Remote Sensing: Principles and Applications

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Lecture No -25
RS Image Acquisition and RS Systems – Part 8
(Temporal and Radiometric Resolution)

Hello everyone, welcome to the next lecture on the course remote sensing principles and applications. In the last lecture we discussed about the spectral characteristics of the system. In this lecture, we are going to discuss about the other two characteristics that is temporal and radiometric characteristics of remote sensing system and also we are going to see little bit more deeper about the data characteristics of whisk broom and push broom scanners.

So, when I first introduced you the characteristic of a remote sensing system, I told four important resolutions, spatial, spectral, temporal, radiometric. We covered in detail of both spatial resolution and spectral resolution. Now, we are moving on to temporal resolution. Temporal resolution in general indicates how frequently we can get data over a particular region of interest. Say for some applications like weather forecasting or detection of hurricanes, we may be needing data once every 30 minutes.

Data in the sense it may be images or any other form of remote sensing data. So, the images may be acquired once every 30 minutes or 15 minute. For certain application, like crop monitoring we may need data once every week. For some other applications such as urban sprawl monitoring, mapping of urban growth, we may require one good quality image every year covering the urban area and so on. So, based on our needs the frequency with which we need the data will vary.

Similarly, all remote sensing systems have an inbuilt characteristic of how frequently it can give the data. And that is known as temporal resolution. So, temporal resolution is in general determined by the orbit in which the satellite is. Say for example if the satellite is in geostationary orbit it will be constantly looking at one particular region of the globe and hence will provide image once every 15 minutes or 30 minutes depending on the image collection characteristics.

So, in general satellites in the geostationary orbits will have the highest temporal resolution. Mostly weather monitoring satellites will be launched in geostationary orbits and they are required to look at the same region continuously. For satellites in the near polar orbit, which revolves around the earth from north to south the frequency with which we can get the data depends on the orbital height. That is the height above which they are circulating the earth and also the swath width which is the total area in the across track direction covered by the satellite. These two will define the temporal frequency with which we get the data.

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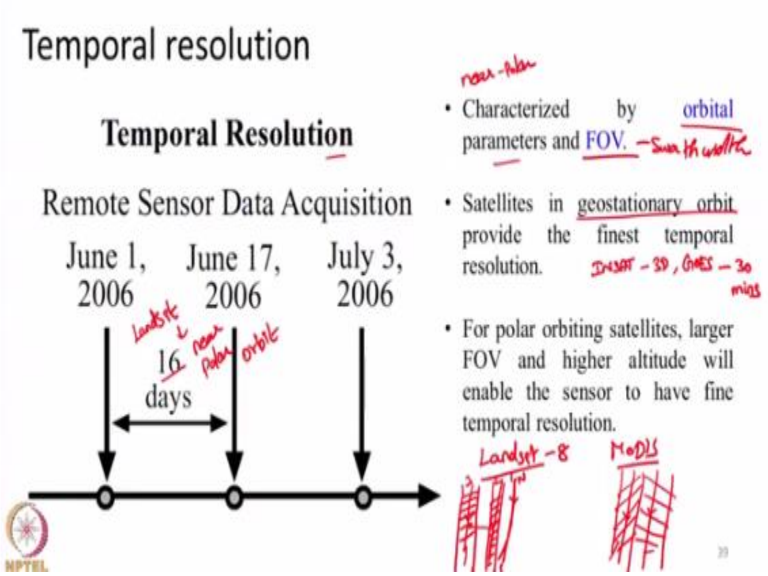

Temporal resolution

Temporal Resolution

Remote Sensor Data Acquisition

near-polar

- Characterized by orbital parameters and FOV. – Swath width
- Satellites in geostationary orbit provide the finest temporal resolution. INSAT – 3D, GOES – 30 mins
- For polar orbiting satellites, larger FOV and higher altitude will enable the sensor to have fine temporal resolution.

So, this is given in this particular slide, temporal resolution general means how frequently we can get the data, for example. Landsat satellites provide data, once every 16 days, so this is in near polar orbit. Similarly satellites in the geostationary orbit, such as INSAT-3D or GOES give data once every 30 minutes, so this is in geostationary. I told you that for satellites in the near polar orbit, the temporal resolution is characterized by orbital parameters and FOV that is the swath width. So, how these things will define the temporal resolution, let us look take two examples. One is Landsat another is MODIS. Both of them are in pretty similar orbital heights around like 700 kilometers.

