# Remote Sensing: Principles and Applications
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## Lecture-36
## Thermal Infrared Remote Sensing-Part-2

Hello everyone, welcome to the next lecture in the topic thermal infrared remote sensing. In the last class, we got introduced to the concept of thermal infrared remote sensing and also, we started discussing about emissivity and its importance in understanding the thermal properties of object. So, today we will continue with this particular topic. In the last class, we defined spectral emissivity and its importance and based on spectral emissivity, how objects can be classified? So, what are some important factors that control the spectral emissivity of objects we will see now.

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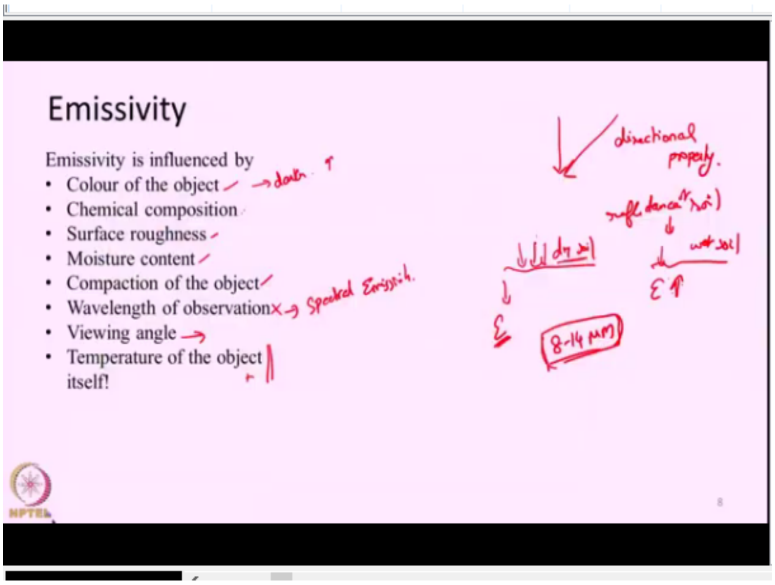


So, spectral emissivity is influenced by the colour of the object, darker objects typically has higher emissivity, chemical composition, the chemical nature of the object, surface roughness like how rough or how smooth the surface is, moisture content, compaction of the object, wavelength of observation. This is important because that is why we repeatedly call emissivity as spectral emissivity.

Emissivity varies with wavelength, with the viewing angle, whether we are viewing it from nadir or whether we are viewing it from some other angle, all these things will influence the emissivity of the object and hence emissivity has directional property and sometimes the temperature of the object itself will influence the emissivity, but we may not very much care about this because for the normal temperature range, this may not be a major factor.

But all these other factors, colour, surface roughness, moisture content etcetera will change it. Say for example, if you compare a dry soil and a wet soil, when it is dry it will have certain emissivity value. When it gets wet, the emissivity most likely would have increased if other conditions remain normal. But this is applicable only in the thermal infrared range.

In other wavelengths, this relationship may not be valid. Emissivity may also decrease especially in microwave lengths, but in this particular thermal infrared wavelengths 8 to 14 μm for dry soil emissivity will be low, for wet soil emissivity will be high. And similarly, we also know that when we add water to soil, its reflectance goes down, we have already seen this, the reflectance property of soil.

So, the reflectance decreases and emissivity will increase. So, normally it will appear dark and its emissivity will be high. So, the colour, composition, moisture, surface roughness, all these things will affect emissivity. In order to emphasize the importance of emissivity I have given 2 examples here.

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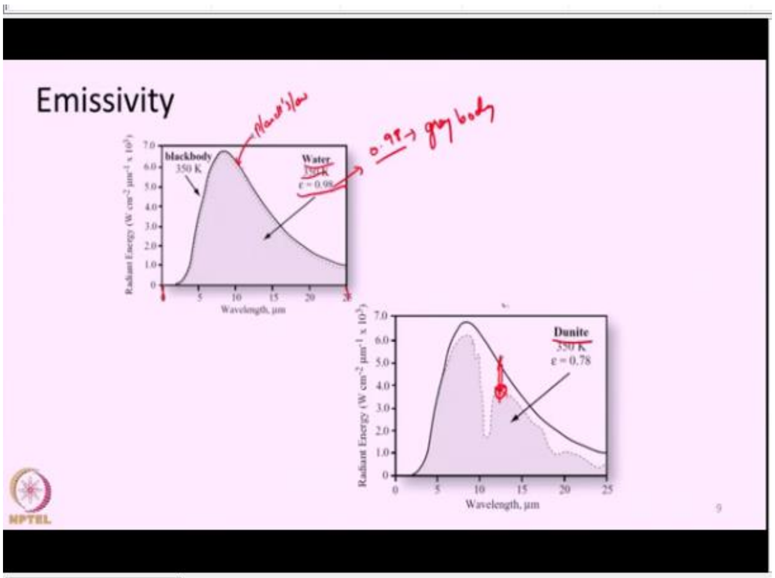


