Remote Sensing: Principles and Applications

Prof. R. Eswar
Department of Civil Engineering and Interdisciplinary Program in Climate Studies
Indian Institute of Technology-Bombay

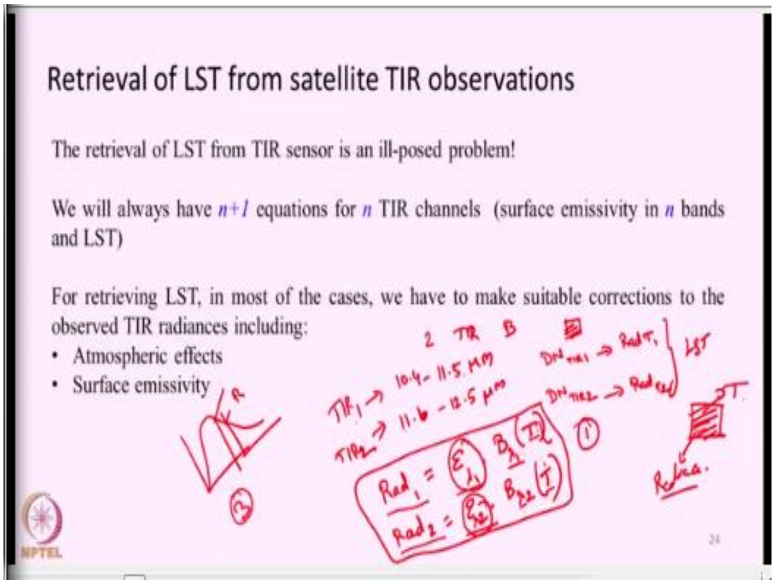
Lecture-38
Thermal Infrared Remote Sensing-Part-4

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. In the last lecture we discussed about the definition of radiometric temperature for a mixed pixel. We spent considerable amount of time in defining how radiometric temperature has to be calculated for mixed pixels and the implications of such definition. If you want to upscale the data to a coarser resolution from 100 meter resolution to 500 meter or 1000 meter resolution let us say, what will be its implication, how to do it? Such sort of theoretical principles we dealt in detail.

In today's lecture we will move to the topic of retrieval of land surface temperature from single channel thermal data. Let us take an example of Landsat series of satellites. Starting from Landsat 4, Landsat series of satellites had a thermal infrared sensor. So, using that we can calculate land surface temperature. So, now we are going to see how to do it. But our concentration will be primarily on sensors with only one thermal channel. why not 2 thermal channels? Let us take an example of another sensor called MODIS, which is one of the most widely used sensors for several applications.

If you take that sensor, it has 2 thermal channels band 31, 32 and they have an operational LST product currently available. That is, as an end user we need not calculate the land surface temperature from them. Land surface temperature data is already available to us; we can just download and use it for our applications. But if you take Landsat series of satellites at the time of recording this lecture or going through this particular course, there is no operational land surface temperature product available, so what it means? As an end user they will give us the calibrated DN values and it will be our responsibility to calculate land surface temperature from that DNs and use it for our applications. So if we know how to retrieve surface temperature from that particular data, it will be helpful for us and that is what we are going to see in this particular lecture.

(Refer Slide Time: 02:56)



So, the retrieval of land surface temperature from satellite data is an ill-posed problem, what is an ill-posed problem? For each band of thermal channel, we can write one equation. Let us say our sensor has 2 bands of thermal channel around 10.4 to 11.5 and the next be around 11.6 to 12.5 micrometers. So, for a given pixel we will have DN in thermal channel band 1 and DN in thermal channel band 2, using this we can calculate radiance in thermal channel band 1, radiance in thermal channel band 2 and using these 2 we can calculate LST. So, to calculate LST we will use the same Planck's law.

Radiance in band 1 = emissivity in band 1 × Planck's law of band 1 at temperature T eqn.1

Radiance in band 2 = emissivity in band 2 × Planck's law of band 2 at temperature T eqn.2

Here the temperature T is not going to change. Whatever be the band or whatever be the wavelength we observe, surface is at a true temperature T, that is not going to vary with wavelength.

