REMOTE SENSING FOR NATURAL HAZARD STUDIES

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Lecture 3a: Errors in Remote Sensing Part A

Hello everyone, this is the third lecture of the NPTEL course on remote sensing for natural hazard studies. In this lecture, we will learn about the errors in remote sensing data. So, we have two parts to this particular lecture. So, this is part 1, and then the next will be part 2. So, we will start with the errors in the remote sensing data. So, what are the sources of errors that you can see here? So, when the sun is illuminating this particular ground, some of the energy is being reflected and reaching the sensor, and in between, we have an atmosphere that has cloud coverage as well as atmospheric constituents in terms of aerosols, gases, and dust particles. So, that also interacts with the incoming radiation that we learned in the previous lecture; these atmospheric constituents can lead to the scattering and absorption of the incoming radiation, and that leads to path radiances. So, those are the additional information captured by our sensor along with the real information. So, when we have this particular scenario, what are the different sources of the error here? You can see that the surface topography can also lead to errors in your remotely sensed data because somewhere we have hills and somewhere we have these kinds of features or topography, and our sensors are here, which are looking with a constant field of view at these areas, right? So, depending on the elevation and depression, the pixel size will also vary, and since the Earth is also rotating on its axis, that introduces error into our data. So, this is the path of our satellite. Now, coming back to this atmosphere, these atmospheric constituents will also interact with the incoming radiation and will give some error in our data. It is also possible that our instrument, or one of the sensors or a few of the detectors, can stop working temporarily or maybe completely. In such a scenario, we have many sources of error in our remote sensing data. Now, you will understand it better here. So, let us say this particular satellite is looking at this particular ground, and this satellite basically has this sensor, and this sensor has many detectors that are looking at the ground with their field of view.

