



So, the temperature profile turns out if you go out now, the temperature profile is generally like this approximately to a certain height beyond that it will change. So, this height beyond that it will change is seen somewhere in the troposphere it changes beyond that point it becomes the temperature profile changes for other reasons but that is the reason or no we are not interested in that region very far away. We want to see what is happening very close to the surface.

Now, let us say this is at 2pm what happens as we go closer to the sunset, when the sun is setting this is happening because you have this kind of behavior mainly because this radiation is during the daytime the radiation heats up this soil or land faster than it heats the air. So, radiation directly heats the radiation directly heats the soil. And when this is hotter as a result this temperature of the soil is very hot. You can see that normally when you are in summer times or in the peak daytime, the land is very hot.

You can see it is much hotter than what the temperatures in the air. So, as a result of which there is a positive temperature gradient in this direction, the air above the surface heats up from the soil it does not heat from the sun directly with the soil heats much more rapidly than the sun because if you look at radiation, the rate of radiation is fourth order of temperature, the rate of convection, conduction are all first order.

So it really heats up faster, radiation heats up really fast, it also cools really fast. So, when there is a radiation this is very hot. So, therefore, the air closer to the surface is hotter than air above. So, you are expecting to see this kind of a gradient in the temperature. What happens when radiation when there is no radiation, say at 7pm, 6:30 or 7pm, sun is set no radiation, what then starts happening? The soil then starts cooling, it cools very rapidly it is given up all its heat.

Then you see a certain small decrease the temperature the air is still hot, but the soil has started cooling so, you start seeing this kind of behavior. The air is warmer than the soil has cooled down really fast and you have heat transfer is it going in the reverse direction and this and this is slower process than radiation. So as you go deeper into the night you are likely to see this kind of behavior well into the night.

Then when you have morning 6am or 7am sun rises, you start to start going reverse because now you will start seeing things like this. The reverse is happening the sun, the land starts heating up very quickly and it then starts heating the air on top of it. So use the gradient start moving this way. The following you can see it very clearly. When you have in winter conditions, extreme winters when you see fog for in places where there is form that happens.

You can see that in the daytime you did not see any fog in the nighttime, the land cools very rapid. And if the conditions are humid and it is a minimal for formation, it will forms near the surface. The moment sun rises what do you see, when you see fog formation, we have this term called lifting of the fog. How many of you have seen lifting of the fog? What it means what it looks like is the surface is full of fog, then suddenly the land will clear.

The fog looks like it is going up it is clearing up from the surface is clearing up because of what is happening here. Next to the surface land is heating up air is heating up all the water droplets fog is draw water droplets liquid water droplets they are evaporating and there is no more particle there. It is all vapor phase it is clear. But the reason that we are still heating up it is taking time. So it is happening slowly.

It is it is happening by conduction or convection or whatever the process is, there is no wind there is no convection, conduction mainly so it happens very slowly. So, this profile, this is called as what is called as an environmental, environmental lapse rate. It is called a lapse rate because it is temperature profile as a function of height. The environmental lapse rate varies from place to place throughout the day, season to season.

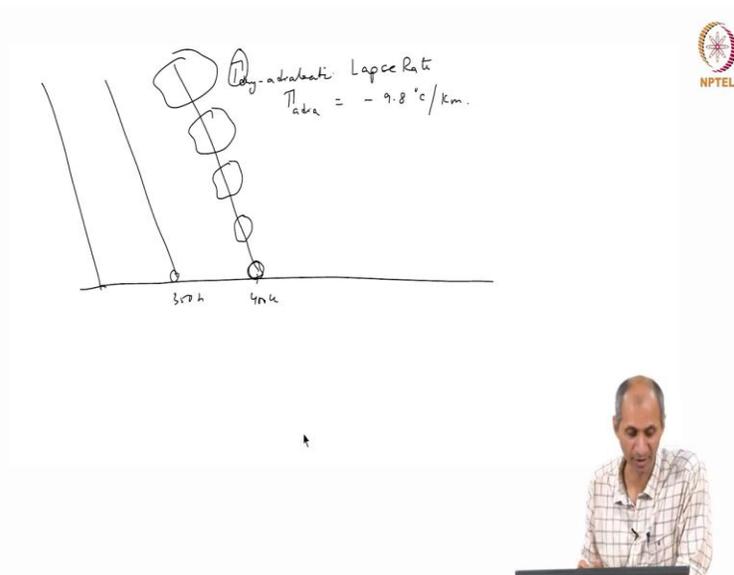
So every day you go you will find some profile right now we will find a profile. Tomorrow morning you will find a different profile. But by and large, this is seasonal for a place like Chennai you environmental lab rates are generally known for it the people have been measuring it for a long time they know that this is what will happen. This is the general lapse rate and the temperature profile goes in some direction.

