Remote Sensing: Principles and Applications
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Lecture-37
Thermal Infrared Remote Sensing-Part-3

Hello everyone, welcome to the next lecture in the topic thermal infrared remote sensing. Till last lecture we got introduced to the concepts such as what thermal infrared remote sensing is, what a black body is, what is meant by emissivity of an object and so on. And particularly in the last lecture we discussed various definitions of temperatures like thermodynamic temperature, that is the temperature we will measure with the thermometer in physical contact with the object of our interest. Then we saw what is known as a radiometric temperature. If we retrieve the temperature of an object by observing its radiance and knowing the emissivity of that object, then it will be known as radiometric temperature. This thermodynamic temperature and radiometric temperature will be the same for objects that are homogeneous and isothermal in nature.

We also define what is known as a brightness temperature. So, brightness temperature means say some radiance is reaching the satellite sensor, if we substitute that radiance in the inverse Planck's function to calculate the temperature then it is known as brightness temperature. So, the brightness temperature is essentially the temperature a black body will have in order to produce the same radiance that is being observed by the satellite sensor. If you compute brightness temperature then effectively we are not correcting that particular temperature for emissivity effect and atmospheric effect, because when the radiance is travelling towards the sensor in space the surface emissivity will play a major role in defining what energy is being emitted and also it will be further modified by the atmosphere while the radiation passes through it. So, these 2 effects will be there in a radiance that is reaching the sensor. While computing brightness temperature we simply take this radiance, substitute the value in inverse Planck's function and calculate a corresponding black body temperature. That is why I said brightness temperature means you can think it off as an uncorrected temperature or temperature that is not being corrected for surface emissivity and atmospheric effects.

So, today we are going to discuss the complex nature of TIR observations. TIR stands for thermal infrared. So, what is the complex nature of TIR observations? Let us take one particular land area, a sensor is looking over it, most naturally a sensor will not look only at one particular object, it will have a small area defined on the ground, we call it as the GIFOV, the ground projected instantaneous field of view.

The aerial extent which is seen by the sensor in one go or in a given instant of time, within the GIFOV can be more than one surface feature present, there can be a cropland, there can be trees, there can be buildings, water bodies and so on. So, all these things will have their own temperature, maybe a water body will be little cooler, a building may be warmer and so on.

So, each object within that will have its own temperature. Similarly each object will have its own thermal emissivity. So, these 2 things combined together will impact or will affect the total radiance that is reaching the sensor. So, the final radiance that is going to reach the sensor is effectively the average of all these things.

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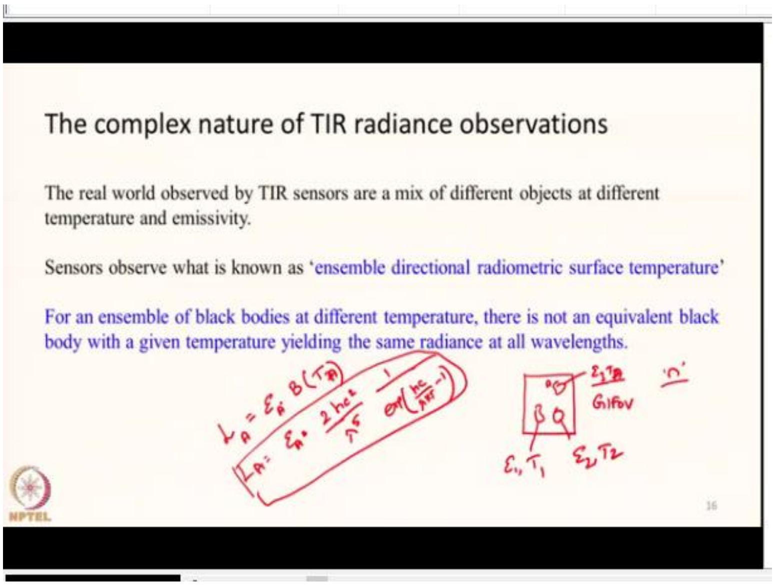

Let us say we have one GIFOV here. So, there can be many different objects present, each object will have its own emissivity, will have its own temperature. So, it will have its own radiance, say this is object A, the radiance L from object A is given by emissivity times the Planck's function of that particular temperature T_A.

$$L_A = \varepsilon_A B(T_A)$$

$$L_A = \varepsilon_A \frac{2hc^2}{\lambda^5} \frac{1}{\exp\left(\frac{hc}{\lambda KT} - 1\right)}$$

So, this will be the radiance from one particular object, say object A, similarly there can be n objects within a given GIFOV or within a single solid angle subtended by the sensor.

