Remote Sensing and GIS
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Lecture - 14
Thermal and Microwave Remote Sensing

In this lecture we will see thermal and microwave remote sensing. So let us start with thermal remote sensing. So what exactly we mean by thermal remote sensing that we will see by addressing this atmospheric window. So let us understand, already I have explained you this atmospheric window in many of my lectures. So this atmospheric window means where we have maximum atmospheric transmission right.

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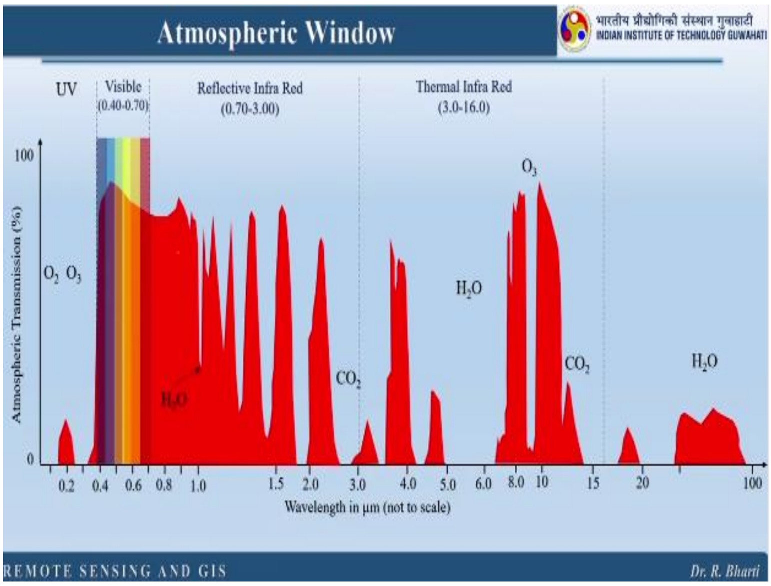

So these wavelengths, here you can see the red colours are basically showing the atmospheric transmittance, right. So here these wavelengths are allowed through our atmosphere to reach our surface and then it can travel back to the space. So there is no hindrance in our atmosphere for these wavelengths, but not all the wavelengths are completely free from this absorption and scattering.

So that is why there are few wavelengths in this red colour also you can see some of the places like here, like here, like here you have less transmission right. So what does it mean? It means within this wavelength though we are calling it atmospheric window there are certain wavelengths which are not allowed through our atmosphere to travel and reach to our surface, right.

So these are basically atmospheric window. So now let us understand in terms of thermal remote sensing, this is the wavelength range for this thermal infrared. So our sensors are active in this particular wavelength region and the information which are captured through this thermal infrared sensors. So they will be carrying the temperature and emissivity, right. So here let us understand this.

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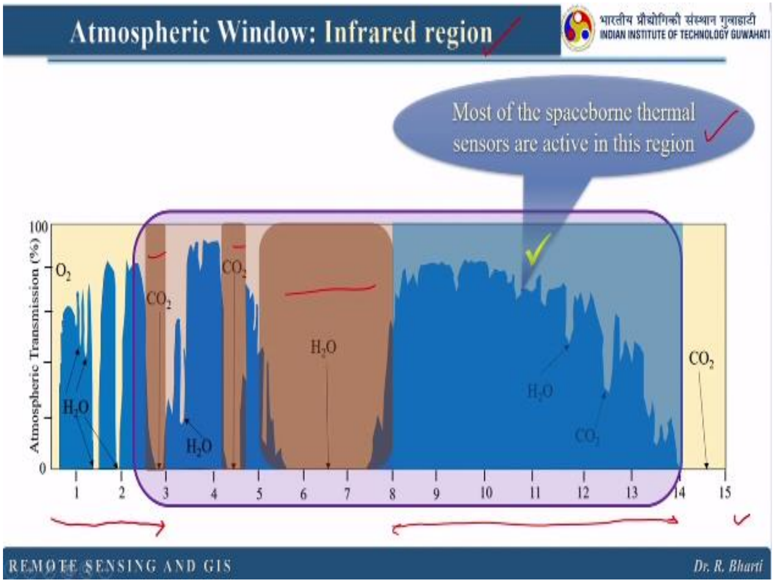

So I have another diagram, here you can see this is only for the infrared region, remember, this is for the complete infrared wavelength where we consider that till this 3 micrometre or 2.5 micrometre basically we have the reflected energy. So whatever energy sensed by our sensor that will be reflected from the surface, whereas 3 to 16 micrometre or here it is up to 15 micrometre, the energy which are emitted from the surface they are captured, right.

So this is the window for thermal infrared then these are the wavelength you can see they are not allowed through our atmosphere. So basically if you see effectively from 8 to 14 micrometre we have good atmospheric transmission, that means the energy if we can capture in this particular wavelength they will have better information right, because here transmission is continuous and there is no in between gaps.

So if my sensor is working in this particular area, this particular area or this particular area, we may not receive the emitted energy from the surface. Now let us understand this particular wavelength right, so which is highlighted here, you can see, right, this is the wavelength which is actually you can find in all the thermal infrared sensors. So that is why I have written most of the spaceborne thermal sensors are active in this region because atmospheric transmission is good.

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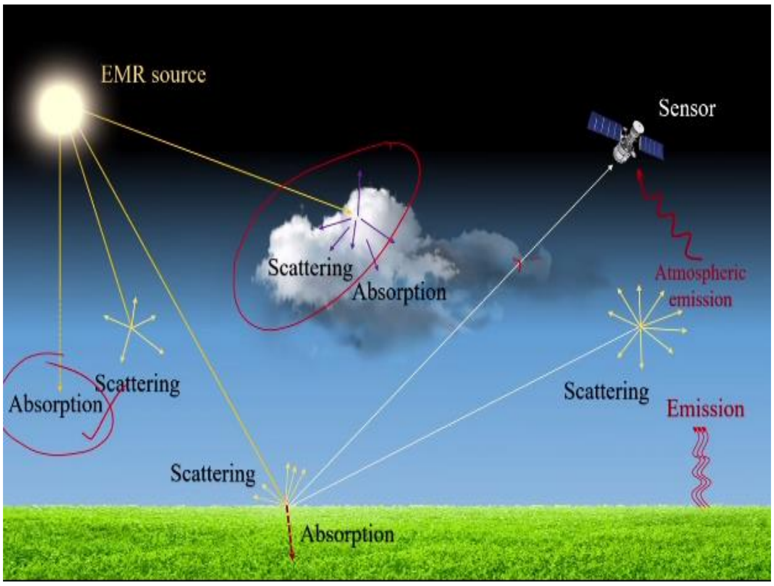

So let us understand what exactly we measure here, already I have explained you in previous lectures, but let us go through once again. So here we have our source of light and when the light is coming from the sun to our surface in between we have atmosphere and these atmospheres have gases, some hays, some aerosol, then water vapour, so those things are present in our atmosphere and what they cause? They cause absorption and scattering.

So here that is why I have written absorption. This is by our atmospheric constituents. Now same time we have scattering and sometimes it is because of the cloud and some of them will reach to our surface and in surface, do you remember that interaction between energy and the matter, so what will happen some amount of energy will get reflected, emitted, transmitted, absorbed, right.

So the resultant reflected energy or emitted energy that will reach to our sensor by facing this scattering and absorption phenomena. Now ultimately we have received the information. This we are talking about the reflective region, where we have reflected energy and our sensor is active between 0.4 to 2.5 or 3 micrometre and this is the domain for reflective energy, right. Now what happens when some amount of energy is absorbed by the target.

Then ultimately to maintain the surrounding temperature we have to or the object has to release the extra energy, right and that extra energy will be emitted in longer wavelength region and same time we have emission from the atmosphere, right. So these 2 information will be captured by our thermal infrared sensors, right.

So there are few fundamental question we need to answer, then it will be very clear to you right.

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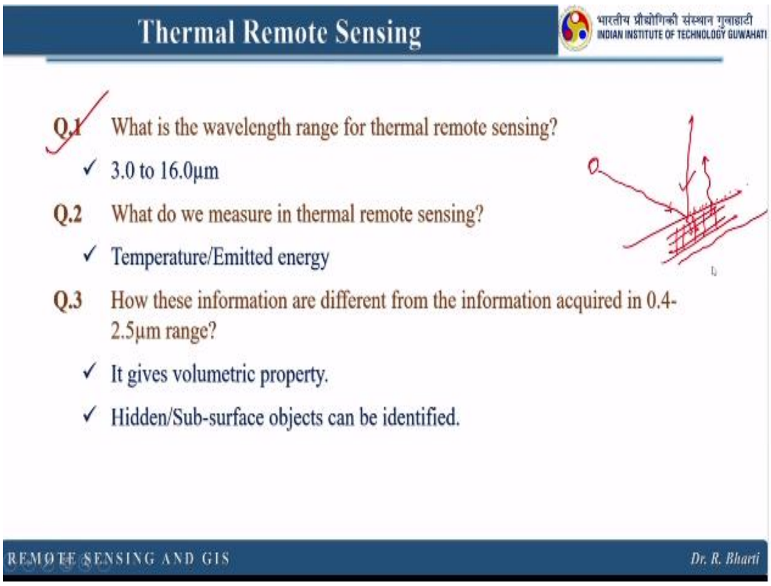

So first one is what is the wavelength range for thermal remote sensing, right. I hope you can answer this one because already I have explained this. Now the next question is what do we measure in thermal remote sensing. Already I have explained you this. Now the third question is how these information are different from the information acquired in reflective domain?

Reflective domain means 0.4 to 2.5 micrometre wavelength range. Now let us go through one by one. So the range will be 3 to 16 micrometre, somewhere in some books you may find that 2.5 to 14 micrometre or 2.5 to 16 micrometre is the thermal range, but remember this 2.5 to 3 micrometre, this wavelength has both the information, emitted and reflected, and the atmospheric window is not good there.

So generally we avoid this 2.5 to 3 micrometre wavelength range and in general 3 to 16 micrometre is considered as thermal remote sensing wavelength range. Now what do we measure? So basically we measure temperature and emitted energy from the surface, right. Now how this information are different from information acquired in reflective domain. So first of all you have to understand this is your target and you have a source.

And when we are talking about reflected energy basically this incident energy gets reflected from the surface itself, but when we say when the material is absorbing some amount of energy, right. So the absorbed energy will be stored in the object. So basically this is a volumetric property. So depending upon the object composition, the amount of energy will be stored and later on it will be released. So the released energy is known as emitted energy.

So basically if we talk about reflected energy, that is actually surficial phenomenon where as in emitted energy this is a volumetric phenomenon because here the energy is stored in that material, right, and reflected energy is reflected from the surface itself. So this is the basic difference between the reflected and emitted energy. So the information will be definitely different.

So it gives you volumetric property and because of that hidden or subsurface object can be identified. Now let us see some example, so this is the first example.

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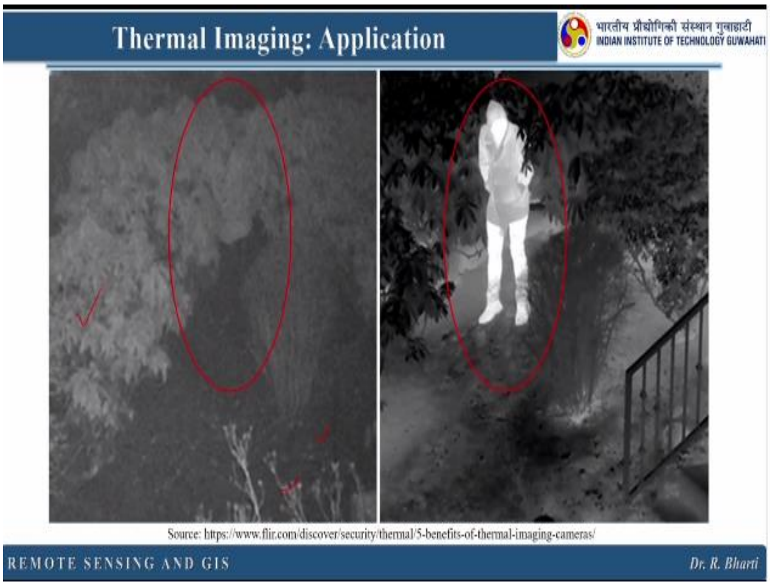

This is a normal photograph in visible range taken in evening or may be late night. Now you can see there are few trees here, some shrubs, grasses are there. This is visible, right, but can you find anything here? No. Something has been camouflaged why because we do not have night vision, right, and this visible imagery is nothing but like what we see. Now let us understand when we have thermal infrared images, what extra information we have?

We have the hidden person, which was camouflaged here, right. It was not visible here, but here it is very evident like this is there is a person who is hiding, right. So this can be used as a night vision camera. Let us see next example. So this is in military uses.

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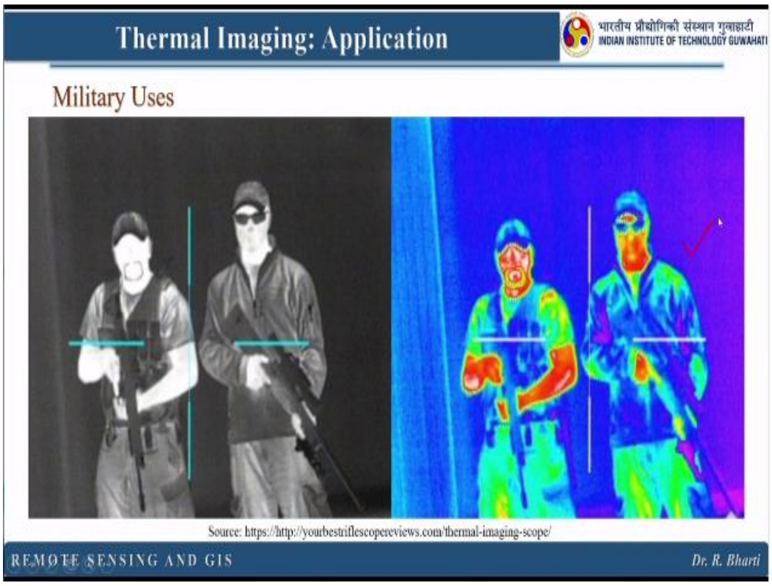

You can see in the night time this can be easily identified, right. With normal camera it cannot be.

