Remote Sensing: Principles and Applications

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Lecture-65

Application of RS in Water Resources Management-Part-2

Hello everyone, welcome to the next lecture in the application of remote sensing in water resource management. In the last lecture we just briefly defined water resource management and we also saw some of the tasks that or some of the sub domains that is encompassed within the term water resource management. We have also seen the different variables required in water resource management that can be retrieved from remote sensing.

We started discussing about evapotranspiration and we defined what evapotranspiration is, we saw vegetation index based models, Penman Monteith or Priestley-Taylor based models and we also discussed the surface energy balance equation. So, today we will continue with the topic and we will see how the surface energy balance equation is solved using remote sensing data sets.

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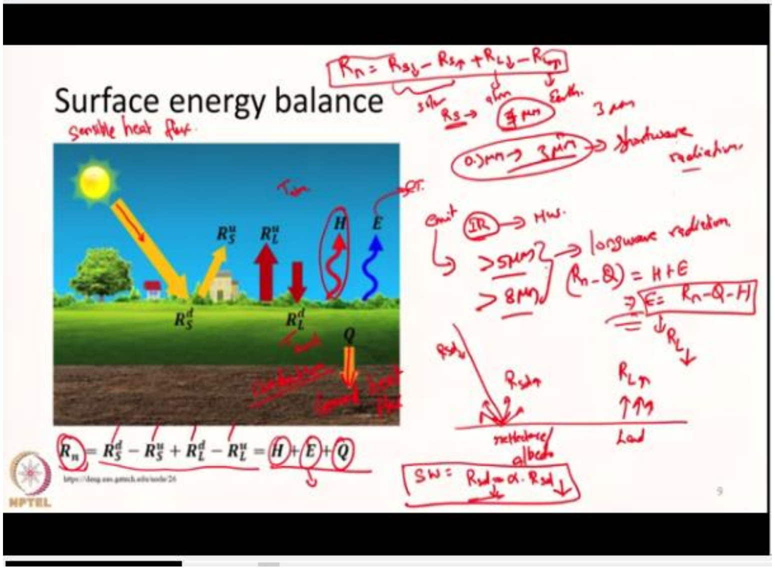

Surface energy balance

$$R_n = R_S^d - R_S^u + R_L^d - R_L^u = H + E + Q$$

https://deng.eas.gatech.edu/node/24

So, we have seen in the last lecture what surface energy balance equation is? So, what normally we will do in remote sensing is, we are interested in getting this E term, evapotranspiration. So, we will try to estimate each of the radiation components separately, we call it as R_n. so, this R_n-Q.

It can be denotes as Q as well as G. So, R_n - Q = H + E. This implies E = R_n - Q - H. so, this is the generic representation of evapotranspiration using the surface energy balance equation. We try to estimate all other variables that are involved in the surface energy balance equation and estimate ET as a residual.

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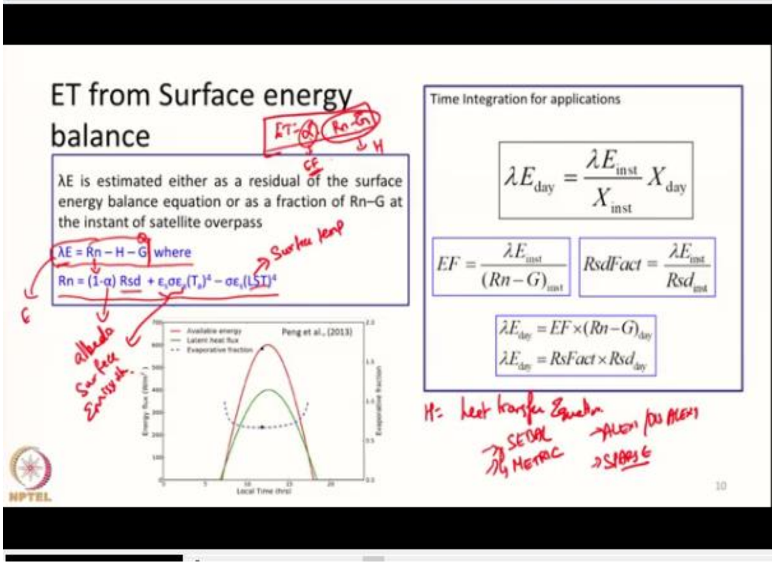