Now, this is what is happening in the system. So this region is called as the inversion the temperature inversion. The temperature inversion means in the daytime temperature is reducing as a function of height as height, but here temperature is increasing as height, this is called an inversion now, we will see why this innovation is important from the point of view of pollutant transport. So, in this system this is the environment.

This is how the environment looks in terms of temperature in the system if I drop a parcel of air coming from a pollutant source for example, if I have an engine, if I am running diesel generator or something in the middle of a field, what will happen so, it is generating some gas at some temperature and you want to see what will happen to this gas to air passes. So, I am taking the case of an engine or something.

Because it is releasing like parcels of air at given intervals again, this is puff releasing a puff of air and so, we can see what happens to it so, several things can happen to it depending on what is the condition in the environmental lapse rate. So, what will happen to a parcel when it is released?

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So, normally for rely the parcel here is expected to follow what happens is, if temperature is higher, it is going to want to go up the 2 things are at play here 1 is buoyancy is making it go up, whereas, it goes up if there is no exchange of energy, its volume also expands like this and it

cools, thirds cooling and expanding 2 things are happening and the rate at which it is cooling and expanding. Just call it if it is assumed to be dry and adiabatic it is called dry adiabatic lapse rate.

It is an ideal number the reason they assume the adiabatic is there is heat transfer. What it means by a vertical is there is no heat exchange between the surroundings and this part of this parcel is just behaving energy is conserved inside, but because it is moving up because of buoyancy, as it goes to a slightly low pressure area, it expands, the volume expands and temperature drops and so on.

So, the temperature of this parcel is changing as it is going up and it is changing in this fashion. And this can be derived by using thermodynamics and statics. I will give you the derivation. We would not do it in class, but I will put it there in your notes. It is very simple derivation it is dry adiabatic lapse, but what it assumes is the air is dry and there is no heat transfer the adiabatic part of it is in our assumption that it moves fairly fast between one position and another position.

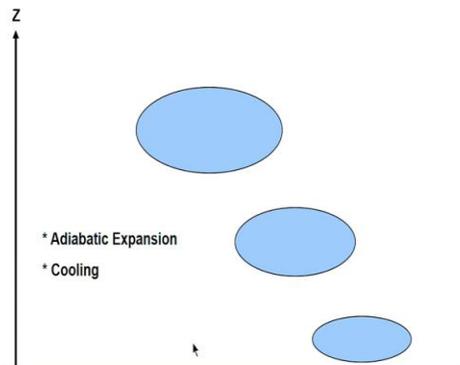
So there is not enough time for it to come to thermal equilibrium within neighborhood so it is always it is always moving fast may not be true. But it is a nice reference point for us to have. And it is given by the symbol gamma, we call it as gamma adiabatic. This is expected to be the trajectory this particular any air parcel we will take and the value of dry adiabatic lapse rate is - 9.8 degrees centigrade per kilometer which means that irrespective of what the starting temperature of this is, it will cool in this fashion.

Which means I have air mass that is a 400 Kelvin I have air mass at 350 Kelvin, all of them will go in the same direction see  $\Delta t$  by  $\Delta z$  is the same. Now, you can imagine if I superimpose this the system trajectory of a pollutant this was what the pollutant will do because of initial conditions, if I put superimposed on this environmental lapse rate, what will happen to their air mass is, what is the consideration.

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## Atmospheric Stability



So we will quickly go to this is what is called adiabatic expansion and cooling is what we just described the term call atmospheric stability that that comes into plates.

