Geographic Information Systems
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Lecture-38
Various Techniques to Generate Digital Elevation-3/3

Hello everyone! and welcome to this Geographic Information System course. Today we will continue the discussion about various techniques to generate digital elevation models. So, 2 parts we have already completed, now this is the last part about the digital elevation model generation. As you know that we have discussed how to generate digital elevation model using stereo pairs implying photogrammetric techniques? I gave examples of SPOT or Cartosat satellites also, completely remote sensing-based method.

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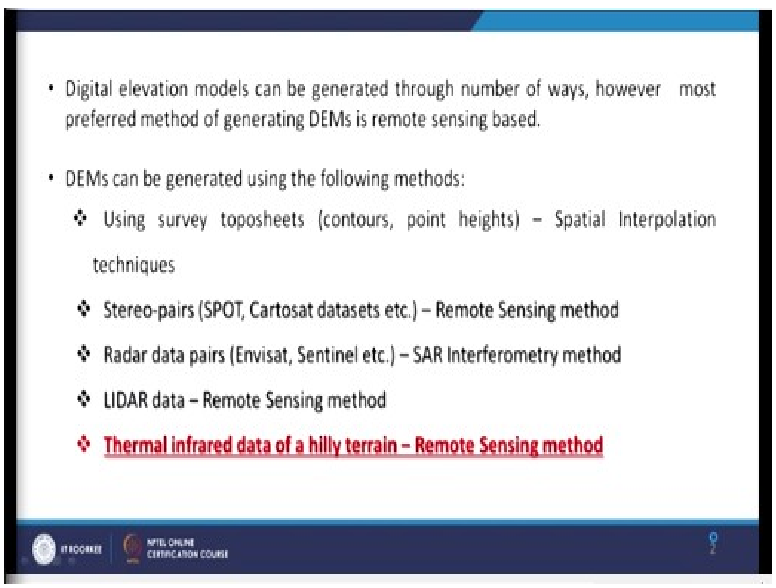

Another method is the radar pairs or implying SAR interferometry. Though SAR interferometry itself has become a big subject but from our course point of view, I very briefly discuss about this. And, I also discussed about the Lidar technology which is again remote sensing based technology. And now in this discussion we are going to focus on how we can exploit thermal infrared data especially of a hilly terrain for generation of a digital elevation model.

Why specifically for hilly terrain? As you know that ground surveys are relatively easily possible in areas which are plain. But ground surveys (field base surveys) in hilly terrain are really challenge or very difficult and some time many areas are completely inaccessible to humans. And therefore, generating a digital elevation model of a hilly terrain, for example like higher Himalayas is very-2 difficult.

And therefore, this technique can really help us to exploit this thermal infrared data and relationship which we are going to discuss to generate a digital elevation model. Relatively coarse resolution thermal infrared data is available from NOAA-AVHRR data.

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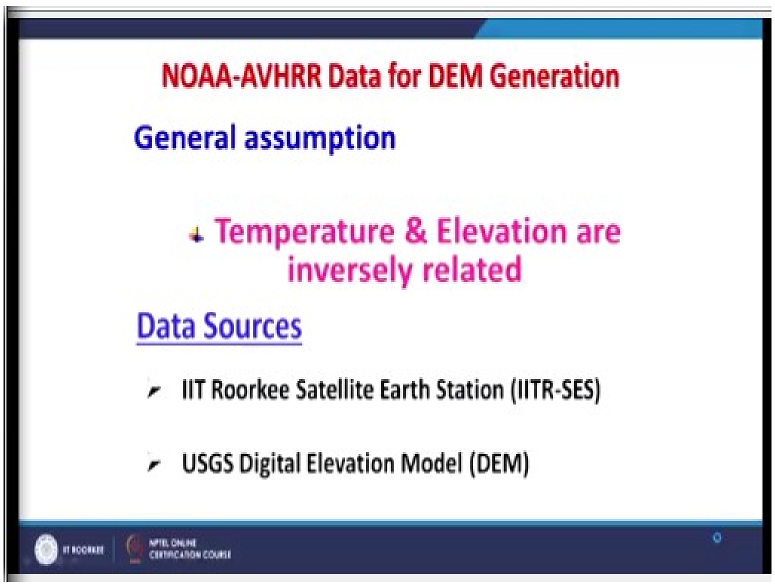

And NOAA is a name of satellite; AVHRR is an advanced very high-resolution radiometer, though its name said high resolution. But 30 years back that was definitely high resolution but compared to today what the data available, it is not really high resolution, it is 1-kilometer spatial resolution. But in an entire day it can cover the same terrain twice and that is very advantageous from that point of view.

So, though the resolution is less but it can provide still good quality of data and this is the satellite or this is the sensor NOAA-AVHRR sensor is the most used data world over, in the field of remote sensing. Because data since beginning has been free and anyone can have their own satellite earth stations because data is in public domain or indirect broadcasting mode. So, if you are having your own satellite earth station, you can directly get the data of your area and surrounding from this satellite. Now as you know that there is an inverse relationship between temperature and elevation. And that means that as we go higher in altitude, we get less temperatures.