But the radiance that we are going to observe from satellite is going to vary with respect to different wavelength. Say in TIR band 1, the wavelength is 10.4 to 11.5, in band 2 the wavelength is 11.6 to 12.5. So, the bandwidth is different for channel 1 and channel 2. Hence the radiance coming out in different wavelengths will be different, that is point number 1. Point number 2, emissivity also will vary with wavelength. I said emissivity is spectrally variant, so emissivity will be different at different wavelength. The 2 temperatures T in the two equations are the same. so that is unknown 1. And we have emissivity in λ_1, unknown 2, similarly emissivity in λ_2 that is unknown 3. From satellites we can calculate radiance in channel 1. Similarly from satellite we can calculate radiance in channel 2. So, we have 2 equations but we have 3 unknowns, emissivity in band 1, emissivity in band 2 and temperature of the object itself. So, this is the case of TIR observations, if I have n thermal channels then I will have n equations and n + 1 unknown. That n + 1 unknown indicates emissivities in these n thermal channels plus that land surface temperature.

So, whatever be the number of bands you have in the sensor, always there will be one more unknown than the number of bands. So, if you have only one thermal sensor like in the case of Landsat satellites, Landsat 4, 5, 6, 7 had only one thermal channel. You will have 2 unknowns one emissivity in that band, one land surface temperature. If you have 2 bands you will have 2 emissivities + 1 land surface temperature, this is like a recurring problem, it is not going to stop.

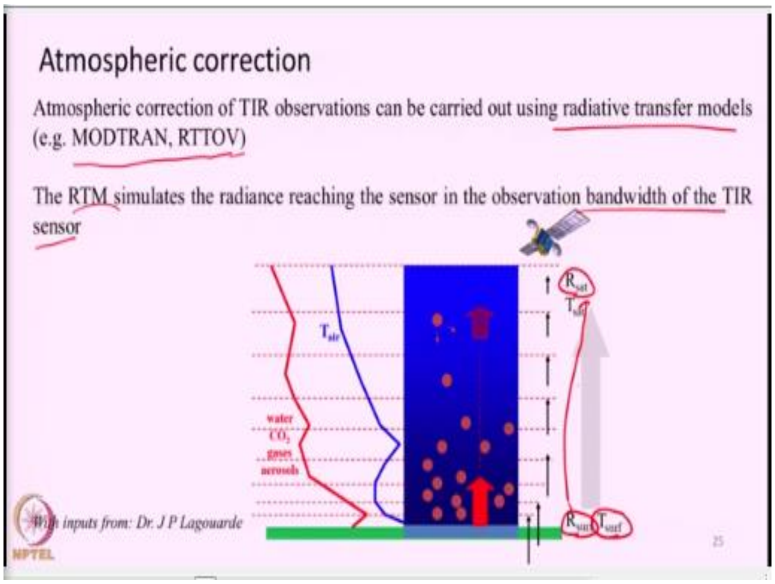
That is what we say retrieval of LST is an ill-posed problem. So, we need to correct, the radiance observed from the satellite both for atmospheric effect and emissivity effect. Somehow we have to bring in emissivity from outside or we need to use some other constraints basically. So, I told you we have n equations and n + 1 unknowns, so we should somehow get any one of the unknowns and substitute the value to it.

So, in this way we can reduce the number of unknowns. So, normally for sensors with a single thermal infrared channel, we have to calculate emissivity separately. When we do LST retrieval from Landsat series of satellites,

- We will take the DN from the sensor
- Convert the DN to radiance
- Atmospherically correct the radiance to bring it to surface value
- Independently calculate surface emissivity
- Combine these 2 and put it in Planck’s function
- Calculate the surface temperature

This is the general outline of how to calculate land surface temperature from single channel TIR sensor. We will see in detail how these steps are being done.

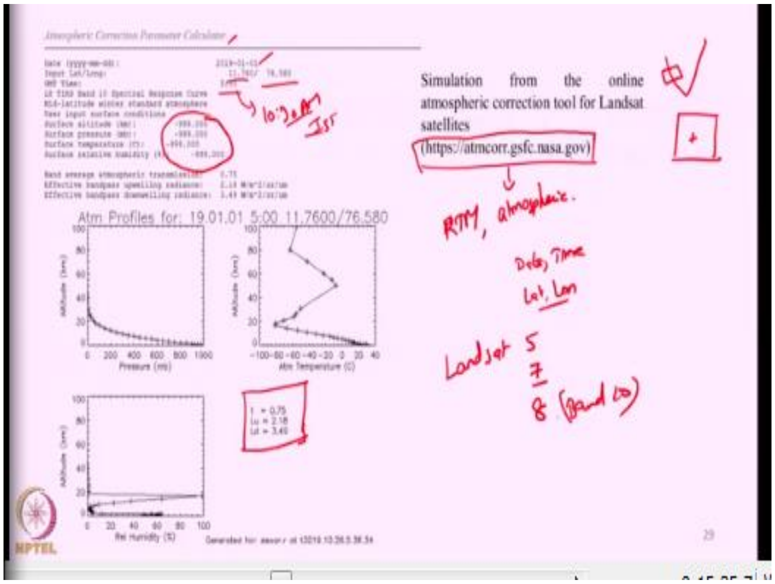
(Refer Slide Time: 09:24)



