Environmental Air Pollution

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Lecture No. 22

Meteorological Measurements and their Interpretation

In today's lecture, we will talk about meteorology and wind measurements. As you would recall, meteorology affects the transport and dispersion of pollutants; wind is the primary mover for the transport of the pollutants, wind speed decides how quickly the pollutants will disperse and wind direction decides in which direction the pollutants will go.

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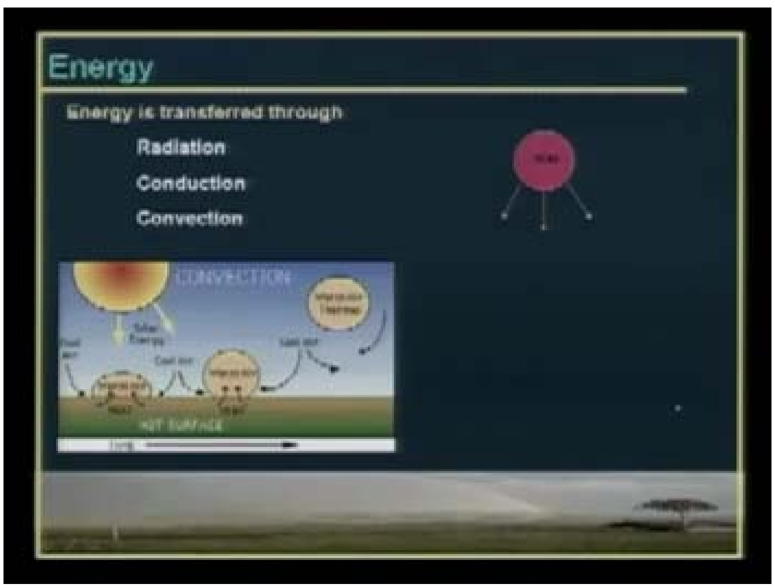

To come to wind measurements, we have to go through some basics about energy and to say why a wind blows at all. The reason for the wind to blow is the difference or unequal heating of the earth's surface as [01:06] temperature difference, there is a pressure difference and the wind would always travel from an area of high pressure to low pressure. Essentially, the energy that reaches the earth decides the heating part. We will go through some basics. As you can see here in the slide, energy is transferred through the three mechanisms that we all have studied in our high schools: radiation, conduction and convection.

When we talk about air pollution or the movement of pollutants on earth, it is largely the convective currents that decide the dispersion of the pollutants because that the convection occurs in the ground surface, the ground gets heated as you can see and the hot air or the warm air goes up as you can see on the picture on the left-hand side and the cool air comes in. Convective currents are passed and they are the primary reason for the transport of the pollutants.

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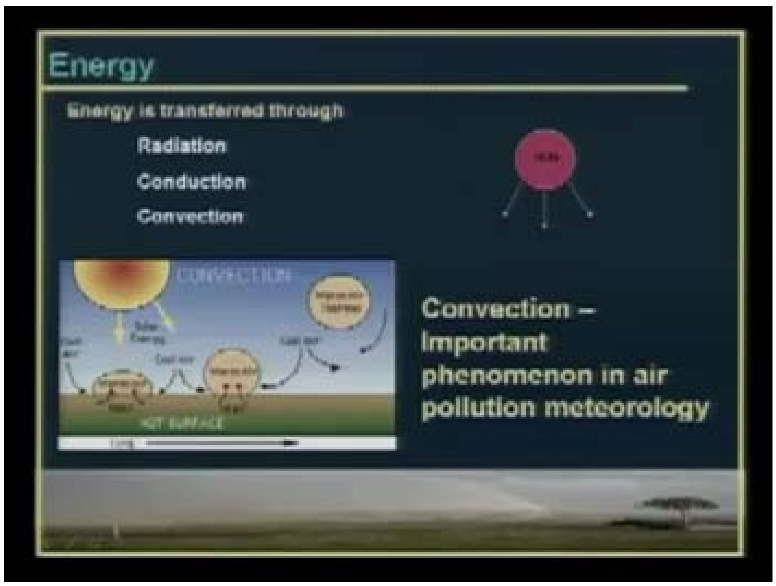

Again, you can see that convection is an important phenomenon in air pollution meteorology. With this convection, the wind blows and the wind direction decides where the pollutants will go. What are the factors affecting the wind with the energy balance and then that could also affect the wind pattern and the wind speed, wind directions, etc.

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Ground cover, what kind of surface is there – is it a snow surface or water surface or plain ground or is it a desert or land covered with vegetation; then, the cloud cover, how much cloud is there in the sky – that decides how much heat or how much energy will come on the surface; there are certain gases, greenhouse gases (which you can see here) – the gases that decide how much should be the pollutants or the heat would be trapped and then that may cause the warming of the atmosphere; and also pollution that is largely due to aerosols, which can absorb heat – these are all the factors that decide how much is the amount of energy that would reach and would be stored into the earth's system.

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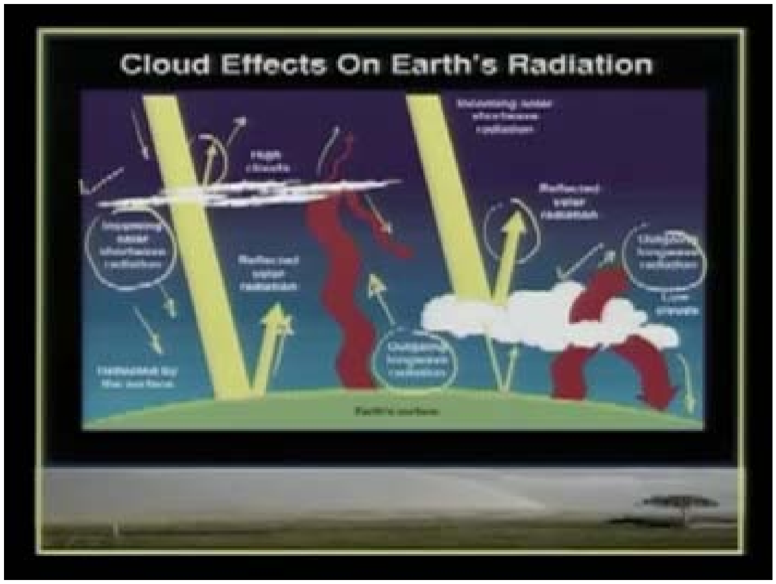

If you take a little bigger picture and see the role of clouds here, you can see here that the heat is or the energy is coming from radiation, but there are two types of clouds that we will talk about. The first is high clouds, which are thin, and there are other clouds, which you can see here as I am ticking the mark – these are low clouds but thick clouds. What happens is as the energy comes onto the surface, some portion is reflected back to space again and the solar radiation that is coming here is the shortwave radiation, where ‘short-wave’ means the wavelength of the radiation is very very small – it is in the range of nanometers or micrometers and we will see why it is so; part of the energy that is coming here is reflected back and part of the energy is reflected or given out in the form of the ongoing longwave radiation.

What is coming here is the short wave and the red thing you are seeing here is the long wave. Long wave comes because once the earth gets heated up, it starts emitting heat energy and so we have to look at the total balance. Once this heat energy goes up, part of this would be reflected back as you can see here in the system (Refer Slide Time: 04:57) and part may go back to space. Same thing if you look at the thick cloud, you see the thickness of the arrow here, most of the things are reflected and a small amount reaches the surface.

Similarly, as you see here, part of the ongoing longwave radiation will go through space and part of it will come back to the ground. You can see that cloud plays a very important role and we will see what it means in terms of heating and cooling. Before we go, we also need to understand one more terminology called the albedo.

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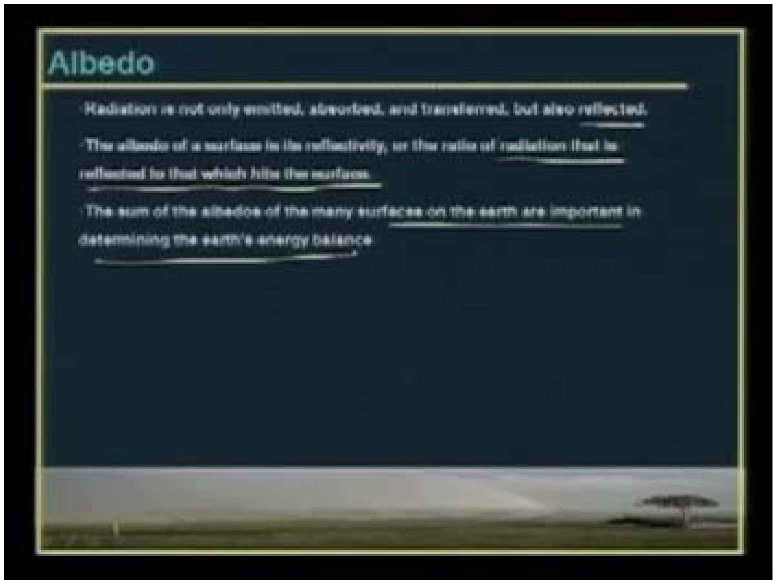

What is albedo? The radiation is not only emitted, absorbed, transferred but also reflected. The terminology important here is reflection of the energy. The albedo of a surface, which is surface-specific, is the reflectivity – how much would be immediately reflected or the ratio of the radiation that is reflected to that which hits the surface. The amount of radiation that is hitting the surface and what fraction and part of that radiation will be reflected – that we refer as the albedo. The sum of the albedos of many surfaces on the earth is important in determining the earth's energy balance. It is not only the absorption, it is not only the longwave radiation or the short-wave radiation, role played by the ground, role played by the clouds or aerosol, but the reflectivity of the surface or albedo is also very important.

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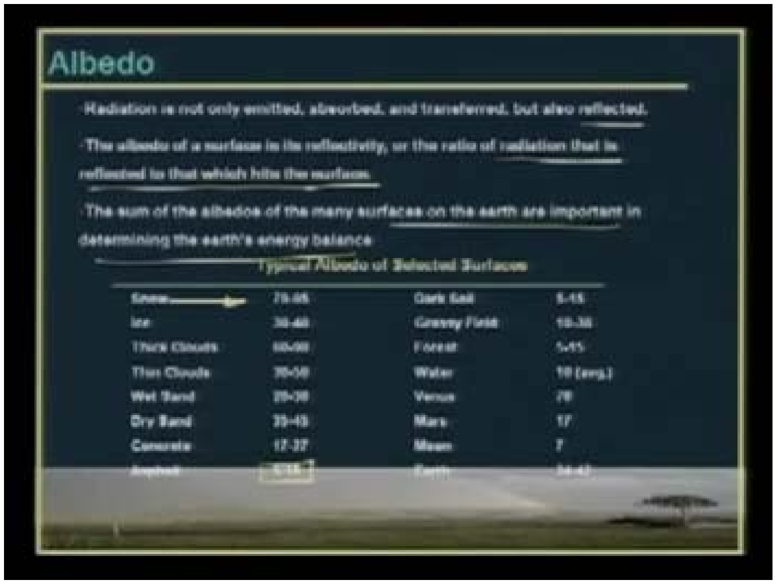

To give you a little feel as to what surface gives what kind of albedo, you can see here. For example, look at snow. You will understand that the reflection from the snow surface is very high – 79 to 95. Similarly, you can see when something is asphalt (that is our road surface), most of this is black in color, most of the energy will be absorbed here, reflection from the black surface will be very minimal, so albedo impact from the dark, black surfaces will be low whereas for a surface like snow that is white in color, the albedo impact will be very large – even that decides about the wind, the temperature and local wind conditions. These are just basic things we need to understand but we will come back to something to give you an understanding of the short wave and the longwave radiations.

