

**Environmental Quality: Monitoring and Analysis**  
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**Lecture – 43**  
**Regulatory Models**

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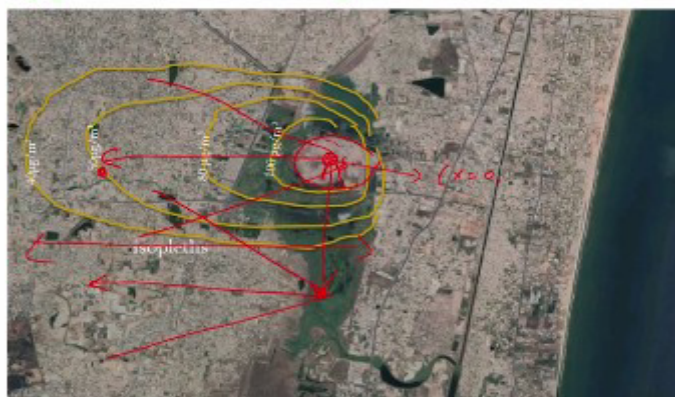
### Application of Dispersion Models

- Estimation of pollutant concentration in air at any given set of coordinates.
  - Assessment of the impact of one source on air quality
  - Assessment of air quality from large number of sources in a given location
  - Application
    - Define a grid of measurement coordinates (also referred to as receptors)
    - Estimate the emission rates of all sources, location of source to a reference origin
    - Estimation of meteorological parameters
    - Estimation of concentration of pollutant at all receptors
- Representation of the dispersion is effectively achieved by plotting ISOPETHS (or lines joining points of same concentration OR concentration contour maps) over a geographical map.

So last class, we were discussing the application of dispersion models. We will just recap from that little bit.

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### Application of Dispersion Models



The superposition of isopleths on a geographical map gives a good indication of the pollutant behaviour and provides guidance for pollution management strategies.

So, one of the applications the way we apply it is superimpose calculation of dispersion models over a given geographical location. So here, what we usually do is in the dispersion

model  $x$ ,  $y$ , and  $z$ , is with reference to an origin. So the origin is the source, we have a source. So in this particular example, let us say the source is here. This is the source; it could be an area source. For now, I am considering it as a point source. If this is the source, then this source will be at  $x = 0$ .

Now, this is a problem, I think yesterday's class we discussed that. So this one source is  $x = 0$ . For another source, there is an  $x = 0$  corresponding to that okay, axis is that. However, when you are looking at concentrations at a given point is the contribution from different source, then you have to adjust the coordinates accordingly. So for example, if I have another source here, there is an  $x = 0$  axis going here and a plume that is probably going out like this, right? This point is, there is an  $x = 0$  is the same, but the  $y$  distance is different compared to this plume.

So if you know the distance between this, then you have to adjust this point. So at that point, you have to adjust what is  $x$ , so which reference are you taking. So you have to add accordingly okay, where the contribution from different sources is additive, there is no assumption that one source interferes with the other, which is not true in reality. If you if you mix 2 air masses, they do not mix nicely. There will be collision and there there will be a local circulation there and all that, all those issues are there, it will neglect all that.

So it assumes that we are just adding, but there are some corrections to that people do, that is a different issue, it is a little more advanced that needs more information about the air mass and all that, but here we are just looking at simple velocity in the  $x$  direction. We are not even doing any turbulent components and all that, we are not. So it is theoretically possible if you since we know the original model, see what we have the full model, it is possible for us to go and do a proper fluid dynamic calculation if you want.

The people have done that with the estimation of dispersion parameters, not using Pasquill-Gifford and all that, using something else, some other correlations. There is a technique to do that, just out of scope of this course, people can do that if you want accurate modeling. The problem is all environmental modeling is which which which all depends on the amount of data you have. If I have real time, velocity measurements changing, I can apply it as and when it is happening, it is like weather forecasting.

