Remote Sensing: Principles and Applications

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Lecture – 13
Radiation reaching sensor - Part 1

Hello everyone, welcome to today’s lecture in the course remote sensing principles and applications. In the last class we saw different ways in which EMR will interact with the terrain features. We saw information about reflectance, transmittance, absorptance. We saw how reflectance will vary with respect to surface roughness, specular reflector, diffuse reflector and all.

In this lecture what we are going to see is after interacting with the terrain features the energy from the feature should reach the sensor for us to collect and analyze later. So, how that particular energy will be transformed and what energy will exactly reach the sensor that is what we are going to see in this particular lecture.

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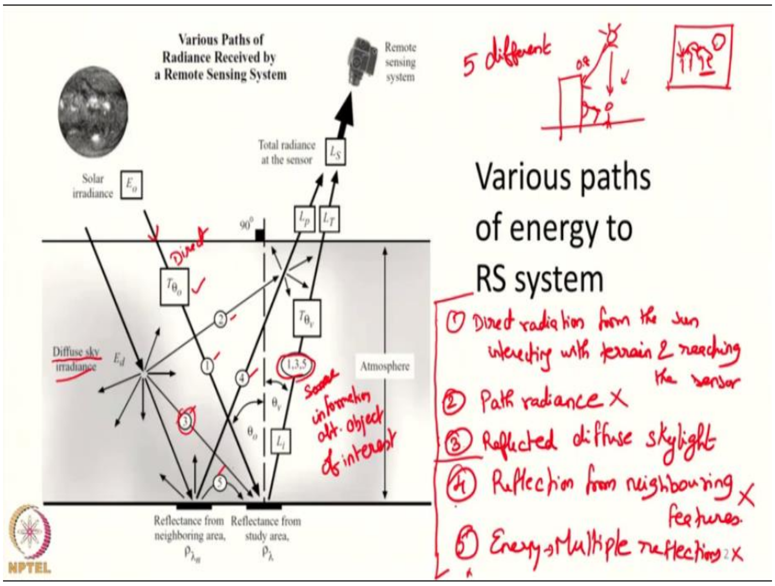

Various paths of energy to RS system

① Direct radiation from the sun interacting with terrain & reaching the sensor
② Path radiance X
③ Reflected diffuse skylight
④ Reflection from neighbouring features X
⑤ Energy → Multiple reflections X

First we will get an overview of the various paths in which energy will reach the remote sensing system. If you look at this particular slide in this figure, I have given 5 different paths. path 1, path 2, path 3, path 4 and path 5. 5 different paths in which the energy can reach a sensor in which energy can interact. What are those 5 paths? First we will take path 1. Path 1 is the direct interest to us. That is the direct radiation from the sun interacting with the feature or interacting with terrain and reaching the sensor. So, this is path 1 which is of interest to us. That is the direct solar radiation that comes in interacts with the terrain, collects information about the objects here and reaches the sensor. Path 2 is we also saw in addition to the direct solar radiation. We also have what is known as a diffuse skylight. That is the energy that remains scattered in the atmosphere will be present throughout. And a fraction of that particular energy will directly reach the sensor and it will be going in all direction. So, that is component number 2 and we call it as path radiance.

And component number 3, again it is related to the diffuse skylight. Instead of directly going to the sensor another fraction of it will be directed towards the object of our interest. It will come down, will again reflect with the object of our interest and will reach the sensor. That we write it as reflected diffuse skylight. Path 4, sunlight will not only fall on our object of interest. If you take one area over which a sensor is looking at. Let us say the sensor is looking from the top over this area and we have a small house here, a tree here, a small pond and everything. Let us say everything is covered within a single area which image is actually looking at. So, we are going to get signals about all these features together. If you are interested in collecting data about this particular building how this looks, we may also collect data about the tree. We may also collect data about the pond everything will interact because solar radiation will fall on it. Everything will send energy back to the sensor. Same thing is depicted here as path 4. So, path 4, what we call as reflection from neighbouring features.

And finally path 5, path 5 is say we are interested about collecting information about any one object. So, energy from sun will be irradiating our neighbouring pixel. Let us say now we want to collect information about this tree. So, sunlight will come fall on the house which is next to tree. And a fraction of it will again fall on the tree which will be reflected. So, that is energy undergoing multiple reflections. Say for example, you are standing close to a building. Sunlight is going to fall on you directly. It is also falling on the building. If this building facade is covered with glass, a fraction of the light will be reflected by this mirrors. It will reach you. And you will receive energy from the sun, from the atmosphere and also from this particular building that is reflecting energy on you. Same thing will happen for other earth surface features too. So, energy which is undergoing multiple reflections, energy will be coming in from objects that are closer to the object of our interest. So, these are the 5 paths in which energy from the sun will reach the sensor.