ET from Surface energy balance

λE is estimated either as a residual of the surface energy balance equation or as a fraction of Rn–G at the instant of satellite overpass

λE = Rn – H – G where

$Rn = (1-\alpha)\, Rsd + \varepsilon_s \sigma \varepsilon_a (T_a)^4 - \sigma \varepsilon_s (LST)^4$

Time Integration for applications

$$\lambda E_{day} = \frac{\lambda E_{inst}}{X_{inst}} X_{day}$$

$$EF = \frac{\lambda E_{inst}}{(Rn-G)_{inst}} \qquad RsdFact = \frac{\lambda E_{inst}}{Rsd_{inst}}$$

$$\lambda E_{day} = EF \times (Rn-G)_{day}$$
$$\lambda E_{day} = RsFact \times Rsd_{day}$$

$ET = \alpha\,(Rn-G)$

EF

H

Surface temp

G

albedo

Surface Emissivity

H= heat transfer Equation

→ SEBAL

→ METRIC

→ ALEXI / DisALEXI

→ SEBS

As I told the evapotranspiration ET is estimated as residual of the surface energy balance equation, λ_E is nothing but the ET term or E term which is equal to Rn - H - G where G is the Q we have seen in the previous slide. Other than this we can also estimate evapotranspiration as a fraction of R_n - G. That is ET is equal to some fraction of R_n - G. If we can estimate this fraction, then ET can be estimated as a product of these two. Here we would not be trying to calculate H in this method, but we will try to estimate this fraction of energy that is going out as (evapotranspiration)×(Rn – G). So, we call this as EF evaporative fraction. So, this is one way or the most common way to estimate ET as the residual of the surface energy balance equation. So, this simple equation is now being expanded here. Here you can see albedo term and LST, the surface temperature we get from thermal infrared remote sensing and surface emissivity.

So, all these things are the variables that can be retrieved from remote sensing. We retrieve LST, we retrieve albedo, we estimate surface emissivity and so on. Using this in addition to incoming solar radiation we can estimate this Rn. Similarly H can also be estimated using the heat transfer equation. So, I am not going to explain in detail how this equation came in, what all the different assumptions behind it, how to estimate it and all. Those things are out of the scope of this particular course. But there also to estimate H, the land surface temperature that was retrieved from the thermal infrared remote sensing data sets is needed. So, effectively combining the surface temperature, albedo, vegetation indices, surface emissivity and all the variables, we try to estimate each and every component of the surface energy balance equation. So, this is the basic principle of how remote sensing is useful for getting evapotranspiration using the surface energy balance principle. Again this is a physical equation that is present, we try to solve this equation by getting different inputs from remote sensing.

Some of the common models that we might have heard is SEBAL, this is based on surface energy balance based model. Another model is called METRIC, they are related with each other, there is another model called ALEXI DIS ALEXI family, there are another model called SPARSE. There are plenty of different remote sensing based models and even very good review papers on the topic. So, basically this itself is a very big field on its own to cover. But just as a summary, surface energy balance based models require land surface temperature data. Without that particular data we will not be in a position to solve surface energy balance based equation. So, this is the primary backbone of solving this equation from thermal infrared remote sensing. In addition to this we will also be needing vegetation variables, like vegetation indices, emissivity, albedo and so on.

So, there are plenty of global data sets available, say MODIS provides its own evapotranspiration product, there is another product called GLEAM which provides global evapotranspiration, then the PT-JPL product is there. So, there are plenty of available ET products at global scale which we can download and use for our applications, even a simple internet based search will take us to the product page of these different products.

So, next we are going to talk about soil moisture and how remote sensing is helpful in retrieving soil moisture. So, to simply define soil moisture, it is the amount of water contained within a soil, whether it is a volume, it contains some amount of soil. Say what is the volume of the soil and what is the volume of water? If you calculate it that is one way of representing soil moisture or if you calculate this box contain this much mass of soil and this much mass of water, if you calculate the mass that is another way of representing soil moisture. These two definitions are basically called volumetric definition or gravimetric definition. Volumetric definition is volume of water divided by volume of soil. So, gravimetric is mass of water divided by mass of soil.

