Remote Sensing: Principles and Applications

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Lecture - 16
RS data: From Radiance to reflectance - Part 2

Hello everyone, welcome to the next lecture in the topic of converting radiance to reflectance quantities. In the last class, we discussed about image formation process, how a digital image is formed and what is actually stored in the digital image. What is the relationship between the energy that came in at the sensor and the digital number stored in image? And how to convert it from radiance to DN and DN to radiance we saw in the last class.

In this class what we are going to do is how to further convert the radiance recorded into surface reflectance. That is what we are going to see in this particular lecture.

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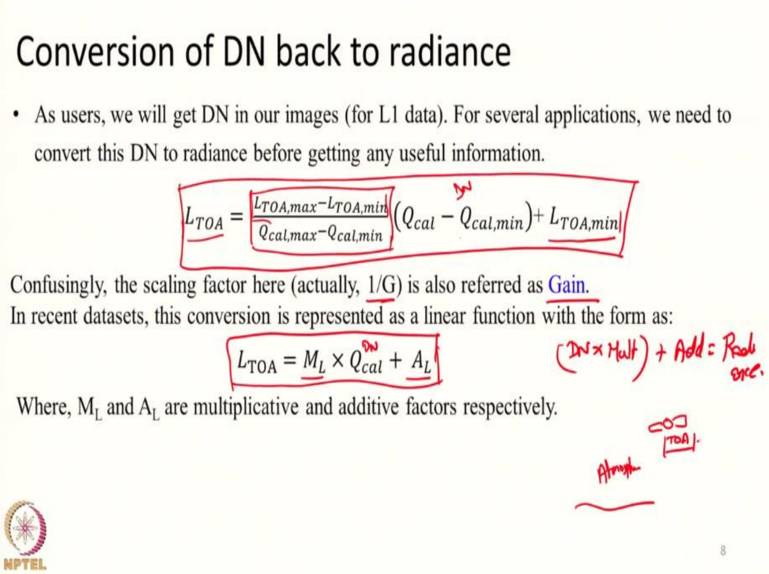

So, just as a recap this was the equation we saw at the end of last lecture to convert the DN stored in the image into the radiance recorded at the sensor. So, for a remote sensing sensor essentially it is the radiance recorded at the top of atmosphere. We always denote it with symbol or abbreviation TOA. Because whatever the energy that came in or went out it has an influence of the atmosphere and whatever is recorded by the sensor always has effect of atmosphere. That is why we call it as radiance TOA or we always talk it in terms of TOA.

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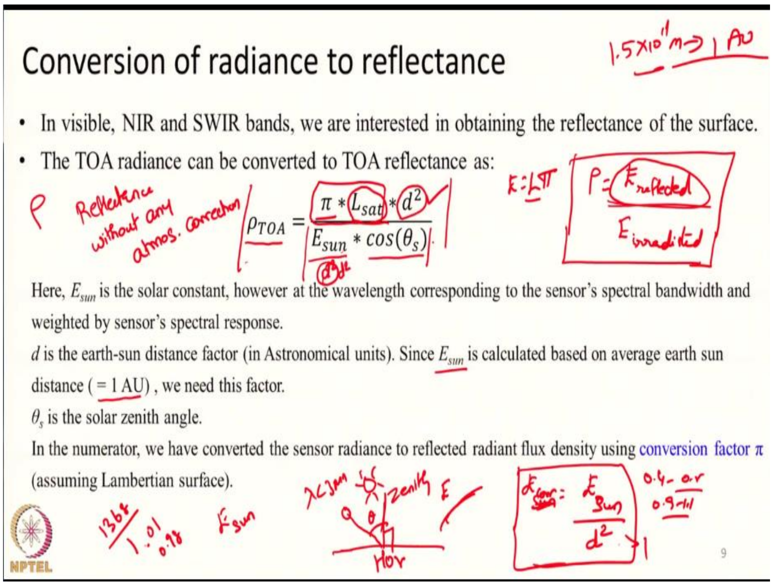

So, how to get TOA radiance to reflectance? First of all, why do we need reflectance? Because that is the property we are basically interested upon. In short wave wavelengths that is less than 3 micrometer wavelengths we are interested in recording the reflectance property of object. By using the reflectance of the object recorded within this bands we will be able to understand the object, its behavior, its properties, etc.

