REMOTE SENSING FOR NATURAL HAZARD STUDIES

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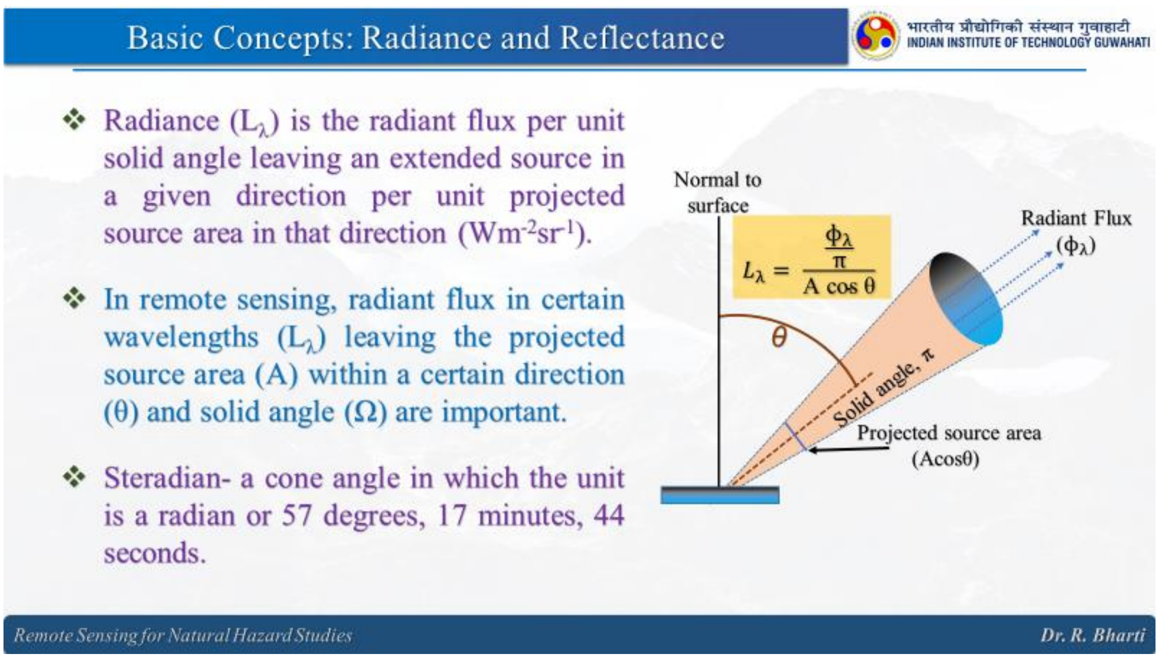
Lecture 2b: Basics of Remote Sensing Part B

Hello everyone, this is the continuation of Lecture 2, i.e., on the Basics of Remote Sensing. So, before we proceed, we need to ask this question: can we use the digital number to identify the material? Digital numbers associated with the pixels are unique; do they vary with space and time? So, I will just try to explain them one by one. So, when we try to capture the images, basically we are trying to capture the reflected energy or emitted energy. So, here we have the sensors, and because of the ADC (Analog to Digital Converter), these signals are getting some numbers right, depending on whether they are 2-bit, 4-bit, or 6-bit. So, we will have different numbers. So, this is called a digital number. So, this digital number, if you just try to understand, is directly affected by the amount of radiation.

If we have cloud cover here, the amount of energy that is reaching this particular surface will be less. So, in that case, earlier we received, let us say, 80, but because of the cloud cover, we may receive 60. Maybe again you put some gases that are not allowing this, and maybe aerosol or dust particles, maybe it will reduce to 20 right. So, these 20 to 80 variations are just because of the atmospheric component as well as the amount of radiation released by the source, right? So, in such a situation, can we consider that they are consistent over space and time? No. So, this is answered.

Can we use this digital number to identify the materials? When they vary with space and time, we cannot consider them a unique property. So, we cannot use this. So, can we use the digital number to identify the material when it is not unique? We cannot do that because, let us say, I have put a mineral called quartz. So, if it has more radiation, right? If the irradiance is high, we will get 80; if it is low, then we will get 20. So, this variation says that we cannot use digital numbers to identify the material because they are not unique through space and time. So, in such a situation, what we do is try to generate or derive a number that is unique through space and time. So, the radiance, now I will explain to you again, let us say this is the source and this is the sensor, this is the surface, and this surface is receiving the intensity or the radiance from the sun. So, we call it irradiance. The amount of energy that is being reflected or emitted and is reaching our sensor is called radiance, right? And then what we do is try to use this ADC, an analog-to-digital converter, to convert this radiance to a number. So, that will be a scaled number.

