Air Pollution and Control
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Lecture 10
Atmospheric Stability and Lapse Rates

Hello friends, today, we will discuss about atmospheric stability and lapse rates. You might have heard, like atmosphere is stable or unstable in the sense whether pollution is being dispersed properly or it is hanging around, so that particular situation on which specific parameters it depends like lapse rate. Lapse rate mean, change in the temperature with the height of the atmosphere.

So, those are known as environmental lapse rate. Then there is theoretical adiabatic rate which is dry adiabatic lapse rate and wet adiabatic lapse rates, so all these things we will discuss today. And in addition to the adiabatic processes, we will also see the role of this ELR and DALR that is the Environmental Lapse Rate and Dry Adiabatic Lapse Rate on the atmospheric stability. Because it will influence the dispersion of or movement of air parcel.

So, whether it is super adiabatic lapse rate or sub- adiabatic lapse rate or neutral or negative or inversed like inversion. Inversion means, like in in normal conditions in the troposphere the temperature decreases with the height. So, in case you meet that particular situation where rather than decreasing of the temperature with respect to the height, if it increases then it is inversion.

In that case vertical movement of your parcels or plumes and pups is completely restricted it does not disperse in vertical movement. Although horizontal movement may be there along with the wind, but this vertical this boundary layer dispersion restricts totally and that is very serious situation. In many you know episodic events this inversion really creates havoc, anyway. So, this we are going to study one by one these contents list.

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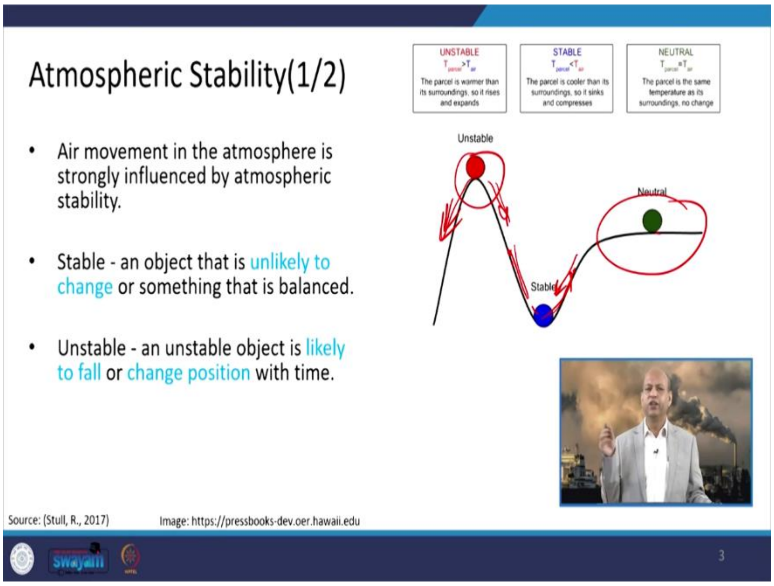

So, when we talk about atmospheric stability first of all let us see this particular you know figure in this like for example, one ball is there. If I take this ball here, then if I leave then it will come back. If I take this ball here, if I leave it will come back here. So, that situation, means, in atmosphere also if there is an air parcel or plume or puff if we take a particular point then if it goes away from that point and it does not come back then it is unstable like this one.

You put the ball here, either it will go to this side or that side, it will not stay there. But if it comes back then it is stable. So, if puffer plume comes back where it is released, it hangs around on that particular altitude or height, then it is stable. And the neutral condition is like it does not change unless we push or we provide some external force, it will remain there only.

So, those kind of three major conditions may be there of atmosphere like it is unstable means a lot of churning is there and a lot of movement of air can be there and dispersion of pollutants will happen. But if it is stable then the dispersion will not happen much and a lot of concentration may build up. Neutral again, means unless external wind power is there, wind velocity is there or some force is there, it will remain there. So, that kind of particular air movement in atmosphere, which is strongly influenced by atmospheric instability that we need to study further.

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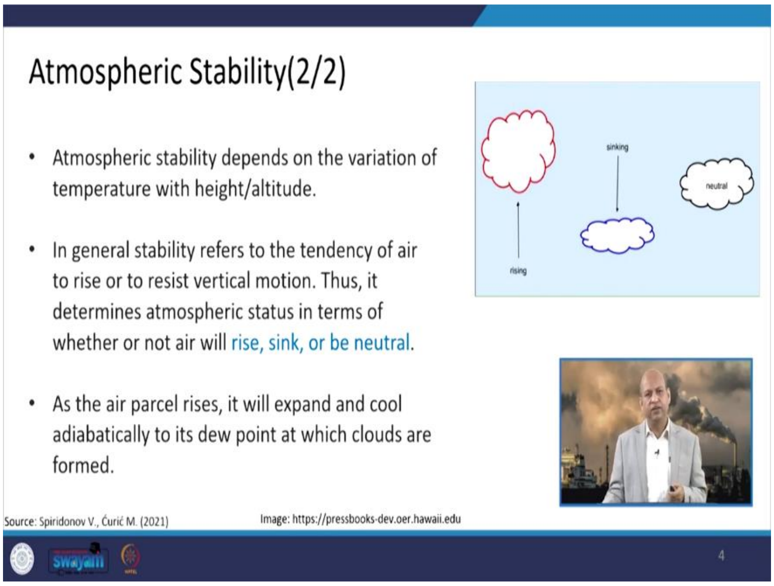

So, when we talk about this atmospheric instability basically, it is nothing but something which is dependent on variation of temperature with the height or altitude. And in general, the stability refers to the tendency of air to rise or sink or means to resist the vertical motion or it helps in vertical motion.

So, basically it determines the atmospheric status in terms of whether some plume or puff or air partial will rise or sink or remain at the same place where it is released. And, this air parcel when it rises, it will expand and when it is expanding, then cooling effect there is there through adiabatic process and that adiabatic process we will see, but theoretically it creates a situation where cloud formation is there because of dew point is reached by this expansion and cooling of the air. But adiabatic process means there is no heat exchange that is the assumption. We will see later on, on that particular point.

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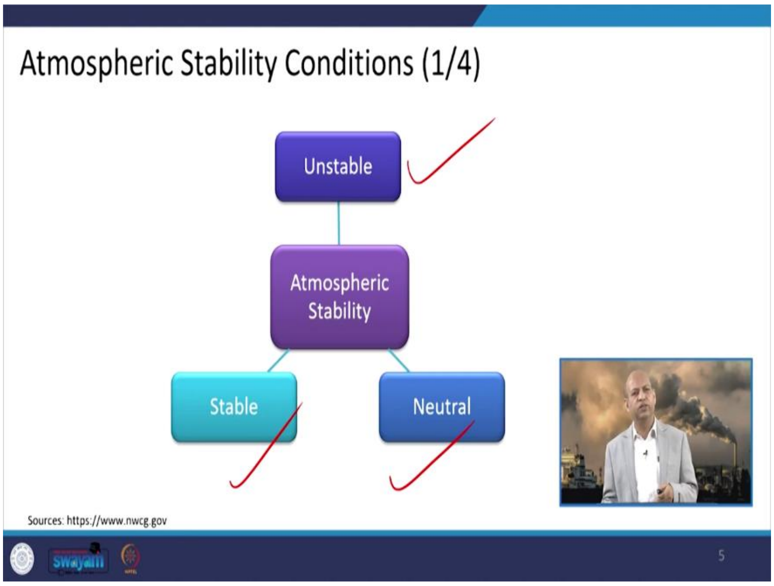

So, basically when we talk about these conditions of atmospheric instability, so, they are broadly as I said, either unstable, stable or neutral, these are three basic conditions. Although, inversion is also one which is extremely stable condition you can call it.

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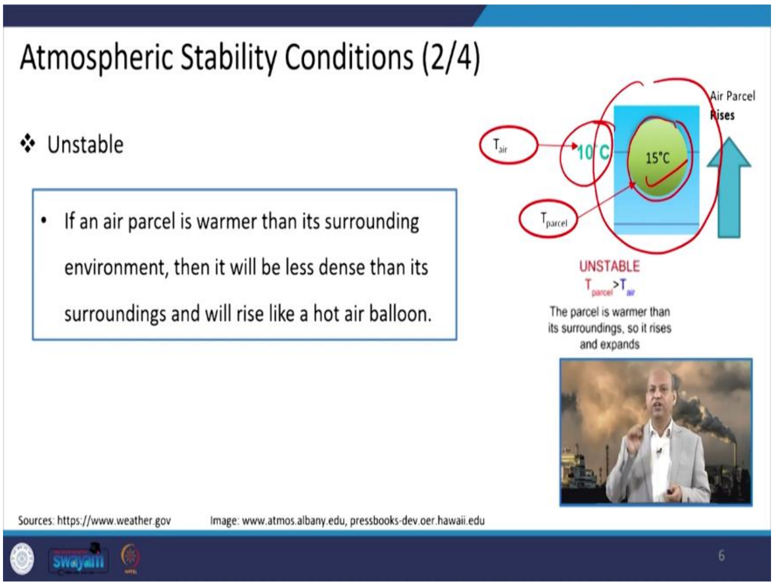

So, when we say that it is unstable that means, when air partial is warmer than the surrounding air. So, there are two temperatures please remember it. One is, the temperature of the air parcel means, some puff or plume which has been released from the stack or air pollution source. So, some temperature will be there of that particular puff or air mass or air parcel. Let us call it air parcel, which is released as air pollution.

So, it has some temperature and it is released in the atmosphere, so the atmosphere also has some temperature. So, in case the temperature of this air parcel which is released as air pollutant if it is higher like 15 °C than the surrounding ear, which is 10 °C here, so, that means this air parcel is warmer, it is lighter, so, it will rise, it will not remain there. So, it will help in dispersion of air pollution. So, this is known as unstable atmosphere. Means it helps in dispersion of the pollutant, it will not help pollution remain there only.

So, that means, difference between the environmental temperature, surrounding temperature and the temperature of air pollution plume or puff of air parcel, the difference decides So, in unstable when air parcel temperature is higher than the surrounding temperature then it is a unstable and the air parcel will go away.

