Environmental Quality:
Monitoring and Analysis

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Lecture No. 36
Transport of Pollutants - Box Models in Water

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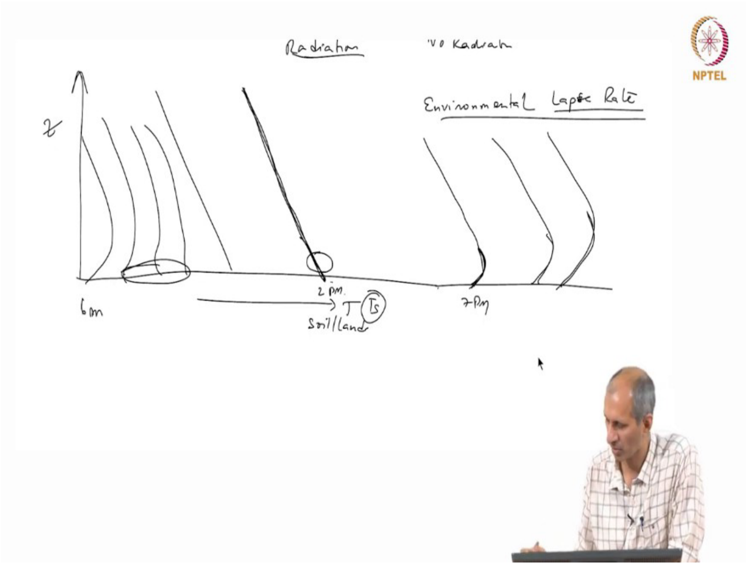

Okay, so, let's consider two things, first thing to be considered is what is called as the temperature profile as a function of height. So, we are saying that vertical convection happens as a result of thermal forces which means there's a temperature difference. So, what is the temperature difference that will result in vertical movement of air masses? So, which means that I need to know what is the temperature profile as a function of height. So I need to know, what is the temperature as a function of height. So, let us say that this axis is temperature, it is also the ground. This is height Z. So, what will be the temperature profile on the Earth's surface? First, this is environmental data, normally if I go outside now, what is likely to be the temperature profile?

So, the temperature profile turns out if you go out now, is generally like this (as shown in the picture), approximately, to a certain height beyond that it will change. So, this height beyond that it will change is somewhere in the troposphere. Beyond that point the temperature profile changes for other reasons, it happens very far away and we are not interested in that region. We want what is happening very close to the surface of the earth.

Now, let us say this is at 2pm, what happens as we go closer to the sunset? During daytime the radiation heats up the soil or the land faster than it heats the air. So, the radiation directly heats the soil. And as a result this temperature of the soil is very high. You can see that normally, when you are in summer or in the peak daytime, the land is very hot. You can see that in summers, it is much hotter than what the temperatures in the air are. 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 because 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, ok. 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 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 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, the soil has cooled down really fast and you have heat transfer is occurring in the reverse direction 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, it starts going reverse because now you will start seeing things like this (see in the picture). The reverse is happening, the land starts heating up very quickly and it then starts heating the air on top of it. So, the gradient start moving this way. You can see it very clearly. In winter conditions, extreme winters when you see fog in places where it happens. You can see that in the daytime you don’t see any fog. In the nighttime, the land cools very rapid and if the conditions are humid and it is amenable for fog formation, it will form fog near the surface. The moment sun rises what do you see, we have this term called lifting of the fog. How many of you have seen lifting of the fog? 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, it's clearing up because of what is happening here. Right next to the surface land is heating up, air is heating up, all the water droplets, fog is liquid water droplets, they are evaporating and there is no more particle there. It's all vapor phase, it is clear. But the region above are still heating up, it is taking time. So it's happening slowly. It is happening by conduction mainly so it happens very slowly. So, this profile is called as an 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 environmental lapse rates are generally known so 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's happening in the system. So this region is called as the temperature inversion. The temperature inversion means generally in the daytime temperature is reducing as a function of height, but here temperature is increasing as height. We will see why this inversion 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 air parcel. So, I am taking the case of an engine or something because it is releasing like parcels of air or 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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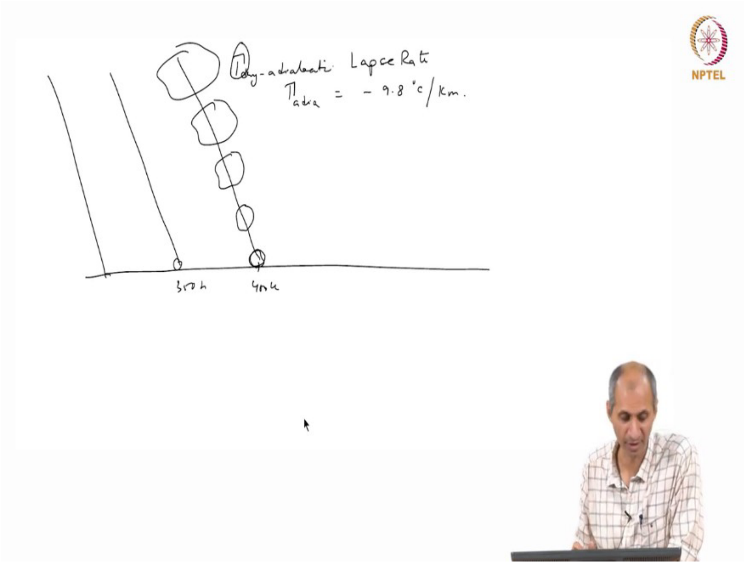

