REMOTE SENSING FOR NATURAL HAZARD STUDIES

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Lecture 4: Optical Remote Sensing

Hello everyone, today we are going to start Module 2: Concepts of Remote Sensing with Lecture 4, which is Optical Remote Sensing. So, we will start this lecture with optical remote sensing. In this lecture, let us start with the Panchromatic, Multispectral, and Hyperspectral. So, I hope you remember this graph. So, here it shows what the different bands measured by Landsat satellites are; the bands refer to the images. So, here we can see the first, second, third, fourth, fifth, and seventh bands of Landsat ETM+ that are captured in these wavelength ranges. And I also explained to you in the previous lectures, let us say this is 400 to 700 nanometers. And if I design a satellite or sensor that can capture one image using this wavelength range, an image can be generated using this wavelength range.
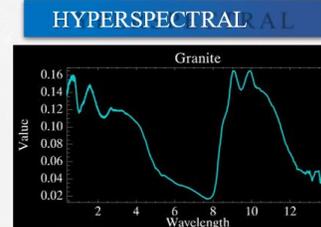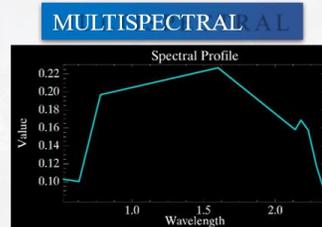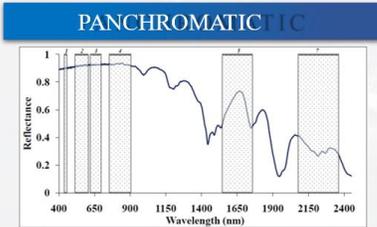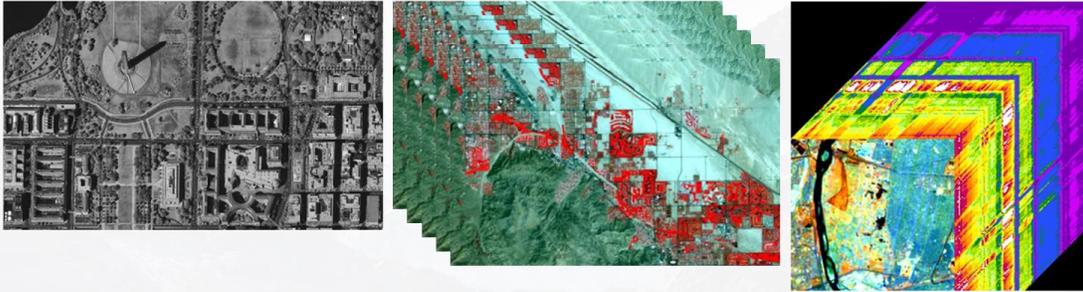
Another can be using a broad wavelength range. So, this is up to the developer of this sensor: what the objective of the mission is, and then accordingly we select what the wavelength ranges are that we have to use to design a particular sensor. So, in this particular sensor, there will be three different types of detectors: one that is sensitive between this and this wavelength, another set of detectors that is sensitive between this and this, and another detector that is sensitive between this particular wavelength range. So, in this scenario, let us say that this particular sensor is the X sensor, which is capable of generating 3 bands; 3 bands mean these are 3 images. And these images have different wavelength ranges that are being used here. So, I hope this is clear, and we also learn what the relationship is between wavelength and energy: as we move towards shorter wavelengths, we have high energy, while as we move towards longer wavelengths, we have low energy.

So, if our image is generated in this particular wavelength. So, here we have high energy. Here, when we move to the second image, it will be comparatively less; when we move further into the longer wavelength, we will have even less energy compared to this. So, the pixel that is generated by this image. The pixel that is generated by this particular sensor or detector will have fine spatial resolution compared to this. Then again, if I compare this spatial resolution with this. Here, this will be finer than this one because we have more energy in the shorter wavelength range. So, taking these things into consideration, we can design a particular sensor that is sensitive across the entire wavelength range, starting from

400 to 700 nanometers. Or maybe 1500 nanometers. So, if I generate a single image using this whole wavelength range. So, this is a broad wavelength range. So, if we are using the broad wavelength range, the energy is very, very high here. So, if we have high energy, then our image or the detector that is looking at a particular area can identify very small energy released by this particular pixel. Because energy is high. So, the energy will be sufficient to travel through our atmosphere to space and be captured by this particular detector. When we move towards a longer wavelength range, we try to increase the size of the pixel. So, that energy will be sufficient to be captured by our sensor. So, here when we are using this whole wavelength range, we have a good amount of energy to be resolved by our sensor.

So, our pixel size will be on the order of maybe a centimeter, or millimeter or meter. So, here this kind of setting is known as a panchromatic image. If we generate an image using a broadband spectral range and the spatial resolution of this particular image is high, we will have more feature details in this particular image. So, this is called panchromatic, and remember one thing: when we are talking about panchromatic images, these images are single-band images. It does not have multiple bands or multiple images captured in the same wavelength. So, here is a single band image which has high spatial resolution or fine spatial resolution. It will have more object information. When we talk about multispectral remote sensing, this is an example of multispectral.