So, one of the detectors will have IFOV. So, with this IFOV, they will be looking at this particular ground. Right, and then we generate the images. So, there is a possibility that the source can also introduce some error if there is a fluctuation in the incoming radiation
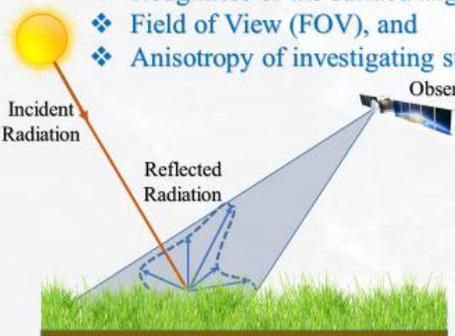
because we need both irradiance and radiance to calculate the reflectance. So, if there is irregular incoming radiation or there is a hindrance because of the atmosphere, that will also lead to an error in our remote sensing data. It is also possible that part of the detectors or some of the detectors may stop working temporarily, and that will also cause an error in our data. We have the atmosphere, then we have the ground; in the ground, the slope can also impact the data. Due to the slope, the surface can appear differently in our image, which is also a kind of error, right? So, these errors are found together in remote sensing data. So, we have to be very, very careful while using these satellite images in our analysis; before that, we have to remove these errors from our remote sensing data, right? So, the parameters that affect remote sensing data that acquire reflectance or emittance energy through remote sensing sensors are influenced by the following parameters. So, here you can see them one by one. So, this first one is the source sensor geometry. So, suppose this is the source of your energy, which is illuminating this particular target. So, this is the target, and then it is reflected and captured by this particular sensor, and as we discussed in the previous lecture, because of the anisotropy, there is an inhomogeneity in our surface. What happens if you change the position of the observer or the sensor is that there will be a different amount of energy reaching this particular sensor, right? So, that source sensor geometry. So, what is the geometry of the source and the sensor, whether this sensor is looking nadir, which means perpendicular to the ground? Or it is with some viewing angle. So, this theta will be there, or whether it is towards this side. So, this theta will be there, right? So, depending on the angle or the position of the source and the sensor, the amount of energy will also vary. Then comes the target of the surface. So, suppose there is a smooth target; the amount of reflection will be different, right? If it is an undulating surface and it is rough, then the amount of scattering or reflectance reaching our particular sensor will be different.
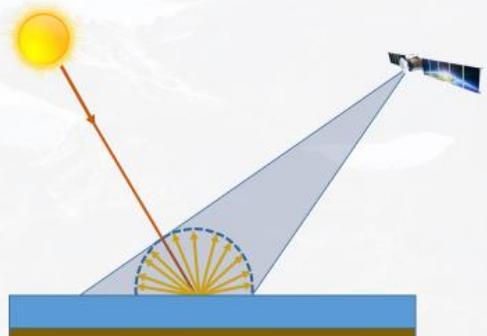
So, that is the meaning of the roughness of the surface target. So, whether the grain size is small or big, it also causes the error or the signal to change. The field of view that we have already discussed is the anisotropy of the investigating surface. So, here you can see this is one example where we have taken the natural conditions and the sun as our source of light. So, this light is falling on this particular surface, and this amount of energy is getting reflected. So, you can see that at this particular angle, the reflectance is high, but our sensor is here, which has this energy, right? So, this energy has to travel through the space to reach our sensor. So, this source sensor geometry is very, very important. Another thing is that when we have the Lambertian surface, if you remember from the previous lecture, the property of the Lambertian surface says that it reflects an equal amount of energy in all directions, and it does not absorb any energy, right? So, in such a situation, the reflectance will be high, but this is not possible with natural or manmade materials because this is a theoretical concept that Lambertian surfaces are hypothetical. So, with a certain chemical composition, we are able to make the Lambertian surface, which does not absorb any energy and reflects an equal amount of energy in all directions. So, here you can see the effects of source sensor geometry and the field of view. So, here you have the position of the source. whether it is here or whether it is here that will also have an impact on the data. So, here the angle will be theta divided by 2; this is θ. So, depending on the position and the field of view of your sensor, the amount of data or energy acquired by your sensor will be different. So, whenever you are correlating with the ground measurement or when you are upscaling the ground information, then you have to take care of the angle of measurement and the source sensor geometry.
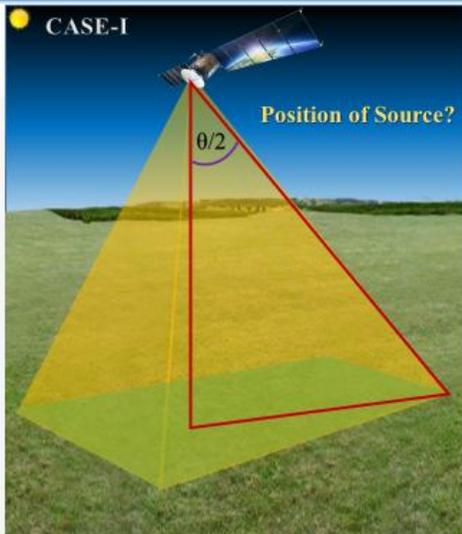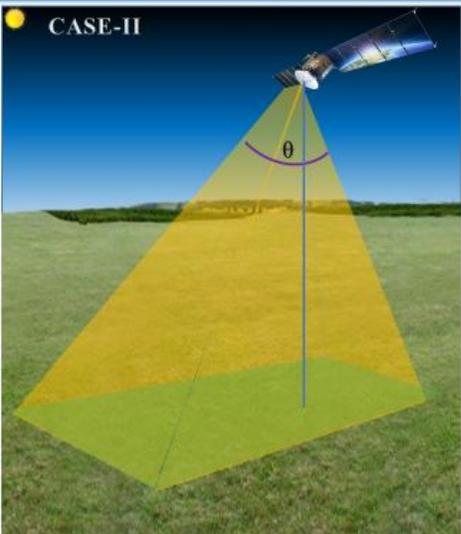