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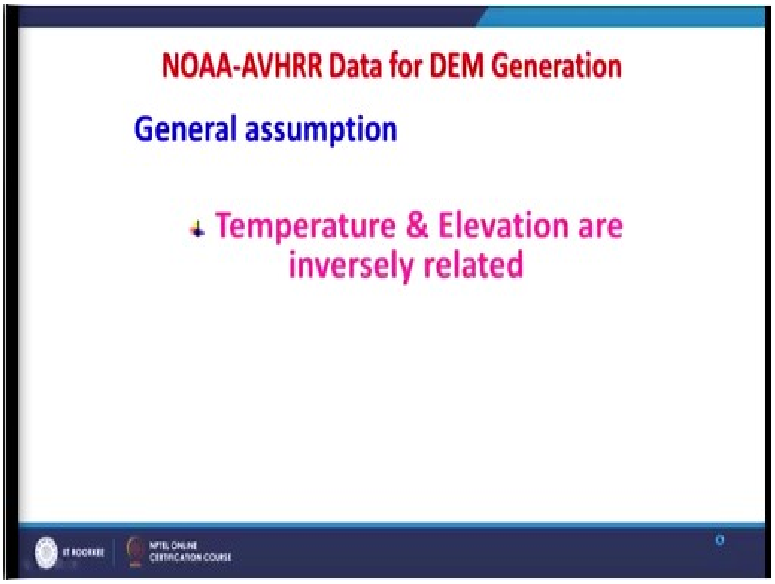

And this relationship can be exploited for this implying the thermal channels because NOAA-AVHRR data is having 5 channels data. And there are 2 dedicated channels which has thermal channels. So, those channels can be exploited to find out its relationship that is the inverse relation and then same can be used. And since 2002 at IIT-Roorkee we have been operating this NOAA-AVHRR satellite earth station and using our own data set. Basically, we developed a digital elevation model for a hilly terrain, for a very difficult and challenging terrain and very successfully we could demonstrate that this can be done.

And we also made a comparison with USGS data and for some controls also we used that one and so. So, as you know that USGS-DEM which is available free of cost. We discussed in the initial discussion related with the digital elevation model generation that it was developed using 250000 survey toposheets and their contour lines were digitized and then later on interpolated and surface were generated for the entire globe.

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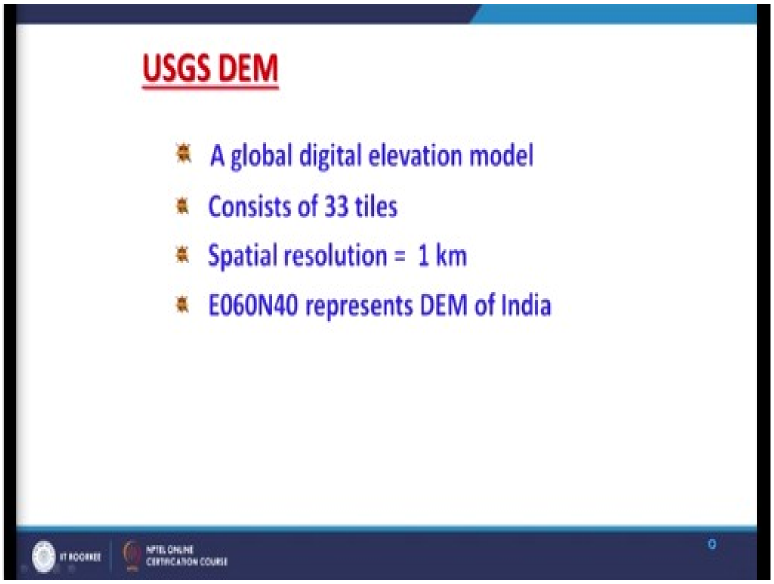

So, this is a global digital elevation model but compared to today's what is available, it is again a coarse resolution one kilometer. But I would insist that always it is not required for anyone to always go for high spatial resolution, either remote sensing data or digital elevation model. Because if relatively it is coarse resolution data, then the area which it covers is really very large or very huge compared to very high-resolution data.

If I give you example from NOAA-AVHRR, in one scene you can cover about 2800-kilometer width or the swath is 2800 kilometer. And if, I go for 1 kilometer resolution satellite image then in 1 swath I can cover only 11 kilometers of the part of the earth. So, that makes the difference from 1000 meter to 1 meter there is an inverse relationship between the spatial resolution and swath.

So, coarser the spatial resolution, wider the swath and vice versa is also true. And this USGS - DEM for entire globe is consisting of 33 tiles, spatial resolution I have already discussed. And these are numbered like this, for northern hemisphere, for eastern hemisphere and likewise. So, for India this is east 60 degrees i.e., the longitude and north 40 degree i.e., the latitude. And this is the corner coordinate for entire India tile.