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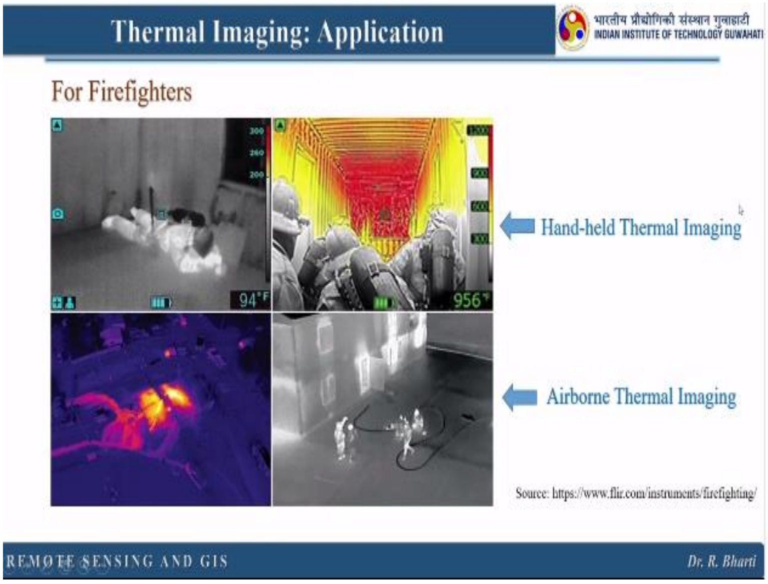

Now for fire fighters, this is very useful when you have handheld thermal imaging camera or airborne thermal imaging camera fixed in an aeroplane or maybe in a helicopter, you can easily find out the hot spots, right.

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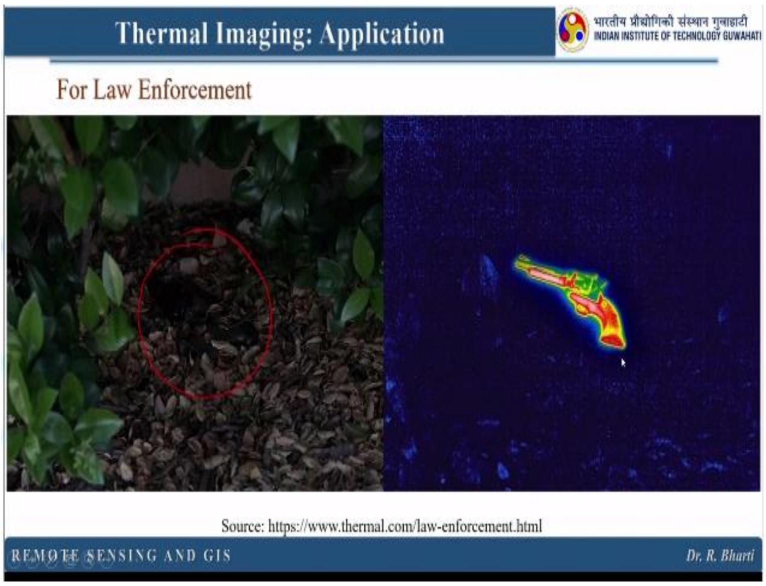

Now the next one is for law enforcement, here this gun was hidden, right, but here it is very evident like this is the gun lying in this particular location. So you can easily track which we cannot do or which was hidden or camouflaged in visible range, right. So there are few advantages which you cannot have with any other wavelength region.

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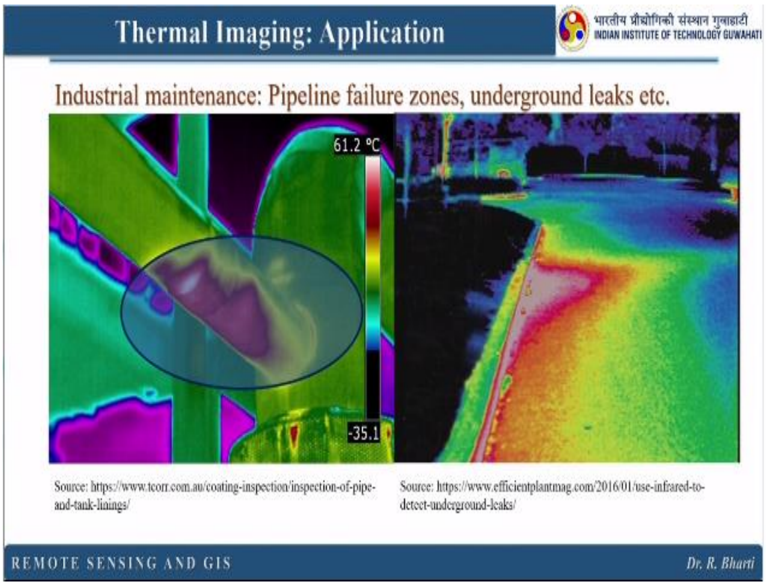

Now the next one is industrial maintenance. So here this is one example where pipeline failures zone right. Suppose you have a petroleum pipeline and you want to find out what are the vulnerable zones where it is likely to get failure or maybe leakage, right. So if you take thermal images then you can easily find out where it is supposed to be or it is likely to be failure, right.

The next example is in leakage, underground leakage, because from surface, from the top it may not be visible, but if you take the thermal images, it will be very evident that it is spreading, right. You can see here. So these are few advantages with thermal remote sensing.

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Now in the night time if you want to monitor the habitats like elephants or you want to identify forest fire, how it is spreading. So in the night time it will be the best images because in the night time all the other temperature will be suppressed only fires can be identified, right.

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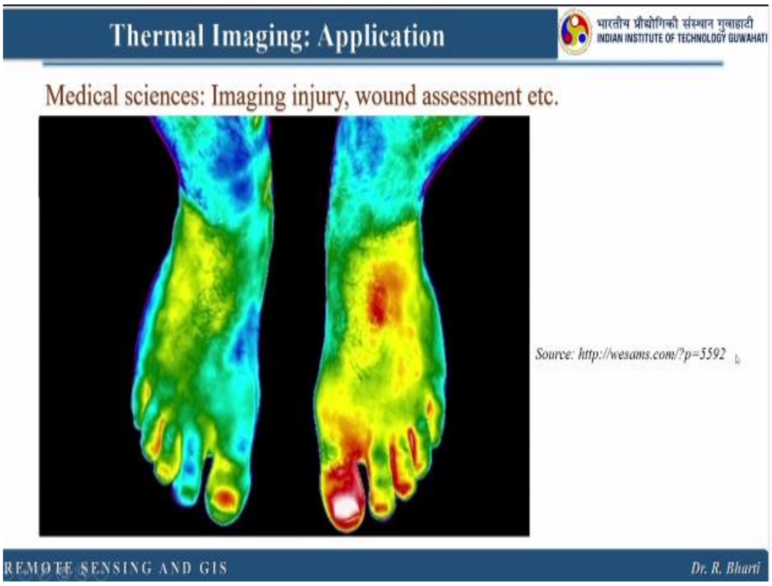

In Medical Science nowadays it is frequently used to identify the injury. So you can see here which was not visible from outside, but if you take a thermal camera, if you take and image, you can easily find out and pin point what are the location which needs treatment, right. So let us understand the basics of thermal remote sensing.

So thermal infrared radiation refers to the electromagnetic wave with the wavelength of between 3 and 16 micrometre, right.

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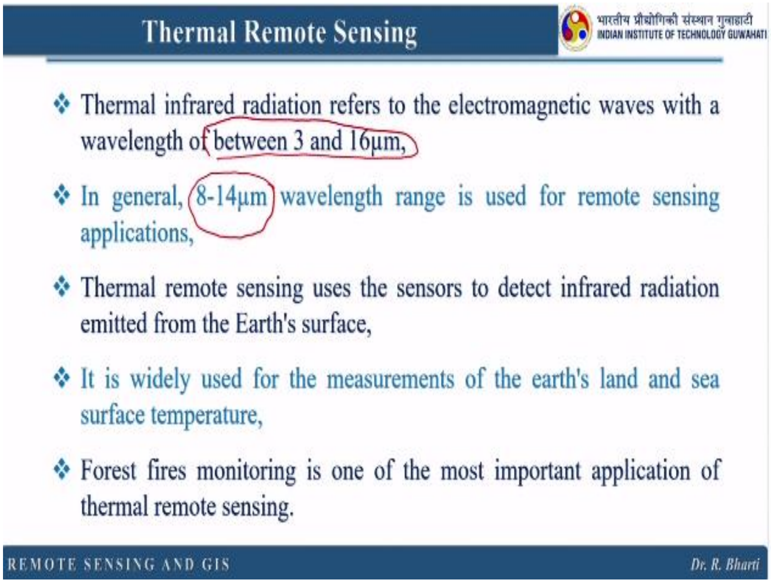

And the next point is, in general 8 to 14 micrometre wavelength range is used for remote sensing application, why so? Because in 8 to 14 micrometre you have good atmospheric transmission, do you remember that atmospheric window slide, my second slide of this lecture, there I have explained why this 8 to 14 micrometre wavelength range is preferred, because of the high atmosphere transmission.

The thermal remote sensing uses the sensor to detect infrared radiation emitted from the Earth surface because in longer wavelength region between 3 to 16 micrometre wavelength range we measure emitted energy. It is widely used for the measurement of Earth's land and sea surface temperature, right, and then forest fire monitoring is one of the most important application of thermal remote sensing.

So this is not only one but there are many other applications which are very important, right, but this is actually one of the major application in forestry. So the application of thermal imaging includes National and domestic security.

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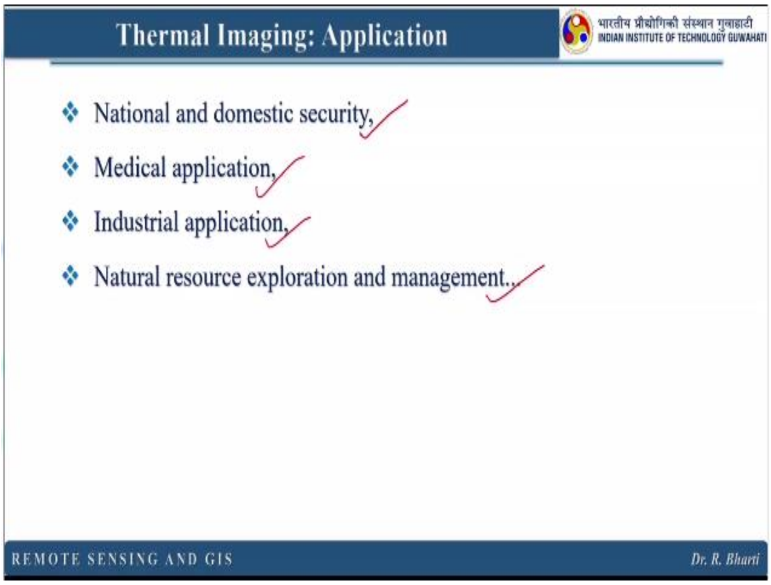

Medical application, industrial application, natural resource exploration and management. So you have already seen the example of National and domestic security, for law and enforcement you can easily use this technology, in medical to find out the bad cells, industrial applications to find out the leakage or vulnerable zones of any pipeline, right and then natural resource exploration and management.

Can we use this technology to identify some economic minerals or rocks which can be of use or which can be used to increase our National economy? Right, so, yes, we can use this technology let us understand this slowly. Now there are different sensors available in thermal remote sensing. So I am going to list very few, very limited numbers.

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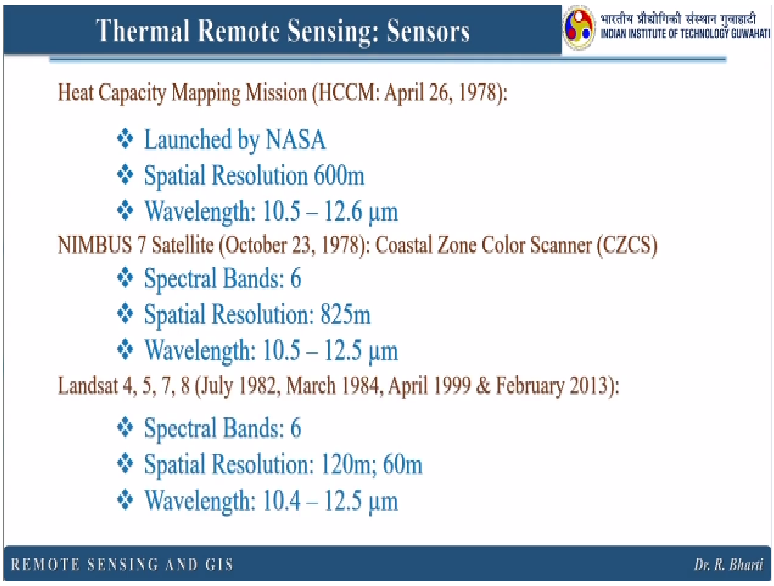

So first one is heat capacity mapping mission that was launched in 1978 right. Then Nimbus 7 satellite this was in 1978 again, then Landsat 4, 5, 7, 8, now we have Landsat 8, recently launched, which was launched in February 2013 and this is one of the very popular data which is used in thermal remote sensing. So it has many other bands, but the thermal bands are very useful.

