Remote Sensing: Principles and Applications
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Lecture-39
Thermal Infrared Remote Sensing-Part 5

Hello everyone, welcome to the next lecture in the course remote sensing principles and applications. We are discussing the topic of thermal infrared remote sensing, and in the last lecture we discussed in detail about the procedure to estimate or to retrieve land surface temperature from sensors with single thermal channel. And our major concentration was retrieval of LST from Landsat series of satellites.

So, just as a recap, we derived LST by first calculating radiance from DN. we have already seen how to do it in the previous lectures. From that radiance we have to do atmospheric correction using an online atmosphere correction tool which will help us to correct for the atmospheric effects. Apart from it we need to estimate surface emissivity in the spectral channel corresponding to Landsat sensors. Once we do this, we substitute the terms in the general radiative transfer equation and then we can retrieve LST by inverting the Planck's function. As a brief summary we will just look at the slide.

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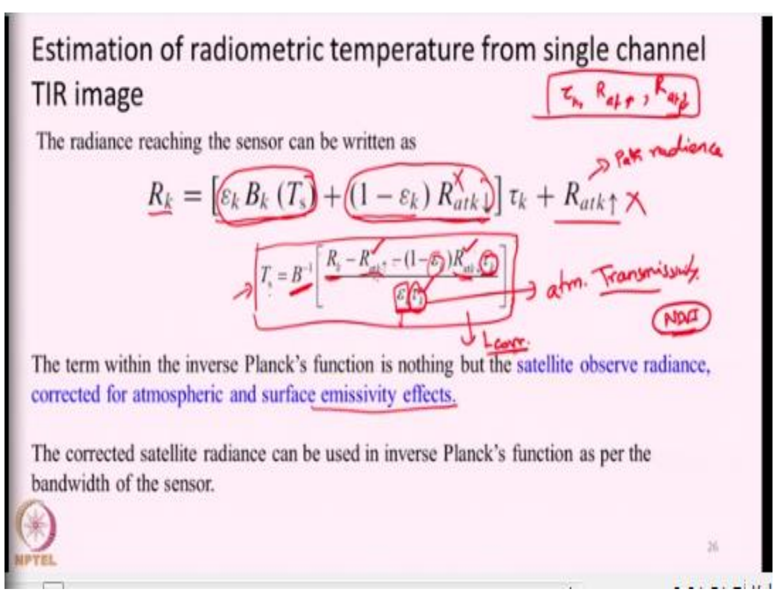

So, here in this particular slide this is the equation we used for the retrieval of LST. So, the inverse Planck's function of the radiance received at the sensor after being corrected for atmospheric effect and surface emissivity effect.

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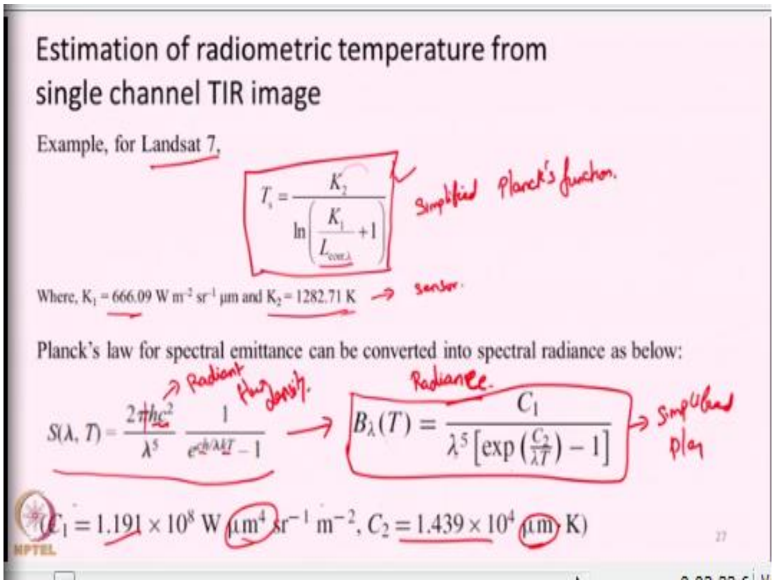

And atmospheric correction tool we have already seen. And if we substitute all the values, if we correct that satellite observed radiance and substitute in the simplified Planck's function. This is specific for Landsat sensor, this constants K 1 and K 2, these will vary for sensor to sensor. So, this equation is specifically for Landsat satellite with the corresponding K values for Landsat 7.