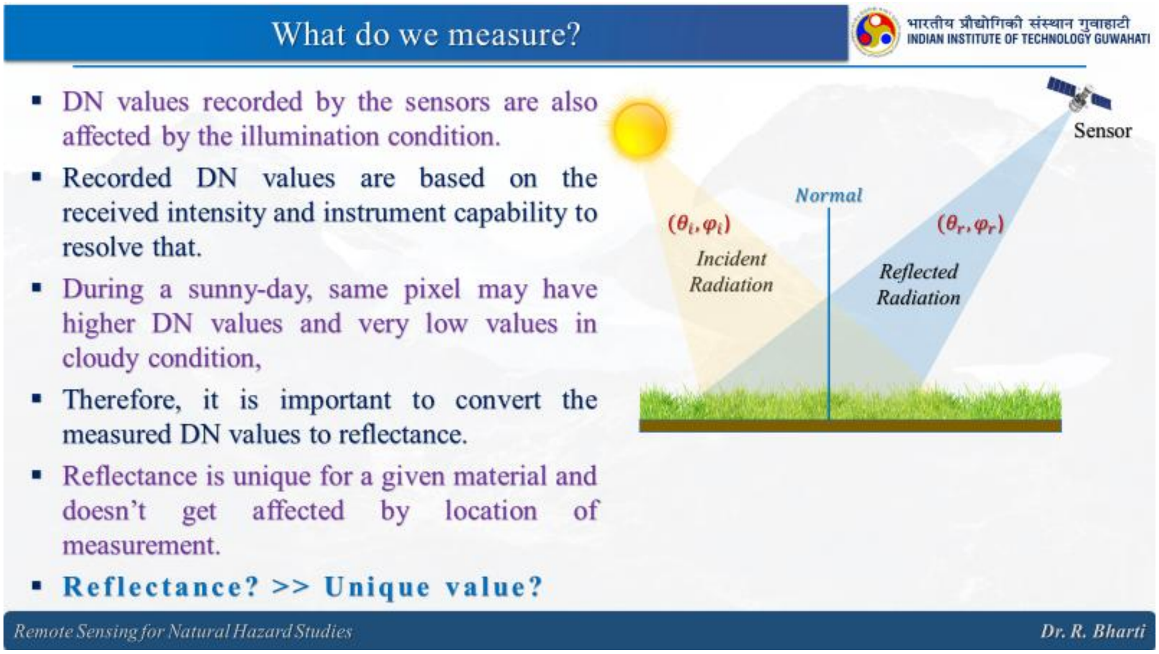
So, the DN value is a scale number depending on whether it is 2 bits, 4 bits, 6 bits, or 8 bits; these numbers will be decided. If your sensor is 2 bits, you will have 2 to the power of 2. Right, if it is 8 bits, 2 to the power of 8. So, if it is 8-bit, you will have a range of 0 to 255 because the total is 256, right? So, 0 to 255 is 256. So, in such a situation, it directly gets changed when we are changing the radiometric resolution. So, this radiance, irradiance, and this DN number, none of them can be considered a unique property right. Because our material is located here, whatever energy is coming to it will interact with the material composition, and then, depending on that amount of energy, it will be reflected. So, this reflected energy is reaching our sensor in the form of radiance. So, now what we have to do is change this DN number to radiance and then to reflectance. So, once we have this, we can consider this to be unique; we will discuss that part again.



We will start with the radiance, which is L lambda; it is the radiant flux per unit solid angle leaving an extended source in a given direction per unit projected source in that direction. So, here the unit of radiance is watts per meter squared per steradian. So, this watt per meter squared per steradian will be used to define our radiance. In remote sensing, radiant flux at a certain wavelength leaving the projected source area A within a certain direction theta and the solid angle are important. So, you can consider this to be the solid angle. Right, and this is the amount of energy that is reaching the surface, and then it is getting reflected, which is coming as radiant flux. So, here we have this watts per square meter per steradian unit. A steradian is a cone angle in which the unit is a radian or 57 degrees, 17 minutes, and 44 seconds. So, the reflectance is defined as the ratio of radiant flux reflected from a surface to the radiant flux incident on it, and it is a unitless property, right? So, remember, reflectance is a dimensionless property. Now, I will try to explain this using the diagram.

