisions between the cloud droplets. I am saying small droplets they will come along they will collide between droplets can play a significant role in producing precipitation. So, the processes by which cloud droplets can grow into rain droplets are 2 which are collision is one process and coalescence is another process which kind of combines the effects of collision. So, large drops from form on large condensation nuclei or through random collisions of droplets.

So, we have already seen what are condensation nuclei these are the nuclear over which condensation or let say condensation will happen. So, these droplets are attractive in nature for the water molecules right. So, as the droplets fall when they are falling inside the cloud larger droplets fall faster, of course naturally than the smaller droplets.

So, the large droplets overtake and collide with smaller droplets in this process or in their path. So, the merging of let say these tiny cloud droplets by collision is generally called as the Coalescence. So, we have to note that the collision does not always guarantee coalescence. I mean coalescence is the process in which a droplet of a given size becomes even larger in it is path by combining or by making the merger of smaller droplets happen within itself to itself right.

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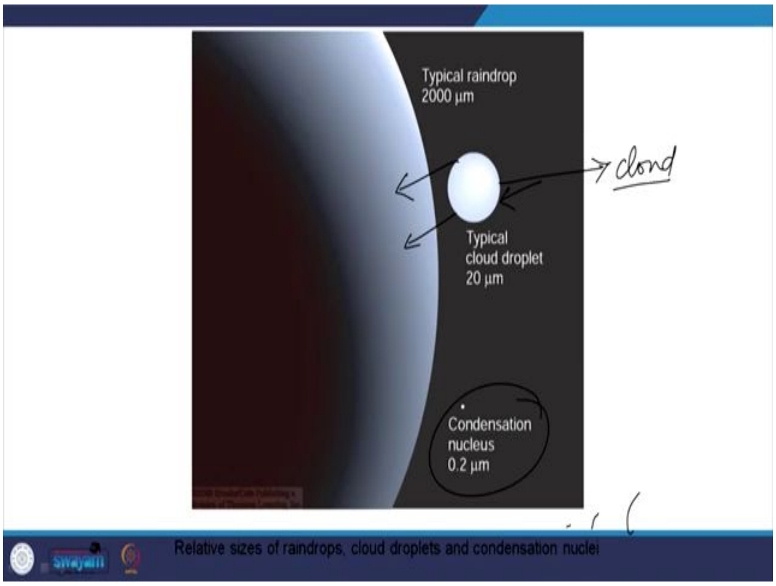

So, typically if you look at the sizes a size comparison of these various different. So, we are talking about the condensation nuclei we are talking about rain droplet, we are talking about the cloud droplet right. So, the condensation nuclei is very small its of the order of micrometers. So, here what is given is that condensation nuclei is typically of the order of 0.2 or 0.9 micrometers. So, this is the cloud droplet this cloud droplet is the one which forms when condensation happens, ; this is the cloud. So, a collection of these tiny droplets is what you call as the cloud you always remember that ok. When this droplet grows to this size of 200 micrometers then you call it as a rain droplets.

So, the process from here to here is basically the collision and coalescence right. So, just for remembering this you always remember the cloud condensation nuclei are the smallest in diameter and the typical rain cloud droplet is of the order of 20 micrometers these droplets will collide they will combine to form bigger droplets. Once the bigger droplet has formed it will fall and it will create precipitation and this rain droplet is typically of the order of 2000 micrometers right.

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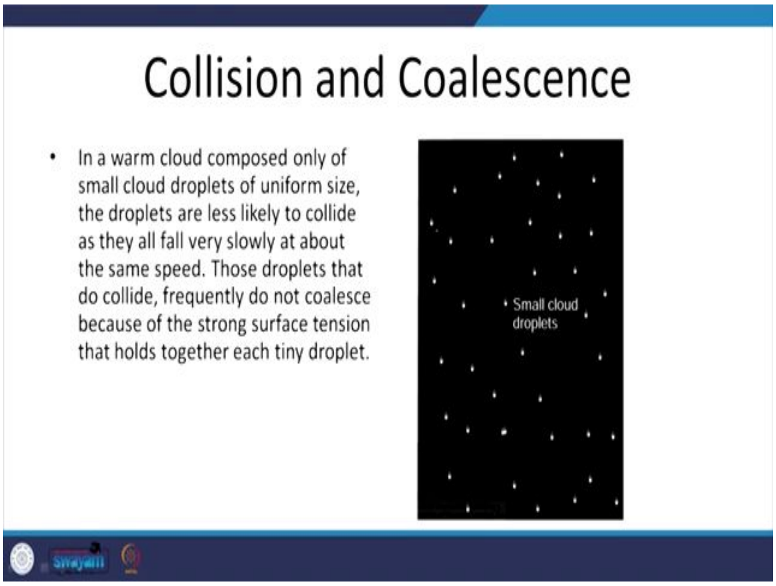

