Remote Sensing: Principles and Applications
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Lecture No -26
RS Image Acquisition and RS Systems – Part 9
(Characteristics of Whisk Broom and Push Broom Scanner)

Hello everyone. Welcome to the next lecture on the topic remote sensing image acquisition and characteristics of the data. In the last class we discussed the concepts such as temporal resolution, radiometric resolution and also we started discussing about the characteristics of data collected by whisk broom scanner. In this lecture we are going to continue looking at the characteristics of whisk broom and push boom scanners. In the last lecture I told you that the data collected by whisk broom scanner will undergo increase in GIFOV.

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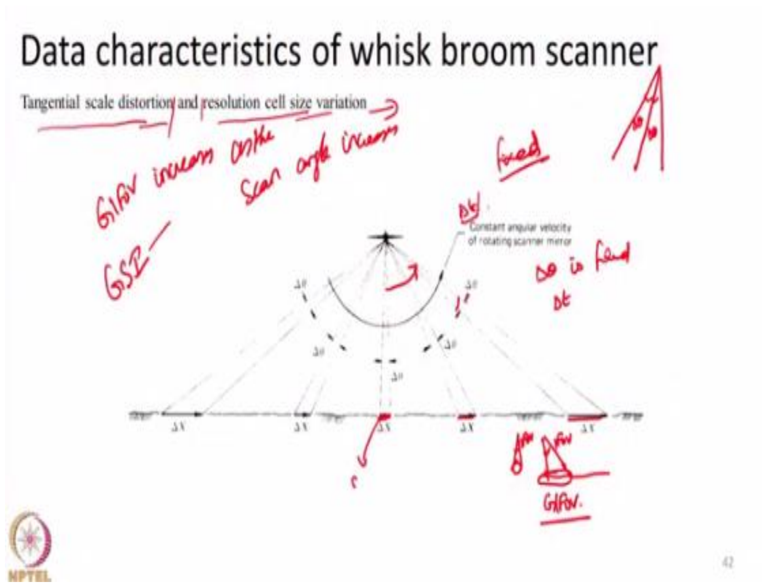

As the scanner moves away from the nadir, an increase in GSI ground resolution cell size variation occurs. I will tell you with one example of how this is happening in sensor called AVHRR.

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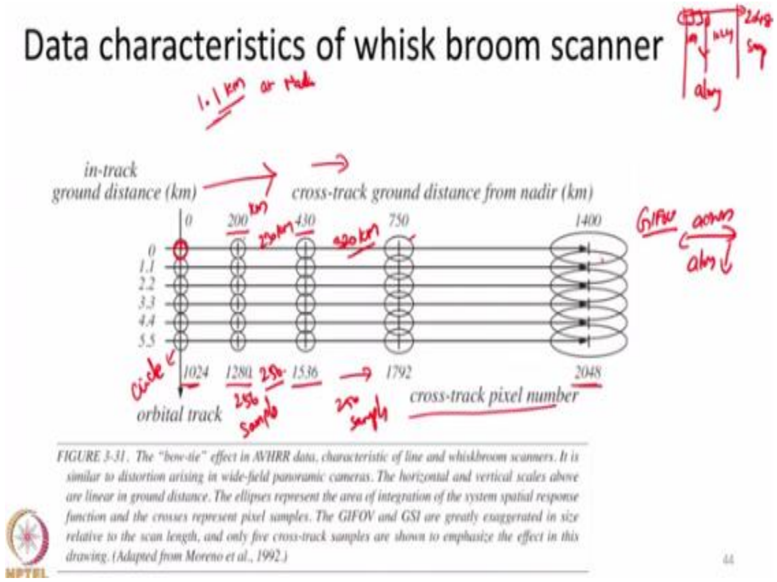

AVHRR is one sensor which works under the principle of whisk broom scanner. So, now the sensor has a spatial resolution of 1.1 kilometer at nadir. So, this is example of the data, so this collects 2048 pixels 2048 samples. See if this is the along track direction. This will be the across track direction and hence this sensor will collect 2048 samples that is, 2048 pixels will be there in the across track direction. So, this is across track pixel number.

