Elements of Solar Energy Conversion
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Lecture – 03

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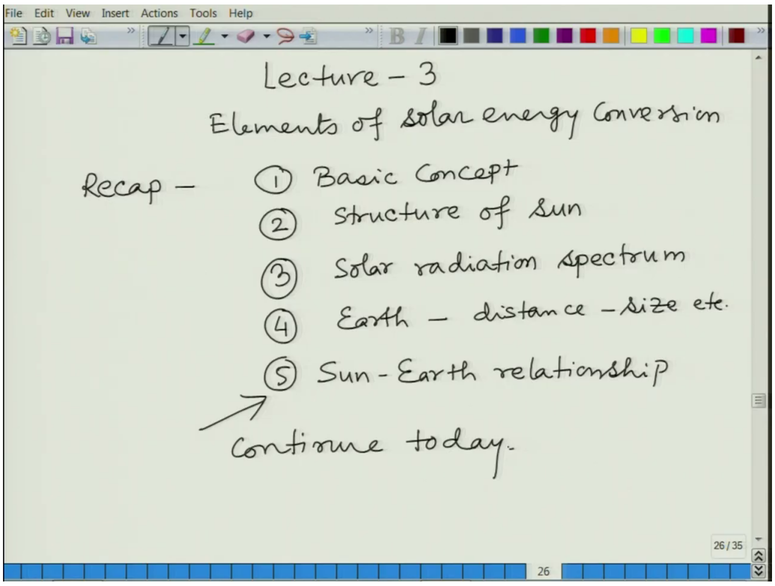

Welcome back this is the 3rd lecture we are in and this is the lecture series on Elements of Solar Energy Conversion; elements of solar energy conversion ok. So we have started in the fashion that we will grow up from the basics. Some recapitulation from what you have learned from your school days.

So in first 2 lectures what we have covered so far are the basic concept related to the solar energy that is coming onto our earth. Then we have looked at the structure of sun ok and we have also looked in detail the solar radiation spectrum ok; the wavelength wise distribution of the whole energy that we are receiving on the surface of the earth.

Then 4th thing we have looked at is the details of earth with respect to the sun ok. Its distance, size, etcetera ok, and at the end of the second lecture we have started to look at the sun earth relationship ok. This we started to look at and we will continue looking at this particular thing today also ok. So we will continue on this ok.

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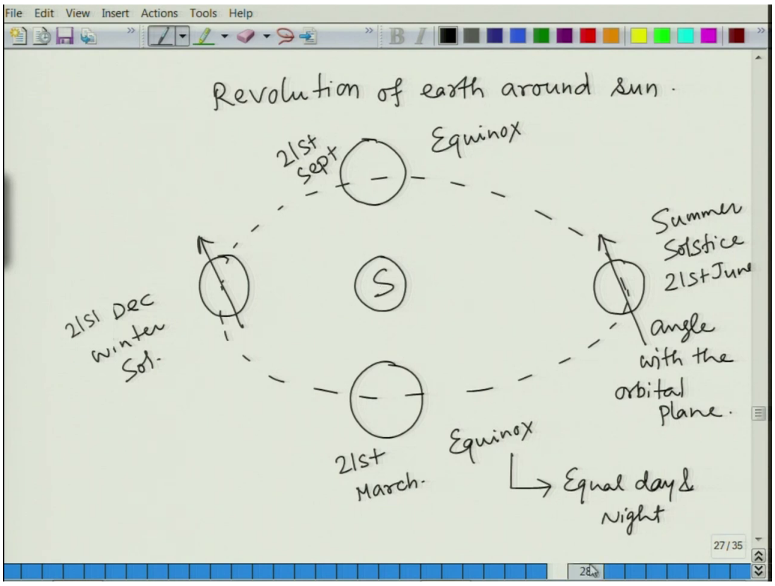

So let us go ahead with that, so in the last class, I have talked about the revolution of earth around the sun ok. And we have seen that earth has an elliptical orbital and we have sun at one of the foci of this ellipse ok. And the interesting part is that here the relative size of the sun and earth look same, but you know what are the relative sizes ok.