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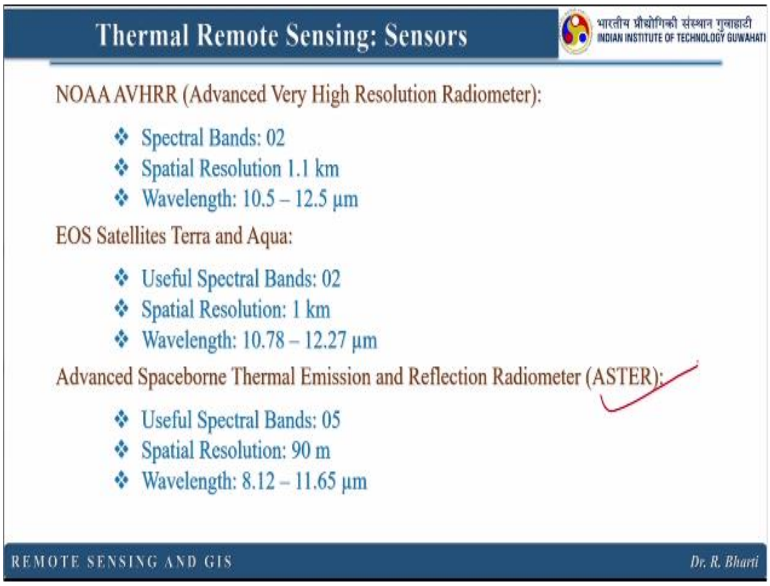

NOAA AVHRR right, then EOS satellite Terra and Aqua, then Advanced Spaceborne Thermal Emission and Reflection Radiometer which is commonly known as ASTER, right. So you can see special resolution 600 meter, 825 meter, 120 meter, 60 meter, right, then 1.1 kilometre, 1 kilometre, 90 metre, but we do not have very good spatial resolution in thermal infrared, why? This is the question you have to think, right.

Now let us understand what exactly we measure in thermal remote sensing and what is the mechanism, right. So you can consider any object, so objects above 0 degree Kelvin that is this - 273 degree Celsius.

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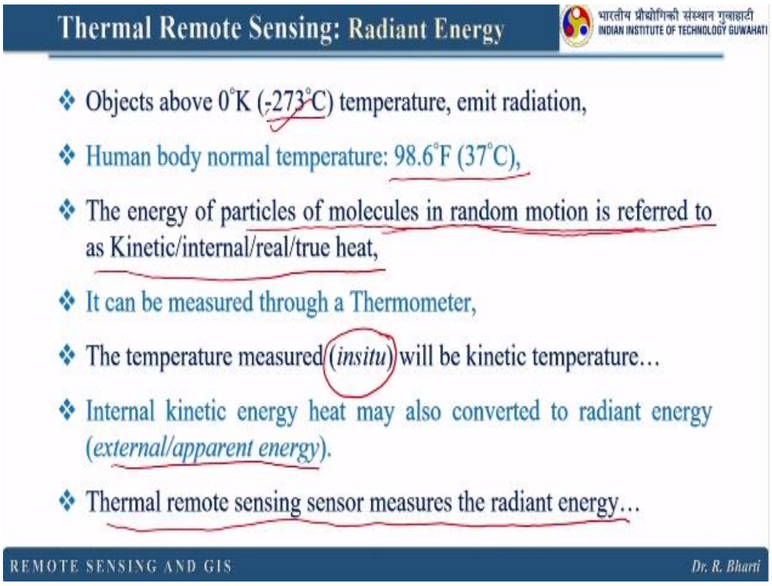

So that emits radiation. So any object above this particular temperature will emit radiation, right. Human body normal temperature is this one, so all the time we are emitting some energy, that we can see in the thermal imaging images, right. The energy of particles of molecules in random motion is referred to as kinetic, internal, real or true heat. So this is known as kinetic temperature right or sometimes internal temperature, real heat or true heat.

Names are different but basically we are referring the energy of particles of molecules in random motion. So because of this we are having some temperature and that we measure through a thermometer, right. The temperature measured insitu, so here this is very important. If you measure temperature at the point of that or at the location of that object that will give you kinetic temperature, right.

So if you are measuring the temperature of any human body or of any object where there line then that will be known as Kinetic temperature. So the internal kinetic heat may also converted to radiant energy which is external or apparent energy, right, and this we measure through this our remote sensing sensors. So here thermal remote sensing sensors measure the radiant energy.

Remember we measure radiant energy through our thermal sensors, right, which is located in space or maybe airborne or maybe with the hand held instrument, but we always measure this radiant energy. So let us see some fundamentals why we exactly get this particular temperature or the emitted energy and what is the mechanism. So in detail, so let us start with Stephen Boltzmann law.

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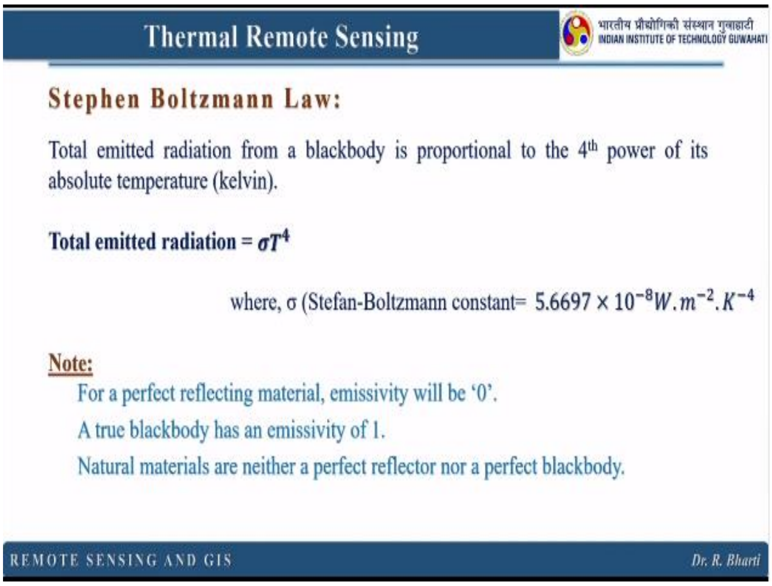

The total emitted radiation from a black body is proportional to the fourth power of it is absolute temperature. So total emitted radiation is equal to sigma T to the power 4, where sigma is the constant and T is the temperature, right. If you know temperature you can calculate the total emitted radiation. If you know total emitted radiation and sigma is known then you can calculate the temperature, right.

So basically if any one of them are known you can easily calculate. So let us understand for a perfect reflecting material why emissivity is 0, right. So if this is my target or this is the surface which has been illuminated by this particular source, right and which is getting some amount of energy will get reflected, some amount of energy will get scattered, right and some will be transmitted, some will be absorbed, right.

So if we assume perfect reflecting material that means the total amount of energy which is falling on this particular surface will get reflected. So this will be 100% reflectors. So in that case all the other parameters will become 0. So in that case there is no absorption, so emissivity will be 0, this is very obvious right. A true blackbody has an emissivity of 1, so when we call a material blackbody? When it can absorb all the incoming radiation, right.

So this is the definition of true blackbody. So let us assume this is my target, right and we are referring this a true blackbody. So this is true blackbody. Now what does it mean, it will absorb all the incoming radiation. So it will store those energies and then later on it has to reemit this one, why because it has to maintain the equilibrium with the surrounding. So in that case whatever energy received by this particular target was absorbed.

And later on it was emitted, right. So in that case if we have true blackbody emissivity will be 1, right. Natural material are neither a perfect reflector, nor a perfect blackbody. So we call them grey bodies right. So when we have grey bodies that means part of the energy will get reflected, part of energy will get absorbed, part of energy will get transmitted, right. So object will have some emissivity and the object will have some reflectance.

The object will have some transmittance, the object will have some absorbance, right, that is the case with grey bodies.

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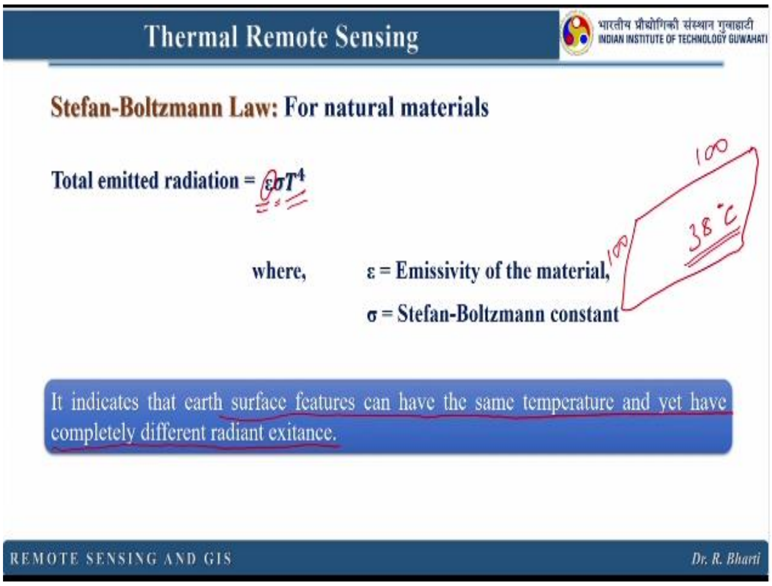

So now what happens when we deal with natural materials. So we add here this emissivity. So initially emissivity was not there. Now for natural material, total emitted radiation will be equal to emissivity multiplied with sigma that is your Stefan Boltzmann law and T is your temperature. So for natural material it will be emissivity which will play very critical role. So it indicates that Earth's surface feature can have the same temperature.

And yet have completely different radiant existence, that means the temperature of a given area can be same, maybe 38 degree, right, 38 degree Celsius, but suppose if this is 100 by 100 kilometre area, right. So in that case can we assume that this 100 by 100 kilometre area consists of same material? In nature it is impossible, but though we are having same temperature, why because they are maintaining the equilibrium with each other and they are emitting the energy.

So if we go without this emissivity factor that means all material will become same, right, but that is not there. So in nature all the materials are different and they are changing from one place to another place, so here the emissivity will play a very critical role that we will see in next slide.

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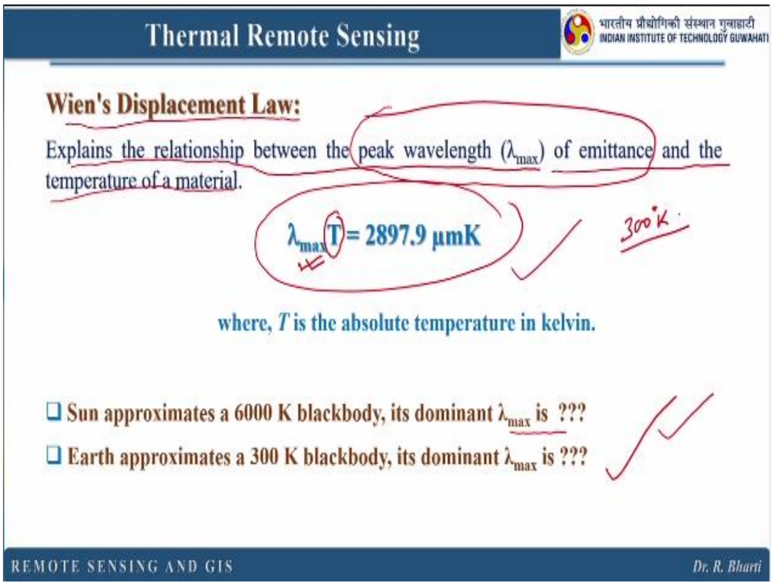

Now how do we find out the lambda max, where is the peak wavelength of emittance. So for that we have to refer this Wien's displacement law. Here it explains the relationship between the peak wavelength that is lambda max of emittance and the temperature of a material. So basically here if you see this equation, the lambda max is unknown. Suppose we do not know the lambda max of any material, right.

But we know the temperature, we can measure using thermometer. So suppose if we have 300 degree Kelvin for any given material, we can find out what will be the lambda max of that particular material. So here if we know the temperature, we can easily find out what will be the lambda max. So the peak wavelength of emittance, this is very important right. Now here the Sun approximates a 6,000 Kelvin blackbody right.

It is dominant lambda max will be can you calculate, yes it is very easy, then Earth approximates at 300 degree Kelvin black body its dominant lambda max will be. So this is for your exercise, use this formula and calculate what will be the lambda max for Earth and

Sun, in which wavelength you can receive the maximum remittance from Sun as well as Earth, right.