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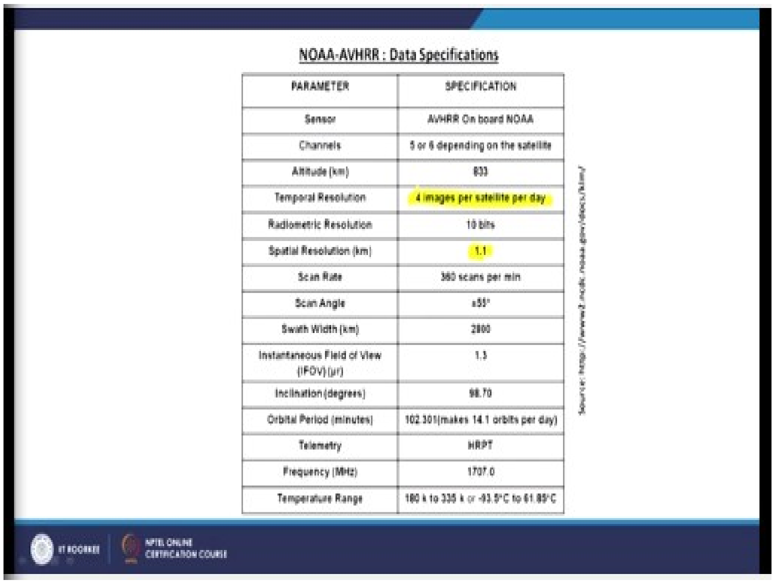

NOAA-AVHRR : Data Specifications

PARAMETER	SPECIFICATION
Sensor	AVHRR On board NOAA
Channels	5 or 6 depending on the satellite
Altitude (km)	833
Temporal Resolution	4 images per satellite per day
Radiometric Resolution	10 bits
Spatial Resolution (km)	1.1
Scan Rate	360 scans per min
Scan Angle	±55°
Swath Width (km)	2800
Instantaneous Field of View (IFOV) (μr)	1.3
Inclination (degrees)	98.70
Orbital Period (minutes)	102.301(makes 14.1 orbits per day)
Telemetry	HRPT
Frequency (MHz)	1707.0
Temperature Range	180 k to 335 k or -93.5°C to 61.85°C

Now if you see the specifications about NOAA-AVHRR, as I have already said that the spatial resolution is about 1 kilometer i.e., 1000 meters. And it depends where it is located but nonetheless you can acquire at least 4 images per day but at the same time, the same area can be visited at least once in a day. In a daytime and another in nighttime, why nighttime it is possible, because it has got the thermal channel.

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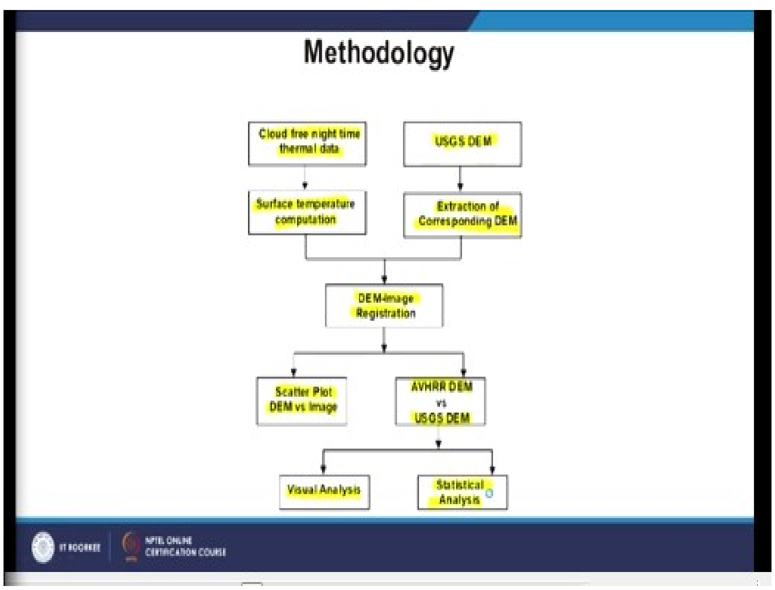

And these thermal channels can be exploited to generate digital elevation model which is what we are going to see. So, what we need basically? We need cloud free nighttime thermal data. Now, if somebody is trying to generate a higher spatial resolution digital elevation model implying this thermal remote sensing technique then there is a way also. And nowadays a

Landsat OLI series i.e., Landsat-8 is also having thermal channel and the data is available at 60-meter resolution.

So, from 1000-meter you can come to 60-meter and then still you can exploit this inverse relationship between altitude and temperature. And you can try to generate a digital elevation model at 60-meter resolution as well. Anyway, if we discussed the methodology part so you require a cloud free nighttime, see why nighttime? Because solar heat in differentiation is minimum in the nighttime.

And luckily these satellites overpass in the early morning local time, maybe 2 o'clock or 3 o'clock. So, at that time the fact of differential solar heating is minimum and therefore it is always good to go for nighttime thermal data. One may think that how in nighttime I will detect the clouds? Because all channels in nighttime will not work; at least 2 visible channels of NOAA-AVHRR.