Similarly for other satellites such as Landsat 5 or Landsat 8, we have corresponding equations. So, once we have such equation if we substitute the corrected radiance we will get this. So, this method is known as retrieval of LST using radiative transfer equation. Actually given current circumstances, even without access to any sophisticated models, we will be able to retrieve land surface temperature using this method. Because the atmospheric correction tool is available to us, emissivity can be calculate using NDVI, and substituting in this equation we can retrieve land surface temperature.

One more popular way of retrieval of land surface temperature from Landsat series of satellites is what is known as single channel method, that method we are not going to see in detail here. But rather than doing the atmospheric correction separately for each and every component it aims to simplify this, like they will take only the primary components which will cause change in the sensor observed radiance, most likely water vapour or CO_2 concentration. And they will try to relate the radiance with respect to land surface temperature. If we know the water vapour content and other parameters we can just substitute them in those equations, retrieve land surface temperature. So, that method we are not going to see because for using that method, we may have to access some atmospheric data at the time of satellite overpass or use some sort of atmospheric models, retrieve data from such models and substitute it. But the single channel algorithm or single channel method is one of the popular ways in which LST can be retrieved.

This method is for sensors with one thermal channel that is why the name itself is single channel method. For sensors with 2 or more than 2 thermal channels like even the recent Landsat 8 has 2 thermal channels within it band 10 and band 11. Unfortunately we cannot use band 11 until now because of some artifacts but let us assume that we have 2 thermal sensors available to us in the same sensor, say MODIS has 2 thermal channels. In that case we can resort to a method known as the split window technique or the split window method.

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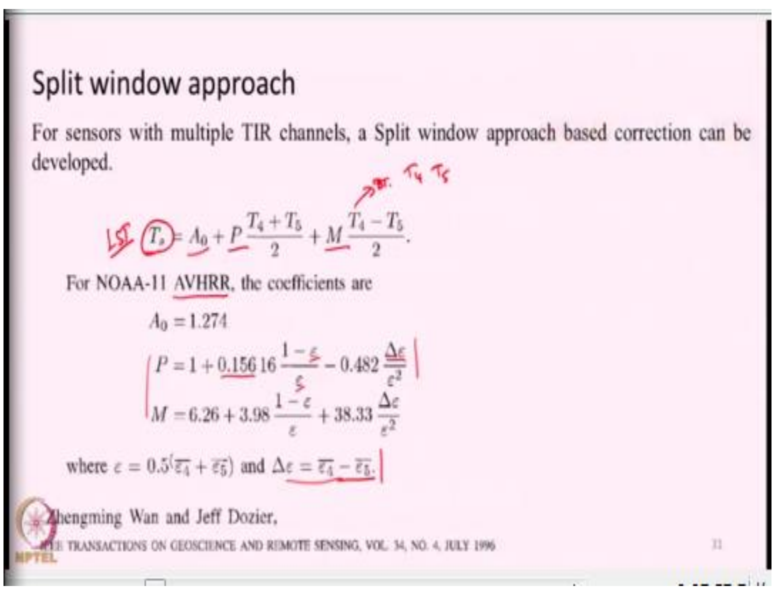

So, in the split window method the general assumption is the differential atmospheric absorption. That is 2 thermal channels will be selected in a contiguous manner. Contiguous manner means say 10.4 to 11.5, 11.5 to 12.5 the 2 thermal channels in the sensors most likely will be closely spaced with each other. So, assuming atmospheric absorption will not vary much within the bands and emissivity will not vary within these bands people will develop equations relating the radiance with land surface temperature or the brightness temperature with land surface temperature. So, such equations once developed people will use high performance computers and atmospheric tools to refine it to a greater extent.

For example one equation is given in this slide; this equation is for a sensor called AVHRR which had like 2 bands. If you see this equation, the T_s is the land surface temperature, A_0, P and M are coefficient. And ε is the emissivity, $\Delta\varepsilon$ is the difference in emissivity and so on. And T_4, T_5 are brightness temperature observed in the corresponding bands 4 and 5 in AVHRR. So, this equation basically relates the brightness temperature observed from that particular sensor with the actual land surface temperature. And brightness temperature is just sensor observed radiance converted into blackbody temperature.

