Environmental Air Pollution

Prof. Mukesh Sharma
Department of Civil Engineering
Indian Institute of Technology, Kanpur

Lecture No. 28

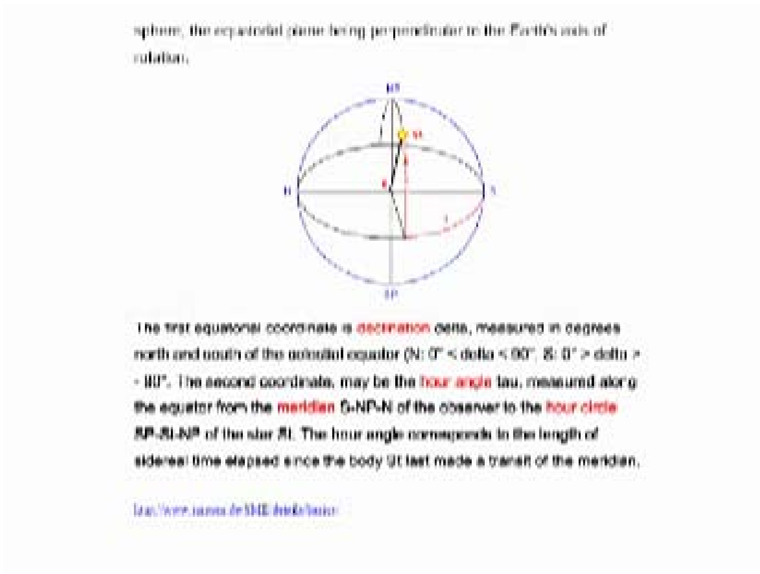
Air Quality Modeling - 1

If you recall yesterday we had very quickly of course had gone with these slides and we had defined the H and the alpha – that you recall.

(Refer Slide Time: 00:36)

But this was onto the horizon. Then we also went on to define on the standard coordinate system that was on the equatorial coordinates where you see your equatorial plane to be the plane of reference.

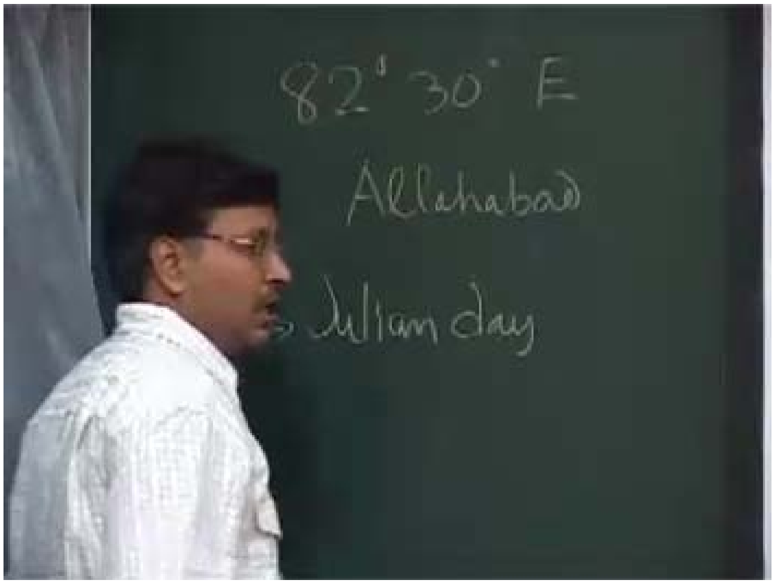
(Refer Slide Time: 01:06)



So we define here if you recall again declination – that we put as delta and hour angle as tau. Keep these things in mind but we will not talk about these things anymore – we will talk something else, but we will use this information with little knowledge that we have got about [01:17]. Now remember that what we are trying to do is to estimate R and the R in the table… because that R will tell me if my insolation is strong, moderate or light. With this background, we will try to estimate the R and if I ask you what are those parameters, factors on which R could depend, you will answer me what time of the day we are talking about – that is the first thing, you will also tell me where are we – are we sitting in London or we are sitting in Kanpur or Banaras, that is so… and then you will ask what is the longitude of the place, the latitude of the place, the time of the day you are talking about and in addition to time of the day, you also will say what is the date, what is the day – is it the January 1st or it is the December 31st or June 25 because solar radiation… just as a hunch, you will say that will depend on these things – where you are (that is longitude, latitude), time of the day you are interested in and day of the year.

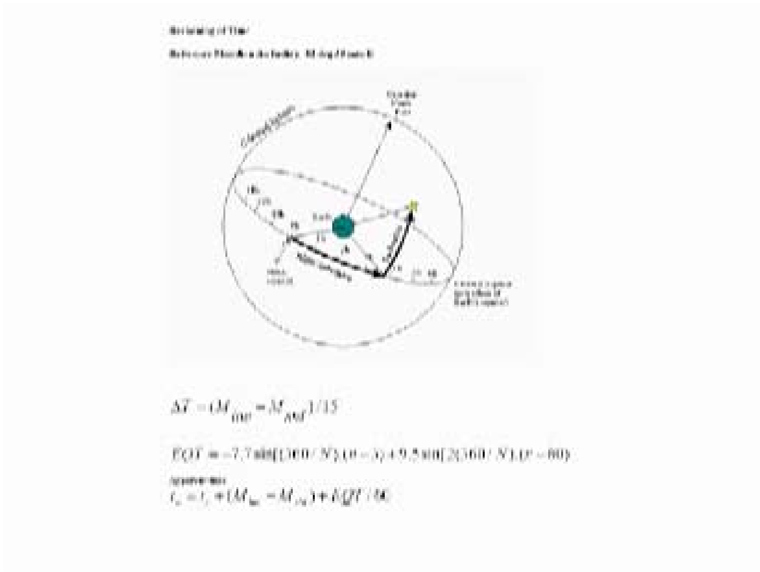
So with that background in mind, we will try to do something so that we can calculate the R and the first thing for that we need to define is… so the time is a…. Well, I want to find out what is the stability or what is the incoming solar radiation at some particular time. Suppose you said, let us say 11 o'clock in the morning but if you say 11 o'clock, is this 11 o'clock in the real sense – is it really 11 o'clock? This 11 o'clock is really with reference to some standard meridian that is our reference point. When I am saying 11 o'clock, it is really 11 o'clock at the reference meridian, so suppose by…. What is the reference meridian in India for time, to measure the time? That is in… I have not written that, that is… I will tell exactly 82, 82 and I will tell you exactly just because these numbers you do not have to remember them; here you go, 82 degrees 30 minutes.

