Remote Sensing: Principles and Applications

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Lecture-35
Thermal Infrared Remote Sensing-Part-1

Hello everyone, welcome to the next lecture in the course remote sensing principles and applications. In the last lecture, we discussed in detail about different spectral indices that are available to us with special emphasis to monitoring vegetation. We also noted what are all the different ways or different spectral bandwidths in EMR, we should combine in order to derive those spectral indices and I also introduced you to some simple applications or some simple themes where such indices are being applied. So, from this lecture, and next 2, 3 lectures, we are going to see in detail about the thermal infrared remote sensing.

Before going on to this particular topic, I would like to tell an additional point about the spectral indices that we discussed in the last class. While finishing the last class, I just briefly mentioned about various indices, but, we have to be careful when we use such indices obtained from different satellite sensors, that is for some of our applications, we may be needing to combine data in the last 30 years, 25 years and so on. Our application maybe spanning over very long time interval, under such circumstances, we will be in a position to gather data from more than one satellite sensors and use it in kind of like a time series. Say for example, first 10 years I use data from a sensor called AVHRR, the second 10 years, I want to use data from MODIS, such kind of scenario may occur or sensor may go or may be taken out from the service and a new sensor might have replaced it. Under certain circumstances we have to switch sensors as our application needs data over a very long time period. Under certain circumstances, we should be really careful, that is we cannot quickly replace or suddenly replace vegetation index data obtained from one sensor with another sensor.

Because the vegetation index that we have used or that we have obtained will depend on sensor characteristics. The spectral bandwidth of the sensor, what are the central wavelengths of the bandwidth, what is the spectral response function of the sensor, all these things will influence the vegetation index. So, mixing data from different sensors is not a straightforward task. And we should always be careful when we want to combine data from multiple sensors especially when we are going to use it in one single time series.

So, first one year data from one sensor, second one year data from another sensor, we should not do this, there should be some sort of inter calibration to be done when data from 2 different sensors has to be combined and used in one single time series. This is one important point we have to remember. And second point that we have to remember is the spectral indices that we obtained are influenced by the sensor viewing angle and illumination geometry and also atmospheric effects.

Even some indices are capable of reducing the effects of atmosphere, but still some residual of atmospheric effect will always be there and also the sensor viewing angle, solar illumination geometry, all these things will influence our vegetation index. So, we should always keep these things in mind when we want to arrive at some really important result or some high impact research using analysis of such vegetation Index. We should keep these things in mind; we have to try to remove all these effects for the maximum extent possible before we use them. So, these things are important points that we should keep in mind when we work with data especially this spectral indices data obtained from different sensors.

Coming to today's lecture, today, we are going to start with the topic of thermal infrared remote sensing. So, what exactly thermal infrared remote sensing is? So, thermal infrared remote sensing deals with measurement of temperature of the surface and using it for various applications. So, we will see what thermal infrared remote sensing is. Why is it called so and what are all the different or what are the difficulties we may encounter while processing the data from thermal infrared satellites? and maybe few important concepts that we should know. So, let us get introduced to the concept.

Before moving on to the concept of thermal infrared remote sensing I would like to quickly recall the basics of heat conduction methods that we have studied in our high school physics. So, when heat energy has to transfer from one point to another point in space it can take 3 different paths conduction, convection and radiation. So, heat conduction is a process in which heat energy will be transferred from point A to point B by physical contact of molecules in the medium.