And since this is from nadir it will be 1024 on the left side 1024 on the right side or east west we can say. So, this is just one half of it. It starts from pixel number 1024 goes up to pixel number 2048. At nadir everything is fine, the sensor has a circular GIFOV and it collects data with a radius of 1.1 kilometer. Now as the sensor moves away from nadir just see what happens. Here the sample number is 1024 here the sample number is 1280. So, the difference is 256 samples. So, 256 samples got collected in 200 kilometer distance. The next 256 samples from here to here got collected now. So, now the difference between them is 230 kilometers.

256 samples got collected in ground distance of 230 kilometers. The next 256 samples on ground now got collected with a distance of 320 kilometers and so on. So, here the number of pixels or the number of samples collected is the same. But you can see as the scanner moves away from the nadir in the across track direction same number of samples is getting collected but the ground distance covered by the scanner increases.

It was just 200 kilometers for the first 256 samples closer to nadir. The next second set of 256 samples was collected over a ground distance of 230 kilometers. Then it became 320 kilometers and so on. So, if you look at the GSI or the ground distance covered per sample the ground distance per sample increases that is the GSI or the ground projects sampling interval or GSD ground projected sample distance increases as the sensor or as a scanner moves away from the nadir.

Similarly the GIFOV that is the projection of detected element on the ground that will also elongate, will increase in size. That is also depicted clearly here. It was like a perfect circle no distortion in shape as the scanner moves away from the nadir it becomes an ellipse rather than being a circle and it starts to overlap because there is an increase in GIFOV size both in the across track and along track direction.

In both the directions GIFOV will increase and distort. So, this is because of the geometry with which the data is collected. You know if a circle is projected at an angle it will become an ellipse. Same thing is happening here with respect to GSI also. What is the effect of it? What is the implication of this? I already told you that whatever is the energy, coming out from a single GIFOV will be averaged and stored as one single value within the system.

As the scanner moves away from the nadir the GIFOV becomes pretty large. In case of AVHRR sometimes it may be even more than 3 kilometers. It should be 1.1 kilometer but it goes all the way up to say 3 kilometers sometimes at very end of the scan line. So, what will happen? Instead of collecting data over area of one square kilometer it is now collecting image over an area of 3 kilometers by 3 kilometer square.

So, whatever be the feature present there, all the radiances will be averaged together and stored within one single pixel of size 1.1 kilometer. So, essentially we are averaging energy over a very large area and storing that particular energy in a pixel assuming a pixel of size 1.1 kilometers. So, what essentially we are assuming in mind, we are assuming that the radiance recorded in that 1.1 kilometer pixel essentially came out from a ground area of 1.1 kilometer by 1.1 kilometer.

That is not the case if the pixel was at the end of the scan line then the radiance recorded in that particular pixel actually came from a ground area of 3 to 5 square kilometers, a much larger ground area. So, this is what happens in whisk broom scanners. We are collecting energy over a larger footprint of the ground averaging them a single radiance value everything is now stored in a pixel of 1 square kilometer in case of AVHRR.

So, normally in sensors with very large scan angles such as MODIS, AVHRR if some pixel falls at the end of the scan line then naturally the ground area covered for that particular pixel will be much larger than the pixel size itself. So, if the pixel size is say 1 kilometer the energy collected by that particular pixel will not be 1 kilometer by 1 kilometer. It may be 3 kilometers or 2 kilometers definitely larger than it as it moves away from the nadir. Only at nadir the GIFOV will be 1 kilometer by 1 kilometer. It will be preserved.

This we should always keep in mind when we work with data from scanners with very high scan angle. So, we should not always think that the pixel size of 1 kilometer will have the data collected from a ground area of 1 kilometer. That is not the case. We should always look at the scan angle of the scanner at which the data got collected.