(Refer Slide Time: 04:07)



82 degrees 30 minutes East – that is the reference meridian I have and internationally the time is measured through Greenwich Mean Time. For example, our friends from France – their reference meridian will be this reference meridian passing through the Greenwich, but this is the reference meridian when the sun is right on top at this place; this is 12 o'clock all over India, but in actual sense is it really 12 for us? No, because if it is 12 o'clock let us say at Allahabad in terms of the radiation which I am getting, it might be… it might be what, less or more? Less. Less. It may be something like 11:30 for me whereas at Allahabad, it is already 12 o'clock, so when we are doing the actual calculation, we have to take the actual time – we cannot take the standard time. Do you agree with me? This is at Allahabad. The time when you want to find out the stability or incoming solar radiation – you have to modify your time.

(Refer Slide Time: 05:32)

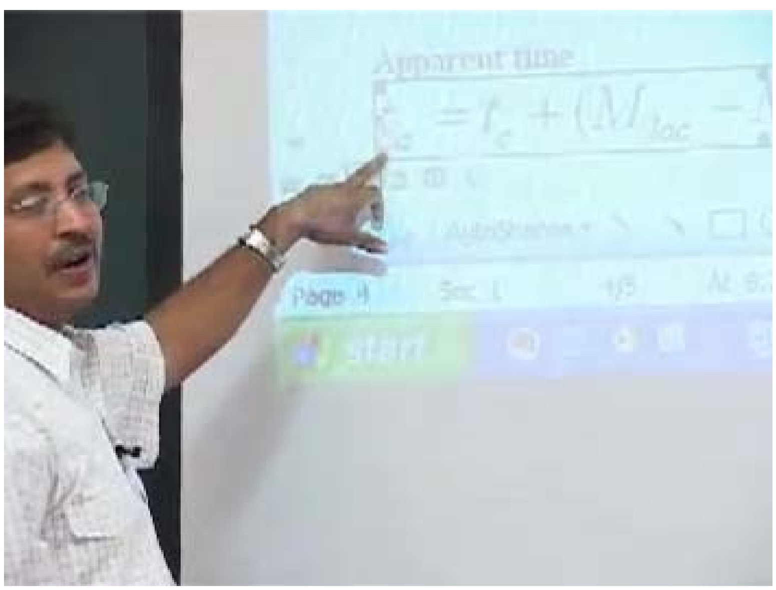


That modification is what you see as the change in the time. You see here this is the local meridian and this is the standard meridian (Refer Slide Time: 05:39) divided by 15 and this is the time you will get in hours, so first thing we have to immediately correct is our time. Is that part clear? If that is clear, now I will ask you another thing: 12 o'clock or let us say June 30 and 12 o'clock let us say on December 25th – even after correction in terms of the solar radiation, are they the same? No, they are not the same. Then it means it also depends on the position of the sun. So somehow, we have to change the time based on the position of the sun. I am just developing the argument so that it is easy to understand.

What we do normally is we take average position of the sun and the time is defined, but in real sense the actual time will depend on sun's position and what will sun's position depend on? The day of the year I am talking about, because the sun's position will be variable depending on the day of the year – 1st January, 30th January, they all will change but actually the time that we see in our watch – that is depending on the mean solar position. But we are trying to do a more accurate job, so we have to have what we call as the equation of time. What I will show now in the next one is the equation of time and that shows… the equation of time really shows the difference between the mean solar time versus apparent solar time and what we need is apparent solar time – the time that is existing right now because of the day that I am referring to.

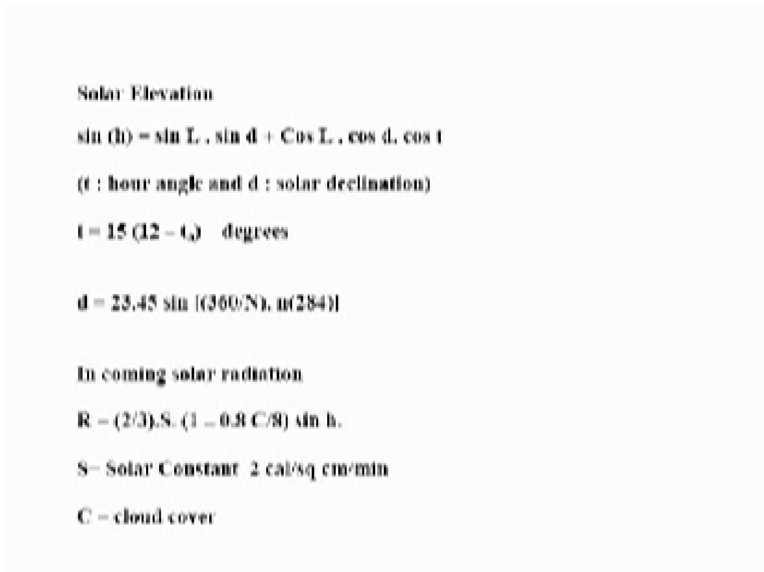
The other correction I must do is based on the equation of time and that is what you see here, equation of time EQT. I will pass on all the information to you, do not worry about that and I will also explain to you what these are. The equation of time: there are two corrections that I must do in my time. What you see here, the larger N is the number of days in the year – it could be 365 or 366 depending on which year you are talking about and the small n as you see here – that is what we call as Julian day; it means it is a day starting from January 1st as 1st and let us say February 1st as 32 – that is my Julian day counting from day 1 as January 1 and going up to 365 days. It is not difficult to derive this equation but we will somehow not do that one, but you can find out the equation of time and what is this really? This is the difference because of the position of the sun – difference of the mean position to the apparent position, so this correction also… when you want to find out the actual time of the day, we should correct based on the E Q two. So do you understand all variables here? N and small n – that is all I need to know. Now I can say what is my apparent time or time that is more useful, more meaningful for me to find the solar radiation. Agreed?