So, let us say how does it happen how does this action happen and what kind of physical effects we will come into picture when this is happening. So, what can probably add the formation of rain droplets and what can hamper the rate at which the rain droplets are formed right. These kind of things that we are going to learn.

So, in a warm cloud composed only of let say small cloud droplets of uniform size, the droplets are very less likely to collide as they fall very slowly at about the same speed right. So, those droplets that do collide frequently do not coalesce, because of the strong surface tension that holds together the each tiny droplets right. So, if the let say small cloud droplet, so the generally the falling will be smaller and also the surface tension of each droplet each spherical droplet will not permit more water to condense into it and thereby growing in size.

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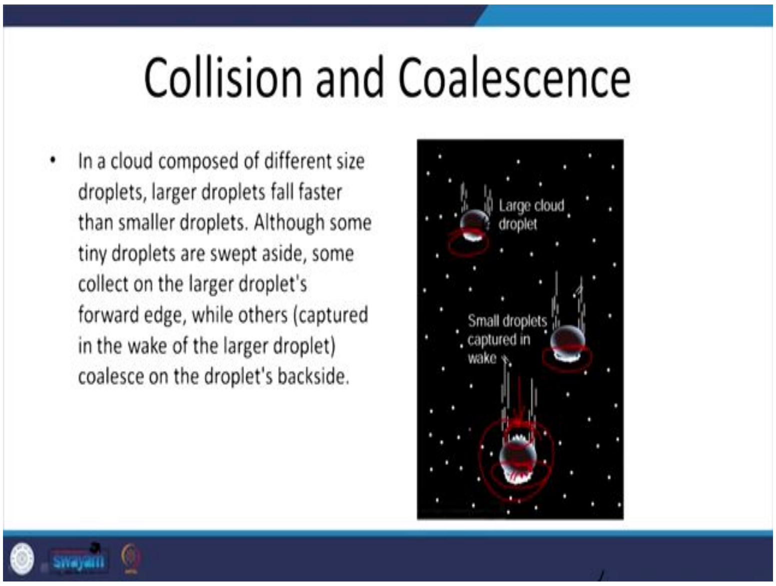

So, in a let say in a cloud composed of different size droplets. So, earlier we have seen a cloud which is made up of tiny droplets all of them are very tiny. Where you have less chance of developing precipitation. But if you consider a cloud which is composed of different size droplets let say, larger droplets fall faster than the smaller droplets naturally right. And all those some tiny droplets are swept aside, some collect on the large droplets. While others captured in the wake of the larger droplets coalesce on the droplets backside right.

So this is what I mean to say, this is so some droplets may actually bounce back they may not coalesce into this. You see this one like these are the droplets which are collected and these droplets which fall from this side of the wake right. So, this droplet when it collapse all these tiny droplets this will go bigger in size and then it probably may reach the size of the rain droplet and you will eventually see precipitation. So, what are warm cloud, what happens in the warm cloud?