So the interesting fact that we discussed is the angle at which the rotational axis of earth is with respect to the orbital plane, so this angle with the orbital plane and that makes everything very interesting. So you have seen and that axis is maintained all the time. So let me just remove this; this whole ellipse is little bit more exaggerated; it is actually only the distance changes by 1.7 percent ok.

And what we have seen that there are few positions which are worth noting. First is the summer solstice ok, which is 21st June and summer means the northern hemisphere summer, which is winter in the southern hemisphere and 21st December is the winter solstice and 2 equinoxes that we have, this is 2 equinoxes that we have. One is the autumnal equinox, which is 21st September and the spring equinox which is 21st March.

Equinox means, this equinox means equal day and night ok and the solstices they stand for the maximum or minimum day length ok. For summer solstice, we have the maximum day length on 21st June and 21st December, we have the minimum day length, which is the winter solstice ok. This we have looked at this was sun and these positions we have looked at.

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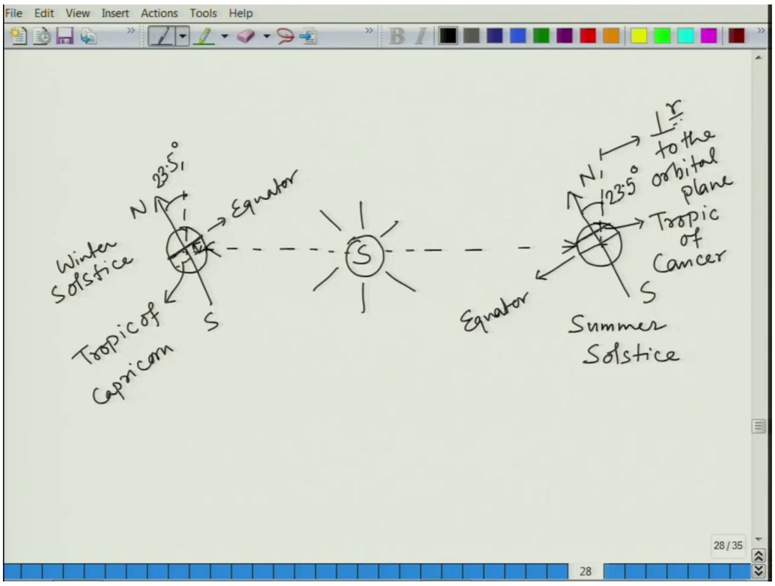

Now if we extend this little further and we just zoom in the 2 solstice point ok; so let us do that. So solstice point, they are exactly opposite to each other ok. And if this is our sun and this is our summer solstice right and we have this axis which is tilted to the orbital plane by. So if this is the perpendicular to the orbital plane, this tilting angle is 23.5 degrees ok, 23.5 degrees.

And similarly, the tilting angle does not change. It is again 23.5 degrees approximately; again we will see exact value of it in a hope, in a bit ok. So this is the winter solstice. So you can see here that where the sun ray is actually reaching normal to the so if this is the equator. So the sun ray that is reaching normal is here right, so if we say this is the tropic that we get ok. So this is called tropic of Capricorn ok.

So this is the maximum distance, this particular distance is the maximum distance from the equator, if you go south, that the sun will radiate normally ok. Beyond that it will not radiate normal to the, I mean normal to the plane. So here also in summer, what we get? This is the equator ok, so this is our equator and the normal radiation happens here right.

So if we draw a line corresponding to that which is nothing but a circle around the whole earth and this particular line is called another tropic; but now it is tropic of cancer ok. So what we get here is that, due to this tilting of earth rotation axis with the orbital plane of its revolution. We get two extreme limits, one in the northern hemisphere and another in the southern hemisphere beyond which sun never radiates normally.

