Digital Elevation Models and Applications
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Lecture - 18
Applications of DEMs in Solar and Wind Energy Potential Estimations

Hello everyone and welcome to Digital Elevation Models and Application course. And this is the 18th lecture in which we are going to discuss how Digital Elevation Models can be used for a estimation of solar and wind energy potentials. This is very very important derivatives one can have using Digital Elevation Models. So, these in these 2 energy sources solar and wind, how these we can employ, we will be discussing very briefly here.

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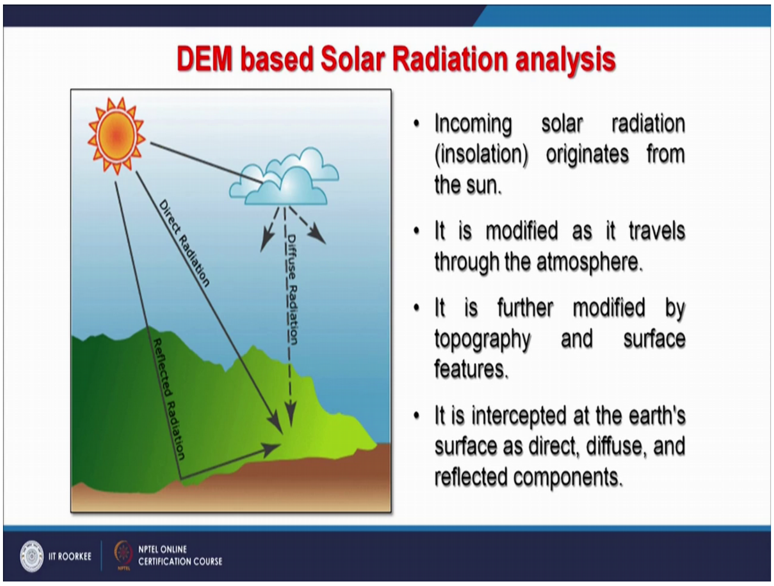

As we know that the and the sun solar radiation that may reach to the earth surface directly or maybe through diffuse radiation and may be through the reflected radiation.

So, if this is the location on the surface of the earth. Then, the radiation can reach through 3 ways; that is the Direct radiation, Diffuse radiation and Reflected radiation and they also, they say we use the word insulation for the incoming solar radiation. So, whatever the radiation which is coming through whatever the sources is all combined in form of insulation.

So, we call as Incoming solar radiation or insulation that originated from the sun and as we know that it gets modified while it is travel through the atmosphere because between the earth's surface and the sun, there is a atmosphere which modifies this solar radiation to some extent. But even then a large amount of solar radiation reaches to the earth surface.

And this may this insulation may also get modified because of topography and surface features. Topography in a hilly terrain; insulation is completely different than in a flat areas like indo gangetic plain and also surface features like maybe vegetation, forest, water bodies and so on. And also it might get intercepted at the earth's surface as direct diffuse or reflected components.

So, but the estimations which we are going to make about a solar radiation or for solar energy may combine the entire complete insulation that all 3 components.

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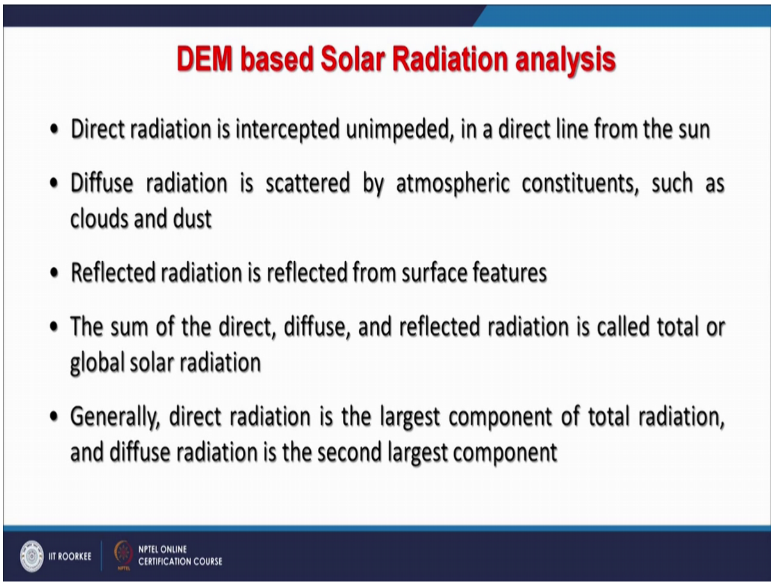

So, as we know that direct radiation it intercepted. So, as we know that direct radiation it intercepted unimpeded, in a direct line from the sun. That is the direct sunlight where is reaching. Direct solar radiation will reach diffuses scattered by atmospheric constituents, may be such as clouds or dust or other materials which are present in the atmosphere; some gases can also diffuse the radiation. Whereas, reflected radiation is from the surface features and especially this reflected radiation we get in a in a hilly terrain or areas which are having taller buildings.

There reflected radiation a component is much more in insulation. And this the sum of this direct, diffuse and reflected radiation as I have been saying is or we can call as a global solar radiation or total basically, total solar radiation. And generally, the direct radiation is the largest component of total radiation; diffuse radiation is the second largest component and the third one which is the reflected one, will have the very little in that consense.

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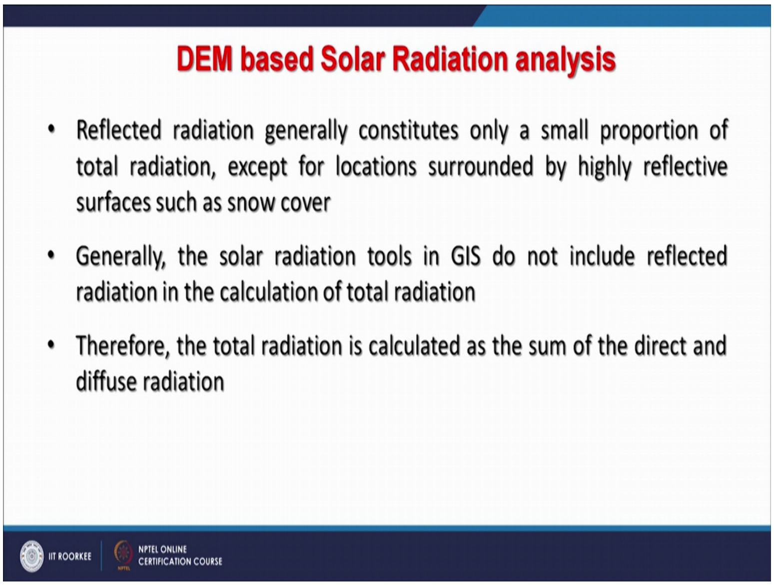

So, reflected radiation generally constitutes only a small proportion of the total radiation which is reaching to the earth except for location surrounded by highly reflective surfaces such as snow cover. And you know that the snow cover areas where you are having glaciers of fresh snow, the solar radiation because of reflection is very high. And the therefore, it people wear goggles to reduce that radiation reaching to their eyes; otherwise, it is very harmful.

So, generally this solar radiation calculations can be done on a GIS platform. The main input is going to be again a Digital Elevation Model. But, what it will calculate? Not all three components, but only the total radiation component will be calculated. And therefore, the total radiation is as we have discussed is the sum of all three components.