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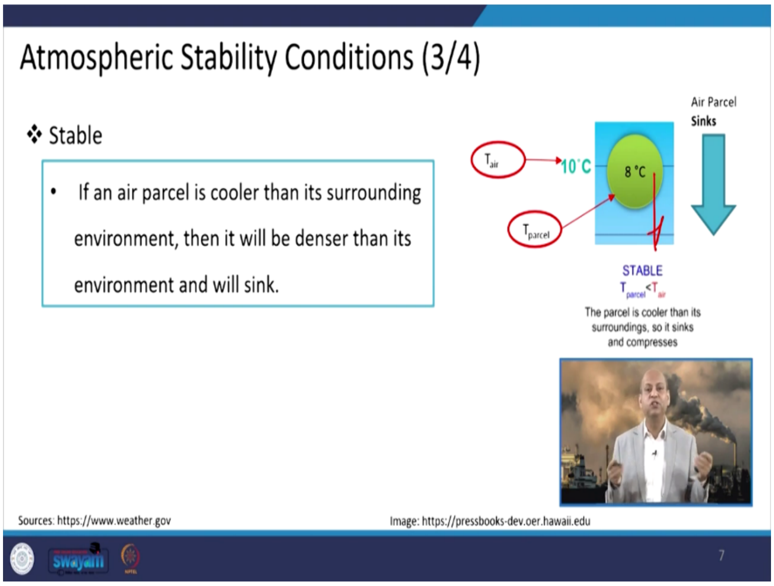

In a stable condition, suppose warmer conditions are there and the temperature of the surrounding air is warm more and this the parcel temperature is less in that case this parcel is heavier. It is not lighter, it is dense, so, it will come down. So, that means, it may go towards the ground and it will create pollution problem, this is the stable atmosphere basically.

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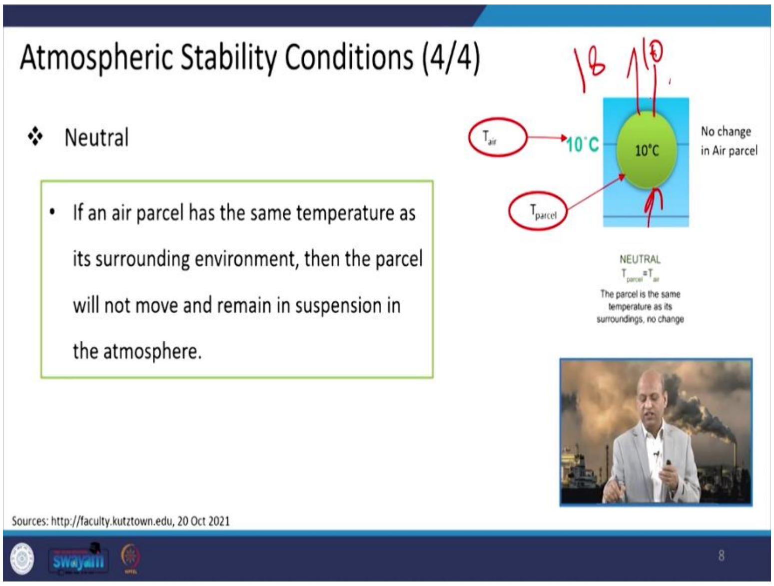

When we talk about neutral then the temperature of the parcel, temperature of surrounding here it seem so, it will remain there unless you push it. Like if you push it then it will go there and there itself it will remain if temperature again same. But if temperature is different, like if temperature of the surrounding is less on higher side if it is 8 and if it is 10 then it will rise. If it is 18 and if it is 10 then it will come back. So, that kind of situation will decide whether the parcel of the air will go away from the situation or the point where it is released or it will remain there.

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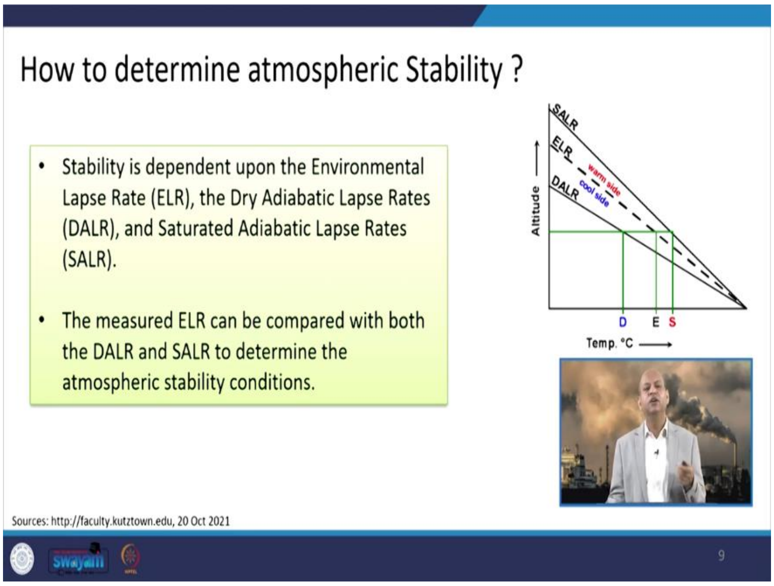

So, how do we determine this atmospheric instability? So, basically, we see these lapse rates, the environmental lapse rate is this one you can see here. And this is DALR Dry Adiabatic Lapse Rate. So, the point is now, how to determine atmospheric stability. So, here we can see like this is the Dry Adiabatic Lapse Rate this solid line. Dry adiabatic lapse rate basically which is theoretical lapse rate we will see, but I can say that it is like 10 °C decrease of the temperature with 1 kilometer or 1 °C per 100 meter in the troposphere, so that is known as dry adiabatic lapse rate.

And then ELR maybe, something lower than or higher than DALR. So, it is like environmental lapse rate which is existing in the atmosphere. So, you can see here this DALR is there dry adiabatic lapse rate then environmental lapse rate and SALR saturated adiabatic lapse rate. This is because of moisture or wet atmosphere. So, the major DALR can be compared with both the DALR and SALR to determine the atmospheric stability. Because ELR is the thing which is this surrounding air atmosphere, which can change every day, and within the day, every hour it can change, but DALR and SALR almost constant those rates of the temperature decrease with the height depending upon whether we are considering the dry air or moist or wet air.

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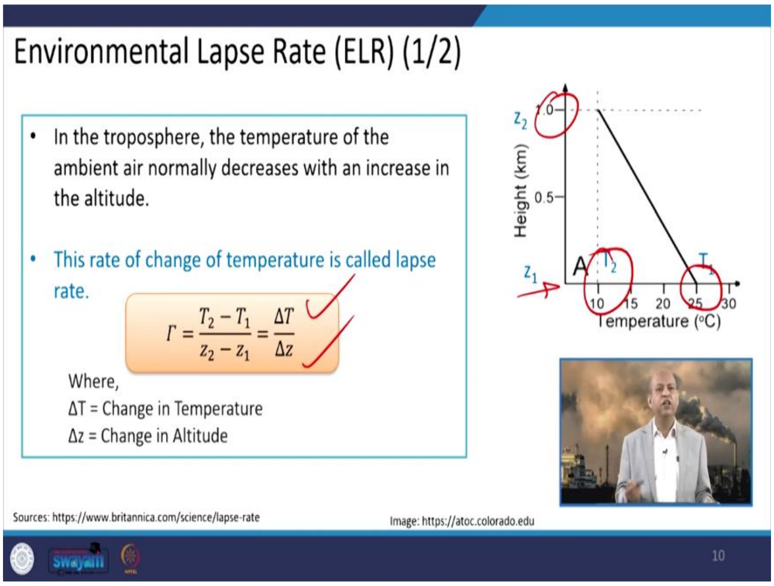

So, here if we see this environmental lapse rate, which is nothing but the difference between the temperature and the according to the height.

$$\Gamma = \frac{T_2 - T_1}{z_2 - z_1} = \frac{\Delta T}{\Delta z}$$

So, if we assume like at Z1 height, the temperature is T1 and at Z2 height if temperature is T2. So, we can see the difference of the temperature T2 minus T1 divided by Z2 minus Z1 that is delta T by delta Z. So, this is the tau or know it is known as the change of the temperature or lapse rate. So, this is the lapse rate. And it can be either adiabatic lapse rate or environmental lapse rate. But environmental absolute when we talk so in the atmosphere with the height what is the temperature recorded, measured.

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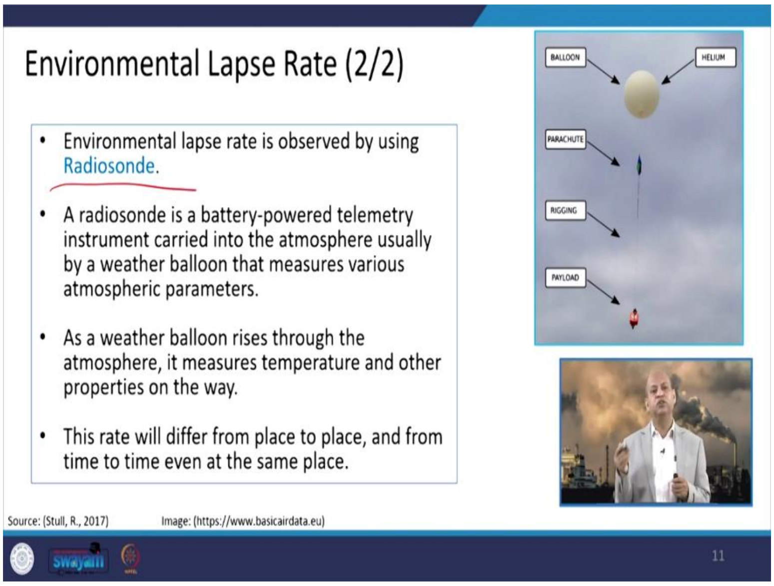

So, now if we see this environmental lapse rate how do we measure it. Basically, this Radiosonde experiments are done. So, meteorologists usually do this in the balloon those instruments are put and then a sensor-based readings are there. So, as balloon goes up it gives the reading with respect to the height. So, you can determine what is the rate of the decrease of the temperature or increase of the temperature, whatever situation is there with respect to the height.

So, those temperature recording is done, and then it is plotted with the height, so we then know what is the rate of decrease or increase of the temperature.