If you look at the path 1, 3 and 5, they are the one which carries information about the object of our interest. On the other hand, path 2 which is directly scattered from the sky the diffuse skylight or path 4 which is the signal going on from the neighbouring features, they are not actually of our interest because that is not the signals we want. Among these 5 paths, we will be actually able to calculate path 1 what is exactly coming in the from the sun. We will be able to model it to some extent. Path 3, the reflected component of diffuse skylight. We will be able to model it to some extent.

And then path 5 which is energy undergoing multiple reflections. It is extremely difficult to model it because we do not know how the terrain will interact, or how the terrain is oriented, what fraction of light is falling on from different features that is extremely difficult to model. In addition to this that particular component will be too low. Too low in the sense since energy from the sun is undergoing multiple reflections say like we will look at the example of this building and this man. Let us say the building glass has a reflectance of say 0.8, whatever energy is falling on it 80 percent of it only will be reflected towards you. Not even 80, if it can reflect in different directions only a fraction of energy will be reflected towards you. So, as the number of reflections grows the energy will go lower and lower. And this will become too low. So, path 5 is difficult to measure or model but it is too low. And hence we can safely neglect. And also path 4 that is the signals from neighbouring features. If it happens in remote sensing we cannot do anything about it. Like normally when we do our various applications our images contains signals from our neighbouring features neighbouring pixels we have to use it judiciously.

So, that is kind of inbuilt within a system we cannot do much about path 4. So, we can say it is inbuilt in the system, we can leave it. So, essentially the path which we are really interested upon is path 1, path 2 and path 3. These 3 are the major things which we are interested upon. Path 4 and path 5 we are kind of neglecting. Path 5 is too low. So, hence we can neglect it. And path 4 has such sort of adjacent reflection and so adjacency effect comes in, it is difficult to remove it. So, we have to live with it. So, we say like as if it is not present. So, essentially the first 3 components the direct reflected skylight, path radiance and diffuse skylight that is being reflected by object of interest is what we are really interested upon. So, this is the primary energy that reaches the sensor which we will use for our various applications. If we look at some text books they may say path 2 and 4 as path radiance. So, 4 is the adjacency effect and path 2 direct diffuse skylight component both of these can be clubbed together and called as path radiance. Paths 1, 3, 5 depicted in this particular slide can be treated as the ones which carries the signals of our interest. So, now we will see little bit in more detail about how energy interacts, what energy will reach the sensor, how to calculate it and so on. First we will concentrate on shorter wavelengths. That is visible NIR and SWIR wavelengths.

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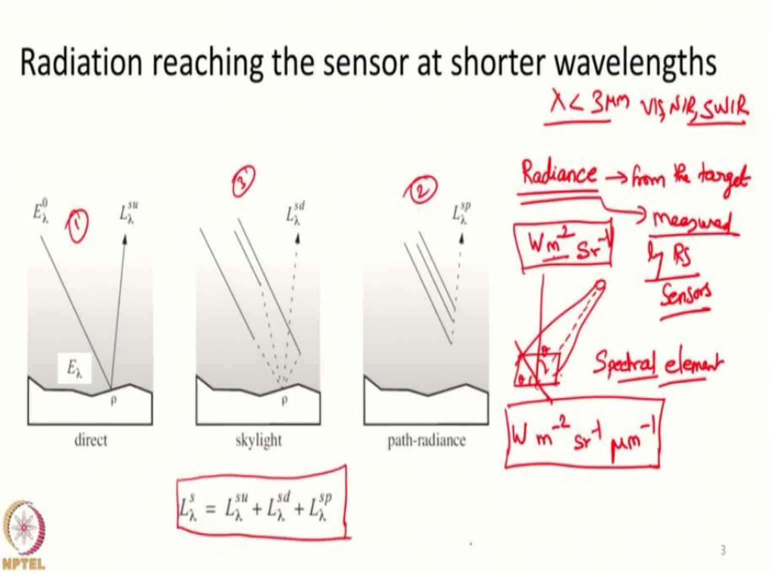
Radiation reaching the sensor at shorter wavelengths