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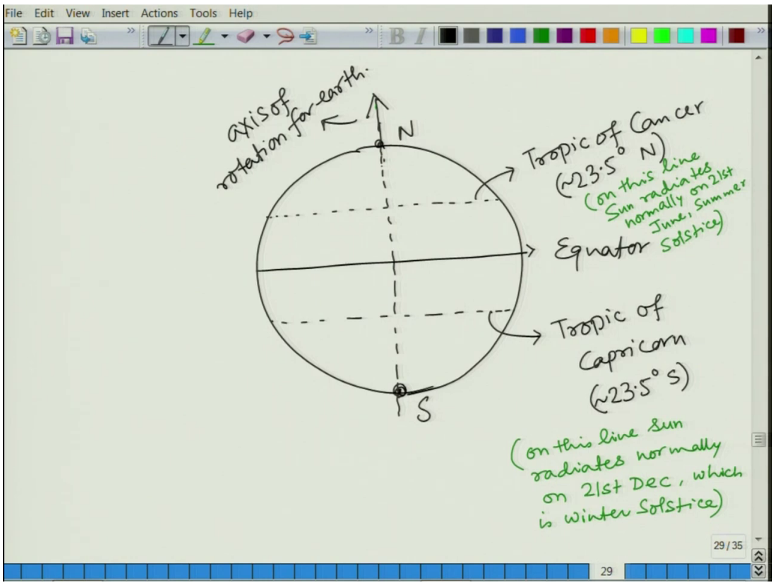

So if we look this closely, let us say this is our earth ok and let us say this is our equator. This line is our equator, which is again a circle around the earth. So now if we draw this normal to the equator, then the poles are actually, so basically if we say these are the poles. One is North

Pole; the other one is South Pole. Then what we get? Due to this tilting angle, we have 2 lines which are equidistant from the equator.

This one we called tropic of cancer ok, which is actually designated by this 23.5 degree north latitude. So this latitude, longitude will come in a while, and in the south hemisphere we have tropic of Capricorn and this is 23. Again, let me stress that this is approximate value. It is not exactly 23.5 ok.

But for easy remembrance you can use this value. So this is tropic of cancer and tropic of Capricorn. And what it says? This tropic of cancer let me use the another color. Tropic of cancer on this line; on this line sun radiates normally, normally means perpendicularly that you know.

Sun radiates normally on 21st June, which is the summer solstice ok. And on the other direction we have this tropic of Capricorn. On this line sun radiates normally on 21st December ok, which is the winter solstice ok.

So yeah, and this north south let me use the color, previous color, so this north south. This is the axis north south the pole joining line is the axis of rotation for earth which determines the day and night thing ok. So that is the first thing that we need to look at.

And now what we will do? We will look we will actually designate few reference frames from which we need to look at the sun and the motion of the sun. And for that, what we need to require is changing these reference frames and the interrelation between these reference frames ok.

So that is what we are going to look at in the next ok. So first thing the most intuitive thing is that just close your eyes and imagine; that you are standing in the middle of a big round very flat big round you are standing in the during the daytime and you are looking at the sun. So you are the observer and sun is the observant that is what you are looking at. Now we will fix our reference frame with you ok. So let us do that.

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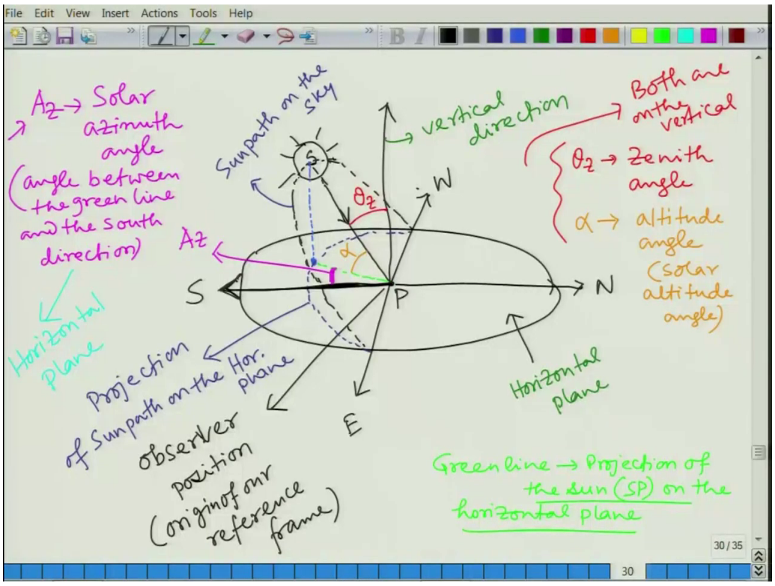

So let us say this is the plane of the ground on which you are standing ok. So basically, this is circular and we have to draw it like this. Because we want to look at the three dimensional view and the middle of the circle at the center you are standing. So here is the observer position ok. So now whenever you are standing you can define the north, south, east, west from wherever you are standing ok.