Here, the first criterion is that the number of bands should be more than 3 or equal to 3. So, the minimum is 3 bands. And then another thing referring to this particular plot is that you can see here that these spectral ranges are different and have gaps in between. If you see this, here you have a gap; here you have a gap. That means the gap is where we have not generated any image, or there is no specific sensor that is capturing this particular wavelength information. So, we have six images. Now, when we have 6 images, that means the same area is captured by 6 different sets of detectors sensitive to different wavelength ranges. So, these 6 images will have different information related to your surface or the object.

Concepts of panchromatic, multispectral, and hyperspectral

PANCHROMATIC   MULTISPECTRAL   HYPERSPECTRAL

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So, if we consider the first pixel of the first image, which is capturing the same area located in the first pixel of the second image. Likewise, the first pixel of the third image, the first pixel of the fourth image, the first pixel of the fifth image, and the first pixel of the sixth image are basically representing the same area on the ground. So, if we consider this first pixel here to the. of all these bands, that means we will have 6 different values captured in 6 different wavelengths. Remember these wavelengths. So, if we try to plot this information, here you have wavelength and here you have, let us say, reflectance, for example.

Now, the first information goes here, which is maybe here; second, it goes maybe here; third, it will go here; fourth, it will go here; fifth, it will go here; and sixth is going here. So, once we have this, we can have a plot that represents the characteristics of the material, the object, or whatever area is captured within this field of view of 1 pixel size. So, the 1-pixel size is, let us say, if it is 25 by 25 centimeters or, let us say, 1 meter by 1 meter. So, this particular graph represents the behavior of the material present in this field of view, which means this whole pixel behavior. So, the smaller the pixel, the more separation you will have in the object that is clear from the panchromatic image. So, this is the multispectral where the number of bands should be a minimum of 3 or more, and there may be a possibility that there will be a gap between the first image and the second image, or the third image and the fourth image. So, these gaps are allowed in multispectral. So, this is called multispectral remote-sensing data.

So, now I will show you one curve that can be referred to in order to understand this particular concept. Here the same plot is the first value coming here, the second value here, the third value here, the fourth value here, the fifth here, and the sixth here and then it is

connected with these straight lines. So, once we refer to this, we can identify the material, whether it is X material, Y material, or Z material. Now, if you refer to the basics of remote sensing, we say that a material's chemical composition and internal atomic structures are responsible for this kind of spectral plot. Where, if let us say, this is one of the plots. So, this characteristic absorption position, let us say this is lambda 1, and this is reflectance and this is material X. So, if this is reflectance, which is a unique property, remember that if this material is giving you one characteristic absorption feature at lambda 1, that means X can be identified using lambda 1. Now, similarly for Y, there may be a possibility that it has two absorption features in this particular wavelength range. So, if I have to identify Y, then I have to look for these two because material can give you one single characteristic absorption feature or a set of characteristic absorption features, and based on that, we identify. Now, referring to this multispectral setting.

Now do you see that between this point and this point all the information is present? No, why? Within this wavelength range, we do not have any images. Since we do not have any observations in this particular wavelength range, we are missing this information; maybe it is supposed to be like this, which is missing in this particular multispectral data. But when we have different types of measurement where we have contiguous measurement, there is no gap between the first and the second image. So, we will have this kind of measurement, and the minimum number of bands is 10, and the wavelength difference between the start and end of this particular image is the bandwidth. So, that should be in the order of 10 to 20 nanometers. So, this minimum number of bands, 10 to 20 nanometers, should be 10, and this is contiguous. So, this is contiguous. So, this means that there is no gap between the first and second, and earlier we had these gaps. So, once we have this kind of setting and generate such images, and once we have this kind of measurement where the number of bands is more than 10 and the bandwidth is in the order of 10 to 20 nanometer. and it is contiguous in nature; we call it Hyperspectral Remote Sensing Data.

And you see the spectral behavior changes because you have so many measurements here. So, once you have this kind of measurement, it gives you more information about the material characteristics, such as its chemical composition and internal atomic structure, and then you can more precisely identify the material. So, when you are using hyperspectral remote sensing, you can identify what kind of minerals, what kinds of rocks are present in the pixel area, what kinds of vegetation species exist, and what the different types of water are, whether it is mixed with suspended sediment; such information can be easily identified with hyperspectral remote sensing. So, we start with my panchromatic, then we move to multispectral, and then we also understand the hyperspectral concepts. Now this particular slide will give you more information about broadband multispectral, hyperspectral, and ultraspectral remote sensing. So, when we talk about this broadband, you can see there is only one image generated using this particular wavelength range. So, once we have that, that means we have enough spectral range and the energy will be very, very high, whereas

this multispectral will have both. In multispectral imaging, the same wavelength range is used to capture different images. So, here you can see that many images were generated, and in between, we also have a few gaps.