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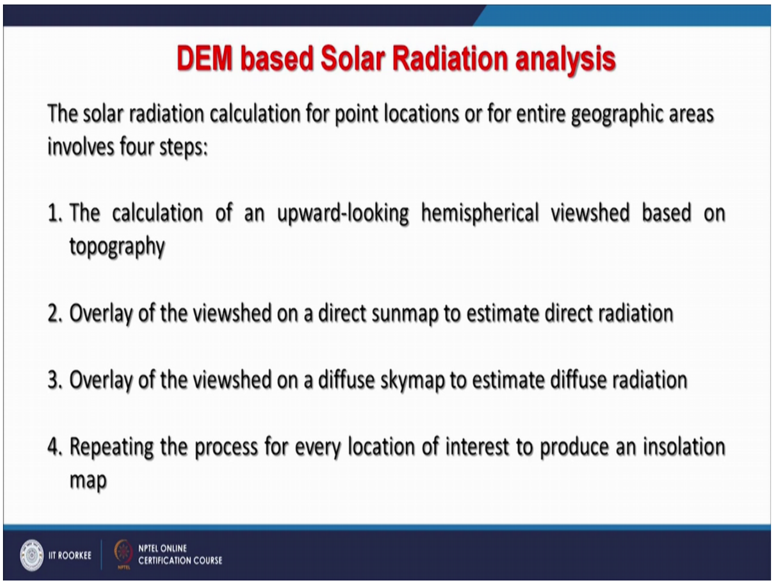

Solar radiation can be calculated for a point location or for a entire given a Digital Elevation Model or area.

Now, there are 4 steps which involves. While, calculating solar radiation based on a Digital Elevation Model and that is the calculation of an upward-looking hemispherical view shed based on topography. So, far we have not discussed the typical viewshed analysis which is based on digital elevation model, but this view shed which is used in case of solar radiation is little different that is only upward one. The viewshed analysis which we will be discussing in future lectures is a not really a upward, but looking along the horizon.

So, there are 2 different kinds of viewshed; one is for solar radiation looking upward, another one is looking along the horizon. So, in the first step is the calculation of upward-looking hemispherical viewshed based on the topography. How? Basically what does it mean here is the how much sky is available to us? Because that will allow us to understand how much solar radiation will reach?

So, if I am in a valley in a hilly terrain; then, the sky which is available to us is a very small. If you if you know the sky plot in case of a global positioning system or these navigation systems. So, if we are in the valley our sky plot will have on a these satellites, only along a line or along a valley. And therefore, our signals reduces same thing here that this hemispherical viewshed will be very restricted if I am in a valley.

But if if I am on a mountaintop; then, I the entire sky is available for solar radiation to reach to that point. So, therefore, this view shed analysis hemispherical upward-looking viewshed a step is very much important and towards the solar radiation analysis. The second one is the overlaying this viewshed on a direct sunmap to estimate the direct radiation. So, this sunmap can also be calculated using digital elevation models.

Then, overlaying of this viewshed on a diffuse skymap to estimate diffuse radiation and the fourth step is repeating the process for every location of interest to produce an insolation map. And this, I will show you some example. As we know that since radiation can be greatly affected by topography; especially, this is hilly terrain versus plain area and some surface features may be vegetation, may be snow cover and ice glaciers.

So, the key component of calculation of algorithm requires the generation of an upward-looking hemispherical viewshed; that is the first step for every location in a Digital Elevation Model.

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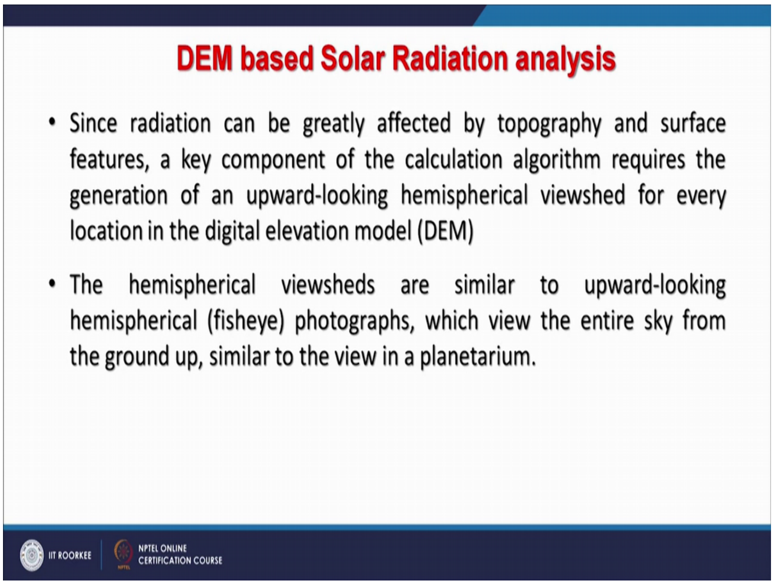

So, that is then this say hemispherical view shed are similar to upward-looking hemispherical or fisheye photograph, which view the entire sky from the ground up word, similar to the view on a planetarium.

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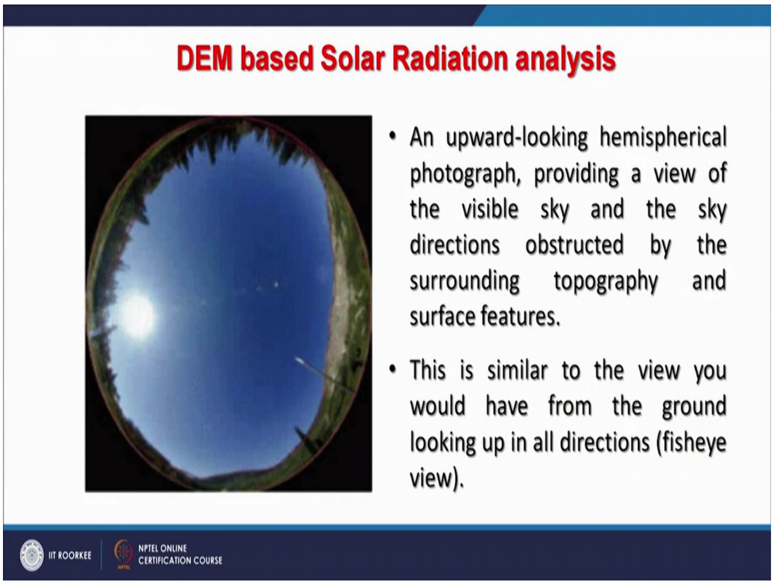

And this is what is mean by this hemispherical view shed.

If we are having some trees in the surroundings; then, this viewshed is going to be little restricted. If we are having mountains in the surrounding or some hills; then again, this viewshed would be little restricted. But if I am in a completely flat area, where no ground features are present like in a desert area like in Rajasthan or in the Bikaner area, we may get a complete free or a 360 degree a complete circle of a viewshed upward which will not have any destructions from mountains or hillocks or vegetation.

So, an upward- looking hemispherical this photographs the fisheye kind of thing providing a view of visible sky in the sky directions obstructed by the surrounding topography and surface features. Because this is how it will restrict the energy to reach to that particular point which is in the centre and this is similar to the view as we have seen looking in case of fisheye. This is how a eye of a face looks the outside world.

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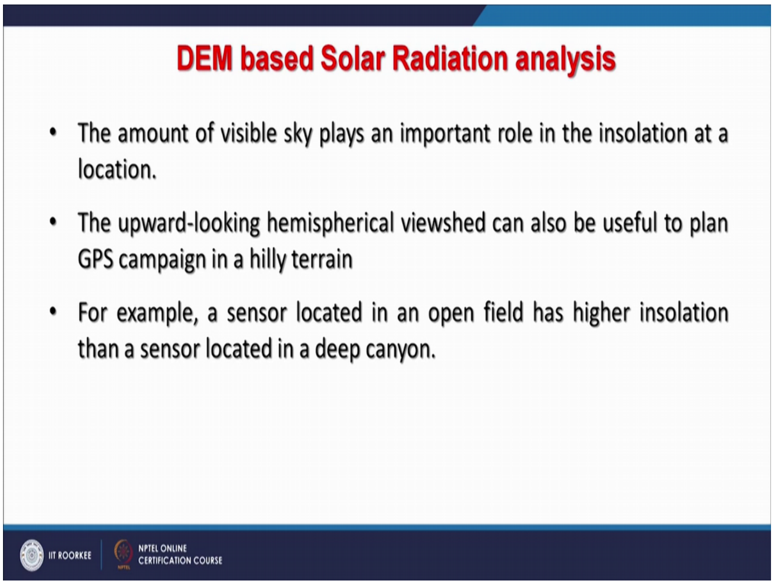

The amount of visible sky plays an important role in the insolation at a location and that will come of course, through this viewshed analysis. So, upward-looking hemispherical viewshed can also be useful to plan GPS campaign in a hilly region as I have given the example earlier. For example, a sensor located in an open field has higher insolation than a sensor located in deep canyon.