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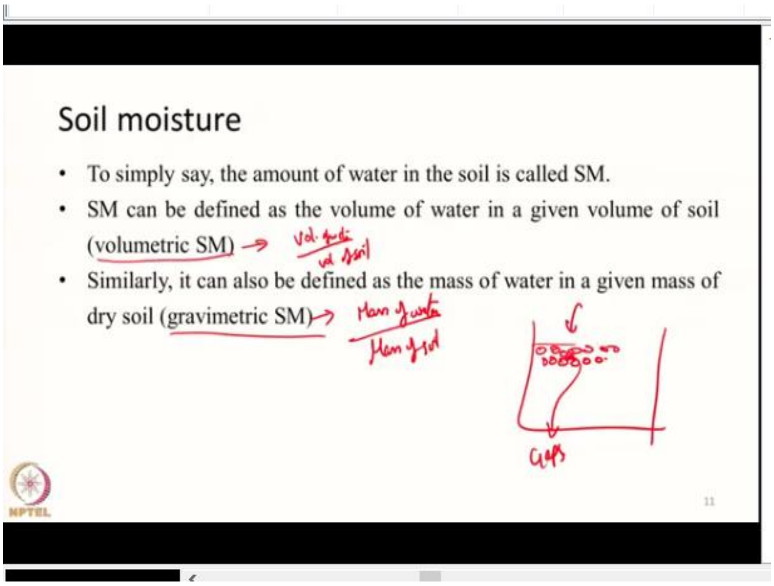

Soil moisture

- To simply say, the amount of water in the soil is called SM.
- SM can be defined as the volume of water in a given volume of soil (volumetric SM)
- Similarly, it can also be defined as the mass of water in a given mass of dry soil (gravimetric SM)

Estimation of soil moisture is of paramount importance to agricultural applications, drought monitoring, meteorological applications and so on. Since it is one of the important variables in the earth system which is required for several applications, we call it a state variable. So, estimating the soil moisture again is not a straightforward task. Normally we would not observe soil moisture directly, we have to do some other measurements and get soil moisture out of it.

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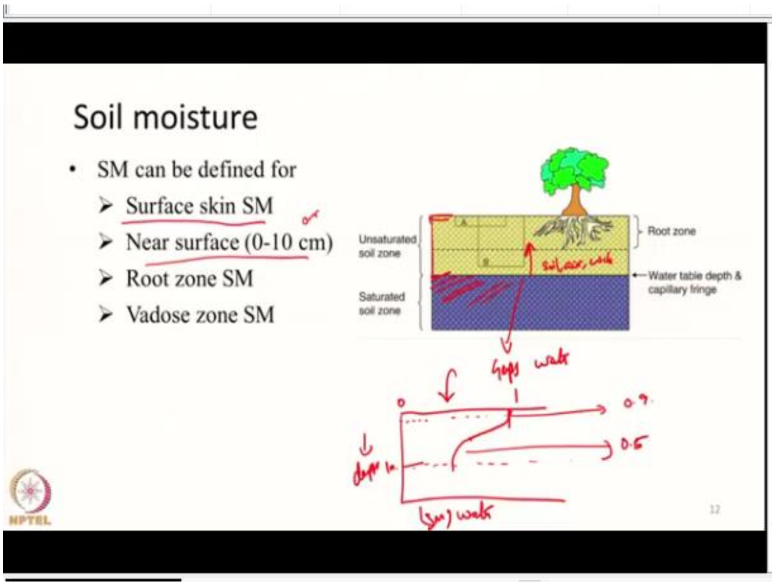

Soil moisture

- SM can be defined for
  - Surface skin SM
  - Near surface (0-10 cm)
  - Root zone SM
  - Vadose zone SM

So, the soil moisture can actually be defined as surface or skin soil moisture, only at the surface. Say you are just touching the surface without going in, how wet you feel? It is an indicator of surface soil moisture or the skin soil moisture. You can estimate soil moisture at the near surface with respect to say 0 to 5 centimeter or 0 to 10 centimeter depth. So, that we call near surface soil moisture or we can also estimate roots on soil moisture, say some vegetation they extend their roots under the soil, it may extend to some distance say half a meter, 1 meter or some large trees will have 10s of meters of roots. So, those vegetation can actually extract water from soil up to the depth to which they have the roots basically.