But there is an infrared channel and these 2-thermal infrareds. And they are still operating, they will also record. So, implying the thermal infrared channel, one can very well detect clouds. So, it is easy, it is not difficult to find out the nighttime cloud free scene from NOAA-AVHRR data. However, when I give this comparison with the Landsat then acquiring nighttime Landsat data that is not available generally on their portals.

But I am sure that if you make a special request to them, then it is possible to even acquire nighttime data from Landsat. Because they are not acquiring the data but a satellite always overpasses in nighttime in that area. So, surface temperature computation is done after acquisition of data.

Now digital elevation model of the same resolution i.e., USGS topo resolution and then of course you require the same corresponding DEM, why it is required? Because we want to have some values about elevations and especially the minimum and maximum elevation value of the area. And therefore, the best resource is a USGS-DEM which we can definitely use just for having these 2 values for the area. And then of course, you require DEM to image registration. So, that means you are working for the same geographic extent.

If you want to see the results and compare with DEM and image, you have to plot a scatter plot to find out a relationship, which I will show you. And then you can further study that AVHRR and DEM generated from 2 different techniques, you can do a visual inspection or visual analysis and of course one can also perform statistical analysis.

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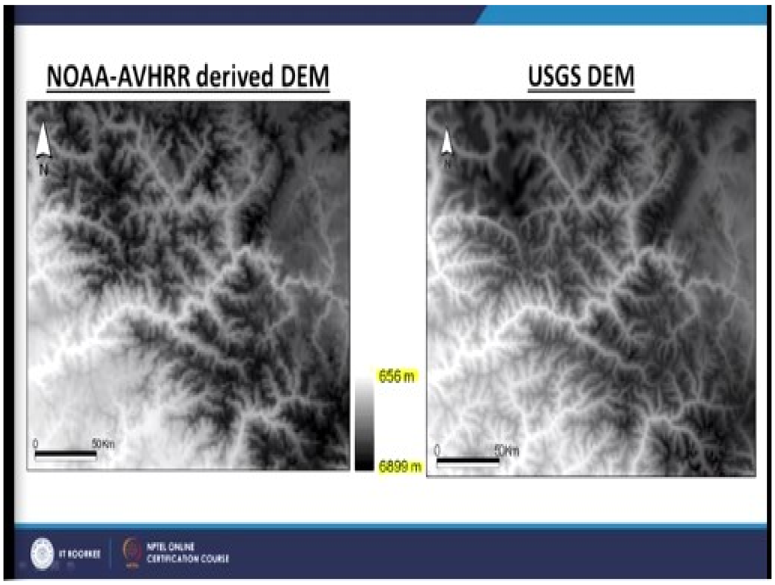

So, this is on the left side what you are seeing is a NOAA-AVHRR derived digital elevation model. And on the right side what you are seeing is USGS-DEM, both are having 1 kilometer resolution. As visually you would find that there is hardly any difference but when we will see statistically there will be some. Since these minimum or maximum values are coming from a USGS DEM therefore both are having the same minimum and maximum value.

Because using those values, the output of this USGS-DEM has been is re-scaled. Now visually you can see, there is hardly any difference but when we plot a scatter plot, still we find that there is a very high correlation visually in this one.

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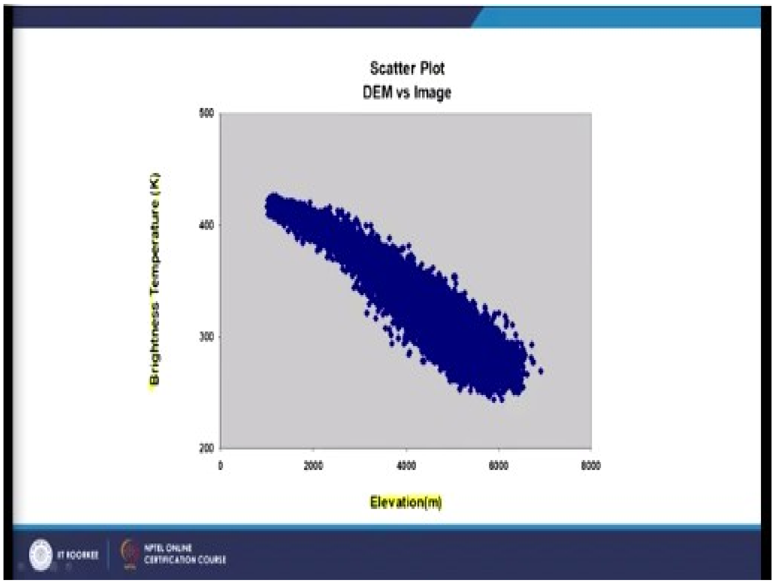

So, on one side you are having elevations derived from USGS and the other side you are having the brightness temperature derived from NOAA-AVHRR data when you plot, this is what you see.