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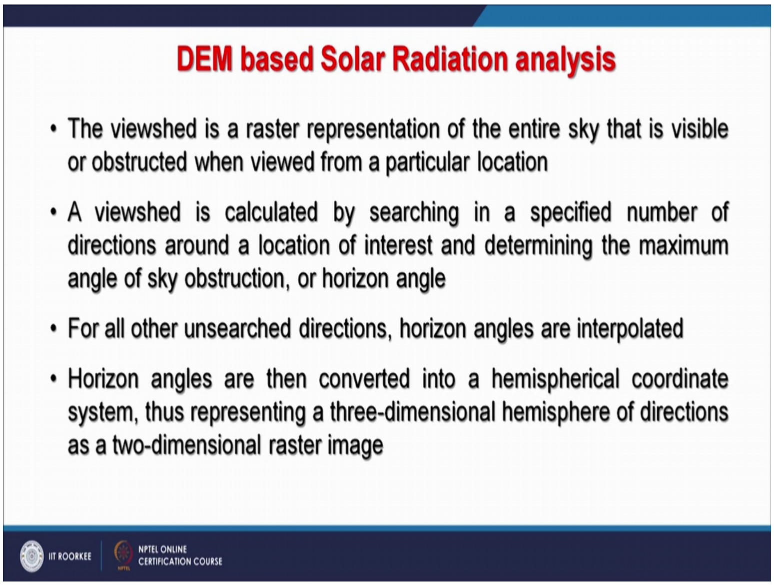

And viewshed is a raster representation because we are using a Digital Elevation Model which is a raster model and of the entire sky that is visible or obstructed when viewed from a particular location and up looking upward hm.

So, this viewshed is calculated by searching a specified number of directions around the location of interest and determining the maximum angle of a sky obstructions or horizon angle and for all other unsearched directions horizons angles are interpolated and likewise, we calculate the viewshed.

These horizon angle are then, converted to a hemispherical coordinate system because this is not a planner co-ordinate system and thus, representing a three-dimensional hemisphere of directions as a two-dimensional raster image. So, this much calculation is required.

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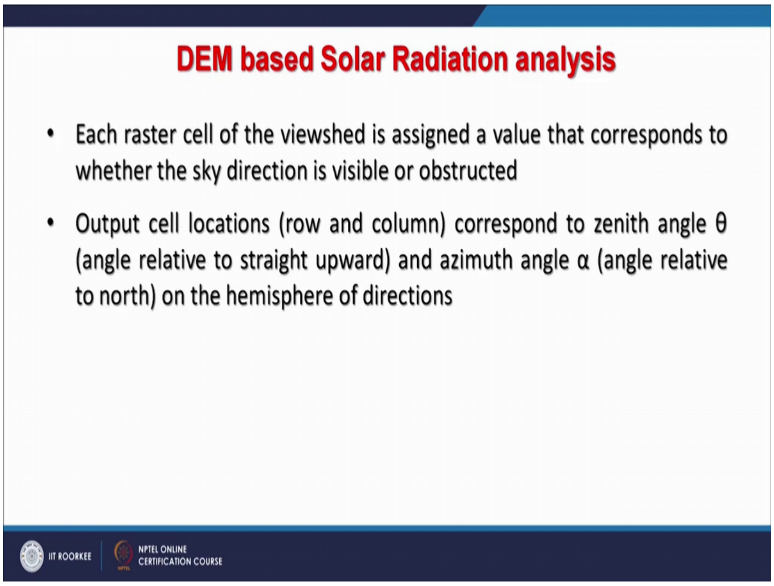

And each raster cell of viewshed is assigned a value that corresponds to whether the sky direction is visible or obstructed. And output cell locations because ultimately we are going to have in form of rasters.

So, row and columns correspond to zenith angle theta and that is the angle related to straight upward and azimuth angle that is the angle related to north on the hemisphere of the direction. So, along the parameter we have the azimuth angle and a from perimeter towards the centre we will have the zenith angle. So, these 2 angles are important here is the example.

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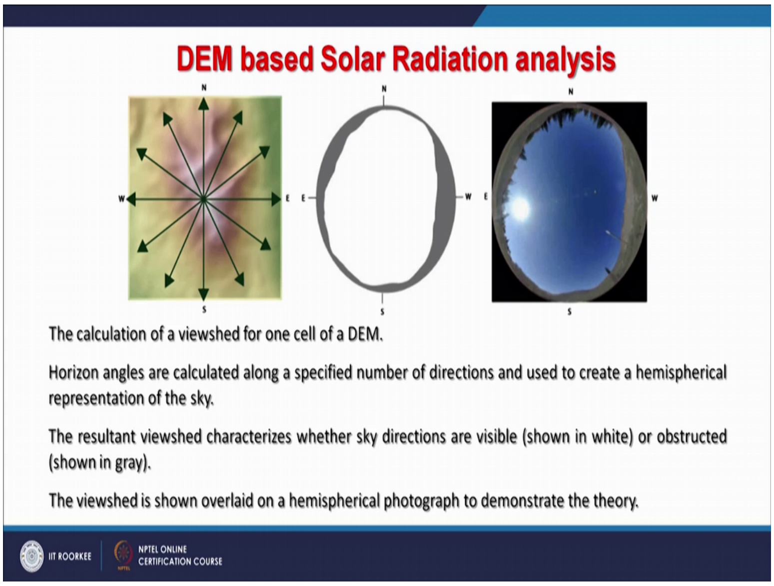

Like this is our digital elevation model. So, different directions will have different values or a azimuth here. And if I take the same viewshed example or fisheye lens example; then, this is the area or the sky is just open at this location.

So, the calculation of viewshed for that particular cell at would be involving that horizon angles are calculated along a specified number of directions used to create a hemispherical representation of the sky and the what resultant viewshed directions. Whether sky directions are visible as shown here in the white colour or obstructed as shown in the gray colour. And the viewshed is shown here is overlaid over a hemispherical photograph to demonstrate this theory.

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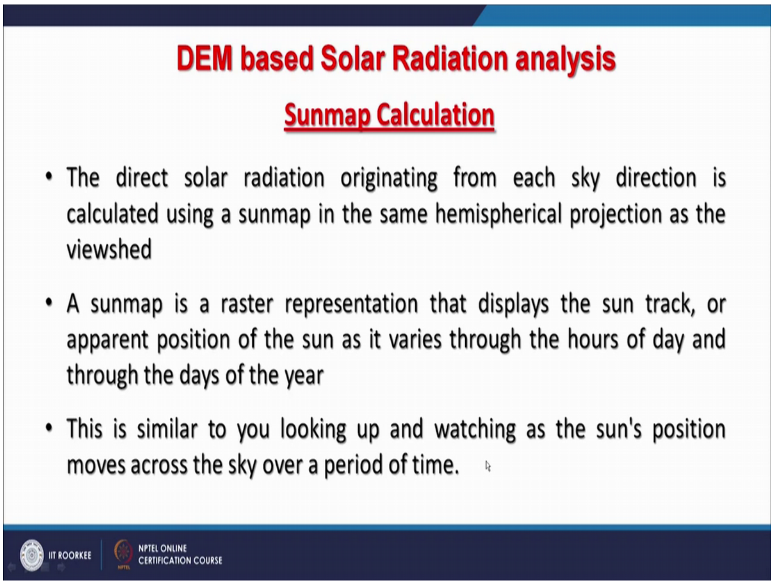

So, a next step is calculation of Sunmap. That is the direct solar radiation origin originating from each of sky direction is calculated using a sunmap in the same hemispherical projection as viewshed because for each location, the upward-looking hemispherical calculation has to be done. So, it will be the different projection system, but ultimately it has to be projected in a planar form and sunmap is a raster again representation and that displays the sun track or apparent position of the sun, as it buries through the hours of the day and through the days of the year.