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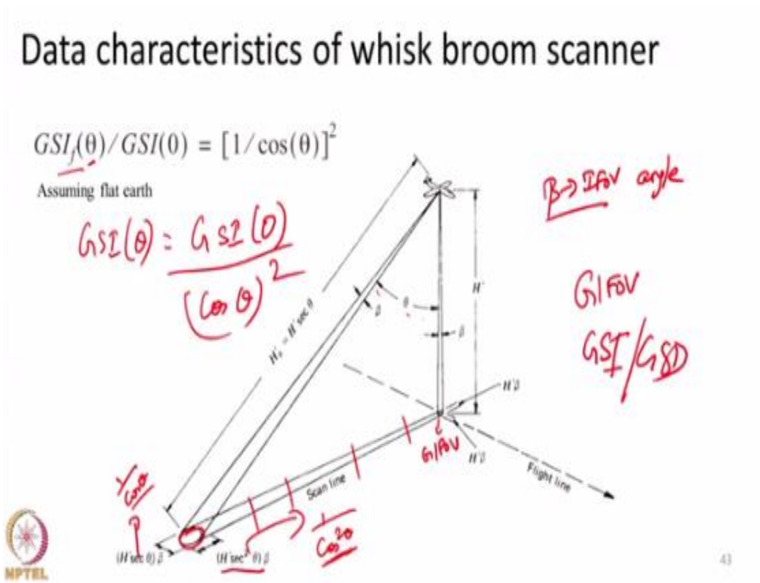

In this particular figure it is little bit clearly explained how the GIFOV will vary. So, this is the variation of GIFOV, here GIFOV element is like a circle for the system. The β, the IFOV angle is fixed for a system. It is not going to change. But as the scanner moves away from the nadir, now it has moved at a triangle θ away from the nadir the GIFOV has now increased by a term of $1/\cos^2\theta$ in the across track direction and $1/\cos\theta$ term in the, along track direction.

So, the distortion of GIFOV is not uniform in both along track and across track. It varies but essentially it varies in terms of $1/\cos^2\theta$ in the across track $1/\cos\theta$ in the along track. This is for the variation in GIFOV. Similarly GSI also will vary. GSI at an angle θ away from the nadir is equal to GSI at nadir divided by $(\cos\theta)^2$.

$$GSI(\theta) = \frac{GSI(0)}{(\cos\theta)^2}$$

So, the GSI the ground sample distance will also be keep on increasing in addition to GIFOV. You should always remember the GIFOV will increase the GSI will increase GSI or GSD will increase. So, here again coming back to this AVHRR example this ellipse denotes the GIFOV this lines represents the points at which the samples were collected that is essentially the GSI. So, this we should always keep in mind that the data collected by a whisk broom scanner always has enlarged GIFOV problem an enlarged GSI problem as the scan angle goes away and away from nadir.

Actually this is the main drawback of all sensors having a very wide swath angle. We can make all that we can just increase the scan angle of all the sensors and start collecting data over large areas of the globe, possible. But as the scan angle increases the distortions will also increase and hence not all systems has this large scan angle. Only certain systems which has the need to cover the globe really quickly such as MODIS or VRS sensor and all they are equipped or they are provided with a large scan angle. Because they are sent with an application they should cover the globe regularly at a much larger temporal frequency. That is why they have been provided with such a large scan angles but they will have their own distortions which we should always keep in mind when we work with such data sets.

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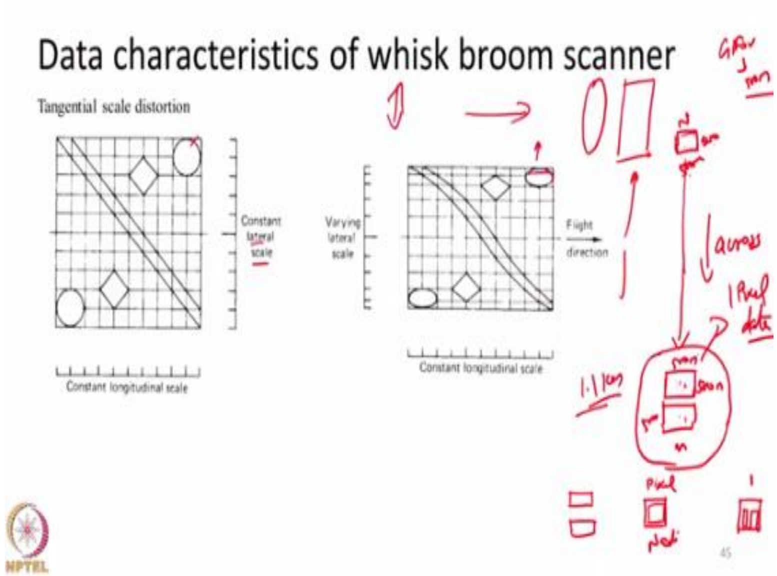

Now just we will see one example of geometrical distortion that will happen in this whisk broom scanner that is what is known as a tangential scale distortion. So, what exactly is a tangential scale distortion? a very good example is given here in this particular slide. Here you can see an image of an area taken as it is. So, the scale is, lateral in both along track and across that direction.