So, we can define the soil moisture present within the root zone or even we can define soil moisture all the way up to the ground water table. Say this is the ground water table, so after this, all the pores or all the gaps in the solid earth will be filled with water, we call it as saturated zone. Above this zone there will be a mix of soil, a air gap plus water filling within the gap. So, we can also estimate water available in the soil column, all the way up to this saturated zone. So, for different, different applications people will normally define soil moisture in difference sense, surface soil moisture, near surface soil moisture or root zone, water zone etcetera. So, the depth of measurement will vary and as the depth changes, the estimates we make also changes.

Let us say in the surface you have just watered the soil. So, the soil moisture will be very high, as soon as you wetted the soil using some water the soil moisture will suddenly increase in the surface, then slowly it will go down. Say this is the root zone in 1 meter depth. If I calculate the soil moisture within the first 5 centimeters I may calculate it as 0.9 very close to 1, it is just water. If someone else calculates soil moisture up to 1 meter depth it can be something like 0.5. So, that is like a huge difference, the depth of measurement is going to change the way how moisture is distributed within the soil column. So, this is really important to understand. So, how remote sensing is helpful to retrieve soil moisture?

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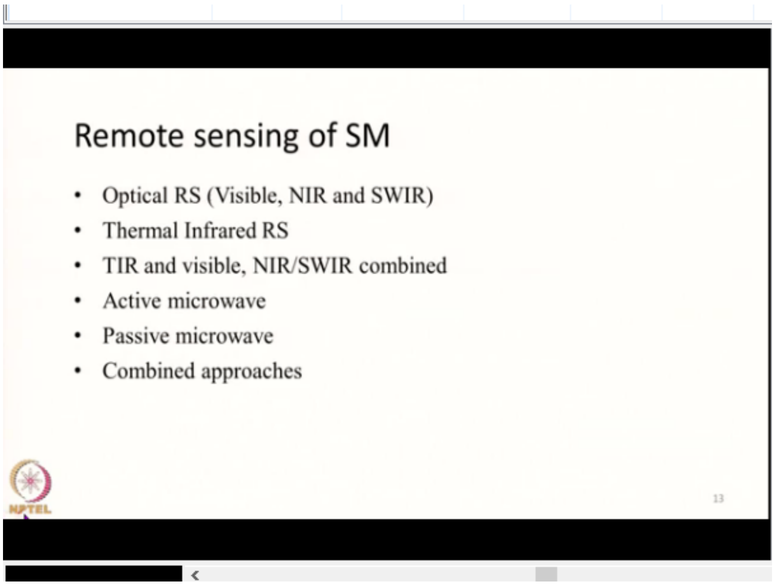

Remote sensing of SM

- Optical RS (Visible, NIR and SWIR)
- Thermal Infrared RS
- TIR and visible, NIR/SWIR combined
- Active microwave
- Passive microwave
- Combined approaches

Almost the different, different kinds of remote systems that we have seen optical, thermal, active microwave, passive microwave, combination of any of these are all helpful to retrieve soil moisture in some sense, we will quickly see certain examples of how these different kinds of remote sensing is helpful to retrieve soil moisture.

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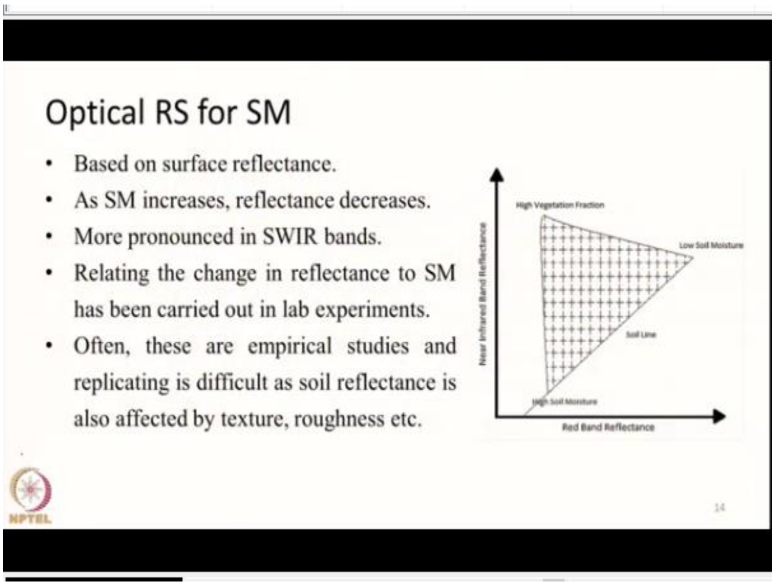