So, this particular slide says that when you have the incident radiation and the reflected radiation at the same angle, right? So, you will be putting one sensor here; the same sensor

is used here. Right, and then it will also have a field of view that will measure the incident radiation; we call it irradiance, right? So, this irradiance is used to calculate the reflectance. Remember from the previous lecture, reflectance is equal to radiance divided by irradiance, and the unit is watts per meter squared per steradian. So, when we use the same sensor to measure this particular irradiance value at the ground, we will have this unit. The same sensor is used here. So, here we also have the watt per meter squared per steradian, right? Then these units are canceled, and reflectance will be unitless, with the value ranging between 0 and 1. If you use a different sensor or suppose the sensor that you are using to measure the irradiance value does not have the right field of view, it is a 180-degree measurement. So, in that case, what will happen is that this steradian will not be involved. So, it will be watts per square meter, right? So, when we have the watt per meter squared per steradian, then watt per meter squared, then your reflectance will have the per steradian unit. So, this is called the BRDF and BRF concept.
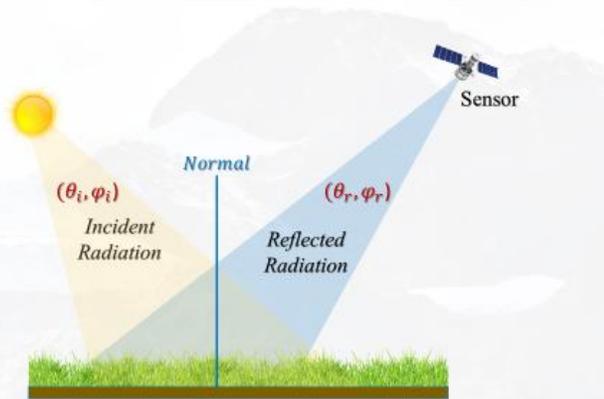
You can refer to. So, in this particular lecture, since the time is limited and our objective is mainly the natural hazard. So, we will not spend much time on this. So, if you are really interested in learning this, you may refer to my publication on the BRF and BRDF. Now, here you will see what I am talking about: the atmospheric, geometric, topographic, and radiometric errors. So, these errors are very, very prominent in your satellite images, and some of the errors you do not have to worry about if your application is different. So, like atmospheric correction, geometric correction, topographic correction, and radiometric correction, you may remember that we discussed the scattering. So, this scattering is greater in the shorter wavelength region. However, in the longer wavelength region, we don't have much of a problem with this scattering. Similarly, the absorption is greater in the longer wavelength region because, as you know, if a material is absorbing energy, it will release

energy in the longer wavelength region. The emission will take place at a longer wavelength. So, the absorption will have more impact in the longer wavelength region, while scattering will have more impact in the shorter wavelength region. So, the atmosphere is always present; it doesn't matter which wavelength you are working on, but you will be surprised to know that when you are using 400 to 2500 nanometers. This wavelength is more affected by the scattering, and beyond this, it will be more affected by the absorption processes. So, we will see these things in detail.

So, the first one is the atmospheric error, the error introduced by atmospheric attenuation, right? So, because of the atmospheric constituents like clouds, gases, and dust particles, aerosols will interact with our incoming radiation, modify it, and change its direction; because of that, we are not able to predict the direction of this scattering. So, those things are very, very critical when we talk about the atmospheric error. So, here you can see one of the examples, and it says that it has an atmospheric error; you can see the white patches. So, there are methods that can be used to remove the atmospheric errors, and you can see this is after the processing of atmospheric errors. Now, the next one is the geometric error because of the acquisition and the platform variation. What happens? Images are getting tilted, and because of that, we are not able to find their appropriate location on the ground. So, before we use them on the ground, we have to remove the geometric error, and this is one example. So, this image is tilted, and after the processing, it will acquire its original position, and then we can use this pixel information because this pixel will have latitude, longitude, and the DN value, right? So, these latitudes and longitudes can be used to identify the pixel on the ground. Now, the next one is a topographic error. As I told you in the previous slide, because of the slope, we also get the error, because if, suppose this is

the sensor, this is the source. So, this illuminates this target, and we assume that wherever our pixel or the detector is looking, that is flat ground. So, what if there is more slope, so that the error in terms of the area that will be in your satellite images, right? Now, the next one is radiometric error; it is introduced by the sensor system. So, one of the detectors or some of the detectors may stop looking at the ground once they stop acquiring the information. Sometimes it happens for a moment, and sometimes it happens for a longer duration. Sometimes it is also possible that they get out of order, the calibration goes wrong, and then, because of that, the radiometry of this particular sensor will be bad.