Now this is the along track direction this is the across track direction. Now I have told you that as the sensor scans, as the scanner moves away from the nadir, the GIFOV will be keep on increasing. It will become like an ellipse or it will become like a rectangle. so what will happen? Let us say there are two buildings one exactly covering the size of GIFOV of the pixel.

Let us say some feature 500 meter by 500 meter is there. Now this is at nadir and let us say the GIFOV of the system is also 500 meters. This will be covered as one single feature. So, it will be represented as it is. Now let us come to the end of the scan line, let us say there are two adjacent buildings each of size 500 meters by 500 meters. If these two buildings were at nadir they would have been imaged as two separate points in two separate pixels.

But now let us say this is at end of the scan line this is across track direction. Now the GIFOV has become let us assume 1.1 kilometer. Let us say the GIFOV has increased at the end of scan line. So, now the GIFOV will be covering both the buildings together. So, initially at nadir the GIFOV was just 500 meters, building size was also 500 meters it was imaged perfectly. Now at the end, the GIFOV has increased. It is now covering two buildings together. So, what will happen? Because of this both the buildings will appear little squeezed. Because this will be stored as just one pixel data. But instead of showing one building per pixel both the buildings will be located let us say this is the pixel at nadir. This is the pixel at the end of the scan line.

Here you will see the image of only one building at nadir. At the end of scan line because both of these two buildings were covered by the same GIFOV element, this pixel will have both the buildings covered in one pixel. So, when we see those pixels what we will feel those two buildings actually have a smaller size than what actually it is. So, as the scan angle increases objects will appear squeezed together in the across track direction that is depicted here in this example also.

Here it is like a perfect circle actually but because of this scan angle distortion it is now squeezed and appearing as an ellipse. Similarly this diamond is now squeezed in the across track direction. So, these two are squeezed and they will appear little shorter in size. They will be squeezed only in the across track rather than along track. So, objects will appear squeezed in the across track direction when compared with the along track direction. So, a circle present at the end of the scan line may appear like as an ellipse rather than appearing as a circle. It will be squeezed in the across track direction.

This is what is known as tangential scale distortion. Objects will be squeezed, will appear like distorted or squeezed as the scan angle moves away from the nadir continuously. So, till now we discussed the characteristics of whisk broom scanner. We saw few examples of how the GSI changes, how GIFOV changes and all. So, these are some of the important limitations of whisk broom scanning.

So, that is why now most of the systems are moving to push-broom scanning. Push broom scanning avoids these sort of geometrical distortions to a large extent.

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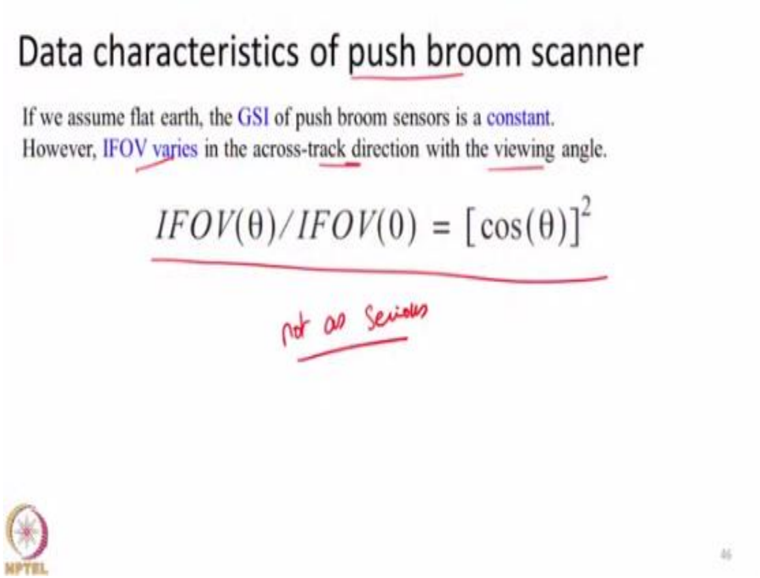