So, seasons change all these parameters will be incorporated while calculating the sunmap for a particular location. And this is again the analogy here it is similar to you looking up and watching the suns position moves across the sky over a period of time. So, if I am located in a place and look upward; then, I can see how the sun from where it appears, where it disappears and so, this sunmap calculation will incorporate those information's.

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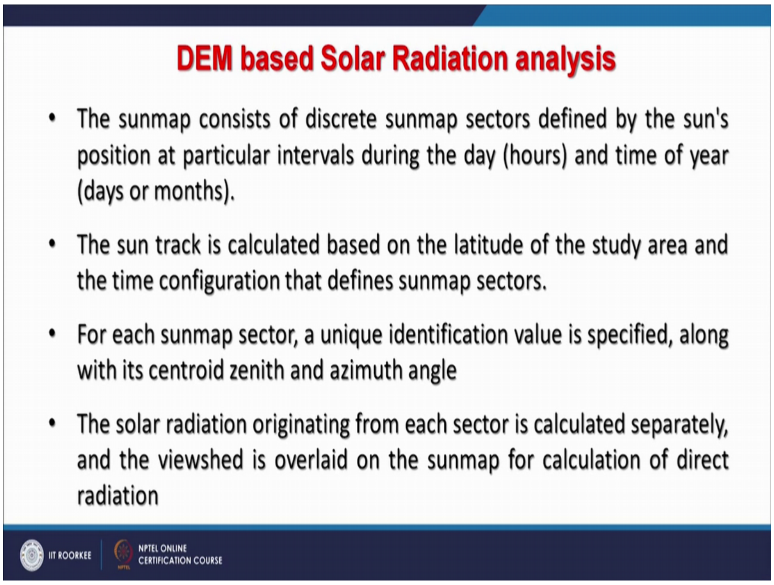

Sunmap consist of a discrete sunmap sectors which will be see through quickly through an example which are defined by the suns position at a particular interval during the day; that is maybe hours and time of the year the days and months. Because in season to season is change, but day of the hour of the day in the morning, it is different and in the evening, it is different and then, in the noon, it is different.

And the sun track is calculated based on the latitude of the study area and the time configuration that defines sunmap sectors. And for each sunmap sector, we will see in a diagram that these sun maps sectors are unique identification values is specified along with its centroid zenith and azimuth angle. And the solar radiation originates from each sector is calculated separately and the then, the next step is overlay over the viewshed and so, that we know that where it will reach and where it will not reach.

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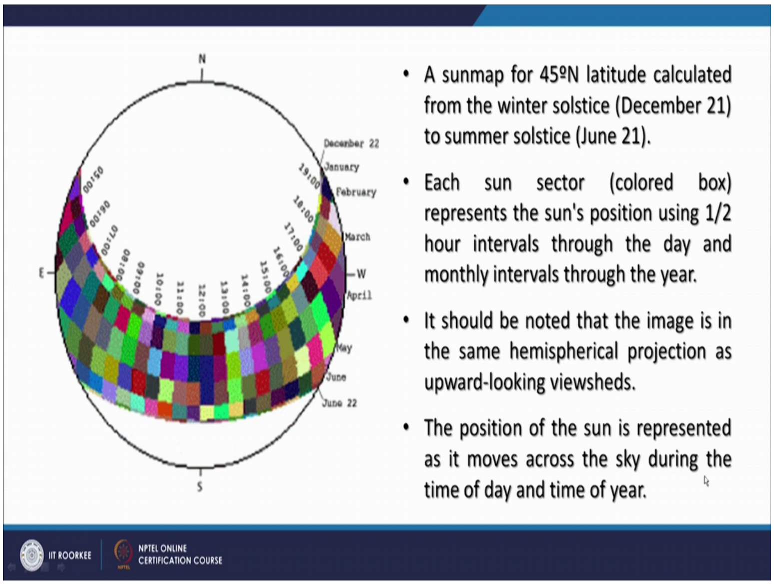

And likewise this is a typical sunmap one example is shown here. For a when solar winter, solstice is on 21st December and summer solstice on June 21st at a latitude at 45 degree. So, when this scenario is there; then, each sector is representing the time of that particular day and also along the parameter you can see the months how they vary. So, between December after 21st.

So, you are having 22nd December up to 22 June, this sunmap has been calculated in different sectors. So, each sector is representing different time of the day of the sun position as a month changes. So, say if I take the example here, then in April these sun sectors is quite large; whereas, in month of December the sunmap in the or the sectors in sunmap are very small. So, likewise we know that how much time the sun is going to be there over a part of the earth at a particular latitude.

So, it it will of course, change latitude to latitude as we know in the polar regions in higher latitudes sun may remain one may may remain in summertime for 6 months and in winter time in northern pole in winter time may not be any sun. But in this middle altitude regions like 45 degree and so, this is the scenario which we get here. So, as mentioned earlier that the sun sector which has different colour shown here, represents the sun position using 1 and half hour intervals. So, you are seeing these sectors like 15 hours is a, this is 14 hours.

So, they therefore, each half an hour, there is one sector through the day and monthly intervals, through the year these months are shown here. And this image that the sunmap is in the same hemispherical projection as we have this viewshed and therefore, this overlay is possible.

So, the position of the sun is represented as it moves across the sky during the time of the day and time of the year.

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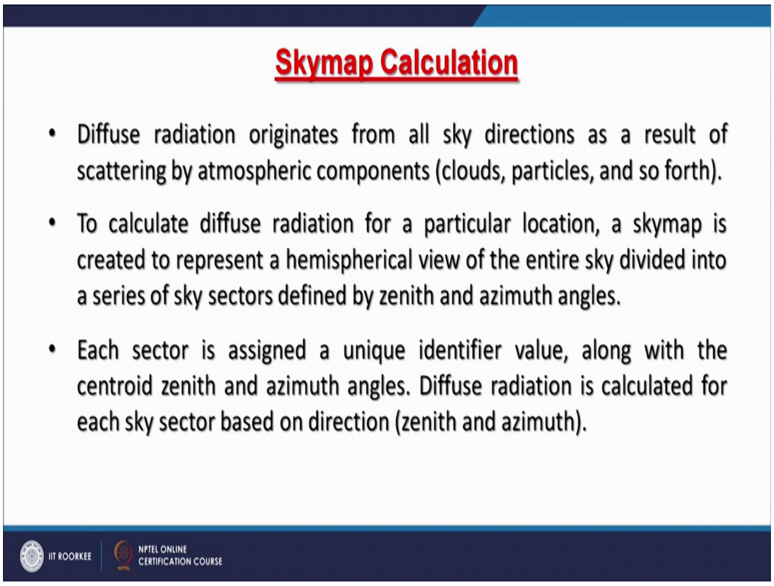

Now, a in this skymap calculation that we, we will be overlaying this example, but this diffuse radiation has to be also incorporated that diffuse radiation originates from all sky directions as a result of scattering by atmospheric components, cloud particles and so on.

And this to calculate diffuse radiation for a particular location a skymap is created to represent them a hemispherical view of the entire sky divided in a series of sky sectors defined by zenith and azimuth angles which we have already discussed. And each then, sector is assigned a unique identifier value along with the centroid zenith azimuth angle and this diffuse radiation is a calculated for each sector based on the direction that is zenith and azimuth.