(Refer Slide Time: 10:05)



So what you see here is the apparent time (Refer Slide Time: 10:06) – this is the time; whatever time you are referring to, suppose it is 11 o'clock but this 11 o'clock is based on the standard time. This must be corrected based on your local meridian and this should also be corrected based on the Julian day because solar radiation will depend on the sun's position. That is how you find…. This (Refer Slide Time: 10:33) is really your apparent time or if I can say, it is your real time but of course for convenience, we have the standard time or reference time but we are trying to estimate something else for which I need apparent time. This is your standard time: correction for meridian, correction for the sun's position (Refer Slide Time: 10:54). Is that clear? Let us go further. If you remember the sine H, we had defined H. The next thing that we need to find out is the computation of solar elevation, for that again we have a formula here.

(Refer Slide Time: 11:26)



Solar elevation depends on sine L, sine d, cos L, cos d and cos t. I will explain to you what these are; sine L: L is the latitude of the place, longitude we have already used, so now we are using the latitude, d is solar declination – we defined that earlier with all those pictures you saw and t is nothing but hour angle, so we will try to define…. This is clear to you, so we have to define d and t. Where do the d and t come from? t is the hour angle and the hour angle is between you and the sun that is on the cycle; hour angle depends on what every hour the change in the 15 degrees, so you see here, whatever the apparent time which is corrected, see the difference with respect to 12 o'clock; from the mean sea position if it was right on your head, this 12, 12 will be 0, so how far is in… in time domain you have gone from 12 o'clock – that will give you the hour angle, so that hour angle…; this is your actual time – that may be 11 o'clock or 10 o'clock after having done the corrections, so this way you can get the solar hour angle of the sun; we have also defined the hour angle of the sun earlier if you recall, so this way you can get the t.

Now, the declination: we have defined what is the declination and the method which we use to find out the declination is the following and declination has to depend on N – that is the sun's position, so this way you can find out the d and you already know the t, you know the L, so you can find out the sine H. Can it be in the negative? Can it be negative? t can be negative as well, it does not matter but then one thing I must say this t_A is on 24-hour cycle. Do not try 1 o'clock; if you are referring to 1 pm, you will write that as 13 – that is one thing that you should note; whatever that comes out to be… so you can find out the t. I worked out one example, so we will do that example also; just five minutes ago, I finished one example and we will see that one. Now, you are in a position to calculate the solar elevation. Clear? Once you calculate the solar elevation… There is a little correction here… no, this is fine.

Now we have to ultimately get the R and that R we need to go back to the table that I have drawn sometime back and compare this R versus the standard R to say if the solar radiation is high, low, moderate or weak. You can find out the R – that is 2 by 3 S, which is the solar constant, it means the solar... this is equal to 2 calories per square centimeter per minute – that is the standard thing you are getting and that needs to be modified depending on where you are and how much is the cloud cover because the thing which we have not considered so far was the cloud cover – how much is the cloud in the atmosphere because that will obstruct my incoming solar radiation. This is the equation for finding out the solar radiation: 2 by 3 S which is equal to this 1 minus 0.8 C is a cloud cover, cloud cover here if you recall last time I said cloud cover was 2 by 8, but here remember that 8 is already there, so you have to only see out of 8 how much is the cover.

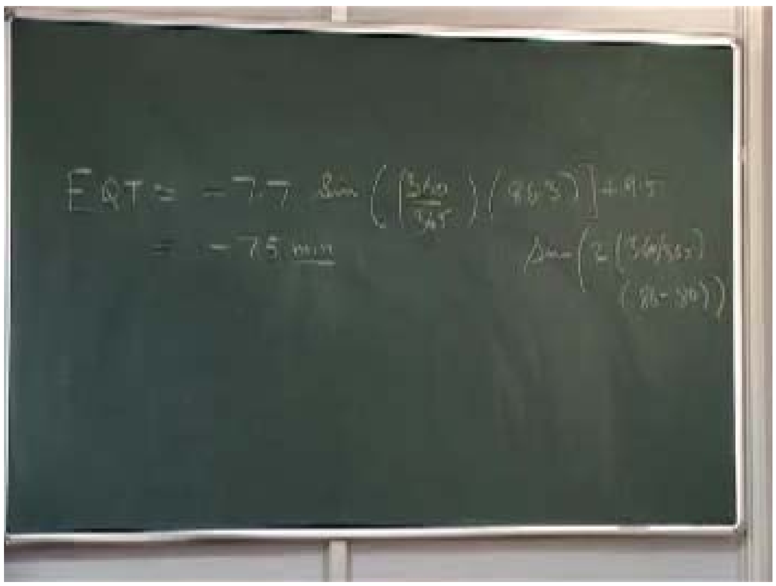
Suppose you go outside and if I divide the whole sky in eight parts and out of eight parts, you have the cloud in probably two parts, so this C will be 2 and this answer you are getting is in per minute – do not forget that because S is in per minute. If you go back to your table which you have where we tried to define the… if the radiation or the insolation is moderate, low, high, those units are Langley per hour, so to compare this R versus the table that I gave you, you have to multiply this by 60 degrees. Once you know the R (that depends on many things that we have gone through), what is the other thing you need? We started this discussion with the Turner scheme of 1969. Turner says, “Do not worry about anything; go to the airport, get some data and you can find out the stability.” In whatever we have done, is there any problem getting the data so far, except cloud cover? I said that the people at the airport will collect that because that is very important for them – how much is the cloud cover. Maybe it is a little approximation but I can essentially find out the stability in each hour, which is very important for me because all my turbulence depends on the stability. It is a little complicated in terms of algebra, but I can do the job. The other thing you will need is the surface wind. This R again you compare with the first table I gave you, the surface wind that was there: 2 meters and this and that and 6. Then I can really find out the stability. I do not think I should have anything below this but let us just scan... C is the cloud cover and this information is enough to calculate the stability class.