You have the sun as a source of light; this is our surface, and this is the sensor, right? So, light is falling on this particular surface, getting reflected for the time being; we are ignoring the atmosphere to understand this basic concept: radiance, irradiance, and reflectance. Now, the amount of energy that is coming and reaching the surface is called irradiance. This amount of energy that is reflected is called radiance. Now, here we have the DN number. We have converted the DN number to radiance using the scaling factor that is available from the space agency when you download the data. So, now assuming that you have a radiance and you also have an irradiance because of the same sensor, you can put it here. And then you will measure how much energy is reaching the surface, and the same sensor is placed here to measure how much energy is reflected from the surface, right? So, once we have this, then we will do the ratio. So, reflectance is equal to radiance divided by irradiance. So, here we have the watt per meter square per steradian; here we also have the watt per meter square per steradian, the units of radiance and irradiance, because we are using the same sensor here and here. So, once we have that, reflectance will be unitless, and it will range from 0 to 1. So, 1 is the highest one, 0 is the lowest one. So, the value of reflectance will always be between 0 and 1. Now, coming back to our atmospheric conditions and whether dn values can be used as unique values or not. Now, you will be able to understand since both the DN values and the radiance are being affected by the amount of irradiance. However, when we calculate the reflectance, we are taking this ratio and removing the impact of irradiance. So, here you can see that reflectance is the ratio of radiance to irradiance, and it is a unitless property. So, because of this, it can be considered a unique value. So, if I put a quartz here, I can measure it in India, the US, or Canada. Everywhere, this will get the same value it is getting in India, the US, or Canada. So, this reflectance will be a unique value that is consistent through space and time. Whether you measure it today, tomorrow, or maybe after one year in different places, the quad should have the same reflectance value, and that is the basis of remote sensing: why we are using remote sensing. So, the transmittance is defined as the ratio of the radiant flux transmitted through a surface to the radiant flux incident on it. This is again a unitless property; absorption of the electromagnetic radiation is the process where the energy of the incident light is taken up by the matter. So, this absorption, transmittance, reflectance, all of these are unique properties, unique values, which can be used to measure or identify the material. Now, we will try to understand these concepts: spectral reflectance, Lambertian surface, and diffuse reflector. So, we will go one by one. So, let us understand spectral reflectance. If you remember that what we use to generate or calculate the reflectance, we used radiance and irradiance values.

So, when we have reflectance, we use radiance and irradiance. Now, this is the general concept: the reflectance is a ratio of radiance to irradiance. But when we talk about remote sensing data, where we have 4, 5, 6, or 10 bands, we have to do it wavelength-wise. So, let us say the first band is generated using this 400 to 500 nanometers. The second band is 500 to 600 nanometers, the third is 600 to 700 nanometers, and the fourth one is 700 to 800 nanometers.