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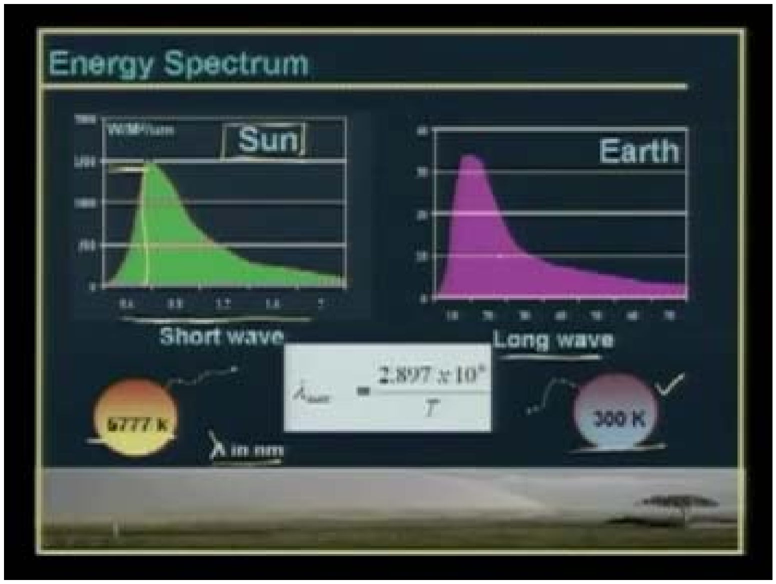

Last time, we showed that the radiation that is coming from the sun is mostly in the short-wave range and the range you are seeing here, 0.4, 0.8, 1.2 is the nanometer of the wavelength. The temperature of the sun is taken as 5777 Kelvin and the wavelength that will have the maximum energy can be found out from this equation; just remember that this lambda here is in nanometer. You get something close to 0.5 nanometer, where there is a peak in terms of energy. When we come to the earth, the earth's temperature is low and so the radiation from the earth will be in the long wave as you can see here. See the difference in the wave: it was 0.8 here and that could be 10, 30, 40 here.

You can also estimate at what wavelength the maximum radiation will occur from earth. The concept must be clear: from the earth, most of the radiation that comes is in short-wave form because the radiation that is coming from the sun is in short-wave form – the sun acts as a black body as the temperature is very high; the radiation that comes by virtue of heating on earth is at lower temperature, close to 300 Kelvin and the radiations will be longwave.

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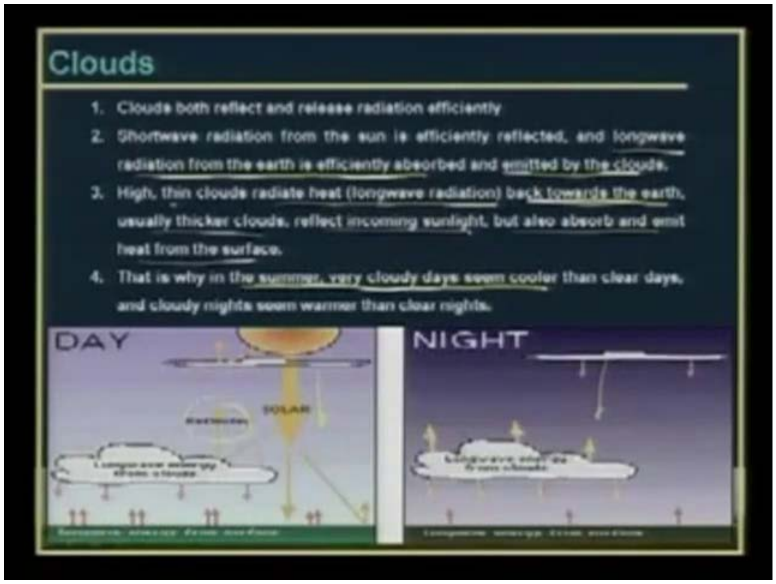

What does it really mean in terms of hot weather and cold weather? You can see here day and night. Clouds both reflect and release the radiations efficiently – that is point number one. Shortwave radiation from the sun is efficiently reflected and longwave radiation from the earth is efficiently absorbed and emitted by the clouds. What we see here is that the longwave radiation from the earth is efficiently absorbed and emitted by the clouds. High and thin clouds, so we will talk about two clouds. High and thin clouds radiate heat in the longwave radiation back towards the earth, whereas thicker clouds usually reflect the incoming sunlight but also absorb and emit heat from the surface.

What it really means here is that when the solar radiation is coming in, it can reflect very efficiently but then, it can also absorb the heat. What it really means in terms of day and night is that in the daytime, you will see why very cloudy days seem cooler in the summer – when the days are cloudy, the solar radiation is stopped; if it is cloudy in the nighttime, of course there is no radiation that is coming in, but what you can see is that the radiation that is absorbed by the clouds is reflected back. You can see that if you have cloudy nights, then the temperature will be a little higher and if you have a cloudy day, the temperature will be somewhat lower. This is the study about temperature but the focus of this lecture is really about the wind system. In the measurements of wind, there are two important things: one is the direction and the other is the speed.

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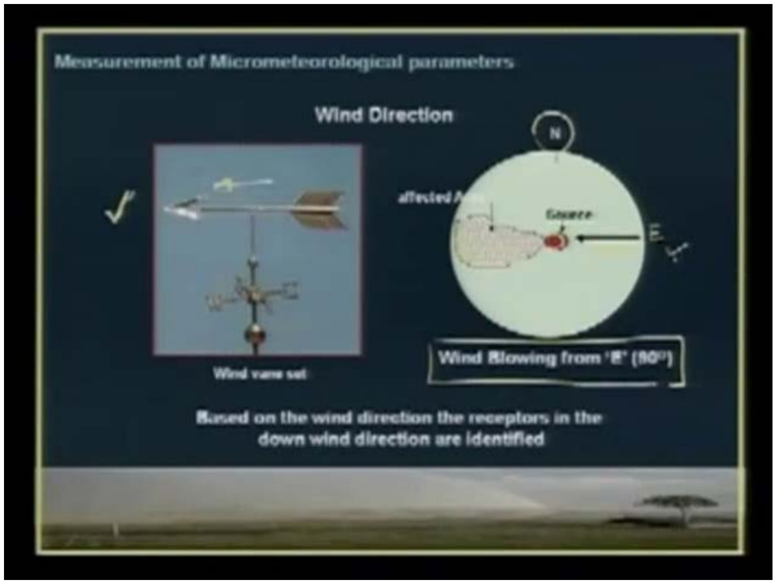

You must have seen this picture on your left-hand side. This is a very common picture and you must have seen it on television. The arrow is showing the direction of the wind and the direction of the wind is measured in terms of north, east, west and south. We will go on to more details and see what are the other directions in which the wind can blow and how this is classified. The important thing to see in this figure on your right-hand side is that suppose this is my north direction, my wind is blowing from this direction, this direction will be east (Refer Slide Time: 12:09) and this is a pollutant source. The wind will transport the pollutant in the direction opposite to the wind direction, so this will be the area that may be affected because of air pollution but let us understand how these winds are measured and how we represent the wind system so that we understand it better.

The important thing to understand here is the wind blowing from the east is 90 degrees – I will explain in a moment about the 90 degrees, but one concept that is important (we will discuss the concept a little later also) is that the wind direction is the direction from which the wind is blowing. Sometimes, people have an unusual or improper concept – they think that the direction in which the wind is going is taken as the wind direction but that is not correct; the direction from where the wind is coming is taken as the wind direction. For example, in this figure, you say the wind direction is east – it means the wind is coming from the east. If you want to show in degrees (I will explain that to you later), then the wind direction is 90 degrees east – we will see what 90 degrees really means, but this concept is important: the wind direction refers to the direction from which the wind is coming. Now, I will give you some more concepts as to how wind directions are understood in a slightly complicated way, because the wind direction could be really infinite, but there are ways that scientists have evolved to show the wind direction. First of all, let us consider an example that we can understand very easily.

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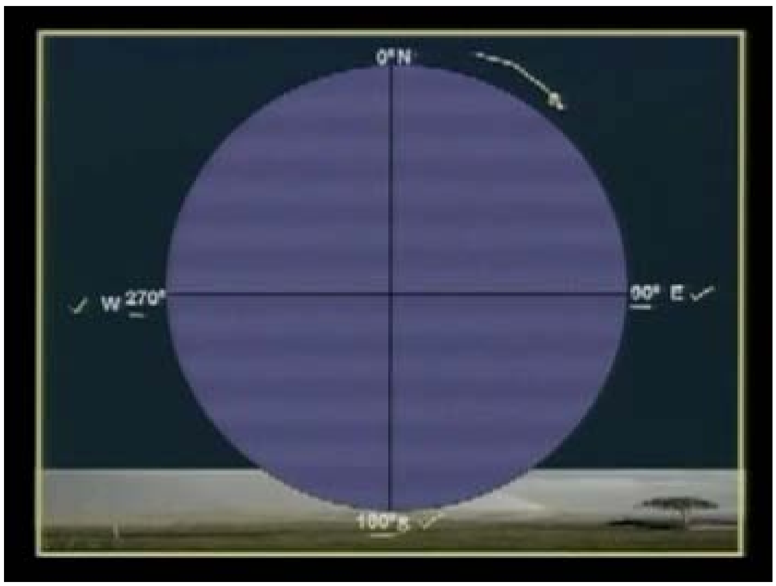

What I am drawing here now are the four wind directions that we all understand very well. Let us see what those four directions are. You can see here north, you can see east, you can see south and you can see west. This is the same as measuring the angle. Suppose I am going in the clockwise direction and I start measuring the angles. Suppose I am starting with 0 angle and I am calling that as north; at east, the angle will be 90 degrees, it will be 180 degrees at south, it will be 270 degrees at west. Let us remove this (Refer Slide Time: 14:52). However, just giving the four directions is not enough, because as I said, there could be many wind directions. What scientists have done is they normally expect at least 16 wind directions.