I have a little example so that you can get a better feel of the things. I do not need to have this one; I can write it, do it on the board and so let us put this one off. I will take a little help because I have the real numbers that I went through this morning very quickly, just before coming to the class. I took a typical example of Kanpur, for example. What is today? Today is 28th. Well, I did for 27 – that was a little mistake. I want to find out the stability at 11 o'clock today or let us say yesterday, so what I will do is go through this example quickly so that you can understand.

(Refer Slide Time: 19:17)

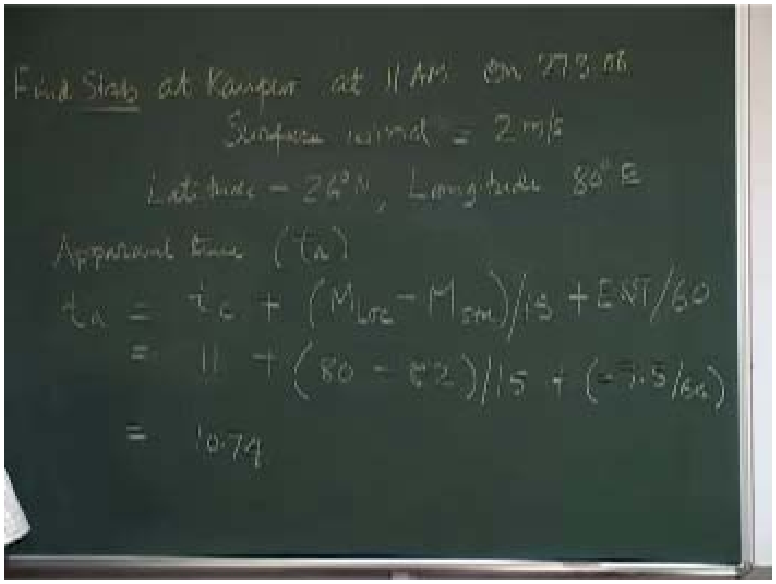
Now the objective what we have is find stability; when I say stability, it is the atmospheric stability at Kanpur at 11 AM on 27.3.06 – that is what my objective is. I have found out the longitude and latitude and then the other thing you have is the surface wind: 2 meters per second, latitude is 26 degrees and the longitude is 80 degrees. Do you say 60 degrees East? What do I write? East and here.… (Refer Slide Time: 203:36). The first thing I did was find out the apparent time – that is t_a; t_a is the… I do not have the formula but whatever the t standard at that time plus corrections: local minus $M_{standard}$ by 15 plus equation of time, but if you recall, the equation of time was in minutes, so divide by 60. What I will do is quickly write here 11 plus (80 minus 82) by 15 plus I calculate the equation of time.

(Refer Slide Time: 22:05)



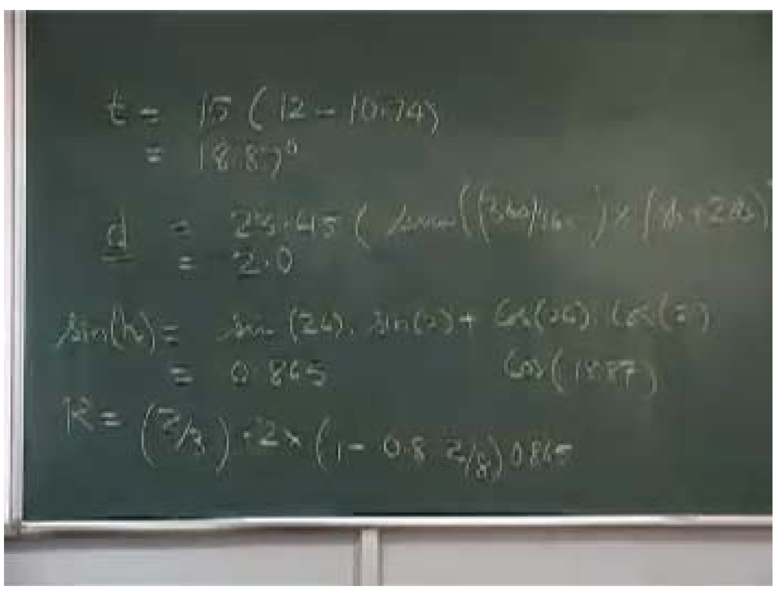
I will write it here to things make things clear. Equation of time was minus 7.7 sine 360 number of days in the year 2006 will be 365; 365 times you see it was small n minus 3. Can you tell what that small n will be? because I am doing one year 27 March 86. 86, so we will write here (86 minus 3) plus 9.5 sine 2 times (360 divided by 365) times (86 minus 80). That came out to be a very small number, that came out to be… and the way the equations are written – all angles you can take them in degrees, so you can specify in degree but always remember: when you have a trigonometric function, then all angles are taken in radians, but this is the way it is simplified and written, you can take all of them in degrees.

(Refer Slide Time: 23:59)



If that is the case, I can write this as minus and that came out to be 10.74, so your time is really not 11 o'clock but little less than 11 o'clock – I am carrying in decimal, I am not writing in hours and minutes. Clear?