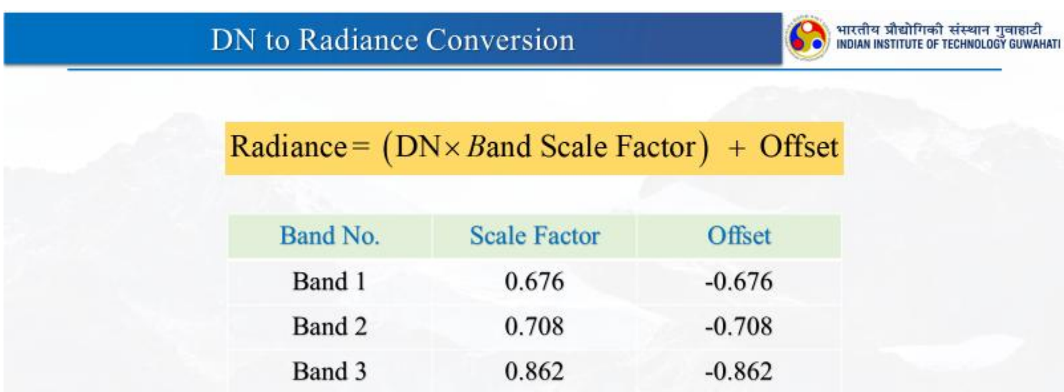


Now, if I have to calculate the reflectance, which is this one, right? What we have to do is consider one-pixel value, which is basically the DN value, and that we have converted to radiance. So, we have the radiance value from here, right? And for irradiance, we will use the same sensor to measure the irradiance at this particular wavelength only. So, now the reflectance of 400 to 500 nanometers is equal to the radiance of 400 to 500 nanometers divided by the irradiance of 400 to 500 nanometers. I hope this is clear. So, once we do that, we are able to generate the reflectance image for this particular image. Earlier, it was a radiance image. Now, using this concept, we have generated the reflectance image. So, the first image is available. This is reflectance R from 400 to 500 nanometers. Now for the second image, we will again consider the irradiance measured in this particular wavelength, which is 500 to 600; then we will also have one reflectance image, then the next band, and then the next band. So, this is the reflectance calculation by wavelength. So, with respect to wavelength, we are calculating the reflectance. Now this information we can use; if we have this for the same area, all these images, then we can use these values, the reflectance value, to draw this kind of graph. Here we will have the wavelength, and here we will have the reflectance; then these values will be here somewhere. This is just an example. So, this kind of spectral curve will be generated for 1 pixel using the reflectance value. So, this is called spectral reflectance. Now, sometimes what happens is that our remote sensing sensors are capable of generating only point information, right? So, one of the examples is a spectroradiometer. So, that is capable of measuring the irradiance and radiance at different wavelengths. So, in such a situation, what happens is you have two columns: you have irradiance, and this is radiance, and this is the location. So, let us say that for this particular area, at one particular point, you have used that instrument to measure the irradiance, radiance, and this wavelength. So, let us say this is 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and this is 1, right? So, here you have one value x1, x2, x3, x4, x5, x6, x7, and here you have radiance y1, y2, y3, y4, y5, y6, y7. Here, we can write the reflectance. So, considering this is a set of tabular data that has been generated by the spectroradiometer. So, for this particular point, the instrument has generated irradiance and radiance information for different wavelength regions. Now, if I have to calculate the reflectance, it will be radiance divided by irradiance.

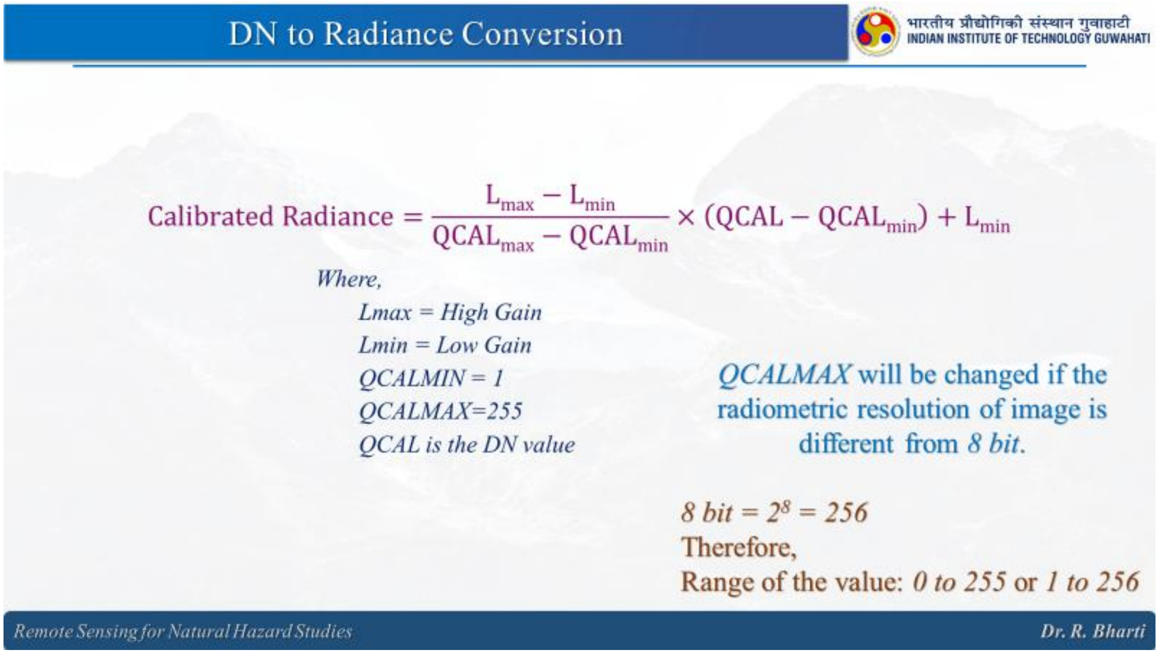
So, y1 divided by x1, y2 divided by x2, y3 divided by x3, y4 divided by x4, y5 divided by x5, y6 divided by x6, y7 divided by x7. So, if we have this kind of calculation, we are basically trying to generate the reflectance value with respect to wavelength. So, this is called spectral reflectance. I hope this is clear when we have satellite images and tabular data for the point information. So, in such situation how to calculate the spectral reflectance. Now we will continue with this, and we will go to the next topic, which is the Lambertian surface. Now the Lambertian surface is a surface that reflects an equal amount of energy in all directions. So, considering this as a Lambertian surface. So, here the light that is coming from any source can be the sun or your own source of light. So, this surface will reflect an equal amount of energy in all directions. So, here it is assumed that this particular surface is reflecting all the energy that is falling on it. So, this reflected energy will be 1. Remember, reflectance ranges between 0 and 1, and since we are talking about the Lambertian surface, it reflects an equal amount of energy in all directions, and it does not absorb or transmit any energy. So, in such a situation, the value for the reflectance of this particular surface will be 1. So, if we consider, you may remember the black body concept, right? So, a black body absorbs all the incoming radiation. So, in such situation what will happen your black body will receive 0 reflectance. So, if I put a black body here, then the property of the black body is that it will absorb all the incoming radiation, right? So, once it absorbs, it has to maintain equilibrium with the surroundings; in such a situation, it will emit energy in the longer wavelength region, but in the reflective domain, it will have no signal. So, the reflectance for the black body will be 0, and the reflectance for the Lambertian surface is 1. Similarly, if you consider emissivity, the emissivity of the black body will be 1. Because that will receive the highest number, the emissivity for the Lambertian surface will be 0. So, that is very, very important when we are dealing with remote sensing instruments. So, I hope you will see some of the instruments in the future, and then you will recall all these concepts. Then comes the diffused reflector. So, the diffused reflector says that when you have the sensor here.