So, normally if I release a parcel here, what happens is, if its temperature is higher, it wants to go up. There are two things at play here. One is buoyancy which is making it go up, but as it goes up if there is no exchange of energy, its volume also expands like this and it cools, so it's cooling and expanding two things are happening and the rate at which it is cooling and expanding, if it is assumed to be dry and adiabatic is called as a 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 parcel of air, 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 won't do it in class, but I will put it there in your notes. It is very simple derivation it is dry adiabatic labs, but what it assumes is the air is dry and there is no heat transfer, the adiabatic part of it is in 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 with its 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 of any air parcel 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 the delta t by delta z is the same. Now, this is the trajectory of a pollutant this is what the pollutant will do because of its initial conditions, if I put or superimpose on this environmental lapse rate, what will happen to their air mass is, is what is the consideration.

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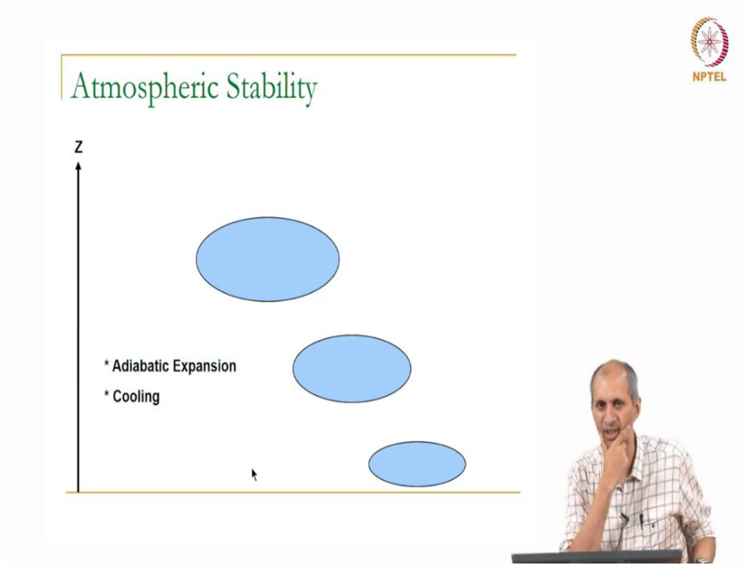

So we will quickly go to the what is called adiabatic expansion and cooling is what we just described the term call atmospheric stability that that comes into play.

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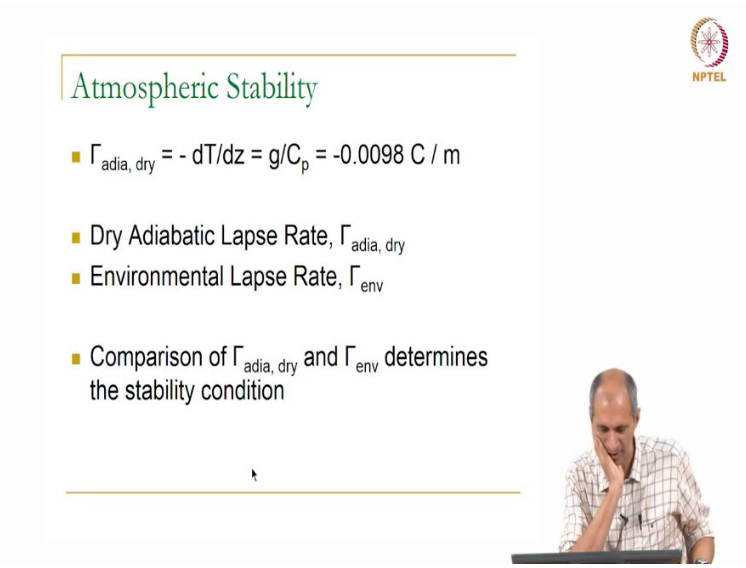

So what we look at is the following. So, this is adiabatic lapse rate.