$\lambda < 3\mu m$ VIS, NIR, SWIR

Radiance → from the target → measured by RS sensors

$\boxed{W m^{-2} sr^{-1}}$

Spectral element

$\boxed{W m^{-2} sr^{-1} \mu m^{-1}}$

$$\boxed{L_\lambda^s = L_\lambda^{su} + L_\lambda^{sd} + L_\lambda^{sp}}$$

This particular figure will actually tell us the different paths in which energy will reach the sensor for wavelengths typically less than 3 micrometers. That is visible, NIR and SWIR bands. As said before it has only 3 paths depicted here. The direct path, path 1, path radiance, path 2 that is the diffuse skylight directly reaching the sensor and this is path 3, the reflected component of diffuse skylight. Path 4 and path 5 from the previous slide, we are neglecting here. So, these 3 paths will effectively contribute to the radiation that reaches the sensor. And one more thing what we have to recall is the energy that reaches the sensor or which will be directed towards the sensor is actually the radiance from the target.

Radiance is the energy or power per unit square of projected area per unit solid angle. That is if we have a unit area and a sensor is looking at it from an angle say θ. So, what is the radiation leaving this particular area? Every meter square of area when the area is projected normal to the sensor. So, now I am rotating the surface element such that it is appearing normal to the sensor then we calculate what is the area of the projected element? From this we calculate what is the energy leaving towards the sensor per meter square of projected area in a given unit solid angle. This is what is known as radiance. And that is what essentially our remote sensing sensors are measuring or measured by RS sensors.

So, we have to essentially calculate the radiance that is leaving the surface and reaching the sensor. And also one more thing you have to notice in remote sensing. Whenever we talk about these energy terms, always remember they always have a spectral element attached to it. Spectral element attached to it means it has a wavelength dependency. We will always talk about some certain bands of wavelength say red band, green band, blue band, visible band and so on. So, the radiance to be more specific it is actually the spectral radiance. Radiance leaving the object of our interest per unit meter square area that is projected area per unit solid angle in a given bandwidth per unit micrometer of wavelength. So, the units of spectral radiance is watt/meter^2/steradian/micrometer of wavelength. So, this is the unit of radiance which leaves the target and reaches the sensor.

We know that there are 3 major parts in which energy can reach the sensor. We are going to calculate or derive some basic equations to know how much radiance will reach the sensor. First we will discuss those equations in the shorter wavelengths.

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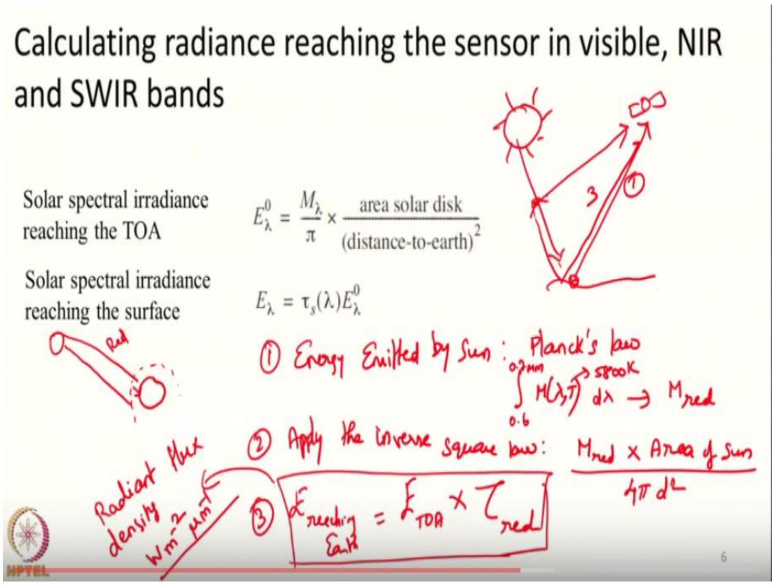

Calculating radiance reaching the sensor in visible, NIR and SWIR bands

Solar spectral irradiance reaching the TOA $E_\lambda^0 = \frac{M_\lambda}{\pi} \times \frac{\text{area solar disk}}{(\text{distance-to-earth})^2}$

Solar spectral irradiance reaching the surface $E_\lambda = \tau_s(\lambda) E_\lambda^0$

① Energy Emitted by Sun : Planck's law

$$\int_{0.6}^{0.7\,\mu m} M(\lambda, \xrightarrow{} 5800K)\, d\lambda \rightarrow M_{red}$$

② Apply the inverse square law: $\frac{M_{red} \times \text{Area of Sun}}{4\pi d^2}$

③ $\boxed{E_{\substack{\text{reaching}\\\text{Earth}}} = E_{TOA} \times \tau_{red}}$

Radiant flux density $W m^{-2} \mu m^{-1}$

In shorter wavelengths, we know sun is the primary source of energy. Solar radiation is coming in and interacting with the object of our interest. This is a sensor. So, this will reach. So, this is path 1. And diffuse skylight component what is present here path 2. And this diffuse skylight reaching the target going towards the sensor is path 3. So, we are going to calculate these 3 paths now.