Landsat 8, 7 or 5 for whatever landsat series the swath width is roughly around 185 kilometers. If you look at MODIS that is also in similar orbital height but it has a very wide scan angle. It can scan 55 degrees, So, it has a wider FOV. And it can collect data with a swath of 2300 kilometers, approximately. For Landsat the swath width is just 185 kilometers. Its FOV is something around 15 degrees. For MODIS it has 55 degrees FOV and its swath width is 2300 kilometers. So, when satellites rotate from north to south, earth is rotating from west to east. So, when satellite finishes one orbit Earth would have moved to certain distance. Now the satellite would be coming over a different region. So, like this it will start covering different parts of the globe. So, that is given here. This is orbit number 1, orbit number 2 may be here, orbit number 3 may be here and so on. So, there will be certain ground distance between these two orbits in the order few thousands of kilometers in the equator. Let us say the orbit is just 185 kilometers for Landsat.

You can see from this particular schematic example that there exists a large gap between two orbital paths and the swath width covered. On the other hand for MODIS the orbit will look more or less the same. But due to its very wide swath something of the order of the 2300 kilometers. So, essentially due to its very wide swath width it will be able to cover the land mass or whatever feature on earth surface almost up to its next orbit level. Let us imagine both of them are going parallelly just for explanation sake I am telling. Let us say we have two orbits and two satellites are moving at certain distance from each other. Now if this can image all the area and this sensor can image all the area without any gaps. Say these two combine together can cover all the region between them without any gap means what will happen, they will provide gapless data between them.

Similarly you can imagine when MODIS goes from multiple orbits around earth due to its wider swath, it can cover a large area of the globe in one go and hence every one day or every two days maximum, it can cover the entire globe. So, the temporal resolution or temporal frequency of MODIS is one to two days. We will get one image at least once in every two days in case of MODIS because of its wide swath.

On the other hand for Landsat due to its very narrow swath width we will not get image with that high frequency. But we will get image only when the satellite overpasses the area. So, only when the satellite goes around your region of interest it will acquire image because of its narrow FOV and smaller swath. But for MODIS due to its wide scan angle it can scan regions that are far off from it, it can cover large region underneath.

So, if MODIS is going like this it can scan from the region far off on both of its sides. Landsat cannot scan like that. Landsat scan is restricted to a very small angle and its swath width is just 185. So, based on the orbital height and its FOV (the angle of scan) the temporal resolution of systems will vary. So, based on our applications we may have to choose data from several satellites combined together. Say for example, Landsat has data only once every 16 days. So, if we need any other data with such high resolution, we may combine Landsat with Sentinel 2 which provides you data once every 5 days or 10 days depending on whether you are using one satellite or two. So, we can combine multiple satellites in order to get frequent data. Combining data from multiple satellites has own issues, but that is one way. But in general what I wanted to say is temporal resolution means how frequently we can get the data from the system.

And the temporal resolution of geostationary satellites is pretty high in the order of few minutes thirty minutes one hour and so on and they has the highest temporal frequency. For satellites in the near polar orbit the temporal resolution is fixed by the orbital characteristics, especially the orbital height, the path in which it goes all those things plus the scan angle FOV that will determine the temporal resolution.

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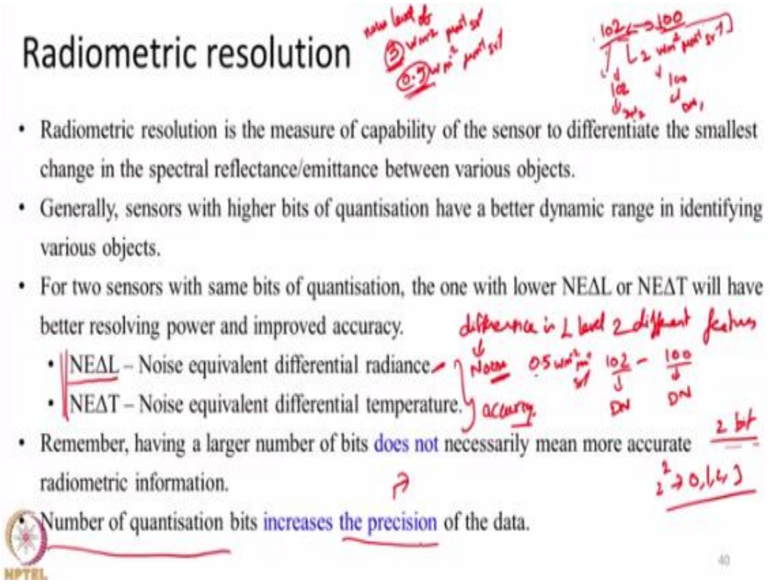