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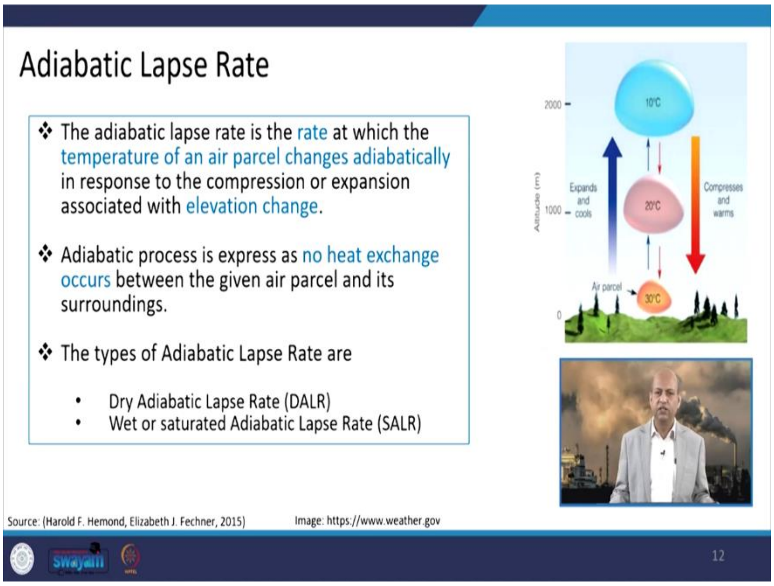

In adiabatic lapse rate basically, this is the theoretical change in the temperature with respect to the height and it is in response to the compression or expansion of the air with respect to the height. Like if you go up so, the air parcel expands and cools down the temperature decreases. If you bring down then more pressure and the density increases, and it warms up so temperature also increases here, you can say. So, adiabatic process is basically no heat exchange that is the assumption. In adiabatic process we assume there is no heat exchange between the parcel and the surrounding air.

And then these adiabatic lapse rate can be dry adiabatic lapse rate or wet or saturated adiabatic lapse rate. As I said, if we consider the moisture or that available in the air, so, then we can call it as SALR or Saturated Adiabatic Lapse Rate. Otherwise, for practical purposes for calculations, we generally use dry adiabatic lapse rate and that is more popular.

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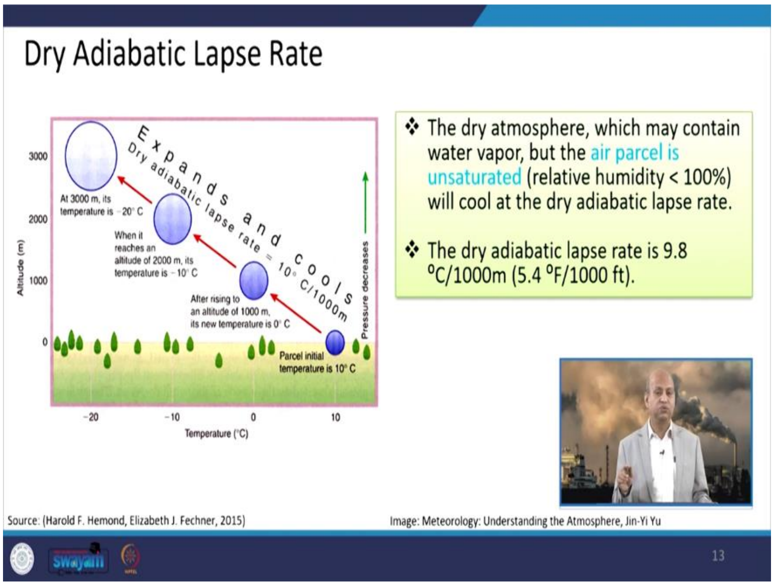

So, in dry adiabatic lapse rate you see like this air parcel is going up and up so, it is expanding and cooling down, and that with the rate of 10 °C per kilometer or 1 °C per 100 meter, so, that the calculation can be easily done, we will see. And this is unsaturated so it is not relative humidity 100 percent. But when it is saturated, then we call it SALR Saturated Adiabatic Lapse Rate.

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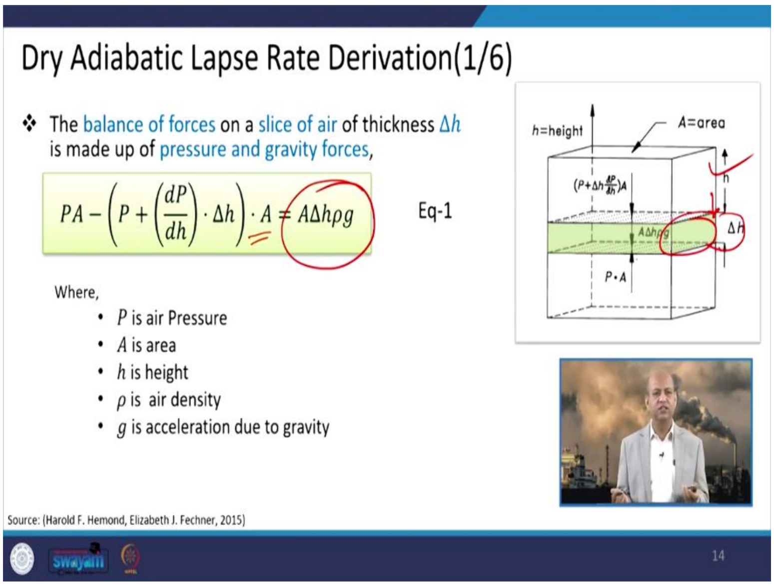

So, now, if we talk about the derivation of dry adiabatic lapse rate, so, you can see this very simple figure which is self explanatory. One column has been assumed which has area, area A and delta h that is the slice of this air, we have assumed delta as height. So, the pressure at this point and the above point after this delta h if they are measured and if we determine the forces at these points so the mass, the force exerted by this mass of the air in this slice is equal to the difference between the pressures at these two points multiplied by the area so, that you can see.

$$PA - \left(P + \left(\frac{dP}{dh}\right) \cdot \Delta h\right) \cdot A = A\Delta h\rho g$$

……….. Equation 1

p is the air pressure A the area and h is the height of this column and delta is the height of this particular slice, and ρ is the air density and g as you know the acceleration due to gravity.

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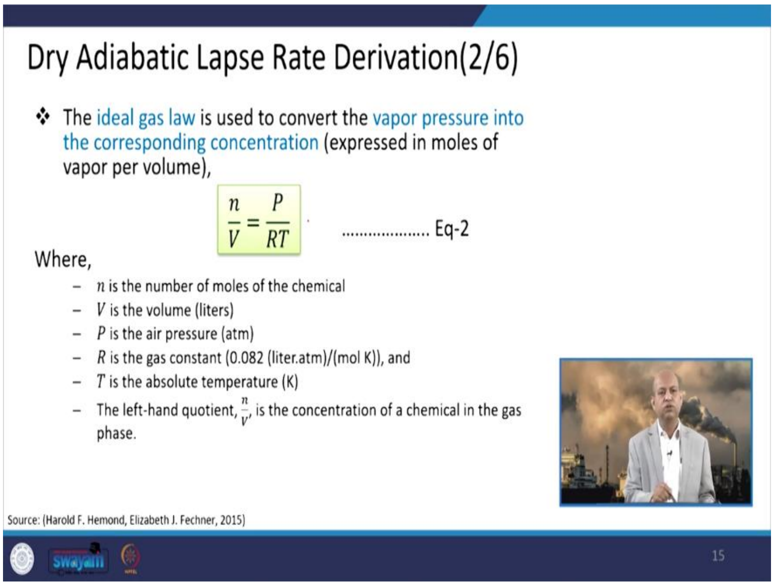

So, if we apply this ideal gas law very simple. So, vapor pressure into the corresponding concentration which is used to convert the vapor pressure into corresponding concentration.

$$\frac{n}{V} = \frac{P}{RT}$$

…………………… Equation 2

So, the moles vapor per volume, so, n by V, n is number of moles of the chemical V is the volume in liters and P upon RT. So, this is equal because of this ideal gas law which is all of you know, so, this can be used in in this particular derivation.

So, later on if we want to carry out this density part, so, you can have this ρ is equal to the number of moles air per unit of volume n by V we multiplied by the average molecular weight MW of air, which is around 28.96 grams per mole. So, by substituting this relationship into the ideal gas law, which we have seen in equation 2, so, we get this particular relationship.

$$\rho = \frac{n}{V}MW = \frac{P}{RT}MW$$

……………… Equation 3

$$\frac{dP}{P} = \frac{-MW.g}{R.T}dh$$

………………. Equation 4

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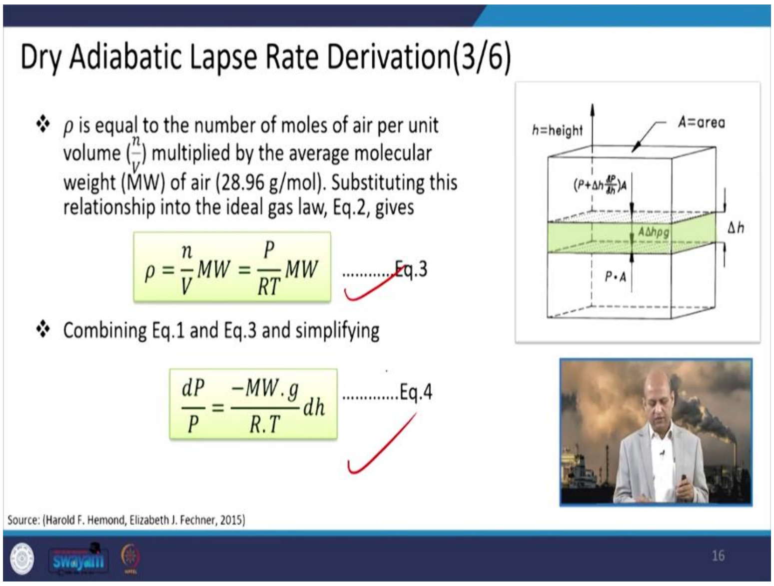

And when we combine the equation 1 and equation 3 then we get this particular relationship the pressure variation $dP/P=(-MW.g)/(R.T)\ dh$ with respect to the height.