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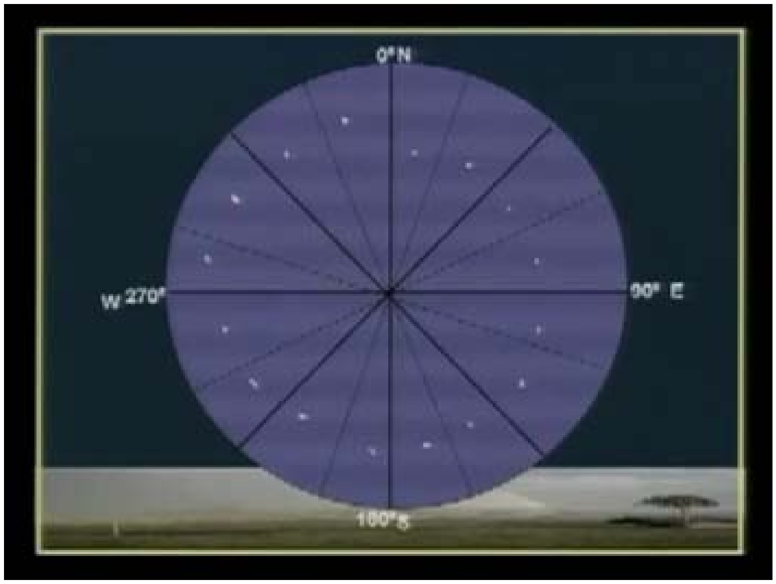

What we can do is I can divide the blue circle that you are seeing into 16 equal parts and then I can give 16 different names to the wind directions. Let us do that. What I am going to do is that I will divide this blue circle that you see here into 16 equal parts; one, two, three, four, five, six and you will find here that the whole circle is divided into 16 equal parts. We can quickly even check, if you like. This is one, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen, fourteen, fifteen and sixteen. What we have done is we have divided the circle into sixteen parts and now what we will do is that we will try to give names to these parts and we also can define the angle – that would decide and tell me what the wind direction is. Let us give some names.

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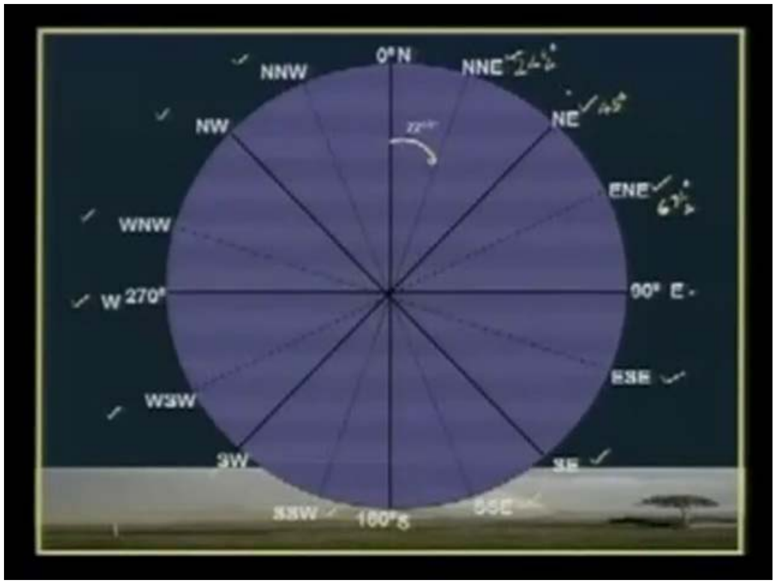

What you can see is that certain names are given to these 16 directions. You understand north, east, south and west, but if the wind is from the first part, it is called north-northeast; similarly, the wind that is in this direction is called northeast; this is east-northeast, this we have discussed, east-southeast, southeast, and south-southeast. Why it is called south-southeast is that I should really be saying it is south of southeast; this is southeast (Refer Slide Time: 17:05) and this is south of southeast, so this is called south-southeast; this is south of southwest, so this is called south-southwest, then southwest, west-southwest, west, west-northwest, northwest and north-northwest. These are the names that we give to the various wind directions.

Simple but as I said, I can not only give the names of the wind directions but also measure them – north-northeast, south-southeast, etc. It is probably even better to represent the wind direction by degrees – then I can precisely pinpoint where the wind is blowing from. Let us give the angles. What is the angle this is making? This angle is, as you can see, is 22.5 degrees. If this is my wind direction, I can also say 22.5, this will become 45, this will become 67.5 and then this will become 90. We can even give degrees if you like – if we know the exact degree, then we can imagine where the wind is coming from. But for quick understanding, the wind is normally presented in the direction as it is – north-northeast, northeast, east-northeast, etc. Let us remove this. When I want to say my wind is from the north, what it really means is what degrees will occupy the north direction.

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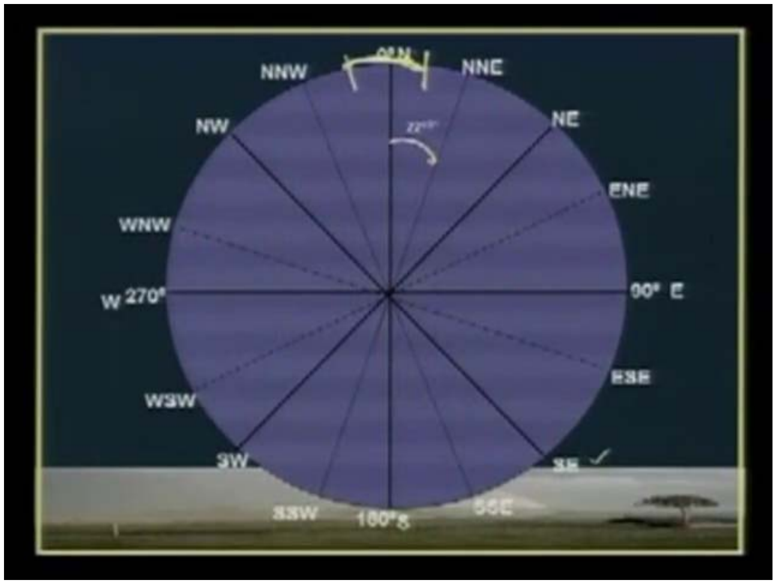

It means if my wind is half-way in between here, half-way in between here and the wind is blowing anywhere from here to here (Refer Slide Time: 19:47), that is what I want to call as the north direction. This angle will be half of 22 and this angle also will be equal to half of 22. Let us divide this so that we can clearly show what range of degrees we would refer to as the north direction. Let us do that.

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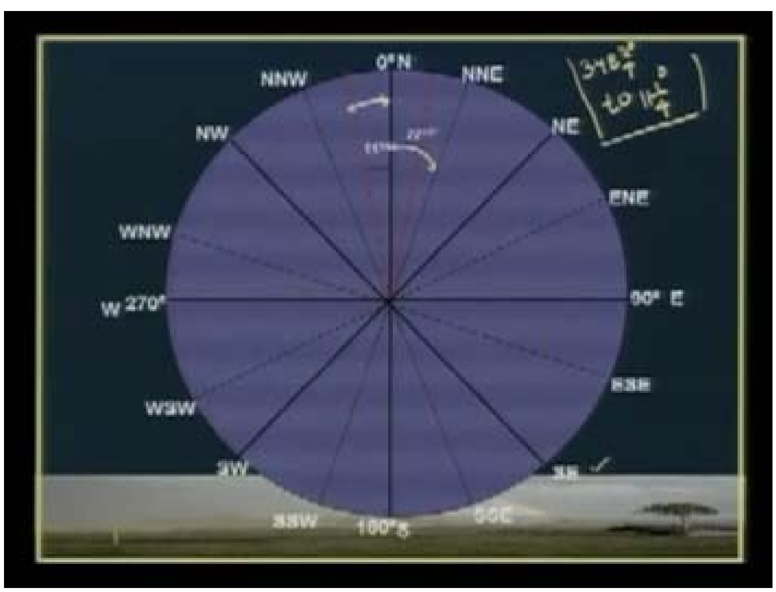

What we are seeing here is what degrees will represent the north direction. Essentially, what I should do is divide this part in half (Refer Slide Time: 20:25) and divide this part in half. Let us do that. What I have done is I have divided this angle between north and north-northeast or bisected this angle and I also bisected the angle between north and north-northwest. If I measure this angle, how much would that be? This will be 11.25 degrees. So what should be my wind direction? Suppose my wind direction is between…. I can subtract 11.25 from 360, so this becomes 348.75 or let us say the wind direction is between 348.75 and 11.25; let us write 11.25 degrees and let us write degrees here. This implies the wind direction is north. Why? It is because the measurement on this circle is basically this angle (Refer Slide Time: 22:04). This angle is starting from 348.75 and going all the way to 11.25. Once I have the degrees, I can found what direction the wind is blowing from and we can do it similarly at different places.

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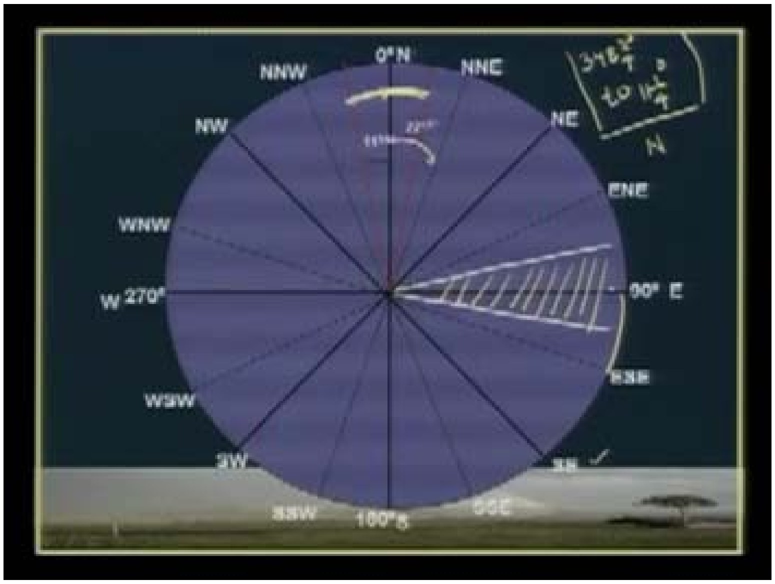

I can divide this into equal parts (Refer Slide Time: 22:25), and then I can bisect half of this angle. So as long as the wind is blowing from this sector, I would call that wind direction as east or essentially I will take that wind direction is east and in degrees, it will be 90 degrees.

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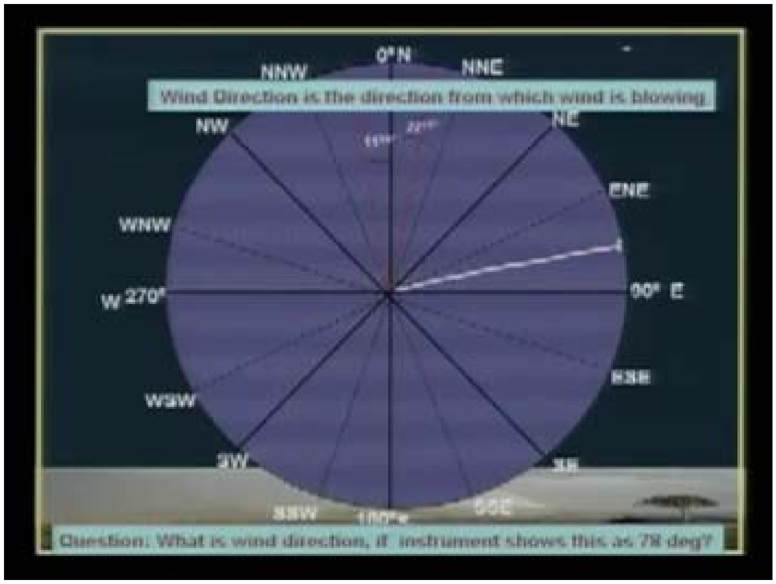

The important concept we said earlier and again want to repeat is this: what is wind direction? Wind direction is the direction from which the wind is blowing – this is a very important concept. So if I say the wind direction is northeast, it means the wind is coming from northeast or in other words, if I say that the wind direction is 45 degrees, it means the wind is coming from northeast; if I say the wind direction is 180 degrees, it means the wind is coming from south – that is a very important concept. Let us do one more example or question. The question is, as you can see on the bottom of your screen, what is the wind direction if the measurement shows this as 78 degrees? Where would 78 degrees be?