So, that will vary with respect to band, atmospheric artifacts and everything**.** But the final actual land surface temperature should not vary in whatever band we look, that is the physical concept. So, this brightness temperature is now related to land surface temperature using these coefficients. So, with this particular equation as soon as we have surface emissivity we can just substitute them, calculate these coefficients and get land surface temperature. This sort of equations relating radiance to LST or brightness temperature to LST has been developed based on lot of assumptions behind it and lot of processing that has happened even before the sensor is launched. People will simulate the radiance using a radiative transfer models with lot of atmospheric conditions. They will try to see, if this is atmospheric condition, if this is the surface condition, what is the radiance there? All possible combinations will be tried out and finally such equations will be derived. So, once such equation is derived, as a end user we can use it simply and get the data. Or most likely when such equations are derived, LST product itself will be generated by the satellite managers may be like for MODIS, NASA does it. Even in India, for the INSAT 3D sensor which is a geostationary satellite, the LST product is available from ISRO MOSDAC website, we can download.

So, such sort of products are available when this split window methods are established. But as end users or at the scope of this particular course we are not going to go deeper into how such equations are derived, what are the physical concepts behind. But I just wanted to introduce you for sensors with more than one thermal channel, such methods exist which enables the agency acquiring the data to process it into LST and give the users.

So, now we can directly go and download LST data from MODIS, we can directly go to MOSDAC website and download LST data from INSAT 3D satellite. These things are possible, we need not sit and retrieve LST because of these sorts of methods. But for Landsat satellites till now we only have to retrieve LST. And one simple method I have already explained to you which will be useful to you in several applications and research activities.

The next topic we are going to see is what is known as the thermal properties of terrain and how it will influence the observation of land surface temperature. Any material on earth surface will have certain characteristics with respect to heat energy or heat content.

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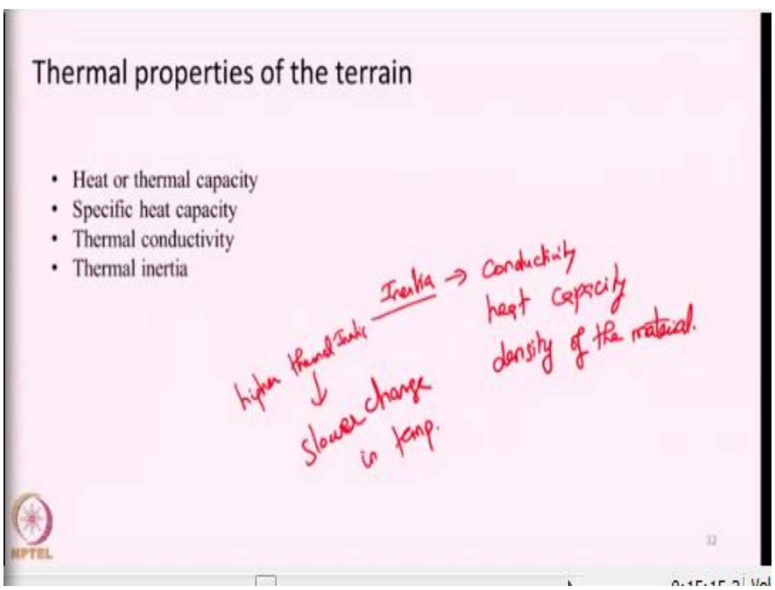

The first thing is heat capacity or thermal capacity. Let us say there is a material, so how much heat energy we should supply to that material in order to raise the temperature by 1 Kelvin or 1 degree Celsius. So, that amount of heat energy is the heat capacity of the material. If the material is able to withstand lot of heat energy its heat capacity will be pretty high.

Some materials will quickly raise temperature even with a small amount of heating. Maybe a very simple example is, in a gas stove, heat water in one burner and heat milk in the other one. And if we measure the rate of change of temperature between them, those 2 liquids will behave differently because of the difference in heat capacity of that particular liquids.