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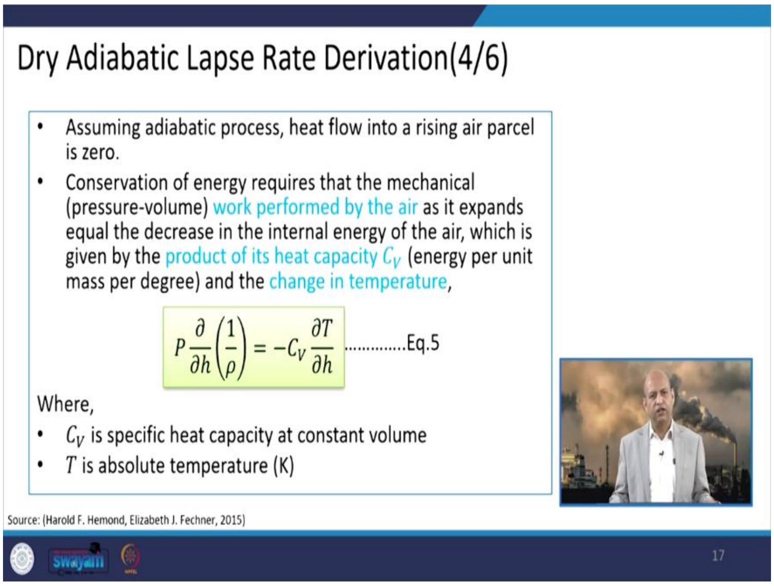

So, ultimately, we get this particular relationship this $P\ \partial/\partial h\ (1/\rho) = -C$v $\partial T/\partial h$, where Cv is a specific heat capacity of at the constant volume, and T absolute temperature in Kelvin.

$$P\frac{\partial}{\partial h}\left(\frac{1}{\rho}\right) = -C_V\frac{\partial T}{\partial h} \qquad \text{……………….. Equation 5}$$

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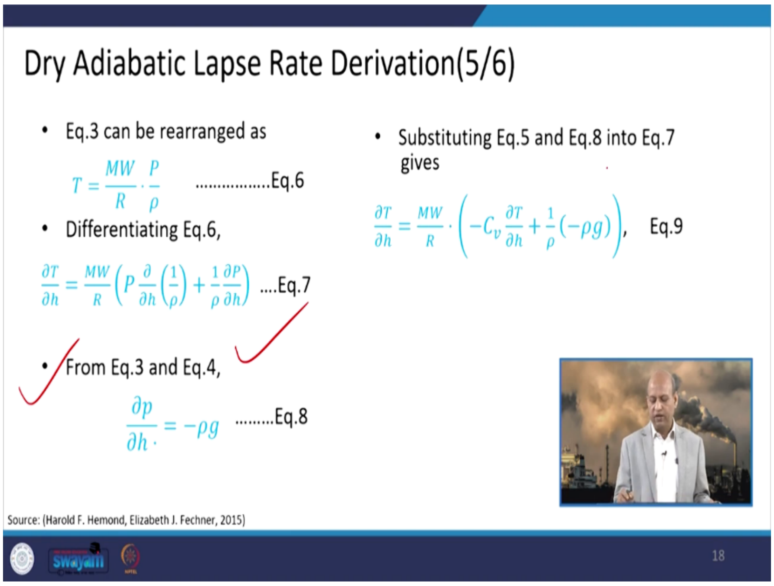

So, these equations this equation 3 is rearranged afterwards when we have seen all these relationships. So, ultimately you get from equation 3 equation, equation 4 this kind of relationship [$\partial p/\partial h = -\rho g$]. And then substituting equation 5 and equation 8 into equation 7, so you get this particular relationship.

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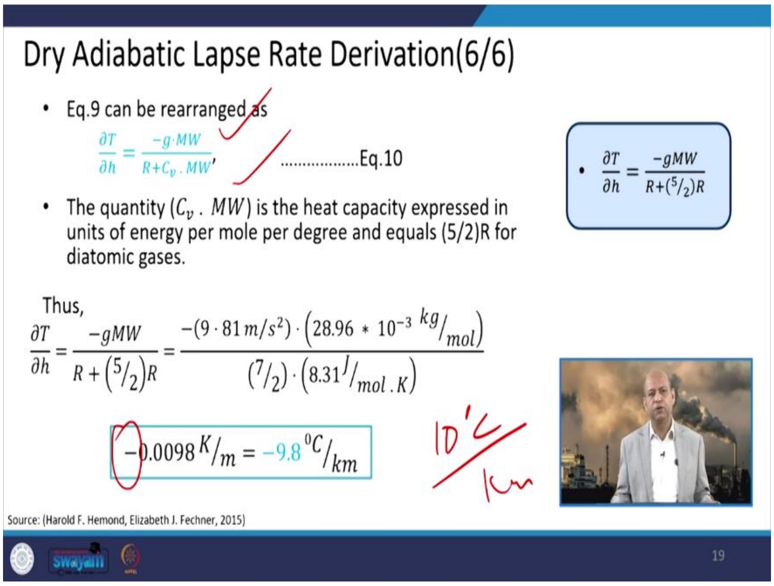

When you put those values so this

$\partial T/\partial h$=$(-g \cdot MW)/(R+C$v.$MW)$ …………. Equation 10

Now, we put these numerical values of all these, so, you get value of this point 0098 Kelvin per meter or minus 9.8 °C per kilometer. So, approximately you can say that 10 °C per kilometer or 1 °C per 100 meter. So, minus sign is nothing but you go up upper in the atmosphere in the troposphere from the earth surface and temperature decreases, so that is the you know this significance of minus sign otherwise, basically the value is 10 °C per kilometer or 1 °C per 100 meter.

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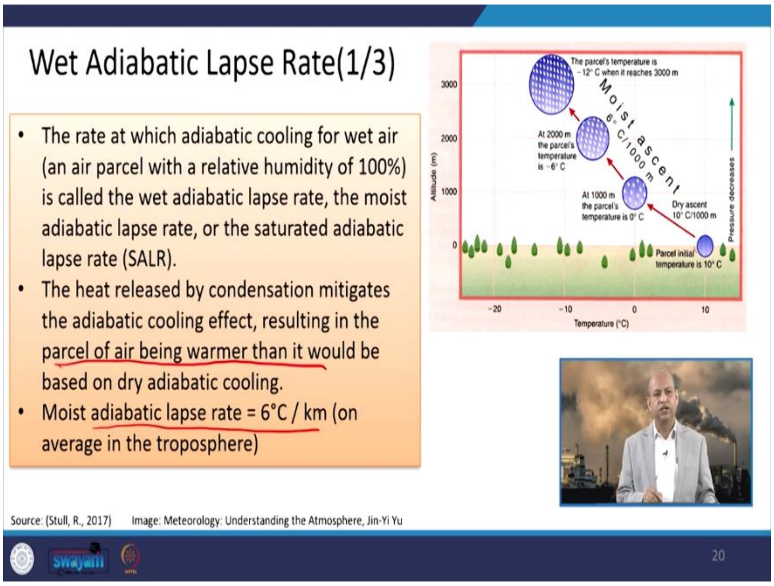

When we talk about wet adiabatic lapse rate. So, when this humidity is 100 percent then we consider this wet adiabatic lapse rate otherwise dry adiabatic lapse rate is enough for all practical purposes. And then when we are considering this moisture, so, moisture also plays role. When you go take this parcel here and then this heat released by condensation.

When you go up so, the temperature decreases condensation happens so the heat will be released by condensation. The moisture will be condensed and the heat will be released. So, the temperature of the parcel will be a little bit higher, you can say, warmer. This air parcel will be warmer than it would be based on the dry adiabatic lapse rate. So, that is why the most adiabatic lapse rate or saturated this adiabatic lapse rate is around 6 °C per kilometer, whereas in dry adiabatic lapse rate it was 10 degrees Celsius, so that difference is there.

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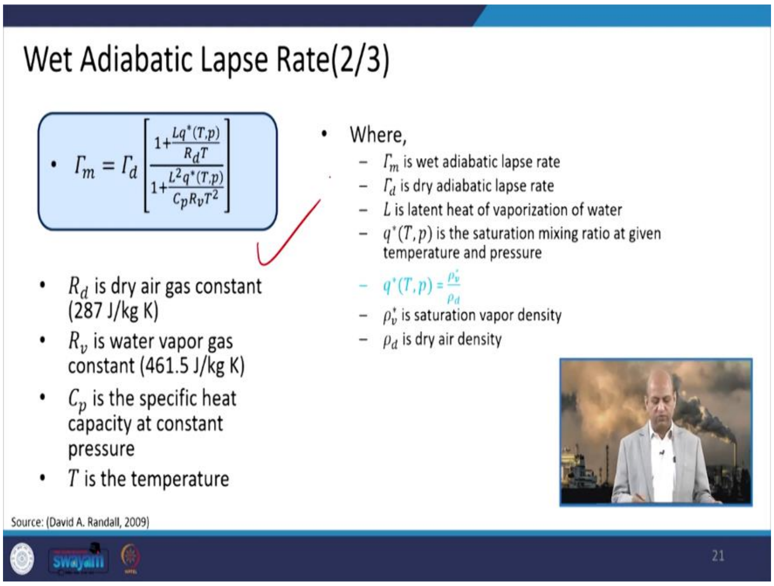

Anyway, so, this is the equation basically when you want to calculate, so these very simple formulas you can use for calculating of this wet adiabatic lapse rate.

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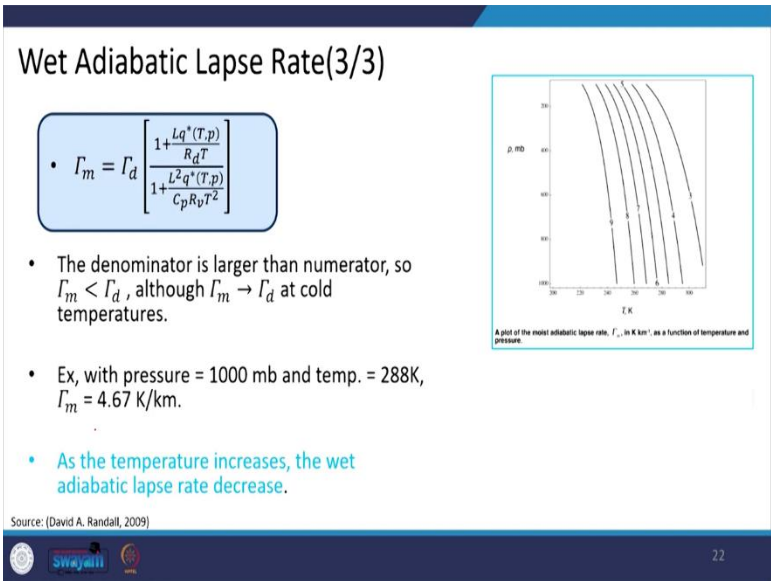

So, you can see the relationship of wet adiabatic lapse rate with respect to the height and the temperature variation in this figure is shown, so this is the relationship which can be used for drawing this particular figure. Well when we talk about you know specific instability conditions, that can be combination any combination of this DALR, ELR and SALR. DALR is Dried Adiabatic Lapse Rate SALR Saturated Adiabatic Lapse Rate and ELR is Environmental Lapse Rate. So, combination of this can be of different kind. Like for example, if we talk about absolute instability. This is the condition which happens when this dry adiabatic lapse rate is more than this saturated adiabatic lapse rate and more than this ELR Environmental Lapse Rate.