First we will talk about path number 1 that is the direct component of solar radiation. So, if you look at the direct component of solar radiation we have to first calculate what is the energy emitted by sun and what energy reaches the top of atmosphere and what energy reaches the terrain. We all know as sun's radiation travels through some distance, the energy goes down. We saw the inverse square law. The radiant flux density decreases with increasing distance. We have to calculate that. Then we will calculate what is energy reaching the top of the earth's atmosphere. So, earth's atmosphere has certain scattering and absorption properties. So, that energy will be further reduced, that also we already studied. So, what fraction goes down and what reaches the sensor. We have to calculate each and every step.

We have studied most of these things. We will quickly recall them. The first component, energy emitted by sun. We can calculate it in a simple fashion using the Planck's law. So, if you integrate Planck's law between whatever wavelength you are talking about. Say for example I am now interested about calculating the radiance reaching the sensor in red band. So, red band essentially we can say it is 0.6 micrometer to 0.7 micrometers. So, we have to first calculate what is the energy emitted by sun in this particular wavelength. So, integrate Planck's law between your limits 0.6 to 0.7 micrometers $\int_{0.6}^{0.7} M(\lambda, T)$. So, sun's temperature you can assume it to be 5800 Kelvin. If you do this integration we will calculate what is the energy emitted by sun in the given wavelength. We call it as red band.

Then second, apply the inverse square law. This is the energy that is the radiant flux density per unit meter^2 area of sun because that is what Planck's law will give per unit meter^2 area. But sun we saw it is a big sphere. So, we multiply this with area of sun and divided it by $4\pi d^2$. This also we have done. And if you remember, using this only, we calculated what is known as the solar constant 1368 watt/meter^2 of radiant flux density. That is for entire bandwidth total energy that reaches the sun in all wavelengths.

Here we are talking about one particular spectral band. So, essentially you first apply Planck's law. Calculate the energy emitted by sun within that particular wavelength band. Then you apply this inverse square law whatever the problem you have done earlier which will give you the energy from the sun that reaches the top of our earth's atmosphere within that particular wavelength. So, we have calculated how much energy reaches earth's atmosphere within say in our example red band. Now we have to calculate what is the energy that reaches the earth surface? How to calculate it? Rather than calculating each and every component. We will take what is the total amount of energy lost in the atmosphere. So, we represent that particular component as absorbed energy and what remaining is coming in. So, that particular remaining energy coming in we are interested upon. So, energy E reaching the earth surface is equal to E top of atmosphere multiplied by transmissivity of atmosphere in red band.

$$E = E_{TOA}.\tau_{red}$$

What transmissivity is? So, let us say 100 units of energy reaches the top of the atmosphere. Out of that 100 unit, if 70 units of energy reaches the earth surface then transmissivity is 0.7. That is transmissivity. So, this will give us the energy from the sun reaching the earth surface. So, for the first path we have just calculated what energy will reach the earth surface. So, technically speaking this particular energy whatever I am talking as energy is actually radiant flux density in actual radiometric units. It will have a units of watt/meter^2/micrometer wavelength. So, this is actually the radiant flux density or spectral radiant flux density what we have studied in radiometric classes. So, this is the power from sun that reaches the earth surface.

So, it has 3 paths. We have calculated it in 3 steps. Next step is energy has travelled and reach the surface. A portion of it will be reflected back, a portion of it will be absorbed a portion of it will be transmitted that we know. But whatever it be, remote sensing sensor will collect essentially the reflected energy. So, we are now going to calculate that particular component.