Optical RS for SM

- Based on surface reflectance.
- As SM increases, reflectance decreases.
- More pronounced in SWIR bands.
- Relating the change in reflectance to SM has been carried out in lab experiments.
- Often, these are empirical studies and replicating is difficult as soil reflectance is also affected by texture, roughness etc.

First we will start with the optical remote sensing for soil moisture. Optical here means using surface reflectance in the visible, NIR and SWIR bands. So, we have already seen that whenever water is added to soil its reflectance will go down and the reflectance is more pronounced in SWIR bands. So, this we have discussed in detail when we discussed about the spectral reflectance characteristics of different land surface features.

So, reflectance is an indicator or soil moisture is one of the primary control of reflectance as soil moisture increases, reflectance will decrease. Using this property people has estimated the moisture content of the surface in some studies. But almost all the studies that try to relate the change in surface reflectance with soil moisture are empirical in nature. Empirical in the sense they are either done in controlled lab conditions or in field conditions which are well known normally. Because reflectance not only depend on soil moisture but also depend on several other factors. Say for soil, its organic content will reduce the reflectance. So, when there is organic soil and inorganic soil, let us assume both of them have same moisture content, but organic soil may still appear darker because of its organic content.

So, these are all some other variables which will change the reflectance of the soil. So, we know that soil moisture will influence reflectance, but there is no direct relationship that we can establish and that we can apply to various regions to estimate soil moisture, but there are some studies which used this reflectance with soil moisture to do it, but not often used.

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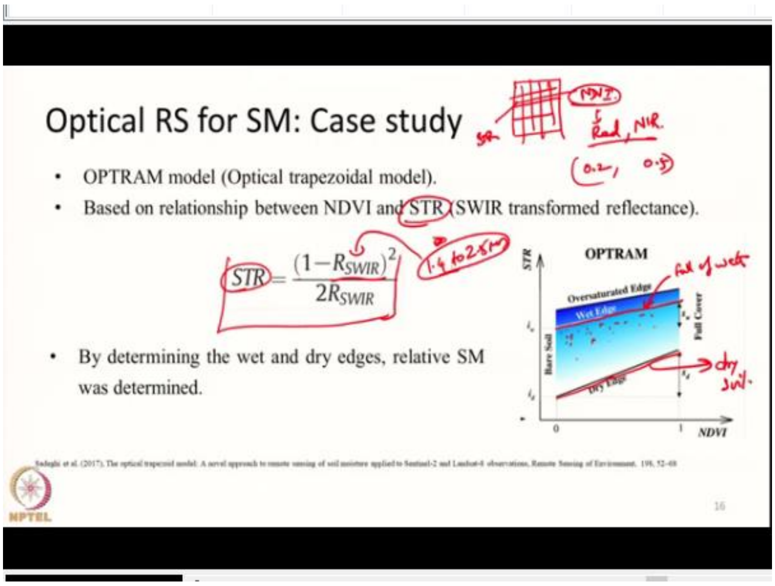

Optical RS for SM: Case study

- OPTRAM model (Optical trapezoidal model).
- Based on relationship between NDVI and STR (SWIR transformed reflectance).

$$STR = \frac{(1 - R_{SWIR})^2}{2R_{SWIR}}$$

- By determining the wet and dry edges, relative SM was determined.

Sadeghi et al. (2017). The optical trapezoid model: A novel approach to remote sensing of soil moisture applied to Sentinel-2 and Landsat-8 observations. Remote Sensing of Environment. 198, 52-68

However, recently there was a model developed called OPTRAM optical trapezoidal model which showed that, with using the reflectance data it is possible to retrieve soil moisture. So, there the authors have used what is known as the STR that is SWIR transform reflectance. That is, we have the surface reflectance data in SWIR band typically lying between say 1.4 to 2.5 micrometer within this range. If we measure the surface reflectance then transform it to some sort of a scaled variable,

$$STR = \frac{(1 - R_{SWIR})^2}{2R_{SWIR}}$$

So, this is the STR, the transform reflectance. Then for each pixel within a image, we will have this STR value and correspondingly we will have NDVI value for that particular pixel.