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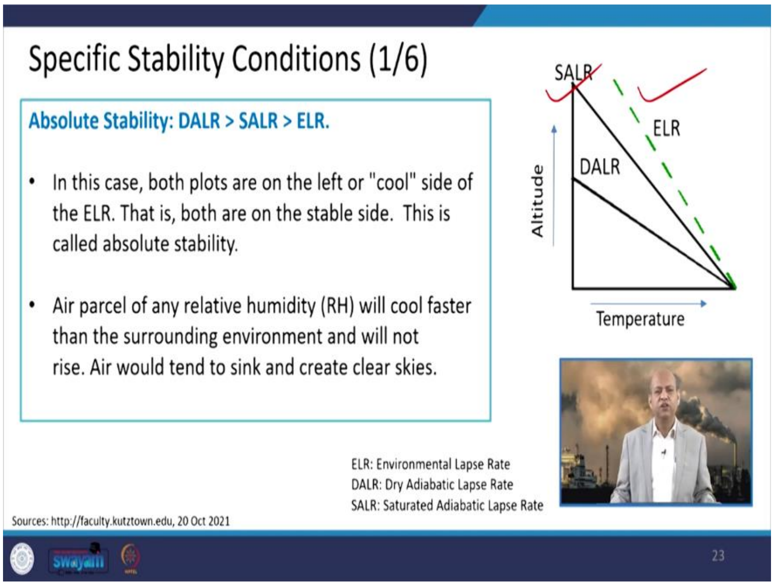

So, in this case, both plots are on the left side of this ELR or cool side of the ELR. This is warmer and this is cooler. That is why this is known as at absolute stability. Means, it is not unstable, rather it will be kind of air parcel of any relative humidity will cool faster than the surrounding environment, and will not rise it will rather come down. So, air would tend to sink rather than going up. And because sinking of this air creates clear skies and radiation goes faster and means colder environment you can feel, but this vertical movement of air parcel is suppressed in this stable atmosphere.

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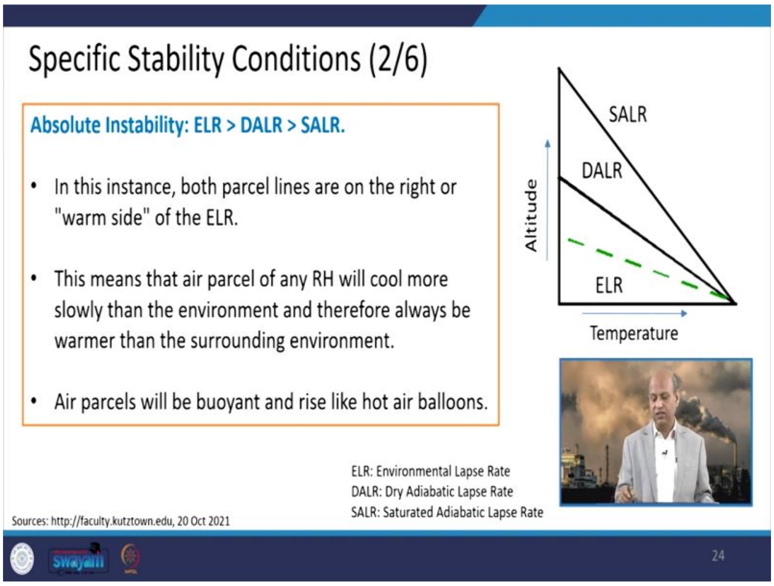

When we talk about like absolute instability where this ELR environmental lapse rate is you know, higher than DALR and SALR. So, you can see this means the air parcel of any relative humidity will cool more slowly, not faster, more slowly than the environment. So, it will be warmer than the surrounding environment, so it will go up. So, that really helps in dispersion of pollutants.

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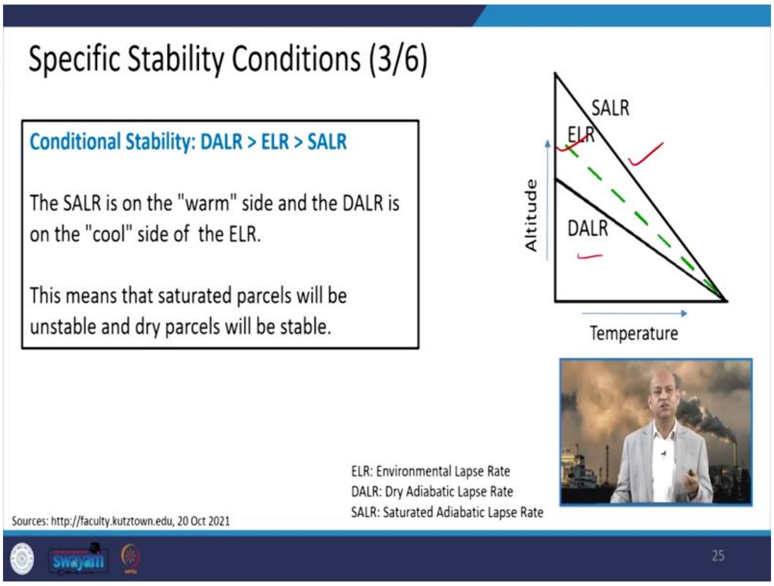

When we talk about some conditional stability like DALR is more than ELR and ELR is more than SALR so those kinds of conditions may be there. In that case, SALR is basically on the warmer side of ELR and DALR is on cooler side of the ELR. So, the SALR is on the warm side and the DALR is on the cool side and it will have meaning that the saturated parcels will be unstable, saturated parcels will be unstable it will go up, but unsaturated parcels or dry adiabatic lapse rate following parcels, they will not go up. So, this is a conditioning stability you can say.

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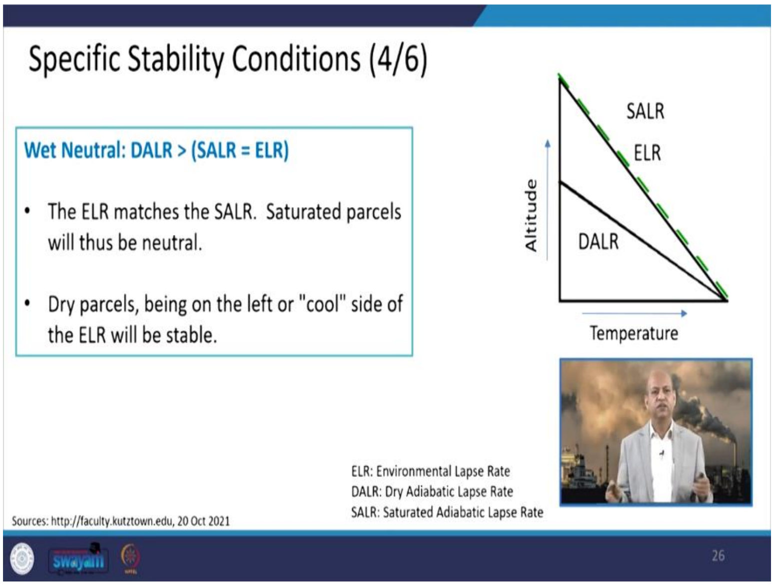

So, dry parcel will be stable, they will sink and saturated parcels will go up, means, they will rise. When we talk about like wet neutral, so, DALR is more than the CLR and SALR and SALR and ELR both are same. In that case, the dry parcel being on the left side or cooler side it will sink it will be stable. It will be stable, but wet this saturated adiabatic lapse rate is parallel to ELR so they are neutral. This will neither go up nor come down, it will follow the same pattern.

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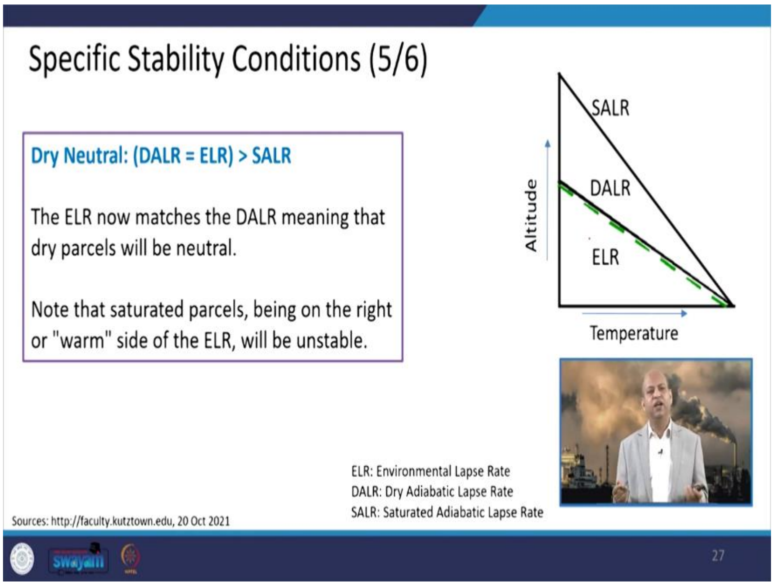

When we talk about dry neutral adiabatic lapse rate, so this is basically this ELR and DALR parallel and SALR is on warmer side. So, well the saturated parcel being on the right side or warmer side it will be unstable it will rise, but the ELR and DALR same so the dry parcels or unsaturated parcel will hang on particular point where it is released.

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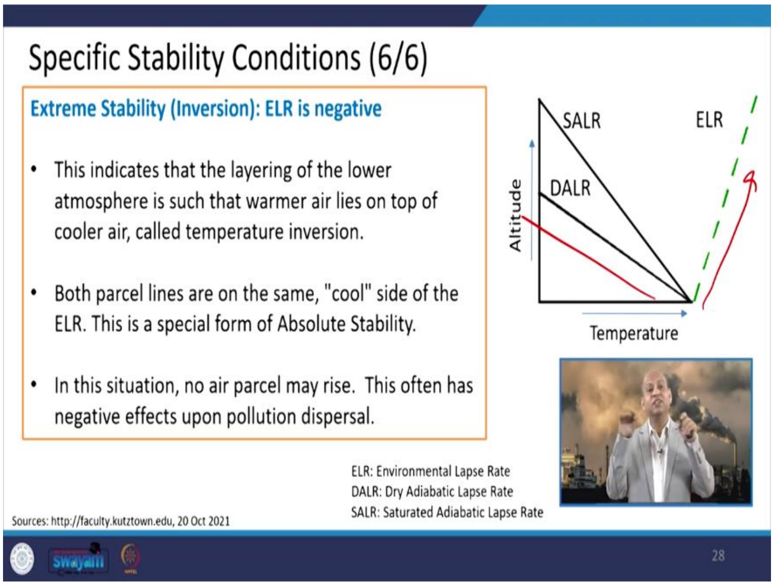

Then this is very dangerous situation as we know inversion. When this environmental lapse rate is basically following the trend reverse trend means rather than decreasing of the temperature with height it is increasing, this is increasing. This is the decreasing temperature here the temperature is decreasing when we go this side, temperature is increasing when we go to this side.