And hence we are interested in retrieving the reflectance. How to do it? That is what we are going to see now. So, here in this slide, first we are going to calculate what is known as TOA reflectance. What is TOA reflectance? Reflectance recorded at the top of atmosphere that is reflectance obtained without any atmospheric correction. This is what is meant by reflectance TOA, ρ_{TOA}, ρ is the symbol used to denote reflectance, TOA is top of atmosphere. So, top of the atmosphere reflectance means reflectance without doing any atmospheric correction. Reflectance is defined as the radiant flux density that got reflected divided by the radiant flux density that irradiated the surface. This was the definition of reflectance that we saw earlier.

What is the irradiance that illuminated the surface will be in the denominator? What is the irradiance that actually left the surface after reflection will be in the numerator? Divide them both, we will get the reflectance of the object within the hemisphere in which we are working. We are going to do the exact same step here. We are going to calculate the 2 terms in the numerator and denominator. Divide them one by the other to get the top of atmosphere reflectance. First we will calculate what is on the denominator that is the energy radiant flux density on the surface. So, first thing in the short wave wavelengths λ less than 3 micrometers typically sun is the primary source. And in the previous lectures I told you that for each wavelength band say 0.4 to 0.5, 0.9 to 1.1 we will be able to calculate what will be the energy from the sun that reaches the top of atmosphere. In one of the previous lectures I explained you how to do it. And also we saw there will be some sort of transmissivity effect of the sun's radiation coming in and so on. Lot of atmospheric effects I explained in detail when discussing about the radiance reaching the sensor.

Now this is our first step of getting reflectance. We omit all sort of atmospheric effects. We assume atmosphere is not there then what will be the reflectance that is what we are going to calculate now. The coming slides will explain how to take care of atmospheric effects. So, first we will be able to know what will be the energy that was emitted by sun. We call it as E_{sun} in this particular slide.

So, radiant flux density that was emitted by sun which reached the earth surface, we calculated a value of 1368 watt/meter^2. That is for the entire bandwidth like entire electromagnetic spectrum from 0 to infinity wavelengths. 1368 watt/meter^2 which we called as solar constant. But this number will vary with the bands which we are working on. We know that the peak energy from the sun comes in around like 0.55 micrometers around the green band. So, if you calculate the E sun around the green band it will be much higher in the order of say 1700 or 1800 watts/meter^2. So, the E sun values or the irradiance from the sun will vary with the wavelength you are working on.

Normally whenever a sensor is launched, the sensor people itself will give the bandwidth with which the sensor is designed to work. This will be the value of E_{sun} that you are going to expect at the top of atmosphere. That will be clearly given to us. So, E_{sun} actually will be given to us a priori. If this is the bandwidth of sensor then at that particular band this will be the irradiance from the sun. That will be known to us.

Most of the sensor manufacture like NASA, ISRO also will have record of what is the E_{sun} for its sensors. If we know E_{sun} value that is at the top of atmosphere, then we can neglect atmospheric effects as the first step then we can assume whatever the value there comes in and fall on the surface, as simple as that. But remember one thing, the irradiance from the sun is calculated assuming average distance between earth and the sun. That is 1.5×10^{11} meters which we used in all our numerical problems is essentially the average value overall within an year this is the average value of distance between earth and the sun. But every day this will change.

Because earth is rotating in an elliptical orbit around the sun. So, the distance between earth and the sun is going to change continuously. So, the energy what we calculated for the average distance is not going to be the same every day. It is going to vary with varying months or varying days. The position of earth and the distance between earth and sun is going to change continuously. So, we need to correct for this varying distance factors. So, that is why if you look at the equation this d^2 term is there.

$$E_{sun} = \frac{E_0}{d^2}$$

where E_0 is the one that is actually calculated. So

$$E_{corrected} = \frac{E_{sun}}{d^2}$$

where E sun is the value given for that particular band assuming an average distance and d is the actual distance. So, the average distance we call it as one astronomical unit that is 1.5×10^{11} meters. So, if this number let us say that the same 1368 watt we will take and one astronomical unit, that is for one average distance I have to convert it for the value may be 1.01 astronomical units or 0.98 astronomical units and so on.