Each having its own radiance that can be computed using emissivity and Planck's function and each have its own small aerial extent fraction. Say a building might have occupied 2% of the GIFOV, a water body might have occupied 15% of the GIFOV. So based on how much area they are covering within the single look of the satellite, all the radiance will be averaged together. And the sensor will see a average radiance of all these features. So, within the GIFOV the sensor is not going to see any one particular object, it is going to see the radiance that is resulting due to the presence of many different features as each object will have its own radiance. Everything will be kind of averaging themselves to get recorded in a sensor.

Now as a user what we will do? This radiance will be converted into DN, stored in a satellite image, as a user we will get the DN, convert it into radiance. Using the radiance we will calculate the temperature of the object. I will explain how to calculate object temperature with some simple steps in the coming slides. But as of now, let us assume from this radiance we are calculating the temperature.

So, now essentially what we have? We have this T_{rad} calculated from satellite. At the time of image acquisition there were many different objects, each having its own physical temperature T_1 T_2 T_A and so on. So, these 3 things may be very different or they may be like varying a little. But in essence the temperature of each and every object will be different from what is seen by the satellite. As this satellite based temperature is coming from several objects, we call it as ensemble directional radiometric surface temperature.

An ensemble is the radiance recorded by the satellite and the temperature calculated out of that particular radiance is not due to any one particular feature on the ground. It is going to be a mixture or it is going to be like an average radiance of all the features contained within the GIFOV and the temperature computed out of that particular radiance will be actually different from each and every individual objects. That is why we call it as an ensemble, it is a mixture of several things and it is also directional.

Directional means the sensor might be looking the ground at nadir, sometimes the sensor may be looking away from the nadir, so every object will have different reflectances when we look from different direction, same way emissivity will also differ when we look from different direction. Because reflectance is equal to (1 – emissivity), we know reflectance differs in different directions; same concept will apply to emissivity also. So, objects will emit differently in different directions. Say if a sensor sees a land patch from this particular direction and another sensor sees the same land patch from a different direction. The radiometric temperature recorded by these 2 sensors is going to be different because of the variation in look angle, variation emissivity effect and so on.

That is why strictly speaking the surface temperature that we calculate from satellites should be known as an ensemble directional radiometric surface temperature. Let us look at this particular slide for an ensemble of black bodies at different temperature. There is not an equivalent black body with a given temperature yielding the same radiance at all wavelengths. Let us assume we have one black body within one particular GIFOV, satellite measures the radiance out of the black body. Using the radiance, we can calculate the temperature back. They will match because it is a homogeneous pixel, it is a black body everything will match. Let us say now 2 black bodies are present and 2 black bodies are at different temperatures. Due to the variation in temperature, let us say black body A has higher temperature. So, black body A will emit higher energy, black body B will emit lower energy and the sensor will see a average energy. Using that average energy, if you calculate a temperature out of it then that particular temperature and the average temperature of these black bodies they will not match.

So for ensemble, it is almost impossible to have an equivalent blackbody at any given temperature T to produce the same radiance, that is 2 black bodies are there their average radiance will be something, it will be impossible for you to find another black body which will yield the same radiance at some temperature at all wavelengths.

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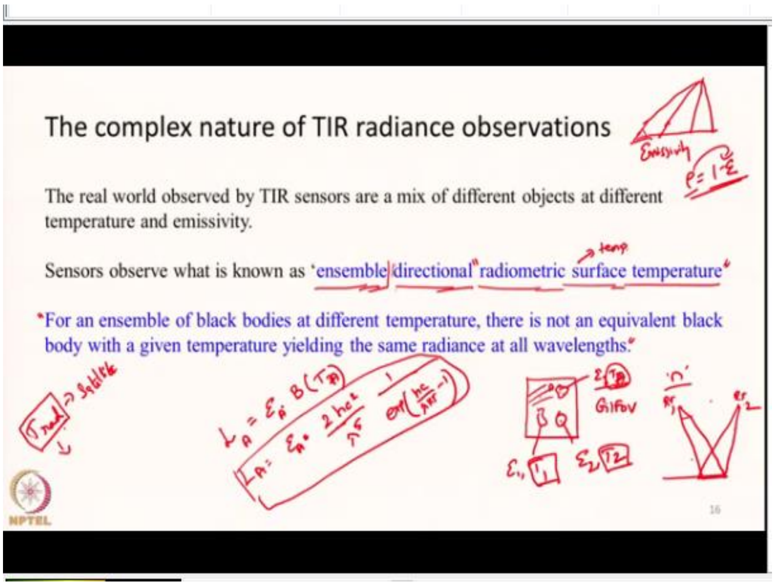