Very similarly all the materials will have its own heat capacity. And since materials can vary in mass, in order to normalize it, there comes the specific heat capacity. So, specific heat capacity is the amount of heat required to raise the temperature of an object by 1 Kelvin or temperature of an object with 1 kg mass by 1 Kelvin. So, now we are talking about how much heat energy we should supply to raise the temperature of 1 kilogram mass of the material by 1 Kelvin.

So, the material can be any weight 10 kilograms, 20 kilograms whatever, but how much heat we should provide for 1 kilogram, that is specific heat capacity. Then the other important property is thermal conductivity. Thermal conductivity is simply put, how fast heat will be conducted from one point to another point. Example let us take a metallic rod, if we heat one end of the metallic rod, quickly the heat will be transferred to the other end. And take water, put it in top of a gas stove, we supply heat at the bottom of the vessel, it will be transferred to the water column through convection. So, how fast the heat moves from one point to another point, but thermal conductivity is mostly dealing with solid, but I gave water as an example**.** So, conduction process happens in solid basically.

And all these things combined together bring us to a more important property that we will be interested in thermal remote sensing and that property is thermal inertia. So, what exactly inertia is, we might have studied in our school physics that inertia is the inability of a body to change its state of motion or state of rest, when some forces exerted on it. When an object is moving, it will resist coming to a certain stop. Or if some material is at rest some force should be applied, so that it starts moving. So, whatever be the object they will have some sort of inertia to resist this change of state. Similarly thermal inertia means the ability or the resistance offered by a body for change in temperature**.** So, when you are trying to heat up some object continuously, if the object has very high thermal inertia it will heat up very slowly, the temperature will raise pretty slowly.

Some objects will heat up very fast, it has low thermal inertia. So, thermal inertia deals with the resistance of an object to change in temperature. Higher thermal inertia means lower the change in temperature, lower thermal inertia means higher the change in temperature. So, this thermal inertia property depends on the specific heat capacity of an object, the conductivity of an object and also the density of an object (mass/volume=density).

So, the thermal inertia depends on this thermal conductivity, heat capacity and density of the material. All these things will influence the inertia and higher the thermal inertia will lead to slower change in temperature of the object. But why do we need this property? Why we should worry about this thermal inertia? In remote sensing we are sensing temperature, for some applications just sensing temperature at one time maybe enough. But for some other applications like meteorological applications and all we may need to get the diurnal variation of land surface temperature. What exactly diurnal variation of land surface temperature is? Diurnal variation means variation of a certain property in a given day or with respect to time, within a time span of one day, that is in 24 hours how the temperature changes. Actually this depends on surface property and this kind of diurnal change will help us to infer some details about the earth surface maybe for energy balance studies, maybe even in olden days people were using this concept for geological mapping and all those things. So, let us look at this thermal inertia property and this diurnal variation of temperature about few objects.

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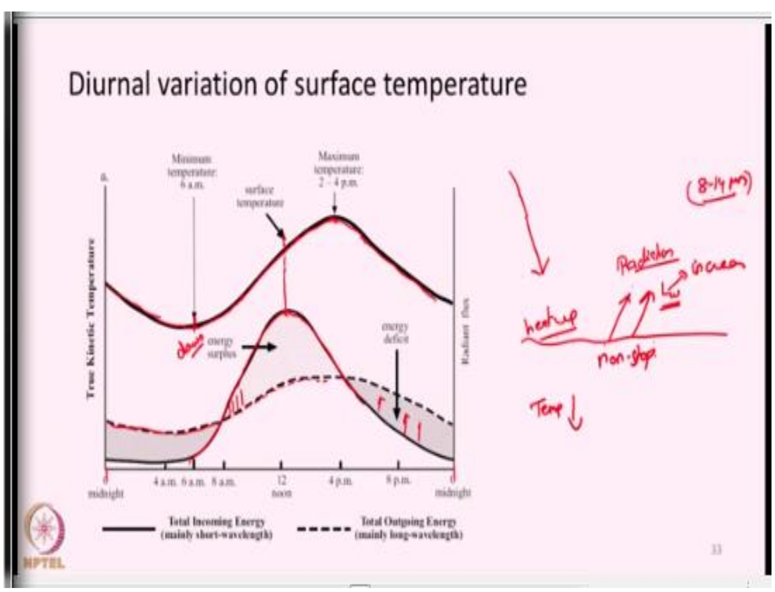

So, this particular slide gives us the diurnal variation of surface temperature. This is from midnight of one day to midnight of next day. Let us take any part of the earth surface, earth will be continuously emitting energy, this is kind of a non-stop thing. As long as earth has some internal energy, this radiation will be keep going on or will be keep on going up towards the atmosphere.