So, this is a blackbody curve, as given by Planck's equation, that dark black line and this dotted grey line is for water, at the same temperature 350 Kelvin, but water has emissivity less than 1 and in the infrared range, we can assume water to be a grey body and hence the emissivity can be treated more or less constant.

On the other hand, let us consider a material called dunite, it is a mineral, it is a selective radiator and the emissivity will be keep on varying. So, at a given wavelength, the emissivity in order to properly change, this Planck's equation value to the actual value emitted by it either we should measure this and we should bring it there in order to calculate it.

So, we should know the emissivity values. So, what will be the typical emissivity values of real life objects in the wavelength that we are talking about? That was between this 8 to 14 μm wavelength, the wavelength or the emissivity of most of the earth's surface features will be fairly high, above 0.85 or above 0.9 maybe we will look at this particular chart given in the slide.

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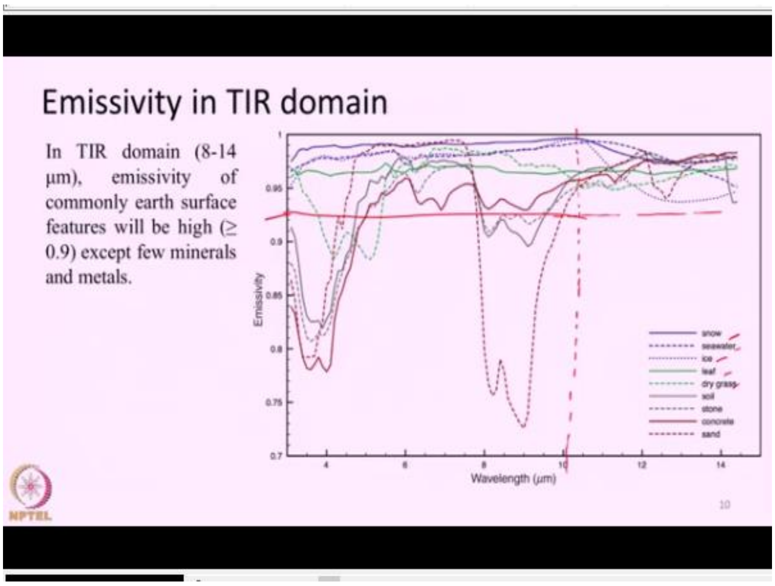


Say after this 8 μm even we can start at 10 μm because as I said, most of the earth observing satellites typically measures between 10 to 12 μm. So, if you look here, we can observe that between 10 to 12 μm range under where most of the thermal satellites are observed, the emissivity of most of the commonly occurring earth surface features like snow, sea water, ice, leaf, grass etcetera, is fairly high above 0.9 range.

So, this is more or less a general property of earth surface objects. In thermal infrared wavelengths 8 to 14 μm emissivity will be pretty high and the values will not vary very widely, but in passive microwave remote sensing, that is in microwave wavelengths, emissivity varies very widely.

But in thermal infrared wavelengths emissivity will not vary very much. It is fairly high about 0.9 and mostly it will lie in that particular range say 0.85 to 1 or 0.9 to 1, for most of the naturally occurring earth's surface features like soil, vegetation, water and so on. So, the emissivity of some commonly occurring objects on the earth's surface is given in this slide.