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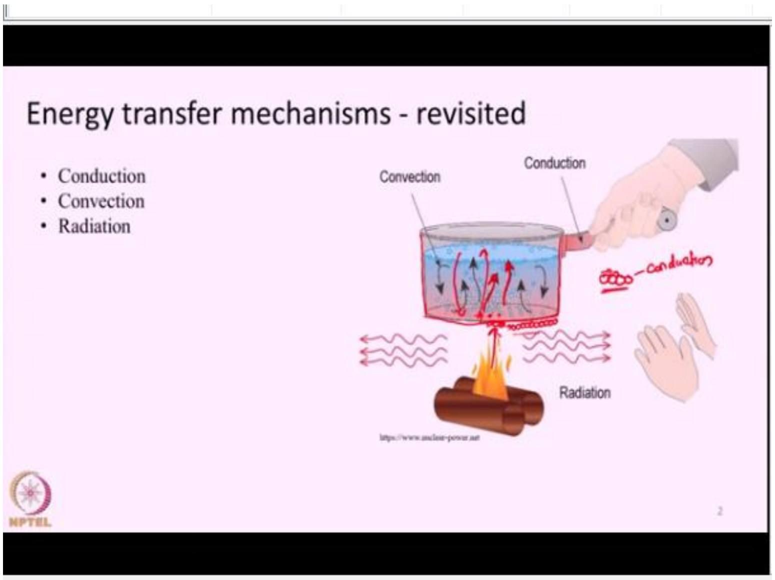

For example here is a stove that is burning and we have a pot of water to be boiled just kept over the stove. The vessel we use will be metallic vessels during cooking processes. So, this will be a good conductor of heat. So, the heat energy supplied from this burning stove will be transferred along the vessel through the physical contact of molecules. This vessel is solid in which the solid molecules will be tightly bounded with each other.

So, first the heat energy will reach the molecules at this point where exactly the flame supplies energy to it then slowly through this physical contact the heat energy will transfer from molecule to molecule. So, the molecules themselves may not move but due to this physical contact or closely packed configuration of molecules heat energy will move from one to the other. This is conduction.

So, molecules will not move but heat will be transferred from one molecule to other. Next is convection, convection is the process of heat transfer through physical motion of molecules in the medium, that is after heating up the vessel, the heat energy will move towards the water molecules. So, the water molecules near the bottom of the vessel will first get heated up and will start moving towards the upper surface. And cold water from the upper surface will move towards the bottom. So, slowly there will be a transfer of water molecules from top to bottom and bottom to top and those molecules that are moving from bottom to top will transfer this heat energy to the other parts within that particular vessel. So, here heat energy is transferred by proper movement of molecules within the medium. The molecule itself will move taking the heat energy away from one point to another point.

The third way of heat transfer is radiation, a non contact way. That is if we go near a burning stove we will feel the heat or if we go near a burning furnace we will feel the heat from certain distance. So, similarly solar radiation reaching the earth's surface, all these process need not have any medium, heat energy can just transfer from point A to point B.

That is where we learnt that electromagnetic radiation, energy transfers in form of electromagnetic radiation. So, this is a radiation principle even without any medium, energy will transfer from one point to another point. So, in thermal infrared remote sensing we are going to concentrate on this particular way of heat transfer, the radiation. So, radiation may have energy transfer, but why I mentioned all these 3, conduction, convection, radiation? Normally when we study about earth and its different processes, energy transfer occurs from one part of earth to another part or from one medium to another medium. Later when we discuss about some common applications of this thermal infrared remote sensing, we may have to use this conduction, convection, radiation way of heat transfer.

But in this lecture the introductory part of thermal infrared remote sensing we will concentrate on the radiation way of energy transfer from one point to another point. We all know that any object above the temperature of 0 Kelvin will emit radiation on its own due to its own internal energy content, that we have seen and that is the major process that drives earth system.

Sun is emitting energy because of its temperature and that radiation is reaching the earth and that is driving the major processes within the earth's surface. So, not only to sun all objects on the earth's surface including humans, living things, nonliving things, everything will emit energy due to its own temperature and its internal energy content and it is possible to measure the radiation coming out of any object and use it to calculate the temperature of that particular object.

Say one of the very common example that we see in our everyday life is taking our body temperature using a handheld thermometer, we might have seen in several spots, especially during the COVID pandemic times. People or medical workers will point a non contact thermometer towards our forehead or near our wrist. So, that is essentially a radiometer which will measure the amount of radiation coming out of our body and using that radiation it will estimate the temperature of our body.