So let us say that this is the north direction ok, so exactly opposite would be the south direction right. And here on the perpendicular line we will have east and the other direction will be west right. So this is on the plane of the ground. Now what we want? We want to observe the sun ok.

So let us say we have sun somewhere here in the sky ok. Let me animate this little bit, so this is our sun position in the sky ok. Now if we look at the ray that is coming normally to your eye that is the ray. So that will give us the solar position location, because you are looking directly towards the sun ok. Now you can think of rectangles.

First is to look directly to the sun how much inclination you have to have keep your eye at? So from the horizontal level, how much you have to look up to look at the sun? So that is the angle that we are interested in and what is that angle? Ok. Let me just say before I say this because I expect that you will learn along with me in this course and to build up intuition, you will actually do the things that I am suggesting ok.

So then you may get into trouble if you go and directly look at sun; you your retina of your eye may get damaged, so please do not do that. And I will take this opportunity to distract a little bit. Looking directly at the sun is detrimental or damaging to your eyes all the time. It is not only for the time of eclipse, ok.

So there are lot of these taboos during eclipse. You should not look at, you should not eat and all those things. But the rays that are coming from the sun, it is nothing different from the from a normal time to that of eclipse. What is different? During eclipse the total amount of radiation that is coming to your eye is much much less ok. That is why you can keep looking at it ok, because the total intensity is much less.

So as you can keep looking at it the major radiation that is coming is directly going into the retina and that is detrimental. And that is why people say that you use some specified glass through which you can look at the observe the eclipse ok. So for the normal sun, any sunny day if you look at the sun, it is as damaging as any other day, including eclipse. But the problem is you cannot even look at it, because it is so bright even on a cloudy day.

It is so bright that you cannot even look at it. That is why people particularly tell about the eclipse point. Anyway, that is a little distraction, but these intuitions you need to build that is the knowledge ok. So not the information that I am giving you, but the intuition that you are building up from the course, that is what I am looking for ok. Now if you think of this, that sun is actually moving from east to the west when you are actually in a diagonal circle.

So if you can think of that there is a certain path which is following the sun is following. Of course sun is not moving the apparent motion of the sun. But more often than not, I will use sun is moving because that is how we are going to look at it ok. So this particular circle or semi circle that I have drawn here is the path of the sun during a day ok.

So now we have two planes and this particular this is the let me use different color, so this is the horizontal plane right. The big round that I told you to imagine and now we have on top of this we can draw the vertical direction ok. So this is the vertical direction that is exactly perpendicular to the horizontal plane.

Now you can observe that you can draw or you can drop a projection of the solar position on the horizontal plane right. So before you draw that projection, what you can do? Let me just delete this. I have deleted the sun as well ok. So this solar path circle that I have drawn, so this is the sun path on the sky.

So we can project this semi circle on the horizontal plane also right. So let us say this is the projection of this particular sun path on the horizontal plane. So this is the projection of sun path on the horizontal plane ok. Now what you can do? Now if you drop a perpendicular of the sun position, you will find a point on the horizontal plane ok.

So basically this is the local point at or the instantaneous position of sun, if you drop a projection at the moment when you are looking at the sun right. So from here what we can do? We can connect this particular point to the observer position that is your position ok.

And so here you can see that there are two very important angles that you see from this figure. One is the ray that is making with the vertical line ok. So this angle, we call this angle the zenith angle ok, theta z is the zenith angle ok. And the other major angle that you see here is this angle. The sun ray that is making with the horizontal plane and that is called sorry that is not the one ok.