Then comes the concept of a diffused reflector. So, the diffused reflector is different from the Lambertian surface because the diffused reflector reflects an equal amount of energy in all directions, but it will also have some amount of absorption and some amount of transmission. So, this diffuse reflector is slightly different from a Lambertian surface. This slide is meant to explain the basic concepts of reflectance. So, here you can see the sun is illuminating this particular target. And if the observer is here or if your sensor is here, it will receive some amount of reflected energy. But if you change the position from here to there, what will happen? The amount of energy will also get changed. So, that is why it is very, very important to make sure at what angle you are doing this remote sensing. This is the Lambertian surface, which we talked about earlier. So, this Lambertian surface reflects an equal amount of energy in all directions. That is why it does not matter whether you are here, here, here, or here; you will receive the same amount of energy.

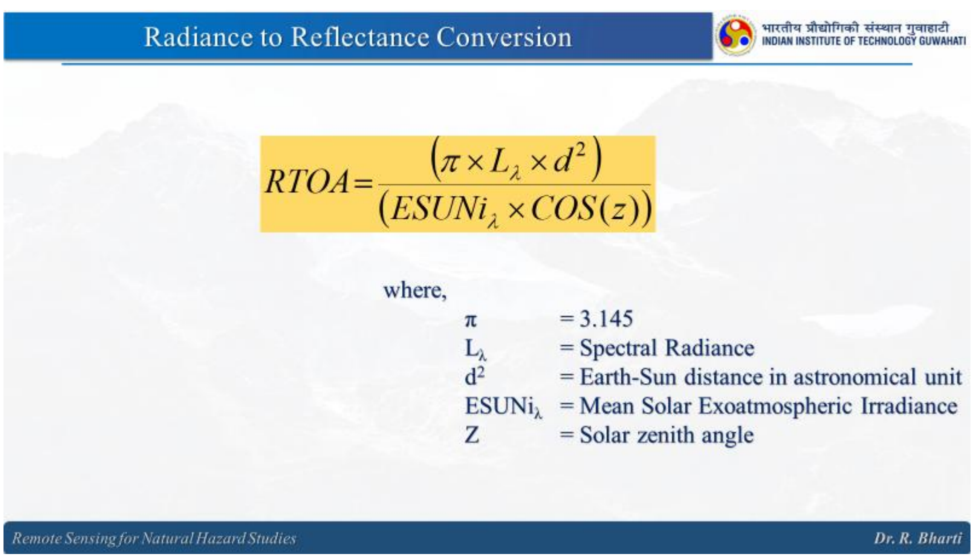
However, when you change this to a natural surface, it will vary with position. Right, because these surfaces are not smooth; these are rough surfaces. Coming back to the digital number that we measured earlier. So, the DN value recorded by the sensors is also affected by the illumination conditions. So, here you can see that the illumination condition controls the amount of reflected energy from the target. Recorded DN values are based on the received intensity and the instrument's capability to resolve that; during a sunny day, the same pixel may have higher DN values and very low values in cloudy conditions. Therefore, it is important to convert the measured DN values to reflectance because reflectance can be considered a unique value; it does not change with space and time. Reflectance is unique for a given material and does not get affected by the location of the measurement. So, once we have that, we can consider this reflectance as a unique value. So, how do you convert dn to a radiance value? So, to convert the DN to radiance, we can use this formula.



