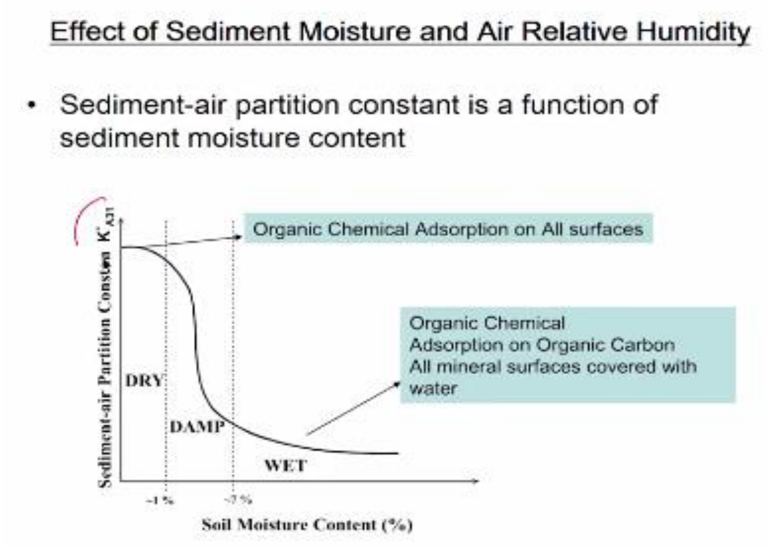
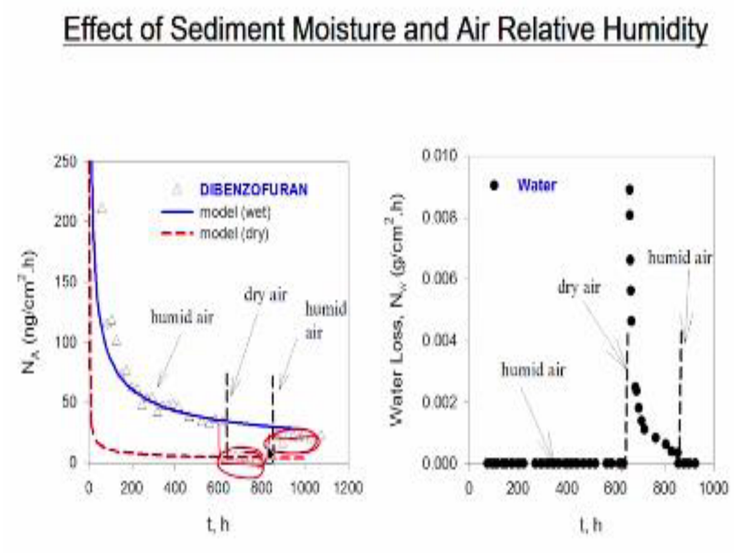


Effect of Sediment Moisture and Air Relative Humidity

- Sediment-air partition constant is a function of sediment moisture content

So this is again the thing that we discussed in last class. When this kind of thing happens, moisture content in the soil is changing as a result emission will change. The partition constant is changing, this is changing.

(Refer Slide Time: 33:06)