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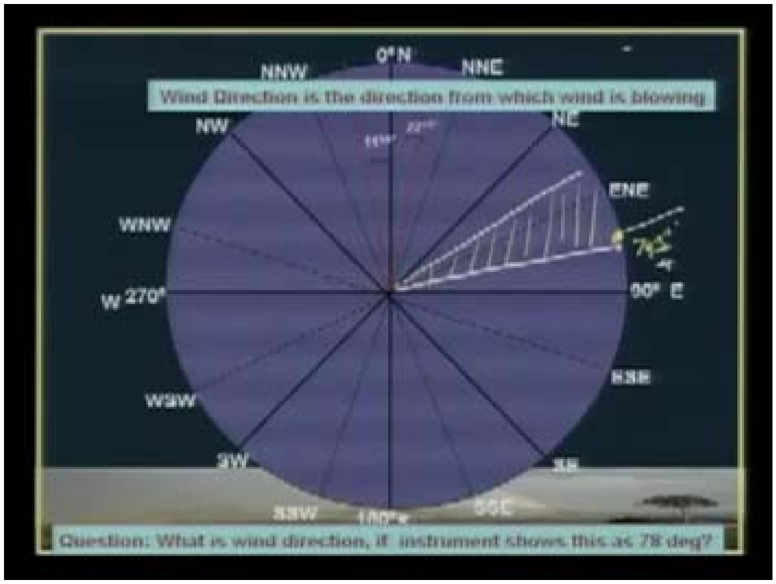

Here, if I divide this into equal parts, how much will this be? 90 minus 11.25, so this will become 80 and 79, 79.75 and my actual wind direction is 78, so it is somewhere here – my wind direction is like this (Refer Slide Time: 24:15), so I divide this into half here, so the wind is blowing in this sector. It means my wind direction is essentially east-northeast. Depending on the degree of wind direction you have, you can find out whether it will be northeast or east-northeast or south or east-southeast – that should be a simple thing once you have understood it. Let us go to the next slide.

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Now, we are talking about measurements. What you see on your screen is a photograph of a wind measurement system. This side I will circle (Refer Slide Time: 25:16) and that is called wind anemometer and this measures the wind speed; this one is called wind vane and what it measures is the wind direction. Although we do not ourselves manufacture these – experts do it, we should at least know the underlying principles as to how the wind speed is measured.

In wind monitors, the anemometer (a device that is measuring the wind speed) shaft (you can see the shaft somewhere here) rotation is sensed by a non-contact photo chopper assembly, which develops a train of pulses whose frequency is proportional to the anemometer rounds per minute and therefore wind speed. What happens is that the photo chopper is placed inside this one, the shaft moves and because of the movement of the shaft, the shaft completes one round, the photo chopper chops the photo and that pulse is taken up by the microprocessor and then this is corelated with the wind speed.

As you can see here, the microprocessor system counts the number of pulses received from the anemometer and performs the necessary divisions to give the wind speed in kilometers per hour. The units for wind speed measurements are normally either meters per second or kilometer per hour – both units are commonly used. Wind speed and wind direction system is there and [27:48] the vane, this little tip… actually, this is a little pointed (Refer Slide Time: 27:54) and this is what is showing the direction – the wind is essentially blowing in this direction. That is how you can find out the wind direction. Let us also see some other kinds of wind measurement systems.

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In this measurement system as you can see here, there is only one shaft and this is again some kind of anemometer – you can see that and this is a wind vane. So on one shaft itself, both can be installed and you can measure both wind speed and wind direction.

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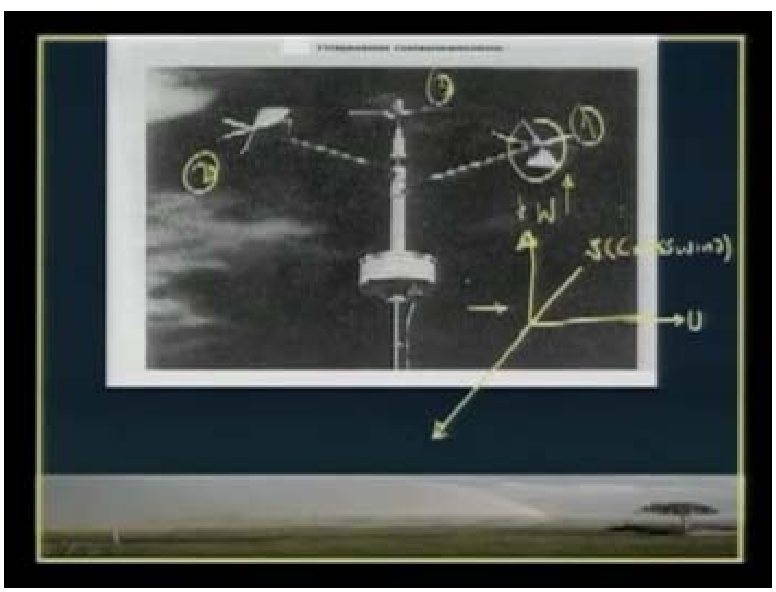

Let us go to another type of system that you can see here. This can give three components of the wind speeds. Again this is an anemometer. This is direction 1, direction 2 and this will give as direction 3 or if you want to understand, it might be good idea to put it like this. The wind will have three components. U is the wind direction that you see – it is going like this (Refer Slide Time: 29:18); there may be a small wind in this direction as well, which we call as V – the other name for this is the crosswind direction; crosswind gives how much the wind is perpendicular to the main wind flow; also, it is sometimes useful and interesting to measure the vertical component of the wind, which we refer to as W – that is the speed of the wind in the vertical direction and do not be mistaken: this vertical direction can be upward or also downward.

In fact, sometimes it is a matter of interest for us that we want to find out all the three wind components. U is the prominent predominant horizontal wind direction and that is sometimes more important than the other wind directions or the wind speed measured in the other directions, because this is my mean wind direction in which the pollutants will be transported.

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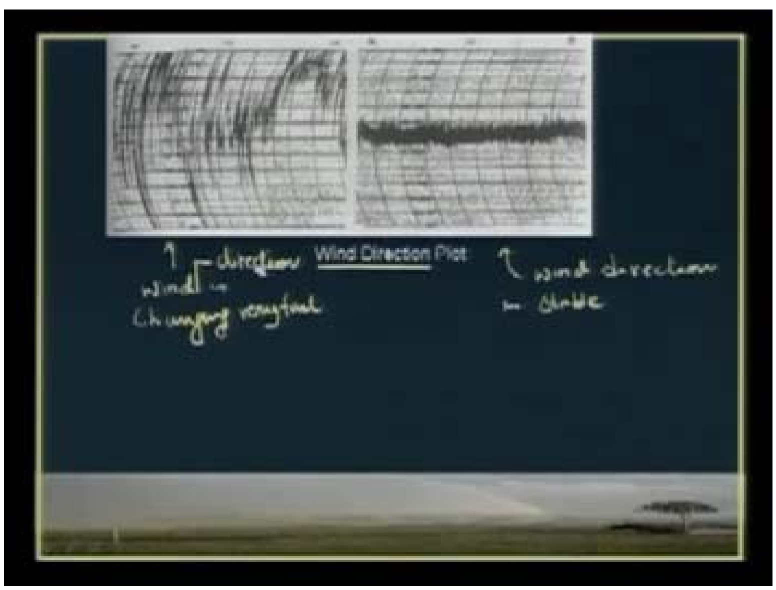

If that is clear, let us go to how the plots are seen. Nowadays of course, we have computers to do most of the computing for us, but earlier the wind directions were recorded on chart paper as you can see here. Both the charts are showing the wind direction. As you can see here, the wind is changing very fast (Refer Slide Time: 30:59) or rather, I should say the wind direction changing very fast but here, the wind direction is stable. It will probably not be clear to you as how it is recorded and so what we would is that we will manually develop and I will show you as to how this is really seen, because the picture is not very clear.

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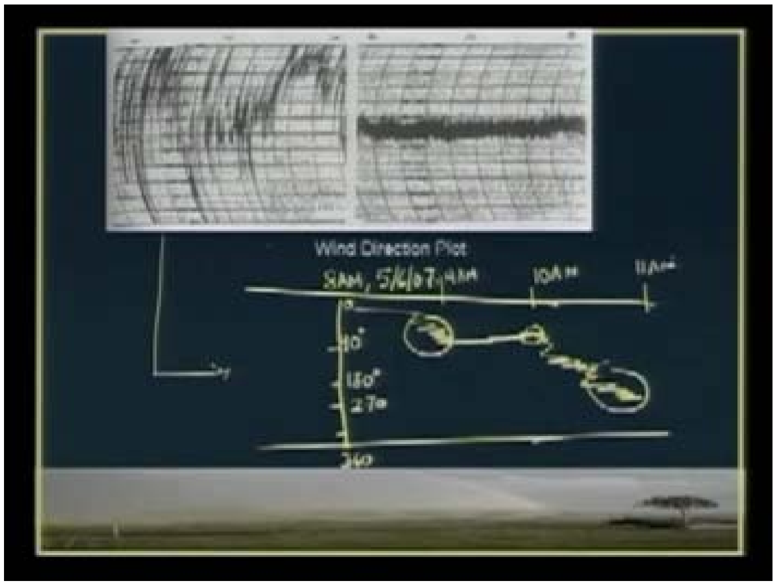

Generally, there is a chart and this chart is written in terms of degrees. This can be 0 degrees, this could be 90 degrees, this could be 180 degrees, somewhere it could be 270 and here I will write 360. As the wind direction changes, we can write and we normally write like this: 8 AM starting point and let us say we are measuring this on the 5th of June. This chart really moves and the pen keeps on writing, as you can see. Suppose this time was 9 AM, this was 10 AM and this one was 11 AM. Basically, I am reproducing the same chart here with a little bit more clarity.

In the morning at 9 o'clock, the wind direction was about 90 degrees, the wind direction was still 90 degrees at 10 o'clock, but between 10 and 11, the wind direction was something like 270 degrees. One can manually read this chart but nowadays, we have computers to do all the calculations and the reading part, because we are now producing micro signals and those signals can be read and also stored. In earlier times, when we did not have powerful computers, everything was done manually. This was the wind direction chart. Similarly, you can also have wind speed charts – I will quickly go through the wind speed chart.