So, as per the definition, the minimum number of bands should be 3, and gaps in between are allowed. So, this is continuous measurement wherein wavelengths are not used to generate the images. Now, when we move to hyperspectral, we have hundreds of bands. And this is contiguous in nature. There is no gap between the first image, the second image, the third image, the fourth, and so on. So, here you will have a very good spectral resolution. If we have this ultraspectral, it is a concept where we have thousands of bands, and the bandwidth will be further lowered. So, the starting bandwidth here can be in the order of, let us say, 410, then 420, and 430.These three images are generated at 410, at 420, and at 430, but here, if we see, it is much finer. So, here you will have, in the order of a few nanometers, here it is 10 to 20, here it is comparatively broader wavelength. Here is a broadband that uses a very long wavelength range to generate one image. Here you have a minimum of 3 images; here you have tens or hundreds of images; here you have thousands of images. So, that is the difference between panchromatic, multispectral, hyperspectral, and ultraspectral. I hope this concept is clear to you. Now, we will see the advantages of hyperspectral remote sensing, multispectral remote sensing, and panchromatic images because we have different applications, and for different applications, different types of data products are needed.
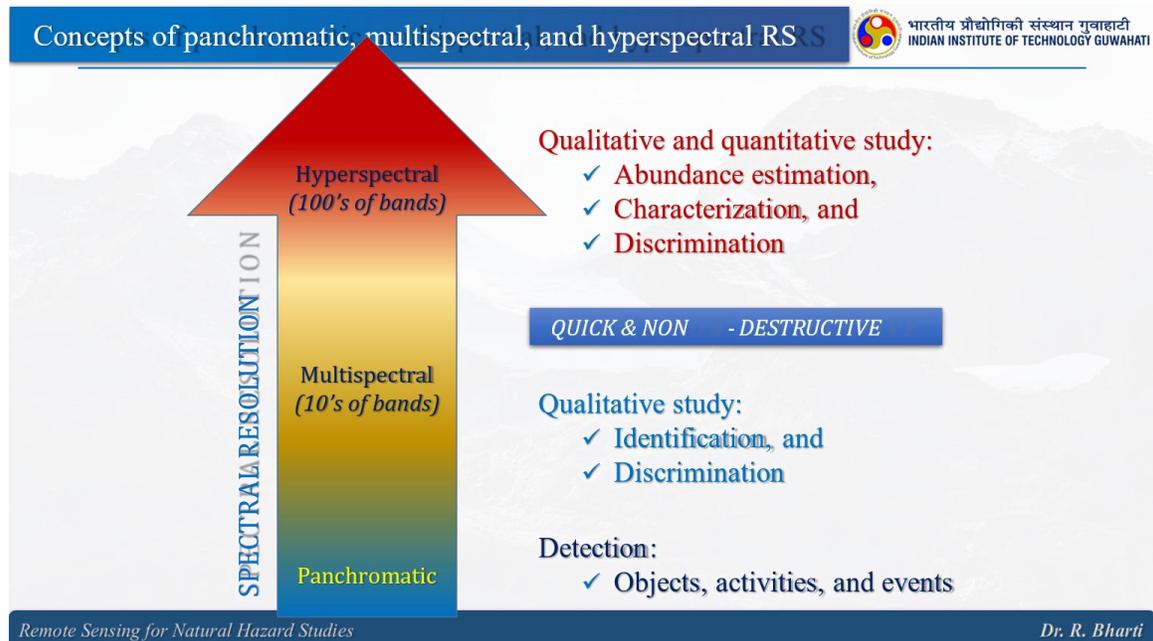
So, starting from this panchromatic, what we do is. We identify the objects, activities, and events that are the prime objective of our panchromatic image. Now, once we are moving towards this multispectral, we have only one image. So, here one pixel will give you one

value, but when we move to multispectral, you have multiple images or bands, which means for a single pixel you have multiple values that can be used to identify the material. So, when we move from here to here, our spectral resolution increases, and as we move towards hyperspectral, we have even higher spectral resolution.

So, once we are moving towards this multispectral data, we go for the qualitative study; the identification and discrimination are very, very easy because we have a spectral profile. So, here it will be with a few points. Now, once we have this multispectral data, we try to see the advantages of the hyperspectral data that we will have. So, in hyperspectral analysis, we will have a qualitative and quantitative study, which can be used for abundance estimation, characterization of the material, and discrimination of the target. It is very easy with the hyperspectral data when we compare it with multispectral and panchromatic, and remember that remote sensing image analysis will give you information about the object characteristics, and that is quick and non-destructive in nature. Here, because we are not changing the form of the target, we are just trying to gather the information that is coming from the source, and based on the behavior of the light in different wavelengths, we try to analyze it and find out what material it could be, whether it is x or y.