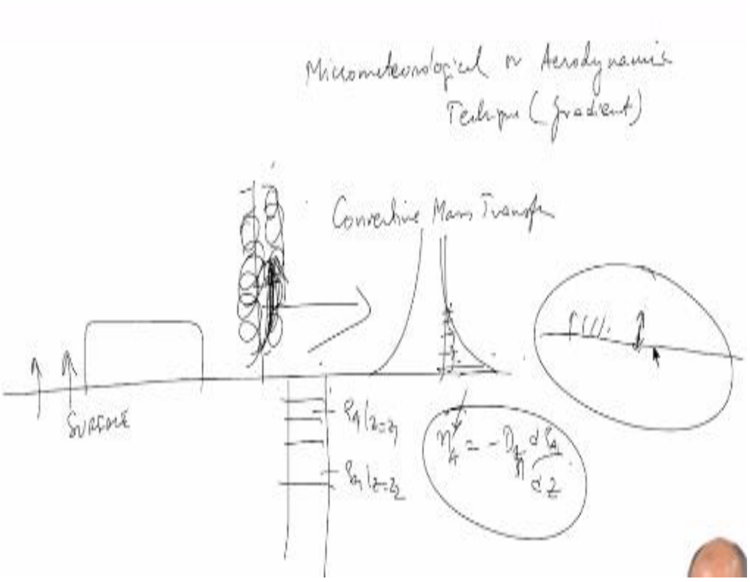


Effect of Sediment Moisture and Air Relative Humidity

This experiment is done in the lab where it shows that there is a chemical called dibenzofuran and this is experimental data. When the mud is dry and this is the model, the blue line is the model that shows, and then at some point we dry the surface by sending in dry air, okay. So the water content increases. The water flux increases because it is now being dried and then the water increase and then everything is dry. During this period, you see that the flux drops down.

The flux for the dry period is down here, dropped down several factors okay. Then again when you hit it with humid air, it goes back up here, okay. So this is illustration of this. When the partition constant changes, the flux changes, okay. Okay, now this is the flux when you are able to measure the flux using a box, putting a box on it. As I mentioned that a lot of times you cannot do that and at the time when you cannot do that, you have to leave it open.

(Refer Slide Time: 34:22)



When you have a surface and you have to measure the flux and it is difficult for you or it is unreliable for you to enclose a surface, you need to still measure the flux and we do it by what is called as a gradient technique or a micrometeorological technique. I am just going to talk a little bit about it, aerodynamic technique. It is also called as a gradient technique. So, for example, you can do this inside the sediment soil, right, I can take a gradient. If I know the concentration of pore vapor at $\rho_{A1}|_{z=z1}$ and $\rho_{A1}|_{z=z2}$.

If there is a difference, I can use $n_A = -D_{A31} \frac{d\rho_A}{dz}$. I can use solution of this equation to calculate what is the flux if I know the diffusion coefficient okay. Basically, I am using a gradient to calculate a flux, yeah. The idea here is can you do the same thing here? You cannot, because the mechanism is not the same. What is happening here is this turbulence that is happening and turbulence is happening in convective eddies that are this kind of structure while it is moving in this direction, right.

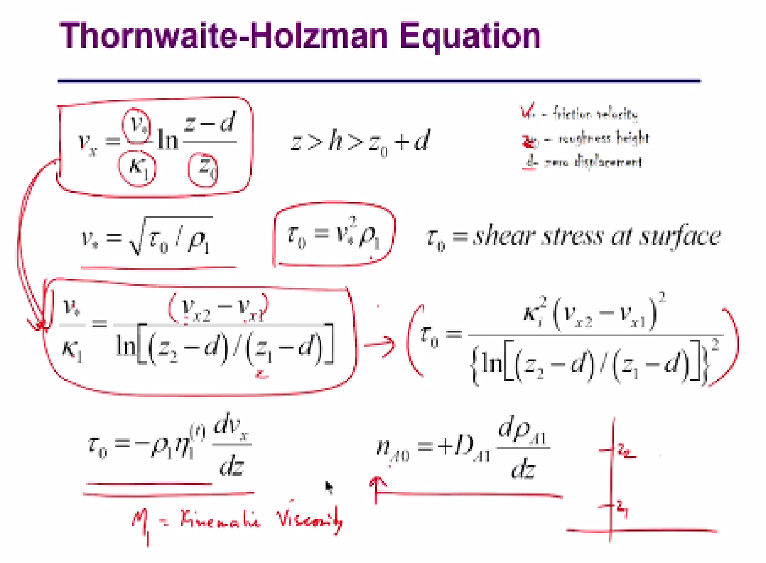
What we are taking advantage of here is that we would like to see if there is a vertical component of the fluid that is going in the upward direction, Yes, this is convective mass transfer right. This is convective mass transfer and therefore we are trying to take advantage of the convective mass transfer component in the z direction to see what is the concentration difference and we will also see if we can somehow measure the net flux based on that concentration difference at a given location, okay.

Because it is moving in this direction, but there is one component that is moving in this direction also, okay, not clear? This is the essence of the convective mass transfer argument that the transfer is happening, there is a gradient in this direction right. When we measure it, we will see that there is a gradient that appears, concentration gradient that appears like this, it is very high at the surface and it is decreasing away from the surface, yeah.