This becomes like weather forecasting because weather prediction you are predicting wind speed and temperatures and all that. This you are doing that and on top of it you are adding one chemical component in the same model, people do that. There is modeling that people work with, in conjunction with weather, they add a chemical model interact that is how they do prediction of pollutants across global scale. There are lot of different software that will do that in which dispersion is one component okay.

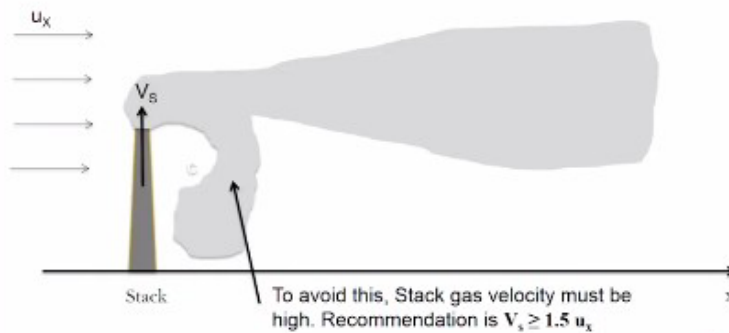
But here, we are talking about a very specific dispersion model Gaussian dispersion model application and this is a first step, very quick screening tool, approximately it gives you what is what can happen. So, if you have an additive component, it is usually the worst case scenario. So, that is what it is done. So, any questions on this, so one of the other points that I would like to make in this slide is when we superimpose this on a map like this okay, depending on the scale of the map, you can consider this as an area source.

So, for example, if we consider Perungudi garbage dump in South Chennai. Let us say that there is a lot of emission occurring from this entire thing. It is about a kilometer in dimension across. Now, if I am interested in this, I cannot take this as a point source, this is reasonably big okay. So, I have considered it as an area source and I will assume uniform emission per this entire area and then I can model it that way, but if I zoom out, this entire thing will become a dot on the map and then I cannot use it like an area source it's a point source from a point of view of the scale at which you are looking at. The maximum extent of this (Perungudi dumpsite) is a few kilometers, 3 kilometers or 4 kilometers, but if I am looking at a large forest which is extending 10-15 kilometers or if I am looking at the impact of this when I zoom out on the entire city of Chennai, this will be a dot and this is essentially a point source okay.

These are some of the things you have to, depending on what you are calculating, you have to adjust the model parameters. We will come to the exercise that the regulatory models that we generally use, at that point you will know what we are talking about.

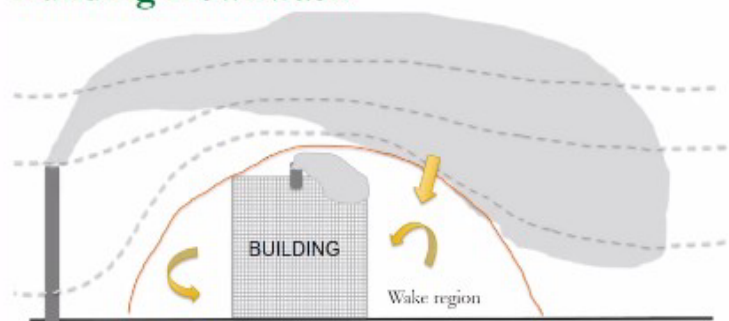
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## Stacktip Downwash



Due to low pressure just downwind of the stack, there might be suction from the plume causing exposure to the receptors there