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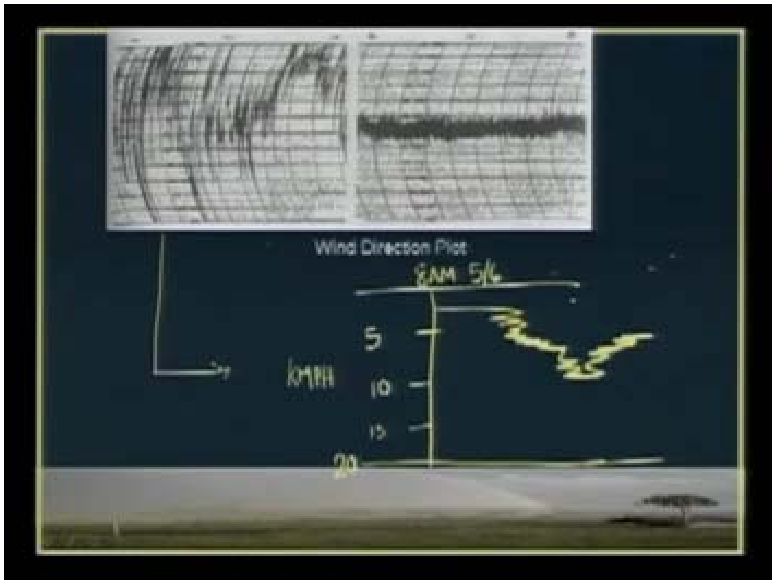

Nothing very fancy about it but something similar. Here, in place of the directions, we keep the speed. Let us say 5, 10, 15 and 20. The units may be kilometers per hour. Same thing you write here: 8 AM, 5th of June. Then, you can measure the speed and you can find what was the speed out at different time intervals on different dates. The two things that are important for us are wind speed and wind direction. One can measure both and one can utilize them in some of the systems in which you want to track the movement of the pollutants.

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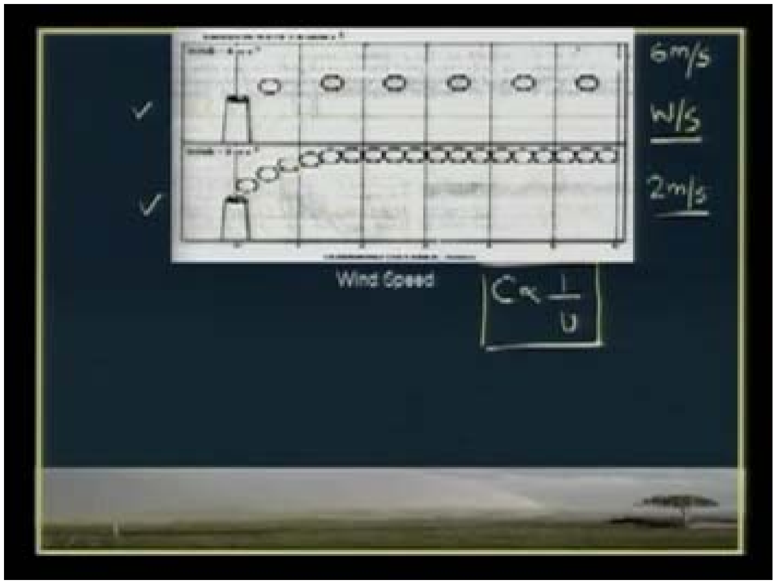

This is a little graph or picture you see here that is showing the wind speed and the effect of wind speed on the concentration. Imagine that there are chimneys that are identical here and here (Refer Slide Time: 35:50) and here, the wind speed is very high. What is the range of the wind speed we are talking about here? 6 meters per second. Suppose the wind speed was reduced and the wind was only 2 meters per second, you can see here that the pollutants can travel fast, so the concentration will be smaller here. This is because three parcels of the pollutants are still in this region, but because of the high wind speed, pollutants are dispersing away and they are moving away, so only one parcel of equal mass is there.

Normally, we consider the concentration of the pollutant is inversely proportional to the wind speed – that is a very important concept and we will use it later in our succeeding lectures; this is very important. Speed can directly cause the decrement in the concentration. We have already seen the wind direction and we know which place or which location the pollutants will have an impact on. With this concept, there is another concept that we have to discuss: calm conditions.

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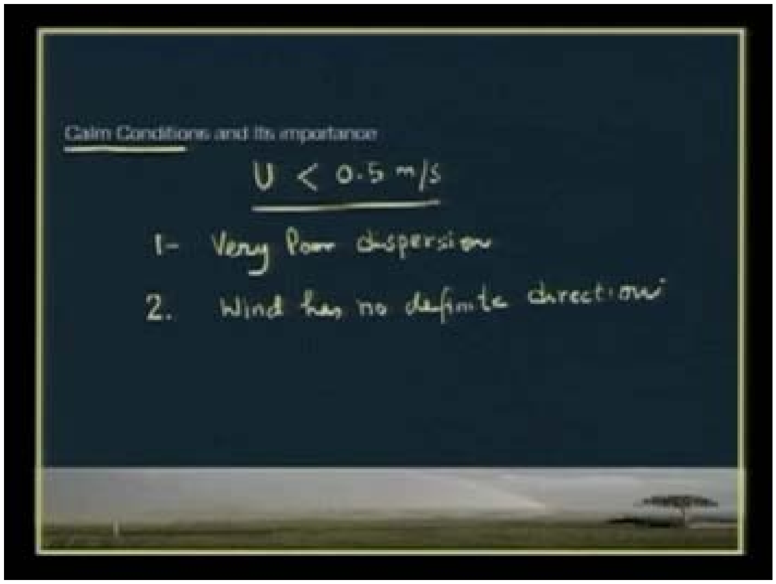

You must be wondering as to what are calm conditions, because we always have the wind. There are certain conditions that we call as calm conditions. Calm conditions are there when the wind speed, which we are representing as U, is less than 0.5 meters per second – we call that as calm conditions. It means that the wind is blowing but it is very calm because the wind speed is very very low. It is not that we cannot measure the low wind speed but it is a matter of convention to call this wind speed, which is less than 0.5 meters per second, as calm wind speed or as calm conditions.

What is the importance of the calm conditions? Since now you have a little concept of dispersion, the first thing is that it will cause very poor dispersion. In the location where you live, suppose the wind is most of the time calm and most of the wind is 0.5 meters per second, then it means there is a likelihood or more chances of pollutants getting accumulated and concentrations going very very high. So, one thing that it immediately tells us is that in areas where calm conditions are more, we should try to avoid having large industries or most of the pollution sources.

The second important point about this is when the conditions are calm, it also implies that the wind has no definite direction – it means the direction changes from place to place. That is also a very troublesome situation. I will show you why it is a difficult situation when we have calm conditions and when wind direction is not constant and it is really changing from place to place within a short time.

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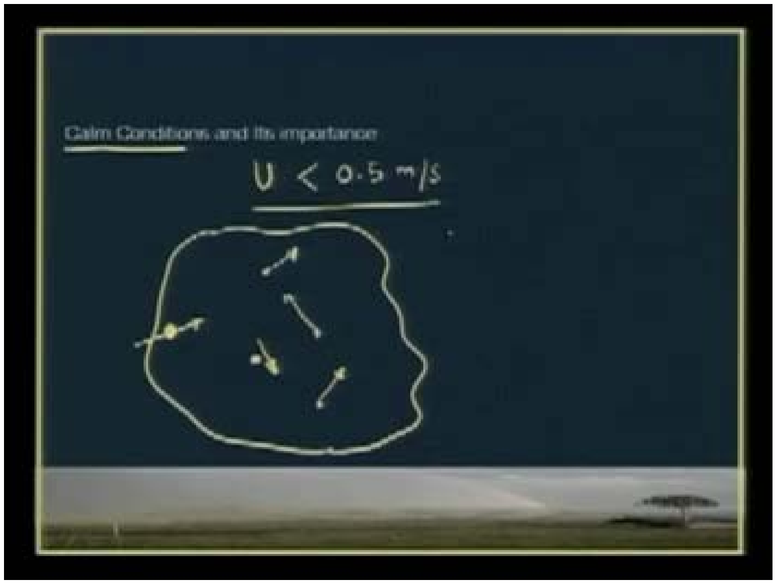

To give this little concept to you – the point number two that I was referring to, let us say the wind was calm, suppose this is your city and you have a pollutant source or chimney or a power plant at this point. Now what happens when the wind speed is low – 0.5 meters per second? It may have some direction but the moment I go at different locations, for example if I go and measure the direction here (Refer Slide Time: 40:16), the direction might be like this. Within a short distance in a city, let us say within 1 kilometer or half a kilometer, you can see the wind direction can change. If I go here, you might see that the wind direction is like this; if i go here, the wind direction may be like this; if i go here, the wind direction may be like this. So, the wind vector or the wind direction can change very quickly when the wind speed is very very low. What does it really mean in terms of the problem?

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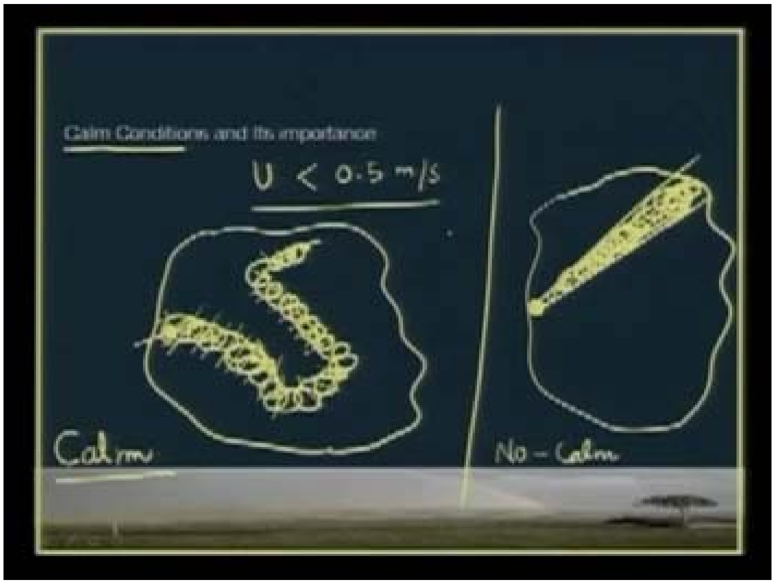

Suppose you had some emission or some kind of accident, pollutants will be emitted and then the pollutants will travel. Since the direction is changing, they travel like this; then the direction is changing and they travel like this; then again, the direction is changing and they travel like this. This will be the path of the pollutants as they travel. Suppose my conditions were not calm (same kind of city, if i could draw it exactly), you had the same location here and suppose it was a calm condition; no-calm condition means wind speed is high and it means that it will have a definite wind direction and the pollutants will travel like this.