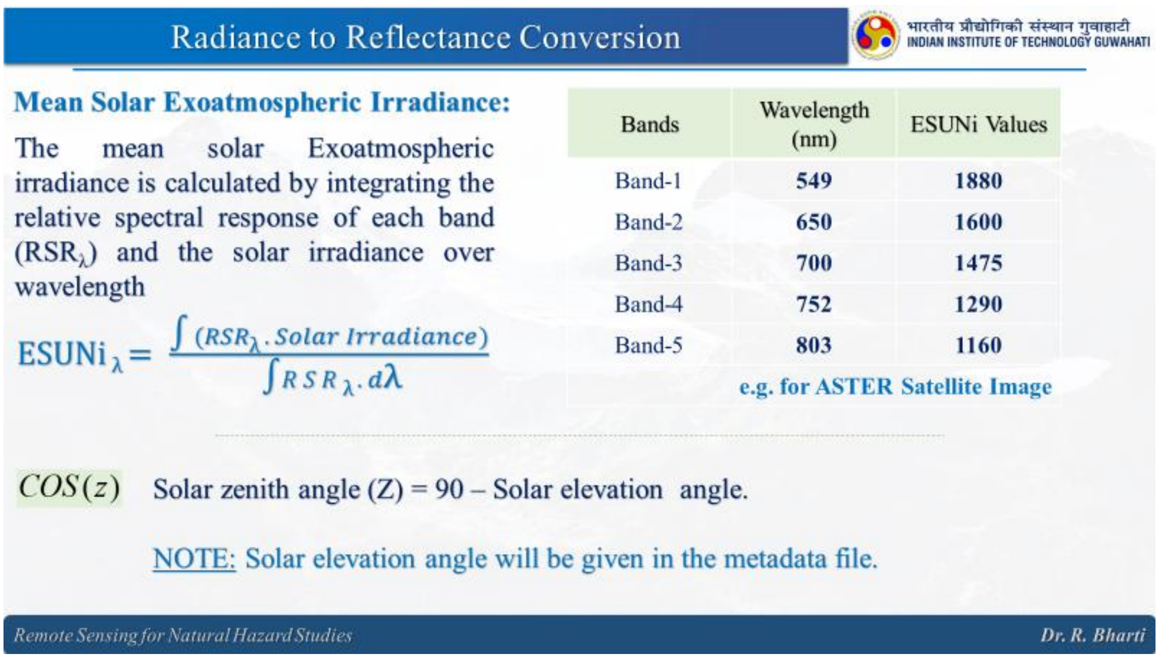
So, here the radiance is equal to the DN value multiplied by the band scale factor; this information will be provided by the space agency that has launched the satellite, and the offset will be available to you. So, for example, some of the satellites have this band 1 scale factor; this offset is this. Once we have that, you can calculate the radiance. Right, and in the other condition, when you have more information about your sensor, you can calculate the calibrated radiance. Here we use the L_{max}, which is the high gain, then low gain, and the $Qcal_{mean}$ and $Qcal_{max}$, which is the radiometric resolution.



If it is 8 bits, it will be 1 and 255, or 0 to 255. It depends on the radiometric resolution that qcal is the DN value that we have to convert to calibrated radiance, right? So, using this formula, you can calculate that the calibrated radiance Qcal max will change if the radiometric resolution of the image is different from 8 bits. So, for 8 bits, this is how we calculate. Now, we have the radiance value. So, we can calculate the radiance to reflectance ratio. Now, we can use this formula; this is RTOA, and this is reflectance at the top of the atmosphere, because the irradiance that we are going to use is measured at the level of the sensor, right.