## Building Downwash

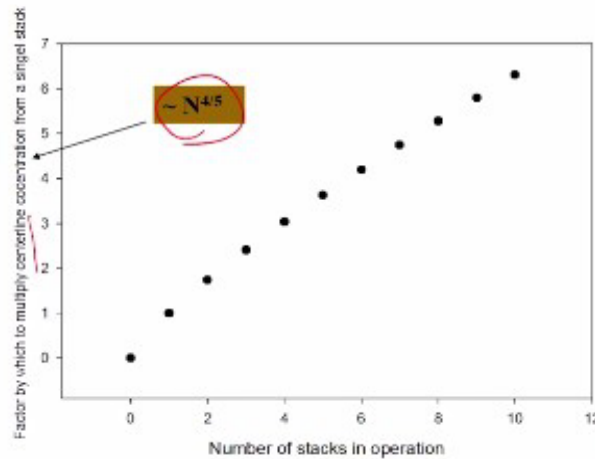


The presence of a BUILDING in the path of air causes streamline separation resulting in the formation of low pressure regions called "wakes". These can pull in the pollutant plume from a different source. Alternatively, sources on top of the building that are within the wake will circulate locally causing higher concentration and exposure.

The dimensions of the WAKE must be estimated and then the sources must be located appropriately for optimum clearance and least air pollution impact.

So, we talked about stacktip downwash, building downwash and all that last time.  
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## Multiple Stacks in Line

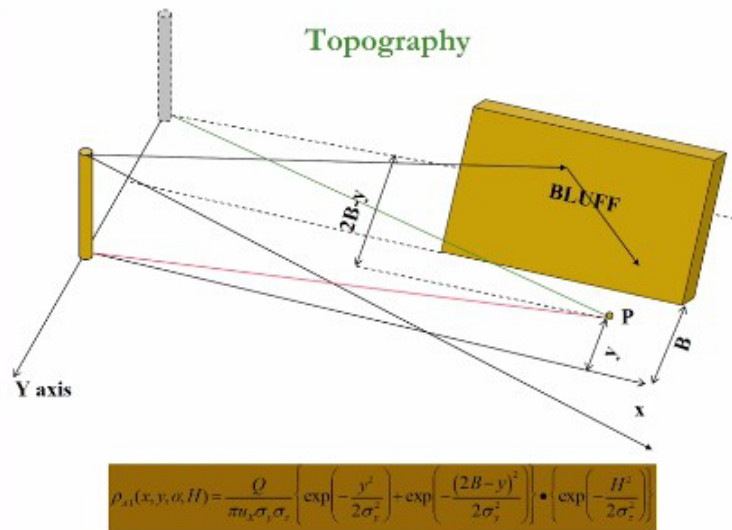


So, this is the multiple stacks. So, you have several stacks. All of them contributing to this thing, so it is usually additive, but here you are seeing that it is not just additive, it is slightly lower than  $N$  raised to 1. What we mean is the contribution factor by which we multiply centerline concentration from a single stack. So you have multiple stacks in line. So what it means is that the contribution, the additive contribution is not exactly additive, it is found experimentally that it is about  $N$  raised to 4 by 5.

So, number of stacks is not straight additive, it is lesser than that, which means that there is some loss in the process of doing this. It is an experimentally found. You find out that it is not adding, there will be some loss as I said, it does not reach this receptor, it goes somewhere else, maybe there is mixing, it goes up and down.

Usually, conservation of mass means that if there is a reduction somewhere, there has to be an addition somewhere else. So which means it is not simply adding, some inequalities are there. You cannot make mass disappear somewhere, it has to go somewhere else, so unless it is reacting. What it means is that it is not simply adding. Non-interacting plumes is the assumption which is not true.

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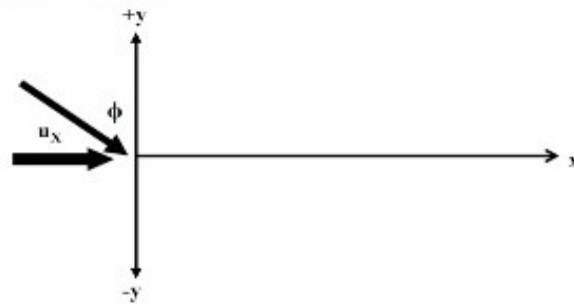


Generally, when you are talking about plumes, air masses they mix and there is other secondary effect to that, which is still not very clear. In order to quantify them, you have to go and do a fluid mechanic model. See, all the models that we are talking about assumes very nice uniform these things, uniform flow, nice boundary layers and all that, but in turbulent flow it's chaotic, you cannot really predict very well.