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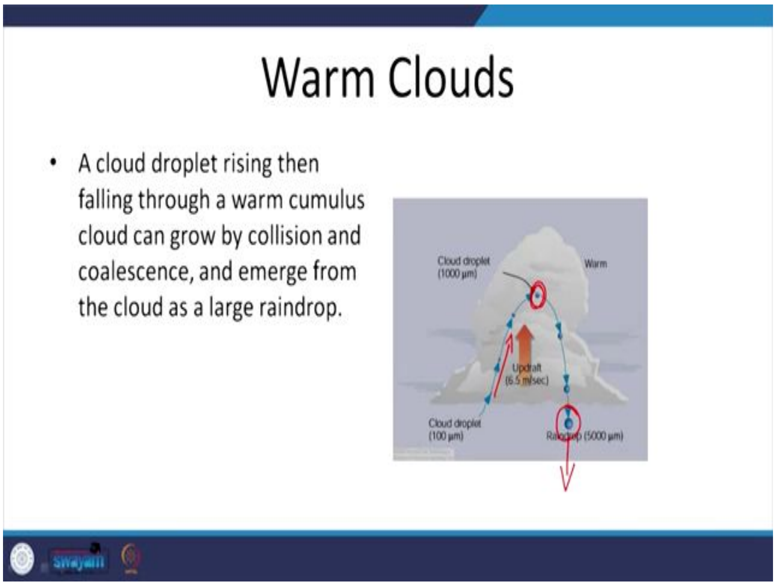

A cloud droplet rising and rising then falling through a warm cumulus cloud can grow by collision and coalescence and emerge from the cloud as a large rain droplet. Due to the turbulent processes if this droplet rises. So, this will some point it will reach a cloud droplet size, then it will if when it reaches the rain droplet size it will fall and it will create precipitation.

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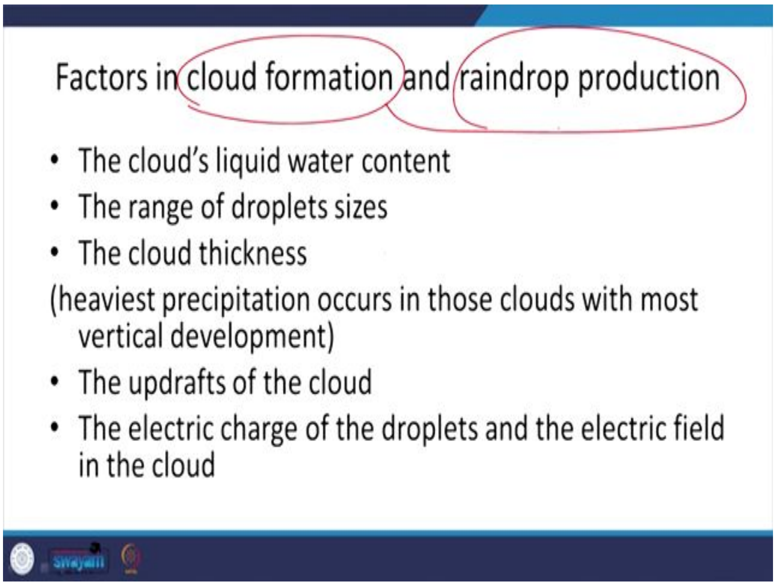

So, the factors that factors that depend or that decide the cloud formation and rain droplet production. Let say what are the various factors which influence the rates at which cloud droplets or these are done.

So, the clouds liquid water content is ultimately the primary factor which will decide the cloud formation rate. the range of droplet sizes what sizes do you have the droplets in. Let say the cloud thickness what is the what is the vertical development of the cloud, how thick is the cloud. Heaviest precipitation generally occurs in those clothes with most vertical develop like we said already right.

And the updrafts of the cloud how the cloud is supporting vertical movement inside the cloud or how the wind shear or how the turbulence is happening. So, the electric charge on the droplets and the electric field in the cloud. So, these factors will influence the cloud formation and rain droplet formation. So, first we have to realize the formation of cloud, then inside as the stability or let say when the cloud becomes unstable, it will eventually be rain right.

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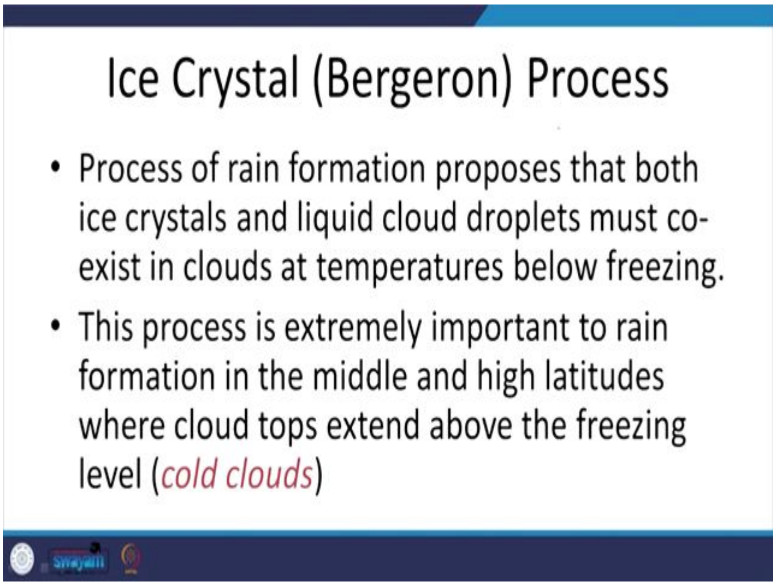