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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 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 that force that is pushing it up is mechanical force, there is always wind on top of all this, so wind is pushing it up. If it goes up because of wind, what will happen is the temperature of this parcel is always going to be higher than that of environmental in the surroundings, which means it has 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 be lower than what it is in surroundings. So therefore it continues to go down. So it is an unstable situation. So it is like if I am correctly balancing a pen on my finger, and then if I tilt like this, it is stable it is going back to its original position. Suppose I am here (not at the center of mass) and somehow I am balancing it, if I am giving it some force, which means I am removing the support, this will fall down so that is called an unstable ok. So, the wind and 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 as this neutral lapse rates. 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, it’s mainly the wind which 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 dotted line is the adiabatic lapse rate, pollutant supposed to go there.

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, the 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 inversion causes this 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 which is that dimension of that z dimension is very large in the case of an inversion like this it is not going anywhere it is contained within that, for example, if I release, 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 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 ρ_{A1} is going to be smaller in the case of an unstable environment. In neutral, it depends on how the wind is taking it, there is no real indication as to how far it will go, it depends on the wind alone.

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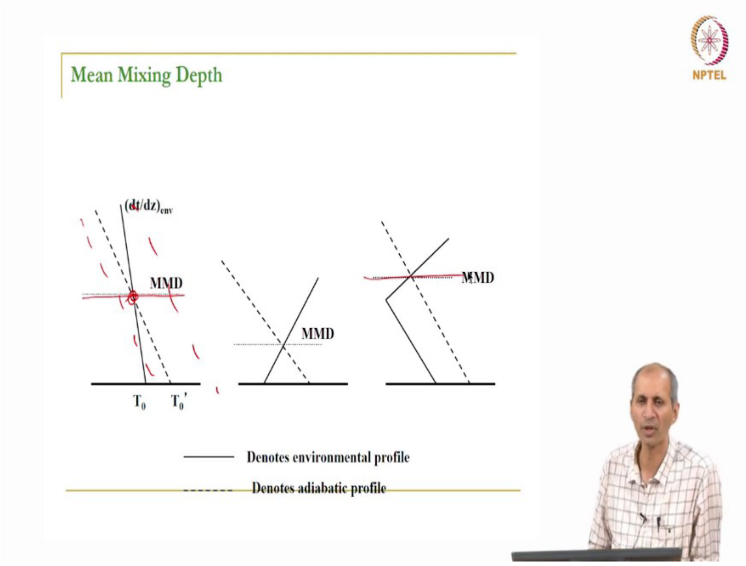

So this is the definition of what people call as the mean mixing height which is the intersection of the adiabatic and environmental lapse rates. So, the environmental lapse rate is known at different times of the day, if you know what is the temperature of your pollutant, you can calculate various adiabatic lapse rates. So, adiabatic lapse rate can be anything, it depends on the temperature at the ground, at what temperature is the release happening. So, there is a particular location where the mixing will happen, where mixing height will be there. So, one of the things that people or the way they also look at it is from a long term perspective. It is very laborious, very stressful and very difficult for everybody to look for every source. It is difficult for us to get how far it is going to go because we are in the mixture we have lots of pollution sources, all of them are releasing 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 downwind those kind of things, ok. 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 then they use that number in order to do modeling of atmospheric pollutants. Main mixing height is reported for different locations and it changes with many parameters 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 a visible phase of dispersion. So, there is a source this is called as a stack this is a general atmospheric dispersion jargon. 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, you can see a very classic, 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 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, 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't 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 either it is water vapor condensing or it is particulate matter in some particular manner, it gives it some shape and color. So, this boundary is known as a 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 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 the 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 the only diffusion process that is happening and buoyancy that is happening. No other convection is happening this temperature is only moving my mass is moving by buoyancy and buoyancy also stops at some point 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.