So, the first step let us look with the atmospheric correction. So, I have already told you in previous lectures that how and all atmospheres will modify the radiance reaching the sensor, we need to correct for it. That is at the time of satellite overpass, observe atmospheric variables like temperature, humidity, pressure, water vapour, concentration, CO_2 concentration etc. Substitute all these values in a radiative transfer models, simulate how atmosphere will behave, how much emission will be coming out from atmosphere, how much will be atmospheric absorption, all these things you can simulate using those values and correct for the atmospheric effect. So, that is schematically given in this particular slide. So, here atmospheric correction of TIR observations can be carried out using radiative transfer models.

Some examples for this models are called MODTRAN, RTTOV etcetera; these are some of the famous or familiarly used radiative transfer models. So, these radiative transfer models will simulate the temperature of the surface, the radiance coming out of the surface and the radiance reaching the satellite, how this radiance has been transformed to this radiance? What are all the components of atmosphere that changed this? All these will be simulated by this radiative transfer model. Some of the models are available to us publicly like RTTOV models and all. We can download and use it without any commercial problems. But sometimes as a end user we may not have access to such things and we may not have the computational resource to run these models or we may not have the atmospheric data to run these models. So, how to do it as an end user? Is there any simple way to do this? Yes, especially for Landsat series of satellites there is one simple way to do this.

(Refer Slide Time: 11:42)



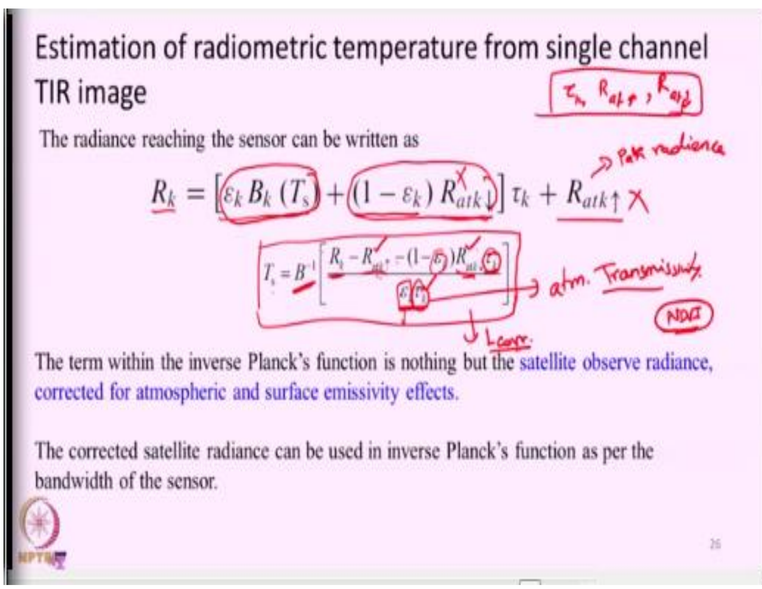
The way to do this is to use an online atmospheric character tool. What exactly is an online atmosphere character tool? In this slide I am giving you the output of how that website will work. So, the website address at the time of this course recording is atmcorr.gsfc.nasa.gov. It is basically a website which has links to radiative transfer model RTM plus an atmospheric re-analysis model.