The value will be in terms of fractions 0.98, 1.02 and so on. If the distance is more than this average value then the denominator will be greater than 1. If the actual distance between earth and sun is less than this average value then the denominator will be less than 1. So, this d^2 term is actually to correct this. Essentially this will be in the denominator but instead of writing it in denominator here we have written it here.

So, this d^2 term is to correct for the varying distance between earth and sun. So, then L_{sat}. This also we know. Because from DN we know how to calculate radiance recorded at the sensor. We are now ready to calculate it. For a Lambertian surface, we know E = Lπ. So, L is what we have recorded in the sensor. In order to convert it into E we are multiplying with π.

So, this $L_{sat} \times \pi$ is the actual numerator term, that is $E_{reflected}$. So, this $E = E_{sun}/d^2$ is the energy that reached the earth surface by sun and $\cos(\theta_s)$ is to correct for the sun's zenith angle like sun's illumination geometry. If you assume a horizontal surface then the normal to it will be the zenith angle made by sun with respect to that zenith.

In previous classes in some derivations I introduced you to this cos θ term, why it is coming. It is just to account for the variation in sun's geometry. It means sun is not lying exactly overhead and the sunlight is coming at an angle. So, the energy that came in from sun is actually (E_{sun}/d^2) cos θ_s where θ_s is the solar zenith angle and the irradiance from this surface that is reflected is $L_{sat} \times \pi$.

So, if you do this we will actually be calculating what is the surface reflectance recorded at the sensor without doing any atmospheric correction or neglecting the effects of atmosphere. So, in order to convert the radiance recorded in the sensor into top of atmosphere surface reflectance, the formula is

$$\rho_{TOA} = \frac{\pi \times L_{sat} \times d^2}{E_{sun} \times \cos \theta_s}$$

However we know atmosphere is there. Atmosphere will influence this radiation. So, we are essentially have to correct for this effect of atmosphere. How to do it? Before going on to this, I will just tell you why first of all we need this TOA reflectance. Anyway TOA reflectance is not corrected for atmospheric effect. So, why do we need to compute it? We need to compute it because it corrects for the solar illumination geometry. That is, the radiance reaching the sensor has effect of solar illumination, atmosphere and topographic effect. What is the variation in surface topography whether the surface is flat; surface is like mountain, ridges, valleys etcetera. What is the variation in atmospheric effect and also what is the variation in sensors viewing angle?

All these things are going to change the radiance recorded in the sensor. So, in the TOA reflectance actually the radiance, when we divide it by (E_{sun}/d^2) cos θ_s we are effectively removing the effect of solar radiation. Based on amount of solar radiation, the radiance is going to vary. For higher incoming radiation, higher will be the radiance recorded. So, based on the day of year, the energy from the sun will vary because of seasonal effects. And we are actually correcting it. So, one of the effect which affects the radiance is corrected now even without doing the atmospheric correction. So, that is why it is better to do radiance to reflectance correction or reflectance conversion even we do not have any atmospheric information.

At least one of the effect we are removing from the radiance recorded by the sensor. Now we proceed on. One effect we removed. The effect of solar elimination the effect of incoming solar radiation we have removed. We have converted it into TOA reflectance. Actually we need surface reflectance that is after correcting for atmospheric effects. How to do this?

Here also we assume the sensor is viewing from nadir when we do our corrections.

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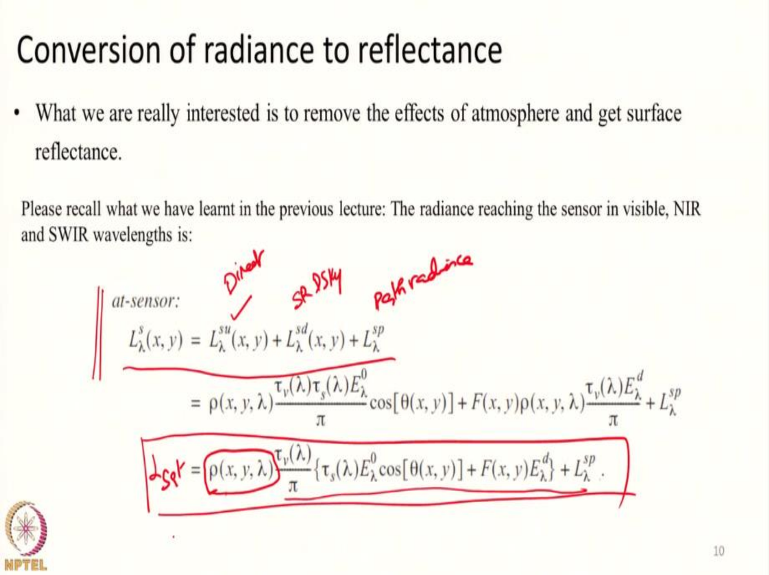