Yeah. So this angle is called alpha and this alpha is called altitude angle ok. Or we I mean the alternative term is solar altitude angle often we omit the term solar ok. This is solar altitude angle. Why it is called altitude? Altitude means height right. So the observer he has to look up by certain angle to look at the sun right. So that is why we call it altitude angle. Now another angle we can observe here which is on the horizontal plane ok.

What angle is this? This angle which is the projection of the sun ray; so this green line that you see in the diagram that is the projection of the sun ray; so let me just name this so that its easier, so this is P ok. So projection of the sun ray sun ray is what that is the SP line in the diagram that we see that is the SP line ok.

So if you project that on the horizontal plane, that is the green line. Now this particular this angle we call A z or this is solar azimuth angle. Why it is called solar azimuth angle? Because we are taking the projection of the sun rays which is the green line and what is this is the angle between the green line and the south direction right.

So if you look at this angle, this is angle on the horizontal plane and the angle is between the green line here; which is the projection of sun ray on the horizontal plane right. Projection of sun ray on the horizontal plane and the south direction so this is the south direction and that is what we call this solar azimuth angle.

So from this figure we are understanding three very important angles which we are going to use N number of times in this course. So please pay attention and I would rather insist that you close your eyes and try to visualize this whole picture. Because on a two dimensional plane of paper we are drawing a three dimensional figure, so these angles are difficult to visualize.

So please try it give it a conscious effort to visualize these things ok. So these 3 angles if you can see that this zenith angle and the altitude angle both are on the horizontal plane ok. So both of these both are sorry, this is not the horizontal plane but vertical plane ok. So both of these angles are on the vertical plane and the other one so the solar azimuth angle this is on the horizontal plane ok.

So this is a very important figure where we have taken the observer at the origin of the reference frame ok. So here the observer position is the origin of our reference frame ok. And the horizontal plane is what we have and the vertical direction ok. And we have determined the solar position by 3 angles. One is the zenith angle, how much the sun is tilted from the vertical line ok.

And then solar altitude angle, how much you have to look up to look directly at the sun. And then solar azimuth angle, it tells you wherever the sun is if you drop a projection directly on the horizontal plane, how much that would deviate from the south direction, so that is your solar azimuth angle ok. Now let us change the reference frame itself ok, look at the same thing.

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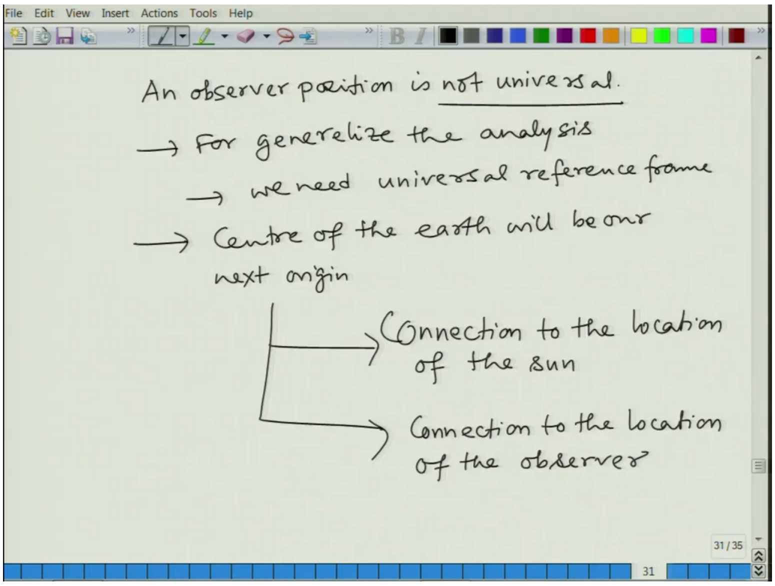

But let us change the reference frame itself because observer position, why we need to change the reference frame? So an observer position is not universal. What do we mean? That we cannot just tell that I am staying here at Kanpur and you are staying maybe at Chennai.

So we do not have the same sun position, so I cannot simply define any angle which is fixed to me, the observer. So we have to generalize it to any location, so that is the point what I mean by not universal.