So, go to this particular website, enter the date and time of your satellite overpass, enter the latitude and longitude over which your satellite image is acquired. Say this is my image, it is acquired over certain portion in India let us assume. So, at what date and time it was acquired, what is the latitude and longitude of the central area of the image? We can give by looking at the image, if you give information like this, 1st January 2019, this is the latitude, this is the longitude, this is the GMT time 5 AM, GMT time in roughly 5 AM means 10:30 AM Indian standard time, I have given only this data. For this data, and for different satellites Landsat 5, Landsat 7 and Landsat 8 band 10, this website will simulate the atmospheric variables that we need for our atmospheric correction procedure. How this website works? As I said before the website has in background a radiative transfer model and an atmospheric model running behind. As soon as we give the date, time and latitude and longitude, from the atmospheric model, it will take all the variables required, feed it as an input to the radiative transfer model, give these things to us as output.

So, if we are interested in calculation of land surface temperature from satellite data especially Landsat satellite data, this website is of primary use. But just imagine one thing; this is applicable only for Landsat series of satellites, Landsat 5, 7 and 8 that also only for band 10 in Landsat 8 that is one thing. And also this website will give us output for data acquired on or after year 2000 before which this website will not give us any outputs.

But landsat has data acquired right from say 1980's, but for that time period we cannot do atmospheric correction using this particular website. But for data acquired after the year 2000, we can use this. So, for the last 20 years, it will be possible for us to correct Landsat data using a very simple way. But this is a very crude procedure, which means this takes everything from atmospheric models. We are not giving any live ground observations, so we have to keep this in mind**.** Now let us assume using this website or using some other way we have calculated the atmospheric parameters needed for our computations. How to correct for the effect of atmosphere? Just recall the radiance reaching the sensor in thermal band, what we have discussed in earlier lectures.

(Refer Slide Time: 15:53)

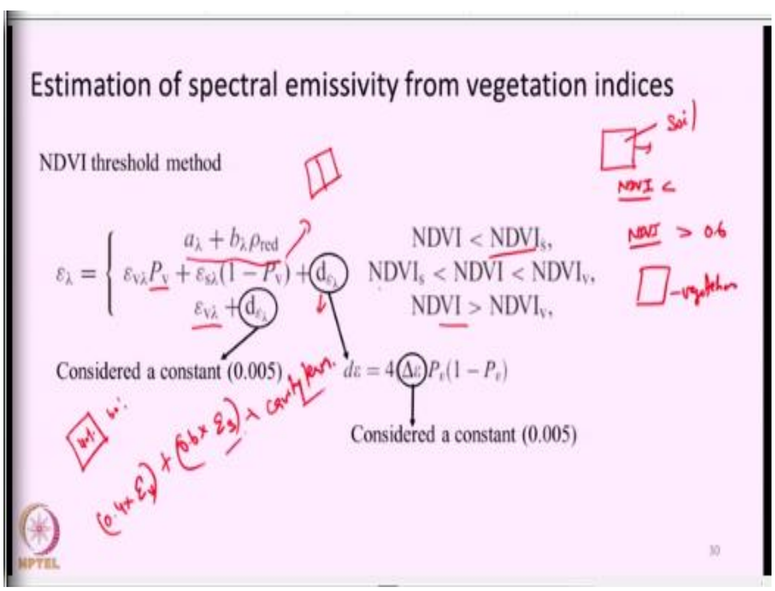


So, the radiance reaching the sensor in thermal band is a combination of direct surface emission, surface reflected downwelling component of atmosphere plus path radiance. It has 3 components, we have already seen it. Our actual interest is this, the surface component, what is being emitted by the surface due to it is own temperature. We do not need path radiance. We also do not want this particular term, atmospheric downwelling radiance. So, if you remove this and invert this equation we will get this particular formula. The land surface temperature T_s or LST whatever we can call is equal to the radiance reaching the sensor minus the path radiance minus the surface reflected atmospheric downwelling component divided by emissivity into atmospheric transmissivity.

We know what transmissivity is, we have defined this or explain this in detail in previous lectures. So, from that website or using that radiative transfer model, we will be getting the upwelling path radiance, the downwelling radiance and the atmospheric transmissivity. So, τ_k, atmosphere upwelling and atmosphere downwelling**,** these 3 components we will get from that particular website or using the radiative transfer models.

So, for a given bandwidth these 3 values will be known either using an RTM or using that particular online atmospheric correction tool. But still we do not have this emissivity term, so next step we will look at the way how to estimate surface emissivity.