So, this is one example of radiometric error you can see, and this is after the correction, right? So, this part is clouded with white patches you are not supposed to see. Do you see this particular portion, right? So, after the atmospheric correction, you see that these images are enhanced. So, let us talk about the atmospheric errors. So, atmospheric attenuation introduces errors in the satellite or airborne images. The atmosphere is composed of various stable and variable constituents. So, here, the nitrogen, oxygen, and several inert gases constitute 99.9% of the total air. Carbon dioxide, water vapor, and solid and liquid particles contribute to the variable components that may vary with region, season, and weather conditions. Because you might have experience in your area, during the summer you will have more dust; in winter it will be much less, and during the rainy season you will have different problems. This weather condition varies by season as well as by region, right? The suspended liquid or solid particles are generated from volcanic eruptions, sandstorms, forest fires, industry, transportation, construction, etc. So, these are called aerosols, which include haze, smoke, and fog. So, this aerosol includes all the output of the forest fire industry, transportation, and construction, along with haze, smoke, and fog. The atmospheric correction is a process by which the effect of atmospheric attenuation on the satellite images can be removed. So, this is a very, very important step in using remote sensing. First, you have to download the data, and then you have to see whether your data requires correction or not; that you will be able to see, right? So, before any quantitative analysis, atmospheric correction is mandatory.

Interaction between atmospheric components and electromagnetic energy, the most efficient absorbers of energy, includes ozone, carbon dioxide, and water vapor. The absorption bands in the electromagnetic spectrum are distributed as ozone, carbon dioxide, and water vapor. Now you see, remember that atmospheric window. So, here we had this kind of spectrum, right? And this was the transmittance, and this is the wavelength. So, wherever you have a higher value, that means these wavelengths are allowed by our atmosphere. This is just an example; right, this is not the real spectrum. So, when we refer to the atmospheric correction, these gases play a significant role. So, you can see the first one, the ozone has characteristic features at 0.22 to 0.32 micrometers, then at 0.6 micrometers, at 4.7 micrometers, 9.6 micrometers, and 14 micrometers. So, these wavelengths are getting affected by the ozone layer, right? Then comes carbon dioxide. So,

1.4, 1.6, 2 micrometers, 2.7, 4.3, 4.6, 5.2, and 15 micrometers are affected by carbon dioxide. Then comes the water vapor.

This is 0.94, 1.1, 1.38, 1.87, 2.7, 3.2, and 6.3 micrometers. So, these wavelengths will cause the error in your data. why? Because these will not allow these energies to pass through our atmosphere. So, now we will look at this particular problem from a different perspective. Now, let us say you have a satellite image; you have the sun illuminating this particular area, and this sensor is looking at this particular ground. Your spectrum is that you are generating multiple images, and those multiple images can be considered as one pixel, and then you will be generating this particular spectrum. This kind of spectrum, so this is reflectance; this is wavelength. This might be because of the surface, but if you refer to this carbon dioxide, let us say this is 2.7 micrometers. So, at 2.7 micrometers, you will get the noises right because of the presence of carbon dioxide. So, for Earth exploration people, this might be treated as an error. However, for the atmospheric scientist, this is the data. So, this is the data. So, what we will do is use this particular wavelength region and the behavior of the signal that is present here to study the presence of, or how, carbon dioxide is distributed in that particular region, right? So, this is one of the very important aspects that I wanted to discuss.