This is the same kind of thing that we talked about in the reflection. Suppose there is what we call a bluff means, this is like either a mountain or a building or something in the path in the y direction. The ground reflection we talked about is a z direction reflection, so there can also be y direction reflection if there is a big building or a big mountain and there is a source, so it is there is there is constriction for the plume to expand on both directions. So, then you can see that you are adding another term just like what we did for the z direction, we are adding another term here. The geometry of that is all given here in this.

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## Line Sources



For wind at an angle  $\phi > 45^\circ$ , and continuous line source

$$\rho_{A1}(x, y, 0; H) = \frac{2q}{\sin(\phi) \cdot (2\pi)^{1/2} \sigma_z u_x} \cdot \exp\left[-\frac{H^2}{2\sigma_z^2}\right]$$

$q$  = rate per unit length (g/m-s)

There are some line sources. So in the line source equation, this  $q$  is different. You can see that the equation is slightly different because  $\sigma_y$ , is considered negligible. This is a continuous road extending infinitely and your wind is coming perpendicularly here, so it is a crosswind, yeah. Emission is occurring this direction, all the vehicles are traveling on this road. So you will have one plume like this, the next plume like this, next plume like this, next plume like this, that is what crosswind compensation is equivalent to having the same thing. So, there is no  $y$  term here, the  $y$  term is neglected because whatever is originating from here is going here, but whatever originating is appearing here. So, essentially, it is it is not a factor, it is almost uniform as there is uniform in the  $y$  direction, only the  $z$  direction is changing and the axis change.

$$\rho_{A1}(x, y, 0; H) = \frac{2q}{(2\pi)^{1/2} \sigma_z u_x} \cdot \exp\left[\frac{-H^2}{2\sigma_z^2}\right]$$

So the  $y$  term here is vanished, goes away from here, but this term  $q$  here if you look at the dimensions of this equation here, this is  $L$  by  $T$  and so  $\rho_{A1}$  has to be  $\frac{M}{L^3}$ . So, the numerator  $q$  here has to be  $\frac{M}{L}$ . So, it is the emission, the rate per length of the road.

So, for a given section of the road, you can calculate using this. Then of course  $q$  you have to calculate by doing you need to know what are the vehicles on the road and the emission factor based on composition of vehicles.

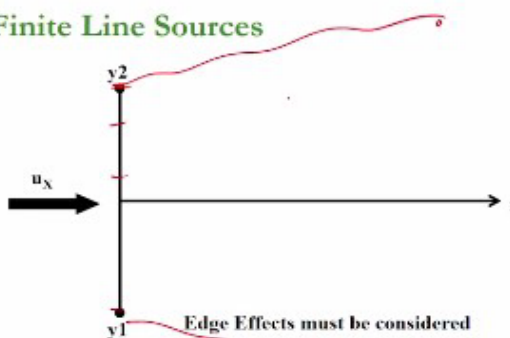
So people do count the number of vehicles of each category, so you have and it is a bit complicated to do the emission for vehicles because it also depends on the speed of the vehicles, it also depends on the type of vehicle and all that. So there is, if a vehicle travels at a certain speed certain distance, then the emission is certain amount for that distance of travel. So, when they consider this emission factor estimation, we need to know what is the speed of the vehicle also, how much they travel and so it is not straightforward.