(Refer Slide Time: 18:18)



For calculation of surface emissivity there are again plenty of methods available, variety of ways are there. For our course we will not go into detail about explaining all the methods but we will look at one simple method called the NDVI threshold method**.**

So, NDVI threshold method means it basically assumes any given pixel on the land surface has vegetated or non vegetated components. Most likely non vegetated component means soil components. So, emissivity of vegetation can be considered as constant say 0.97 or 0.98 and emissivity of soil also can be estimated. So, if we can estimate these 2 things, we can combine them linearly to calculate the emissivity of a pixel. So, in principle or in a simple term, for a given image, analyze the data or analyze the time series of data and find out.

The basic assumption for the threshold method is, If NDVI is less than certain threshold then the pixel is full of soil. If NDVI is more than a certain threshold, then the entire pixel is full of vegetation. If NDVI is lying somewhere between these thresholds; then that pixel is composed of both soil and vegetation, it is a linear mixture. So, how to calculate it? This model will simply assume if the NDVI is less than NDVI of soil, assume soil emissivity to it. If NDVI is more than NDVI of vegetation, assume vegetation emissivity to it, and if NDVI lies in between a threshold, calculate the emissivity linearly. Linearly means, calculate what is the fraction of vegetation within the pixel. Let us say a single pixel has 40% vegetation and 60% soil. So,

Emissivity = (0.4 × emissivity of vegetation) + (0. 6 ×emissivity of soil) + some cavity term.

So, this is the simple principle of this NDVI threshold method. So, normally for NDVI of vegetation, we will assume a constant value say 0.98. but soil emissivity will vary a lot depending on various factors. So, for calculating soil emissivity we will develop a relationship relating reflectance in red band with emissivity in thermal band.

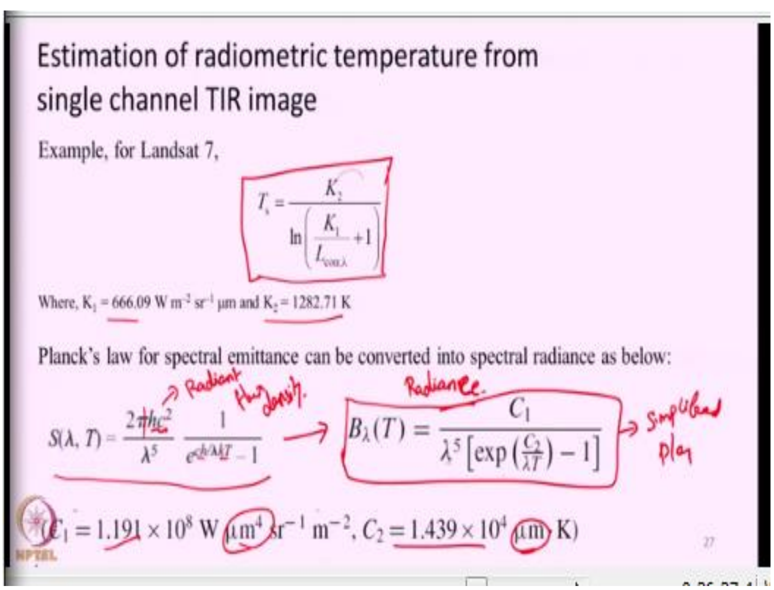
We can develop certain equations, there are many literature showing this particular relationship. So, using the reflectance in red band and these developed empirical equations, you can calculate soil emissivity. Combining the soil emissivity with vegetation emissivity, you can calculate emissivity of a mixed pixel. There are plenty of literature available but I just wanted to introduce to you a one simple way of estimating emissivity. So what you have to remember is, emissivity of a pixel is normally calculated as a linear combination of emissivity of vegetation and emissivity of soil.

Emissivity of vegetation is considered more or less a constant, whereas emissivity of soil is derived from reflectance in red band and combining these things we can calculate emissivity. This is one of the very simple methods called the NDVI threshold method, in practice it is easily doable and people are using it to a large extent.

So, now we have emissivity and we have already atmospherically corrected the data. Now let us go back and look at the previous equation. If you look at this equation, the atmospheric terms are already known. Most of the single channel methods use NDVI as the primary indicator of surface emissivity because vegetation plays a major role in controlling the emissivity of a pixel. So, using NDVI somehow we can calculate emissivity. So, we know all the things needed. Radiance observed at the sensor, all the atmospheric parameters and emissivity has been calculated. If we know everything we can put it in Planck's function, invert all the values to get the surface temperature.