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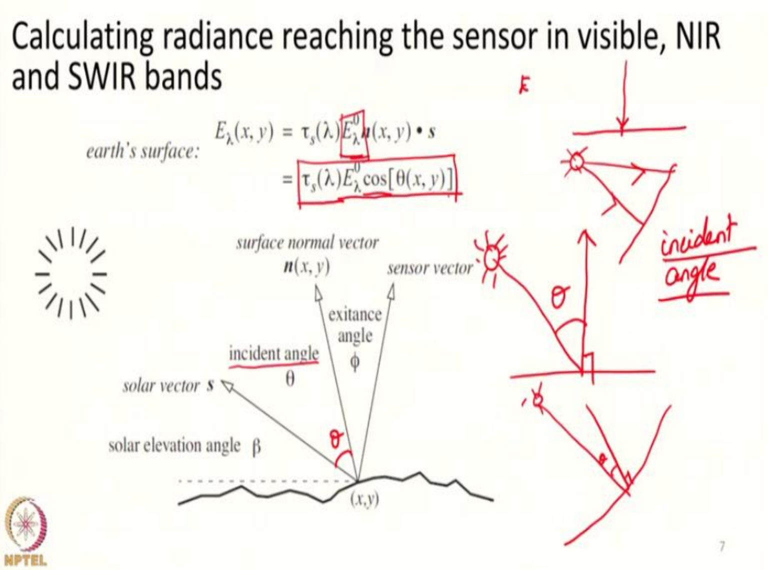

Calculating radiance reaching the sensor in visible, NIR and SWIR bands

earth's surface: $E_\lambda(x,y) = \tau_s(\lambda)\boxed{E^0_\lambda}\boldsymbol{n}(x,y)\bullet \boldsymbol{s}$

$= \boxed{\tau_s(\lambda)E^0_\lambda\cos[\theta(x,y)]}$

Say E, this is the energy from the sun that reach the terrain. If the surface is flat and if the sun ray came in perpendicular to the surface, no problem everything will be coming in together. But normally most of the earth surface features are not flat. And also not every time sun radiation will come directly from overhead perpendicular to the surface. Most of the time it will be coming in at an angle. Let us say there is a small slope and sun's radiation is coming in from a certain angle. So, essentially whatever the energy that is coming in from the sun will be modified for this solar geometry effect. Solar geometry effect means if the sun's radiation is directly falling perpendicular to the surface, the entire energy will be used to irradiate the surface. On the other hand, if the surface is slightly sloped or if the sun is not overhead it is coming in at an angle, then the incoming energy will be distributed over actually a larger area. It means larger the zenith angle, larger area in the ground will be irradiated by sun. We have to correct for it.

So, this is like even when we studied about the radiant flux density in radiometric classes we always assumed surface is flat put a hemisphere over it calculate all the energy coming within it. That is how we studied. If the surface is not flat then comes a cos θ term into picture. The θ is how much is the angle between the surface normal and the solar incident angle.

Let us say surface is like this. Sun is here. This is normal to the surface or we will say it as vertical. At what angle sun radiation is falling in. If this is not the case if surface is oriented like this, then you have to again draw a normal like this if sun is here you have to calculate at what angle solar radiation is falling in. So, this is what you call it as incident angle. This is to account for at which angle sun's energy is coming and falling on the surface.

If sun's energy is coming directly perpendicular to the surface no issues all the energy from the sun will be directly irradiating that particular area. But if it is coming in at an angle with respect to vertical to the surface or normal to the surface then we need to account for with what angle the sun radiation is inclined. That angle is called angle of incidence or incident angle.

For a horizontal surface, incident angle is just the solar zenith angle. For a sloping surface, you have to draw a surface normal at the point and then calculate it. Normally we will calculate it with different means. I will explain it later when we talk about topographic correction. I will tell briefly about this. So, now you just know that if sun radiation is not exactly coming in perpendicular to the surface, there comes a cos θ term where θ is the incident angle between surface normal and the incoming solar radiation. We have to correct the incoming solar radiation for incident angle. And that is given by $E\lambda \cos \theta_o$. So, $E\lambda$ is the energy that reach top of atmosphere, cos θ is to correct for this. And we have corrected it for τ_s. So, this is the actual energy that will be reaching the earth surface.