So, this is basically this DALR and SALR on cooler side, and so neither saturated parcels nor unsaturated parcel will rise they will rather sink. And this is kind of cap this inversion acts as a cap. It will not allow vertical movement of the air pollutants.

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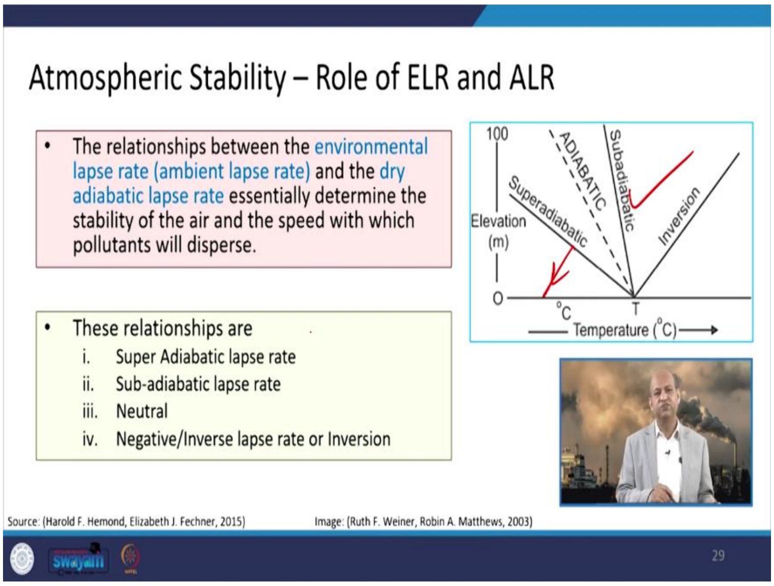

Well, so, what is the role of this atmospheric stability in determining the ELR and ALR? So, the relationship between environmental lapse rate that is the ambient lapse rate or actual absolute you can say, that is not theoretical. When we are talking about DALR and SALR those are the theoretically derived lapse rates. When we are talking about ELR that is the actual lapse rate which is existing in the atmosphere.

So, the relationship between the environmental lapse rate or the ambient lapse rate and the dry adiabatic lapse rate essentially determine the stability of the air and the speed with which the pollutants will disperse. So, you can see this is the adiabatic lapse rate. And this is severe sub-adiabatic this is super adiabatic means if temperature is decreasing faster then it is unstable.

So, unstable atmosphere is known as super adiabatic lapse rate follows the super adiabatic lapse rate. Sub-adiabatic means the temperature decreasing but slowly so, that is kind of moderately stable. Inversion means rather than decreasing temperature is increasing so that is very completely kind of suppressing of the pollutants. So, these are basically the super adiabatic lapse rate, sub-adiabatic lapse rate or neutral means if you know this ELR and this DALR are same then we call it neutral conditions.

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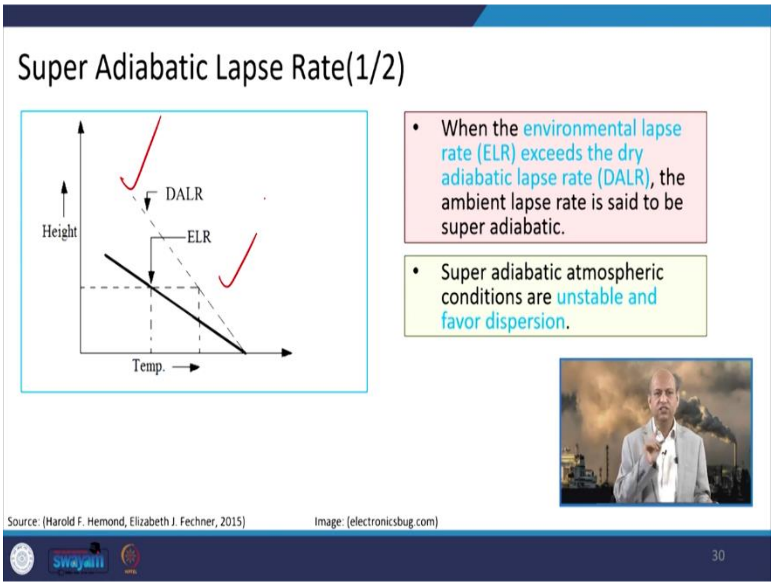

So, here you can see this DALR is dotted lines and ELR is the solid line. You can see the ELR is no faster. It is the temperature, actual temperature decrease is very high speed. So, this is super adiabatic lapse rate, and this is the unstable and it favors the dispersion. And the environmental lapse rate is exceeding the dryer adiabatic lapse rate because the temperature is decreasing faster in existing atmosphere, than the theoretical DALR, so, that is the super adiabatic lapse rate or unstable atmosphere.

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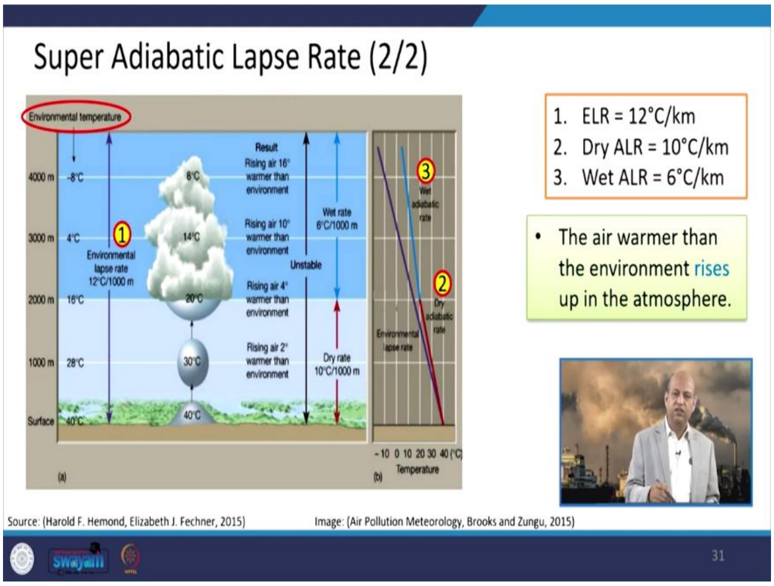

So, you can see here in this particularly super adiabatic lapse rate you can see pollution, the pollutants rise above and they go above and above and then temperature decreases, when they are expanding and losing the heat, so those kinds of things are there.

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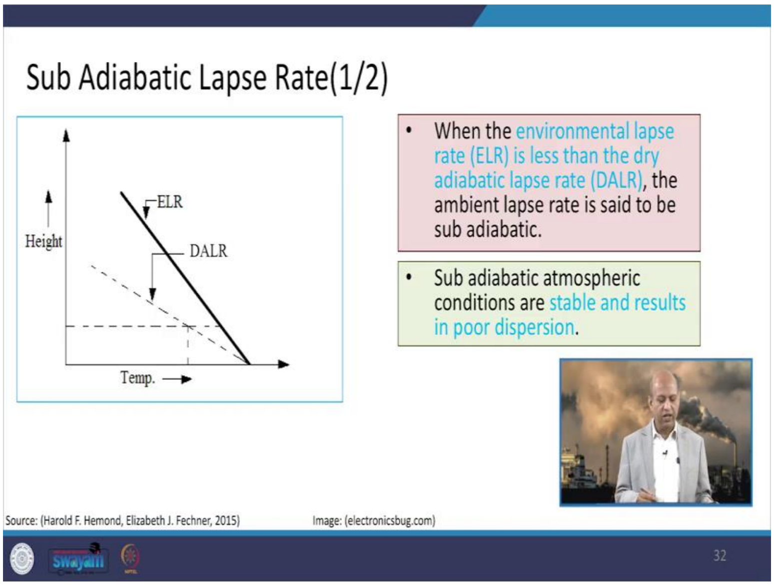

Well, when we talk about sub adiabatic lapse rates, so that means, the environmental offset is slower and DALR is faster than the ELR like shown in this.

So, in sub adiabatic lapse rate this DALR is faster means the dry adiabatic lapse rate is their theoretical lapse rate is faster temperature decreasing faster in comparison to the ELR and ELR it's slower, so that is the sub-adiabatic lapse rate or a stable atmosphere you can see here.

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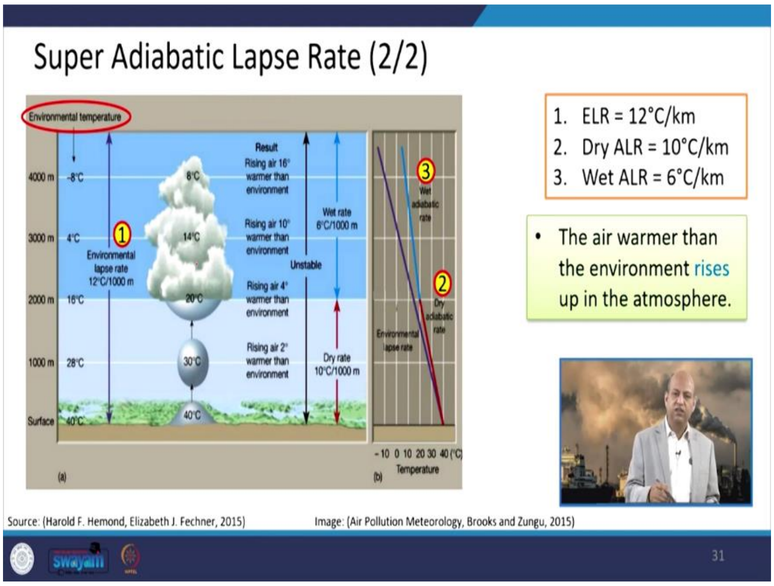

So here the it will not go up rather than it will sink the pollution or plumes will sink.