Radiometric resolution

- Radiometric resolution is the measure of capability of the sensor to differentiate the smallest change in the spectral reflectance/emittance between various objects.
- Generally, sensors with higher bits of quantisation have a better dynamic range in identifying various objects.
- For two sensors with same bits of quantisation, the one with lower NEΔL or NEΔT will have better resolving power and improved accuracy.
    - NEΔL – Noise equivalent differential radiance
    - NEΔT – Noise equivalent differential temperature.
- Remember, having a larger number of bits does not necessarily mean more accurate radiometric information.
- Number of quantisation bits increases the precision of the data.

The next topic that we are going to cover is radiometric resolution. We already got introduced to this particular concept when we discussed how digital images are formed. I told you that the incoming energy will be sampled and quantized. Quantized means it is converted to a Integer number based on some scaling factor. So, the range of integer numbers used depends on how much quantization we give to the system. Some system has 8 bit quantization, so the DN can vary between 0 to 255. Some system has 10 bit quantization, so the DN can vary between 0 to 1023 and so on. So, the number of quantization or the number of bits you provide for every band of data for every pixel of data will determine how many different grey levels we can get. Maybe first we will see an example then we will come back to the theoretical concepts related to radiometric resolution.

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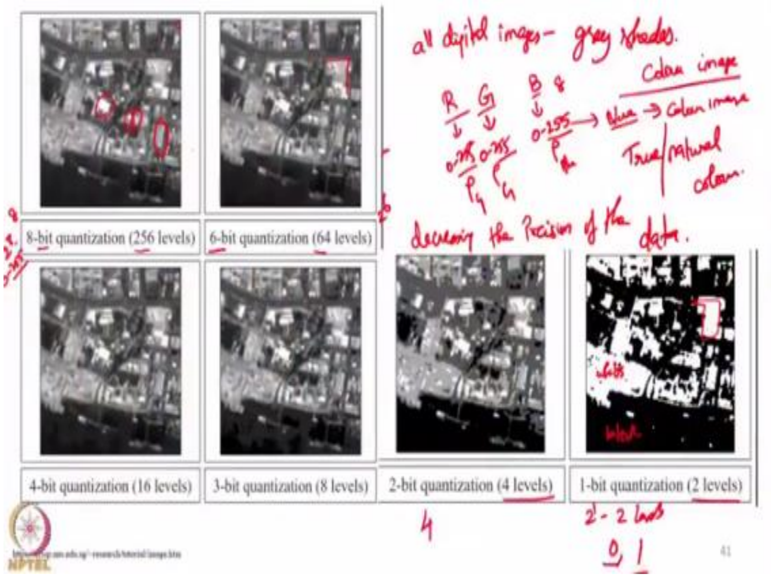

In this particular figure we are having a same image with different quantization levels. That is for each pixel for representing the incoming signal we have used 8 bit 6 bit 2 bit and so on. So, 2 power 8, that is 0 to 255 values it can take here. It is 6 bit so 2 power 6, here it is 1 bit, so it is 2 power 1, just 2 levels and so on. So, each picture denotes the image of same area represented with different quantization levels.

Here we can see the number of different grey shades in the 8 bit quantization image is pretty high. We can see certain features here, this bright spot here, two tank like structures here, there are a lot of tiny dots on so on. As the number of quantization bit reduces, the amount of information that we can get from the image goes down drastically. The number of grey levels that our eyes can see reduces a lot. Here actually, it is just black and white, only two levels. Either it is zero no data or it is one. That is black or white thats it. So, the number of grey shades contained in an image will be determined by the number of quantization bits we use.