If the scanning introduces more distortions then finally the geometric accuracy will be affected. Geometric accuracy means, for a ground point having a coordinate of (x, y), if we calculate the coordinate from the image we should get the same coordinate (x, y). Let us say there is a building standing at point (100, 100) coordinate on the ground. From the image also the building should have a same ground coordinate, (100, 100). But just imagine in whisk broom scanning if everything appears squeezed together in one pixel we may wrongly calculate the coordinate of that building, if we do not correct for geometric distortions. So, whisk broom scanners come with their own geometric distortions which affect the geometric accuracy of the image.

There is always a need to do correction of these images. That is a major limitation of whisk broom scanner. In push broom scanner all these sorts of distortions are reduced to a large extent. Because in push broom scanner if you assume a flat earth then the GSI will not change. Because in push broom scanner we are having lot many detector elements. Each detector element will cover simultaneously the different parts of the area in the ground and whatever energy comes in will be saved. So, the sampling interval is actually set. Because I told you in the earlier classes the GSI for push broom scanner is determined by the spacing between two adjacent data elements. That is fixed when the system is launched and that is not going to change.

So, GSI is not going to change for push broom scanner. But the IFOV will change, because the pixel at the center will have a full conical angular coverage. But the detector at the end may not have that particular coverage. So, the IFOV will change that is given in this particular slide and the IFOV varies in the across track direction due to the viewing angle. IFOV will vary with this particular ratio.

But in general the distortion in push broom scanner is not as serious or not as troublesome as the distortions occurring in this whisk broom scanner. So, naturally push broom scanners because of their fixed detector pattern which is not going to change and since there are no scanning involved, that particular image will have higher geometric fidelity or higher reliability in comparison to images acquired from whisk broom scanners.

This is a major advantage of using a push broom scanner over whisk broom scanner. So, already we saw one advantage that push broom scanner provides a very high dwell time in comparison with whisk broom. That is a major advantage but one more advantage is the geometric fidelity of the images acquired by push boom scanners much higher than the geometric characteristics of data collected by whisk broom scanner.

Now some distortions we have seen that can come because of angular scanning geometry or data collection geometry and so on. But as the sensor is moving or as the satellite is moving, there can be change in attitude of the satellite which can cause geometric distortions. So, what is attitude of a satellite, we will just take an example of an aircraft. So, let us say an aircraft is moving like this.

So, this is the flight direction. Let us take this as x axis the direction in which the flight is moving and this is y axis that is towards the screen, z axis is the vertical. We will take three axes. Now the flight is moving like this. Let us imagine if I hold the x axis and rotate the flight, what will happen? The flight will rotate like this. So, this is known as roll. Then the pitch is when I hold the y axis and I rotate it now. So, what happens, the plane nose moves up or down. This is known as pitch.

So, rotation along x axis is known as roll, rotation along y axis is known as pitch. Similarly I now hold the z axis and rotate. This is known as yaw. So, pitch is the nose of the airplane going up and down. Roll is this plane itself rotating and yaw is moving along the z axis. That is what we call attitude or distortions in attitude of a platform.

In airplane we can feel this if we are travelling for long distances. The flight will undergo a roll especially when the captain banks the aircraft and it can have a pitch during landing they will increase the pitch. So these distortions pitch, roll and yaw together we call it as the attitude of the platform.

Similar to aircraft a satellite can also undergo minor variation like this. Even if the satellite is project planned to move in one particular direction without any movement, sometimes some unwanted things can happen. Solar storm, atmospheric drag, change in gravity on the earth's surface all these things may change the position of the satellite, may cause some distortions in the attitude pitch roll yaw, which will cause distortions in the image.