So for a given study region, try to plot the values of NDVI and this STR for all the pixels. Let us say for one pixel the NDVI is 0.2, STR is 0.5. So, this is like a coordinate. So, the x coordinate is 0.2, y coordinate is 0.5. So, similarly if we plot it for all the pixels then it will appear in form of a scatter plot like this and within this scatter plot we can define 2 edges. One is called the dry edge and the top end is called the wet edge, where the wet edge signifies the soil that are full of water and the dry edge signifies that are dry soils. So, once we fit this envelope then for any pixel having a corresponding value of NDVI and this STR we can calculate the moisture content. So, this is a very simple exhibition I am not going to discuss in detail about how the model works, what are the physical assumptions behind it and all.

In early days many people were not able to successfully retrieve reflectance based soil moisture, but in the recent past, few studies have demonstrated that retrieval of soil moisture is possible from optical remote sensing datasets. But again there will be high influence of vegetation, other variables which can change the reflectance. So, all these things we have to keep in mind while retrieving reflectance based soil moisture.

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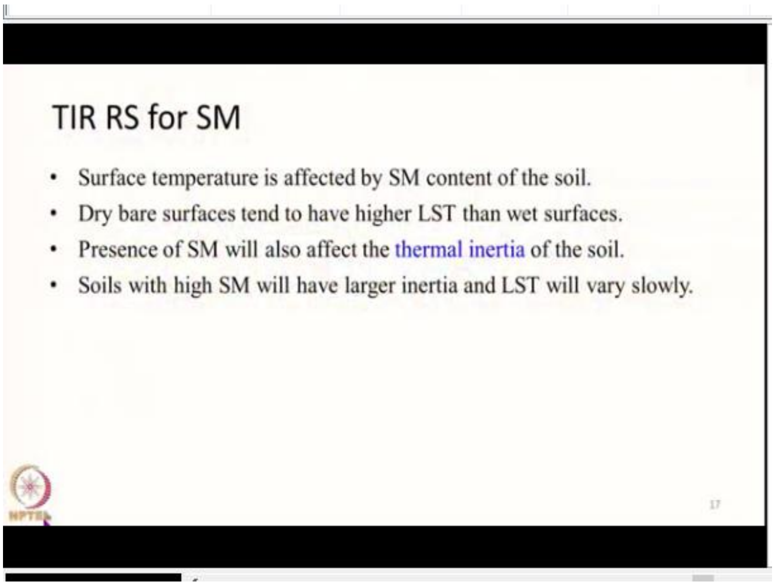

TIR RS for SM

- Surface temperature is affected by SM content of the soil.
- Dry bare surfaces tend to have higher LST than wet surfaces.
- Presence of SM will also affect the thermal inertia of the soil.
- Soils with high SM will have larger inertia and LST will vary slowly.

Next we are going to see soil moisture estimation using thermal infrared remote sensing. Surface temperature will change when a soil is dry or wet. If the soil is dry most of the incoming radiation will be used up to heat up the surface. So, the surface will be at a higher temperature, whereas, if we add water to the surface then the incoming radiation will be used up by the water to evaporate and then the energy will be used up by the water itself for this phase transformation.

So, the surface temperature would not have increased to large extent. So, wet soils will be cooler, dry soils will be warmer. Using this technique people has estimated soil moisture. In addition to this the thermal inertia of the soil also will vary, like wet soils have high thermal inertia, their temperature will not change much within a day, whereas for dry soils the temperature will change drastically within a day. So, observing multi temporal surface temperature measurements like what is possible from geostationary satellites, it is possible to retrieve soil moisture. An example for thermal inertia is given below. This is over a particular area or a field in Karnataka state from ground measurements basically. Here you can see the surface temperature measurements actually shows very large difference in diurnal cycle whereas, when the soil is wet the diurnal cycle is more subdued.