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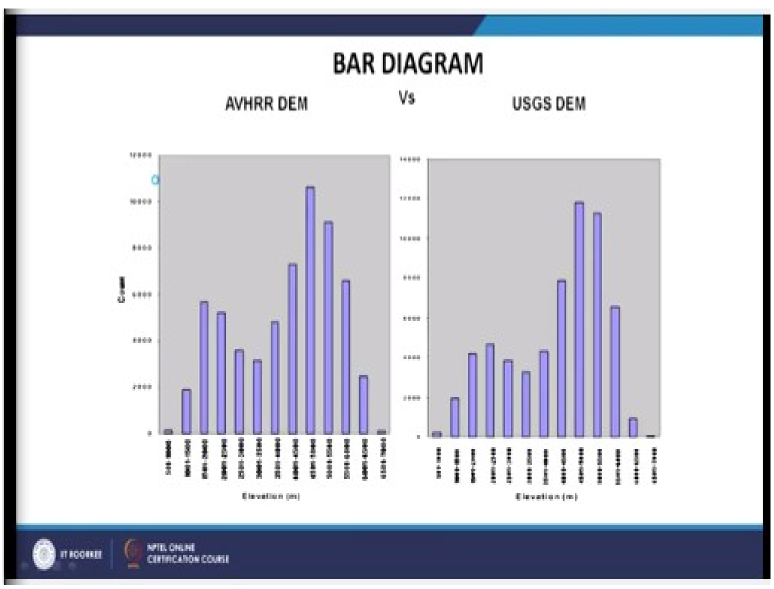

Also, for different elevation ranges, when you perform further analysis, you find that the histogram pattern is almost same. That means in almost each elevation ranges, it is matching quite well with the USGS-DEM as you can also see very carefully.

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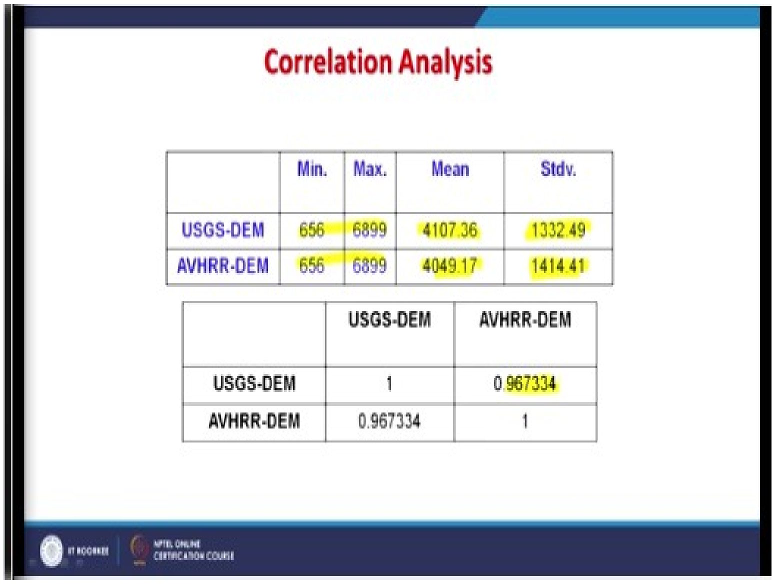

Now when we perform this correlation analysis, we find that, of course, minimum-maximum would be same because USGS-DEM minimum-maximum has been taken to re-scale NOAA-AVHRR-DEM but mean value here is a little higher than NOAA-AVHRR and same with standard deviation i.e., relatively low and this is higher in that sense. And when we do this correlation, we find a very high correlation i.e., 0.967334 which is almost 1.

So, it is having very high correlation with NOAA-AVHRR and USGS-DEM. And therefore, it proves that while implying thermal images of nighttime from any satellite, if we need just for the same area, we need a reference for 2 elevation values i.e., minimum and maximum. Once those are there, we can re-scale the entire thing and can generate a digital elevation model of very good quality.

But again, because no technique is ever perfect or universal, every technique will have it is own problem or issues. So, one issue here is, if there is a dense vegetation cover you may not get that good results so, that is one limitation. Of course, for better results, you require a nighttime image but if they are not available then you have to resort to the daytime thermal images which may bear this differential solar heating issues.

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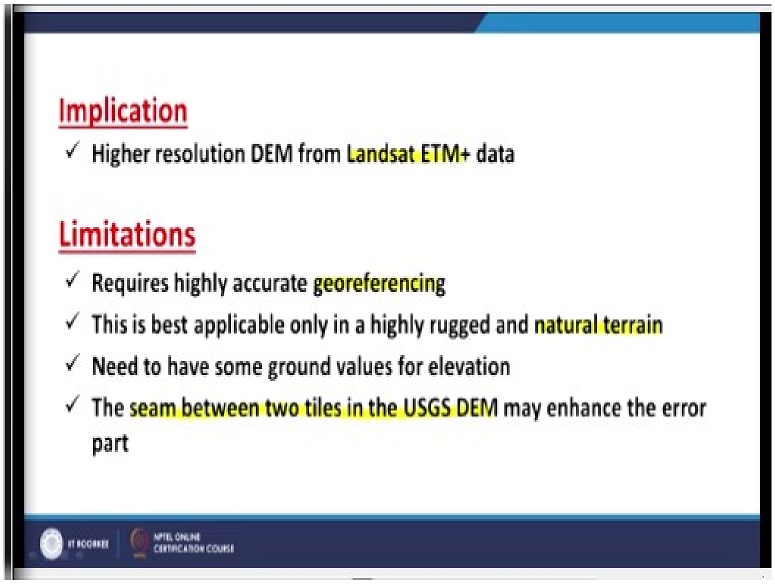

So, higher spatial resolution as I have said from Landsat ETM+ or later series Landsat-8 OLI series, you can create a digital elevation model. And I have already said, since it is a relatively coarse resolution satellite image which is NOAA-AVHRR, so the accuracy of geo referencing has to be very high, so, that is one essential requirement.