Now this particular slide is just refreshing the concept of the atmospheric window. I hope you remember the atmospheric windows. Here we discussed what atmospheric transmission is and how the different wavelengths behave in our atmosphere. So, in the atmosphere, there are a few wavelengths that are completely or partially blocked by some of the energies allowed by our atmosphere. So, this information can be used by the sensor developer to determine which particular wavelength we should use to develop a sensor and what our possible applications could be. So, here you see that in the visible range you have 400 to 700 nanometers, and in this infrared, which is 0.7 to 3 micrometers. Then thermal infrared and here you have all these atmospheric constituents which are interacting with the incoming radiation and the resultant is reaching our surface and then it is getting reflected. So, I hope you remember this, and based on this, we will try to see what kind of remote sensing we can possibly do from space. I hope you remember the reflective domain, where we use the 400 to 2500 nanometer range for the measurement of reflected energy, and here you see from 2.5 to 14 micrometers that are used to measure the emitted energy. So, here this particular wavelength range is very, very important when we talk about thermal remote sensing. And most of the space bond thermal sensors are active in this particular region you see.

 So, for this reason, in the previous lecture, I have already covered part of optical remote sensing. So, the reflective domain, which is 0.4 to 2.5 micrometer, and then I also explained to you the DN, radiance, and reflectance, why reflectance is a unique property, and how we can utilize this information to identify the material or to generate information about the target. Now, this particular slide explains that thermal remote sensing also has the impact of atmospheric emissions.

Since we are talking about this thermal wavelength, which is 2.5 micrometer to 16 micrometer, and in this region, what we measure is the emitted information or emitted energy by the target. And this particular wavelength, we will be seeing in detail how we can utilize it to extract the information. So, the wavelength range for thermal remote sensing is from 3 to 16 micrometer. However, I told you that 400 to 2500 nanometer is the reflective domain.
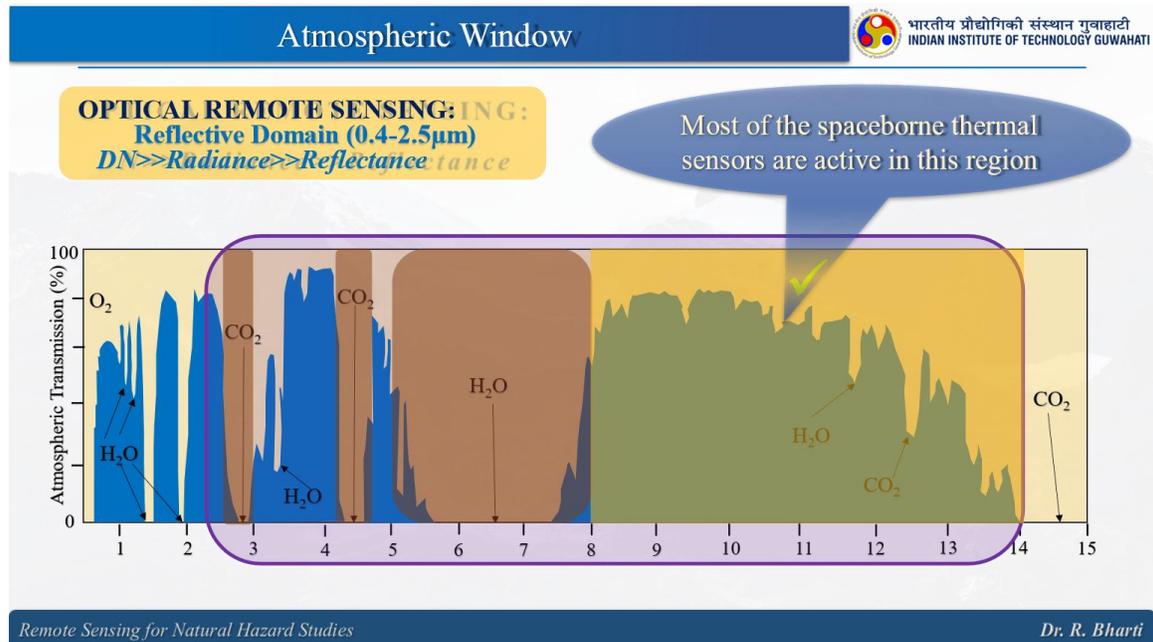
Now, what is happening at 2.5 to 3 micrometer? So, basically what happens is that this is the wavelength range where we have more atmospheric involvement, and then this 2.5 to 3 micrometer range is the overlapping region of reflective and thermal remote sensing. So, it is very difficult to segregate this information. So, we try to avoid this 2.5 to 3 micrometer, and in thermal remote sensing, we use only the 3 to 16 micrometer wavelength range.

Temperature and emitted energies are measured through thermal remote sensing. It provides different information than the reflective domain, which is 0.4 to 2.5 micrometer. Now, what happened in the 400 to 2500 nanometer range? The sun is illuminating this particular target, and then it is being reflected and measured by our sensor.

So, this is giving you the superficial information. because the depth of penetration of 400 to 2500 nanometer is as good as their wavelength. It can be considered a thumb rule that the depth of penetration of any energy is equal to its wavelength. So, if you see here, this is giving you the surficial information, this 400 to 2500 nanometer. When we talk about this thermal remote sensing, where the wavelength is 3 to 16 micrometer, the depth of penetration will be 3 to 16 micrometers. But no, you cannot apply the same logic here because what happens when the object receives energy is that some amount of energy is getting absorbed.