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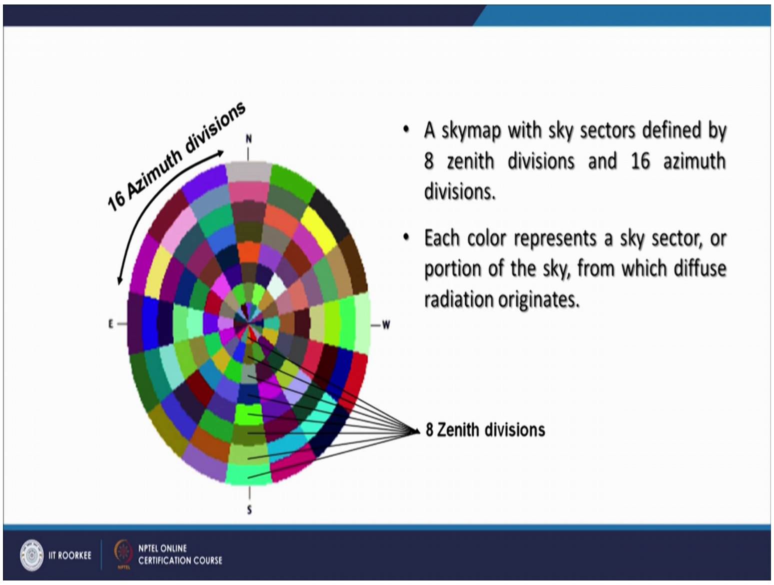

And likewise here, that a skymap is calculated and in which with the sky sectors defined by here 8 zeniths. And so, zenith as mentioned here are coming from this perimeter or outer the circle to the inside and 16 azimuth divisions are there. 16 azimuth divisions are there. North major ones are north south and east west and then, you are having a different.

So, when you are looking upward; then, these directions for east west would change that is why there are different directions. So, these are the 16 azimuth divisions and these are the 8 zenith divisions are there. And again, remember this is again, upward-looking hemispherical projection. So, each colour represents here is a sky sector portion of the sky from which the diffuse radiation originates. So, this is a. So, 3; 3 parameters in order to calculate the total insulation total radiation have already we have discussed. Now say overlaying time. So, overlaying the viewshed the sunmap and sky map.

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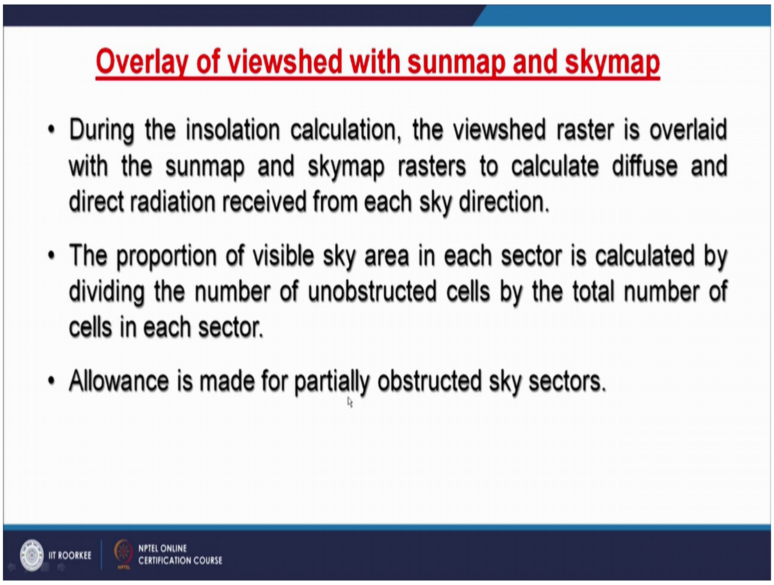

And during the insulation calculation, the viewshed raster is overlaid with the sunmap and skymap raster to calculate diffuse and direct radiation received from sky direction. So, both types of radiation diffuse and direct radiation have come here reflected a radiation if we want to incorporate will require the ground feature information.

So, that means, a land use map has to be there. So, in this discussion we have not included that the reflected radiation. But 2 major because they are the major components to towards the total solar radiation have been incorporates. So, the proportion of visible sky area in each sector is calculated by dividing the number of unobstructed cells by the total number of cells in each sector. During this overlay process and this allowance is made for partially obstructed sky sector.

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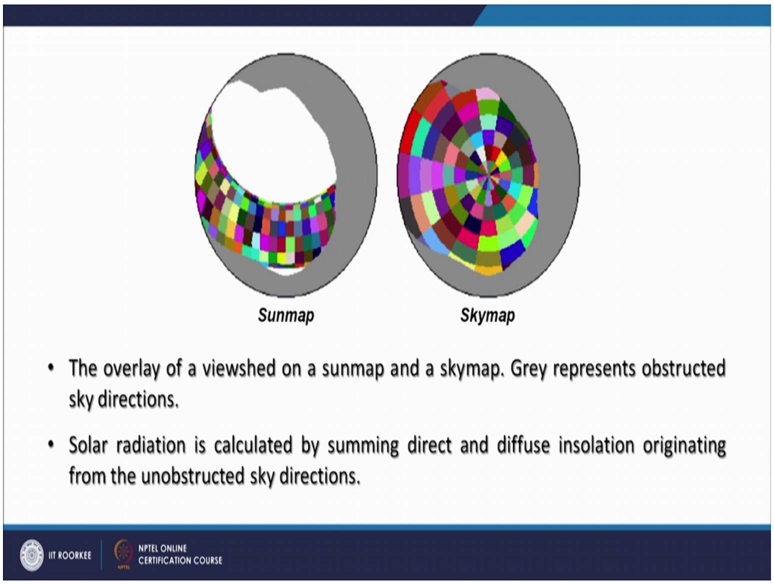

And this is how you get the result, when we apply this a skymap and sunmap; this is what the scenario we get and again, this masking is done that is overlaying is done in this example. So, this is this becomes our sky map. So, the overlay of a viewshed on a sunmap and a skymap and this of course, this is the obstruction which we are seeing in this particular example.

Because of the topographic features which are present may be hillock or hills mountains and maybe some trees and other things and the solar radiation is finally, calculated by summing direct and diffuse insulation which is originating from the unobstructed sky directions. And likewise, you get the complete information of solar total solar radiation minus reflected radiation is calculated.

So, we know at what location how much solar radiation will reach. However, is mentioned that for each location such calculation has to be done. So, when you are performing such analysis on a GIS platform, using a Digital Elevation Model it requires lot of time to calculate because for each location or for rather each cell this has to be calculated. So, it requires lot of time or computation time on a GIS platform for total solar radiation. What are the applications of the solar radiation analysis?

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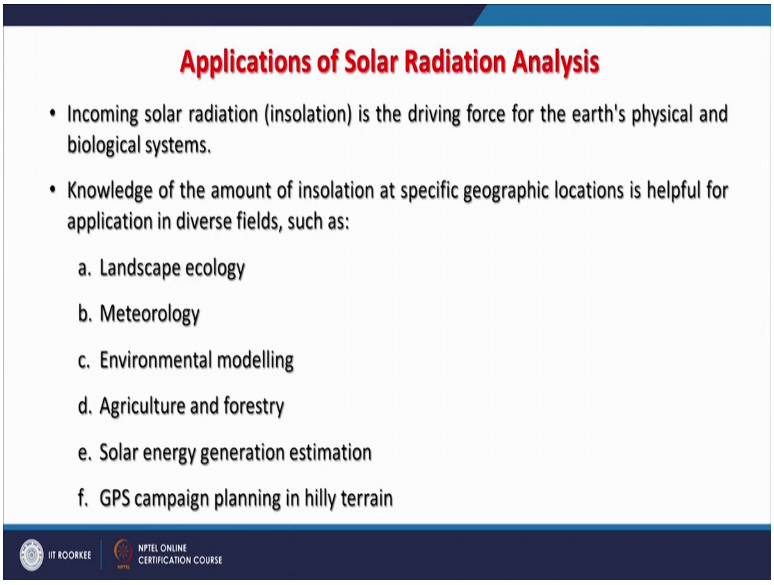

As we know that a insolation that is incoming solar radiation is a driving force of the earths physical and biological systems and Knowledge of amount of insolation reaching at a specific geographic location is definitely helpful for application of diverse field and such as: Landscape ecology, Meteorology, Environmental modelling, Agriculture and of course, finally, a very important one is the Solar energy generation estimation.