These are the long wave radiation, what we are currently using for our thermal infrared studies**.** Right now we are talking about 8 to 14 micrometers only, but this radiation will be spanning across from 3 to microwave range**.** So, this radiation will be taking the energy away from the earth surface. So, when energy is being lost, what will happen? The temperature of the object will go down if no other source is provided.

So, during night time when the sun's energy is absent, earth will be keep on radiating and due to this continuous radiation the temperature will be slightly decreasing. So, this is the surface temperature curve, this will be decreasing because of continuous loss of energy. So, earth will reach some sort of minimum temperature just at dawn when the sun is about to rise**.**

So, when sun rises what will happen? Sun will provide the energy source. So, till dawn no energy is there from sun, after that solar energy will begin to come. When solar energy starts to come and fall on that surface the energy will add up to earth surface and this will heat up the earth surface thereby rising its temperature. The incoming energy is more than what the earth is radiating. As temperature rises more radiation will go, that is we have seen in Planck’s laws, increased temperature leads to increased radiation.

But still during noon time solar radiation will peak; energy will be at surplus. Because of this energy surplus, surface temperature will be continuously raising and at certain point in day time it will reach a maximum state and after noon time solar radiation will go down. But you can observe, there is a time lag between the energy peak and the maximum temperature. Because it needs some time for the earth to absorb this energy and increase its temperature. There is always a lag between peak energy, supply of peak energy and peak temperature. So, what essentially happens is, during day time this external heat energy from sun increases the temperature of earth surface features. Then afternoon again the solar radiation will begin to go down, slowly it will decrease and after sunset it will become zero. This cycle will happen continuously for all the objects and this is the basic concept of diurnal variation of surface temperature.

This incoming energy will change the temperature of all features on the earth surface. And different objects on the earth surface will behave differently to this additional energy, so that depends on thermal inertia of the objects**.** Now we will quickly see some diurnal temperature pattern curve, a typical patterns for few earth surface materials.

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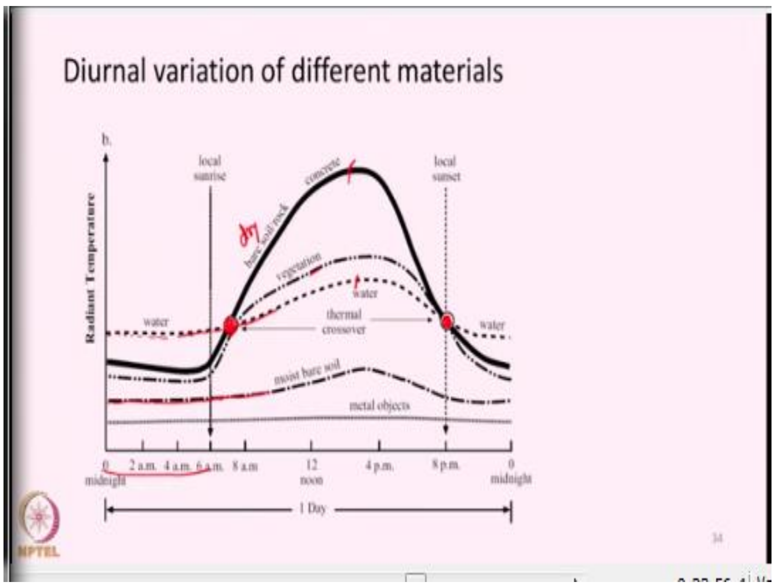

Say this is for bare soil or rock or concrete, this dark black line, this dotted line is for vegetation. This uniform dotted line is for water. It means different features behave differently to the solar radiation or change in temperature. Water has very high thermal inertia, it actually resist the tendency to change its temperature. If you take the difference between the maximum temperature in a day and minimum temperature in a day, it will be quite less. On the other hand for bare soil or dry soil, they will not have very high thermal inertia and they will change temperature pretty quickly. They will heat up and the temperature will rise up fast, similarly during night time they will cool down fast. So, during night water has higher temperature, so it will appear warmer than vegetation or bare soil. But during day time bare soil will have higher temperature, water will have lower temperature. So, these things play a major role when we do thermal remote sensing and what we observe.