So, there are other processes in which we generally see clouds depending on their height of occurrence need not always contain only water that means droplets. They sometimes also contain the ice crystals ice crystals or let say. If the cloud is at very high altitude generally they also contain ice. So, processes of rain formation proposes that both ice crystals and liquid cloud droplets must coexist in the clouds at temperatures below freezing ok.

So, this process is extremely important to rain formation in the middle and high latitudes, where cloud tops extend above the freezing level. So, it is natural I mean if you put your cloud at let say freezing temperatures or sub freezing temperatures, you would not get droplets rather you will get ice crystals right. So, this processes are called as Bergeron processes.

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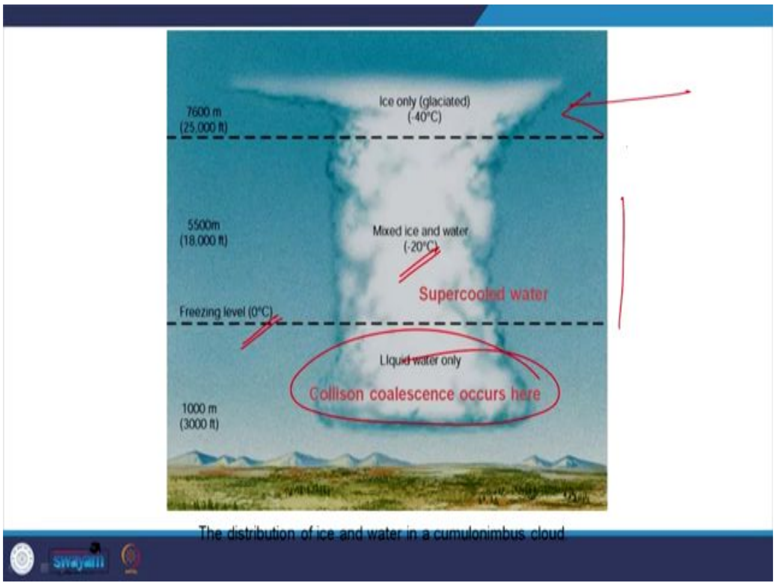

So, let say for example, we take the cumulonimbus cloud which is by far the most magnificent type of cloud that we can see. So, the cumulonimbus cloud supports various phases of water, that means water vapor and ice let say. So, in the bottom most places of the cumulonimbus cloud you will find only liquid water nothing else. That means, let say up to the height of let say the 3000 feet or 1000 meters. So, somewhere in between so this the bottom most part of the cumulonimbus cloud supports liquid water only and this is where all the collision and coalescence occur. I mean collision of the droplets subsequently they are coming together and becoming a bigger droplet and things like that right.

So, when you go up so this is the freezing level 0 degree Celsius is the freezing level. So that means, that means water cannot exist in it is liquid form above this temperature. So, in this middle part of the cumulonimbus cloud you see mixed water and ice and this temperatures could be as low as minus 20 degree Celsius. So, you see little amount of water in the liquid form and also ice when you go to the I mean topmost part of the cumulonimbus cloud it is basically it is only ice. So, it is glaciated I mean it is not that it is a very hard I say these are ice crystals tiny ice crystals which are which are formed, which are formed out of a out of a slightly different physical process right.

So, this is how various different phases of water let say ice crystals or water or mixed phase between the ice and water and only water can exist can coexist in a hugely and in a developed or vertically developed cumulonimbus cloud. So, we will stop here. So, we will continue the discussion on the formation of ice crystals or snowflakes and how we can mathematically understand, how the rates of these processes can be controlled or how this how we can decide the average rate of precipitation in a given situation.