One before investment is made, before a solar power plant is constructed at a location, one would like to know how much a insolation or total incoming solar radiation would be available at that location. And this estimation can be done very easily employing a Digital Elevation Model of that area of course, one other advantage because we calculate the skymap here.

So, in GPS campaign planning especially for hilly region ah; this skymap can also be used. So, if I know in which area I am going to work; suppose, I am going to work in a valley. So, I know what is the skymap or open sky is going to be available. So, obstruction versus open sky that can also be calculated also the applications of under this applications of solar radiation analysis.

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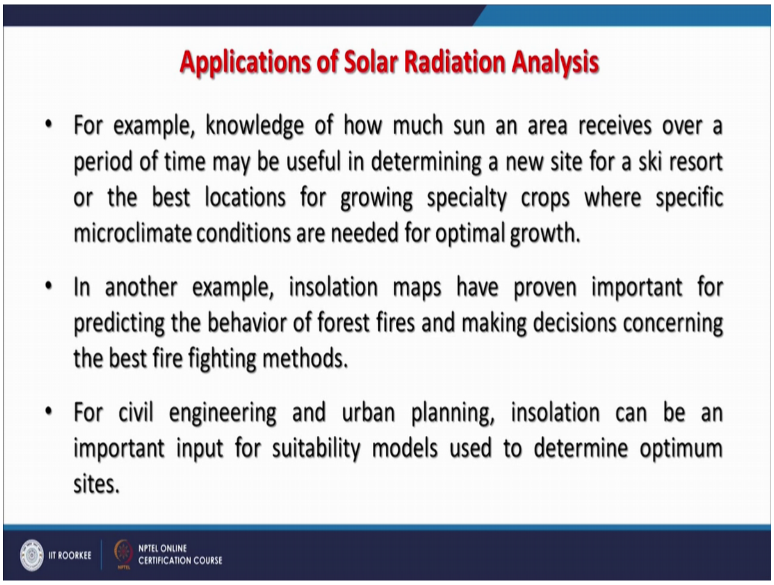

The knowledge of how much sun an area receives over a period of time, may be useful in determining a new site for a ski resort or a best location for growing especially crop where specific micro climatic conditions are needed for optimal growth. These a this solar radiation information can also be used in directly or directly related with the weathering studies or weathering processes which are related with erosion as well.

So, in another example, the insolation maps have proven important for predicting the behaviour of forest fires and making decisions concerns the best firefighting methods because say because of the heat involved. And the radiation which will the areas which are receiving maximum radiation may be proven from forest fire point of view for civil engineering and urban planning insolation can be an important input or suitably models used to determine optimum sites.

In the colder areas or the climate is colder then, solar insolation can be helpful to reduce the heating budget of a building or a house where as in a hot climatic regions like in India; then, this insolation information can again be helpful to find out that which direction would be the best for windows and other open areas. So, likewise a lot of applications are there which can be used and as I mentioned that before, it has to be calculated for a for each location. So, that location have to be selected.

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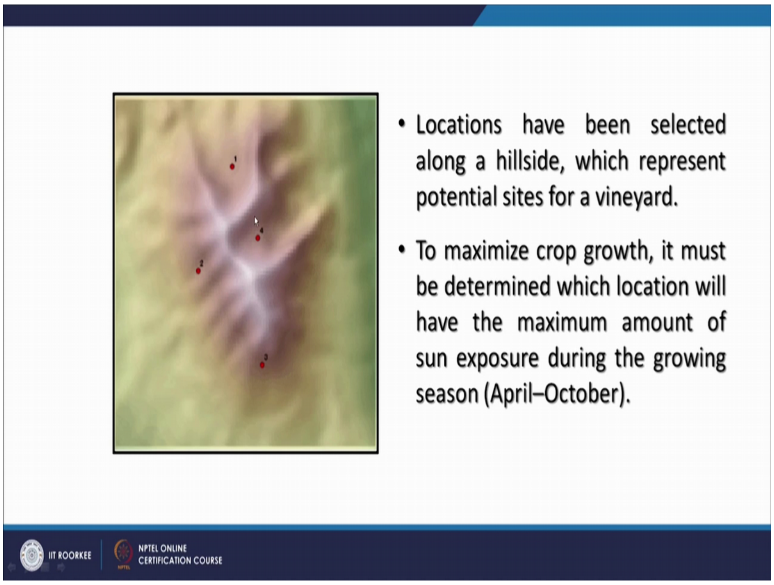

Like in this example 4 locations have been selected, but if we submit for entire a area, it takes hell of time. So, one can start with this that if these are the sites for vineyards potential sites for vineyard. So, 4 locations are shown over a shaded relief model which is drive from Digital Elevation Model. And then, maxi[mum] maximize the crop growth it must be determined which location will have the maximum amount of sun exposure during the growing season say April to October. So, a comparative study can be done very easily and this analysis shows that these red areas.

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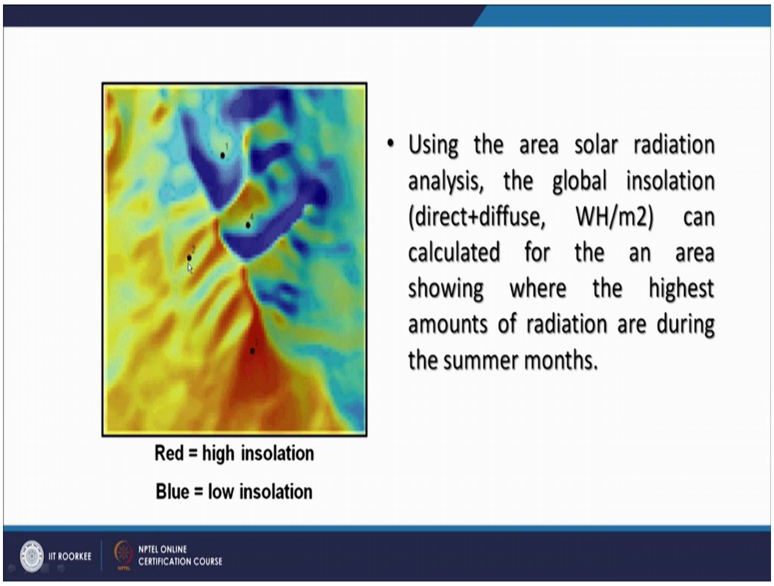

Where, the solar insolation is going to be high and the especially the one the site which is marked as a a 3 and the 2 will have less whereas, the 1 will have the minimum.

So, using this say area, solar radiation analysis the global insolation that is direct plus diffuse radiation can be calculated for an area showing where the highest amounts of radiation are during the summer months. So, if you if you are having some specific requirements you know the window time window and the area window; then, for that a specific area things can be calculated as shown in this particular example. Where, a time window was also given about the summer months. So, global insolation calculation for each side can be located as we have seen that the location 3 is the best in this region.