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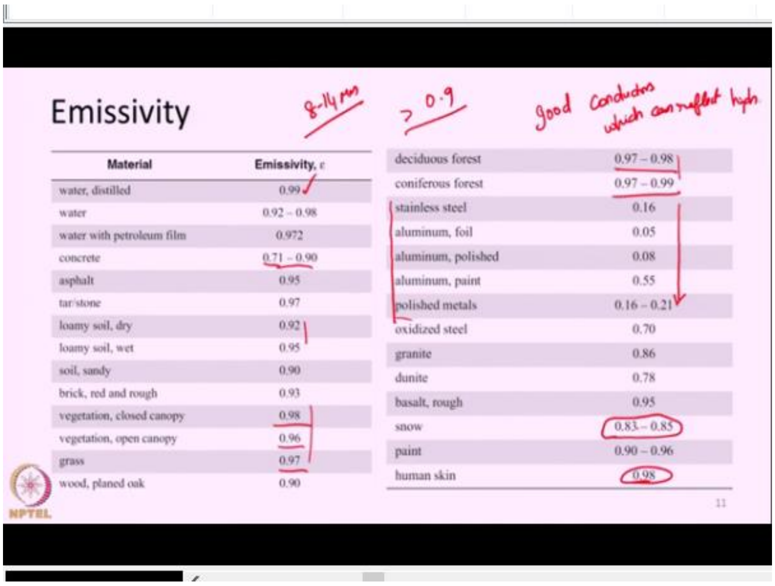


So, under this 8 to 14 μm range of wavelength, the emissivity of various factors like distilled water has extremely high emissivity, normal water occurring in our water bodies has a emissivity of say 0.9 to 0.98, concrete has pretty low emissivity range. If you look at vegetation and forest they will have fairly high emissivity 0.9 or 0.96 and above.

Whereas if you look at metals like aluminum, stainless steel, polished metals etcetera, all these things have very low emissivity values. So, normally metals which are good conductors of heat can reflect a lot of energy and such objects will have low emissivity. All naturally occurring surfaces like soil, vegetation, water has emissivity above 0.9. This is under normal conditions, even human skin has very high emissivity; snow has pretty low emissivity in this particular band. So, we have to take care of it if someone wants to observe snow.

So now we have got introduced to the concept of emissivity and the typical range of emissivity that we can expect in thermal infrared wavelengths or long wave infrared wavelengths. One important law that we should remember in remote sensing or thermal remote sensing especially is known as Kirchhoff's law. Kirchhoff's law relates reflectance of an object with the emissivity of the object. So, we know that whenever some object is interacting with EMR, 3 different process can happen, reflectance or reflection, absorption and transmission.

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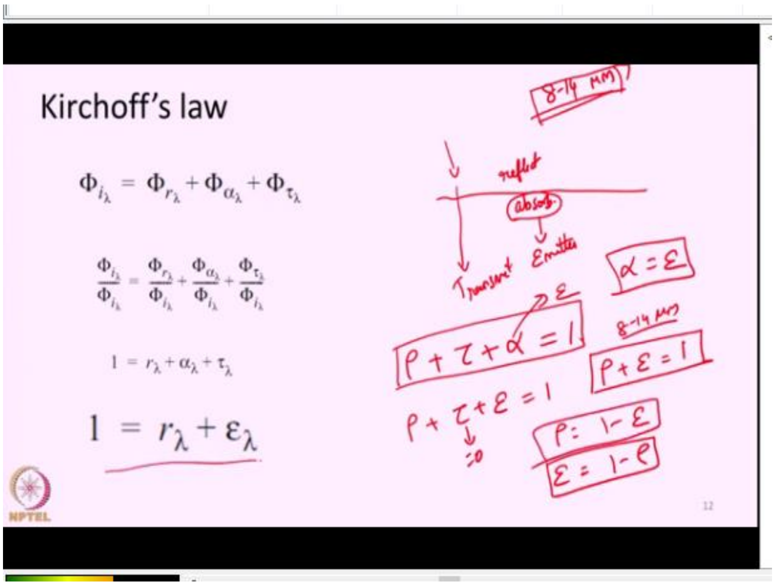


Like let us assume any earth's surface feature, when some EMR is incident over it, it can reflect a part of it or it can absorb a part of it or it can allow a portion of EMR to transmit to pass through it. These 3 things will happen. If an object is a good absorber, then it will be a good emitter. If an object absorbs well then theoretically speaking, it should also emit well because we have learned in thermodynamics that all objects on the earth's surface tries to be in thermal equilibrium with its surroundings normally, when you bring a hot body and a cold body near each other, the hot body will transmit radiation or heat energy to the cold body, they will try to attain one single equilibrium.

Same thing is common for almost all naturally occurring objects. So, if an object is a very good absorber, then its temperature will be keep on rising, absorbing means taking in more energy. So, if it wants to come to thermal equilibrium with its surroundings, it also has to emit equally good, then only it will emit radiation from the other end such that it remains or it moves towards thermal equilibrium with its surroundings.