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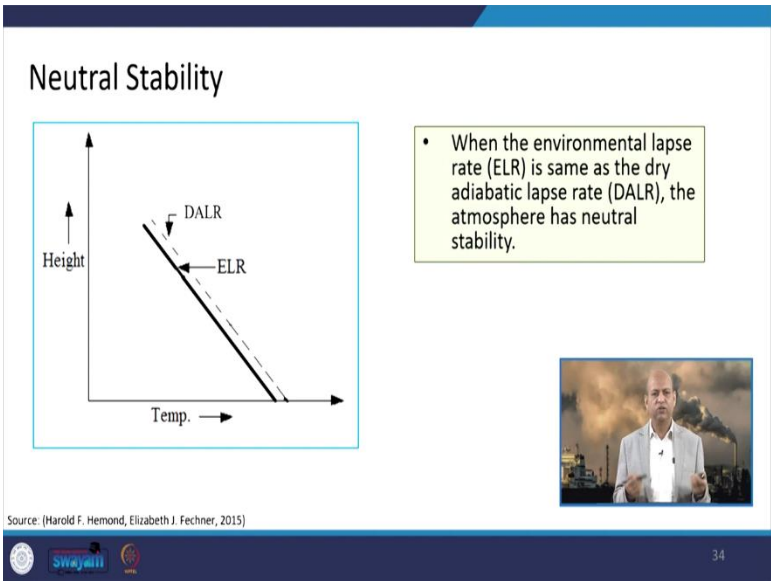

When we talk about neutral means that DALR and ELR parallel, and the pollution wherever it is released, it will hang around but it will go away with the wind.

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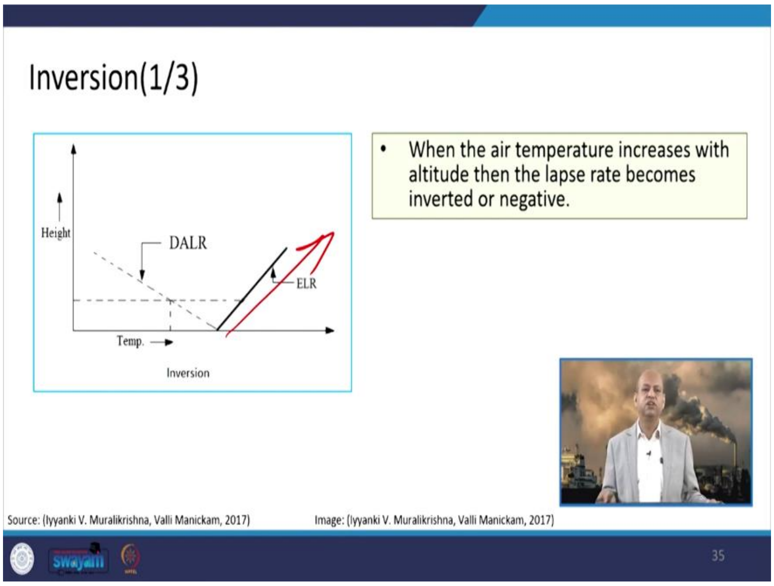

Of course, wind also takes part in removing the pollution from one place to another. Well in inversion as you see this ELR is the temperature is increasing with the height so it will suppress the vertical movement of the air parcel or pollution.

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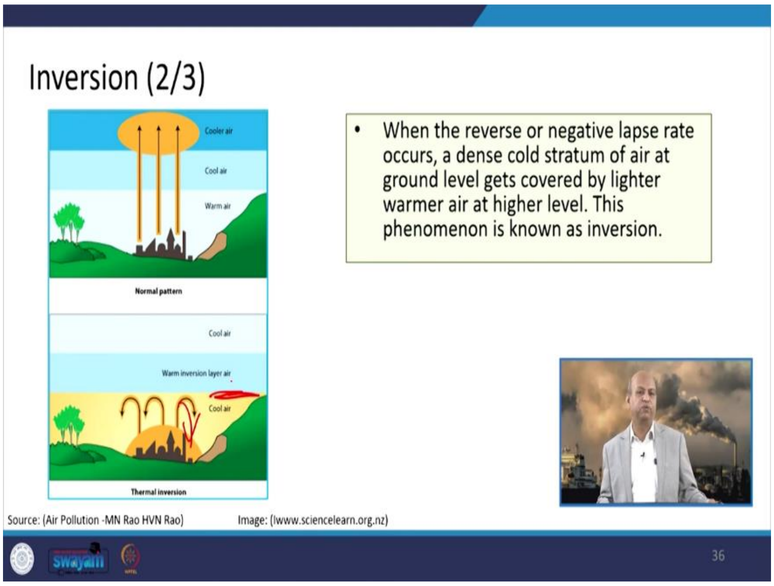

So, you can see here this this kind of thing. So, here like this is normal pattern where temperature is decreasing with the height, so the plume goes up. In this temperature is decreasing, temperature is increasing rather than decreasing with the height so the plume will come back, it will not cross this particular point where this inversion phenomena is there. So, inversion layer is having a kind of cap which will not allow the vertical movement of pollutants.

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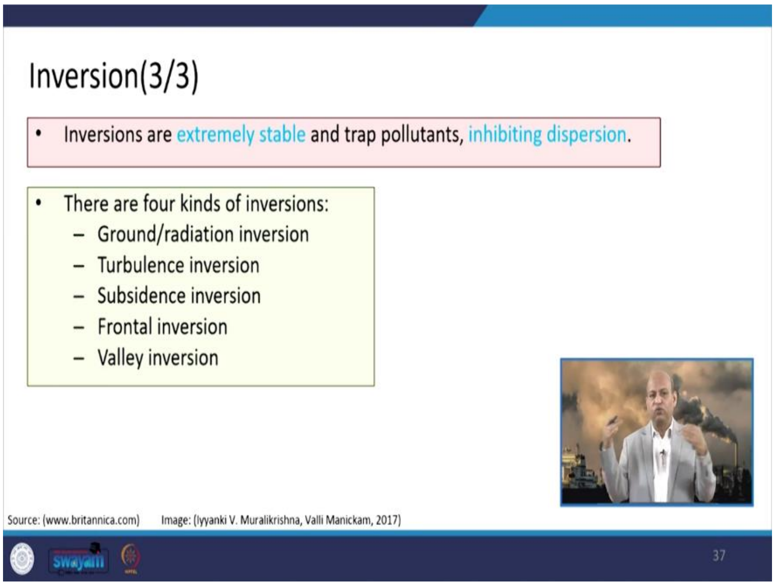

Well, inversions are also of several types. Like ground or radiation inversion thermal inversion also it is known as then turbulence inversion because of winds, turbulence. Subsidence inversion because air mass subsides. Then frontal inversion because of warmer and colder air cross then valley inversion which happens because of valley effect we will see by figures.

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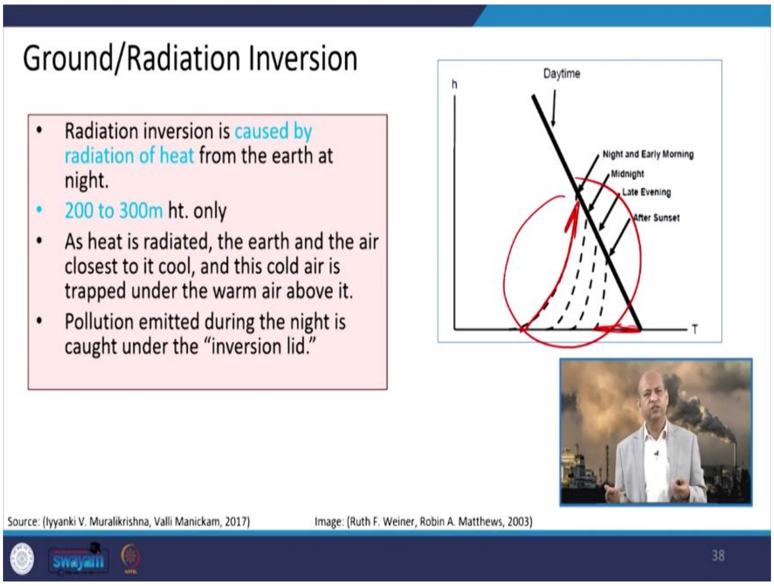

So, in this figure you can see this ground or radiation inversion because of this thermal phenomena exchange. For example, this is the, a particular at a particular place, this is the gradient of the temperature, so, temperature is decreasing with the height. But what happens like evening time, evening time when sunsets, so, the temperature of this surface decreases because it loses heat very quickly.

So, the temperature decreases and the air which is upper those above the surface their temperature does not decrease so quickly. So, what happens the temperature at the surface earth surface and the nearby layer of the air that is less than the temperature of the air layers which is above that. So, the temperature rather than decreasing it is like this, it is increasing with the height up to some height only, we can call. So, this is known as radiation inversion or ground level inversion which occurs in deserts very quickly in the evening times. And in winters also we faced this kind of inversion quite frequently.

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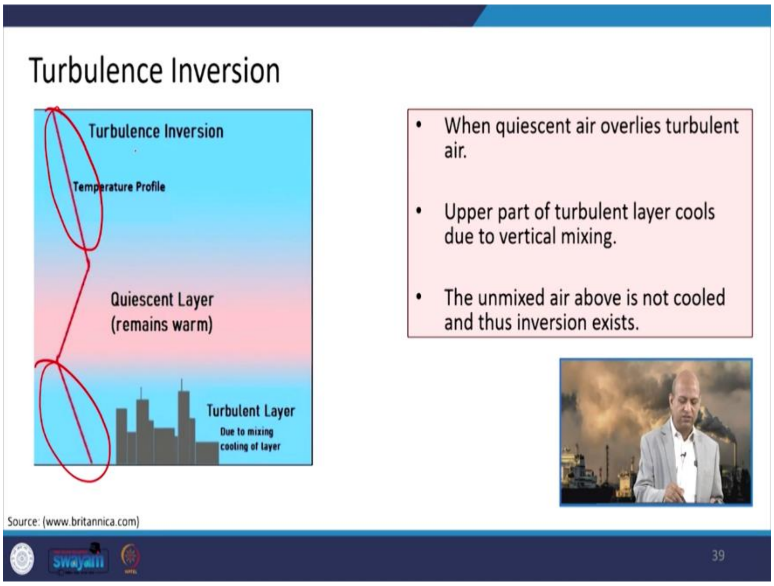

In turbulence inversion you can have particular this upper part of turbulent layer cools down due to vertical mixing. So, the temperature this is like here, this is the temperature decreasing with the height and at the ground level and up to some height again the same pattern, but within this particular layer you will find that the temperature is increasing. So, above the turbulent layer where temperature is decreasing and this turbulence inversion is because of this phenomena. And you will find that in between one layer is there where temperature is increasing. So, that is known as turbulence inversion.