So for generality, so whatever analysis we will do that has to be general that has to be applicable to any location on the earth. So to generalize the analysis we need universal reference frame and what is more universal than the center of the earth right. If we take the center of the earth that same for you and me wherever you are so that is the next reference frame we are going to take the center of the earth will be our next origin ok.

So from there also we now, when we take the center of the earth, we need two connections. One is how sun is located with respect to the center of the earth. And another connection is how the observer is located with respect to the center of the earth. So two connections that we need to make here.

One is connection to the location of the sun and the other connection we need to make is connection to the location of the observer ok. So let us do that. First thing, the easier thing or more familiar thing is the location, I mean connection to the observer.

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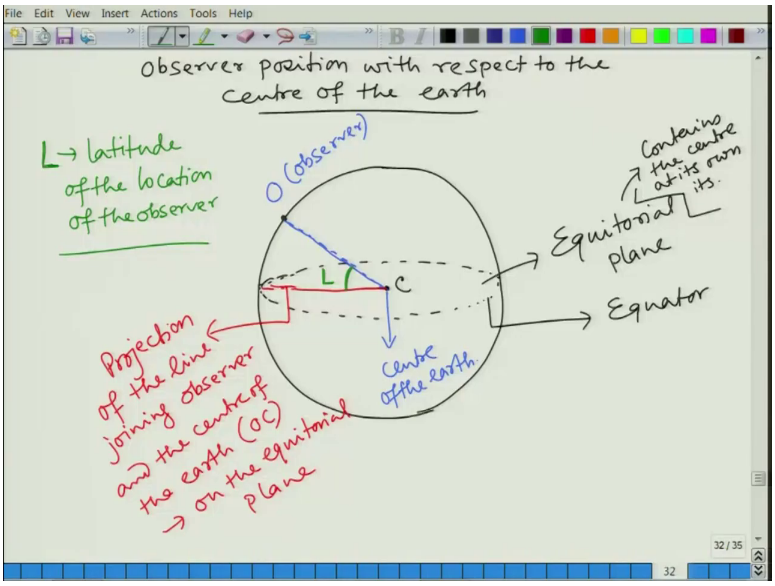

So observer position with respect to the center of the earth that is what we are going to look at ok; so let us say that we have our earth which is spherical and you are somewhere here ok.

So now the center of the earth is here, so you can draw a plane, or you can draw the equator itself, which will give you the equatorial plane ok. So this is the equatorial plane ok, and this particular line itself is the equator ok. So center of the earth is actually on the equatorial plane.

So this one it contains the center as its own center right. So, equatorial plane itself is a circular plane so the center of the earth is same as the centre of the equatorial plane ok. Now, if we want to designate your position with respect to the center of the earth. We need to find out what angle do you make with the equatorial plane? Ok. So first what we did? This is the let me just write this is the observer and this is the center of the earth ok.

Now you just join the observer position to the center of the earth ok. Now let me just delete this and use a different color. So now you project this line, so this line is nothing but projection of the line. Sorry, let me name the center of the earth as C ok. So this particular red line is nothing but the projection of the line joining observer and the center of the earth, which is the line OC ok. So you are projecting this where you are projecting this on the equatorial plane ok.

Now the angle that line OC is making with the equatorial plane, which is this angle. What angle is this? You know this right this is the latitude, so we designate it with L. So L is nothing but latitude of the location of the observer ok. So these things you have learnt in your school days, but these all of these should come very intuitively when you think of a solar energy conversion problem or an installation issue ok.

So where are you? Latitude is important and to uniquely locate the observer position. What else do you need? Again you notice right, this is longitude that you need. So I will use another figure to show you the longitude because it is difficult to show it here ok. So in this figure we have learnt what is latitude and that gives us one of the metrics for telling you the observer location with respect to the center of the earth.