So, during midnight and pre dawn time, if we take thermal infrared measurements, water bodies may appear warmer than typical land surface. On the other hand during day time water bodies will appear cooler than buildings or bare surface. This is due to the variation in thermal properties**.** So, higher thermal inertia, lower will be the change in temperature.

There will be 2 points where temperature of all the materials will coincide or they will intersect. Which means at certain time point mostly very close to early morning sunrise time and similarly close to sunset time, the temperature of various features will be almost the same. That is because at that point we have a thermal crossover, thermal crossover means sun has already come and has just started to shine. So, rocks and other materials are beginning to rise in temperature, water is still resisting. So, that certain time points all temperature of various features will be more or less the same. Same thing will happen in the evening after sunset, bare soil will lose temperature fast, water will be still maintaining the temperature. So, bare soil's temperature will come down, waters temperature will come down slightly and at some point they will meet. This kind of similar crossovers will happen and we are not supposed to do thermal infrared remote sensing at that particular time interval. Because our interest is to map the temperature of various features and these things will influence how we use it for various applications.

Observing or making thermal infrared observations at this particular point of time will not help us to get information about the temperature of the land surface, we will get uniform temperature. So, normally at this thermal crossover point, it is not suggested or not recommended to make thermal infrared measurements, if our aim is to measure the temperature of various objects of surface**.**

While we discuss briefly about the applications, I will tell you about surface energy balance equation, that is how we map evapotranspiration, water loss to the atmosphere. That basically depends on this temperature differences in the surface. So, if we take thermal infrared observations during this thermal crossover time, we will not get much information about it. Similarly for urban heat island studies, it may not be of much use.

So, before we conclude this particular topic I like to briefly introduce you about the directional anisotropy effects that exist in thermal infrared measurements. We have seen directional anisotropy effects in optical remote sensing, visible and NIR bands. Directional anisotropy means basically objects will look different when we look at from different, different points in space, that is the bi directional reflectance distribution function BRDF, all these concepts we have seen before. Even in thermal remote sensing, when we observe temperature, this kind of directional anisotropy will come in.

Because the first major reason is, emissivity is directional, most of the earth surface features will emit differently in different directions, this is a primary reason. And also the application of heat to surface features may be different from different directions.

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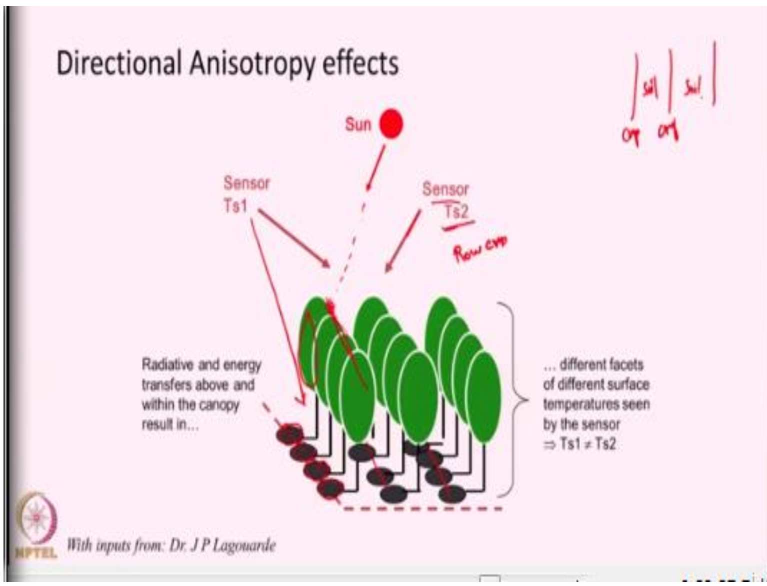

So, sun is here, this is a row crop. So, one line of crop and this will be soil, another line of crop, another line of soil. Let us say one sensor is looking from this direction and another sensor is looking from this direction. There will be a thermal shadow here, thermal shadow means this particular portion on the soil surface will not receive direct solar radiation, all the solar radiation will be blocked by this canopy. Here this part will not receive much radiation, will remain cool itself, like temperature will not raise a lot.