Collection of that data is fairly laborious to do and you have to keep doing it again and again because these things will change with time, because in the morning time vehicles will travel fast and peak time vehicles will travel slowly and so on, all these issues are there. So interpretation and the calculation of this varies. This is an extension of this again when you have an angle. The wind speed is not at right angles, it is an angle to the road, this can happen. So there is another term here called  $\sin(\phi)$  here.

$$\rho_{A1}(x, y, 0; H) = \frac{2q}{\sin(\phi) \cdot (2\pi)^{1/2} \sigma_z u_x} \cdot \exp\left[\frac{-H^2}{2\sigma_z^2}\right]$$

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**Finite Line Sources**



$$\rho_{A1}(x, y, 0; H) = \frac{2q}{(2\pi)^{1/2} \sigma_z u_x} \cdot \exp\left[\frac{-H^2}{2\sigma_z^2}\right] \cdot \int_{p_1}^{p_2} \frac{1}{(2\pi)^{1/2}} e^{-\frac{p^2}{2\sigma_y^2}} dp$$

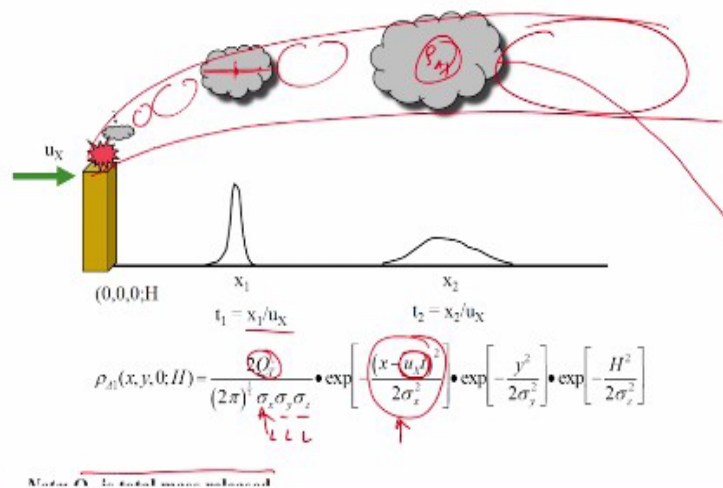
$$p_1 = \frac{y_1}{\sigma_y} \quad p_2 = \frac{y_2}{\sigma_y}$$

But, there is also some cases where there is a finite road, it does not extend all the way and then the end effects the sigma y appears as an end effect in one of the edges of this. So here we have this will appear like this, the concentration up to y here because the road stops here. So, if you are measuring concentration at this point somewhere, then you have to calculate the dispersion in the y direction. There is no crosswind compensation in this case. This is a suggested equation for that.



(Refer Slide Time: 14:01)

### Instantaneous Source – Short Term Puff at height, H



So what we considered till now is the Gaussian dispersion model which is a steady state model, but lot of times you may not have a steady state emission. Some say that you just have a finite, for example is an explosion, it is a large amount of material that is now just released because of one shot explosion. This is very common in air pollution accidents. You have a big tank that has exploded and one big say one ton of chemical has gone up and it is going somewhere.

So we need to find out where it is going, how fast will it go, what is the concentration, this is a very nice classic representation of this Lagrangian model that we are talking about. This is one small volume and this volume is expanding which means concentration in the volume is decreasing as it is going. So when this goes up and this puff reaches, it becomes big or it is carried up and down. It will reach the ground sometime at some point okay and that point whatever will be the concentration inside the puff will be the exposure of that particular thing okay.

So, this is the puff model, the steady state model is modified by including another term here which is in the x direction, so it is no longer steady state. So, you also need to consider the full volume of the puff here. So, there is a third term here that appears and there's sigma y, sigma z, and sigma x term also that appears in this case because it is finite puff. Because there are 3 Ls here, this is no longer a rate term.

This  $Q_t$  is really is  $M$ , total mass released, we have retained the term  $Q$  because it is the same as the previous one, but it is not rate, it is mass, so there is this term here that is  $(x - u_x \cdot t)$ . So, this is a Lagrangian model where we are looking only at the distribution, of here the  $x$  starts in here, the actual value of  $x$  that we are talking about is this  $t_1$  equals the time that we are considering in here is calculated like this by the velocity. There is also another methodology by which people use the puff model to simulate a continuous steady state source. What they assume is continuously there are puffs that are released, which means then the plume, steady state plume can be considered as a series of puffs being released one after the other, okay. So, the advantage of the puff model is you can stop it whenever you want, you can control at what rate the puff is being released, and then so for example, there is intermittent release, there is release for some time, then it stops, and it comes for some time and stops. Steady state model you have to stop the entire model and restart it when it starts again, and if it is unsteady state, it is difficult. So, here there is possibility for you to change those things by assuming that it is a puff and you consider each puff as it is going and where it is going. So, that is one way of doing the model.