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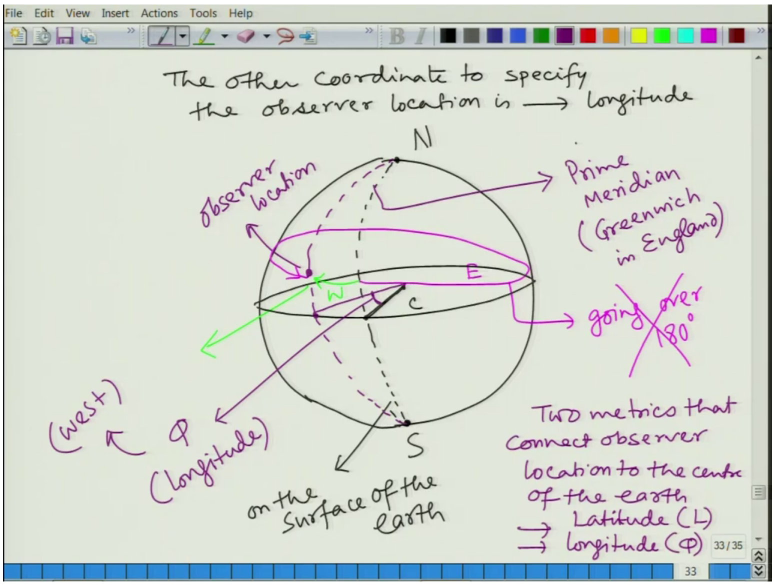

Now the other coordinate to specify the observer location; location is we just talked about it that is the longitude right ok. So what is longitude? Again let me just draw the earth and now it is mandatory that you have to imagine it as a sphere. Otherwise, it is difficult to visualize, so this is the center of the earth again C and now these are 2 poles.

This is your North Pole and this is your South Pole. Now what you can do? You can draw a line joining this North and South Pole cutting not cutting but on the surface of the earth ok. So this is on the surface that is the important part. Now how many lines can you draw? You can draw infinitely many number of lines right, you can draw as many as you want. Like let me draw couple ok, let me use another color for this.

Maybe this is looking like a cricket ball now right ok. So let me draw two of them, why I am saying that right now. So you can draw as many lines as you can joining the two poles on the surface of the earth. Now one line I have drawn which goes through the observer, so this is the observer location. Now, to specify where on the surface of the earth the observer is, we need to have a benchmark.

We need to have a line which is fixed for everybody, then only we can say with respect to this line we are either east or west ok. So what is that fixing line? That fixing line we call the prime meridian ok. So let us say this is the prime meridian ok. And as Europeans started to looking at this critically first, and that is why they had the monopoly of deciding which line and this prime meridian goes through the Greenwich, which is near London ok in England.

As they first did this fixing of this line that is why they could fix it to their location; It is there is nothing sacrosanct about Greenwich but just an arbitrarily determined. But once you determine that serves the purpose of your line that will give you the reference frame. Now you can see that this particular observer.

Can you say that whether it is east or west? Because if you go from this prime meridian in this direction it is west right, but you can as well come all the way round the earth and reach this location. You can say this east right because it is a ball you can come from either side.

So what we say that ok, we have to fix what is east and west and that is what we are not allowed to cross 180 degree ok. So for this line you are going over 180 degree right. More than 180 degree and that is why it is not allowed, so this is east and this is west ok. So, for this particular example, what we can say?

This particular angle that it makes, so we can now say so suppose this is our. So suppose this is our equatorial plane that we can cut through the earth and this particular prime meridian is cutting the equatorial plane at this point and we can connect this point to the center of the earth.

Similarly, the meridian that is passing through the observer location that also we can connect to the center of the earth at the equatorial plane ok; now the angle it is making these 2 meridians this is our longitude right; so this angle and that longitude is designated as phi ok, so this is the longitude and here we can see with respect to the prime meridian, this particular location is towards the west.

So this is what we whatever angle it is, we will call this is phi degree west. That would be the latitude longitude. So this is towards west ok. So now we have two quantities, one is latitude, so two matrix that connect observer location to the center of the earth ok. And this is one is latitude which is designated as L and the other one is longitude, which is designated by phi ok.

So now what we have two quantities that we have which completely tells you where on earth you are located, which are given by latitude and longitude ok. Now we talked about that let me go back, so here we have looked at that ok. This one is now done this we found out what would be the metric to connect them. Now what we are now going to look at is this one ok.