Once it absorbs the energy, it will change its volume; because of the volume, it will absorb a different amount of energy to maintain equilibrium with the surroundings. Extra energy will be released in the longer wavelength region. So, this longer wavelength region is nothing but 3 to 16 micrometer. Now, this emitted energy is not because of the surface; it is because of the volume of this particular target. So, if the volume is different, a different amount of energy will be absorbed.

So, that is why it provides different information. So, different information means it is providing you the volumetric information. It provides volumetric information. Hidden and subsurface objects can be identified. So, since it is coming from the volum, remember it is because of the volume. So, this volume can provide you with information about what is hidden here, whether there is a metallic body or a non-metallic body that you can easily identify with thermal remote sensing. So, we will see some examples in the coming slides, but one thing that is very clear from these basic principles is that if you use thermal remote sensing, you can identify the hidden or subsurface objects. So, one prime application could be identifying the landmines, which is very much possible with the thermal remote sensing data. Now the application for the industrial maintenance pipeline failure zone or underground leaks can be easily identified using thermal remote sensing.

You can see here that this particular section of the pipe has different information about the temperature. So, there could be a leakage right. Here you can see that this underground pipe is leaking, and because of that, this particular area has different thermal properties. Here, this is one way of mapping the underground pipeline to identify which section is leaking and how to go about fixing it. So, this is very relevant information when we transport petroleum from one place to another using underground pipes. The habitat monitoring you can see here at night will give you the right vision.

HABITAT MONITORING   FOREST FIRES

Remote Sensing for Natural Hazard Studies   https://www.fws.gov/news/blog/index.cfm/2017/2/8/The -Night-Lives-of-Forest-Elephants   *Dr. R. Bharti*

So, during the daytime, it is very hard to identify or segregate them from the background. Thermal remote sensing is very useful when we conduct corridor analysis. So, the corridor analysis will tell you how many animals are traveling at night and which path they are using. So, that can be used here. In the forest fire, thermal remote sensing can also help by providing information to restrict the spread of the forest fire, and this is one of the best applications of thermal remote sensing.

Here you can see this particular image, which is very, very interesting. Can you see anything here in this particular area of the image? Generated using a normal camera. But when we have the thermal camera here. You can easily find that one person is basically hiding here. These are the kinds of advantages we will have when we move from the reflective domain to the thermal domain. So, once again we will see the basics. Thermal remote sensing wavelength is between 3 and 16 micrometer.

So, the commonly used wavelength by the satellite is 8 to 14 micrometer. Through thermal remote sensing, infrared radiation emitted from the Earth's surface is measured and widely used for the Earth's land and sea surface temperature. The other application you have already seen, forest fire monitoring, is one of the most important applications of thermal remote sensing. Now we will try to understand why a particular material actually emits. So, any object above 0 degrees Kelvin emits radiation. The energy of particles or molecules in random motion is referred to as kinetic, internal, real, or true heat. It can be measured through a thermometer; we all know that the temperature measured will be kinetic temperature. So, what are we measuring? We are measuring the kinetic temperature. The internal kinetic energy heat may also be converted to radiant energy. So, finally, when we measure the energy through thermal remote sensing, it is the radiant energy this is external

or apparent energy. Thermal remote sensing measures this radiant energy. You might have heard about the blackbody; it is a theoretical material that absorbs all the energy falling on it, and it gets stored there. So, we also know that any body which is above 0 degrees Kelvin will emit energy to maintain equilibrium with the surroundings. So, if it is absorbing 100 percent, that means it will also emit 100 percent. So, we can say it is the true absorber and the true emitter. So, both are 100 percent, but no object in nature is a true blackbody; this is a theoretical concept. A blackbody absorbs all incident electromagnetic radiation regardless of frequency or angle of incidence, and it is an ideal and diffuse emitter. So, it will emit equally in all the direction. So, the emitted energy will be 100 percent.

So, that is the nature of the black body. Now, once we have that, can we measure the emissivity of a particular target with respect to a blackbody? So, the emitting ability of any object with respect to a blackbody is referred to as emissivity. So, we have the target; this is the target, and this is the blackbody, and here, since we are measuring the radiant energy. So, both the material of the blackbody and the target should be at the same temperature. So, it may be 30 degrees. Now, when we compare this emittance or the emitted energy from this particular target with respect to a blackbody at the same temperature, it is called emissivity. So, emissivity is a factor. that describes how efficiently an object radiates energy with respect to a blackbody.