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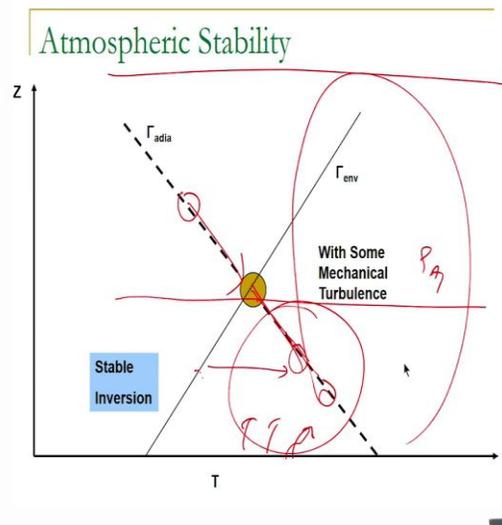
## Atmospheric Stability

- $\Gamma_{\text{adia, dry}} = -dT/dz = g/C_p = -0.0098 \text{ C / m}$
- Dry Adiabatic Lapse Rate,  $\Gamma_{\text{adia, dry}}$
- Environmental Lapse Rate,  $\Gamma_{\text{env}}$
- Comparison of  $\Gamma_{\text{adia, dry}}$  and  $\Gamma_{\text{env}}$  determines the stability condition



For what we look at is the following. So, this is adiabatic lapse rate.

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And so, let us assume that this gamma environmental is environmental lapse rate which is the environmental change in temperature as height as, in the environment that is existing at that particular time. And gamma adiabatic is the trajectory this wants to take so, let us say at this point of intersection, this particle is this gas is decreasing is moving up naturally, but there is a point where it intersects with the environment lapse rate.

Now, with some mechanical turbulence aids here, I push it up a little bit and the force that is pushing it up is mechanical force, there is always wind on top of all this wind is pushing it up. If it goes up, what will happen is when this goes up because of wind, the temperature of this parcel is always going to be higher than environmental in your surroundings, which means it has higher greater buoyancy and it will continue to go up.

In the same way, if I push it down, the temperature of this parcel will always lower than what it is surroundings. So therefore continue to go down. So it is an unstable situation like this. If I am, balancing it, this pen here, if I am correctly balancing it, and then this is if I tilt like this, it is stable it is going back to its original position. Suppose I am here and somehow I am balancing it if I am giving it some force, which means I am removing this will fall down.

If I am balancing it ever falls down. It continues in this direction or other direction so that is called an unstable. So, unstable environment in the presence of mechanical forces turbulence the

way in which the thermal forces are the temperature gradients are it accentuates it is exaggerates the motion of a parcel in the direction in which has mechanical energy is pushing it. So, you will get extremely large movement of the pollutant masses depending on where, how the wind is.

So, the wind and thermal the thermal forces exaggerate add to the already existing mechanical turbulence in order to create a situations called unstable. There is another thing which is called us this neutral is the lapse rates are similar. So, in which the temperature profile of your parcel and the surroundings are always the same so, the temperature has no effect, buoyancy has no major effect on the movement of this parcel.

So, when mainly the wind is determining whether it goes up or down, since the wind is very high, it will go up or down. That is all because the temperature is the same, there is no extra turbulence there is no extra thermal inducement to partial movement. So, this is called as neutral. If you have a system like this, if I push it the environmental lapse rate is bold line and this is the dotted line is the adiabatic labs, retro pollutant are supposed to go.

So if I move it here, what happens it goes up, but when it goes up to temperature, its temperature is lower than that of the surrounding environment. So it is buoyancy is greater so it comes back down the density will be greater it comes back down to the original position same way here. This temperature here, is higher than they surrounding temperature. So, it will want to go back to this point again. Here again this temperature is lower and therefore, buoyancy will drive it back to this point which means it is very stable.

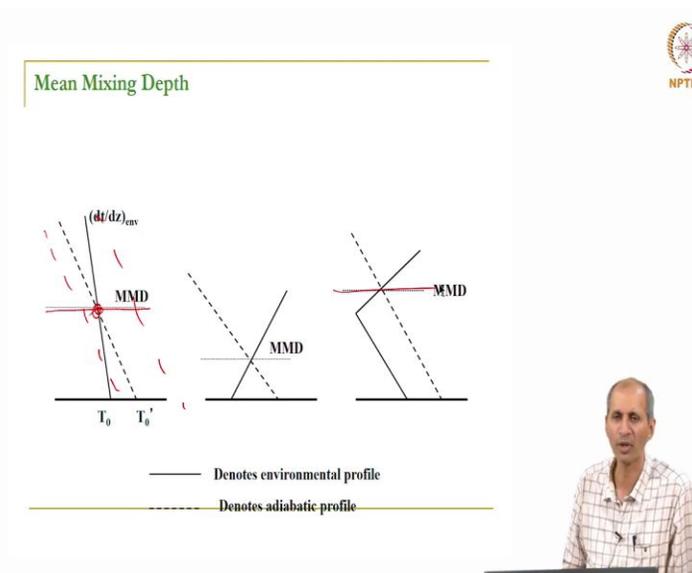
So, this is a stable and it is usually caused by inversion causes this kind of behavior among all of these, which do you think is from a pollutant from a concentration perspective, which do you think is more favorable for air pollution with a stable neutral or unstable what would you want for pollutant concentration to be low you want push it to be low unstable you want it to spread as far as possible.