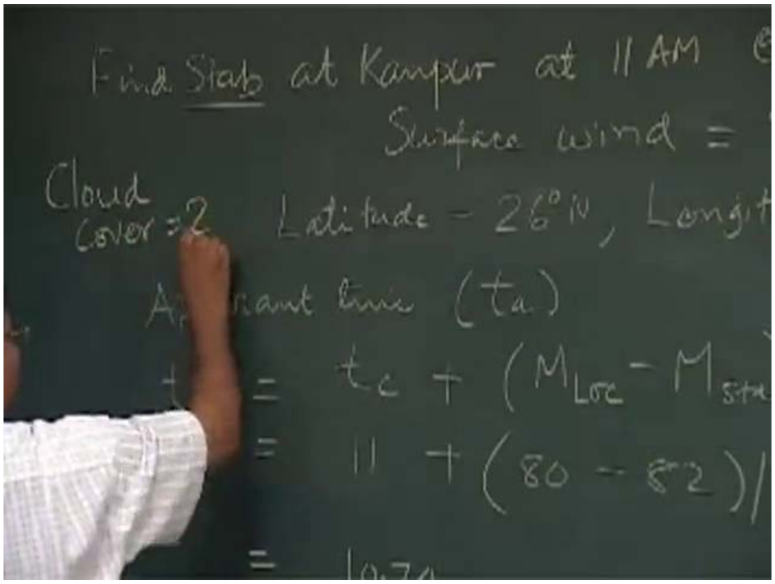
(Refer Slide Time: 24:44)



I got my t_a, then I calculated the solar hour angle – that was t. I am very close to 12 o'clock. What do you expect the value of t can be? That was 15 minus 10.74 or in fact, 12 minus t_a, t_a is

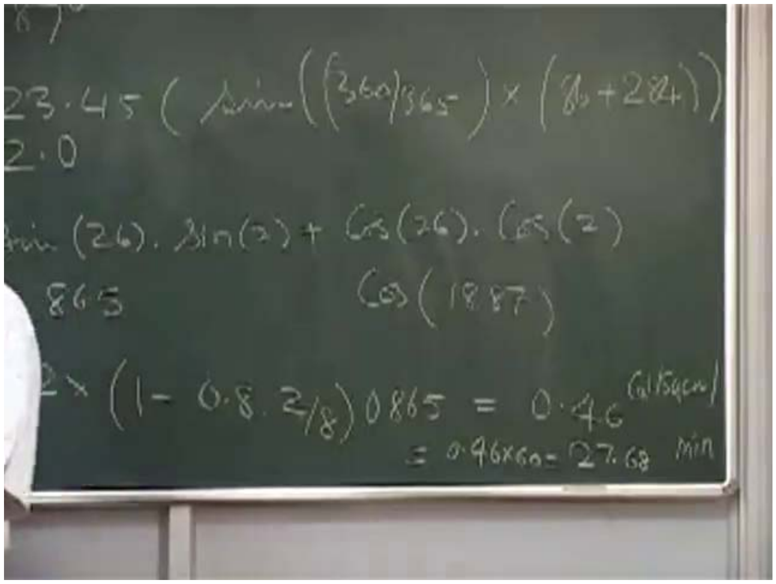
10.74 and that came out to be 18.87 degrees. Then, I can find the declination. The declination was… if you recall, this was 23.45 sine ((360 by 365) multiplied by 86 plus 284) and that came out to be a small number, approximately 2.0 – that was sun's declination. Now I want to find.… What is the next that I find out? [Conversation between student and professor - Not Audible (26:18 min)] What was that? 86 into 284, we can check that. Make it plus, plus 284. What calculation have I done – with plus or with multiplication? I have done with plus, so that number 2 is fine here, there is no problem with this number. Now you remember I have to find out sine h and for that again, I had the formula, this was solar elevation and the formula was something like this.… Whatever that formula was, I will put the numbers straight because I have got the… that is sine 26 times sine 2 plus cos 26 times cos 2 times cos t and that came out to be 0.8565. Sir, these are all in degrees? All in degrees – that I clarified and they are all in degrees. Finally, now I am all set to find out R: 2 by 3 times the solar constant S – that I am writing as 2 – into 1 minus 0.8, I have just taken hypothetical that cloud cover is 2.

(Refer Slide Time: 28:51)



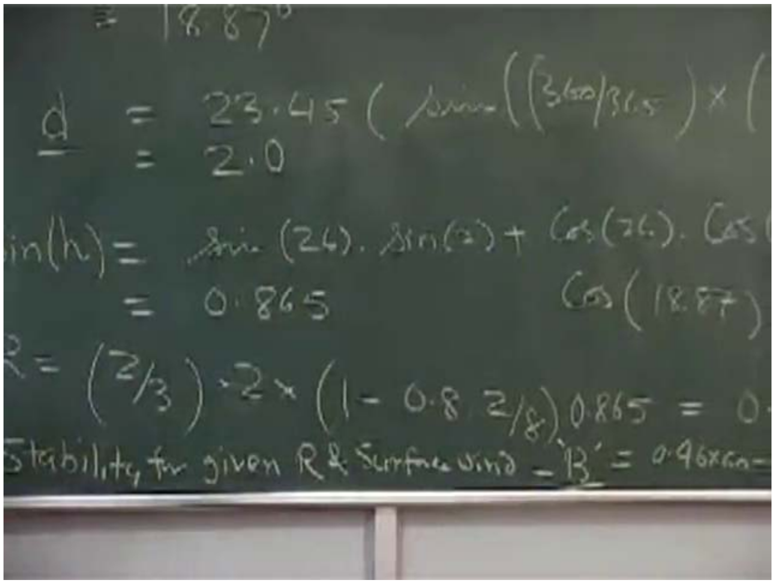
Did I write here? No. You can just take any number; maybe in the morning it was little cloudy, so I took this as 2.