So, if the temperature is lower than our normal body temperature or equal to the normal condition they will let off or they will ask us to take quarantine measures. So, that is a very good example for radiation measurement we use in our everyday life. Similar concept when applied for earth observation we call it as thermal infrared remote sensing.

The average temperature of earth surfaces is around 300 Kelvin and most of the objects on the earth's surface will have temperatures in the range of say plus or minus 60 degrees from this value, say maybe from 250, 260 Kelvin to maybe 330 or 340 Kelvin, most of the objects will be in this range typically except extreme conditions. So, at this temperature range, the emission from the earth's surface if we look at like the blackbody radiation curve we have seen in earlier classes, the emission from earth's surface will typically peak around 9 to 9.5 µm wavelength.

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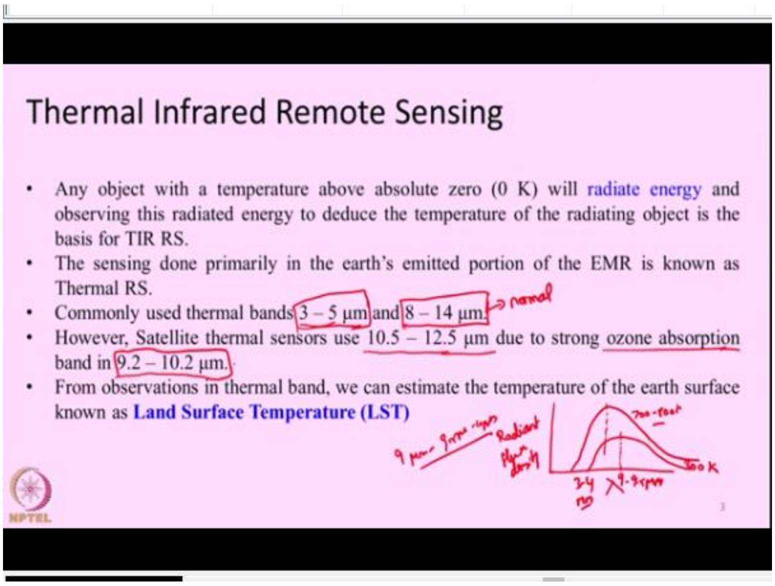

For example this is the wavelength; this is the radiant flux density. So, if we use Planck's law to measure this, the curve may look something like this, the peak will be something around say 9 to 9.5 µm in wavelength and this may start somewhere around say 3 to 4 µm. So, earth's surface features, when they emit radiation it will not be in even near the visible range. That is, because of its own temperature, the earth's emission will start to occur somewhere around say 3 to 4 µm in wavelength and sometimes for water surfaces it may be around the SWIR range, but not in visible range. So, starting from this SWIR range the emission from the earth's surface will start to peak and it will reach the peak around this 9 to 9.5 µm wavelength.

And then slowly it will start to fall after it and it will have a long tail and it will continue. It will not reach 0 immediately but it will continue as a long tail for quite a long wavelength. So, this peak energy around 9 to 9.5 µm is what we have to measure and the radiance is used for calculating the temperature of the object that is emitting it. So in general, rather than talking about just 9 µm we will have a range from 8 to 14 µm, which is essentially the long wave infrared part of the electromagnetic spectrum. So, any radiometric measurements that we do in 8 to 14 µm wavelength range will help us to understand the thermal properties of the object or using that measured radiance we will be able to calculate the temperature of the object. Actually, this is the primary reason why remote sensing in 8 to 14 µm wavelength is also known as thermal infrared remote sensing.

The remote sensing we are doing in TIR helps us to calculate the temperature of the object and also to understand the thermal properties of the object. The blackbody radiation may be happening at a different temperature or a different wavelength range, but for earth remote sensing when we observe it in this 8 to 14 µm wavelength range, we will be able to understand the thermal properties of object. And hence, the remote sensing we do in this LWIR band is commonly known as thermal infrared remote sensing.