Because material is being carried from the surface upwards this way and that this concentration boundary layer that is assumed to be formed is based on, but this is not happening at the same place it is moving down okay, but if you take a large area and you measure the flux here. So, this gradient is already formed. Gradient is already forming right from the beginning of this contaminated zone, mass transfer has started taking place.

So by the time you arrive here, there is a gradient that exists and based on that gradient you can calculate if there is a flux. For that, you need to know what is the vertical structure for the air.

(Refer Slide Time: 37:47)



Thornwaite-Holzman Equation

$$v_x = \frac{v_*}{\kappa_1} \ln \frac{z-d}{z_0} \qquad z > h > z_0 + d$$

v_* - friction velocity
z_0 - roughness height
d - zero displacement

$$v_* = \sqrt{\tau_0 / \rho_1} \qquad \tau_0 = v_*^2 \rho_1 \qquad \tau_0 = shear\ stress\ at\ surface$$

$$\frac{v_*}{\kappa_1} = \frac{(v_{x2} - v_{x1})}{\ln[(z_2 - d)/(z_1 - d)]} \rightarrow \tau_0 = \frac{\kappa_1^2 (v_{x2} - v_{x1})^2}{\{\ln[(z_2 - d)/(z_1 - d)]\}^2}$$

$$\tau_0 = -\rho_1 \eta_1^{(t)} \frac{dv_x}{dz} \qquad n_{A0} = +D_{A1} \frac{d\rho_{A1}}{dz}$$

η_1 = Kinematic Viscosity

So, this is the essence of the reason why we do this, the equation called Thornwaite-Holzman equation. This is also the basis for the estimation of dispersion parameters in air mode okay. because that is also based on same thing, it is vertical structure of air, turbulence in the air, and therefore how does material move in the y direction and z direction as a result of this kind of convective behavior. So there are equations, do not worry too much about, the essence of this is this.

In turbulent this things, the idea is that velocity has a gradient, we already know velocity has a gradient with height and the structure of this gradient is this form usually. It is a logarithmic relation vx is velocity in the x direction, is a function of z, but in this as a logarithmic function of z and the proportionality constant, this is called as v star, v star is called as the friction velocity okay. The friction velocity is defined as this, shear stress at the surface divided by the density and yeah based on this equation, you can derive this.

From here, based on this, I can derive this expression, you can see it for yourself how it is done, essentially the difference in the velocity divided by the log of the height. So, there are 2 quantities here called y0 and d, do not worry about that, you can assume d to be 0, d is what is called a zero displacement. We are at sea level there is no, if you are a normal ground level there is no zero displacement, what it essentially is zero is some, for example if you are on top of a mountain, the zero displacement will be height of the mountain.

So, that is what it means. The roughness height z0. The roughness height is something that is dependent on what structures available on the surface. So, for example, you have grass or you have trees. The boundary layer does not go to 0 nicely at the at ground zero, it will stop somewhere slightly above depending on what is the nature of the surface, okay. So that is called as roughness height. Therefore, at z0, the velocity supposed to be 0, we are assuming at the surface, that is the assumption we make in boundary layer at z = 0, velocity 0.

That is why you do not see another now **v** vx minus, so the generalized expression is this one is vx minus one other v term is there, where we do not assume that the second v is 0. So, what this means is that if you make velocity measurements at two heights z1 and z2, they will likely follow this expression, yeah. If it follows this expression, then the quantities v star can be calculated from that okay. So v star is the friction velocity which you can obtain by the velocity gradient in a given location, right.