The radiance recorded by the sensor has a direct signal component, surface reflected diffuse skylight component and a path radiance. So, if you look at this particular figure the L_{sat} recorded at the sensor has several components. So, this is actually the surface reflectance term. We now want to get this term and remove all these effects. So, our aim is to remove all these effects. This equation we derived in one of the previous classes. So, we are going to take this equation. Work it in a reverse fashion to get reflectance.

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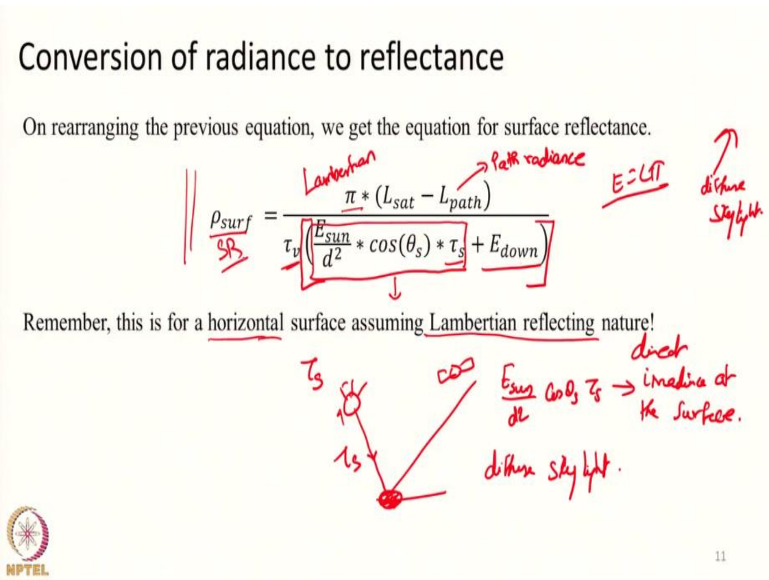

The surface reflectance is equal to $\pi(L_{sat}-L_{path})$ where this is the path radiance that is what is sent to the sky directly from the atmosphere, the diffuse skylight directly reaching the sensor. This term (E_{sun}/d^2) cos θ_s is actually the solar radiation reaching the surface. And this τ_s is the transmissivity between the sun and the earth surface in order to correct for atmospheric absorption and scattering effects.

In previous classes we saw that transmissivity can be 70%, 0.7, 0.8 and so on. What is the transmissivity of the atmosphere between sun and earth that will correct the incoming solar radiation for atmospheric effect because even the incoming solar radiation will be absorbed to some extent by atmosphere. So, that will be corrected.

The actual radiance reaching the surface can be corrected if we know τ_s. (E_{sun}/d^2) cos θ_s τ_s will be the irradiance at the surface plus E_{down} term is there. This E_{down} is to account for or I write this as direct irradiance E_{down} is the diffuse skylight component that reach the surface. So, essentially the denominator term will tell us the total irradiance recorded by any surface on the ground including the effect of atmosphere.

So, the τ_s is atmospheric transmissivity that is how much fraction of sunlight is being allowed inside. And this E_{down} is the diffuse skylight component that reached the terrain. So, this is the total irradiance that is there on the denominator. Now from the radiance recorded from satellite we are subtracting L_{path} that is the path radiance. So, that term is removed. And then you multiply with πin order to assume a Lambertian surface again.

E is equal to Lπ the same relationship we are using. And we are dividing it by τ_v. τ_v is the transmissivity between the earth surface and the sensor because sensor may be somewhere else not exactly in the direction of sun. It will be at a different distance based on all these factors atmospheric transmissibility will vary in that particular direction. So, in order to correct for it we are going to use that.