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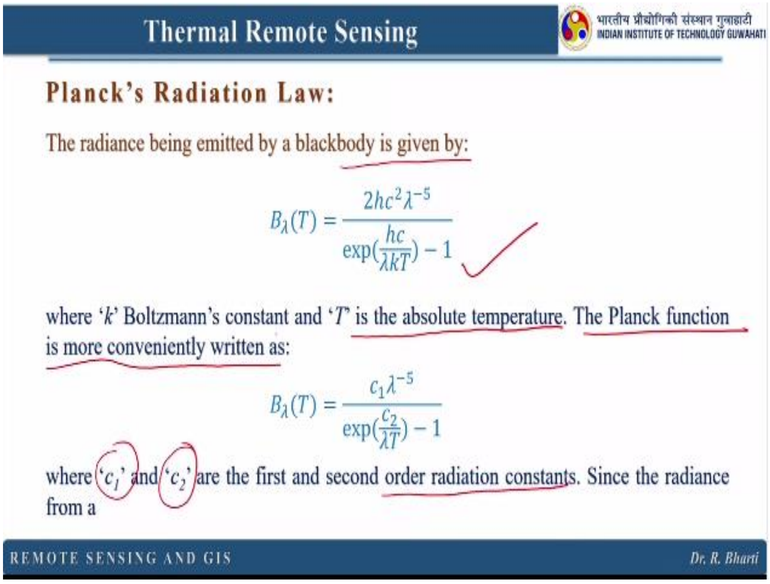

Then the next one is Planck's Radiation Law. So the radiance being emitted by a blackbody is given by this formula where K is Boltzmann constant and T is the absolute temperature. The Planck function is more conveniently written as this and where C1 and C2 are basically the first and second order radiation constants, right.

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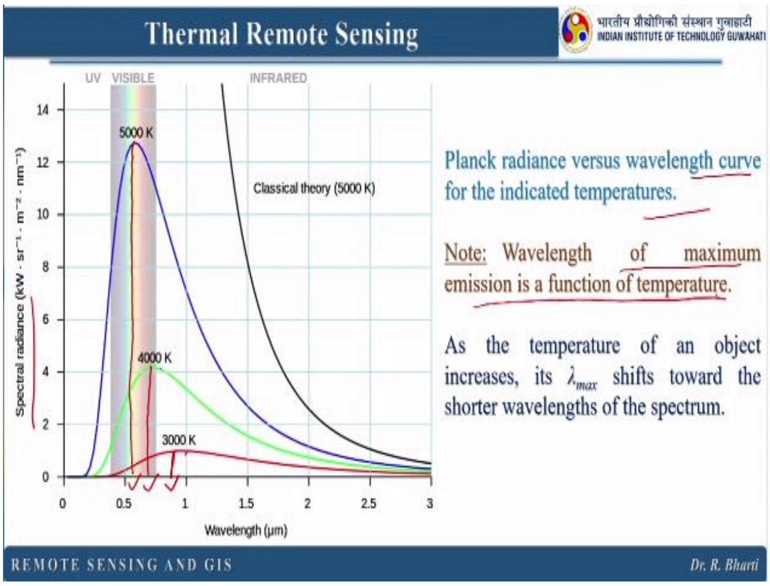

So here if you see this particular curve where 5000 Kelvin, 4000 Kelvin and 3000 Kelvin, they have been written. Now let us correlate with all other basics. Here for 3,000 Kelvin, the lambda max means where you have maximum emittance right. So the spectral radiance will be high, right. So here for 3000, let us assume this as the position where it is giving maximum value.

For 4000 let us draw this line, for 5000 this is the line, correct. So these are the wavelength position where we are getting maximum emittance in case of 3000 Kelvin, in case of 4000 Kelvin, in case of 5000 Kelvin. Now you just see as we are increasing the temperature of the target what will happen? The energy line is safety towards the shorter wavelength. So that is why we say that shorter wavelength have high energy, right.

So this is one of the theory you can correlate. So Planck radiance versus wavelength curve for indicated temperature that is shown here. Now wavelength of maximum emission is a function of temperature, this is evident from this particular curve, so 3000, 4000, 5000 as we are increasing the temperature the lambda max is shifting left side, right. As the temperature of an object increases it is lambda max shift towards this shorter wavelength of the spectrum, that I have already explained, I hope this is very clear to you right. Now let us see radiation from natural surface.

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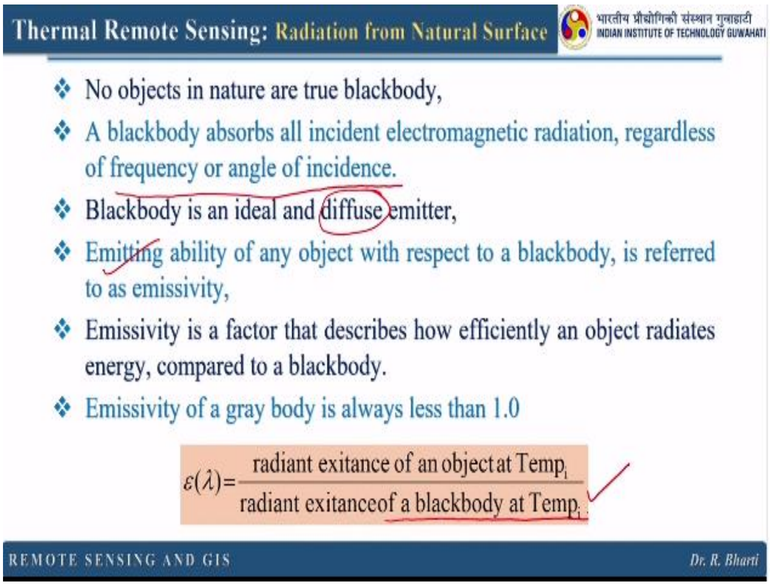

What exactly we are doing here, no objects in nature are true blackbody, so everything is grey body right. A blackbody absorb all incident electromagnetic radiation regardless of frequency or angle of incidence, right. Blackbody is an ideal and diffuse emitter, why because it absorb all the incoming radiation, so later on it will emit. So it will emit in all the direction in equal intensity. So that is the definition for diffuse, so it will not be focused, right.

Emitting ability of any object with respect to a black body is referred to as emissivity, that means if we can measure the radians in thermal range of any given material at a particular temperature, at the same temperature if we can measure the radiance of black body and if we divide them then we will get this emitting ability of that particular material, right. So emissivity is a factor that describe how efficiently an object radiates energy compared to a blackbody.

This is in other words the meaning is same, right. Emissivity of grey body is always less than 1. So again if you just remember reflectance where we have the range of 0 to 1, again when we are talking about emissivity, again the range is 0 to 1, because we are dealing with the grey bodies, not the blackbody. So the standard value is for the black body that is 1, that is the maximum, but in all other cases it will be less than 1.

And this is the formula for your emissivity calculation. So radiant existence of an object at temperature i divided by radiant existence of blackbody at same temperature, right.

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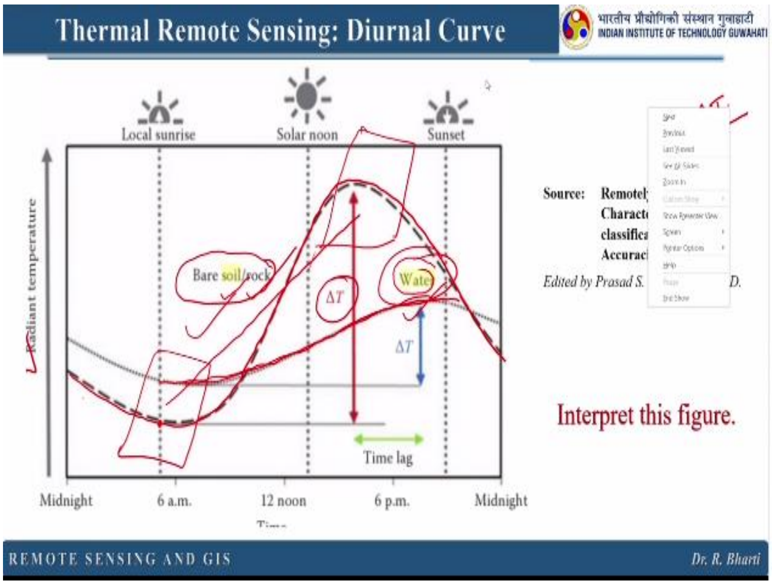

Now this is one example why this thermal remote sensing is very important. So let us interpret this particular figure. Here if we consider the first one like let us go with this bare soil, right, bare soil or rock. So here this is the local sunrise. So this is the spectra for that and this is y axis where we have radiant temperature in x-axis we have time, right and this is diagonal, so it is for only one day.

Now we have started from midnight and here during the sunrise the temperature of this particular material bare rock and soil, this was low, but as we heated through our solar radiation it has increased in the afternoon, right, but again as it is going down the sun is setting down, then the temperature is also going down because the source of energy is not available, right.

So if you can monitor this heating and cooling curve for bare rock and soil that will give you some information about the material composition, right. Now let us see the other example, in case of water you can see this is the curve, right. So how they are different from each other, if you want to segregate water and bare rock or bare soil from the thermal imagers, it is very easy, because the temperature which will be emitted by this particular water.

And the bare soil body that will be different. Now suppose if you have captured one thermal image at this particular time and the second image at this particular time for any given rock, right. So here you can easily find out what is the delta T, the same time you can also do it for water and you can easily find out what is the temperature difference between day and night.

This can tell you whether the material is having the capacity of holding the temperature or not, right. So further we will see how can we use this information to identify or to study any given target, right.

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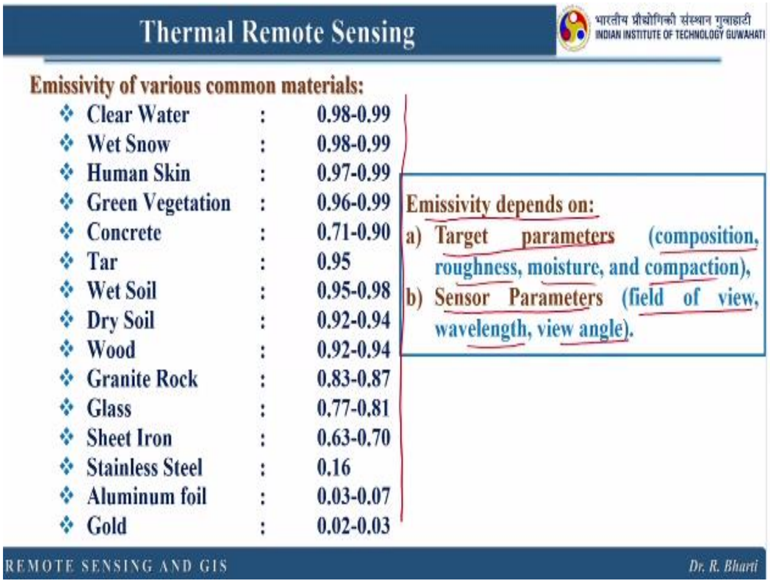

So here you can see the emissivity of various common material are listed here, right. So if you remember when we were not using the emissivity factor in our total radiation what was happening? The material or the area was having the same energy, right, same energy in terms of temperature. So the temperature was same, so we could not be able to find out what type of material is lying in my study area.

But as soon as you include this emissivity factor you can easily find out what material it is. So again you can go to that signature level. So you can use this as a signature because this emissivity is a function of wavelength and material composition. So the emissivity depends on target parameters like composition, roughness, moisture and compactness and the second one is sensor parameters that is field of view, wavelength and view angle.

So remember this already I have explain in my previous lecture where the importance of field of view, wavelength, view angle was explained. So once you have this information you can easily find out the temperature anomalies, right. So one example I will show you here.

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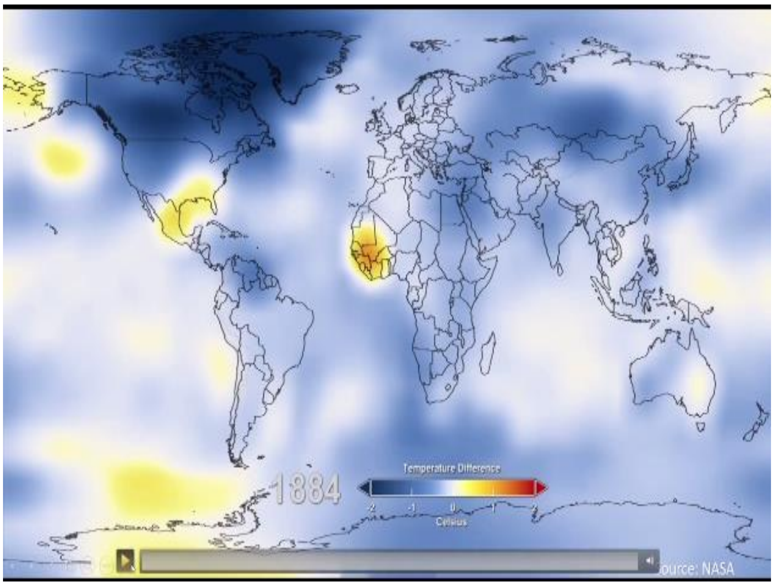

You can see this video very carefully this is taken from NASA and here you can see the temperature change, right global temperature anomaly. So here you can see how with respect to year it is changing, right. So here you can see this scale, the scale, this dark red is 2 degree Celsius and dark blue is -2.

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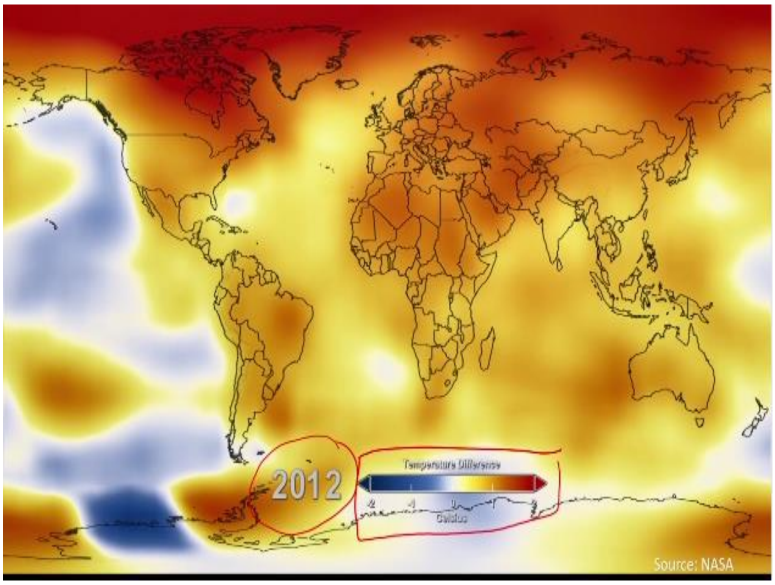

So this is over, now here you can see wherever you find red colour that means you have temperature difference of 2 degrees, where you have dark blue colour like this is one of the area where you have difference of -2 degree and you can locate your area and you can see whether your area is having positive effect or negative effect, right.