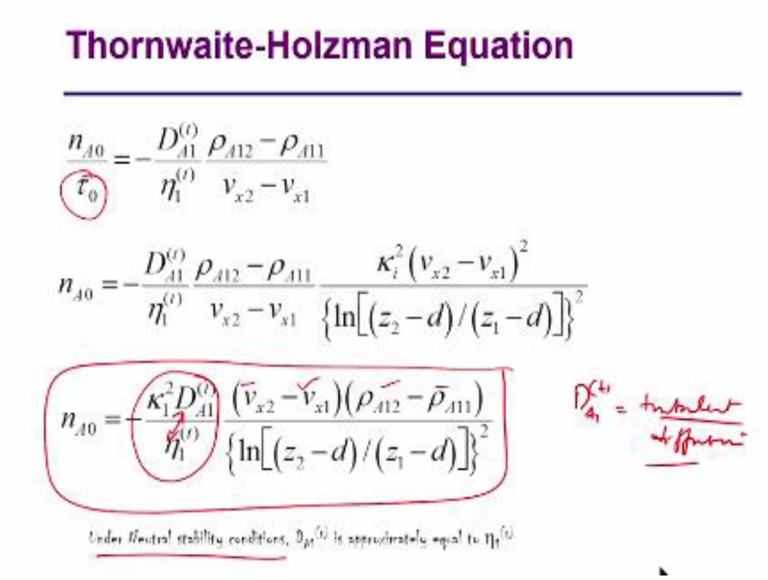
Now from here, you can calculate τ based on this equation, okay Now, τ_0 is expressed in terms of the Newton's law at the surface by this

$$\tau_0 = -\rho_1 \eta_1^{(t)} \frac{dv_x}{dz}$$

$\eta_1^{(t)}$ is the kinematic viscosity, usually we use a different symbol, but this v and that look very similar, so I changed it, it is kinematic viscosity and then this is the mass flux. Now, you see that the signs are opposite for mass flux and the momentum flux because they are in opposite direction. The momentum flux is traveling upwards, mass flux is down or reverse.

Mass is going out, momentum flux is coming down. There is loss of momentum downwards. The velocity is decreasing towards the surface, mass is increasing away from the surface, so this thing change in sign okay. It is all there, you do not have to write it down. So, we are trying to go towards the derivation where so we use these 2 two equations,

(Refer Slide Time: 42:13)



Thornwaite-Holzman Equation

$$\frac{n_{A0}}{\tau_0} = -\frac{D_{A1}^{(t)}}{\eta_1^{(t)}} \frac{\rho_{A12} - \rho_{A11}}{v_{x2} - v_{x1}}$$

$$n_{A0} = -\frac{D_{A1}^{(t)}}{\eta_1^{(t)}} \frac{\rho_{A12} - \rho_{A11}}{v_{x2} - v_{x1}} \frac{\kappa_i^2 (v_{x2} - v_{x1})^2}{\{\ln[(z_2 - d)/(z_1 - d)]\}^2}$$

$$\boxed{n_{A0} = -\frac{\kappa_1^2 D_{A1}^{(t)}}{\eta_1^{(t)}} \frac{(\bar{v}_{x2} - \bar{v}_{x1})(\bar{\rho}_{A12} - \bar{\rho}_{A11})}{\{\ln[(z_2 - d)/(z_1 - d)]\}^2}}$$

$D_{A_1}^{(t)}$ = turbulent diffusion

Under Neutral stability conditions, $D_{A1}^{(t)}$ is approximately equal to $\eta_1^{(t)}$

We take the ratio of these two, we will get this equation and then we substitute τ_0. We substitute

$$\tau_0 = \frac{\kappa_i^2 (v_{x2} - v_{x1})^2}{\{\ln[(z_2 - d)/(z_1 - d)]\}^2}$$

into

$$\frac{n_{A0}}{\tau_0} = -\frac{D_{A1}^{(t)}}{\eta_1^{(t)}} \frac{\rho_{A12} - \rho_{A11}}{v_{x2} - v_{x1}}$$ expression, now to get this big expression.

$$n_{A0} = -\frac{D_{A1}^{(t)}}{\eta_1^{(t)}} \frac{\rho_{A12} - \rho_{A11}}{v_{x2} - v_{x1}} \frac{\kappa_i^2 (v_{x2} - v_{x1})^2}{\{\ln[(z_2 - d)/(z_1 - d)]\}^2}$$

What we are trying to do now is we are trying to get an expression for flux as a function of the velocity and the concentration gradients, yeah.