So, naturally all commonly found earth surface features if they absorb well, they will also emit well. So, absorption and emittance we can replace one with each other, that is say in terms of thermal infrared remote sensing we are dealing with emission of objects, how much energy objects are emitting? So, for our purposes, we change this equation (reflectance + transmittance + absorbtance) = 1.

This equation we have seen already in earlier classes. Now, we replace this absorbtance with emittance. So, (reflectance + transmittance + emittance) = 1. We all know that absorbtance is equal to emittance, that is our major assumption. And then again, look at commonly occurring earth's surface features like sand, vegetation, etcetera, most likely, they will have zero transmittance to thermal infrared wavelengths.

They may not allow the thermal infrared radiation to pass through them, either they may absorb it or reflect it or something. So, naturally transmittance also will be 0 under this wavelength. So, at 8 to 14 μm range, this equation reduces to (reflectance + emittance) = 1 that means, reflectance = 1 - emittance or emittance = 1 - reflectance. So, this is what is given by Kirchoff's law.

So, Kirchoff's law basically tells us that good absorbers are good emitters, that is why we have replaced absorbtance with emittance. Good reflectors are poor emitters. So, if an object reflects a lot of energy in this range 8 to 14 μm normally there is no incoming radiation from sun in this 8 to 14 μm range. So, if somehow we are illuminating with some energy source that is radiating at this 8 to 14 μm range.

And even atmosphere also emits energy in this wavelength only. So, if some energy is falling on an object at this 8 to 14 μm wavelength, and if the land surface object is capable of reflecting a major portion of it, then according to Kirchoff's law, that particular object will be poor emitter. On the other hand, if that object absorbs a major portion of it, then it will be a very good emitter. So, higher the reflectance lower will be the emissivity and vice versa. So, this relationship reflectance = 1 - emissivity we will quite often use when we deal with data processing especially in thermal infrared remote sensing.

We will now try to understand few or different definitions existing for temperature. Temperature is a very common word, but, we can define it in several ways especially when we deal with remote sensing. So, one of the commonly used definition of temperature is what is known as a thermodynamic temperature. So, what exactly is thermodynamic temperature? Let us say, if we want to measure the temperature of an object, what we will normally do? Take a thermometer; put the thermometer in contact with the object. Wait for a few seconds. Take the thermometer out. Make a reading out of it, we will measure the temperature of the object.

So, how this thing is happening basically, we are taking the thermometer and we are bringing the thermometer in physical contact with the object of interest, let us say in olden days how doctors used to measure our body's temperature, they will take a mercury thermometer, put it underneath our tongue. So, they are bringing a thermometer and making it it in physical contact with object of our interest, that is our body.

After coming into contact, they will wait for some time. Why are they waiting for some time? They are allowing the time in order to bring our body and the thermometer to reach a same temperature level that is they want the thermometer and our body to be in thermal equilibrium. So, the time they allow that few seconds of time they are low during that time our bodies temperature will influence thermometer temperature and vice versa.

And both of them will come toward like one same temperature at that level and then they will take it out, they will read a value. Hence, thermodynamic temperature can be defined as the temperature which we can measure directly with a thermometer in physical contact with the object of interest. And also there the object of interest and the thermometer should come to thermal equilibrium and then we measure the temperature of the object. So, the temperature we measured in that particular way is known as thermodynamic temperature.

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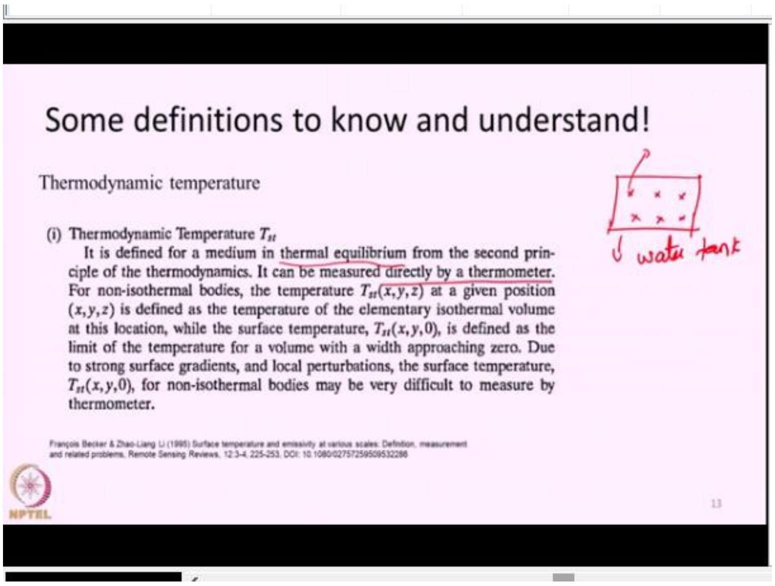