Let us assume a land surface that has 2 objects, black body 1, black body 2, each has occupying half of the area within that particular GIFOV. So, black body 1 is at a temperature of 293 Kelvin, black body 2 is at a temperature of 323 Kelvin. Let us say some sensor that can sense radiation in entire wavelength range 0 to infinity is observing this. The black bodies will emit radiation in many different wavelengths. So, I am creating a hypothetical sensor which will observe in all wavelengths from 0 to infinity. Now in this case what will be the average physical temperature of this particular GIFOV?

Half of the area is occupied by a black body at 293 Kelvin, half of the area is occupied by another black body at 323 Kelvin. So, the average temperature or the true physical temperature of this entire area will be average of 293 and 323 which gives you 308 Kelvin. So, if we physically take a thermometer, measure at many different points within this area and calculate an average, we will end up with this value 308 Kelvin.

So, this is the average physical temperature. Now let us compute these using remote sensing principles. As I told you for the sake of explanation I am going to observe this area using an extreme broadband sensor which can observe in wavelengths of 0 to infinity. So, we all know we will use Planck's function for calculating radiance, when we integrate Planck's function to 0 to infinity what we will get? We will get the Stefan Boltzmann law. Now just because I have defined an extremely broadband sensor for this example I am using Stefan Boltzmann law. Stefan Boltzmann is very easy to compute and show on screen rather than computing all the steps of Planck's law. Planck's function mathematically has more steps to solve.

So, σT^4 is the Stefan Boltzmann law, there is 2 black bodies, so $(\sigma T_1^4 + \sigma T_2^4)/2$. So, if you take the radiance emitted by an object will be 517.517 W/m^2. So, this is the radiant flux density.

So, now if we divide it by π, we can convert this into radiance and if we substitute it back to this particular equation then the radiometric temperature we will be getting is 309.09. So, if we use this particular value to calculate the T average, it will be 309.09 Kelvin. So, here for this mixture of 2 black bodies, the temperature we got from remote sensing observation is 309 Kelvin.

Here actually in this example we have assumed just 2 objects, that too 2 black bodies but in real world a single GIFOV will have n number of features that can be 10, 15, 20 different features, each having their own temperature and emissivity. Everything will be averaged together to produce one single temperature value. But single temperature value that we are observing from satellite will be different from temperature of these individual objects. We will be getting kind of a mixture, that is why we call it as an ensemble directional temperature, it will be a mixed signal coming out from all the different objects. So, it will be very difficult for us to calculate the temperature of any one object contained within the GIFOV.

Unless that object is clearly visible it will be very difficult for us to calculate. So, the normal or the thermal infrared measurements that we make from satellites or indeed complex measurement, it has a mixture of signals emanating from various objects which will prevent us from calculating the temperature of each and every individual object.

The final temperature that we are sensing can be different not completely but it will be different to some extent from the temperature of the different objects contained within this particular GIFOV when the satellite observation was made. Now slowly we will move on to further concepts of land surface temperature, how to retrieve it and all. Before that we will see one example of how a land surface temperature image will look as given in this particular slide.

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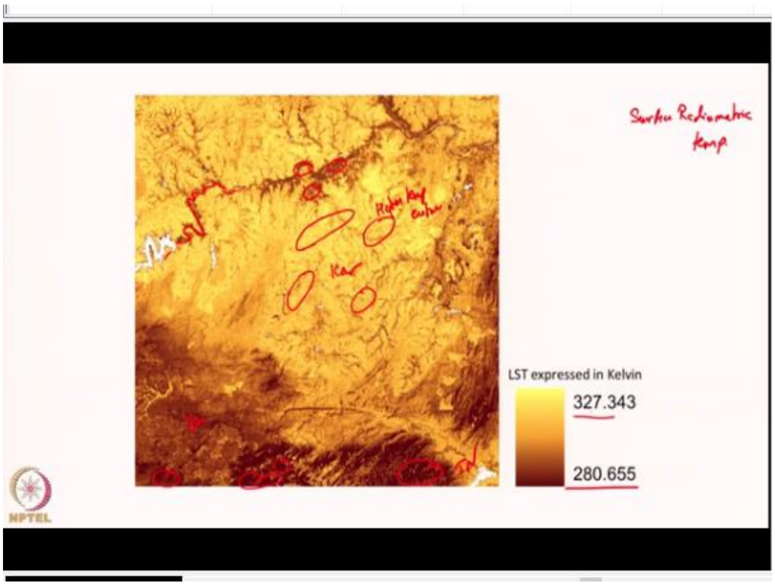