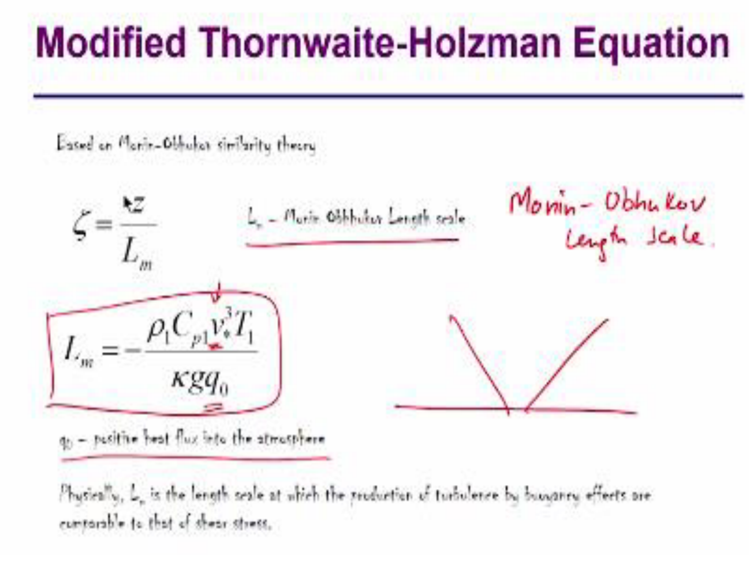
$$n_{A0} = -\frac{\kappa_1^2 D_{A1}^{(t)}}{\eta_1^{(t)}} \frac{(v_{x2} - v_{x1})(\rho_{A12} - \rho_{A11})}{\{\ln[(z_2 - d)/(z_1 - d)]\}^2}$$

So, we have measurements of concentration at two heights, velocity at two heights that will give us some idea of the structure v star, the turbulent structure of the thing, and then we are using these terms here.

When there is neutral condition, which means that there is no, neutral condition means stability is neutral, there is no thermal forces pushing up and down, no buoyancy effects, the terms $D_{A1}^{(t)}$ and $\eta_1^{(t)}$ are supposed to be seem similar, they are the same. $D_{A1}^{(t)}$ and kinematic viscosity and diffusivity are assumed to be same. This $D_{A1}^{(t)}$ is not molecular diffusion, it is turbulent diffusion, some other number okay, turbulent diffusion. We use the Fick's law structure very nicely because we are using gradients.

So, we will use the same Fick's law structure, but it is not molecular diffusivity anymore, it is some diffusivity, it is turbulent diffusivity. So, what this does is here I can calculate the flux from a surface using this equation, yeah, gradient. It is called a gradient method. This only works as long as there are no thermal forces.

(Refer Slide Time: 43:48)



Modified Thornwaite-Holzman Equation

Based on Monin-Obhukov similarity theory

$$\zeta = \frac{\kappa z}{L_m}$$

L_m - Monin Obhukov Length scale

Monin- Obhukov Length scale.

$$\boxed{L_m = -\frac{\rho_1 C_{p1} v_*^3 T_1}{\kappa g q_0}}$$

q_0 - positive heat flux into the atmosphere

Physically, L_m is the length scale at which the production of turbulence by buoyancy effects are comparable to that of shear stress.

For that, there is something called as modified Thornwaite-Holzman equation. When you have thermal forces, you bring into this question. There is something called as a Monin-Obukhov length scale.