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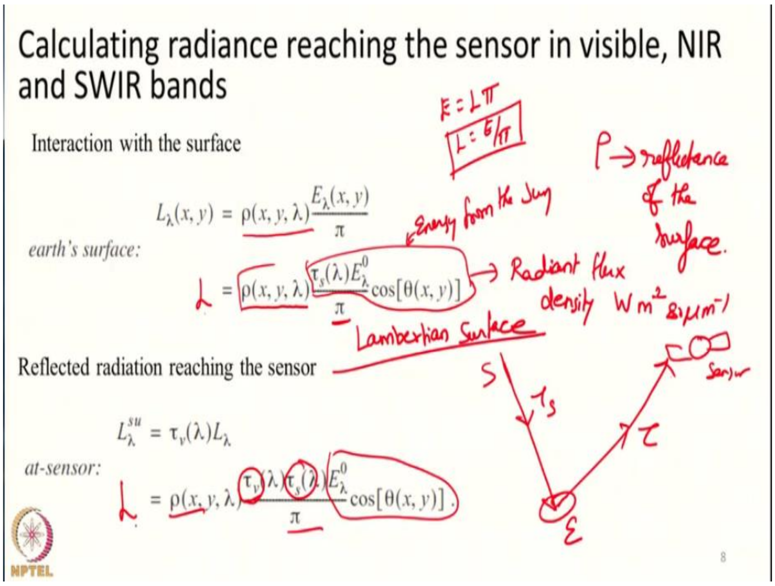

Calculating radiance reaching the sensor in visible, NIR and SWIR bands

$E = L\pi$

$\boxed{L = E/\pi}$

Interaction with the surface

$\rho \rightarrow$ reflectance of the surface.

$$L_\lambda(x, y) = \underline{\rho(x, y, \lambda)}\frac{E_\lambda(x, y)}{\pi}$$

earth's surface:

Energy from the Sun

$$L = \boxed{\rho(x, y, \lambda)}\frac{\tau_s(\lambda)E^0_\lambda}{\underline{\pi}}\cos[\theta(x, y)]$$

→ Radiant flux density $W m^{-2} \mu m^{-1}$

Lambertian Surface

Reflected radiation reaching the sensor

$$L^{su}_\lambda = \tau_v(\lambda)L_\lambda$$

at-sensor:

$$L = \underline{\rho(x, y, \lambda)}\frac{\tau_v(\lambda)\tau_s(\lambda)E^0_\lambda}{\underline{\pi}}\cos[\theta(x, y)]$$

Now after it reach the earth surface it will interact. So, this $E\lambda_o$ τ_s is the energy from the sun. Multiply it with reflectance of the surface where ρ is the reflectance of surface. Say if the surface reflects 30 percent of incoming energy. So, reflectance is 0.3. So, say 100 units of energy came into the surface after correcting for all these τ_s cos θ and all these things. Finally 100 units of energy reach the surface. Out of which 30 percent is reflected means multiply that 100 by 0.3. So, 30 units of energy will be reflected. So, now we multiply with this reflectance. Still now we are talking in terms of radiant flux density. That is watt/meter$^{2/}$micrometer whereas whenever like energy leaves the surface and reaches the sensor we need to calculate radiance the term we are interested upon is radiance.

Assuming the surface is Lambertian. So, we also studied what Lambertian surface is again in previous classes. So, for Lambertian surface,

$$E = L\pi$$

$$L = \frac{E}{\pi}$$

Where, E is the radiant flux density, L is radiance, π is the relation between them. So, L is equal to E/π. Assuming the surface as Lambertian, the radiance reaching or going out of the surface is this entire term divided by π.

So, the radiance reaching the sensor or sorry the radiance leaving the earth surface is whatever it came from sun multiplied by a reflectance of that particular surface divided by π assuming the surface as Lambertian. So, now this particular energy has now interacted with object of interest it has to again go back to the atmosphere to reach the sensor.

So, once again there comes another transmissivity term τ where this τ is to account for the transmissivity of atmosphere in this outgoing direction. Because whenever sun radiation come in, a part of it will be absorbed here. Similarly whenever it goes out toward the sensor a path of it will be absorbed there also. So, it is a 2 way path.

So, the final reflected radiation reaching the sensor is energy coming in from the sun multiplied by τ_s, the τ in between sun and the earth; τ_v, transmissivity between earth and the sensor, reflectance of the surface divided by π. So, this is the radiance from the target of interest that reaches the sensor. So, essentially in today's class what we saw is we first discussed what are the different ways in which energy can reach the sensor.

We saw 3 major paths, the direct radiation coming in from the sun, reflecting with object reaching the sensor path radiance and then third path is the surface being irradiated by the diffuse skylight and that reaches the sensor. So, essentially in today's class we have calculated what is the amount of energy from path 1? So, remaining 2 paths we will calculate it in next class. And also we will look at how to do this for longer wavelengths such as thermal infrared wavelengths.

Thank you very much.