The pollutants will just travel in this area because the direction of the wind is constant. When you have calm conditions, you see how problematic it is and how much large area the wind tends to meander as it travels all the way from one direction to another. As a result, you see the population that might be affected because the pollution is large – the number of people that might be affected, whereas in this situation, only a narrow band of pollutants will be there and only a small area could possibly be affected. This is the advantage and disadvantage of calm conditions or the advantage of not having calm conditions, but the problem of calm conditions. So while planning an industry or while making some considerations, people should always think at what percentage of the time the wind is under calm conditions. This gives you the concept of calm conditions. Now, we will move on to the next slide.

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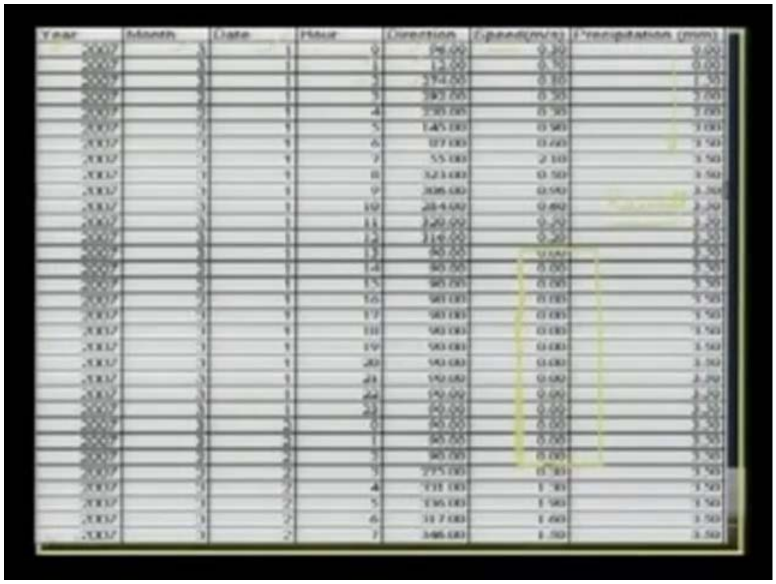

I am showing you the actual data that has been recorded using the anemometer and the wind vane – you can see here the data that we get. The year is 2007, this is the month – month number three is March, the date is 1st March, the hour starts from the nighttime – 1 o'clock in the morning, 2 o'clock in the morning, the direction is always measured in degrees – direction of 96 degrees, 12 degrees, 274 degrees and you can see here that the speed was 0.3, 0.7, 0.8. The interesting thing is that this is a calm condition – we talked about calm so much. This is more than 0.5, so this is not calm. Let us see if you are encountering any wind speed. Again, the situation here is the calm condition (Refer Slide Time: 43:46). Maybe there was some problem with the instrument – we do not know and we need to see that, but certainly the data is screened and shown and it means this is my period that is calm.

Normally, the calm conditions are there mostly in the nighttime – winter conditions, but these results are showing that the conditions were calm even in the daytime – in the day hour. Anyway, as far the concept is there, you understand where the calm conditions are. Also, in most of the stations where you measure the wind speed and wind directions, you will also measure the precipitation or rainfall – rainfall in this case. In fact, I can share with you this data from Kanpur for a wind measurement station installed at IIT Kanpur.

Of course, the data is there but you will find that the amount of data is enormous. Suppose I have to see look at the data of one year from Kanpur, this will be 365 into 24 if I am going just hour by hour – that many data points I will have. To make sense of such a huge data set is very difficult. So what meteorologists and scientists have come up with is a method to summarize the information so that useful, meaningful things can be extracted from the wind measurements that we have done. This is normally what we plot or what we develop.

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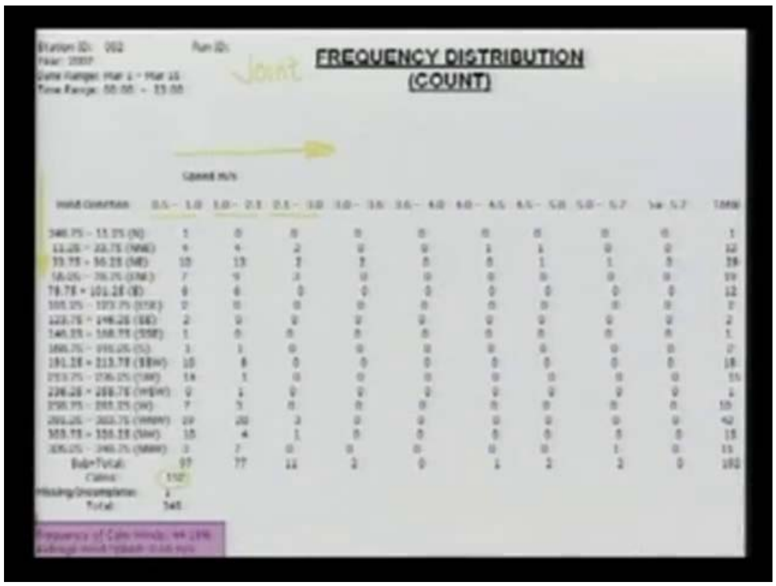

Nowadays, computers do it but what we develop is the frequency distribution and here in fact, we should call it joint frequency. What I mean by joint frequency is on this direction – you can see my arrow, I am plotting the wind direction. Same thing: recall the directions we measured as north, north-northeast, northeast, so here, we are indicating the wind directions. On this side, what I did is I have classified the wind speed into different groups: group number one is 0.5 to 1.0, two is 1.0 to 2.1, then 2.1 to 3.0 and so on and so forth. What will be my count when the wind speed is less than 0.5 meters per second? I will count that as the calm conditions and put it somewhere here. I can show you – yes, here it is, the calm conditions.

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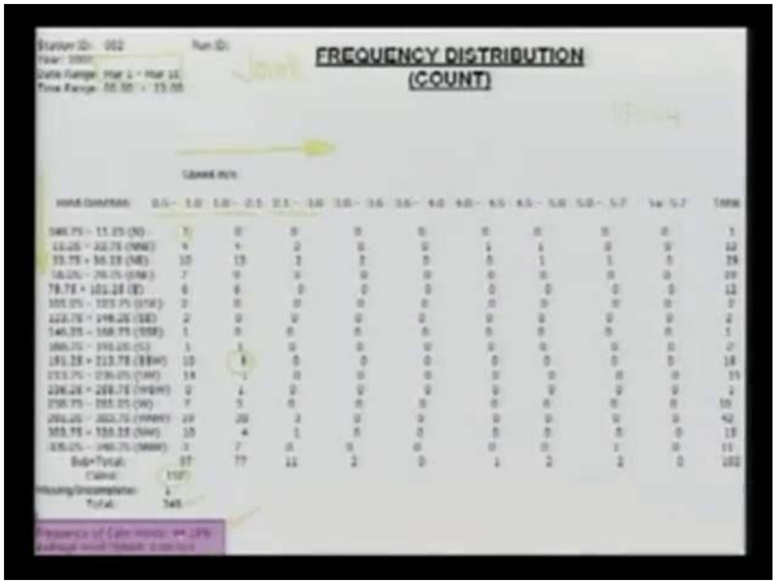

Here, what we have done is that this is the data for March 1st to 15th and we are doing the hourly analysis of the data, so it will be something close to 15 into 24 observations – this will be close to 345 total observations. What we have done here is that for every wind direction, we have seen how many times the wind was in a particular speed category. Suppose my wind direction was north, how many hours was the wind in the speed range of 0.5 and 1.0? It was only one hour when the wind speed was between 0.5 and 1.0 and the wind direction was north. Let us take an arbitrary example, let us pick up the number 8. What it means is that there were total 8 hours in such a way that… go back to this. We will see here what this 8 really represents.

8 shows the wind direction when wind was from south-southwest – there were 8 hours when the wind speed was 1.0 to 2.1 meters per second. How many data points do I have? I had 345 data points but I have converted this into some kind of table. Now the job is still not done. We still need to represent some graphical form – we would like to present some kind of graphical presentation and we will try to make sense of the data. We can also see here that the wind was calm for a significantly high number – 44 percent.

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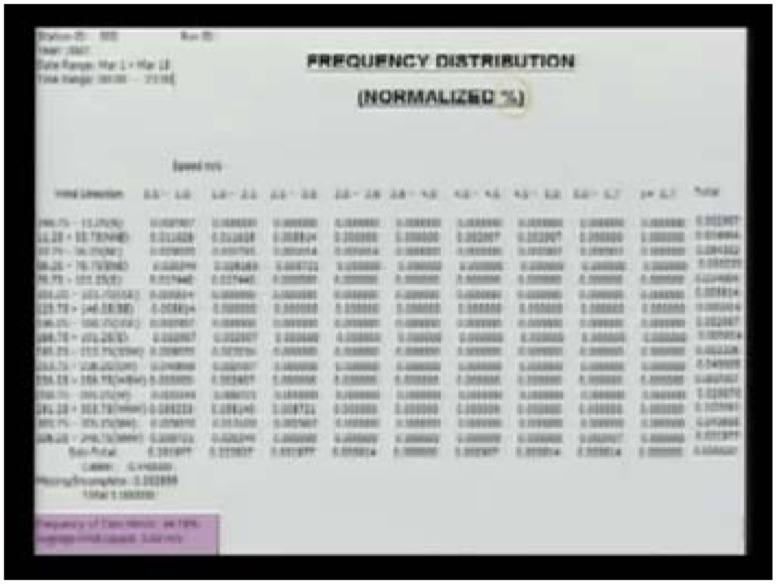

Now, the thing is how we can plot this information. The number of hours are converted to percentage – it is not quite percentage, but it is a fraction.

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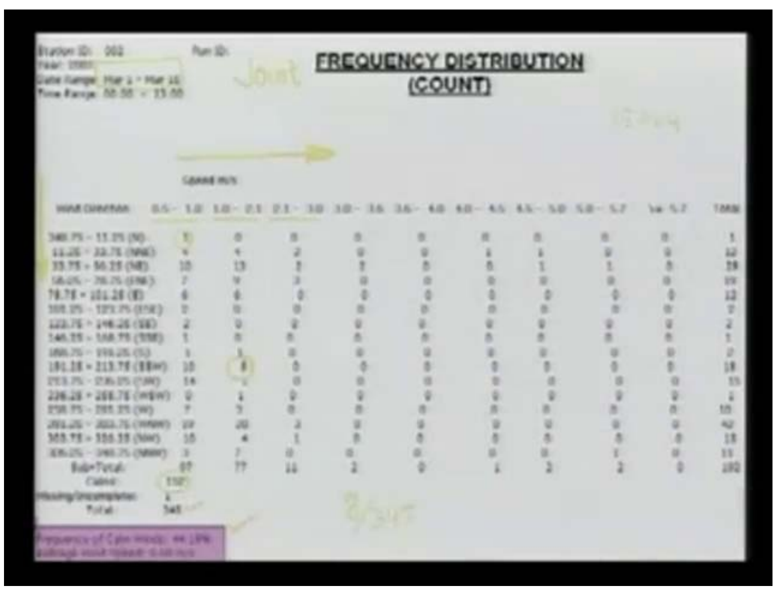

For example if I go back, this was 8. How much percentage of this condition existed? 8 divided by 345.