Because from the box model point of view if it is spreading far, which means it is able to spread far exceeds that dimension of that z dimension is very large in the case of an inversion like this

not going anywhere it is contained within that, for example, if I release, a pollutant here, it is going to go up until this point and stop the inversion is there, it is going to stop. So, if I keep on releasing this essentially makes a ceiling to my pollutant concentration.

So, if I keep on releasing here, this concentration here in this volume is going to go increase gone increasing and therefore that influences the concentration. So, this is the direct reference to so if you have an unstable environment, this height is very high, it has the opportunity to mix in a larger volume and therefore the concentration of rho 1 is going to be smaller in the case of an unstable environment, in neutral depends on how the wind is taking it there is no real indication as to how far it will go depends on the wind alone.

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So this is a this is the definition of what people call as a mixing height the mean mixing height is the intersection of the adiabatic and environmental lapse rate. So, the environmental lapse rate is known at different times of the day, if you know what the temperature of the pollutant is you can calculate various adiabatic lapse rate. So, adiabatic lapse rate can be anything it can be here can be anything, it depends on what temperature is at the ground.

What is the where are you releasing what temperature is the release happening. So, there is a particular location where you can have where the mixing will happen there. So, one of the things that people are the way they also look at it is from a long term perspective is very laborious, very

stressful and very difficult for everybody to for every source. It is difficult for us to far as go going to go we are in the mixture. We are have lots of pollution sources all of them are using at the same time.

And we would like to know what is going to be the average mixing height so that we can predict what is going to be happening down when those kind of things. So, there are some general rules people use in order to do this, we will see that in one of the illustrations problems, but, so, therefore, for that reason, there are mixing heights that are determined for a particular location for a particular season.

Based on the pollution profile in that region, people already know have some idea as to how this looks like and they use that number in order to do modeling of atmospheric pollutants. And that can also mean mixing height is reported for different locations and it changes with and so this concept of stability and mixing height is very important when we are looking at pollutant transport in the atmosphere, we are talking about atmospheric dispersion.

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So what we say dispersion is this is a visible phase of dispersion. So, there is a source this is called as a stack general atmospheric dispersion jargon this is a stack. A stack is any source, but it is a very classic stack, you can see that there is an emission occurring here and you can see that it is spreading the spreading, you can see a very classic this is spreading because it is spreading

in all directions spreading in the x, of course, moving in the x direction because there is wind it is pushing it in this direction.

It is wind in this direction. But it is also moving up a little bit here you can see that it is moving up a lot. It is generally moving in this direction, but it is also going up a lot. So, this vertical dispersion and this horizontal dispersion this y direction in the y direction also disperses the extent to which this happens determines what will be the concentration in this region. So this pollutant mass is enclosed in this you can see it very clearly.

It is not gone out of this region, it is here unless I can see it so sometimes you cannot see this. It is an invisible thing you cannot see any white stuff coming out. Because this white material is because of 2 reasons why there is water vapor condensing or it is particulate matter in some particular manner, it gives it some shape and color. So, this call this this boundary is known as a plume called as plume.

So, the plume the shape of this plume depends on how much it is spreading in both directions in the x and the y. And that depends again on whatever we discuss the 2 things one is to conduct the convection because of mechanical forces, which is the wind and the convection because of thermal forces. So the thermal forces essentially influence the vertical spread mechanical influences both vertical and horizontal.

So, if there is no mechanical force, there is no wind nothing will happen it will just sit there and will grow. So imagine there is no wind, if I light a fire here, you will see that it will just grow like this. And there is only diffusion process that is happening and buoyancy that is happening. No other connection is happening this temperature is only moving my mass is moving by buoyancy and buoyancy also stops at some point there is a it comes in equilibrium it will just sit there and it will move slowly by diffusion. So we will look at all that. So we will stop here today.