So, this definition is taken from one of the seminal papers by Becker and Lee in the year 1995. So, it is defined for a medium in thermal equilibrium. So, I said they will leave some time for the object to come to physical thermal equilibrium and it can be measured directly by a thermometer.

So, this is the common way of measuring temperature, but there we are actually making an assumption, what is the assumption? The doctor is putting the thermometer underneath our tongue and doctor was taking a reading, doctors assume our body's average temperature all across is very close to or equal to the temperature they measured underneath the tongue. That is the assumption they do.

But it may not be the case, the temperature may change at different points of our body, but that is the most representative measurement the doctors can make. Similarly, if you take analogy of some commonly occurring earth's surface features, if you put a thermometer over it, measure temperature, we are assuming that object is in thermal equilibrium and that particular object is homogeneous.

Let us say there is a water tank, someone asked us to measure the temperature of water in the tank. We will take a thermometer and measure just at one particular point within the water tank. It may not be representative, the temperature at different points of the tank may vary. So we will take at least some 4, 5 different measurements, we will take average out of it and present it.

So, the measurement of this particular thermodynamic temperature also assumes the object is homogeneous and isothermal. Isothermal means its temperature is not changing, it is in equilibrium with its surroundings, it is homogeneous in nature, under such circumstances only the point measurements that we make will be reliable. But under normal conditions, this may not be valid. Even within a small tank of water body the temperature may change from point A to point B and also if you measure the temperature at different, different depths, temperature may change. All these things will come into picture.

So, definition of thermodynamic principle is very simple. You take a thermometer, put it in contact with the object of interest, let they come to thermal equilibrium and take temperature. But in practice or in reality, measurement of thermodynamic temperature is a difficult task, because most of the commonly occurring earth's surface features will not be in thermal equilibrium, the temperature will be keep on changing, they are not isothermal. Say even if you take a small water pond, you need to take multiple measurements at different, different points you will get different, different temperatures.

So, these non homogeneity and non isothermal nature of earth's surface features makes it difficult for us to measure thermodynamic temperature for our various applications. Let us say you want to measure temperature of whole city for some applications, we will not be in a position to measure the temperature of each and every point in a city, it is impossible.

So, definition of thermodynamic temperature is very simple, but in reality measuring is extremely difficult due to the very high level of non homogeneity of objects. Temperature will change at different, different points for the same object and also objects will not be in isothermal conditions. Isothermal conditions means say a land surface during daytime, solar radiation will be keep on like illuminating the surface. Surface will be getting heated up, it will be under a constant process of getting heated up. Similarly, during night times surface will be continuously cooling down. So, it will never be in isothermal conditions, either it will be heating up or it will be cooling down. So, the temperature will be either rising or falling continuously. So, finding a proper earth surface feature under isothermal and homogeneous conditions is a bit difficult and hence measurement of thermodynamic temperature is also difficult.

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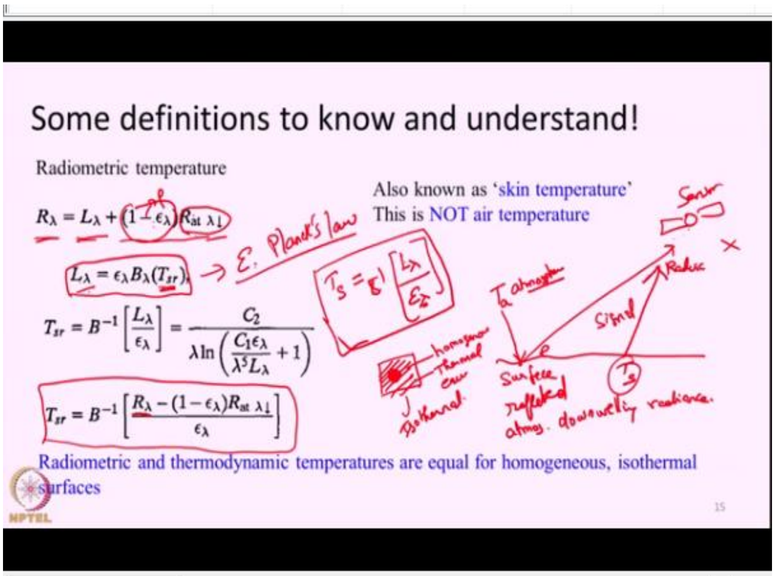