(Refer Slide Time: 28:55)



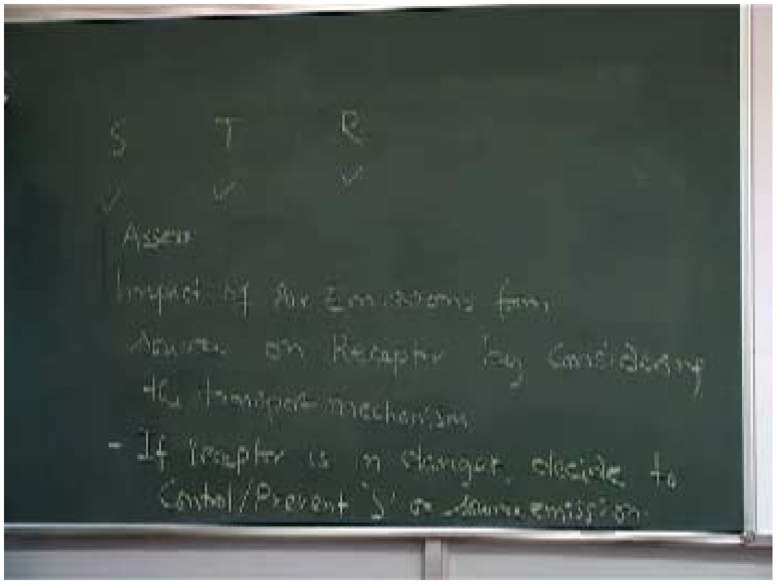
So here, 2 by 8 sine h – that is 0.865. That way, you can find out the the radiation or the incoming solar radiation or insolation – same thing. That number came out to be… calories per square centimeter per minute. Now tell me with your knowledge, what do you expect the radiations to be? Too high, too low, moderate? When do you expect the maximum solar radiation? 12 o'clock. No, solar radiation around 12 o'clock is high. Moderate. You expect moderate because you are talking about 11 o'clock, the sun has not come up at as yet and the insolation will still increase, so let us see. This will be equal to 0.46 into 60. How much did that come out to be? 27.68 Langley per hour. Now what category is this coming in? Moderate. Moderate and we expected it to be moderate, is it not? That is coming out to be moderate. Now, go back to the first table where we had the relationship between the surface wind and the insolation and please tell me the stability – I do not know what that stability is. I expect this to be B or C.

(Refer Slide Time: 31:23)



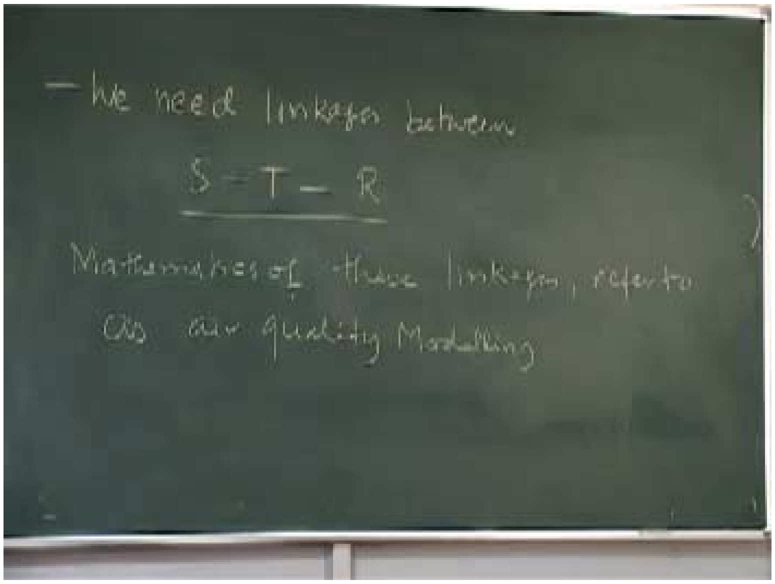
Surface wind is 2. Go back to the tables we gave you about the surface wind and… B. B and you expect it to be B. The stability after going back to the original tables, this stability was for a given R and what else? Given R and the wind speed, surface wind, it came out to be B. Suppose you have all the formulas, now you can find out the stability from anywhere in the world for any time of the year – for any time or any hour of the day. In fact, this is very extensively used because you cannot really find the temperature gradient so easily because then you have to measure at different heights and do lots of things; measurement as a routine thing you cannot do and routine thing you cannot do at many places, but this method you can almost find out all over the world – you can find out the airport within about 200 kilometers or so, so you can find out the stability. This was the Turner scheme – very good, very good approach, very good thought that you can very easily find out this stability without any measuring devices and putting the instrumentation; it may be slightly inaccurate or estimated rather than the actual number but you can find out this one. What is it that we want to do next?

(Refer Slide Time: 33:40)



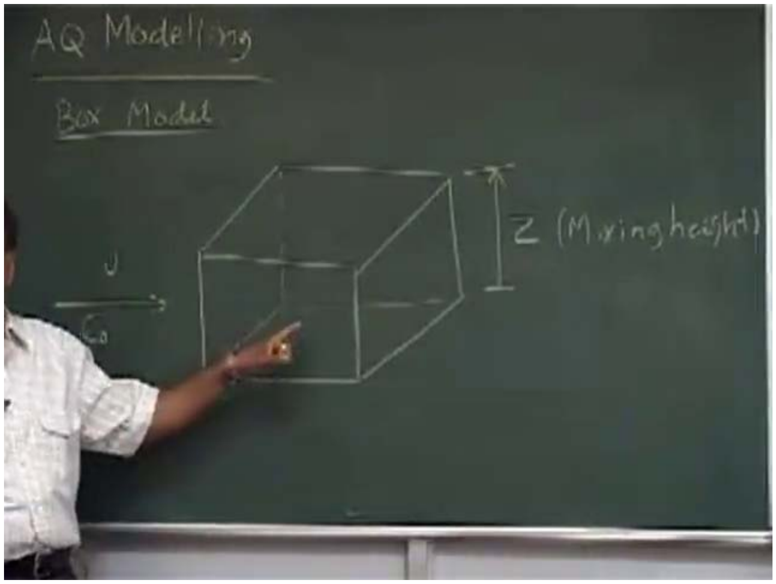
We go back to our basic conceptual model. We have learned about the sources, type of sources and many other things. We knew about the receptors, now you also know about meteorology, this also you know (Refer Slide Time: 33:59). Now, the objective is to make the connectivity between these three exclusively looking things. We studied this thing independent (Refer Slide Time: 34:12), do you agree with me, without really saying what is the impact on this receptor. What is the impact of the source on the receptor – we did not really see that one. We also looked independently at what pollution level a person can suffer, how the vegetation could be affected, how a building could be affected. This also we studied independently (Refer Slide Time: 34:35) – what is the meteorology, what is the movement of the air, what is the turbulence and things like that, although we studied in a very limited sense; we could have more details of this one but if you recall, the objective is to see the impact of air emissions from the source on the receptor by considering the transport mechanism or we can put a word here ‘assess’ – assess the impact of air emission from source on receptor by considering the transport mechanism (which is your atmosphere). Now, this is what we want to do and finally, give a solution. I will write in a little crude language but that helps in understanding: if receptor is in danger, decide to control or prevent, if you like, prevent S or source emission – that is what we want to do.