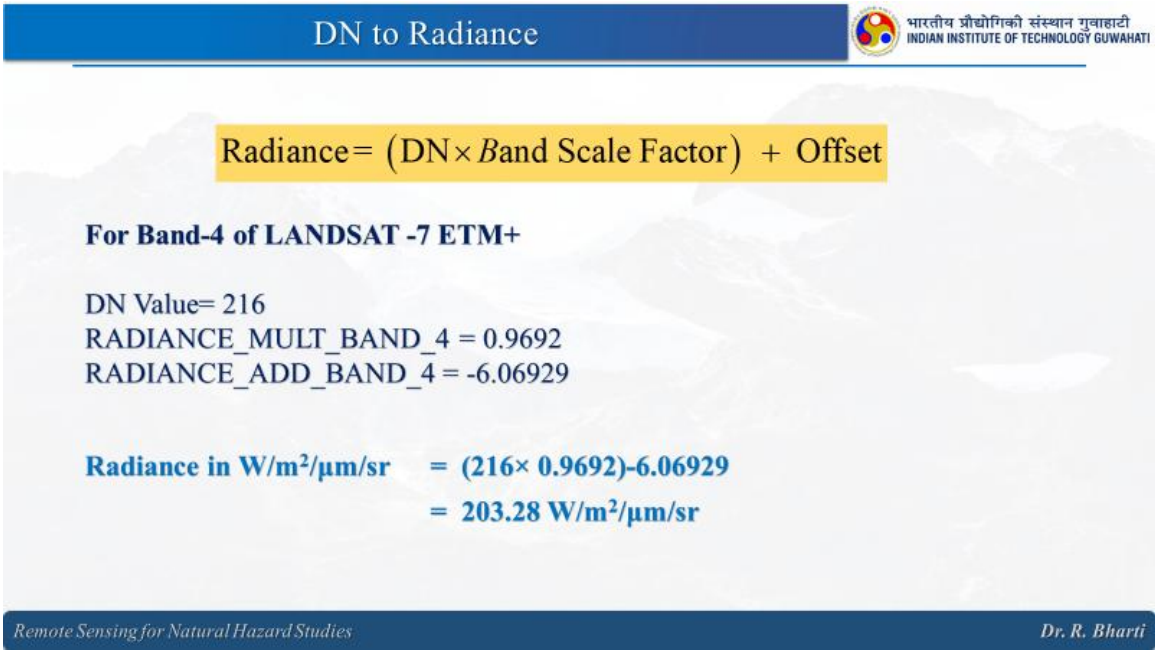
So, that irradiance does not have any interaction with the atmosphere of the Earth. So, in such a situation, we will call it reflectance at the top of the atmosphere. So, here we are using π, L_λ, d^2, which is the Earth-Sun distance in astronomical units (ESUN) that is mean solar exoatmospheric irradiance. Remember, I told you that we are going to use the irradiance measured in the space; right then, Z is the solar zenith angle. So, all this information will be available to you, as well as the Earth-Sun distance in astronomical units that is given in this particular table, and the day of the measurement will be provided to you in Julian date. So, the Julian date starts from 1 and ends with 365; accordingly, you can select the distance value from this table. Then, radiance to reflectance conversion; then comes the mean solar exoatmospheric irradiance.



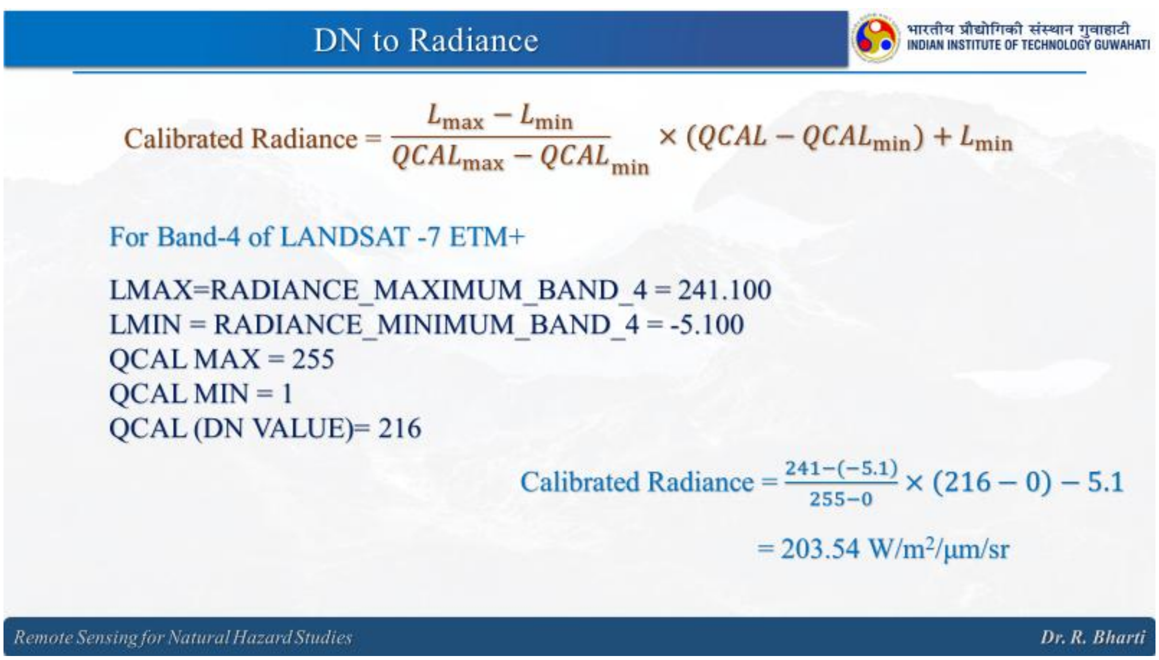
The mean solar exoatmospheric irradiance is calculated by integrating the relative spectral response of each band and the solar irradiance over the wavelength range. So, here ESUNI is provided with this formula. And for this ASTER satellite image, this ESUNi is available for each of the bands that can be used to calculate the RTOA and Cos(Z), which is basically the solar zenith angle, and the solar zenith angle can be calculated using the solar elevation angle. In the metadata file, you will find this solar elevation angle. So, 90 degrees minus the solar elevation angle is the solar zenith angle. Now, this is the ESUNi for the Landsat product, which is from the USGS. So, you can see that all these ESUNi values are given for different bands from different sensors. Similarly, for this ASTER product, this ESUN is given. So, depending on which satellite data you are using, you have to select the ESUNi value accordingly.