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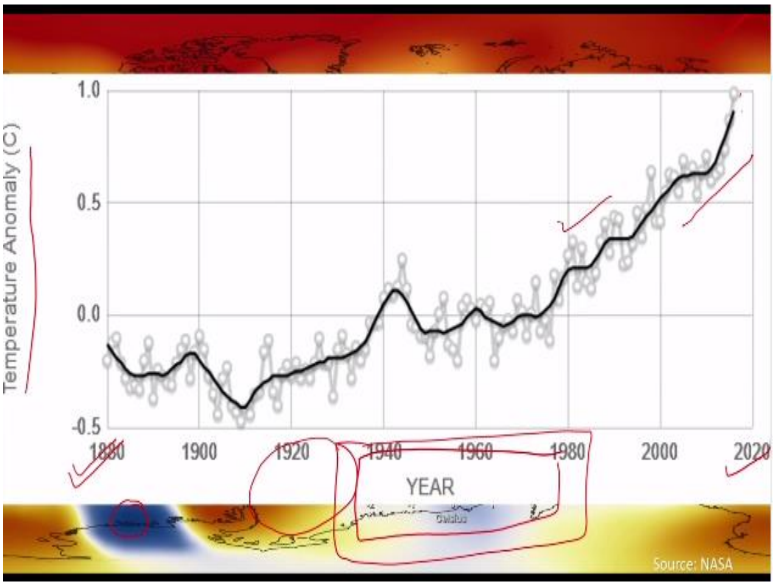

So we have taken this information and we have plotted here and there are some extrapolation, you can see from 1880 to 2020 how this temperature anomaly is changing, right. So maximum we have 1 degree temperature anomaly across the globe.

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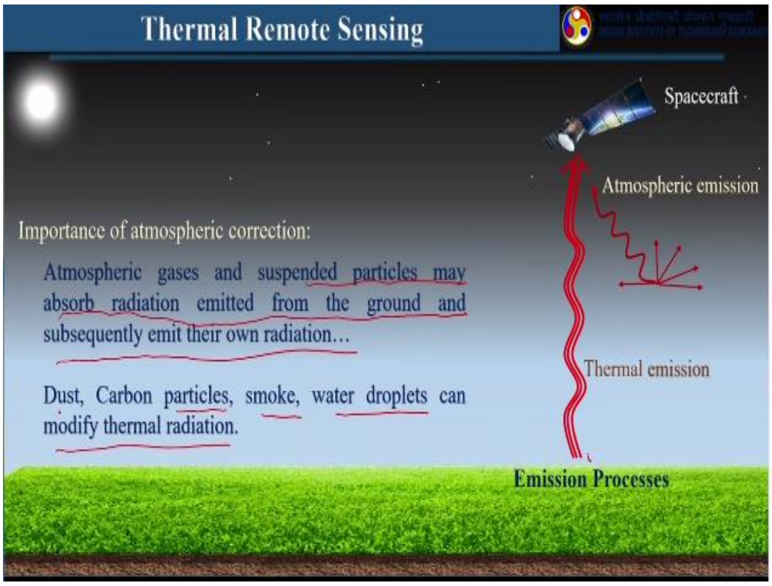

Now let us understand the importance of atmospheric correction in thermal remote sensing because here you have scattering and absorption and once you have absorption you will have emittance. So that is very clear from previous slides. Now what exactly happens here, the atmospheric gases and suspended particle may absorb radiation emitted from the ground and subsequently emit their own radiation.

This is very much possible then next point is dust, carbon particles, smoke, water droplets can modify thermal radiation. So nowadays we have more pollution, so the modification in the signal is very much possible here. So here you can see the main information we are getting from the surface to the sensor, but in between we have atmospheric absorption and scattering and then reemission and that will be also part of this information. So basically these are your path radiances.

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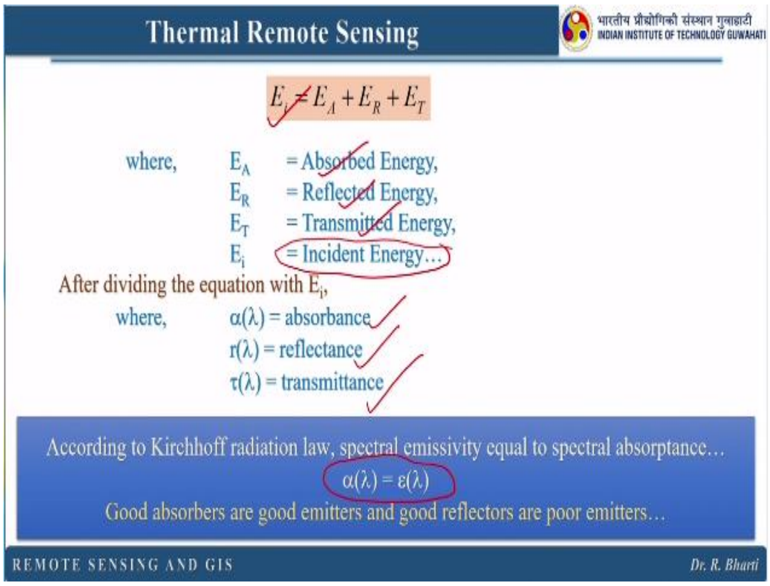

Now let us see this incident energy which is Ei = absorbed energy then + reflected energy + transmitted energy, right and when you divide by this incident energy what will happen? This will be absorbed, reflectance and transmittance, right. So according to Kirchhoff radiation law, spectral emissivity equal to spectral absorptance. So here this is clearly written. So good absorbers are good emitters and good reflectors are poor emitters.

So I have already explained this in blackbody. So if you have a very good absorber, which is absorbing all the incoming radiation that means there will be very good emitter. If the target is very good reflector then there will be no absorption, so in that case this will become 0 and reflectance will be maximum, right.

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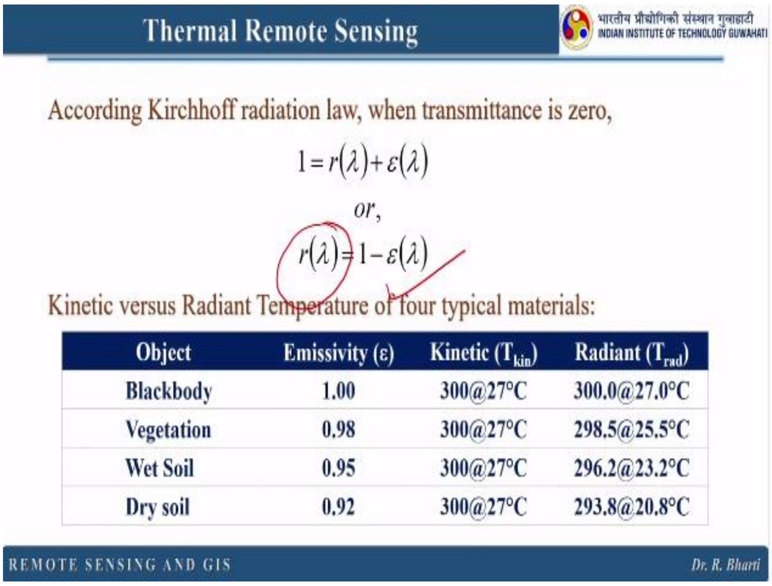

So according to Kirchhoff's Radiation Law when transmittance is 0 then what will happen your reflectance will be equal to 1 – emissivity. So this is used only when your target does not have any transmission. So the kinetic versus radiant temperature of 4 typical material is listed here. So blackbody emissivity is 1, vegetation 0.98, wet soil 0.95, dry soil 0.92. So you can see temperature is not changing, but emissivity is changing.

So we can easily find out what material it is based on the emissivity, but not based on the temperature with temperature you can find out the anomalies, right hotspot. So we will more focus on the emissivity during our interpretation of the composition.

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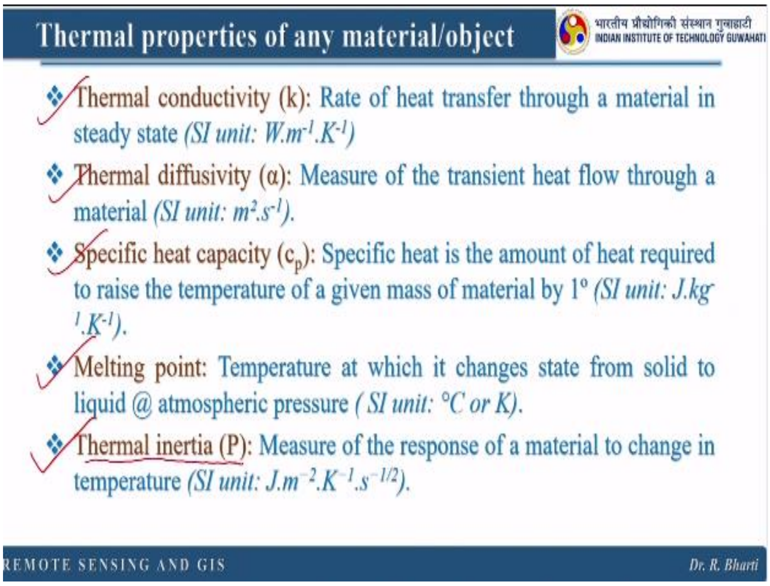

Now thermal properties of any material or object that are listed here. So first one is thermal conductivity, second one is thermal diffusivity, third one is specific heat capacity, fourth is melting point and thermal inertia. So I hope you are familiar with thermal conductivity, thermal diffusivity, specific heat capacity, melting point, but I guess this will be new to you, right.

So what exactly thermal inertia mean, so measure the response of a material to change in temperature. So how inert it is with respect to change in the temperature, right. So now we will see how we can derive this thermal inertia information from our satellite remote sensing data in thermal region right.

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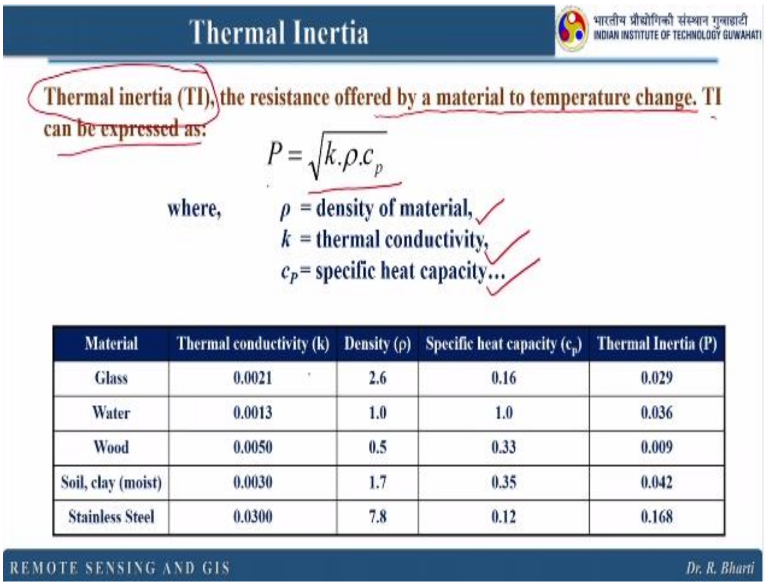

So thermal inertia is the resistance offered by a material to temperature change and TI can be expressed as this, right and where density of material, thermal conductivity, specific heat capacity they are used. So in case if you have a material and if you know what is the density of the material, thermal conductivity of the material, specific heat of the material then you can easily find out what is the thermal inertia value of that particular target, right.

So here you can see thermal conductivity, density, specific heat and then we have calculated the thermal inertia. So this thermal inertia is a very important parameter, but for all the materials can we calculate this thermal inertia? Yes, provided you should have all this information.

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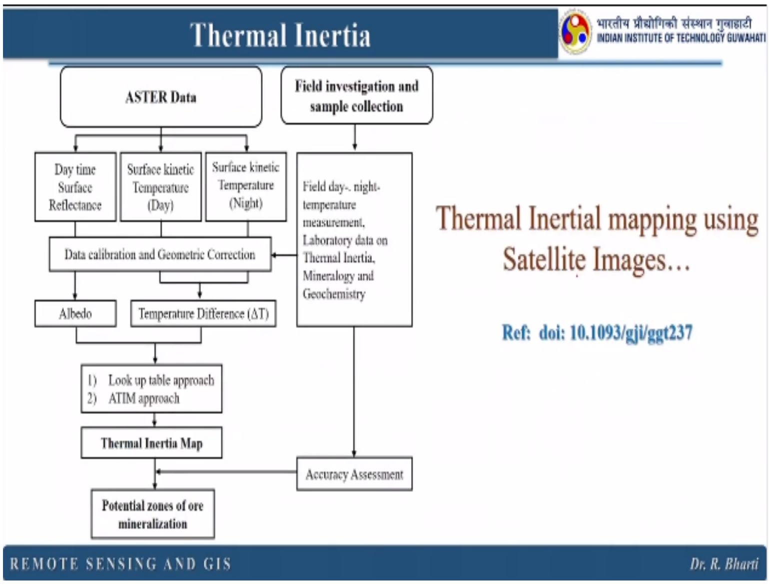

This is one of the published paper where thermal inertia is used to map the ore mineralization in Mamandur area. Here the ASTER data was used because ASTER is having temperature data in thermal region, then field investigation and sample was collected. So from the ASTER data you can calculate or you can get the daytime surface reflectance, surface kinetic temperature, surface kinetic temperature of night.