So, here we have an LST image, LST is land surface temperature or otherwise known as surface radiometric temperature, that is the technical term. So, this shows the temperature map of a small portion on south India, the Kabini reservoir, this is the Kabini river and this is the Kaveri river then this is a mountain, this is a portion of Karnataka, Kerala and Tamilnadu. So, mixture of 3 states, this is the western guards mountain and so on. Look at the colour bar, the dark brown color here indicates lower temperature around 280 Kelvin, yellowish lighter colours indicate higher temperature, here for this map it is 327 Kelvin. So, this tells us if you look at this area we can clearly sense it is a river, it is actually Kabini river that is flowing.

And using the water people do lot of irrigated agriculture near its banks. So, these portions near the river channel are actually water bodies or crop plants that are irrigated using the water from this river and hence they are at a lower temperature. Similarly look at this mountain portions, again the elevation is high, these portion western guards contain lot of trees, vegetation and so on. Their temperature is again lower, look at the central patch, these are mostly agriculture dominated areas, but at the time of this image acquisition they were more or less bare or fallow land and hence not much of vegetation is present, that is why they have a higher temperature. So, what this generally means if the surface is bare and dry without moisture the temperature will be higher for it. On the other hand if you observe the well vegetated areas or over water occupied areas naturally the temperature of it will be lower. So, using this temperature we will be able to understand the energy processes occurring at the surface, we call it as the surface energy balance equation which tells us how the energy coming in at the land gets divided into different, different components.

Using that we will be able to calculate how much water is lost to the atmosphere through the process of evapotranspiration. We can estimate soil moisture, we can estimate vegetation health, lot of different applications are there, may be few applications we will get introduced to, towards the end of this course. But the general application of the radiometric temperature is it will help us to understand what are the different energy processes occurring at the earth's surface.

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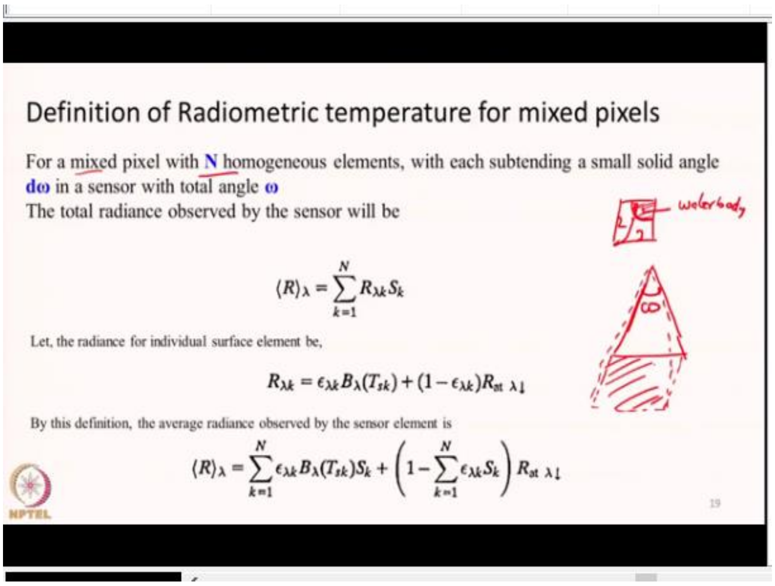

Just 2 slides before I explained you the concept of ensemble directional radiometric temperature. If a pixel or if a GIFOV of a satellite sensor has more than one object present within it, we call it as a mixed pixel that is, that particular pixel is having more than one feature. For such mixed pixels, how to define this radiometric temperature for practical purposes, if you want to define and use radiometric temperature for such pixels, how to do this?

We will quickly see this in the coming slides. Here we assume a mixed pixel that is, a single GIFOV which has several features present within object 1, object 2, objects 3 and so on. It has n homogeneous element, each element is homogeneous assuming say this is a water body and that particular water body is at a uniform temperature throughout. So, similarly there are n different elements and all of them are homogeneous individually at a different, different temperatures.