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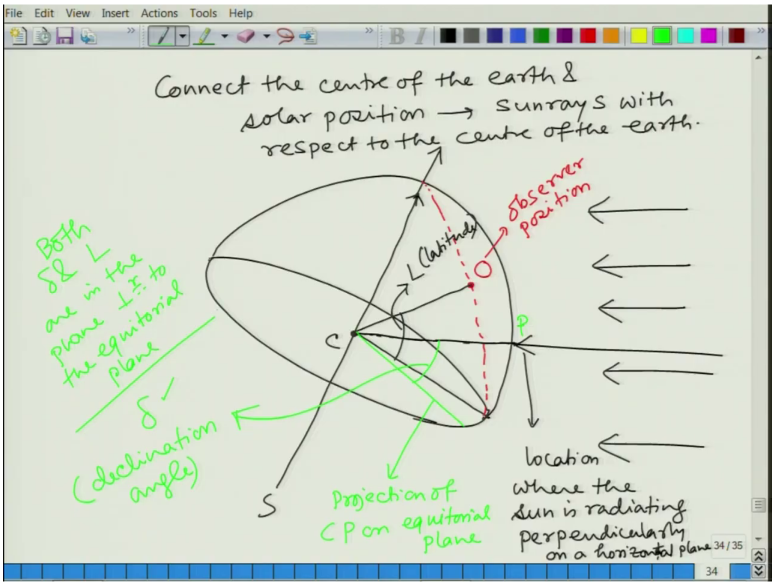

So now we are going to connect the center of the earth and the solar position, or rather the sunrays with respect to through the center of the earth ok. So now you have to imagine again that sun is a very big and very distant source of radiation right. And with respect to that, earth is very small, so whatever we have that you will also learn in your school days, that for a distant light source, you can assume all the rays are parallel right.

Even if they for a point source it is going away all the direction, but for a distant source you can assume them to be parallel and here also you have to see that the rotation axis of the earth is actually tilted to the orbital plane. So now, as we are connecting to the sun, we need to draw it in little bit tricky way.

Let us say that this is the tilted axis that we have and this is the center of the earth and we have an equatorial plane which is like this. And we have we are drawing half of the earth. So that it is easy to visualize and we need to see the equatorial plane. That is why we have drawn the half circle ok.

Now you can assume that the sun rays are coming all parallel from this side ok. So now you can always find one sun ray which is directly connecting from the centre of the sun to the center of the earth right.

So what that sun ray will be? This would be the sun ray that is connecting directly to the center of the earth ok. So this is the location where the sun is radiating perpendicularly right perpendicular to the horizontal plane, perpendicularly on a horizontal plane ok.

Now if you now you can always draw a line on the equatorial plane which is the projection of; let me say that this is the meridian that is actually holding the observer position. Let us say this is O; observer position ok. Now if you connect this center of the earth to the observer location and then drop line or drop a projection on the horizontal plane, ok. So this angle is your latitude right.

So this angle is your L, which is latitude clear. Now you can also drop, so this is the direction of the ray that is coming directly from the sun. Now you can also drop a projection of this line on the horizontal plane ok. So let me, so let us say that this is the projection. What is this?

This is the let me also name this. Let me say this is perpendicular point. Let me say P, so this particular green line is projection of CP on equatorial plane ok. So now what we have? We have two angles; one is projection of ok here yeah, this angle the projection of this line with the equatorial plane.

This angle is called delta or declination angle. So remember what you are doing? You are projecting the line which is coming perpendicular to the face of surface of the earth to the equatorial plane. So this CP line is projected on the equatorial plane and the angle that particular line is making with the equatorial plane is your declination angle ok.

And from the observer, whatever angle it is making with the equatorial plane, that is your latitude ok. And another thing here you can also look at that for the all these angels are on the plane perpendicular to the equatorial plane ok. So both delta and L are in the plane perpendicular to the equatorial plane. That is a very significant point you should notice and remember ok.

So with that, I stop here for today and we will look from this declination angle how it varies and all in the next lecture.

Thank you for your attention.