So, I told you 8 to 14 µm is the common range for under normal conditions. But, under some extreme conditions, that is volcanic emissions are very strong, large scale forest fires, then the emission from such burning features will be occurring in 3 to 5 µm range. Let us assume it as a blackbody curve for object at 300 Kelvin. If we want to draw a same similar curve for an object at say 700 or 800 Kelvin, it may look something like this. So, the peak may be occurring in a shorter wavelength, energy content will be high for 700 to 800 Kelvin. So, normally forest fires and volcanic emissions have very high temperatures and the radiance from them will be peaking around 3 to 5 µm.

So, essentially, for normal earth monitoring activities, the remote sensing will be done in 8 to 14 µm wavelength, but for monitoring the extreme cases such as forest fire, monitoring has to be done in lower wavelength in the SWIR range 3 to 5 µm. But now, we will restrict our discussions to only 8 to 14 µm level and that is the thermal remote sensing we do under normal conditions. So, even though these 8 to 14 µm is like a generic range, most of the satellite based thermal sensors use the wavelength of 10.5 to 12.5 µm. Though we know the peak wavelength or peak emission for earth occurs around 9 µm to 9.5 µm or sometimes 10 µm depends on the temperature, the 9.2 to 10.2 µm wavelength has a very strong ozone absorption band, which will prohibit us from monitoring the earth under this particular wavelength. So, we will not be able to measure that, because of ozone absorption band in the atmosphere. And hence, most of the satellites will move towards the longer portion 10 to 11 μm range in order to observe various features on the earth's surface. And using this measured radiance, we will be able to calculate the temperature of earth surface objects and the temperature we calculate is commonly known as land surface temperature.

So, now we will get introduced to the concept of blackbody. What a blackbody is? When we learned about the emission from objects, we used Planck's law. So, we said if an object is at a given temperature T, that particular object will emit a certain amount of radiation at a given wavelength λ, this relationship is given by the Planck’s equation, we know how to calculate it and we know the certain Planck scale for objects in different, different features like what is given this particular slide.

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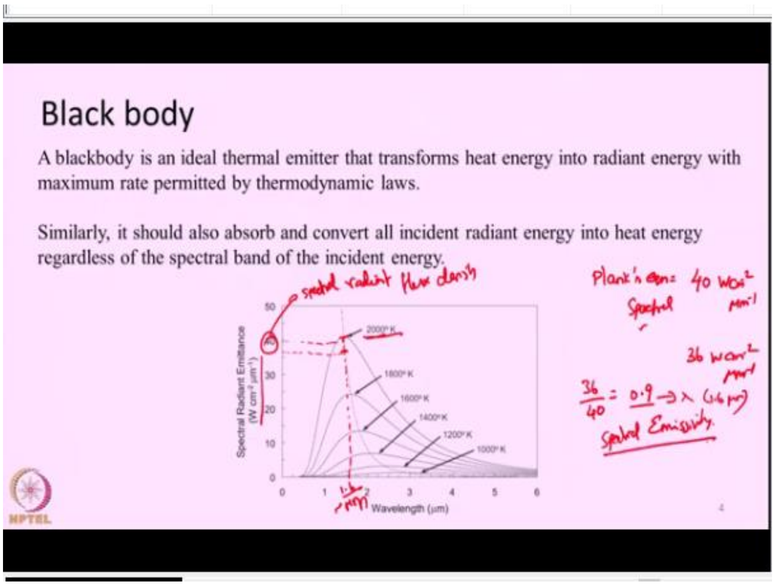

So, here is an example of the blackbody radiation curve and for objects that are different, different temperature. This we have already seen, but Planck's law gives us a maximum limit for the emission to occur. That is, if an object is at a given temperature T, under the restrictions imposed by thermodynamic loss or physical loss, an object can emit this much energy that is like a maximum limit. So, using Planck's law, whatever we are calculating will define the upper limit of radiation. So, no object will be able to emit more than that, at a given temperature, at a given wavelength. That will be the maximum emission that can happen, but most of the earth's surface features may not be able to emit radiation with that particular level or they will not be in a position to radiate energy to the maximum extent as defined by or as allowed by thermodynamic loss.