Now, another thing is that to correct the atmospheric errors, we try to use these characteristic absorption features, and then we estimate the amount of carbon dioxide present in that particular region, which will be used to correct the atmospheric errors. So, this will be your input, and this is your output. So, corrections for molecular absorption and scattering by the stable components are easy since they are non-variable in space and time. So, the molecules that are stable, the stable components of our atmosphere, are very

easy to identify because we know that these particular gases are always present in the atmosphere. So, the absorption and scattering of those gases can be modeled and removed directly from the data. Atmospheric correction mainly involves the estimation of the influence of water vapor and aerosol. Right. The surface characteristics and the received energy are connected by the radiative transfer model. So, this is one basic equation that has been used in remote sensing, where L is the radiance. When you calculate the radiance, we use the observation angle coordinates and the relative azimuth between the solar direction and the observational direction. Zenith angle, aerosol optical thickness, single scattering albedo, and scattering phase function. This information is required to calculate your L. right. So, this is your L.

The atmospheric correction methods can be grouped into two major categories. So, the first one here is relative atmospheric correction, and the next one is absolute atmospheric correction. So, the name itself is very clear that relative atmospheric correction means that, with respect to some assumed value or maybe some measurement, we will be correcting our data for the atmospheric errors. Whereas in the absolute atmospheric correction, we will visit the field at the time of image acquisition, measure all the atmospheric constituents, model them, and remove the absorption and scattering components of our atmosphere. This will give you the true value. This will be near the true value, but it is very popular because it is very difficult to measure the atmospheric constituents for the historical data where we cannot go, and for the inaccessible areas, this relative atmospheric correction is the only option, right? So, in the relative atmospheric correction, you have two methods: one is scene-based, another is scene plus ground-based, and then another one is the absolute atmospheric correction. So, there are various methods that can be used to achieve absolute and relative atmospheric correction. So, here I have one course that is on remote sensing