So, in order to see this particular GIFOV, a satellite will be subtending a small solid angle ω. Within this particular solid angle the GIFOV will be defined. So, this is the GIFOV and this is the solid angle ω. So, what essentially we are going to do with this, if a pixel has more than one feature then how to define the radiometric surface temperature observed by that particular sensor?

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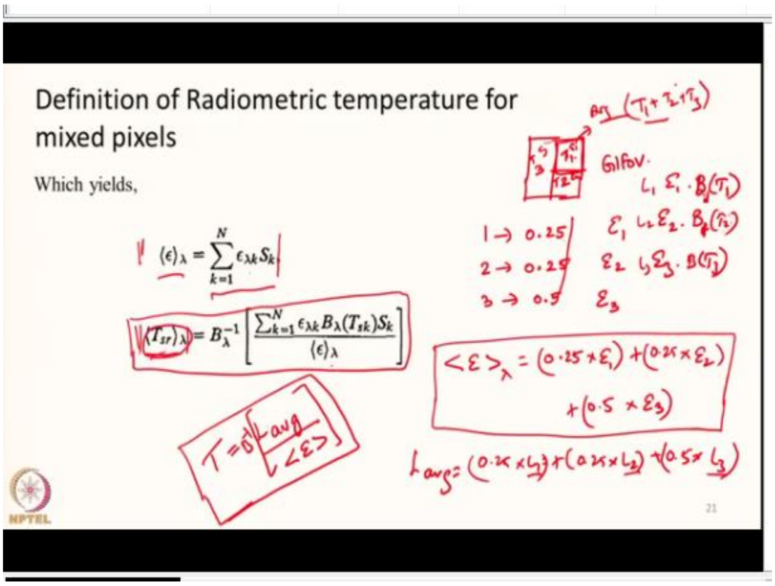

Without going into the detailed derivation, let us move to the last portion of this explanation and I will expand using these 2 particular equations. Now let us say we have 3 different homogeneous objects. Object 1, object 2, object 3, let us assume within this particular GIFOV or within the particular total solid angle subtended by the sensor object 1 occupies a fraction of 0.25. Object 2 let us say occupies a fraction of 0.25, object 3 occupies a fraction of 0.5. Let us assume each object has emissivity of emissivity 1, emissivity 2, emissivity 3. Then the ensemble emissivity of this particular GIFOV is given by the aerially weighted fraction or the aerially weighted value of emissivity of all the elements present within it.

That is the ensemble emissivity at a given wavelength λ is given by (fraction of object 1 × emissivity 1) + (fraction of object 2 × emissivity 2) + (aerial fraction of object 3 × emissivity 3). This will give the aerially averaged emissivity for this particular GIFOV. Because when we estimate land surface temperature normally we will compute pixel by pixel and take the radiance out. we cannot go finer than a pixel in a remote sensing image, whatever radiance got stored in a pixel we will take it. So, we have to work with an average emissivity. So, the average emissivity and the radiometric temperature is given by the following equation.

So, let us say for an object 1 let us assume that radiance is (emissivity 1 ×L_1) where L are let us say B_1, B_1 is the plank's function, (emissivity 2 ×B T_2,) and (emissivity 3 into B T_3 where

here B indicates Planck's function T_1, T_2, T_3 indicates the actual temperature of the 3 objects. This is the radiance from 3 objects. So, the average radiance reaching the sensor is

$$L_{Avg} = (0.25 \times L_1) + (0.25 \times L_2) + (0.5 \times L_3).$$

The radiance of each object is given by emissivity times the Planck's function at a given temperature T and λ. So, this is the L_{Avg}. Now to calculate the radiometric temperature, this average radiance is divided by the average emissivity.

If you take inverse Planck's function out of it, we will get temperature of that particular pixel T. Emissivity for a mixed pixel is defined as aerially weighted average of emissivity of different features present within a pixel. To calculate temperature, we should first calculate the radiance coming out from each and every object, average out all the radiances. Using the aerially weighted average of all the radiances, compute an average radiance for that particular pixel. Using this average radiance and average emissivity, substitute everything in Planck's function invert it to get a temperature out of it.