Emissivity of grey body is always less than 1. Remember, in the reflectance, I also told you that it ranges between 0 and 1, and emissivity is also ranging between 0 and 1. So, for a blackbody, it will always be 1 because it is a true reflector and a true absorber. So, the emissivity of a blackbody will be 1, and this equation can be referred to calculate the emissivity of a target at a particular wavelength, and here we need this information. Radiant existence of an object at temperature i, radiant existence of a blackbody at temperature i. So, if we have these two, this value will be between 0 and 1. So, this can be also considered as a unique value to identify or characterize the material. So, this is also a unique value like your reflectance. You might have observed this in day-to-day life: at midnight, we have the lowest temperature; then in the morning, this will be reduced, and slowly when the sun rises, the material or the target starts absorbing energy, and then the temperature will be high in the afternoon. And then, slowly, it will go down. So, this is called the diurnal cycle of any material. So, this is for the bare soil or rock; this is for water rights. So, here you can see one thing: if we change the material, they have different types of this diurnal cycle. So, why is that? Because it also depends on their thermal properties. So, if we consider bare soil or rock, whether the rock is metallic or nonmetallic in nature, what kind of soil do we have? So, in such a situation, what happens is that we will have different cycles or different temperature changes. So, considering this particular concept, can we use it? Because if you see for the rock, we had this peak at, let us say, 5 PM; for water, it is around 9 PM. So, this difference in the peak is called the delta-T. So, this is the delta-T temperature

difference in the peak of two different materials. But for the same material, if we have to consider this rock.
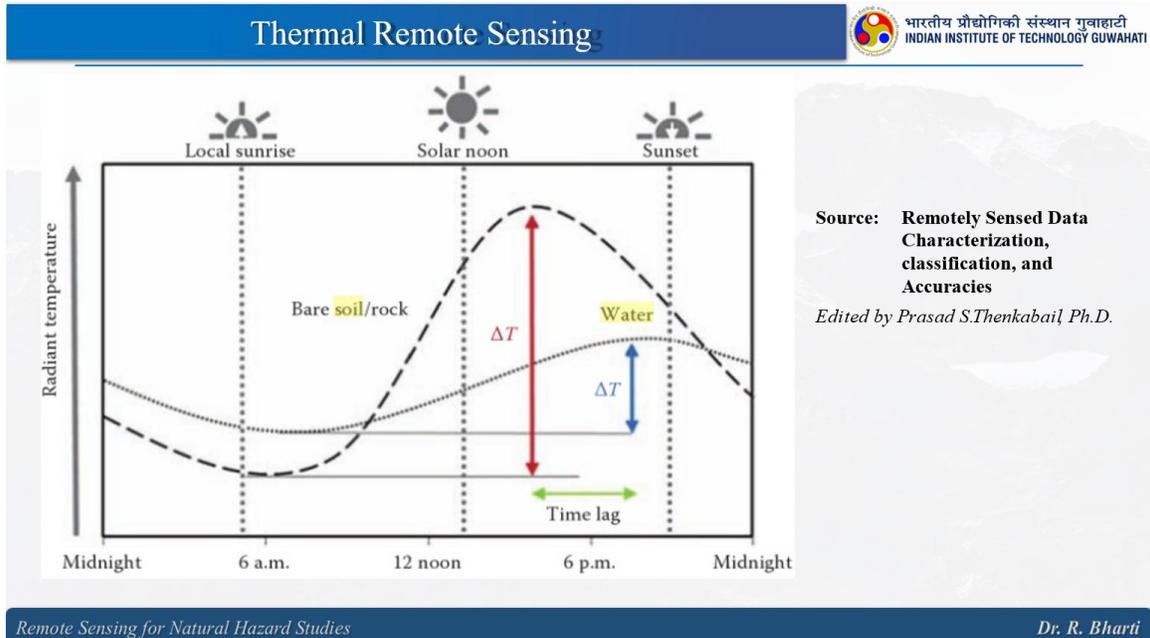
So, this is one position, and this is the lowest point. So, let us say this is maybe 6 o'clock. So, if we have this, then we will have this delta-T for the same material right here. So, how much temperature difference do we have for the same material? So, here we will have different values, and then accordingly, you can subtract them, and then you will get the delta-T equal to this much degree Celsius. So, we will be using this concept in the next slide to further exploit this thermal remote sensing in our application. So, the emissivity of very common materials ranges between 0 and 1, and it also varies for different materials, such as clear water.

Wet snow, human skin, green vegetation, concrete, tar, wet soil, dry soil, wood, granite, rock, glass, sheet iron, stainless steel, aluminum foil, and gold all have different emissivities. So, here you can see that the emissivity of gold is 0.02 to 0.03. So, this is very, very low. Once we have the low emissivity, that means it is not absorbing the energy; it is reflecting more. So, that kind of information can be derived from even the emissivity value. So, if you have to choose which of the materials is a good reflector, you will definitely say gold, or if you have to use this to design an experiment, then let us say gold is costly. Then aluminum foil is the second option we have; aluminum foil also has very low emissivity, which means high reflectance. So, that emissivity depends on the target parameter and the sensor parameter that are listed here.

This is a very good map that was generated by NASA. Here you can see that this particular slide is meant to give you information about how we are using thermal remote sensing to check the thermal anomaly and how the temperature is changing over the year. So, you can

see here that this is the year, and the minimum and maximum are written here. So, how is it changing over time, and remember this is the anomaly in degrees Celsius. So, these colors represent this anomaly, and this value can be considered. Now it is going high, which means the change is in the order of 3 degrees Celsius, and its base period is 1951 to 1980. This graph is a summary of the previous video, and here you can see how the temperature has changed since 1980; this is 2024.