$\zeta = \frac{z}{L_m}$ L_m – Monin Obhhukov Length scale

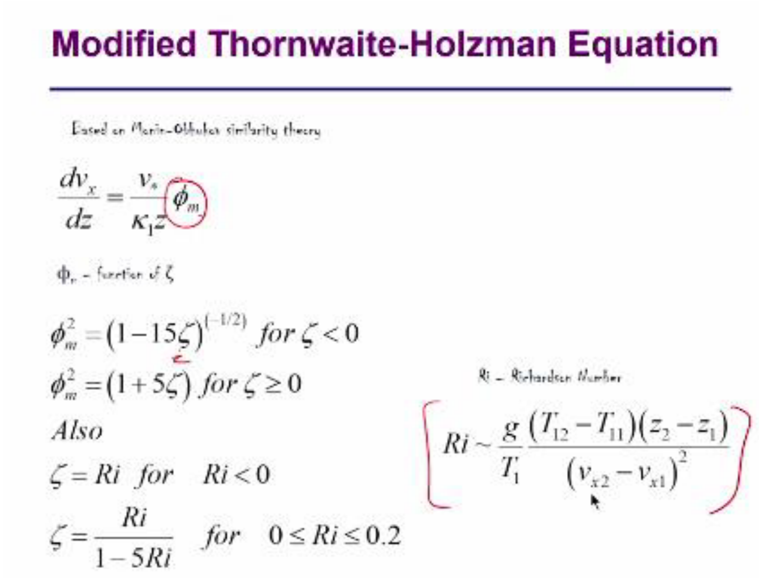
$$L_m = -\frac{\rho_1 C_{p1} v_*^3 T_1}{\kappa g q_0}$$

This comes up there also, you can read, there is one page set of things I have put in your, if you are interested you can read it, and if you go and read AERMOD derivations, this morning Monin-Obukhov length scale comes there.

So, this is Lm, this is physically the length scale at which the production of turbulence by buoyancy effects are of the same order of the shear stress. The buoyancy becomes that important here and then it is defined as this. So, if you look at this carefully, this is a ratio of this this is the friction velocity which is a turbulent length scale. What is in the denominator is a q0, q0 is the positive heat flux into the atmosphere. How do you get a heat flux? What do you need for heat flux? You need temperature gradient, yeah.

So the temperature gradient comes into question. If you calculate Lm, you need two, at least two measurements of temperature, you need a temperature gradient also, yeah. So Lm is that. So there is a negative sign here. Depending on whether the temperature gradient is this way or this way, the stability is defined, the magnitude of the values of the Lm the stability is defined on basis of that, not just the lapse rate anymore.

(Refer Slide Time: 45:31)



Modified Thornwaite-Holzman Equation

Based on Monin-Obhukov similarity theory

$$\frac{dv_x}{dz} = \frac{v_*}{\kappa_1 z}\phi_m$$

ϕ_m - function of ζ

$$\phi_m^2 = (1-15\zeta)^{(-1/2)} \; for \; \zeta < 0$$
$$\phi_m^2 = (1+5\zeta) \; for \; \zeta \geq 0$$

Also

$$\zeta = Ri \quad for \quad Ri < 0$$
$$\zeta = \frac{Ri}{1-5Ri} \quad for \quad 0 \leq Ri \leq 0.2$$

Ri - Richardson Number

$$Ri \sim \frac{g}{T_1}\frac{(T_{12}-T_{11})(z_2-z_1)}{(v_{x2}-v_{x1})^2}$$

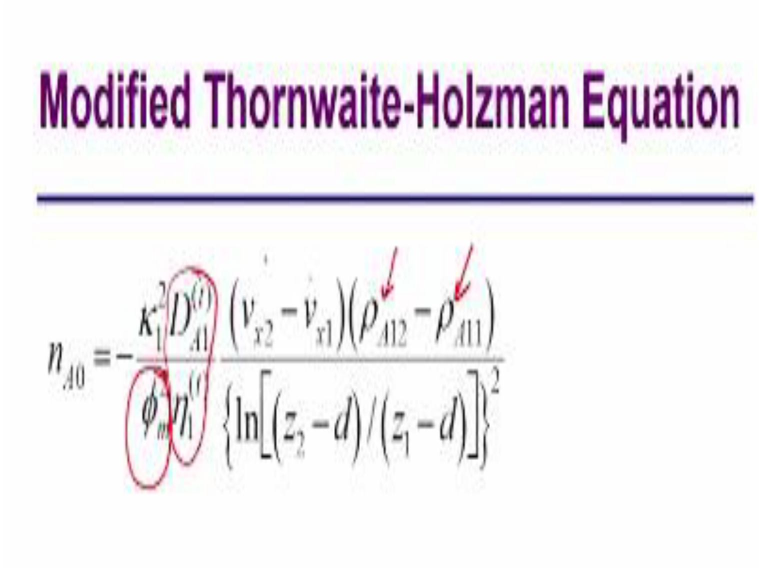
So based on this, we define a bunch of other things. So we add a correction factor called as ϕ_m. This is the original equation that we have, to this we add this correction factor ϕ_m which is now dependent on the stability as well and this when we have a bunch of equations where we calculate ϕ_m for different values of, in the equation previous slide, this number is dependent on z by Lm, z is any height, at any height it is the comparison of that height with the Lm. You can get these values of ζ and ϕ_m based on this Lm.