The next definition is radiometric temperature. So, this is what we are going to measure in remote sensing. So, what exactly radiometric temperature is? Let us say this is a land surface and we have our sensor. So, land surface has a temperature, let us say this is $T_s$ surface temperature and it is radiating some energy, this is the radiance. So, this will reach the sensor. Also atmosphere has its own temperature $T_a$. It will emit radiation towards the earth's surface and it will be reflected back towards the sensor. So, this is the surface reflected atmospheric downwelling radiance. So, these 2 terms actually carry the signal about the earth's surface features. So, based on the temperature there will be radiance and similarly, based on the reflectance of an object that will be radiance. So, these 2 paths will carry the signal about the surface.

So, you can take the radiance reaching the sensor and neglect all other effects of atmosphere. So, the radiance reaching the sensor is practically what is emitted by the object of interest itself and what is emitted by atmosphere. So, this is atmospheric emitted term and 1 - emissivity is basically the reflectance. So, here what is being reflected? So, this term is the reflectance of atmospheric emitted component. This is the surface emitted component. So, the surface emitted component is equal to emissivity time the Planck's equation. So, the emissivity is to correct for how well an object can radiate. So, (emissivity × Planck's law) will give us the actual radiation emitted by the object at a given temperature $T_s$ and this ρ times radiance of atmosphere will tell us the surface reflected downwelling radiance terms.

$$T_s = \frac{observed\ radiance}{emissivity}$$

The $T_s$ surface temperature is equal to observed radiance divided by emissivity of the object, when you give this value to the inverse Planck’s function, then we will get the temperature T. So, what exactly inverse Planck’s function is? Say Planck’s function will tell if an object is at a given temperature T, the object will emit a certain amount of radiation at a given wavelength. You reverse it. So, if I know the radiance, the emissivity and the wavelength of our observation, I will be able to substitute all these values in Planck’s equation and calculate the temperature of the surface.

So, this way of measuring the surface temperature by observing radiance by knowing the emissivity and calculating temperature is known as measurement of radiometric temperature. The temperature you are measuring in this way is known as radiometric temperature. So, that is again given here, in this particular slide. So, the radiometric temperature under normal conditions will be the radiance observed by the satellite $R_\lambda$ - the surface reflected atmospheric emitted terms.

That is also like a path radiance term we have seen it, but here we are neglecting it, we assume it has already been removed. So, purely speaking the radiance emitted by the surface object you correct for emissivity effect and then you invert the Planck's function to get the surface temperature and this is known as radiometric temperature. So, this radiometric temperature and thermodynamic definition of temperature that we have earlier seen will be equal only for homogeneous objects under isothermal conditions. Let us say we have a water body and a satellite is observing a small part of it. So, this is GIFOV, it is observing only that water body continuously.

So, if they entire pixel is occupied by water body, let us assume the water body has a homogeneous temperature and somehow it is an thermal equilibrium, let us say its temperature is not changing, thermal equilibrium and isothermal conditions, under such circumstances only the temperature we measured from remote sensing the radiometric temperature will be equal to the true thermodynamic temperature that you measure with the thermometer.

So, this is a very stringent condition. So, under normal conditions, the radiometric temperature that we measure from satellites will not be equal to the physical temperature of the objects on the earth's surface. Because, as we have seen, most of the objects are not homogeneous and they will not be under isothermal conditions and hence, these 2 temperatures the radiometric temperature that we measure from a distance and thermodynamic temperature that we measured with a thermometer will not be equal mostly. They will be equal only for homogeneous and isothermal surfaces.

The next definition of temperature that we are going to see is brightness temperature. What exactly is brightness temperature? Let us say we have a satellite in space, it is measuring the land surface, it is observing the thermal radiance coming out of the earth's surface, it has measured some value, some $L_\lambda$. Now, to calculate temperature, they can just take the value, put that value in Planck's equation, invert it to get the temperature which is known as a brightness temperature.

Brightness temperature of an object or is defined as the temperature, a blackbody would have in order to produce the same level of radiance as observed by the satellite sensor.