And the second is the best applicable only in a highly rugged and natural terrain. So, more emphasis I am giving on natural terrain, like in higher Himalaya it is more or less undisturbed by humans and is a natural terrain and therefore you get very good results. But if somebody is trying to generate a digital elevation model where a lot of human interventions are there then probably you may not get a good result.

And of course, you need to have some ground values or some elevation values for your reference. So, for that there should not be much problem, these are already available. Now, the other thing is that, the seam between 2 tiles in USGS-DEM may enhance the error part. That means USGS-DEM developed using survey toposheets of different countries.

So, sometimes you would find that even for the same country, they use 2 different projections or spheroid. And that has created a seam between 2 tiles or 2 toposheets. So, if that seam is visible in your USGS-DEM and the same USGS-DEM you are implying and trying to compare with your thermal data driven DEM, you may get this problem. So, visually you can inspect whether there is a seam in the DEM of USGS which you are going to use, in case you are using NOAA-AVHRR data but in case you are using Landsat thermal data then the scenario can be a little different.

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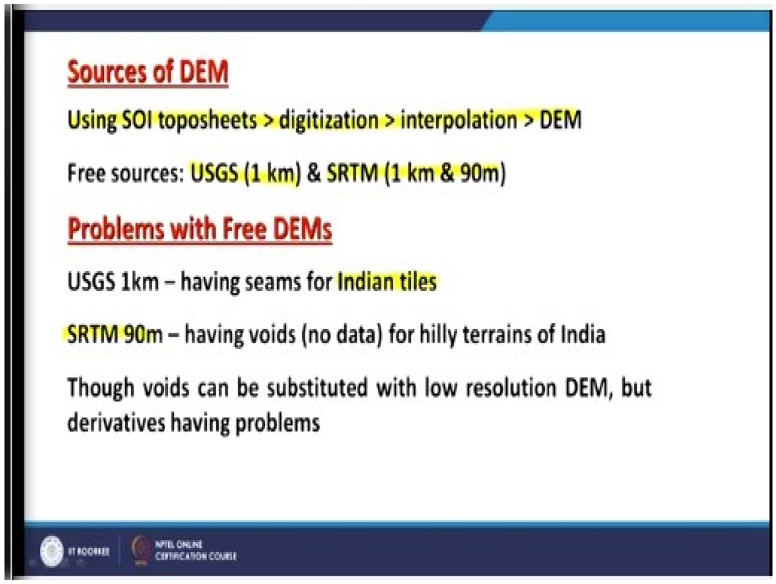

Now this part we will be discussing further extensively but for time being a source of DEM which we have already discussed that you imply the survey of India or survey toposheets digitize contours and then do the interpolations and you get a digital elevation model. And these are the free resources which the topo sheets based USGS-DEM which I have already discussed. So, free resources are 1-kilometer USGS DEM. SRTM was also developed initially for 1-kilometer, 90-meter and now also 30-meter is available.

Now there might be some problem with the free DEM's, the first problem is having seam at least we have observed in case of Indian tiles. So, these seams because of different map projections are different spheroids between 2 deposits, adjacent toposheets, there might be some seam. So, that may give you some poor results. Another one is earlier 90-meter SRTM had voids that is filled with no data, though these voids were replaced with the coarse resolution elevation values like coming from USGS-DEM 1-kilometer.

So, you may encounter this problem also, though you may get void free data but for saying it is void free but in fact those voids have been filled using relatively coarse resolution cells and therefore the problem will still persist. So, though as I have said that the voids can be substituted with the low-resolution DEM but will have some problems.

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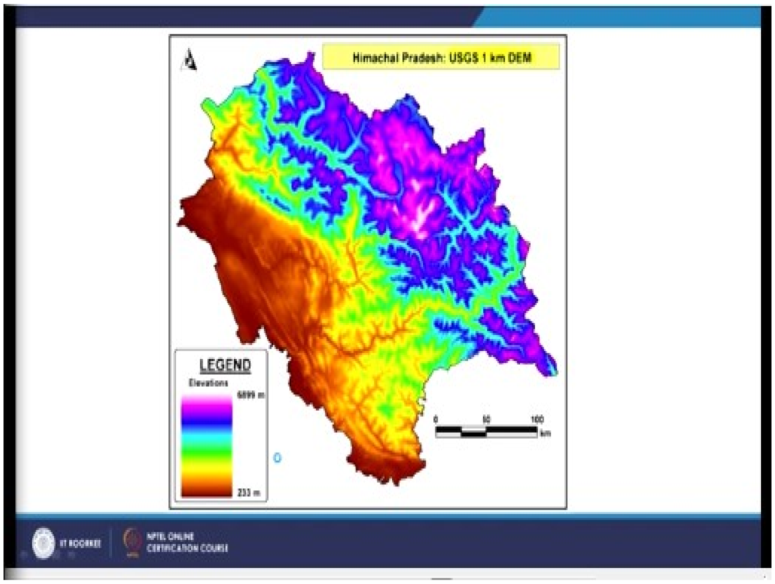

Let me give you some examples of voids. This is a Himachal Pradesh and USGS-DEM 1-kilometer that we are having.