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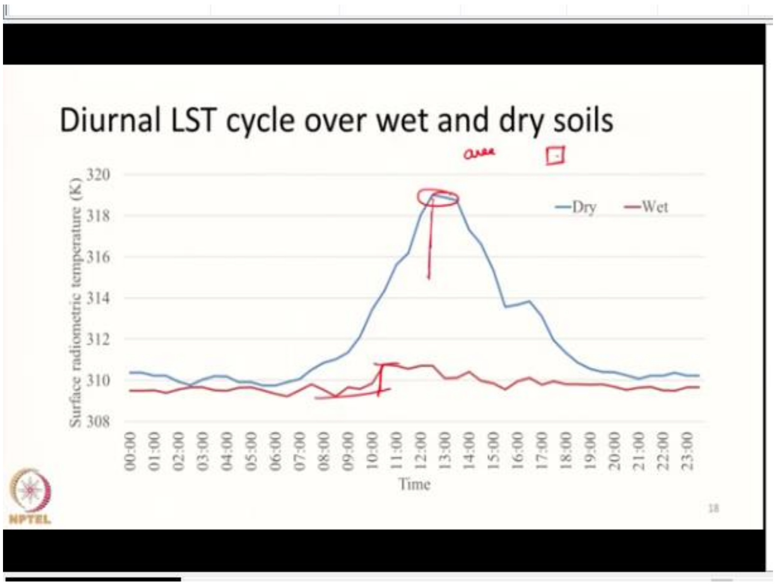

The temperature difference between the maximum minimum is pretty low in order of few Kelvin, whereas it is almost in order of the 10 Kelvin when the soil is dry. So, the thermal inertia property can be used to estimate soil moisture. But again this is not straightforward task, because soil moisture also can change within a day, someone may irrigate or some kind of drying can happen. But some studies have utilized these properties of thermal infrared remote sensing datasets, that is the land surface temperature to estimate soil moisture. So, the combination of optical remote sensing and thermal remote sensing is again useful for the estimation of soil moisture.

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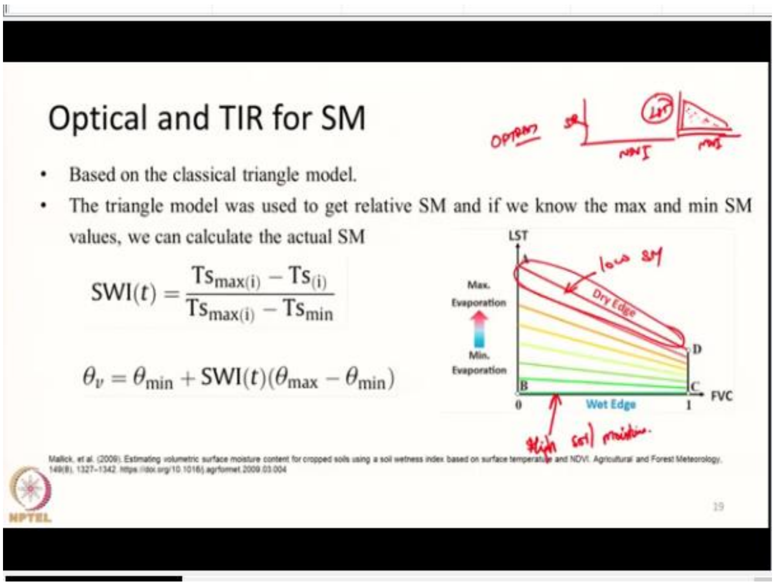

Optical and TIR for SM

- Based on the classical triangle model.
- The triangle model was used to get relative SM and if we know the max and min SM values, we can calculate the actual SM

$$SWI(t) = \frac{Ts_{max(i)} - Ts_{(i)}}{Ts_{max(i)} - Ts_{min}}$$

$$\theta_v = \theta_{min} + SWI(t)(\theta_{max} - \theta_{min})$$

Mallick, et al. (2009). Estimating volumetric surface moisture content for cropped soils using a soil wetness index based on surface temperature and NDVI. Agricultural and Forest Meteorology, 149(8), 1327–1342. https://doi.org/10.1016/j.agrformet.2009.03.004

Similar to OPTRAM model here we plot LST and NDVI, where LST is the land surface temperature that you get from thermal imagery. If you plot it, it will form a triangle like this;

all the scatter will fall as a triangle where this top edge is called the dry edge which represents low soil moisture conditions and this bottom edge is called the wet edge which represents high soil moisture conditions. So, over our study region if we can estimate this LST and NDVI, if we can plot them together and from that scatter plot, we will be defining this dry edge and wet edge and after defining them we can estimate soil moisture. This is again one of the widely used models for estimating soil moisture by combining thermal infrared and optical datasets.