The other option to do this, instead of Lm you can also use what is called as Richardson number. This Richardson number is defined like this,

$$Ri \sim \frac{g}{T_1}\frac{(T_{12}-T_{11})(z_2-z_1)}{(v_{x2}-v_{x1})^2}$$

you see that the temperature gradient in there. So, when you plug all of this in back into your main equation, you will get one big equation which now has 3 gradients. You have a velocity gradient, you have a concentration gradient and temperature gradient which now takes into account everything and now gives you a value of flux.

(Refer Slide Time: 46:35)



Modified Thornwaite-Holzman Equation

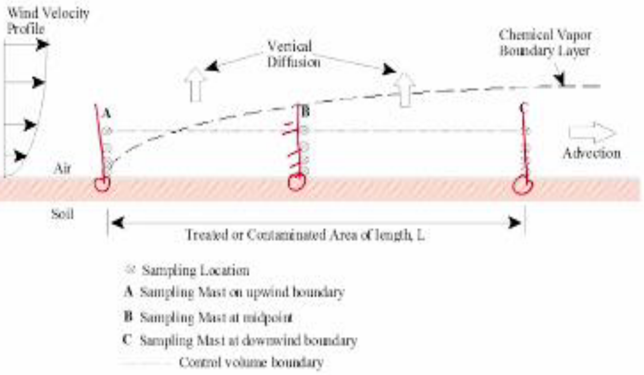
$$n_{A0} = -\frac{\kappa_1^2 D_{A1}^{(t)}}{\phi_m n_1^{(t)}} \frac{(v_{x2}-v_{x1})(\rho_{A12}-\rho_{A11})}{\{\ln[(z_2-d)/(z_1-d)]\}^2}$$

So, this final expression, the corrected expression for the flux at a surface is given by this where the temperature gradient is implicitly sitting here inside this in this equation okay. Here also you can assume DAt and this is the problem, if you assume that to be 1, then of course ϕ_m value will take care of the rest of it. So, this is a bit, it is not a very accurate method as you can see because depending on how many measurements you are making, there bounds to be errors in this and the way we do it, but this is the best we have got at this point.

Added to this problem that the concentration measurements sometimes you do not get instantaneous concentration measurement. You can get instantaneous velocity and temperatures, you cannot get instantaneous concentration, which means that all this is velocity may be changing because it's turbulent, but you cannot use that, you have to wait for that timescale at which you are measuring your concentration gradient. So it is inaccurate that way, but it will still give you an estimate of what the flux is. You can add a factor of 10 if you want for conservative measures point of view.

(Refer Slide Time: 47:47)

Direct Emission Flux Measurement – Field Scale – Aerodynamic method



So what people do is they have a mast. This is a gradient measurement. You can have a mast of different measurements at multiple locations in a given area. So the flux that you get is only for this location and flux you get for this location is this one. So, then you get an average over an area. You have to do all this because now you are unwilling or it is not correct for you to enclose the given air, amount of air in order to measure flux from a given surface, okay?

(Refer Slide Time: 48:19)

Pilot Field Scale Experiment - Aerodynamic Method

Physically it looks like this. There is a field experiment that was done, there you have contaminated mud or something like that, so this is releasing. So you have this mast here you can see and each of these different locations where we have measurements of the chemical, the wind speed, temperature, everything. It’s a massive exercise, so you have to put it, people have done this over different surfaces. They have done it over water. They have done it over agricultural fields. They have done it over this thing.

So this works for vapor phase okay. For particles, it is a different story because particles have aerodynamic behavior and they would not behave nicely, they does not go up nicely. Only particles below a certain size will go up nicely. Particles above 1 micron, 2 microns, they will even deposit on top of your sampling device and all that, so it is a bit difficult to do all that okay.