And that temperature will give you the ensemble directional radiometric temperature for this particular mixed pixel. So, here the one concept we have to remember is when satellite is seeing a mixed pixel, a pixel containing more than one feature, the radiance coming out of all the features will be averaged out and the satellite will be seeing a average radiance. Similarly the emissivity will also be averaged out.

So, when we calculate the final temperature for the whole pixel we need to use this average radiance and this average emissivity to calculate the temperature of that particular pixel. So, the radiometric temperature for a mixed pixel has to be computed like this. In literature there are different definitions of this mixed pixel emissivity and so on, but we will follow this particular simple definition given in one of the seminal papers.

Let us take an example of 3 features, this is object 1 having certain radiance, let me calculate radiometric temperature T_1, here there is object 2 let me calculate radiometric temperature T_2 and so on. Find out the temperature and average it out, let us go back to the same example, this is at T_1, this is at T_2, this is at T_3, emissivity 1, emissivity 2, emissivity 3, it is very easy for us to compute the radiometric temperature of this particular pixel using inverse Planck's function. That is I am computing temperature for each and every element and if I average them out it will be different from what we compute using this particular formula.

That is temperature in the TIR domain is not linearly averageable, you cannot linearly average surface temperature if you have more than one feature present within a pixel or if you want to upscale your image. So, if at all you want to average temperatures, say 10 different objects are there in a given area, if you want to calculate the average temperature of the whole area means you cannot average the temperature of all these 10 objects.

What the satellite effectively sees will be different from this particular average. In order to properly compute this you have to follow a very long procedure. Calculate the average emissivity, calculate the average radiance, use that in Planck's function and invert it.

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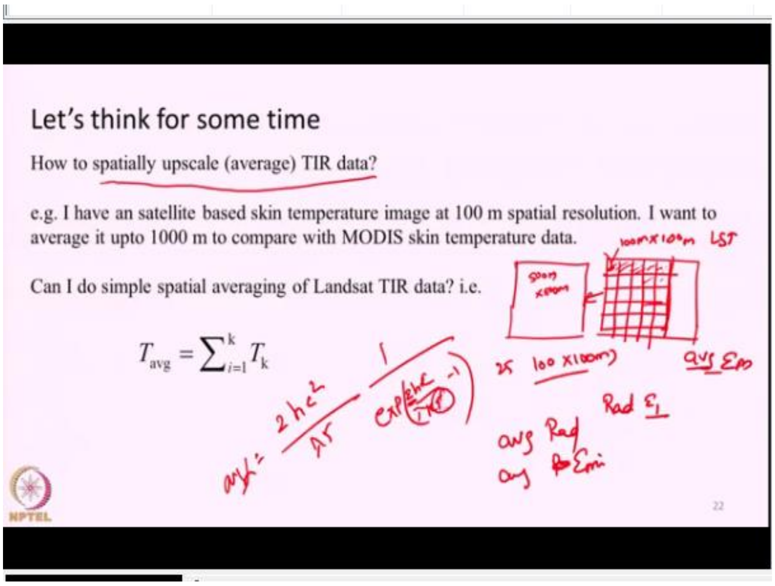

Here in this particular example I am giving you one problem. How to specially upscale or average TIR data? Let us say you have one satellite image at 100 m by 100 m resolution, now I want to convert this data to 500 m by 500 m for my application. How to do this? It is very natural for us to think, within a 500 m by 500 m pixel, there will be 25 100 by 100 meter pixels, so just average the temperature value recorded in each of this 25 pixel, that is it, very simple, that is what we normally think. But we should not do that, we should not just take the temperature and average them out, it may give us a wrong result.

Technically we should do the following, from the temperature or from the original DN recorded in the pixel we have to calculate the radiance of each pixel, similarly we have to calculate the emissivity of each pixel, average the emissivity out in order to get an average emissivity for all the 25 pixels and average the radiance of all these 25 pixels. Using this average radiance and average emissivity, substitute this in inverse Planck's function and invert this equation to calculate the temperature T. So, this is how we have to calculate or we have to up scale the satellite data.

If you want to change the resolution, especially the surface temperature data, we cannot directly average a temperature, most likely it will be erroneous. So, it is always better to be safe rather than being sorry. So, the major aim of telling you or explaining all this concept is temperature estimation in TR domain is a non-linear process. They will not linearly average; their temperature will not linearly add up, the Planck's function is highly non-linear. So, whenever we want to calculate temperature for several objects combined together we cannot average them out, we have to use this roundabout procedure to do this. So, with this we end this particular lecture.

Thank you very much.