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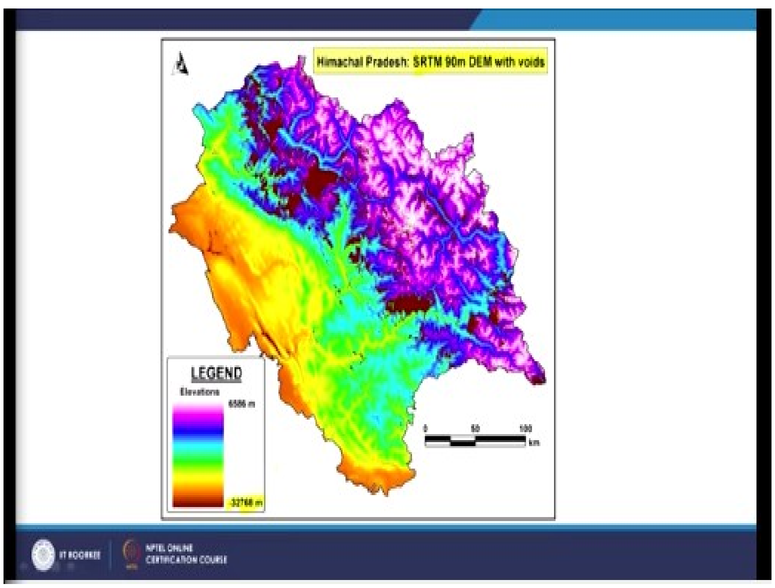

And when we compare with the 90-meter SRTM-DEM, we find that this coloured one dark maroon colour which you are seeing the areas or cells they are nothing but the voids. Because remember that SAR interferometry technique was employed in SRTM, INSAR technique was implied in to generate digital elevation model of SRTM i.e., Shuttle Radar Topographic Mission.

Now, this SAR interferometric technique when we go for glaciated terrain and a snow-covered area, there might be some problem with that data. Because of high water content, absorptions of energy due to high dielectric constant and because highly rugged terrain. And therefore, you may get these dark maroon areas at least in this display or they are having the no data value.

Here the no data value has been assigned -32768 and therefore you are seeing this one. So, implying this 1-kilometer USGS-DEM and we have filled this 1 or replace these no data values with the USGS-DEM 1 kilometer and still you can create a digital elevation model at 90-meter resolution except for those void areas and you do not see any void at this scale, but if you start zooming it, you may find some problems.

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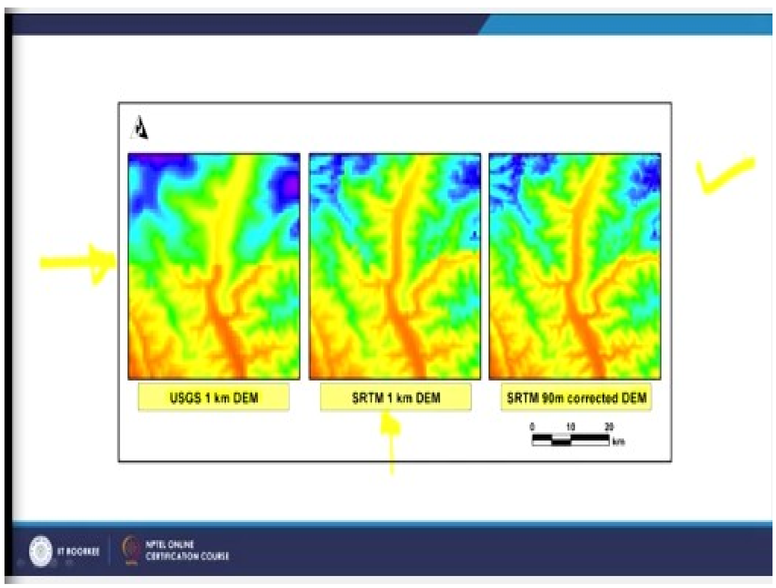

Like here, what you are seeing USGS-DEM, the seam part which I was mentioning here, see this seam, it is very clearly seen here so that means this area belongs to the part of 2 topo sheets. SRTM-DEM 1-kilometer resolution, this DEM has been used or cells of this DEM has been used to replace that voids of 90-meter DEM. So, obviously because 90-meter DEM is having much higher spatial resolution and therefore it looks much-much better and informative than 1 kilometer resolution. Similarly, one more example about 90-meter.