(Refer Slide Time: 36:55)



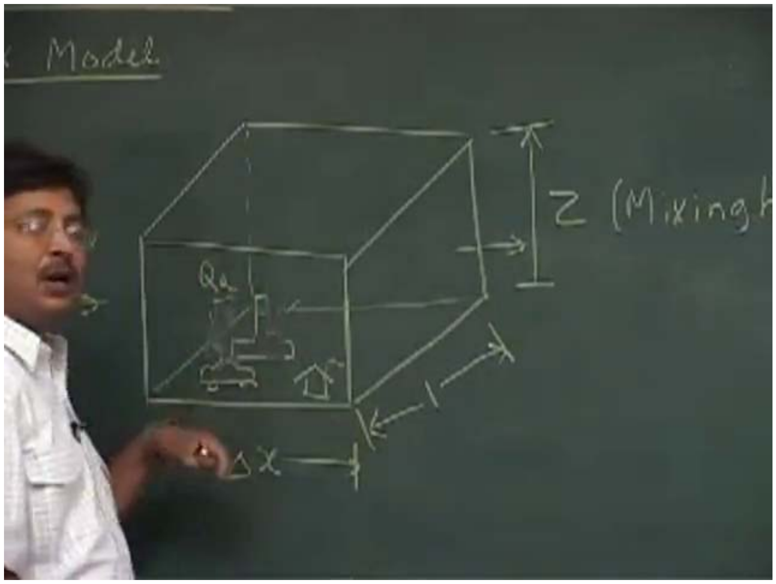
But to do this, we need linkages between source and transport (that is atmosphere) to receptor – that we need to develop and the way you develop these linkages… the mathematics of these linkages, again I will use some crude English, mathematics of these linkages we refer to as air quality modeling – that is what you want to answer ultimately, we want to do the modeling part. We will use the modeling and apply a little mathematics fundamentals because we understand physics fundamentals, we also understand the chemistry fundamentals and now we apply the mathematics to get the linkages between source and receptor. So now onwards, we will be focusing on the modeling and we will do a very simple model.

(Refer Slide Time: 39:04)



If you agree with me, let us call this as air quality modeling. The first model that we will develop is called box model. This is a box model and let us say the wind is blowing in the box, the speed of the wind is let us say U and the concentration of the air which is outside the box – let us call that as the concentration of any pollutant that we are considering and you are saying the pollutants in the box can disperse only up to a certain height. What is that height? Mixing height. Mixing height, so let me call this as Z or mixing height.

(Refer Slide Time: 40:42)

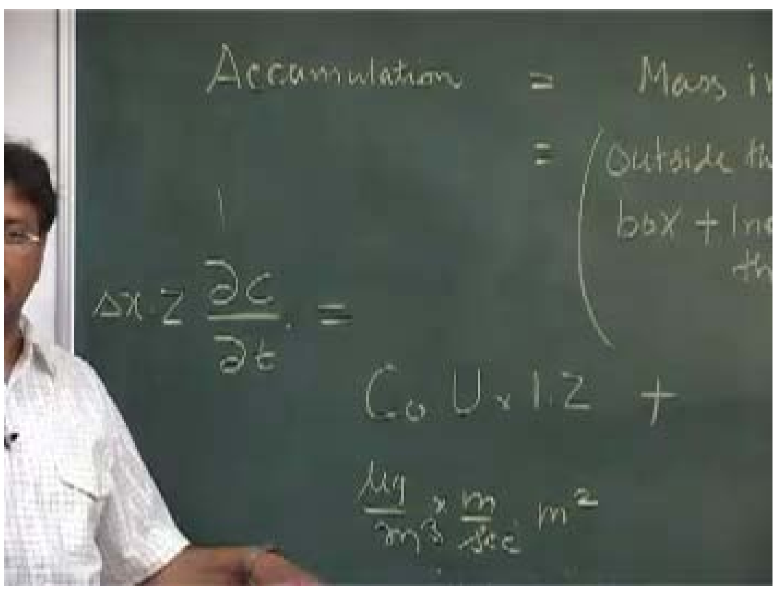


You can also have some sources that are causing the pollution in the box. Suppose we have a factory, we have the cars, we have the houses – all cause some kind of pollution; then this air will flush out this place (Refer Slide Time: 41:07) and that will go out. I am interested in finding out the concentration inside the box.