So, in general for most of the earth's surface features the emission from them will be less than what has been given by Planck’s equation. So, the ratio of these 2, that is, what is the actual radiation coming out of an object at a given temperature T, at a given wavelength λ divided by the radiation value calculated by Planck’s equation is known as emissivity. So, commonly saying emissivity is the efficiency with which objects can radiate energy. For example, say this object at 2000 Kelvin temperature at particular wavelength around 1.6 µm approximately, it is emitting radiance of around 40 $W/cm^2/\mu m$. So, this is spectral radiance or spectral radiant flux density. This value of 40 is a maximum limit for this particular object at 2000 Kelvin at 1.6 µm wavelength, but in reality, real life earth surface objects may have radiation less than that. Let us say it has just 36 W/m^2 instead of 40. So, as defined by Planck's equation the energy that should come is 40 $W/cm^2/\mu m$.

This is the spectral radiant flux density, but in reality the object is emitting just 36 $W/cm^2/\mu m$ of wavelength. So, if we divide this 36 by 40, we will get a value of 0.9 and this is known as the emissivity for that particular object. Spectral emissivity or in general emissivity is the ratio of the actual radiant flux density emitted by the object at a given temperature T divided by the radiant flux density defined by Planck's law for the object or a blackbody at the same temperature. So, this ratio is one of the important property that we should know about all the objects, if we want to calculate the temperature of that particular object using remote sensing principles. Without knowing emissivity, we will be making errors in measuring the temperature of objects using thermal infrared remote sensing.

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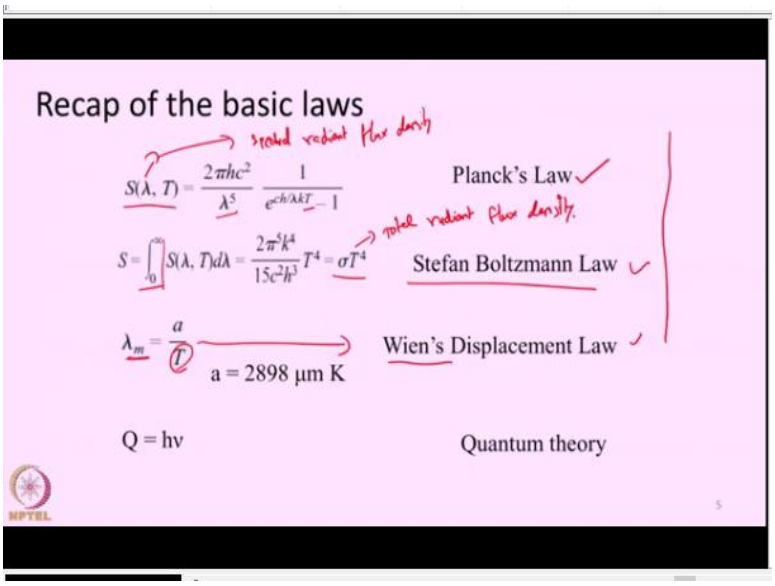

The first and foremost primary law that we will normally use is the Planck's law, that will tell if an object is at a given temperature T at a given wavelength λ what will be the radiant flux density that will be coming out from an object. So, this will basically define the spectral radiant flux density. At a given wavelength λ what will be the emission? Integration of Planck's law in the entire EMR range 0 to infinity wavelength will give us the Stefan Boltzmann law σT^4.