Higher the number of quantization bits, the number of grey levels that we can see will increase. so the finer changes in the grey level helps us to see the image pretty clearly. So, I just again repeat all images are nothing but different shades of grey. Mostly they are grey tone images, black and white images. So, how do we get color image? we get color images by mixing different grey shade images in different bands.

That is we know the three primary colors, blue, green and red each will have its own grey shade image. Let us say it have all quantized 8 bit level 0 to 255, 0 to 255, 0 to 225. Based on the objects reflectance in these three bands Say ρ_{blue}, ρ_{green}, ρ_{red}, the DN numbers will vary. Higher the reflectance, higher the DN number. So, when we produce a color image in our display systems, we will assign the DN in blue to blue display. It will give different shades of blue and then the display system works to us.

Similarly for green it will be displayed in different shades of green. Similarly for red different shades of red. All of these will combine together to give us a color image. This is a true color image or a natural color image. Because we are using blue to blue, green to green, red to red in display system. In remote sensing it is also possible to form images with what is known as false color. Remote sensing images have different bands, NIR band, SWIR band, thermal band and so on. We can talk about one of the reflectance bands NIR. we cannot see NIR directly. So, that image will have different shades of grey and we can give some color to it say red color. So different shades of red we can give. And then data acquired in red band we can give different shades of green and so on. This is called false color composite. So, basically all remote sensing images are essentially containing different shades of grey.

The color images produced by how we combine them and how we display them, maybe we will look deeper into it in one later classes. But these different shades of grey, how many shades of grey that we are using is going to determine the amount of details contained within an image. How much fine it is, we are able to see. So, this is generic information about the number of quantization bits. But this does not actually indicate everything about the radiometric resolution.

If you look at the concept of resolution, I told you it is whether are we able to clearly distinguish two features or clearly resolve two features. So, spatial resolution means are we able to resolve two nearby features spatially. Spectral resolution means are we able to resolve two features spectrally by having narrow absorption bands and so on. Radiometric resolution means are we able to resolve two features using the radiance values that came in.

Maybe like, one road with a tar coated surrounded by a pavement with cement cover on top of it. They will have different shades of grey one will be black and one will be a little bit greyish in color. So, just by looking at the reflectance of the data we are able to identify them as two different features. That is what is radiometric resolution just by looking at the radiance value recorded we are able to distinguish two features.

In radiometric resolution, one important aspect is the number of bits we use. So, based on the number of quantization bits, we have many different grey levels in an image. As the number of quantization bits increases we will be able to see clearly the different features present, that is one aspect. But one more important aspect is how accurate our sensor is, in collecting the data. That is all sensors will have certain level of noise being produced within the system. So, no system is perfect that we know, if the system itself will generate some level of noise within it which cause some data to be created and stored within the system itself. Everything will be created by the system and stored by the system, so some noise will always be there.

Let us say some signal is coming from the ground from two different features. Let us say one number is 102 one number is 100. These represent the spectral radiance of two different features. The difference between them is just two watt/meter^2/micrometer/steradian, very small difference between them. Let us say the system has a noise level of 3 watt/meter^2. These may not be the real numbers or real values just to drive home the concept and I am doing it. So, a system itself has some noise which is more than the difference between these two features. So, what will happen essentially? There are always high chance that these two numbers will be recorded as one same feature. That is we will not be able to distinguish them. Let us say there is same signal, but now the noise of the system is just 0.5.

So, in this case what will happen, the noise of the systems is quite low in comparison to the difference of radiance between these two features. And hence even when the noise is getting added whether in a positive direction or negative direction there are high chances that we will record the radiance from these two features as two different objects. And based on the grey levels we use, they may get a different DN altogether.

So, the DN and the accuracy of the system, how much noise it will produce or how fine it can dedect the difference between two signals, both of them, combine together will determine the radiometric resolution of a sensor. So, one important concept is noise equivalent ΔL that is noise equivalent differential radiance, all system will have a varying noise level. So, at different radiance the noise level will vary. So, if this NEΔL is pretty low that is what should be the difference in radiance level between two different features. So, difference in radiance level between two different features to create a signal inside the system such that this will be more than the noise that is produced within a system.