Then using this you can calculate the delta T what was in the morning and night and then delta T can be calculated and the same time albedo can be calculated using this daytime surface reflectance and once you have that you can calculate this thermal inertia using lookup table approach or maybe using ATIM approach. So if you want to know this methods you please refer this particular paper.

And once we have this satellite based thermal inertia mapping then same time we have also conducted field for day and night temperature measurement, laboratory data on thermal inertia, we have calculated the thermal inertia of selected material, which we have collected in the field and then we have also calculated what is the mineral composition or we have estimated the mineral composition using the conventional technique like XRD, XRF and ICP.

And then we used all these information together and we have assessed the accuracy and finally once we are satisfied then we have mapped or we have represented or we have produced the ore mineralization area.

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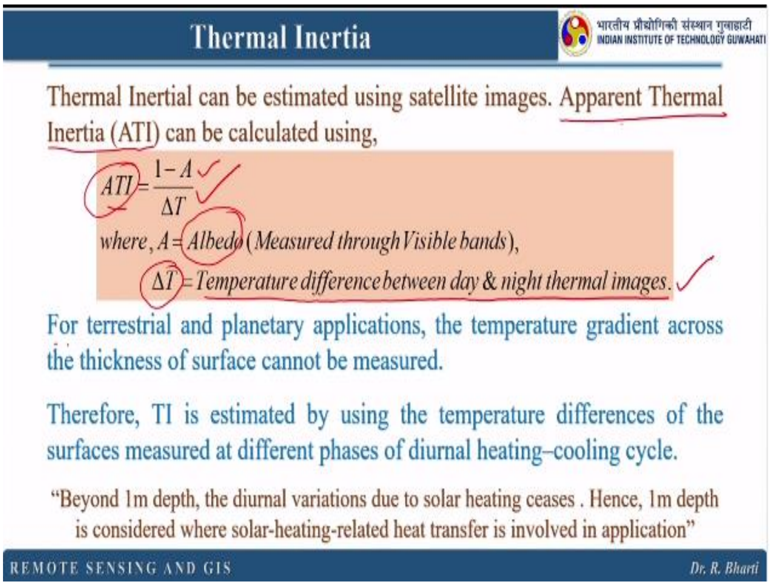

So how do we calculate this thermal inertia, so a very generic formula this is known as apparent thermal inertia, can be calculated using this satellite images where this is for initial assessment. Remember ATI that is basically apparent thermal inertia value is equal to 1 - albedo divided by delta T. Delta T is the temperature difference between day and night thermal images.

So you have ASTER data, in the previous case we have used ASTER data and using the day and night time temperature data surface temperature we can calculate the delta T and the albedo can be calculated using other images starting from 0.4 to 2.5 micrometre and once you have that you can easily find out or estimate apparent thermal inertia value. So for terrestrial and planetary application the temperature gradient across the thickness of the surface cannot be measured.

Therefore, TI is estimated by using the temperature difference of the surface measured at different phases of diurnal heating and cooling cycle and once you have that you can easily find out this delta T and remember beyond 1 metre depth the diagonal variation due to solar heating ceases, right. Hence 1 meter depth is considered where solar heating related heat transfer is involved in application.

So the information which you are getting in terms of emitted energy or temperature I told you they are the volumetric property right. So that will give you the information till this 1 meter depth, beyond that it ceases.

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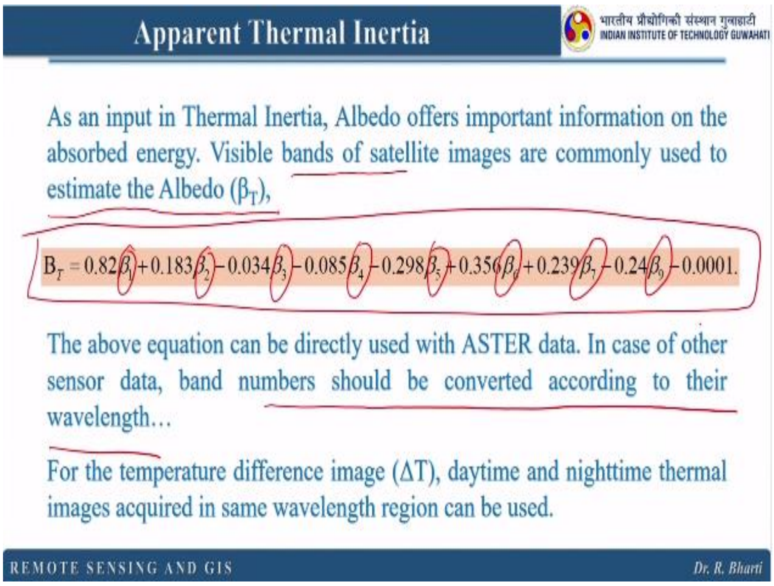

So in apparent thermal inertia as an input in thermal inertia albedo offers important information on the absorbed energy, visible bands of satellite images are commonly used to estimate the albedo, right and here in case of ASTER data you can straight away use this particular equation, right.

The above equation can be directly used with ASTER data in case of other sensor data band number should be converted according to their wavelength or band designation, right. So remember for ASTER you can directly use this formula and where this is band numbers, right, band 1, band 2, band 3, band 4, band 5, band 6, band 7, band 9, right. For the temperature difference image, delta T, daytime and night time thermal images acquired in same wavelength region can be used.

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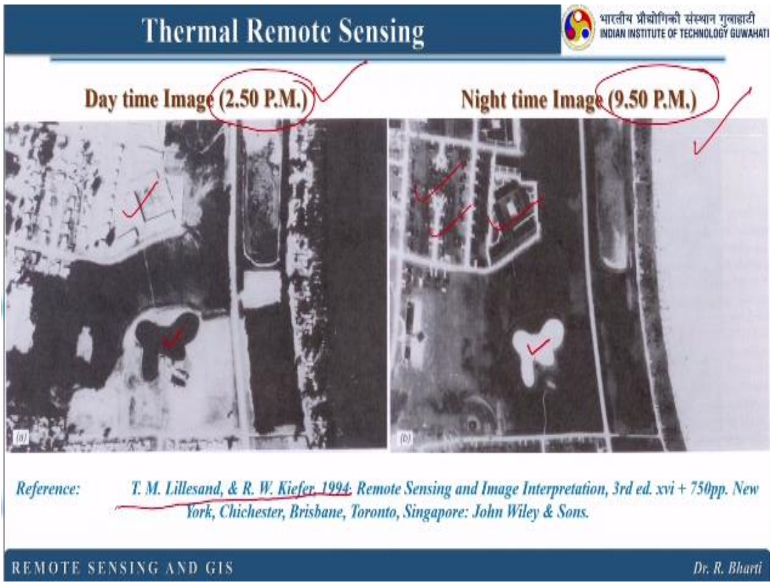

So let us see some example how this daytime and night-time images are coming up. So let us se this daytime which is at 2:50 p.m. right, and this is 9:50 p.m. So we assume that this time the temperature is maximum on the surface and this is night time when we expect that it has cooled down. So here you can see this is some kind of water body and it is having contrast.

All the other material like buildings they are also very clearly evident that they are having temperature difference during the diurnal cycle, right. So this was taken from this particular book.

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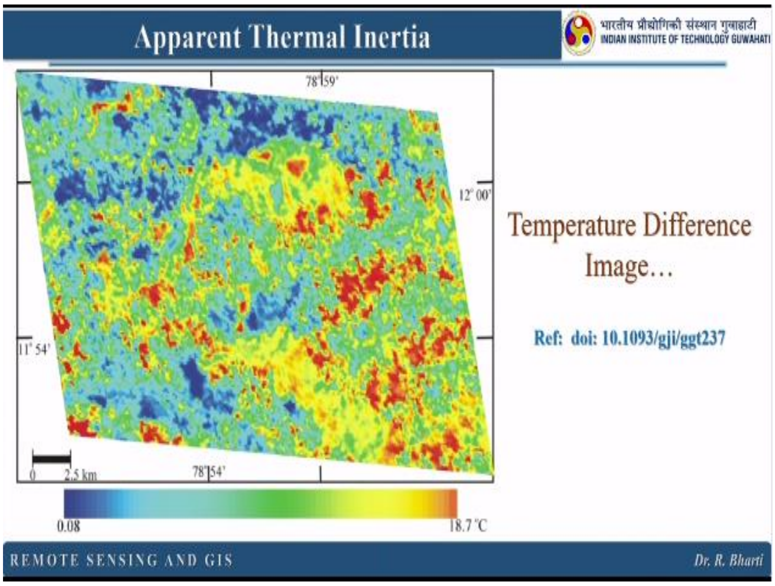

So the temperature difference image when you are using ASTER data it will look like this depending upon your area and the material, but this is one example from this particular paper.

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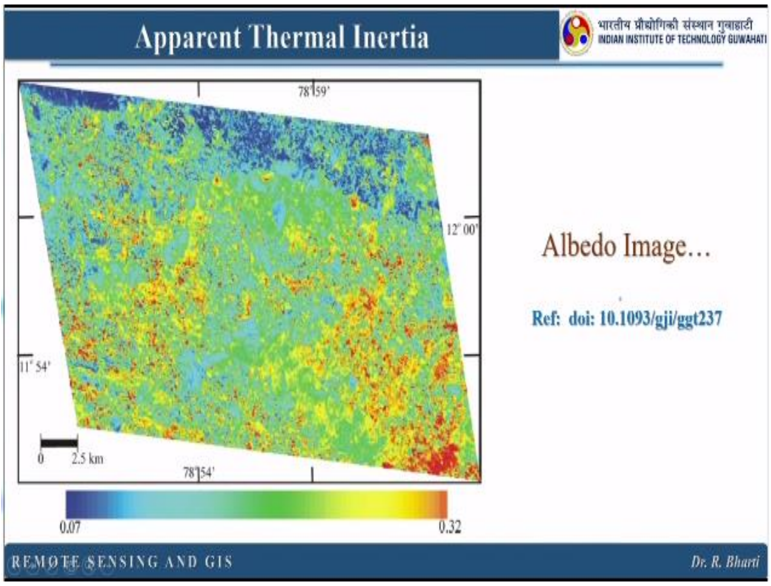

And this is the albedo image, so now you can see this is when we are using temperature data, So temperature data of ASTER is having 90 meter resolution, whereas albedo has been calculated using the 0.4 to 2.5 micrometre wavelength bands. So here your resolution is 30 metre. So this difference you can easily see here. So this is having good spatial resolution compared to your thermal data, right.

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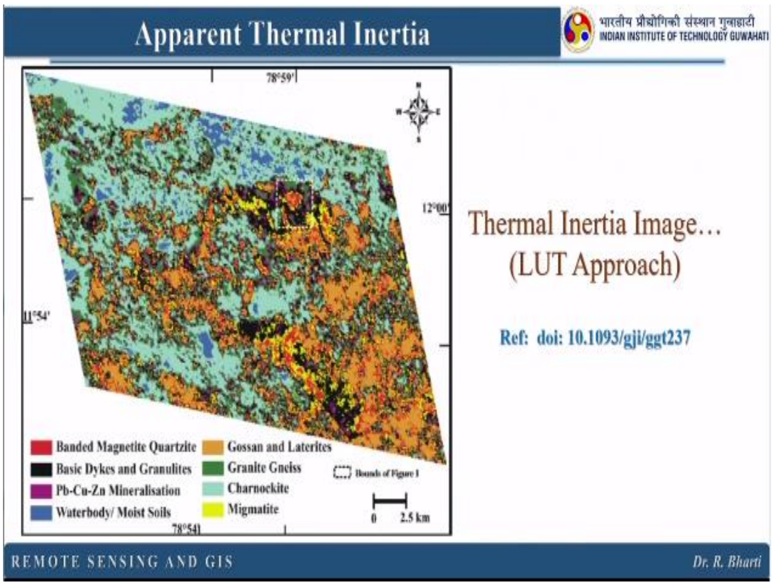

Once you have that if you use lookup table approach this is the output, this is apparent thermal inertia and here all these colours indicate this rocks and minerals, right. Here this is in case of ATIM approach and you can see the symbols and you can correlate with this legend. So now let us see where we can apply this thermal remote sensing.

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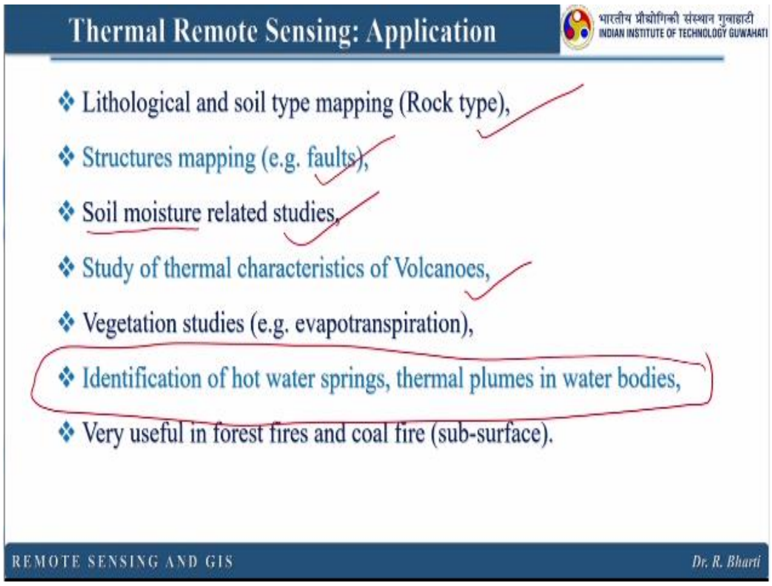

So lithological and soil type mapping, so I have already shown you one example with respect to thermal inertia, then structural mapping you can easily find out the faults and lineaments, then soil moisture related studies because you will have soil moisture that means temperature will be different. Then study of thermal characteristics of volcanoes, so you can estimate what is the temperature of the volcano because if you see the classification of volcano based on the temperature and other parameters their names are different, right.