(Refer Slide Time: 41:20)

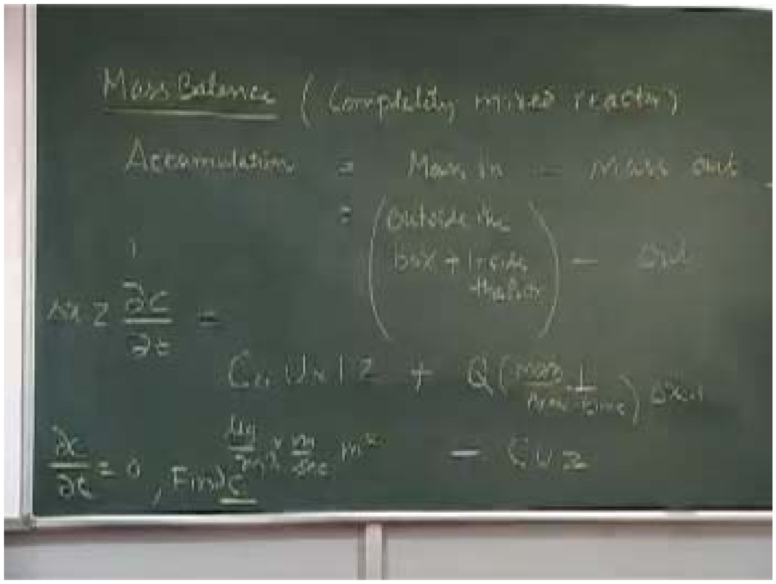
We apply the simple concept of mass balance. We apply the simple concept of mass balance and see the change in concentration. Accumulation inside the box or accumulation rate is mass in minus mass out; mass in will have two components: outside the box plus inside the box, so let us write this one; accumulation will be change in concentration but unit should be mass per unit time, so these units I have microgram per meter cube. Suppose I say this length is unity. Again, I can have n number of boxes, things will be very similar. I can simply take the volume of the box and suppose I am calling this as the length of the box, I am calling this as delta x (Refer Slide Time: 43:14), this I am taking as 1 (Refer Slide Time: 43:19), unit in the Y direction because it will be the same no matter how many number of boxes are there, depending if the source is the same. So what do I do? U times Z (Refer Slide Time: 43:38) and 1. Agreed? Let us check another thing if we want to take the reaction or we do not want to take the reaction because we can even complicate it, if you like, with the reaction.

(Refer Slide Time: 44:22)



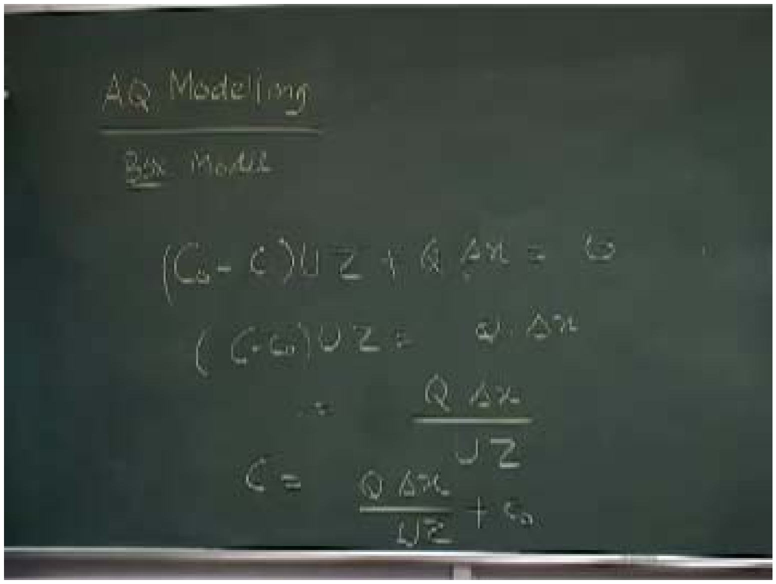
I think you have got it wrong here (Refer Slide Time: 44:09). We are inside the box, so let us take the box, input outside the box, so how much is that? C_0 times U times… do you agree with that? Concentration (Refer Slide Time: 44:45), meters per second (Refer Slide Time: 44:48), so let us check. For this, you have micrograms per meter cube for example, this is meters per second, this is meter square, so what is it that you are doing? It is becoming mass per time. Correct?

(Refer Slide Time: 45:29)



We should write them clearly – even if you are very good, go through this thing. From the box. Suppose this emission rate which is there I am calling this as Q_a (Refer Slide Time: 45:24) – that is mass per meter square; mass rate per meter square, so Q_a which I am saying as mass per unit area per second or time. What is that I multiply this with? delta x. [45:54]. Or do we multiply by Z? No, we do not multiply by Z because mass per unit area is there, the delta x into 1 and you can check that area, area cancels (Refer Slide Time: 46:16), mass per unit time. Clear? Plus or minus how much is it going out is… let us say is the concentration which is completely mixed reactor, so we are saying that C is the concentration in the box, so that will be… because wind speed is the same and C is what we are doing mass balance considering box as completely mixed reactor. Why do you not quickly check if everything is all right? That is fine (Refer Slide Time: 47:16), this is also fine (Refer Slide Time: 47:18) and now you can say the concentration is steady state concentration where we normally do, so I can put del C by del t equal to 0, find concentration in the box. Can you quickly do that?

(Refer Slide Time: 48:25)



Let us do that. You can say (C_0 minus C) times U times Z plus Q times delta x equal to 0, so now you have (C_0 minus C) U Z equal to Q delta x, so C_0 minus C is nothing but Q delta x by U Z, so C will be equal to… [49:11]. What is that? C_0 plus. C_0 plus. [49:17] C_0 plus, is it plus? [49:20] What are you calling C_0 plus…? [49:26] C minus C_0. C minus C_0, sir. Okay. [49:32] Okay, okay, okay, okay, I can say this is C minus C_0, so you should get something like this (Refer Slide Time: 49:50). Plus, sir. Plus here, so that is how you can find out the concentration. This is correct and you put $C_0 = 0$; prior to pollution coming to the box, the initial concentration was 0, so you can put $C_0 = 0$. I think we will stop there and slightly talk more about this and about some other standard models, which you are aware of.