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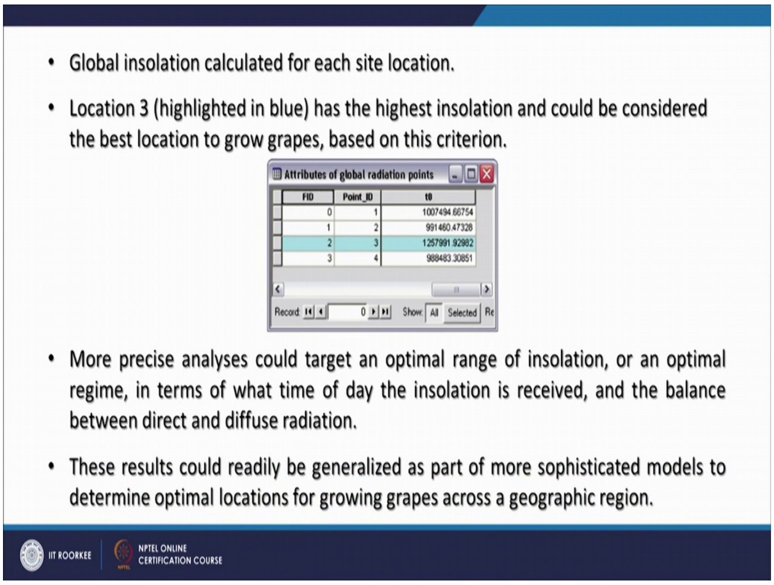

Also some statistics can also be drive from the attribute table of that one and more say precise analysis can also be done; while involving a higher spatial resolution data and some other inputs say there.

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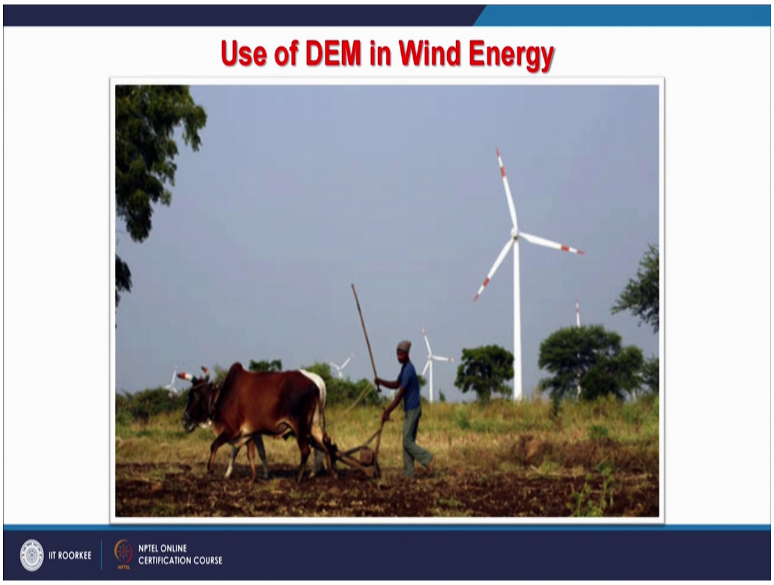

Now, another part of this presentation or this discussion is how to use digital elevation models in wind energy because if it is flat area, the wind may have the same intensity and same direction throughout. But, if it is a hilly terrain and a still we have we are targeting some sites for wind energy; then, we can employ a Digital Elevation Model to find out the best sites and locations to generate or these put the and these wind plants. So, how we can use the Digital Elevation Models?.

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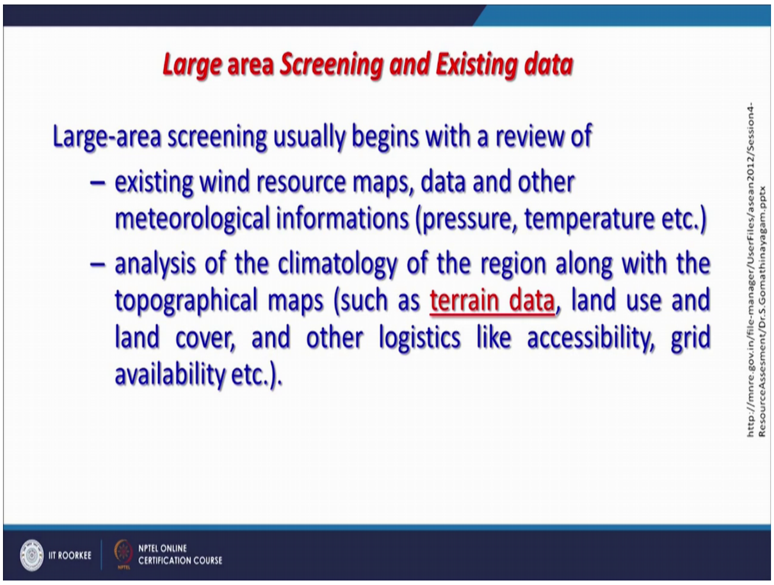

So, basically a large-area screening be has to be done with the existing data.

So, large-area screening usually begins with a review of estimated wind resource maps of that particular area and other data that is especially meteorological data information's; pressure, temperature. And of course, wind speed, wind directions and then, ultimately there then comes the apa[rt] apart from this weather and a climatic data; then, comes the terrain data, land use data, land cover data and other accessibilities or you know logistic data as well and availability of grid and other thing.

So, we our here the contribution through digital elevation models towards the estimation of wind energy is going to come only through terrain data that is from Digital Elevation Model.

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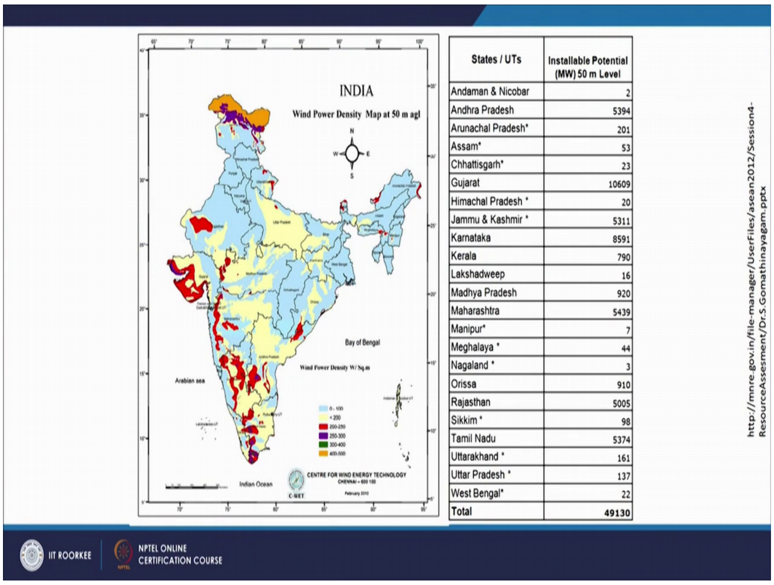

States / UTs	Installable Potential (MW) 50 m Level
Andaman & Nicobar	2
Andhra Pradesh	5394
Arunachal Pradesh*	201
Assam*	53
Chhattisgarh*	23
Gujarat	10609
Himachal Pradesh *	20
Jammu & Kashmir *	5311
Karnataka	8591
Kerala	790
Lakshadweep	16
Madhya Pradesh	920
Maharashtra	5439
Manipur*	7
Meghalaya *	44
Nagaland *	3
Orissa	910
Rajasthan	5005
Sikkim *	98
Tamil Nadu	5374
Uttarakhand *	161
Uttar Pradesh *	137
West Bengal*	22
Total	49130

If I take the example of India then, these are the areas where we are having a very high potential of generation of wind energy because of open areas and less undulations and other things no vegetation not much. So, this is the wind power density map at a 50 meter AGI and these are the areas which are most suitable. Then, you are having some other areas some areas are not suitable.