Now we will try to calculate the radiance using the hypothetical DN values. So, here we are going to use this radiance with this formula for band 4 of Landsat 7 ETM Plus; here the

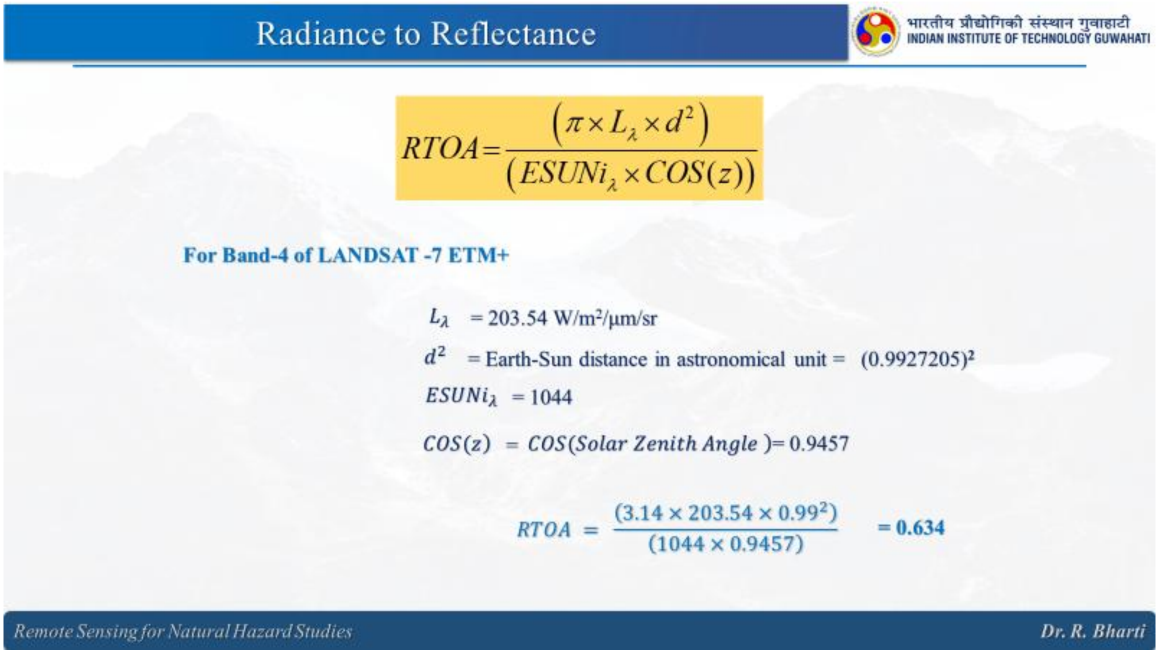
DN value is 216, and the radiance for band 4 is given, right? You can calculate it, and the result is 203.28 watts per meter squared per steradian. Now, taking the other equation into account, we will use the same value for the calibrated radiance and then try to calculate it.



So, here it comes: 203.54. So, there are slight changes when you are going with the scale factor radiance calculation and when you are going for the calibrated radiance calculation.



Now, once we have those values, we can proceed with this RTOA and calculate the reflectance. So, here we are going to use this 203.54 watts per meter squared per steradian and d that is 0.99 squared, ESUNI; we have referred to that particular table of Landsat 7 ATM Plus, and then Cos(Z) we have calculated using the solar zenith angle, which is coming out to be 0.94.



So, using this, if we calculate, we get 0.634; this is the reflectance value. So, this is the unique value that we talked about right. So, with this, I will end this lecture, Lecture 2, and we will continue this course with Lecture 3.

Thank you.