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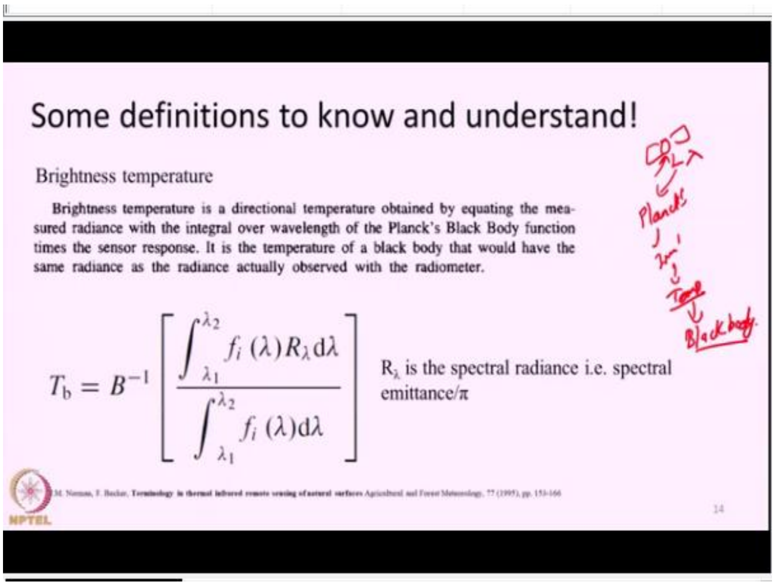


Say I have a satellite sensor up in space, it is measuring radiance $L_\lambda$. We substitute this in Planck's equation and invert it to get a temperature. So, this temperature is essentially a black body temperature because Planck's law is defined for black bodies. So, brightness temperature is defined as the temperature a black body to emit the same amount of radiance observed at the satellite sensor. So, this is known as brightness temperature. We compare this definition with real world objects. A satellite is in high up in space, land surface is emitting energy. It is passing through the atmosphere and my sensor is measuring radiance. In order for me to calculate brightness temperature, what I do? I just take this radiance value, substitute this in Planck's equation, get a temperature out of it that is it. I have not done any correction.

So, this temperature what I calculated just from mere satellite observation is actually not corrected for surface emissivity effect and atmospheric effect and also the sensor response function. I already told you within a given wavelength, within a given bandwidth, the sensor may not have uniform response. At certain bandwidth or each interval of wavelength, the sensor may have a different response, we have already seen it when we define the concept of spectral resolution.

So, please go back to previous lectures about spectral resolution, we have discussed this what are spectral response function of sensor is? So, essentially, when we calculate brightness temperature, we just take the radiance from satellite, put it in Planck's equation and invert it that is all, we are not doing any correction. So, the surface emissivity effect, atmospheric effect and sensor spectral response effect, all these things will be there, when you calculate brightness temperature. So, brightness temperature is kind of a firsthand information I can get. Just from radiance, I am calculating the temperature, we do not bother much about what effect atmosphere made, how much surface emissivity or spectral emissivity the object has? All these things we do not care about. So, this is another way of measurement. But for most of the applications, especially in the thermal infrared domain 8 to 14 μm wavelength, normally, we would not stop at brightness temperature, we will correct it for effect of surface emissivity, we will correct it for the effect of atmosphere and then we will convert it into radiometric temperature.

So, in today's lecture, as a summary, we have seen few examples or a few ranges of emissivity of commonly occurring earth’s surface features. And also we have defined 3 different temperatures, thermodynamic temperature, radiometric temperature and brightness temperature. Thermodynamic temperature is the physical temperature you measure with the help of a thermometer. And the object for which you are measuring the temperature we assume the object is isothermal and in thermal equilibrium. Second thing is radiometric temperature, that is, if there is an object, I measure the radiance out of it, from the radiance knowing the emissivity value of an object, if I estimate the temperature that is known as the radiometric temperature.

Brightness temperature is a temperature of a black body that will produce the same amount of radiance as observed by a satellite sensor. So, essentially the sensor when it absorbs the radiance, it will not be corrected for surface emissivity effect, will not be corrected for atmospheric effects. So, brightness temperatures roughly speaking temperature uncorrected for atmosphere and emissivity effect. Whereas the brightness temperature once corrected for emissivity, atmosphere, sensor response, it becomes radiometric temperature. So, brightness temperature and radiometric temperature are kind of related. with this we end this lecture.

Thank you very much.