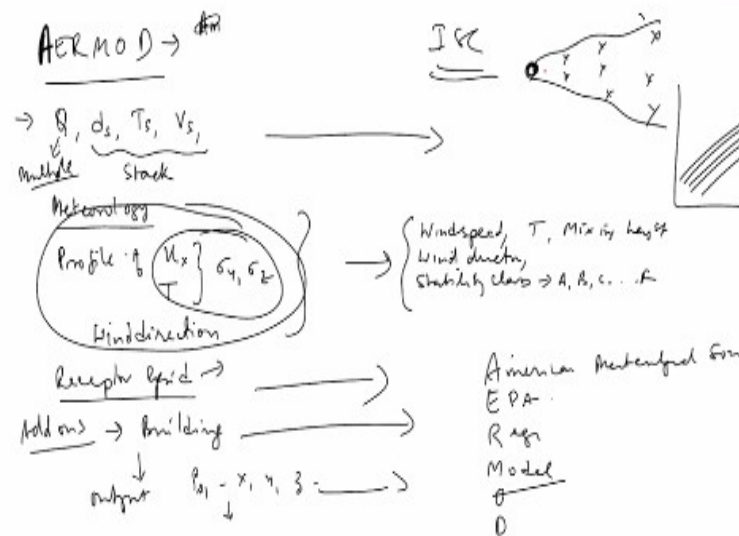
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## Regulatory Gaussian Dispersion Models

- AERMOD (older version – ISC3)
  - Needs Source Information
  - Can handle multiple sources
  - Meteorological Data – Surface and Profile
  - Receptor Information
- CALPUFF
  - Puff Model – Continuous Plume modeled as series of puffs

So, in the current regulatory framework, there are 2 models that are used. One is called AERMOD. AERMOD is the current regulatory model that is used. There is an older version called ISC3 and there is a second model which is now currently used called CALPUFF, the CALPUFF uses the puff model. So, if you give it a rate term, it will convert that into some volume of the puff and volume of puff depends on where the emission is occurring if it is occurring through a chimney or what it does is it generally convert your steady state thing into a puff based model, but AERMOD is a more steady state model.

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The big difference between ISC and AERMOD, the ISC is the older version. They are both similar. So here again, you need same kind of information, the information that you need is the Q the rate, you need the diameter of the source, you need temperature of the source, you need velocity of the source, these are all stack; stack diameter, stack temperature, stack velocity. Then you need meteorological conditions.

Meteorology that you need here is the profiles of wind and the profile of temperature, two things you need because it calculates the dispersion parameter sigma y and sigma z based on the profiles. We will look at it later. When we are looking at emission from surfaces, we will look at this again, we will revisit this topic again that is relevant at that point, right now it is a bit this thing, at that point we will do that. So, it needs data of profiles of wind and temperature in addition to a few other things.

You also need wind direction. So, the temperature profile automatically what they do is they will allow you to calculate the mixing heights and those kind of things in the stability class. There is no stability class in this case. This directly computes the sigma y, sigma z based on these things directly. It is a slightly more advanced model in that way, yeah. Then you need a receptor grid. You need to specify where you want to measure and you can also add, add-ons you can input here is a building for building, effects of building, a building downwash, you can say where are some buildings and what is the dimension of the buildings with reference to the source. You can put multiple sources, you can add multiple sources, many sources, you can have a point source, you can have area source, you can have all that okay. In the receptor

grid, you can specify where you want, what height do you want measurements and everything can be done and the output is usually  $\rho_{A1}$  versus x, y, and z, this is the calculation is done at each point you want specified.