So, when finally the data comes down from the satellite, it will also give information about its position and attitude. At which position it was when the image was collected and what was the attitude; the pitch, roll and yaw of the sensor. Everything will be sent together. So, the people sitting here in the ground will process the data and correct the image for this variation in satellite altitude. So, that is what is given in this particular slide here.

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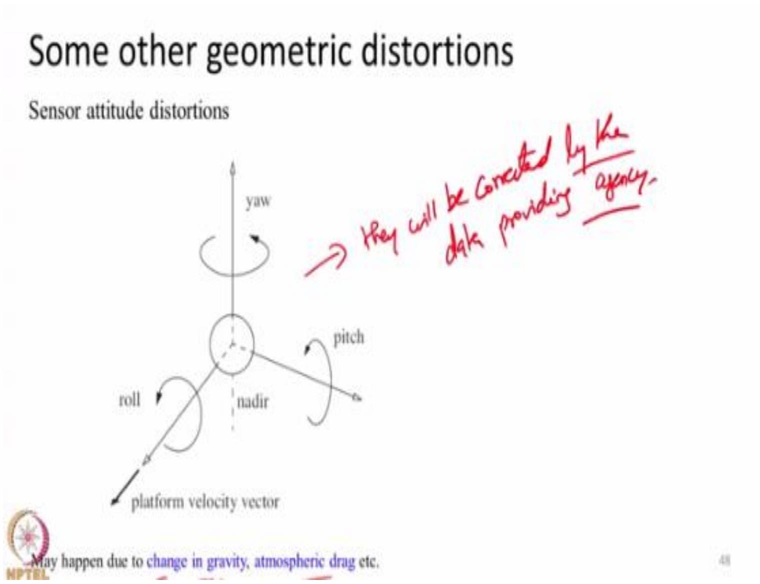

Here I have just, shown you how pitch, roll and yaw is defined and the change in pitch, roll and yaw may happen due to change in gravity, atmospheric drag or some effect of solar winds etcetera. And normally they will be corrected for any distortion in the pitch roll yaw. If a satellite has to move like this while collecting data and suddenly it has undergone a slight roll, what will happen? Instead of collecting ground point here, the sensor would be looking somewhere away from it. So, the geometry of the image or the geometric accuracy of the image is lost, instead of collecting here it is now looking somewhere else. So, that attitude information will be passed on to the ground and they will correct it. Now the satellite is not looking at the ground point x, y it is now looking at some other ground point x 1, y 1. Hence we should correct it. So, these sorts of corrections will happen even before the data reaches us.

So, we need not worry about it but most of the time it is always good to know. So, they will be corrected by the data providing agency who manages the satellite. So, till now we have seen some distortions in the images due to scanner characteristics, due to attitude characteristics and so on. There are other ways also in which the image or the data we get from satellite may get distorted. Some of them are; First thing is a multi-band co registration error.

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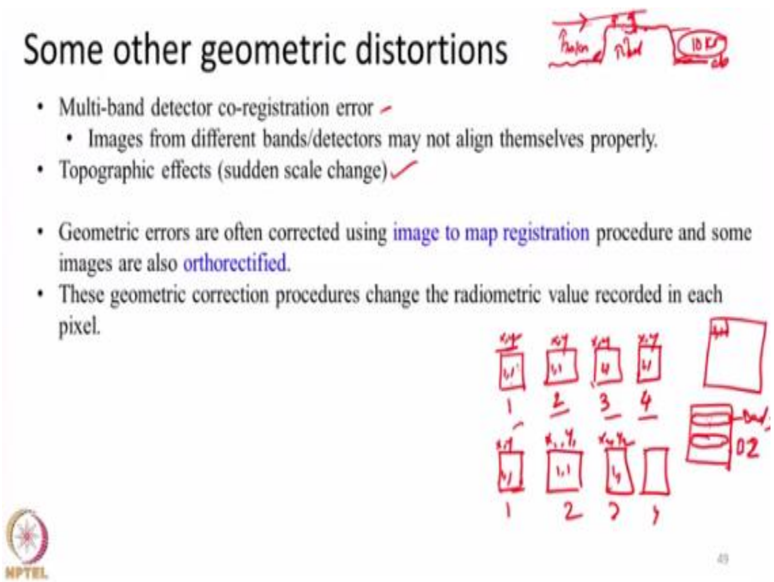