Vegetation studies, evapotranspiration you can estimate, then identification of hot water spring, thermal plumes in water bodies. So these are very important because this you cannot identify with any other wavelength bands and very useful in forest fire and coal fire that is subsurface and one more thing which is not listed here that is identification of palaeo channels.

So palaeo channels are hidden river channels which were active once upon a time. Now they are inactive and covered with the sand or maybe soil. So that you can easily find out using this thermal remote sensing data, right. Here I will show you how we can calculate the spectral emissivity when you are using a thermal imager and which is actually ground based instrument.

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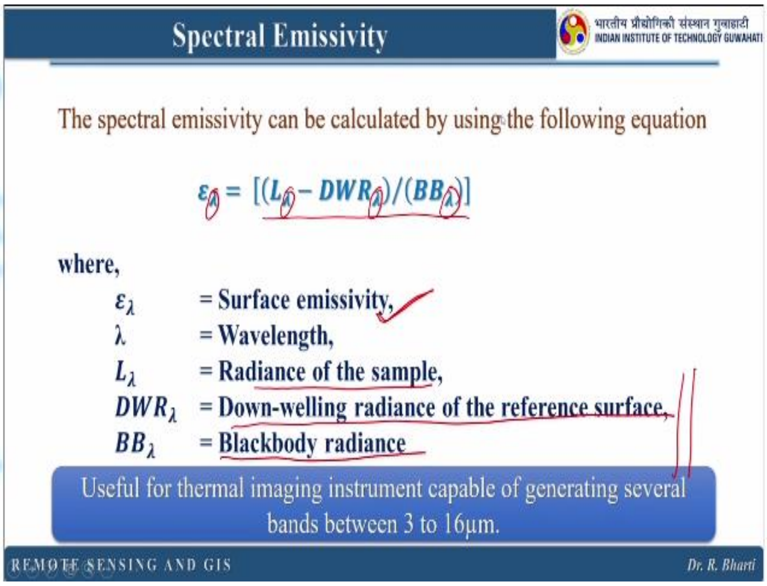

So the spectral emissivity can be calculated by using the following equation and here this is the variables. So here the surface emissivity can be calculated when you are having radiance of the sample, down-welling radiance of the reference surface and blackbody radiance. So when you are having all this information you can easily find out spectral emissivity, why spectral? Because everywhere we are using this lambda.

So I hope you have enjoyed this thermal remote sensing portion and you can start your research by exploring this technology.

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Now let us see microwave remote sensing.

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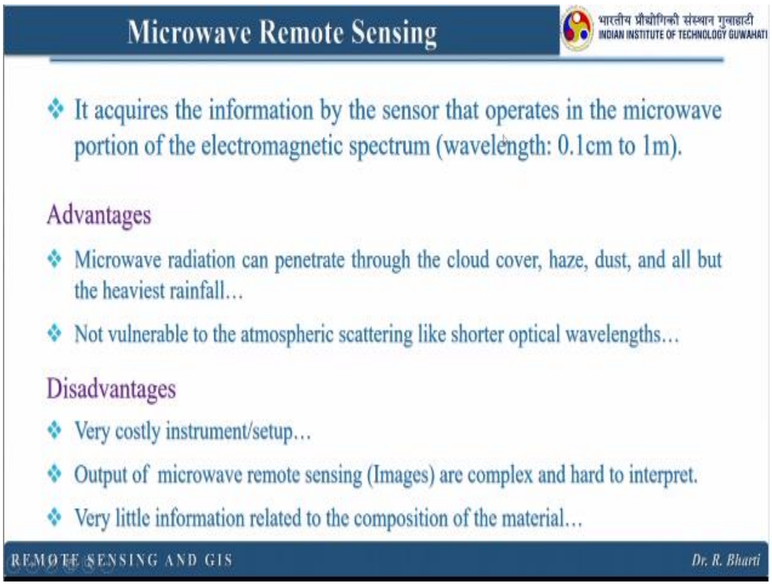

So let us understand what exactly we are doing in microwave remote sensing. So it acquires the information by the sensor that operates in the microwave portion of the electromagnetic spectrum where wavelength is 0.1 centimetre to 1 metre, right, and the advantage of microwave remote sensing is it can penetrate through the cloud cover, haze, dust and all but the heaviest rainfall, right.

And not vulnerable to the atmospheric scattering like shorter optical wavelengths. So here it is very important that you can do all weather condition mapping or the image generation and this is free from the atmospheric scattering because we have already seen in longer wavelength region scattering is minimum or negligible, right, but the disadvantages are like it is very costly and the output of microwave remote sensing are complex and hard to interpret.

So it is not easy as your optical data, so in optical data you have only DN number, but here it will be in complex form A + IV. So let us see one by one and the next point is very little information related to composition of the material, because here this will give you more structural information, right, because this is based on the backscattered energy and in the longer wavelength region and the wavelength region is 0.1 centimetre to 1 meter.

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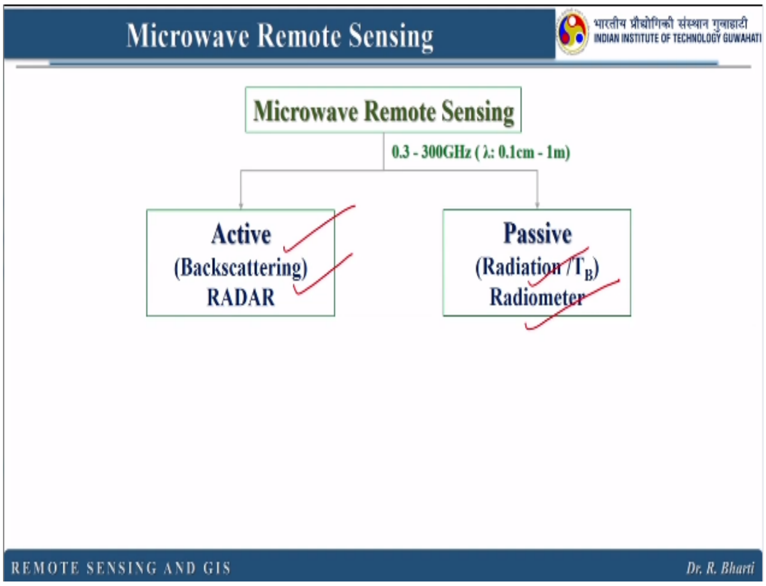

Here also we have 2 types of sensing. First one is active sensing and another one is passive sensing. So in active we call it backscattering RADAR, in passive it is radiation or radiometre can be used.

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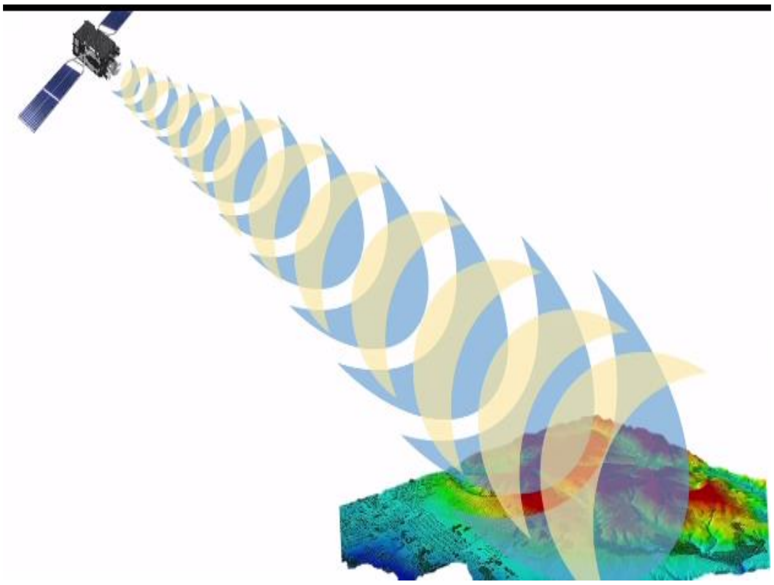

So this is one example, where I will demonstrate how we are using this active remote sensing and how we are illuminating the surface and how the pulses have been sent and received, right. So let us see here this is my microwave sensor which is illuminating this particular surface and the same time once it reaches to ground and it interact with the object then immediately it will back scatter.

So depending upon the object location the object will back scatter the energy before the another objects, right.

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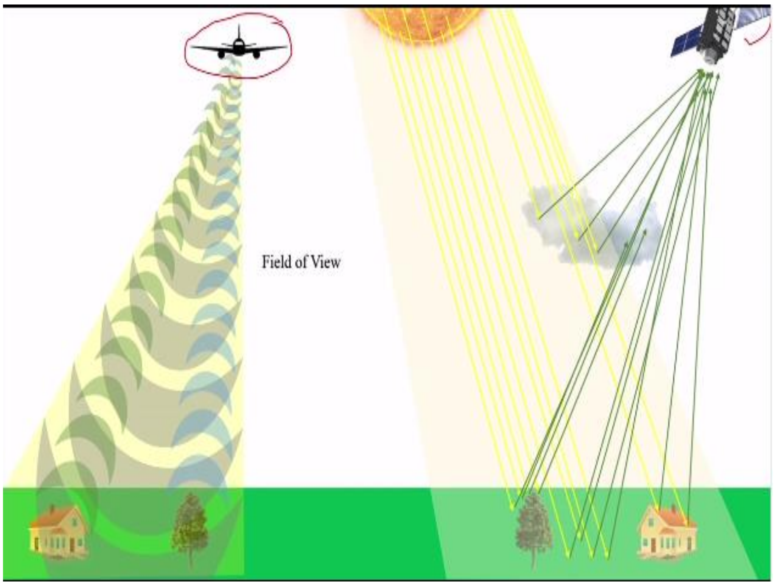

Now here this is another example where your active and passive sensing will be very clear. Now this is my field of view. Let us assume this particular flight is carrying the microwave radiometer and which is actually active, right, so in active what will happen, we will illuminate the surface, here the object which is near to this and which receives this pulses immediately they will backscattered in the first.

So you can see the house is doing this later whereas this tree has received in the beginning. Now in case of passive one, so in passive Sun is our source and here this is our satellite, right. And Sun is illuminating our surface and the backscattered energy will be received by our sensor, right.

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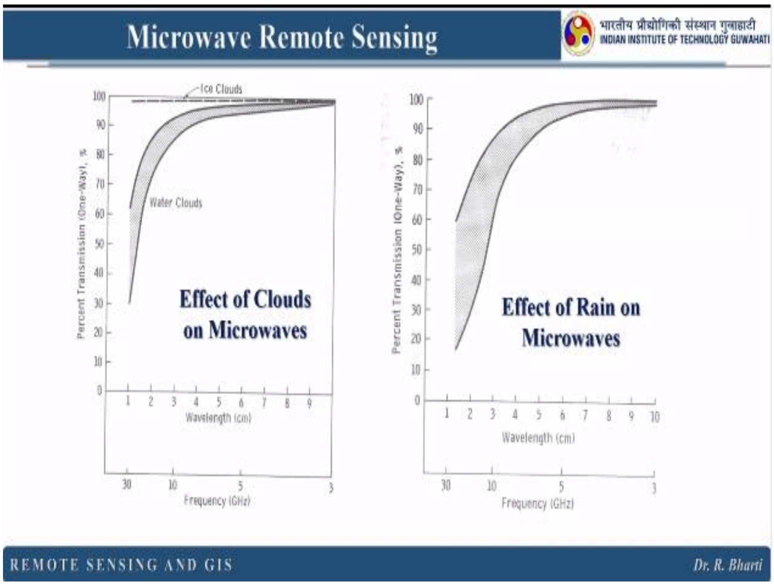

So let us see why this microwave energy is used in many application. So first of all is effect of clouds on microwave is very minimum. So here you can see this curve, this is the percent transmission and this is the frequency or you can see this wavelength, right. So as we are increasing the wavelength what is happening here, the transmission is maximum, here you can see.

The same time the effect of rain on microwave as we are increasing the wavelength the effect of rain is very less, right. This is again percent transmission.