So, this is the simple way of estimating surface temperature from satellite observations. Now as an example or as a case study let us see how surface temperature can be estimated from Landsat 7 satellite**.** So, for Landsat series of satellites we have what is known as a user's handbook or some user guides will be there, they will give equations to do this.

(Refer Slide Time: 24:45)

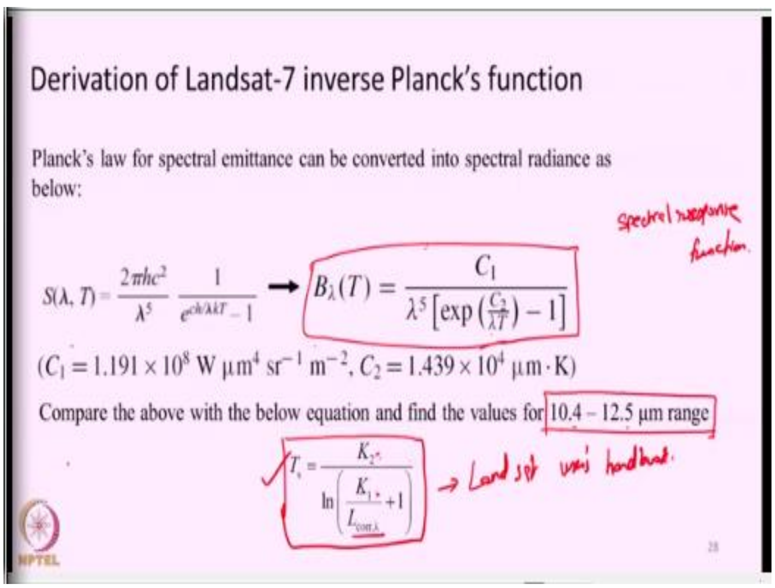


If you look at Landsat 7 or Landsat 8 or Landsat 5, equation will be there but these constants K 1 and K 2 will vary. How this equation has been derived? This equation has been actually derived from the real Planck's function**.** So, in the original Planck's function, radiant flux density divided by π will give us radiance for Lambertian surfaces or isotropic radiators. So, you get 2 hc^2. Combine all the constants, combine hc/kT, if you combine all these things we will finally have a simplified equation like this,

$$B_\lambda(T) = \frac{C_1}{\lambda^5\left[\exp\left(\frac{C_2}{\lambda T}\right) - 1\right]}$$

So, we have combined several constants to create one simple constant and the units have been changed to micrometer of wavelength. So, this is a simplified representation of Planck's law. Instead of using several constraints we are combining them to create one single constant**.**

(Refer Slide Time: 26:28)



Now if a satellite sensor wavelength is defined, say for Landsat 7 it observes in the range 10.4 to 12.5 micrometer. So, using this wavelength and the spectral response function of the sensor if you integrate this over the wavelength we will get the above equation. So, this equation given in the Landsat user's handbook is nothing but a very simplified version of Planck's equation that is integrated over the wavelength range of Landsat satellites bandwidth. So, here the Planck's function has been inverted. Now we know radiance, we want temperature, just reverse them to get inverse Planck's function. In the inverse Planck's function integrate it between the range of whatever the bandwidth of the sensor and we will have one final equation with constants**.**

So, the constant values are available in Landsat metadata file and also in Landsat user's handbook. So, as a end user download Landsat data, from the DN convert it into radiance. At the time of satellite overpass using any radiative transfer model or using this atmospheric correction website, calculate the atmospheric parameters, τ, R upwelling and R downwelling. Correct the satellite observed radiance, independently estimate emissivity, correct the radiance again for emissivity effect. That is apply this equation where all the terms atmospheric upwelling, downwelling, transmissivity, emissivity everything are known. So, this will give you the term what is known as the corrected radiance that is radiance observed by the satellite sensor corrected for atmospheric effect and surface emissivity effect. Take this corrected radiance value and substitute this in our inverse equation. K 1 and K 2 are already defined, and it is available from Landsat user's handbook. If we do this, we can calculate the land surface temperature from Landsat series of satellites.

So, when you find time, try to use several online tools that are available like Google earth engine, and they are some open source softwares available to download data and use it. Maybe in the later series of lectures, I will give you a brief introduction about the datasets available from satellite. So, you can try on your own, using the simple principles how to calculate land surface temperature. So, this is the generic procedure of retrieval of land surface temperature from Landsat series of satellites. With this we end this lecture.

Thank you very much.