Let us say the satellite is collecting images in four bands. This is 1 pixel with coordinate (x,y) band 1, ground coordinate (x2,y2) band 2, band 3, band 4. This is 4 bands. It is collecting image over some ground point (x,y). Let us say this is pixel number (1,1), a 2d image. In all the four band images pixel number (1,1) means first row first column. So, pixel number (1,1) should correspond to same (x,y). Then only we can say all the multiple bands within the image has same geometric accuracy. So, what essentially happens is all the four band sensors are actually located slightly away from each other and the ground points has a very high chances that same pixel in each band pixel number (1,1) may have information about different points on the ground.

Let us say four bands are there in one particular sensor, all the pixel number in the four band image should correspond to same ground point. There are high chances that any given pixel in all the four band images may look at different parts of the ground. It is possible there can be slight mismatch in the ground data collected by four different bands or n number of different bands whatever be the number of bands. This is called as multiband co-registration error. Same pixel number (1,1) in all the bands has different ground points imaged on it. They must be corrected, because we normally stack all the image data one over the other and then we visualize or then we process. So, all the bands, all the pixels should have same corresponding coordinates with its adjacent bands. This sort of errors is quite natural, it can happen in satellites. They are also nowadays mostly corrected by the data providers.

The next error that may come is topographic effects, sudden scale change. Let us say a satellite is flying and there is a terrain like this. Suddenly there comes a large plateau. What will happen and let us say this plateau is quite tall, for example Tibet, pretty high region. Suddenly the orbital height of the satellite will be reduced from the surface. There is a drastic change in the height of the satellite above the terrain at this point. So, when it comes over this, there will be a change in scale because of these points which appear closer and zoomed in. That is what we call topographic effect, a sudden scale change in image due to presence of large topography.

So, these are the two examples of image distortions and they have to be corrected. I told you there will be lot of distortions will that affect the geometric accuracy. How to correct it? Nowadays mostly we need not worry about the geometric accuracy of the data. The geometric standards are pretty high for nowadays images. They are almost corrected for distortions to the extent possible and it is being supplied to us. That is if it is a ground point x,y on the ground, then in the image also you will be able to identify it pretty closely. The accuracy is high now. But how to generally do it? say if we got one image which has some geometric distortion in ground. A ground point is having a coordinate of (100,100) but in satellite if I calculate the coordinate is (75,80) that is the change. How to correct it? Then we need to do a process of what is known as image to map registration. That is we should have a proper map of the area. Let us say we have it in map. We assume all the coordinates are perfect and correct. So, what we do, we take an image and identify some pixels in the image whose ground coordinates are already known. Like this we will identify some 5 to 10 points in the image get that actual ground coordinate from a map or from a GPS survey we have done on the ground.

We will feed it into image and reorient it or create a new image after correcting for geometry distortion. This is known as image to map registration. Similarly when some scanners look at some angles away from nadir, we can also correct to some extent and make sure that the image appears as if the scanner is looking from nadir. That is from top angle a building may appear like a square. But from an angle instead of looking a square or seeing the top, I will see the side of the building. That sort of distortions will be there, we can correct for such distortions. We call it as ortho rectification. We make sure that all the points on the image will appear as if we are looking from the top. So, these are some of the examples in which we will correct the image. Actually these sorts of corrections or the detailed principles will naturally form a part of digital image processing course. So, we will not cover these topics in this particular course but just for your information I am telling all this.

So, in the last few series of lectures we discussed in detail about the four important characteristics of a remote sensing system; spatial, spectral, radiometric and temporal characteristics. After which we also discussed what are the different ways in which images can be distorted or the characteristics of the data. The change in GIFOV element in whisk broom scanners and all actually cannot be corrected even though we can do some sort of geometric correction. But once the GIFOV is enlarged and data is collected over it, we cannot change it practically speaking. So, that sort of characters above the data we should always keep in mind and we should remember them while we work with remote sensing images, with this we end this lecture.

Thank you very much.