If you see the anomaly coming around here, then the anomaly is not that significant. Right. So, the anomaly in the change in temperature over the past few years, starting from 1980, is approximately 1-1.5 degrees Celsius. This is another video that is available from this particular website from NASA. So, here you can see how the temperature has been changing since 1880, and it is projected to go up to 2024; here is the scale. So, again you will find that the temperature difference, or the anomaly in the temperature over the past 30-40 years, is in the range of 2 degrees, 2.5 degrees, or 3 degrees Fahrenheit. Here you see the temperature changes in the order of 2 degrees Celsius maximum, which indicates that the temperature has changed for our planet since 1980, and the anomaly is in the order of 2 degrees Celsius maximum. Like the emissivity domain, you also have the atmospheric impact on thermal remote sensing. So, here you can understand that emission is taking place and the gases, aerosols, dust particles, or clouds are also interacting with the incoming radiation, and because of that, you will have atmospheric scattering or absorption. So, you will have the atmospheric emission that is also compatible with your surface emission, which will give you the additional information that was not present at the surface. Atmospheric gases and suspended particles may absorb radiation emitted from the ground and subsequently emit their own radiation.

Dust, carbon particles, smoke, and water droplets can modify this thermal radiation by their emission in the atmosphere. So, this is very, very important to understand. Now, there is the concept of spectral emissivity. So, we understand the concept of emissivity. So, this is the target. A black body and the temperature is let us say, 30 degrees Celsius for both of them. Now the light is falling on this target; the same light is falling on this black body, and it is getting reflected. Some amount will be reflected here; if it is a black body, it is 0. The target is absorbing, and then further, it will emit the radiant energy. So, this radiant energy will be measured from the blackbody at the same temperature. Now, like the reflection here, we will also take care of the wavelength. So let us say I have generated 3 images between 3 to 16 micrometers. 3 to 16 micrometer. Now, the first pixel of this image—let us say this is here, this is here, this is here—all of them are absorbing or generating using the radiant energy received by the sensor. So, the first pixel of all these images represents the same area. So, here is the first pixel of all these images; then we can have these 3 to 16 micrometer wavelength plots, and the first pixel emissivity will be calculated. So, here are the wavelengths lambda 1, lambda 2, and lambda 3. We will measure the blackbody radiation at lambda 1, then for the target, and then we will calculate

the emissivity; the second will come here and the third will come here. So, this particular piece of information is called the spectral emissivity. Emissivity is a property of the material that indicates how much it emits with respect to a blackbody at the same temperature, and when we consider different wavelengths to measure the radiant energy and calculate the emissivity, we call it spectral emissivity. I hope this is clear. You can see the spectral emissivity. So, the L-lambda minus DWR lambda is divided by blackbody. So, this DWR is basically a reflection. So, surface emissivity, lambda is the wavelength; this L-lambda is basically the radiance of the sample, DWR is the downwelling radiance of the reference surface, and this is blackbody radiation. So, this blackbody radiance will be used to measure the spectral emissivity, and we will take care of this wavelength everywhere. So, if it is lambda 1, it has to be lambda 1 in all the places. Useful for a thermal imaging instrument capable of generating several bands between 3 and 16 micrometer.

SPECTRAL EMISSIVITY

भारतीय प्रौद्योगिकी संस्थान गुवाहाटी
INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

The spectral emissivity can be calculated by using the following equation

$$\varepsilon_\lambda = [(L_\lambda - DWR_\lambda)/(BB_\lambda)]$$

where,

ε_λ = Surface emissivity,
λ = Wavelength,
L_λ = Radiance of the sample,
DWR_λ = Down-welling radiance of the reference surface,
BB_λ = Blackbody radiance

Useful for thermal imaging instruments capable of generating several bands between 3 to 16μm.

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So now, if you refer to hyperspectral remote sensing. So hyperspectral remote sensing is a concept that states we have contiguous measurements and a good number of spectral bands. So, maybe tens or hundreds of bands are. and the bandwidth is narrow. So, the bandwidth here, since we are talking about thermal remote sensing or the thermal wavelength range, will be low. So, this bandwidth is not sufficient to generate a smaller pixel. So, what happens? We have to either increase the wavelength range or the pixel size. So, here it was in the order of 25 by 25 centimeter. And here, if you refer to any of the satellite thermal data, you will find it is in the order of 90 by 90 meter; that is the reason behind this coarser spatial resolution. Now, once we have this limitation from space because the energy has to travel through our atmosphere to be captured. But if we have a field instrument that is capable of generating these narrow bandwidth images in the thermal wavelength range, we can obtain the hyperspectral data. So, we will have hyperspectral thermal remote sensing.