and GIS. So, if you are interested in learning these corrections, then you can refer to the videos on remote sensing and GIS. This is an example of atmospheric correction. So, this image has atmospheric effects, and you can see how it appears after the correction.
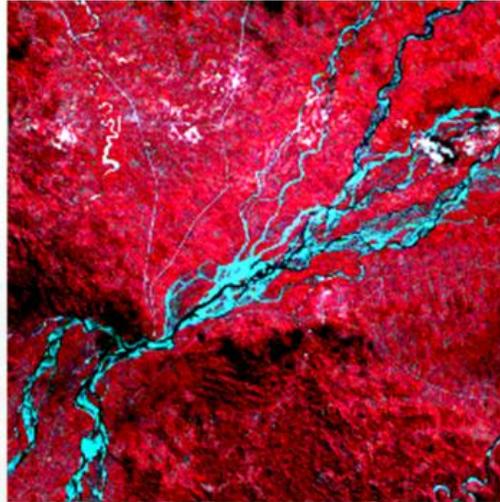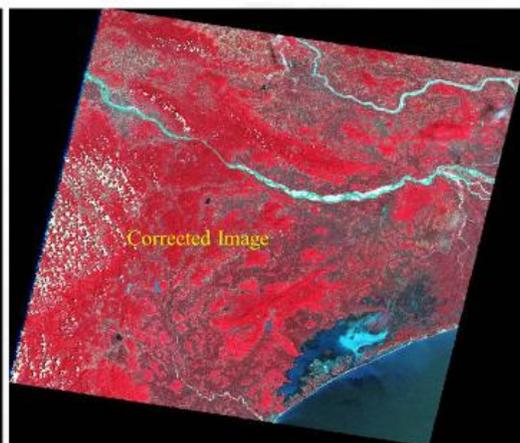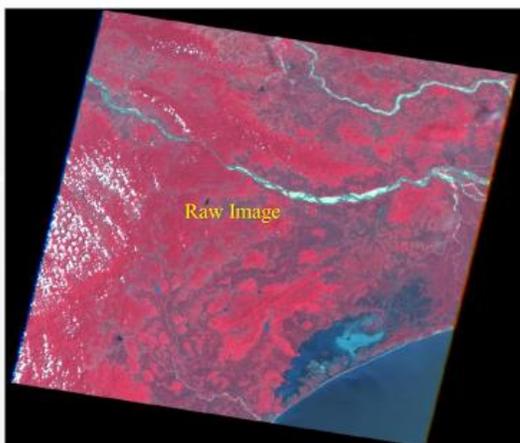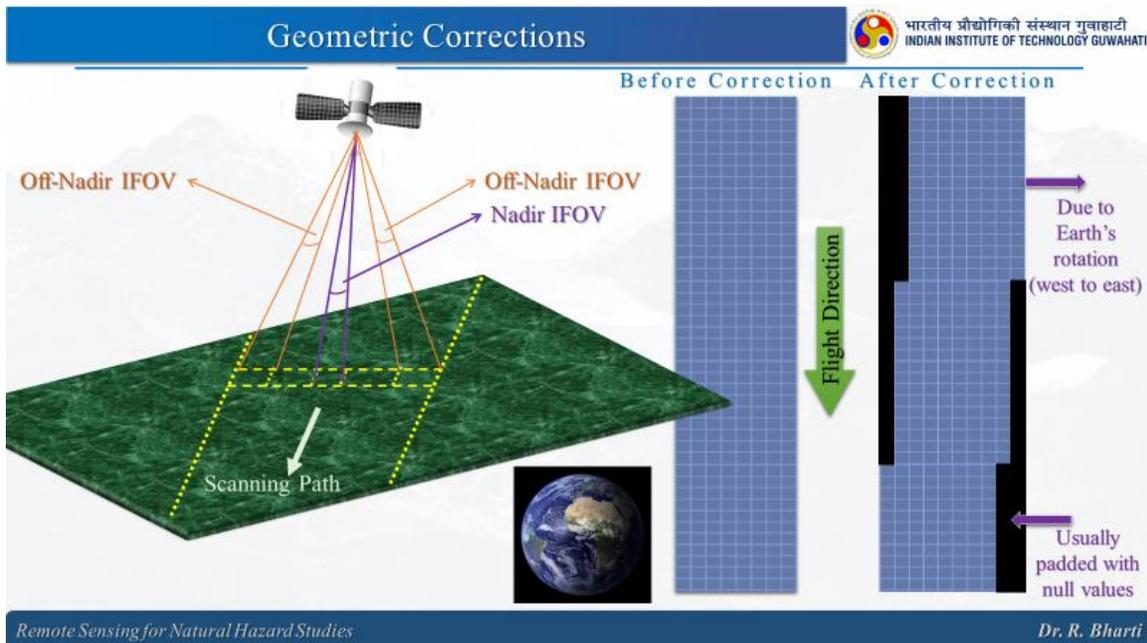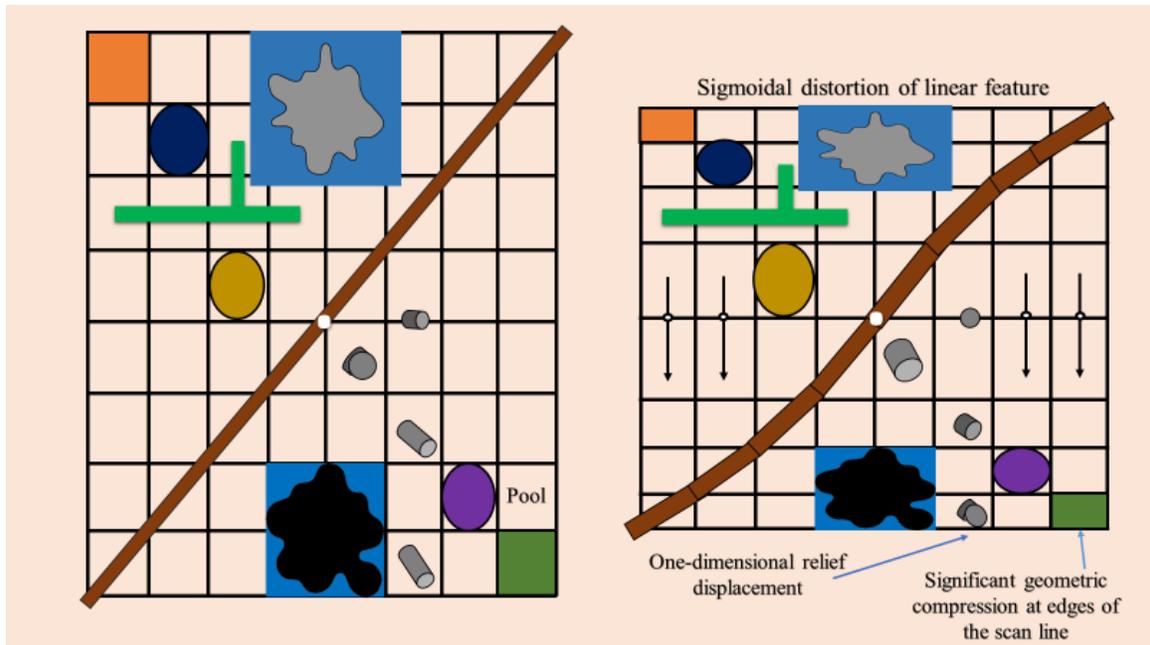