Here we are primarily using NDVI. Because NDVI forms the x axis and LST forms the y axis. So, these are all very simple models for estimation of soil moisture from optical or thermal or combination of optical and thermal remote sensing. And let us see the pros and cons of this optical remote sensing basically.

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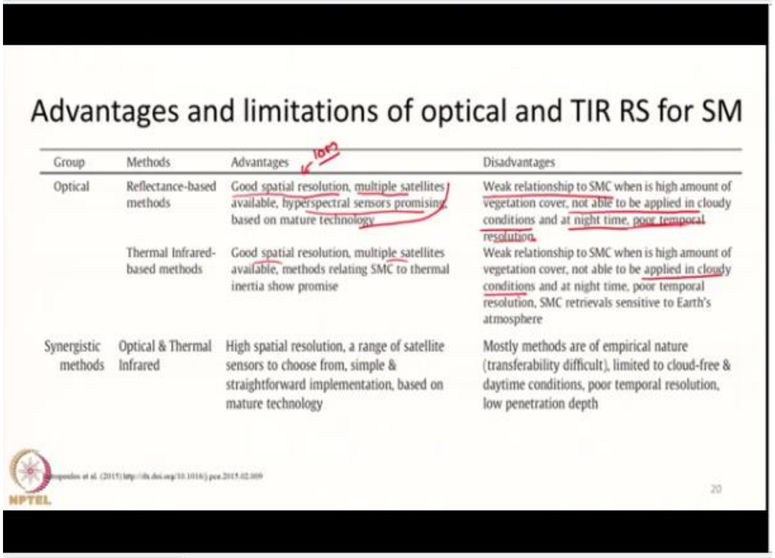

Advantages and limitations of optical and TIR RS for SM

Group	Methods	Advantages	Disadvantages
Optical	Reflectance-based methods	Good spatial resolution, multiple satellites available, hyperspectral sensors promising, based on mature technology	Weak relationship to SMC when is high amount of vegetation cover, not able to be applied in cloudy conditions and at night time, poor temporal resolution.
	Thermal Infrared-based methods	Good spatial resolution, multiple satellites available, methods relating SMC to thermal inertia show promise	Weak relationship to SMC when is high amount of vegetation cover, not able to be applied in cloudy conditions and at night time, poor temporal resolution, SMC retrievals sensitive to Earth's atmosphere
Synergistic methods	Optical & Thermal Infrared	High spatial resolution, a range of satellite sensors to choose from, simple & straightforward implementation, based on mature technology	Mostly methods are of empirical nature (transferability difficult), limited to cloud-free & daytime conditions, poor temporal resolution, low penetration depth

10m

...opoulos et al. (2015) http://dx.doi.org/10.1016/j.pce.2015.02.009

Say first thing reflectance based methods which has a good spatial resolution. Nowadays we have data available at say 10 meter resolution freely. So, we can theoretically estimate soil moisture at 10 meter, multiple satellites are available and for very long time say from 70s onwards we have a good time series of data, hyperspectral sensors are promising. So, all these things are advantageous, very high spatial resolution, multiple satellites, hyperspectral sensor can still provide very good information and so on. But the major disadvantages are the reflectance is weakly related to soil moisture content, because the reflectance can change not only with respect to soil moisture content but also with other things. And also reflectance based models cannot be applied during cloudy conditions, because during cloudy conditions we will not be in a position to observe the earth, we can see only the clouds. At night time we cannot do it because we need sunlight to calculate reflectance and the sunlight will not be available at night. Atmospheric effect plays a major role and also the models that use temperature and reflectance together or NDVI together have lot of assumptions involved.

If those assumptions are not satisfied the model may poorly perform. So, effectively optical and thermal remote sensing can estimate soil moisture, but soil moisture is not highly correlated with what we measure in optical remote sensing or thermal remote sensing. So, this is not one of the widely used techniques. So, for estimating soil moisture microwave remote sensing is often used and we will discuss how microwave remote sensing is useful for soil moisture estimation in the next lecture.

Thank you very much.