So, same thing will happen to all the soils in between. Say some sensor is observing from the same side as where the sun is. So, this sensor will most likely see the sunlit portion of the canopy which is already experiencing direct sunlight. This will make this portion appear warmer, the canopy.

Similarly let us say some other sensor is looking from here, this particular direction. If it is seeing the soil part it may observe a mix of cool soil and shaded portion of this canopy. The other portion of canopy is sunlit; this portion is shaded because of solar radiation. So, this sort of change in solar heating will influence which side of vegetation canopy is heated. If there is a tall tree standing, if solar radiation is from one side, then the tree will be heated up faster than the other side.

Similarly, the other side, the soil will be in shadow, the temperature will be lower. So, if a sensor observes at nadir, it will observe a mix of this warm side of tree, the shaded side of tree and this shaded soil. If a sensor observes from the same side as sun, it will observe the sunlit portion and warmer part of canopy. If the sensor observes from another side, it will observe the shadowed portion of canopy. All these things will change the temperature that we are sensing.

This complicates matters, if we want to measure temperature for certain applications and if we measure from different, different directions we may end up in measuring different temperatures. So, the directional anisotropy is not only a problem in optical remote sensing but it is also an issue in thermal infrared remote sensing. Especially when we need very high accuracy temperature measurements, the direction in which we look will influence the temperature readings.

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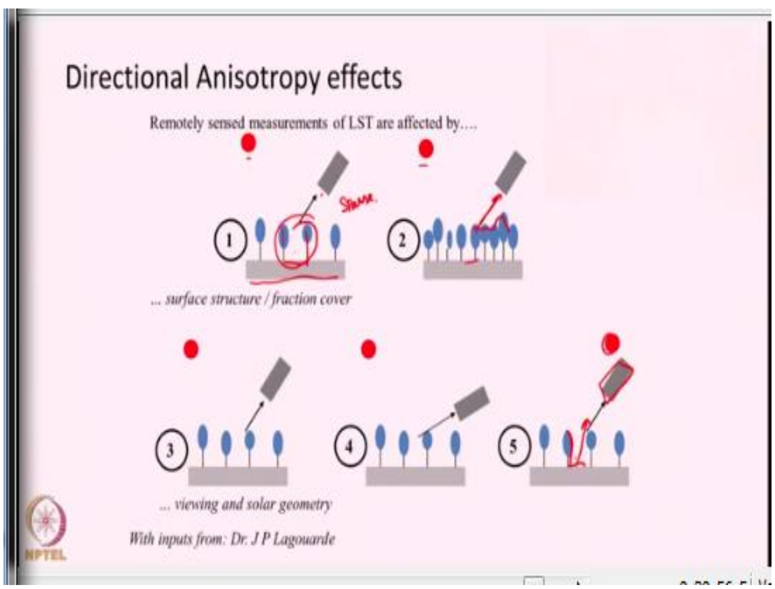

Example is given in this particular slide. Now in this first case we are sensing a sparse canopy. Sparse canopy means there is vegetations present with a large soil gap, then another vegetation stand is present. So, this sensor most likely will see a mix of vegetation and soil giving rise to a complex signal.

If the canopy is dense, in case of a dense forest, all the signals may be coming in only from the canopy itself, no signals from the ground may come in. So, the temperature what we measure may be different. Similarly let us say the sun is here and the sensor is also looking in the same direction, so the sensor is going to observe only the sunlit portion of this canopy and soil, which is going to give a increased temperature. So, all these things, whether the canopy is dense, whether the canopy is not dense, which side solar heating is happening will influence the temperature that we are measuring. So, these things we have to keep in mind when we need accurate temperature measurements for various applications. So, with this we conclude the topic of thermal infrared remote sensing.

In this particular topic we have seen what thermal infrared remote sensing is, what are all the basic theoretical concepts? The different definitions of temperature, emissivity, blackbody, how to retrieve land surface temperature from a single channel thermal sensors? Thermal inertia and its importance in thermal observations and also the directional anisotropy effects. All these concepts we have covered in the topic of thermal infrared remote sensing, with this we conclude this lecture and also this topic.

Thank you very much.