This is another example you have already seen; this is after processing. This is another example. So, in both slides, I have put some examples. So, you will be able to perceive how atmospheric correction works and how your images may look after the processing.

Now comes the geometric distortion in the remote sensing image; this is very, very important. So, in addition to the sensor technology mode of acquisition and platform, remote sensing images may have geometric distortions, right? So, it occurs when we attempt to accurately represent the three-dimensional surface of the Earth as a two-dimensional image. Just for example, you are here, and you are taking a photograph, right? And here you have the ground, which has some undulation in the topography; because of this, you are taking from here or maybe from here. There will be distortion, right, because of the topography. So, this geometry of the Earth will also cause the problem. Now, consider this is one part of the Earth, right? So, this is one section of the Earth's sphere. Now you are taking the measurements for a smaller area. For the smaller area, you may not notice the curvature correctly. But if you consider this whole area the curvature, you can easily feel it right; but here, since we are not able to notice that, it does not mean that it is not there. So, that kind of problem we will have in the geometric error that arises because of the geometry of the surface. So, here are the sources of the geometric error: the perspective of the sensor optics, the motion of the scanning system, and the motion and instability of the platform. The platform's altitude, attitude, and velocity. So, you will understand this in the next slide, where I have put an animation. The terrain relief, curvature of the route, and rotation of the earth are important because what is happening is that the earth is moving; this is the satellite path covering this particular area, and then it is moving in the other direction. So, when it is moving from this point to this point, the Earth is also moving; the Earth is also rotating. So, what is happening there will be a slight shift in the acquisition. So, it will slowly get like this. So, this will shift the scene from here to here, and it may shift to this side. So, this kind of error will lead to the geometric errors that we need to correct before we use these images in our analysis.

Sigmoidal distortion of linear feature

One-dimensional relief displacement

Significant geometric compression at edges of the scan line

So, it removes the geometric distortion and places individual pixels at their proper map locations. So, this geometric distortion suggests that nowadays we are all using Google Maps, and whenever you click a photograph with your mobile camera and check the history on Google, you will find that it shows the globe, and you have taken a few photographs here, a few photographs here, a few photographs here, right. So, how is it that you have visited that part of this world and captured so many photographs? Why? Because these images basically have the latitude and longitude. They are geotagged. Geotagged means they have the location values. So, these location values will help you place the pixel captured through a sensor in its original position, which was not possible in the raw data because of the geometric error. So, here the geometric correction will place the individual pixels at their proper map locations, and the geometric distortion will be removed, right? It also allows for the estimation of accurate distance, area, and direction information.