I repeat let us say two features are there they are having some difference in radiance between them. One feature has 102 another features 100. So, the difference in radiance between this is just 2. If the difference between them is more than the noise equivalent radiance due to the noise within the system it will produce its own radiance. If the difference between them is more than the noise within the system itself then these two will be identified as two different objects. But if the difference between them is lower than the noise within the system, they will be treated as one different object because they are having very similar radiance values.

So, if the noise of the system is very low (NE ΔL is pretty low) then objects with smaller differences in radiance can be imaged as two different features. If the NE Δ L in the system is high then Objects or features with smaller differences in radiance may not be imaged as two different features, they may be imaged as one different feature. This is purely depends on the accuracy of the system that is the noise content of the system how accurately the system collects the data.

Now let us combine this with the radiometric resolution or the number of quantization bits we use. 102, 100 radiance value from two features, with the noise is 0.5 watt/meter^2/micrometer/steradian. So, these two will be detected by the sensor as two different features, that is fine. But let us say I am just going to use a two bit quantization. So, 2 power 2, four levels 0,1,2,3 that is all I am going to use for my DN levels.

If I use this kind of low grey levels quantization bits there are high chances both of them will get the same DN values. That is the sensor has recorded them or detected them as two different features. The noise of the system is pretty low so the two features are detected as two different features. But when the quantization happened because of poor quantization because of very low quantization bits given to the system, these two may still get same DN and saved in the images as one feature. Having same DN means we will see them as just one same feature. I will just go back to this example. Here, just look at whatever the portion having white. Here everything appears white as with one particular DN value. But here this block contains lot of tiny different features, but everything gets stored here as one DN value because of the very low level of quantization we have used.

So, essentially the number of quantization will work in combination with the accuracy of the system in order to or which will finally decide our ability to distinguish different features by looking at the DN values. So, there are two parts one is the accuracy of the detector elements itself and second comes the quantization. Both of them combined together will give us the radiometric resolution or how accurate we will be able to identify two different features. Similar to NE Δ L the radiance concept in thermal remote sensing, we have a concept of NE ΔT. How different the temperature of two objects should be in order for them to produce a radiance which will be higher than the noise inside the system itself. Noise equivalence Δ T noise equivalence differential temperature.

So, the accuracy of data collection and the number of quantization bits will tell us how fine or how many grey levels we will use. So, if we combine both of them together the NE Δ L or NE ΔT they will determine the accuracy with which the data is being observed by the system and the number of quantization bits will determine with what precision we record the data. Even accuracy may be higher again, I am going to the same example, same data when expressed at different lower values of quantization bits the amount of information we get from the image decreases. Or here we are decreasing the precision of the data. So these two effectively combined together, accuracy of data collection the NE Δ L or NE Δ T combined with the number of quantization bits will determine the radiometric resolution of the system. How accurate we are able to distinguish two features radiometrically that is by looking at the radiance values itself. Here you are distinguishing 2, 3 different tank like structures in 8 bit quantization images and in 6 bit quantization image. But you are not able to distinguish it in 2 bit quantization image and in 1 bit quantization image. It is not visible and this affect our ability to distinguish features.

So, till now we have covered all the four important characteristics of remote sensing system, spatial, spectral, temporal and radiometric resolution of a system. But depending on the way the data is collected, the data may have certain distortions or certain characteristics like geometric distortions like how accurate the position of each point on the ground is image perfectly. So, based on the way we collect the image whether it is a scanner or it is a push broom sensor or it is a normal photograph, whatever, the geometric accuracy of the ground points will vary. So, now we will look at some characteristics of the data collected by these remote sensing sensors. First we are going to talk about the characteristics of data collected by whisk broom scanner.