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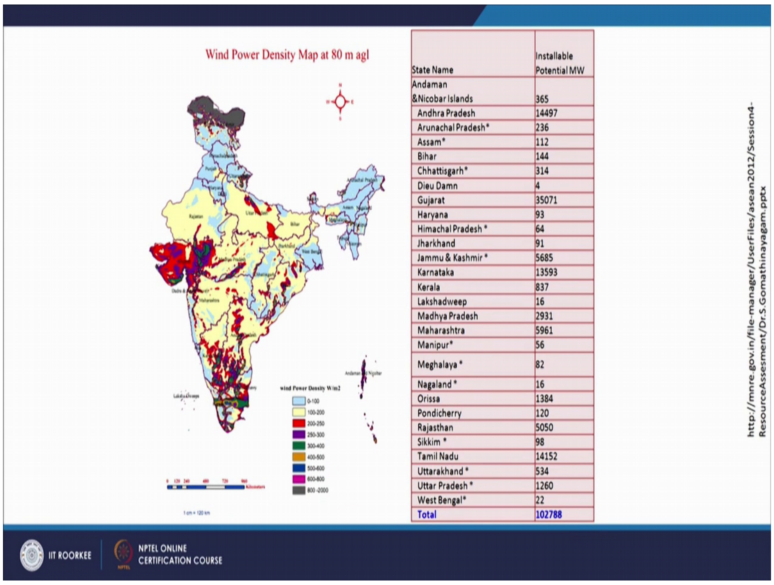

State Name	Installable Potential MW
Andaman &Nicobar Islands	365
Andhra Pradesh	14497
Arunachal Pradesh*	236
Assam*	112
Bihar	144
Chhattisgarh*	314
Dieu Damn	4
Gujarat	35071
Haryana	93
Himachal Pradesh *	64
Jharkhand	91
Jammu & Kashmir *	5685
Karnataka	13593
Kerala	837
Lakshadweep	16
Madhya Pradesh	2931
Maharashtra	5961
Manipur*	56
Meghalaya *	82
Nagaland *	16
Orissa	1384
Pondicherry	120
Rajasthan	5050
Sikkim *	98
Tamil Nadu	14152
Uttarakhand *	534
Uttar Pradesh *	1260
West Bengal*	22
Total	102788

And this has been power density map also for different states is there.

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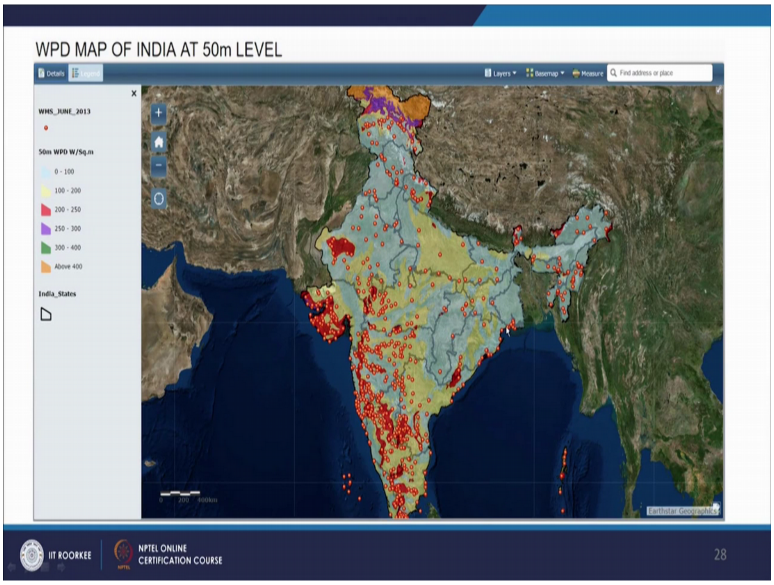

And this wind power density map of India at 50 meter level is also given here, for different locations can be estimated.

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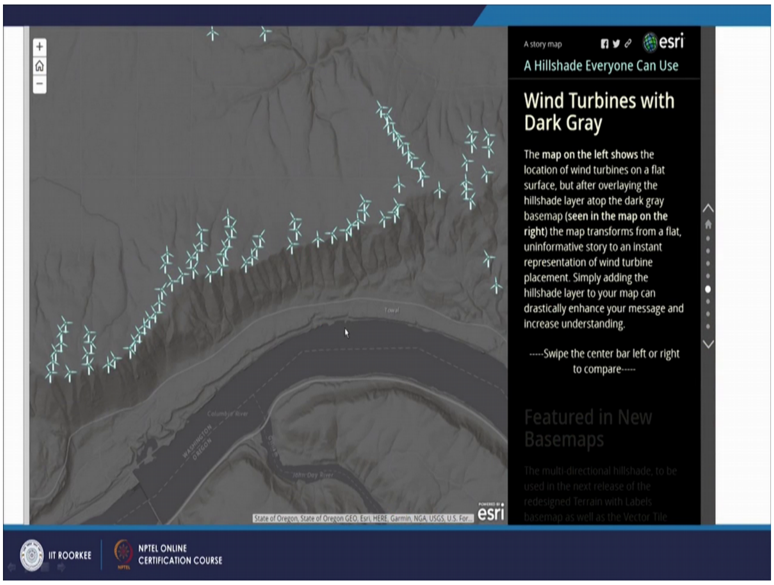

And these are the for example, one example is given here that these are the wind turbines have been located; where, you one can get a the best benefit of wind in a hilly terrain and that example is given here which is again and has been analysed based on this Digital Elevation Model which is shown here in form of a shaded relief model and that best suitable locations.

So, as you can see here, the edges they say they say this escarpment has been found more suitable for wind energy point of view or these you know sites which are most suitable and some other points are also there. But the valley part is not suitable. So, here you will have the maximum wind in this particular example. So, employing a Digital Elevation Model or shaded relief model incorporating other parameters one can one can locate or find a most suitable sites for wind energy.

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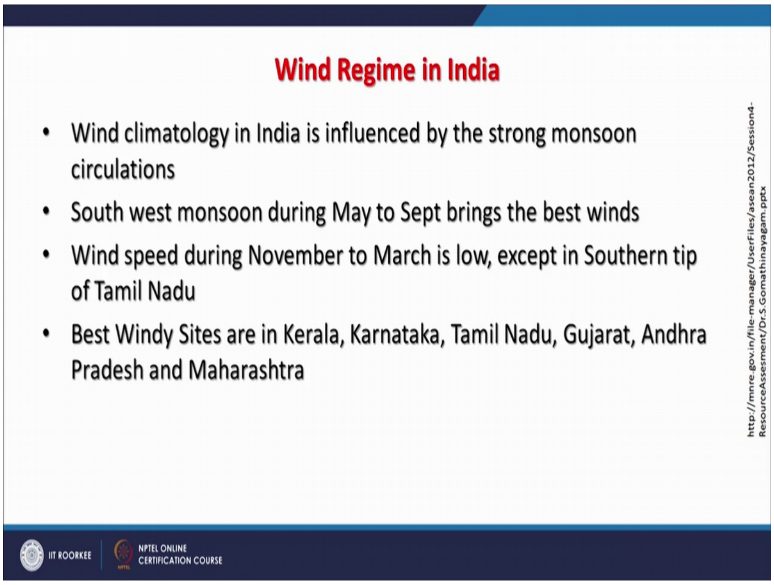

Wind climatology in India is influenced by strong monsoon circulations. So, we are having these information available; probably the information which has been missing. So, far is the topography how topography is influencing that can also be incorporated and we know that the southwest monsoon during May to September brings the best winds.

Wind speed during November to March is low except in southern tip of Tamil Nadu and west wind sites are in Kerala, Karnataka, Tamil Nadu, Gujarat, Andhra Pradesh and Maharashtra. These are the areas which are very open less forest covers and open very close sometimes to the sea. And therefore, they are having quite good potential for wind energy generation. So, this brings to the end of this discussion.

Thank you very much.