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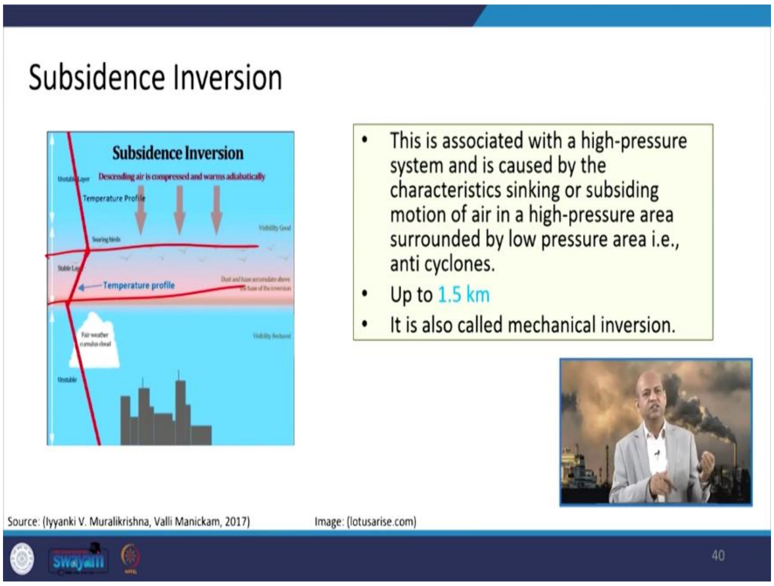

Similarly, you know in subsidence inversion is there. In subsidence inversion what happens like air mass comes down, so, it compresses air and the molecules strike with each other and the temperature increases. So, in this particular layer, you will find at a particular depth, temperature, rather than decreasing it is increasing. So, that kind of inversion may also happen.

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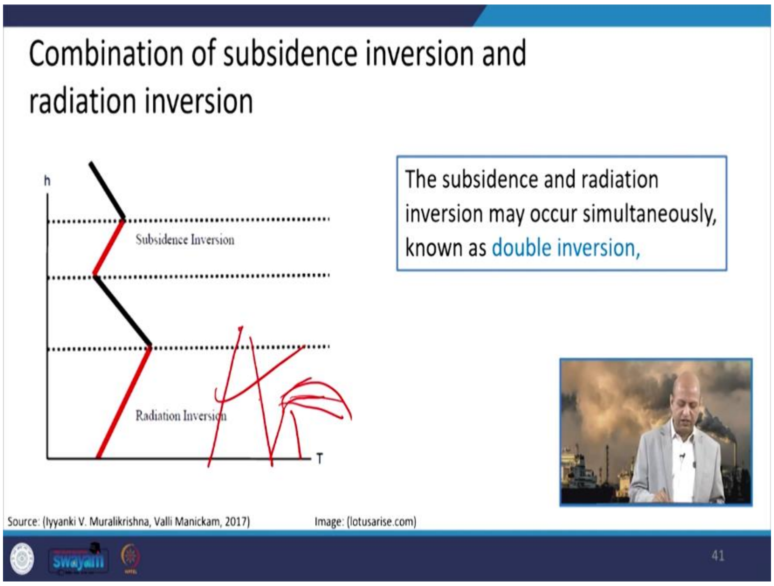

Well, combination of inversions maybe there like radiation inversion and then subsidence inversion maybe there at a particular height, so the combination may also occur. So, for example, suppose this is the stack and the pollution is coming out of this. So, it will not go up it will just remain in this particular layer.

But, if some stack height is above this inversion layer, so, here it will very quickly disperse. So, it will depend up to which layer the stack height is there.

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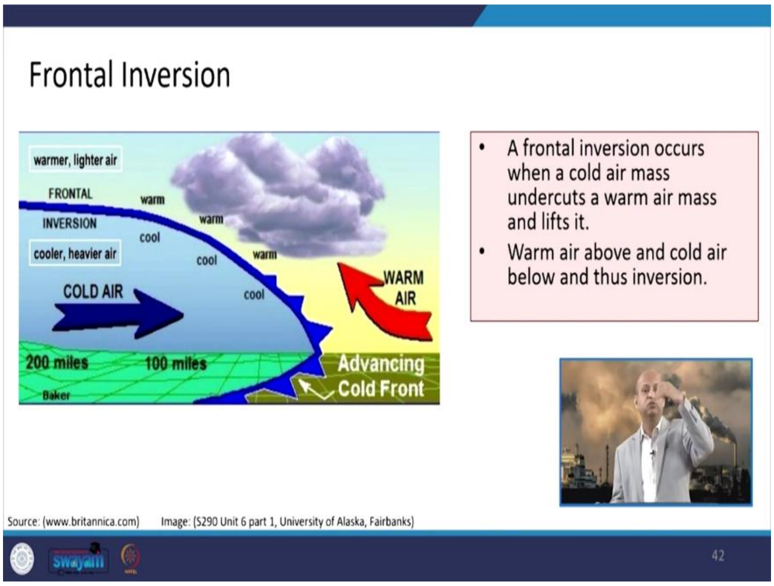

This is the frontal inversion where cool air mass strikes with the warm air, so the temperature gradient again you can see that at some height, the temperature rather than decreasing it is increasing because some warm layers will be on the upper side. So, that is known as frontal inversion.

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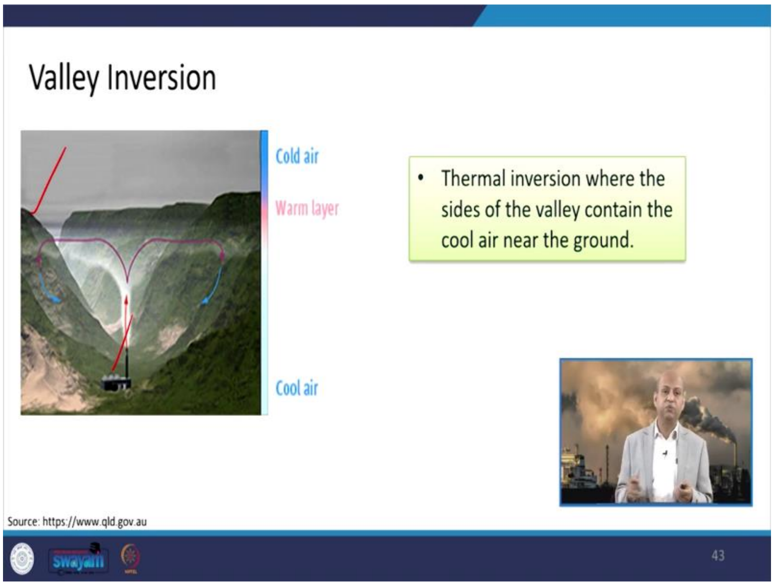

Similarly, in the valley like you know, in the morning when sun comes to our surface becomes quite hot, the temperature is increasing and the valley the surface is cooler in comparison to the height of the those mountains. So, in that also sometimes this kind of inversion occurs and this is diurnal inversion weather daily, because of morning and then the sunset after sunset. So, that that kind of inversion can be there, because of temperature difference at this level and the valley level. So, those may be dangerous when if there are some industries and emitting some pollutants, this will not disperse so quickly.

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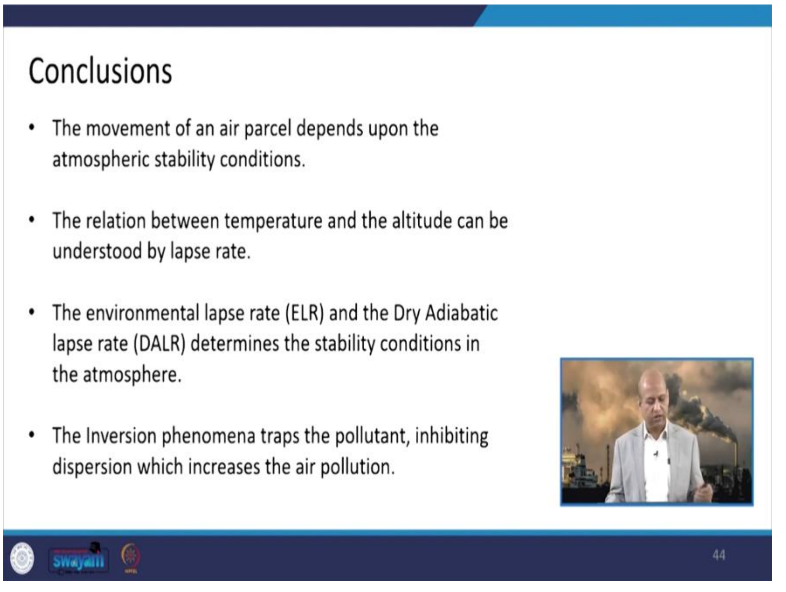

So, in conclusion, we can say that the movement of air parcel or air pollution basically depends upon the atmospheric stability conditions. And the atmospheric stability conditions are basically determined by the lapse rates or the temperature variation with the height. So, the relation between this temperature and the altitude we call it like lapse rate and it can be environmental lapse rate which is actual and theoretical is DALR and SALR dry adiabatic lapse rate and the saturated adiabatic lapse rate.

So, environmental lapse rate and dry adiabatic lapse rates that determine the stability conditions in the atmosphere. And the inversion phenomena traps the pollutant and it is very dangerous phenomena. It inhibits the vertical movement of the pollution. So, which happens when temperature rather than decreasing increases with the height. So those kinds of conceptual understanding I hope you got through this presentation.

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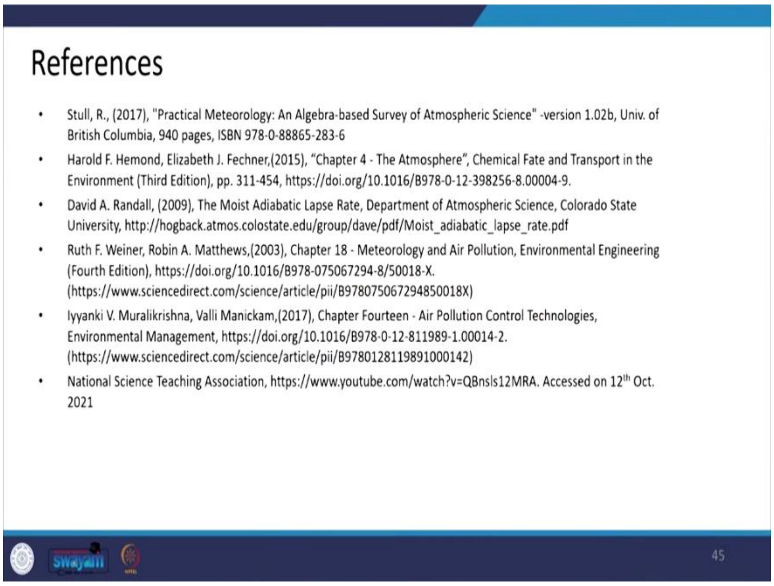

For additional information, you can go through these references. And I thank you for your kind attention. See you in the next lecture. Thanks again.