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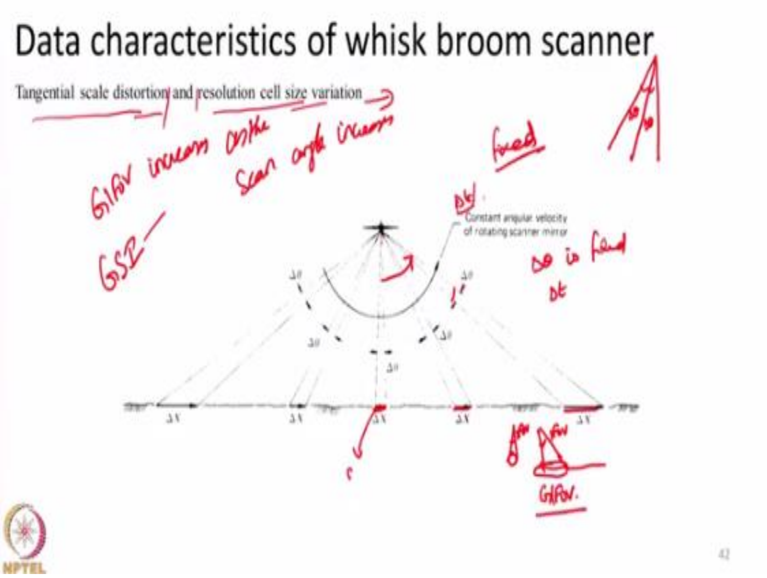

Data characteristics of whisk broom scanner

Tangential scale distortion and resolution cell size variation

Image collected by whisk broom scanner will undergo what is known as a tangential scale distortion and resolution cell size variation. These two are basically the distortions that are inherent in the data collected by whisk broom scanners. When whisk brooms scanning happens sensor will be moving, satellite will be moving like this. Sensor or the scanner will be scanning in the across track direction. And also it will do that at every given constant interval of time Δ t the data coming in from the scanner will be sampled and it will be quantized. So, the sampling time Δ t is fixed, so, it will collect data once every 6 microseconds or 3 milliseconds based on the scanner type.

So, as 6 microsecond elapses sensor may start from here, it will move continuously and collect data from the ground. But that data will be sampled every 6 microseconds producing that many pixels on the ground. That is what we came to know as GSI or GSD ground projected sample interval or ground projected sample distance. Now just think that time between two samples is fixed and the angular distance that is moved by the scanner within a given time interval is also fixed. That is it will make small angle of Δθ for every Δt time. That is given in this particular slide. So, for every time interval of say Δt, the scanner will move an angle of Δθ from this point it will keep on changing. This Δθ is fixed for a given Δt.

Because as the scanner starts scanning from here after time Δ t, it would have come here and cover an angle of Δθ, after another time of Δt, it would have come here. It will convert the same angle Δ θ. So, the angular distance covered under the time taken between each sample is fixed. But now let us assume the ground is flat. Now, the scanner is collecting data from a flat ground.

The angle with which finally it is being projected on the ground that is the distance between the samples let us say. Because every Δt seconds a sample is collected. So, the ground distance covered within the Δt will become larger and larger as the scan angle increases when the ground is flat, the angle is fixed the Δ t angle or the angular distance is fixed between with two samples are taken.

Because of the flat ground, the ground distance between two samples between will be keep on increasing. This is one thing that is the GSI will be keep on increasing as the scanner moves away from nadir. So, if it is from here, the GSI will be without what is basically fixed for the system. As the scanner moves away from the nadir as its scans, then for the same sample time Δt the ground distance or the GSI will be keep on varying. The GSI will be keep on increasing as the scanner is moving away from the nadir.

Similar to GSI, the GIFOV will also undergo some distortion. GIFOV means the projection of a single detector element on the ground. So, as the single director element is looking at nadir it is okay. If it is a circle it would be on the ground as a enlarged large circle. If it is a square it will be on the ground as an enlarged large square. But let us say this GIFOV is now looking at an angle away from nadir.

So, when you project it onto a flat horizontal surface, what will happen? The circular Δ element here will be projected on the ground as an ellipse because of a larger scan angle. So, two things will happen. First thing is the GIFOV increases as the scan angle increases. Similarly the GSI will also increase as the scan angle increase. That is a circular GIFOV element as it moves away from Nadir, the same IFOV angle of the system will have larger ground area coverage. This is enlargement of GIFOV. Similarly I also told you that the sampling interval Δt is fixed for the same sampling interval, the sensor would have covered larger ground distances between two samples.

So, these two concepts, change in GIFOV and change in GSI are important characteristics of whisk broom scanner. We will see little bit more in detail about these concepts in the next lecture. So, as a summary in this lecture, we have seen the concepts of temporal resolution, radiometric resolution and also started discussing about the data characteristics of whisk broom scanner.

Thank you very much.