So, essentially if we use the equation given in this particular slide we will be able to correct for the effects of atmosphere. But we should know what is the path radiance. We should know the transmissivities in both the directions from sun to earth and earth to sensor. And then we should also know what is the downwelling diffuse skylight that actually irradiated the surface.

If we know all these quantities we will be able to correct the radiance recorded at the sensor for atmospheric effects. This equation is derived assuming the surface is horizontal and Lambertian reflecting nature. Here I am assuming surface is horizontal and Lambertian. If the surface is not horizontal we need to do what is known as a topography correction which I will explain later, okay.

So, this equation will help us to convert the radiance recorded at the sensor to surface reflectance which is of our real interest, okay. We said we need to know L_{path}, τ_s , τ_v E down. If we have it, it is easy to correct but how to get those values. Getting those values, substituting them in this equation getting surface reflectance is essentially known as the process of atmospheric correction correcting for the effects of atmosphere.

How to get these values? Ideally what we should do is, most of the satellite has a fixed time of overpass over a region. At the time of satellite overpass we should send or we should measure atmospheric variables in the entire column above the land surface. That is we should measure temperature, pressure, humidity that is the water vapour content, CO_2 content, etcetera, etcetera. All these parameters we have to measure in the entire atmospheric column above our study area. Feed those values into what is known as a radiative transfer model RTMs. The RTMs will essentially use these measured atmospheric variables and try to model if this is the atmospheric variables, how the radiation would have been affected by the atmosphere. RTMs have the capacity to simulate it provided the atmosphere is known. So, the RTM will moderate and that will give these variables L_{path}, τ_s , τ_v and E down as outputs. This is the ideal way of doing atmospheric correction. That is how we should do. But normally we will not be having atmospheric data at the time of satellite overpass.

Unless a proper research is going on, people are planning everything meticulously for various applications we will not be having this atmospheric informations. So, typically nowadays we have lot of models which simulate atmospheric conditions. We have atmospheric models which can simulate at the given place at a given date and time. This will be the or this was the atmospheric condition temperature, pressure, water vapour content, CO2 content, etcetera.

Take output from those models, feed it into RTMs and do the correction. That is also a way which is most of the users are now practicing. Combine atmospheric models with radiative transfer models. As a normal user say I do not have anything at me. I do not have the computation resource like RTMs or atmospheric models. They are all free nowadays like atmospheric data is now available to us. Also nowadays open source RTMs are available.

But still if I want to use I do not have any computation resource to do it what can I still do. I have an image already with me. I want to do some sort of atmosphere correction. Then we can use what is known as an image based atmospheric correction. So, that is the most possible and simplest way we can use if we do not have any other information about atmosphere or we do not have access to radiative transfer models.

So, these are different ways in which we can correct for the effect of atmosphere. Other than this, people also do what is known as a vicarious calibration. Vicarious calibration means I told you that even before a sensor is launched the calibration or the conversion factor between radiance to DN will be known will be fixed. But that will not remain constant as time progresses due to various effects in space, the calibration constants will vary.

So, in most satellite missions, the scientists and engineers associated with them will be periodically doing repeated calibration exercises. That is whenever a satellite is going to overpass they will fix some certain or they will take some study area and they will measure the surface reflectance there beforehand. So, the reflectance of the surface is well known at different angles and so on. So, when the satellite overpass the area, they will take the image. They will calculate radiance or reflectance from the image and try to compare them. This is the reflectance or radiance recorded in image. This is the actual reflectance and radiance recorded on the ground. What is the difference between them? They will correct it.

So, this has 2 benefits, one they correct for the effect of atmosphere itself whenever they do this correction what is recorded in the satellite what is recorded on the ground when they relate them and do a correction they will be able to do atmospheric correction. In addition to this they will also be able to understand how much the sensor calibration has changed. So, this is one way of doing atmospheric correction. But as I said this is primarily done for operational maintenance of satellites or for experimental studies. But as normal users if we have access to some good computation resources we can combine outputs from atmospheric models feed them into RTMs and use it. If we do not have any other resource we can go for image based atmospheric correction models.