So, this will give us the total radiant flux density not spectral but total and the peak wavelength of emission for an object at a given temperature T, the wavelength at which peak emission occurs is given by Wein’s displacement law. So, these 3 laws are the fundamental laws that we have seen in detail in the earlier classes, but we will use Planck's law very repeatedly in thermal infrared remote sensing and its calculations.

So, coming back to emissivity. Emissivity is an important property of all objects. All objects will have lesser value of emittance as prescribed by Planck's law. And one more important thing is objects which emit radiation as defined by Planck’s law are commonly known as black bodies. Planck’s equation defines the upper limit of the curve and the objects which obey that particular law emits with maximum efficiency, they are called black bodies. And real life objects normally found on the earth's surface will not emit radiation as defined by Planck's law, they will have lesser emission and the ratio is what is known as a spectral emissivity.

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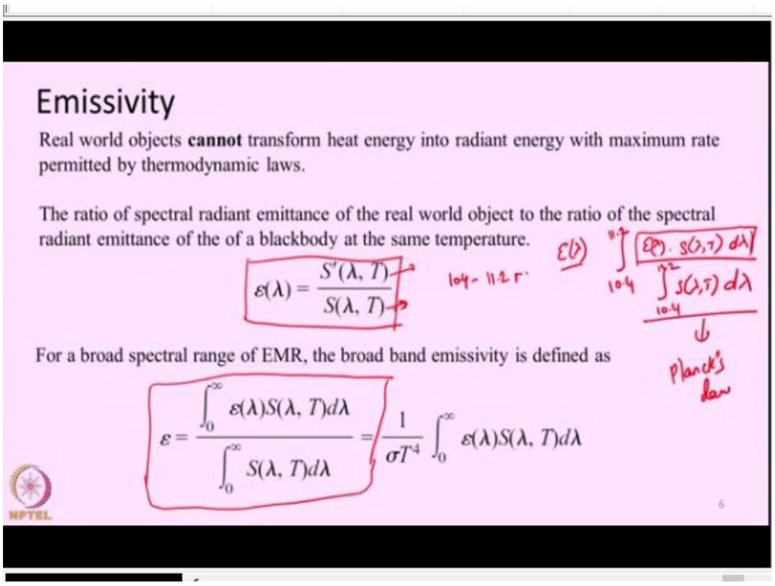

So, this is the general equation that we normally use for calculating the emissivity, the actual radiance from object to the radiation as governed by Planck's law, for a given spectral range we can define a broad band emissivity like this, within a given day say between 10.4 to 1.2 μm what will be the emissivity means, we can integrate these laws or integrate the radiation using this limits. So, here an example is given for the entire range of EMR spectrum from 0 to infinity, but if you want to calculate between 10.4 to 11.2 μm, what is the spectral emissivity? band average emissivity means you can do it using this kind of equation. So, the denominator is basically the Planck's equation. And the numerator indicates the actual radiation coming out from an object. So, such objects are called non black bodies which has emissivity less than 1 and those objects which has emissivity equal to 1 are called black bodies. So, in general most of the earth's surface features are non black bodies.

They may not be able to emit radiation with a maximum emissivity, that is emissivity equal to 1, they cannot satisfy Planck's law. The radiation from the common objects will be always less than 1 and actually under earth's surface conditions strictly speaking no object is a blackbody even what people use in satellite calibration systems etcetera are hypothetical in nature, they are hypothetical black bodies. They are close to a black body, the emissivity may be around 0.9999 or 9995 very close to 1 but they will never reach 1. So, strictly speaking all earth surface objects that we encounter in our everyday life are non black bodies. So, black bodies are the objects which can emit radiation as governed by Planck's law with maximum efficiency and emissivity will be equal to 1 for it. So, maybe we will see how objects are classified based on this emissivity little bit in more detail. So, as I said objects which has emissivity is equal to 1. They are known as black bodies. So, for them emissivity will be equal to 1 in all the wavelengths maybe you will see in this particular slide.