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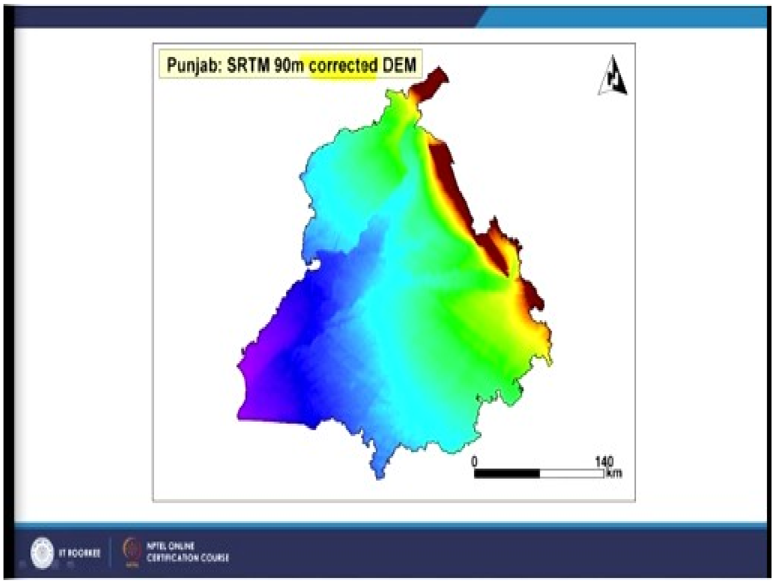

This is again corrected and corrected means a void filled DEM which is there. But in plain areas the voids are very little but in case of hilly areas, sometimes you may encounter lot of void. So, nowadays already void free SRTM-DEM's are available, not only at 1-kilometer, 90-meter but also at 30-meter for the entire globe.

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Application	Mapping scale	Specification		EO S EO sources	Remarks
		Horizontal (resolution)	Vertical (Accuracy)		
- Topographic mapping	1:200.000	30 m.	1 m.	SRTM, ASTER	Free download
	1:50.000	10-15 m.	1 m.	WorldDEM / Terra SAR-x, SPOT 5	DEM Derivatives : •Hill-shading •Contour lines / spot heights
	1:10.000	5 m. or <	1 m.	Aerial photo, LiDAR WorldView2 / GeoEye2	
	1:5.000 or larger	1 m.	1 - 0.5 m.	Aerial photo, LiDAR	
- Flood modelling	1: 5.000 or larger	0.5 - 1 m.	0.5 m or <	LiDAR DTM/ DSM	DEM Derivatives: •Slope aspect •Slope form / length •3-D Visualization
•Landslide mapping	1:2.000 or larger	0.5 m. or <	0.5 m. or <	LiDAR DTM	
•Coastal mapping	1:2.000 or larger	0.5 m. or <	0.5 m. or <	LiDAR DTM	
•Other detailed hazard mapping	1:2.000 or larger	0.5 m. or <	0.5 m. or <	LiDAR DTM	
- Elements at risk mapping	1:2.000 or larger	0.5 m. or <	0.5 m. or <	LiDAR DSM	DEM Derivatives: •Height & volume of buildings •3-D Visualization

Now just in the summary, what I am bringing here? is DEM sources of different applications at different scales. Topographic based maps I have already discussed there are some solutions are available which can be used for flood modeling, landslide mapping and for coastal mapping other details and so on. So, it depends on what scale you are going to work? and what is going to be your target?

Accordingly, you can choose the scale also, accordingly you can choose the different spatial resolution. One important point here is that you are seeing 2 resolutions, one is horizontal another one is vertical for resolutions. The reason is the least count in vertical scale generally is 1- meter whereas a spatial resolution that is the horizontal scale that is x and y. So, x and y may have a 30-meter spatial resolution but the z value may have least count of 1-meter.

So, there we can say that is having a vertical resolution is 1-meter and therefore DEM generally is having 2 resolutions, one is spatial resolution that is the horizontal one, another one, is the vertical which is about the height. So, generally there is a difference, spatial resolution is always less than vertical resolution. So, one has to be really careful while bringing these issues and the rest of the techniques are there which are based on different-different techniques and ground-based radar and like SRTM, ASTER DEM, this ASTER is again a stereo database which has been created for entire world available free of cost at 30-meter resolution.

SPOT you can generate by your own but this ASTER DEM or global DEM, WorldDEM is available free of cost and, of course, the Cartosat is also available at 30-meter resolution. So, lot of digital elevation models derived using implying different remote sensing techniques are now available at different resolutions. And many-many of them are also available at 30-meter resolution, like SRTM, like ASTER DEM, like Cartosat, all are available at 30-meter resolution also. So, by this we are having a lot of choices.

Before you start using any digital elevation model or decide to use any digital elevation model, the best thing is to assess the quality whether it is having good quality or not and that we will be discussing in future lectures. And by implying those techniques, you can assess the quality of your DEM of your area of interest and then imply for further analysis. So, with this, I close this discussion, thank you very much!