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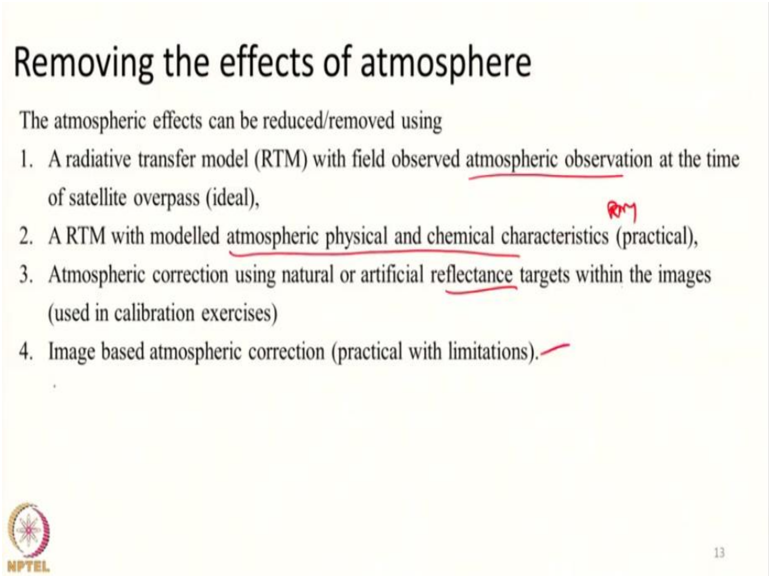

So, the atmospheric effects can be removed using radiative transfer models with field observed atmospheric observation. A radiative transfer model with modelled atmospheric characteristics fed into an RTM. Atmospheric correction using natural or artificial reflectance targets within the images. This is primarily using calibration exercises.

And we can use a image based atmospheric correction. So, these are the 4 different ways in which we can correct for the effect of atmosphere.

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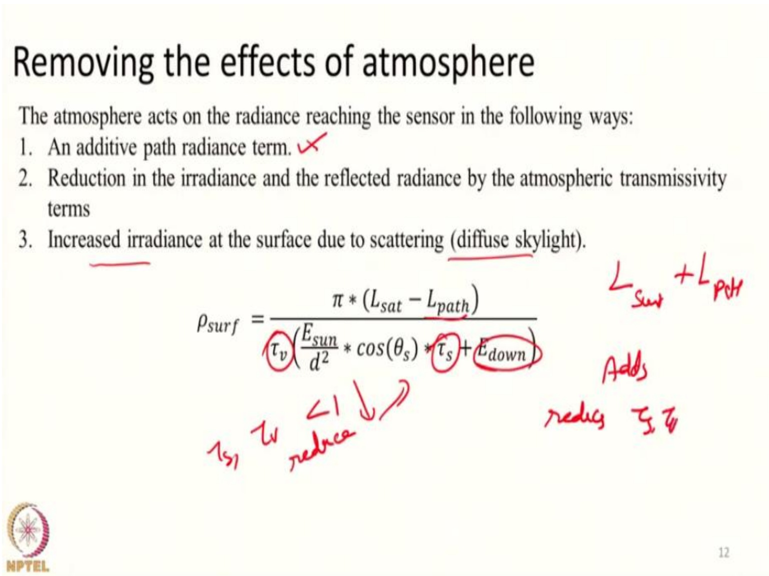

And what are the different ways we are going to correct for the effect of atmosphere is we are going to correct for an additive path radiance term. So, this is like an added component the L radiance from the surface is added with the path radiance. We are going to subtract it. We are going to remove it. So, an additive path radiance term we have to correct. The reduction in irradiance and reflected radiance by atmospheric transmissivity terms τ_v and τ_s.

Essentially τ_v and τ_s will be less than 1 and they are kind of acting as a reducers or they reduce the incoming radiation as well as the outgoing radiation plus there is an additive term E_{down} that is a diffuse skylight. So, atmosphere acts in many different ways. It adds radiance to it, L_{path} E_{down}. It reduces the incoming energy in form of τ_v and τ_s and so on.

So, using the 4 methods I just mentioned to you we are going to correct for the effect of atmosphere. So, in the next class, we will be seeing a simple image based atmospheric correction technique. How to use it? What are the pros and cons? And also we will see one more effect called the topographic correction.

So, in this lecture we have studied about how to convert the radiance recorded at the satellite into reflectance and basically how to convert this reflectance or how to correct this reflectance for the effect of atmosphere. So, that is what we have seen in this class. Next class, we will continue further in this particular topic.

Thank you very much.