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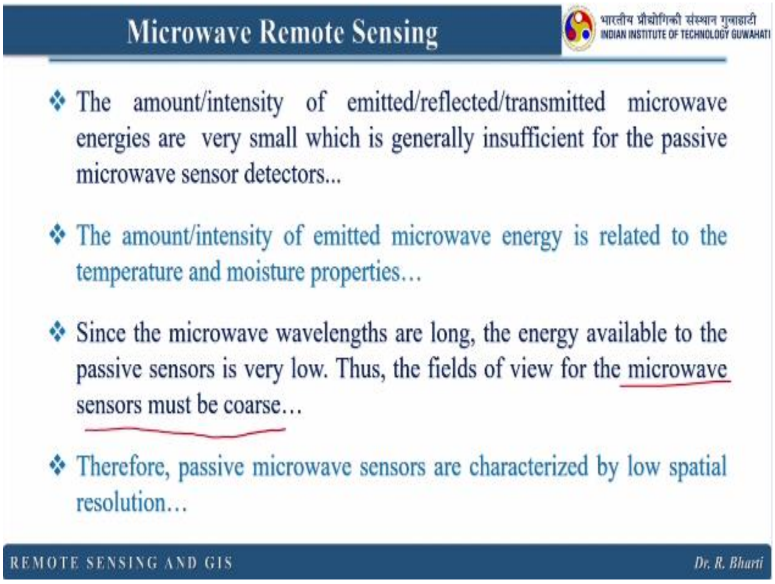

The amount or intensity of emitted, reflected or transmitted microwave energies are very small which is generally insufficient for microwave passive sensor detector. So the amount or intensity of emitted microwave energy is related to the temperature and moisture property of the target. Since the microwave wavelengths are long the energy available to passive sensor is very low.

Thus the field of view for the microwave sensor must be coarse that is the reason we are having coarse resolution in even thermal remote sensing. Now in microwave remote sensing again when we are doing this passage microwave remote sensing, again the pixel size will be larger, right. So that indicates low spatial resolution. Therefore, passive microwave sensors are characterized by low spatial resolution.

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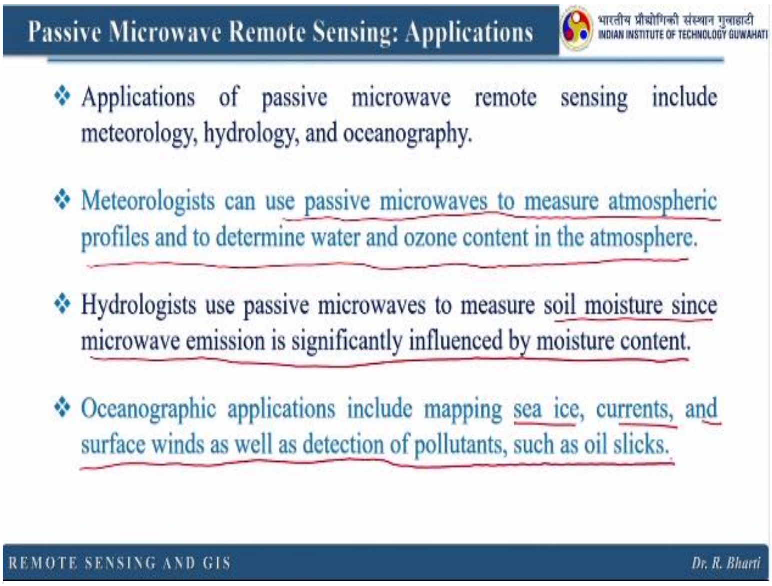

Application of passive microwave remote sensing includes meteorology, hydrology and oceanography, where you do not need that high spatial resolution, the meteorologist can use passive microwave to measure atmospheric profile and to determine water and ozone content in the atmosphere. Hydrologist may use this passive microwave to measure soil moisture since microwave emission is significantly influenced by moisture content.

Oceanographic application include mapping, sea ice, currents and surface wind as well as detection of pollutants such as oil slicks in the ocean, right.

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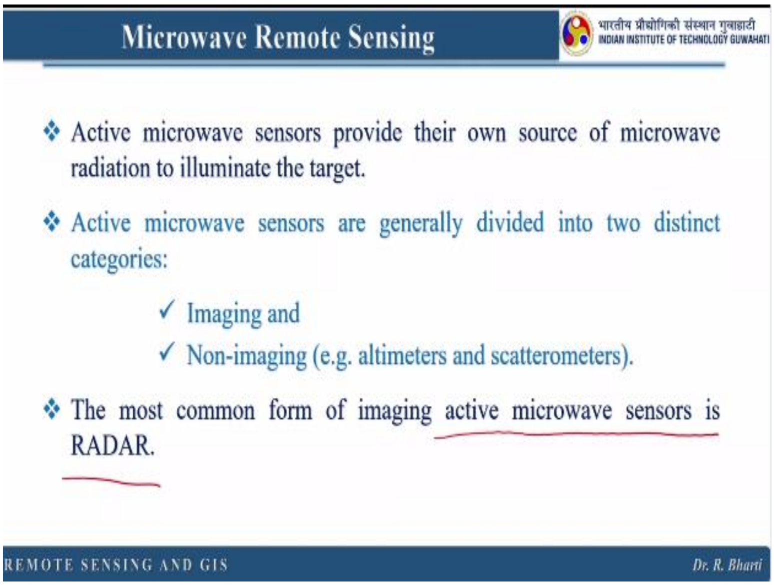

In case of active microwave they have their own source of energy and they illuminate the target with microwave radiation and active microwave sensors are generally divided into 2 distinct categories. First one is imaging and another one is non-imaging. We have also seen this in optical remote sensing. So here we can generate either image or we can generate values in those wavelengths, right.

And these wavelengths will be essentially 0.1 centimetre to 1 metre and this will be the range and depending upon your instrument, the values will be generated, right. The most common form of imaging active microwave sensor is RADAR. So I hope all of you have heard this word RADAR, right.

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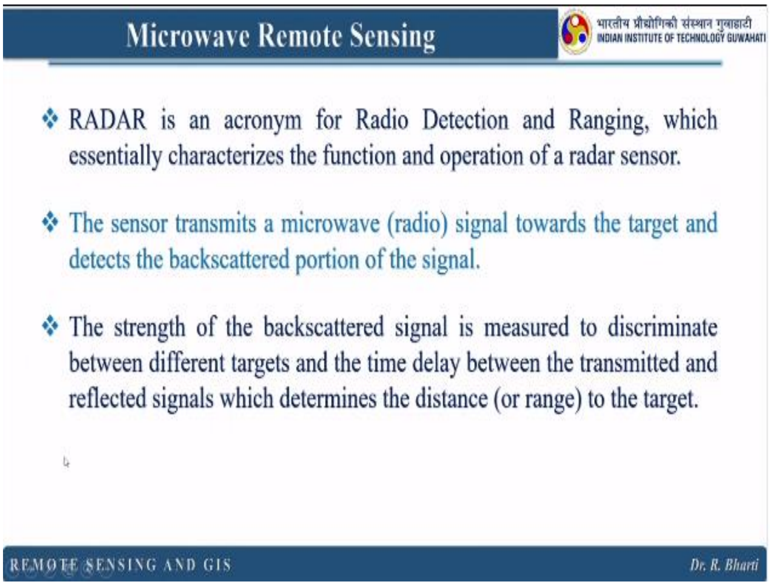

So what exactly RADAR means, RADAR is an acronym for radio detection and ranging which essentially characterize the function and operation of a RADAR sensor. The sensor transmits a microwave signal towards the target and detects the backscattered portion of the signal, the strength of the backscattered signal is measured to discriminate between different targets and the time delay between the transmitted and reflected signals which determines the distance to the target.

So that will define whether this material is situated here, here, here, here, here, depending upon their time, right. So depending upon their location they may receive the energy or the illumination in the first or maybe second and third and the depending upon the time delay between the transmitted and reflected signals which determines the distance to the target. So that is the advantage when we are using this microwave remote sensing.

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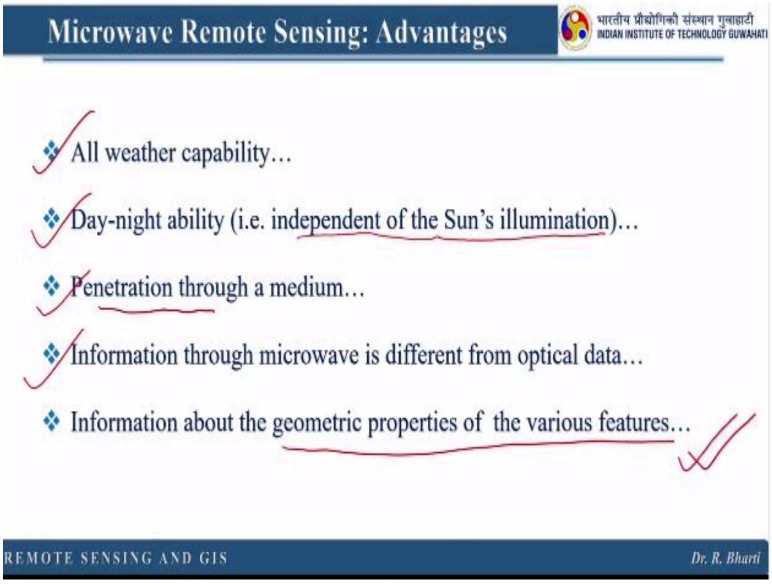

So it has few advantages which are very distinct and you cannot avoid this when you are having such problems. So let us see what are those advantages. So first one is all weather capability, second one is day and night ability. So independent of the Sun's illumination when you are engaged in active microwave remote sensing image generation, right. Penetration through a medium.

So it can penetrate your target, now we will see some example and then information through microwave is different from optical data, how it is different? because this is backscattered and the wavelength is longer. So your penetration will be there, right and then that indicates you will have more structural information rather than having the compositional information. Information about the geometric properties of various feature that is the positive or advantage of this microwave remote sensing.

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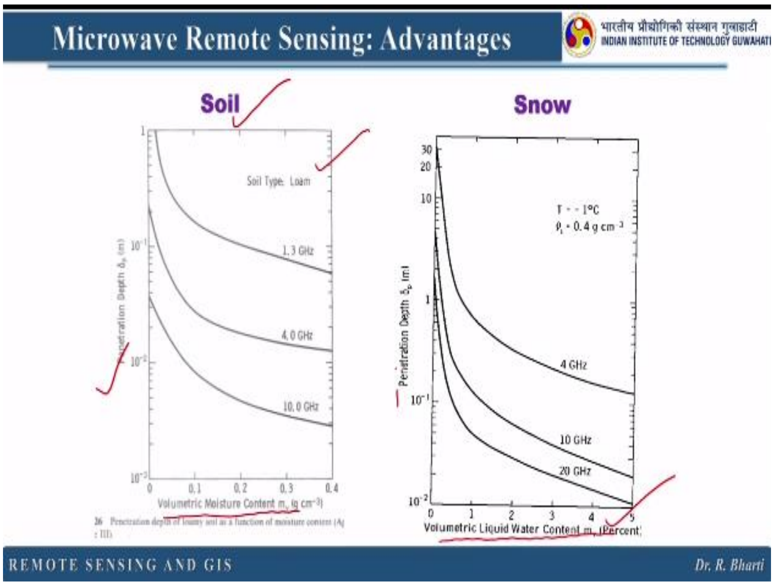

Here you can see the penetration depth for soil, this is the volumetric moisture content, so when you are having more moisture content your penetration will be less or more that you can see from here. In case of snow also as you are increasing the volumetric liquid water content then percentage depth will change, right.

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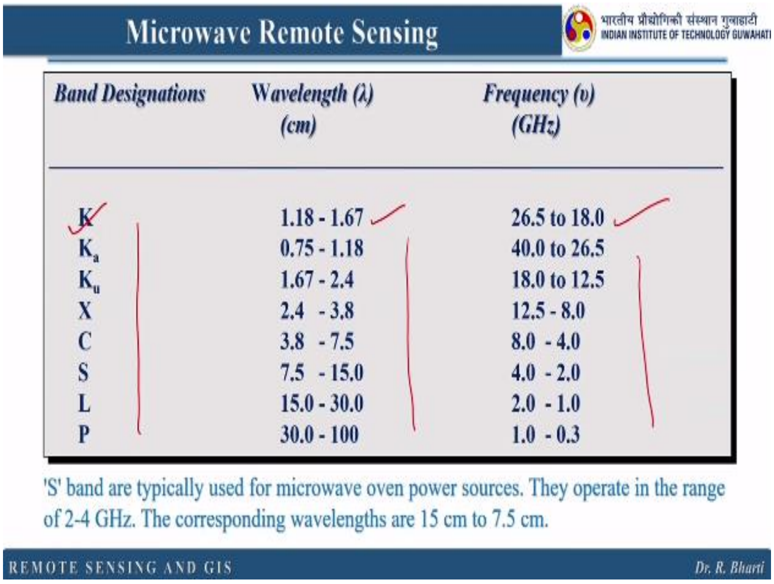

Band Designations	*Wavelength (λ) (cm)*	*Frequency (υ) (GHz)*
K	1.18 - 1.67	26.5 to 18.0
K_a	0.75 - 1.18	40.0 to 26.5
K_u	1.67 - 2.4	18.0 to 12.5
X	2.4 - 3.8	12.5 - 8.0
C	3.8 - 7.5	8.0 - 4.0
S	7.5 - 15.0	4.0 - 2.0
L	15.0 - 30.0	2.0 - 1.0
P	30.0 - 100	1.0 - 0.3

And like in optical remote sensing we had visible band, then everywhere we divided this wavelengths in bandwidth as per the sensor configuration, but here in microwave remote sensing we have assigned some designated number or alphabet for designated wavelength range or the frequency. So for K band, this is the wavelength, this is the frequency. So this you can just go through, right.

And the most common example of this microwave is you can see microwave in your kitchen, right. So S bands are typically used for microwave oven powered sources, right. They operate in the range of 2-4 gigahertz, the corresponding wavelengths are 15 centimetre to 7.5 centimetre. So here now you have to understand we are using this microwave technology in our day to day life, right.

But when we are talking about the space based measurement or airborne measurement or the field measurement in order to identify or study the structural or geometric properties of the study area then application is different, approach will be different, right. So today I will end my lecture here and in the next lecture I will continue this microwave remote sensing. Thank you.