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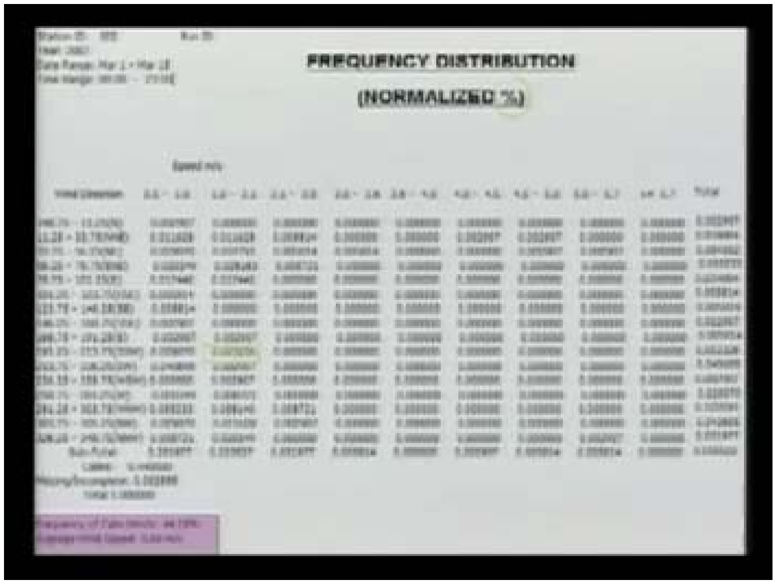

That number will be equal to south-southwest and this. Clear? Now, if I multiply these numbers in the table by 100, then I will get the percentages.

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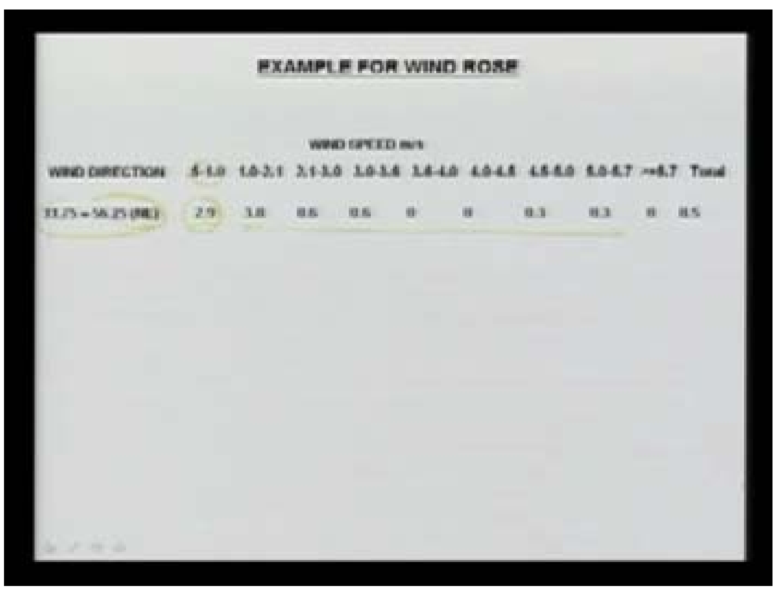

For example, what I have done in the next slide is taken the wind direction as northeast. Let us go back.

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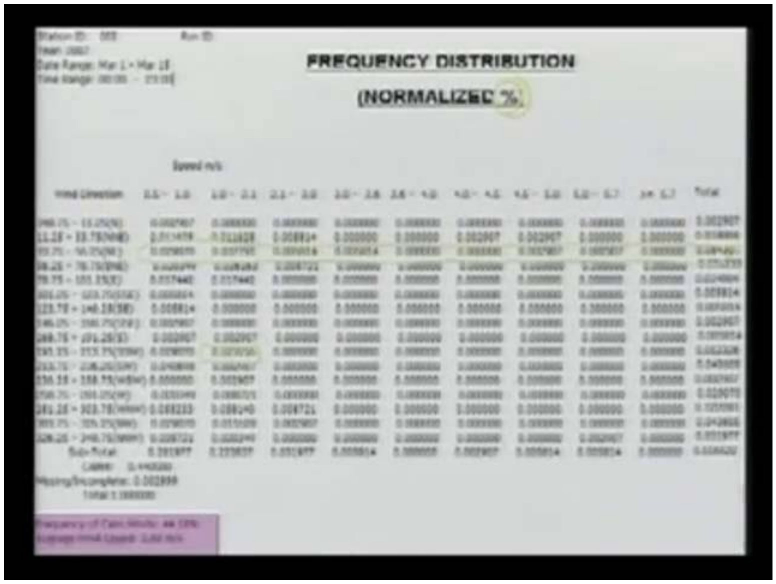

Northeast, I took this data, lifted this data from this table – these data, I multiply by 100 and rewrite them.

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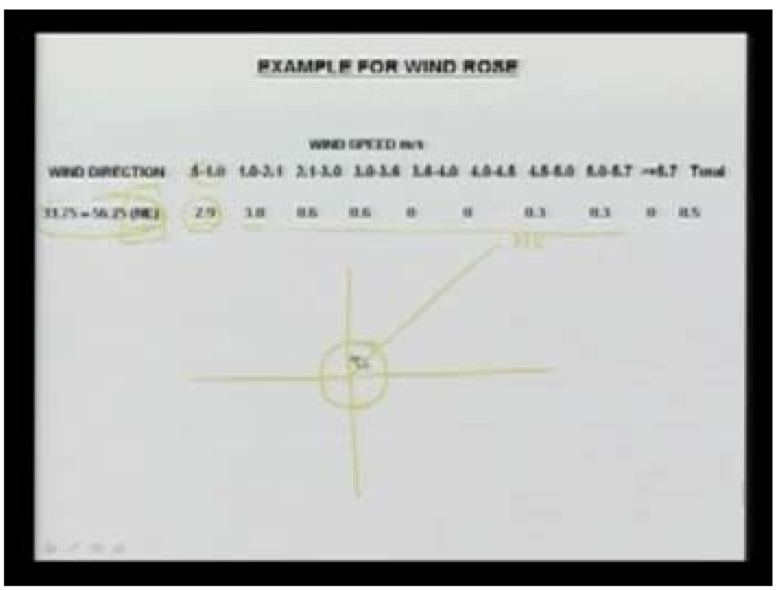

It means that out of all the hours that is my consideration, 2.9 percent of the time the wind direction was this and the wind speed was this. This is what is joint frequency; joint means this as well as this – that is why we call it as joint. We can say that 3.8 percentage of the time, my wind was from the direction northeast and it was in the wind speed range of 1.0 to 2.1 meters per second, so on and so forth. Now, the interesting thing is I must be able to plot it. How do I plot it really is… I will show you for this example. My northeast direction is this because that is what I want to plot, so let me write that this is northeast. Now, remember the calm conditions: the calm conditions were 44 percent. Calm conditions have no wind direction as we said, because the wind direction is changing very quickly. So the first thing we do is we make a circle and write here. I should have this line but anyway, we will see it in a moment.

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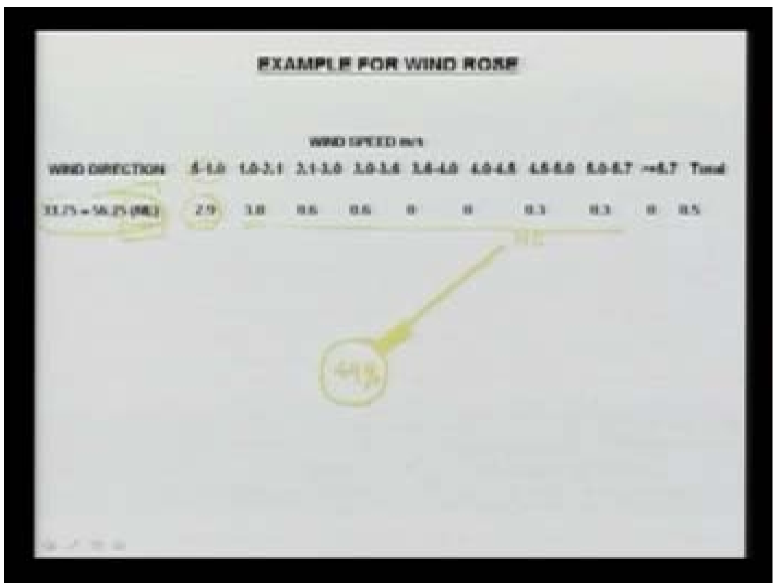

44 percent – that was my calm condition. Now, I am plotting my data to form a windrose in the northeast direction – this is my direction. Now, I go on to the scale and produce 2.9 percent. I can make a scale of this and this is what is my 2.9 percent.

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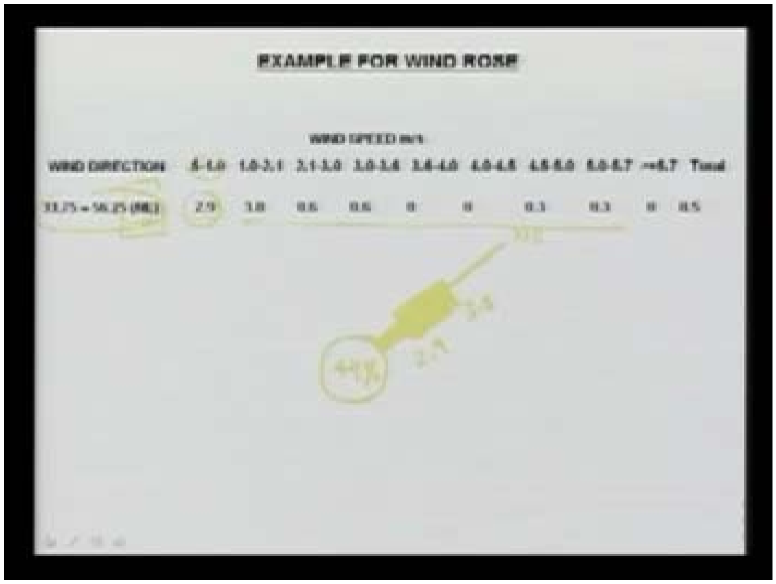

Let us give the next wind class a little different colour. Sorry, we cannot give a different colour but let us make it different; 3.8 percent times, the wind speed was 1.0 to 2.1, so that is a little bigger, I get another block – this is what is my 3.8, this one was our 2.9. After that, again some little.… I will remove this.