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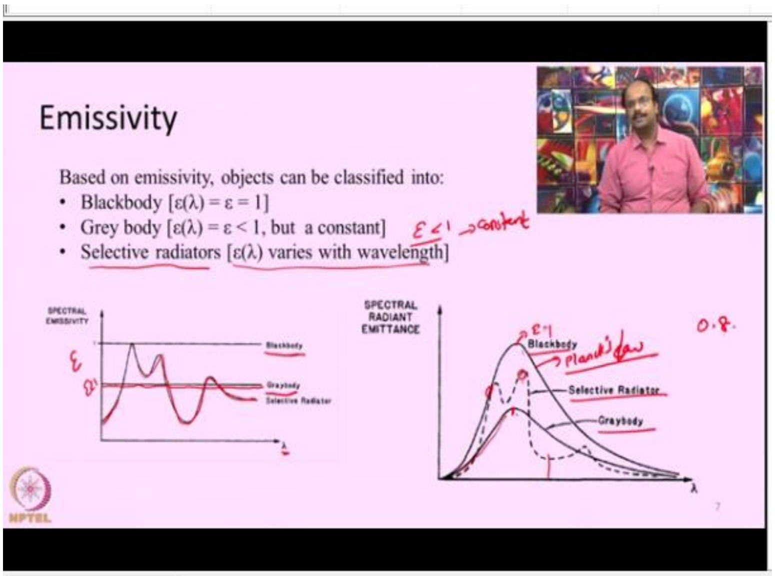

This is wavelength and this is emissivity. For a blackbody, emissivity will be a constant and it will be equal to 1 throughout, whatever the wavelength we measure, such objects are called black bodies. There are certain class of objects for which emissivity will be less than 1 but it will be constant throughout under all wavelengths of our discussion, such objects are called gray bodies. And there are a certain class of objects for which emissivity will vary, it will not be a constant, it will vary with wavelength and such objects are called selective radiators.

So, most of the earth's surface features are selective radiators, maybe example for like a gray body we can say a calm deep water body without any disturbance, water body under thermal infrared wavelengths may have emissivity close to 0.98 or 0.99 so on, but only under thermal infrared but that is not like a perfect gray body, within the wavelength range of this 8 to 14 μm, water body can be treated as closely to a gray body.

But almost for all the earth's surface features emissivity will vary with wavelength, maybe at 8 to 14 μm wavelength they may be a constant, we may think them as a gray body but we know that the blackbody radiation curve does not stop at this particular range, it has a long tail, it even extends to microwave wavelengths. Under such wavelengths emissivity may vary.

So, strictly speaking all the common objects that we know on the earth's surface are selective radiators. So, why do we need to care about the selective radiators, what will happen? Look at this particular slide given here, this dark black line given here is for a blackbody, emissivity is equal to 1. So, essentially this curve is given by Planck's law and this dark black line is for a gray body that is with a constant emissivity.

Maybe if we know let us say the emissivity is 0.8 then the radiant flux density for this particular object will be 0.8 times as given by Planck's law, it is a constant, it is very easy to calculate, but let us take an example for a a selective radiators. For selective radiator since emissivity varies with wavelength, the radiant flux density from that particular object will be keep on varying at certain wavelength, it may be very close to 1. So, at each wavelength the emissivity will be keep on varying. Without knowing the emissivity we will not be able to calculate its temperature and we will end up in a underestimated value of temperature. Unless we know the correct emissivity value and if the emissivity various with wavelength that complicates our things.

We must measure the emissivity of object at all possible wavelengths. So, emissivity is one of the most important concepts to understand thermal infrared remote sensing and without knowing emissivity we will be underestimating the temperature of objects.

So, as a summary in this particular lecture we discussed or we got introduced to the concept of thermal infrared remote sensing, why it has got such a name, and also got introduced to the concept of spectral emissivity, with this we end this lecture.

Thank you very much.