From this, you have to calculate the contour map or whatever you want to use it for to superimpose on source. The AERMOD is this. ISC is the same, this is all the same, you can also do buildings. The big difference in ISC model is the meteorology that it uses is very much like the equations we had, in class what we showed as in the example yesterday last class we had, how to calculate concentration using the Pasquill-Gifford stability classes.

So, the weather the met data that we need is very small, you need the wind speed, we need wind direction and we need a stability class which means that stability class you have to give it, you have to give an hourly stability class or whatever stability class that it should use. Based on that, you give A, B, C or D or whatever till F, it will take sigma x, y and sigma z correspondingly using those graphs. So, you see those graphs that we saw with all this sigma y as the different stability classes, those graphs you can convert them to equations. So you can convert them equation, use those equations in the program here and calculate the value of the sigma y and sigma z. So it is far more easy when you have temperature and mixing height, you have to give mixing height. You have to provide the mixing height from externally. What you are doing is you are calculating all that based on some estimate for the temperature profile in that given area. It does not do it itself, you have to give everything. In a way, this is easier to do when you do not have this data.

This profile data is not very easy to get, very few places it is measured. Indian metrological department measures this in several places, so you can buy it from them or you can request from them, they will give it to you and it may not be available for all the sites that you want, maybe available for some places. So you have the data, then this is the model that you should use. If you do not have it, ISC can be used but you have to mention that you have used ISC. So, there will be a difference between ISC and AERMOD mode, okay.

AERMOD stands for the American Meteorological Society and the US EPA Regulatory Model. So, you can imagine the amount of work that has gone through, the theory behind lot of this section alone is huge because it deals with turbulence in the environment and it is very

unlike turbulence in flow in a pipe or in a channel, it is huge. The scales are big and it is very unpredictable. There is a lot of work that has gone into it.

So, when these models are developed, people verify these with experiments. How do you do an experiment for dispersion? Anytime when somebody develops a model, you are using it to predict something, right, so which means you have to test if the model is correct. How will you test? Wind tunnel, but wind tunnel is not disclosed. You can test the dispersion model using a wind tunnel and all that, but in the field you have to test it, otherwise nobody will use it for risk assessment.

We are using it for risk assessment, so nobody will use it for risk assessment unless you test it. You tell people that this is happening, so one has to use it in a field. So, these experiments are large scale experiments, somebody has to release something, right. So, you have to release some component which is not present in the atmosphere and then verify its concentrations, predict the model, and compare. So, basically what you will do is you will release a certain chemical and you will predict concentrations at different locations.

You will also measure concentrations at those locations, and if it matches, how closely it matches, then you adjust the model to that. So you have made some assumptions in the model, those assumptions you have to justify or say that these assumptions are not valid under these conditions. So, there are a lot of experiments on this conducted long back for these kinds of verification of these models. You can also do it in a wind tunnel, but the wind tunnel is an idealized system, again you will get an ideal behavior.

You can test several things in a wind tunnel. You can test what happens if I put a building what happens, so people do all these things, people study it using what is called a tracer, you must be able to visualize it. There are a lot of classic studies. You go to the EPA's AERMOD development studies, you will see. So right now, people use CFD, computational fluid dynamics to do all these, but you have to still study a physical model. CFD is an equation based model right, whatever equation I put it will use that equation, but the equation is based on observation.

Whether a particular equation is valid or not you have to test it again by experiment. So, people use tracers. They use smoke and to see how the plumes are going and how it is

dispersing, those kinds of things are done. It is a very elaborate science AERMOD is not to take the dispersion modeling and it is fairly complex if you get into it. So, AERMOD has its limitations, the regulatory models have their limitations, but that is if you go and read the document, this is the third project that I am going to give you.

If you read their document, you can see it is very big document. So, what is the limitations and what are the assumptions, some of them we have discussed in class, some of them we have not discussed in class, so you can see that also.