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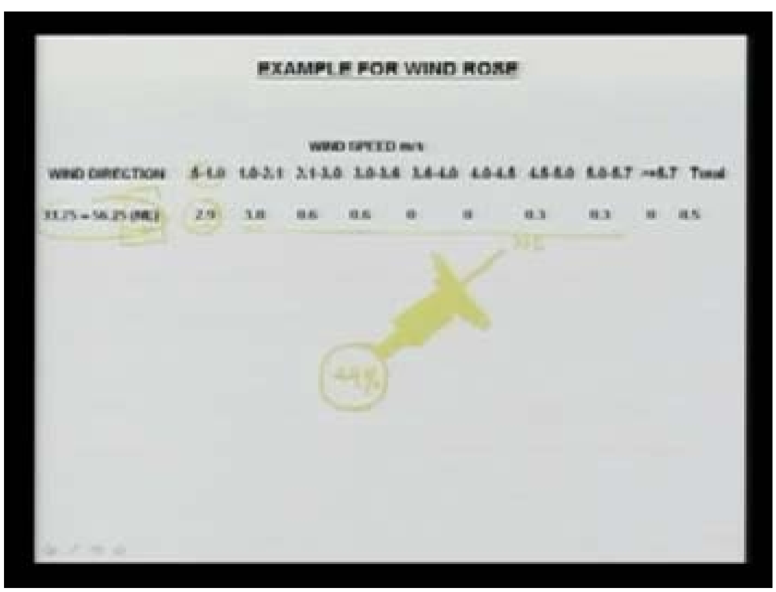

After this again, there is some little 0.6 percent, so a little strip of 0.6 percent; then 0, 0 – I do not plot; then again, 0.3, so I can go here – a little bit 0.3percentage and then again 0.3. I have showed an example only for one wind direction. If we take all the data, we could represent our wind in this way for all wind directions. This is very simple and very interesting. We will show you the final results in the next slide – it looks very colorful and it is very useful.

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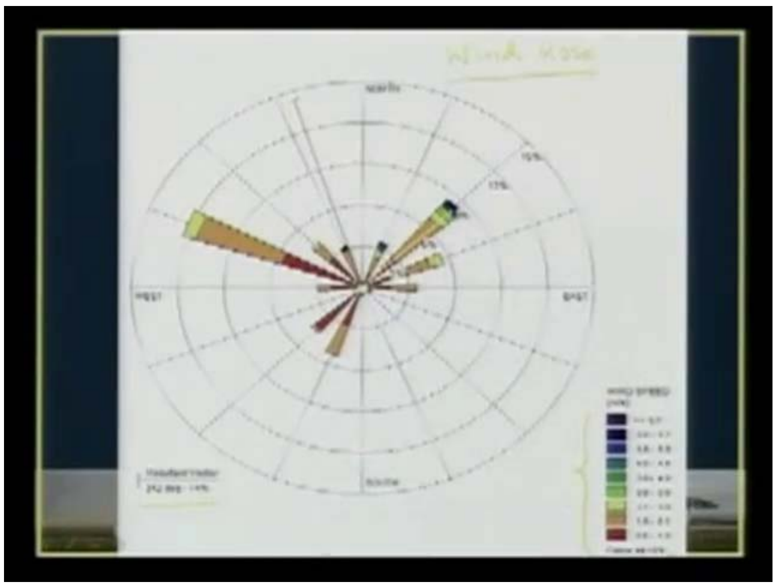

What you see here in the center are the calm conditions and this is what we have now plotted in various directions – what percentage of time the wind was…. We have kind of shown here as to…. This is what I had shown you earlier. This we plotted ourselves – this one (Refer Slide Time: 54:06) in the last thing. You can see here – the last thing we plotted actually but the computer plot will look like this.

Similarly, I can plot along all the wind directions what has been the percentage of the wind speed and then we provide a legend here – you can see here what wind speed. We also provide information on the calm conditions. We also provide the resultant vector – overall, what has been the predominant wind direction and that has been 342 degrees, as you can see here. So all the information that we collected from our machines are finally put into this particular way and then we can learn a lot from this windrose that we have plotted. What is this called? I should have told you before – this is called windrose.

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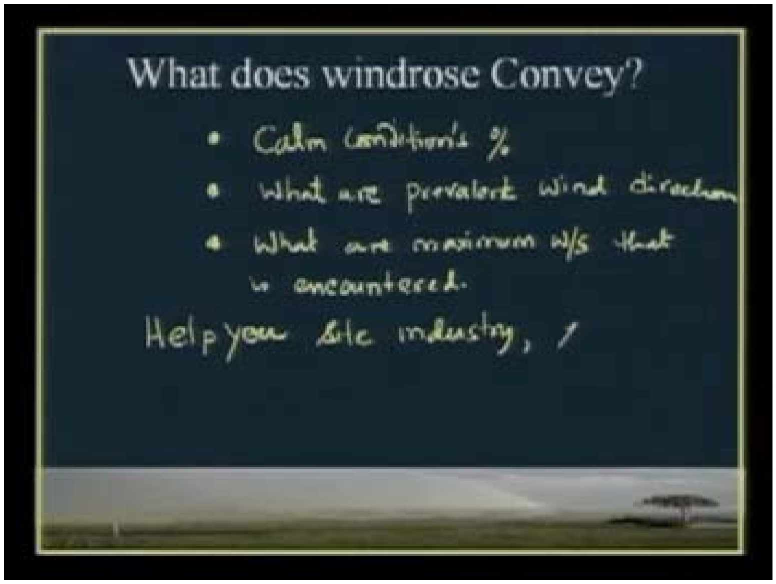

What does windrose convey? I will quickly write. Now you understand what is windrose. It conveys calm condition's percentage – very important thing; it also tells you what are the prevelant wind directions; it also tells you what are the maximum wind speed – let me write that as w/s that is encountered. Very interesting thing and this information can help you locate or site the industry or site your residential colony – very useful thing. Suppose the conditions are largely are calm, then you do not want to have an industry there, because if there is some problem, the pollutants will not disperse properly.

You have seen how useful windroses are. You can plot the windrose for one month, you can plot it for six months, you can plot it for various seasons, you can plot it for the entire year, you can plot it for a decade, you can even see if there is a change in the trend – if the wind direction is changing from year to year or if there has been a change in the wind direction or wind speed suddenly over the decade. That can be very very useful information not only for pollution control or pollution planning but for other studies also. In additon to windrose, pollution control engineers and pollution control scientists also make something called as pollution rose – that is in fact even more interesting.

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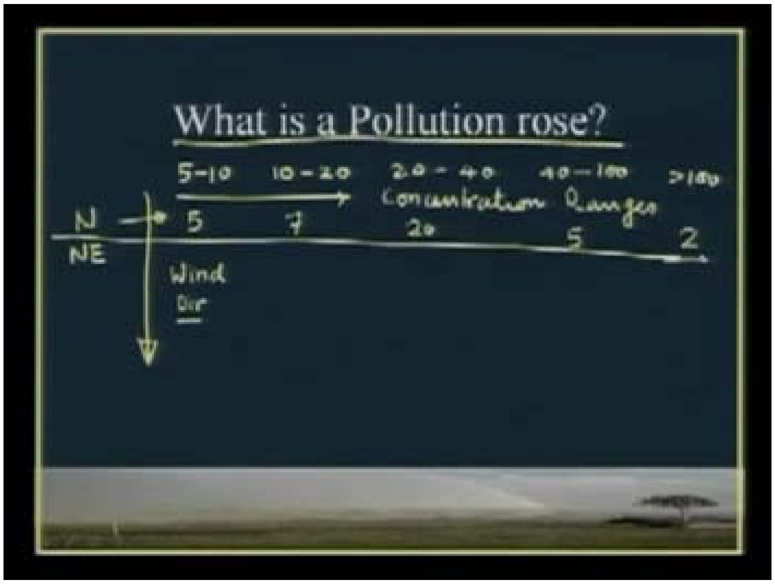

The idea is simple. Just as we did for windrose, we take on this side the wind direction as we have done for the windrose and on this side, we take the concentration ranges of any pollutant. You will recall that last time, we took the wind speed ranges here, but now we can say concentration ranges. Suppose this is my direction north, let us make things little simpler, northeast, and then this side I can take concentration, let us say, between 5 and 10, that side 10 to 20, 20 to 40, 40 to 100 and more than 100 – these are my concentration ranges. Then, I am looking for certain month, for example. So how many hours my concentration…? When the wind was from north, how many times was the concentration range between 5 and 10? Let us say 5 hours in this range, let us say 7 hours in this range and do not forget that we are talking about the wind blowing from north. Let us say it was 20 hours for the concentration range between 20 and 40 and then this is again 5 hours and 2 hours. Once we have this, we can exactly plot it the way we have plotted for the windrose and I will show you actual figure that has been drawn for the Kanpur region.

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You see the pollution rose here and this is Taj Mahal – actually Taj Mahal. Actual measurements were done and then the data were plotted to show the pollution rose. Here the legend you are seeing is not the speed but the concentration ranges – this is the legend here. Then, you can very quickly say that most of pollution to the Taj Mahal is coming from this area, because the wind is coming like this and probably, the pollution is reaching Taj Mahal from this area. You can say that there is almost no pollution from this area, because it is indicating that when the direction is like this, most of the pollutants are brought to Taj Mahal

We can get important decision-making assistance help from the pollution rose. Now, what you can do is you can identify the sources and do pollution control. Similarly, you can also say where there is nothing, even if there is a source here, let us say pollution source, this is not causing pollution, so you can take the decision here. There may be factories or there may be industries or maybe some big source here, for example, the pollutants may also be coming from long distance – that needs to be seen, but the pollution rose will tell you many things. Let me share this actual data taken from a site and you can see how pollution control decisions can be taken just based on simple graphical output that we can generate with very little efforts.

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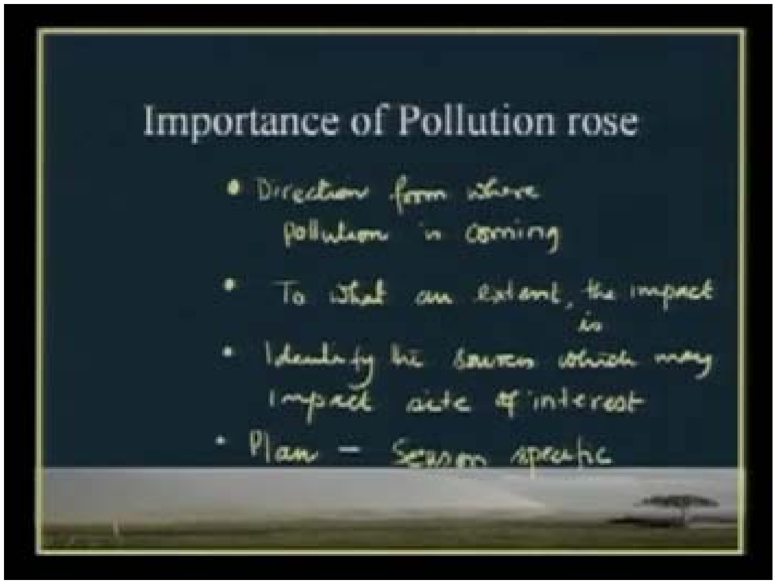

Importance of pollution rose is that it tells you the direction from where the pollution is coming and not only the direction but also to what an extent the impact is. It can help identify the sources that may impact the site or location of interest. You can even plan a pollution control that can be season-specific because the wind direction changes from season to season and so the impact of the sources also change. In winter, most of the pollutants may come from north and in south, they may come from the east. So you can say when it is summer, the pollution sources must be effective from the pollutants that are generated from the south. This way, you can make very useful decisions and can contribute to pollution control.