Now, we will refer to Kirchhoff's law; it states that the incident energy is equal to the absorbed energy plus the reflected energy and the transmitted energy. After dividing the equation by Ei - incident energy, this is absorbance, reflectance, or transmittance. So, according to Kirchhoff's law, spectral emissivity is equal to spectral absorbance. Good absorbers are good emitters, and good reflectors are poor emitters, which we have understood with the help of blackbody. So, blackbodies are good absorber. So, they are good emitter also, but the other material which is present on the surface of the earth which we called grey material. So, the gray bodies are neither good reflectors nor good absorbers. So, our emissivity value will always be below 1, and the reflectance is also below 1. So, we are talking about the natural material or man-made material that is neither a black body nor a good reflector. According to Kirchhoff's law, if we have the reflectance, we can calculate the emissivity, or if we have emissivity, we can calculate the reflectance, by assuming all other components are 0. So, for the kinetic versus radiant temperature of four typical materials, the blackbody emissivity is 1 and vegetation, it is 0.98; wet soil, it is 0.95; dry soil, it is 0.92. So, you can see the emissivity is significantly different for all these different materials and that can be used to identify the material property. Now, referring to the thermal properties of a material, you can consider thermal conductivity, the rate of heat transferred through a material in a steady state; the unit is watt per meter squared per Kelvin. Thermal diffusivity measures the transient heat flow through a material. Specific heat capacity is the amount of heat required to raise the temperature of a given mass of material by 1 degree Celsius. Melting point is the temperature at which a substance changes from solid to liquid at atmospheric pressure.

KIRCHHOFF RADIATION LAW

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$$E_i = E_A + E_R + E_T$$

where, E_A = Absorbed Energy,
E_R = Reflected Energy,
E_T = Transmitted Energy,
E_i = Incident Energy...

After dividing the equation with E_i,
where, $\alpha(\lambda)$ = absorbance
$r(\lambda)$ = reflectance
$\tau(\lambda)$ = transmittance

According to Kirchhoff radiation law, spectral emissivity is equal to spectral absorptance... .
$$\alpha(\lambda) = \varepsilon(\lambda)$$
Good absorbers are good emitters, and good reflectors are poor emitters... .

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The thermal inertia measures the response of a material to changes in temperature. So, this is very, very important because now we are going to see one example of how thermal inertia

is used to identify different materials present on the surface of our Earth. So, thermal inertia is the resistance offered by a material to temperature change. TI can be explained as this. So, here we are using the density, thermal conductivity, and specific heat capacity that will give you thermal inertia. Now, the thermal conductivity, if you see, for all these materials is different; density is different, and specific heat capacity is different.So, that is the thermal inertia. Once we have this thermal inertia, can we use it as unique information to identify the material? So, we tried to use this thermal inertia mapping using the satellite images. So, this particular paper has used the ASTER data field investigation, and samples were collected, and the ASTER data were used to identify the delta-T; this is the temperature difference, and there are two different approaches: the lookup table and the ATIM approach. And then we derived the thermal inertia map. At the same time, the field day-night temperature measurements were carried out; laboratory data on thermal inertia, mineralogy, and geochemistry were collected, and then we tried to correlate these two to see how thermal inertia is used.

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We have used this information together to identify the potential zones of ore mineralization. So, in this particular work, thermal inertia is used, and the apparent thermal inertia is calculated using this equation: 1 - A divided by delta-T; A is basically your albedo. This is the broadband reflectance and the delta-T; remember, the ASTR data was used to measure the temperature difference. For terrestrial and planetary applications, the temperature gradient across the thickness of the surface cannot be measured. Therefore, TI is estimated by using the temperature differences of the surfaces measured at different phases of the diurnal heating and cooling cycles. Remember to refer to my previous slides

where I explained the diurnal heating and cooling to you. Beyond 1 meter depth, the diurnal variation due to solar heating ceases.

Hence, a depth of 1 meter is considered where solar heating-related heat transfer is involved in the application. That means the emitted energy coming from the surface is basically giving you information about the 1-meter column. So, as an input in thermal inertia, albedo offers important information on the absorbed energy. A visible band of satellite images is commonly used to estimate the albedo, and this particular equation is used with ASTR data to calculate the albedo.

Remember, if you are changing the satellite, you have to remap the bands correctly. The above equation can be directly used with ASTR data in cases where the band numbers of other sensor data should be converted according to their wavelengths. For the temperature difference, daytime and nighttime thermal images acquired in the same wavelength region can be used. So, this is one of the example daytime at 2:50 pm and nighttime at 9:50 pm. You can see that during the daytime thermal data, you have different information at nighttime; when you subtract them, you will get the delta-T. So, using this particular concept apparent thermal inertia was derived. So, there were two approaches that were used in this particular work: one is the ATIM approach, and the other one is the lookup table approach. So, some applications of thermal remote sensing are lithological and soil type mapping, structural mapping, and soil moisture-related studies. Study of thermal characteristics of volcanoes, vegetation studies, identification of hot water springs, thermal plumes in water bodies, and their usefulness in forest fires and coal fires. So, with this, I will end this lecture, and we will continue this course with the next lecture.

Thank you.