Remote Sensing: Principles and Applications
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Lecture-66
Application of RS in Water Resources Management-Part-3

Hello everyone, welcome to the next lecture in the course. We are discussing about the applications of remote sensing in water resource management where we discussed about the different ways of estimating ET that is evapotranspiration and also we started discussing about soil moisture. So, we discussed what soil moisture is; the different depths of soil moisture measurement; how it will play a role in optical and thermal methods of estimating soil moisture. Today we are going to cover how microwave remote sensing is useful in soil moisture estimation.

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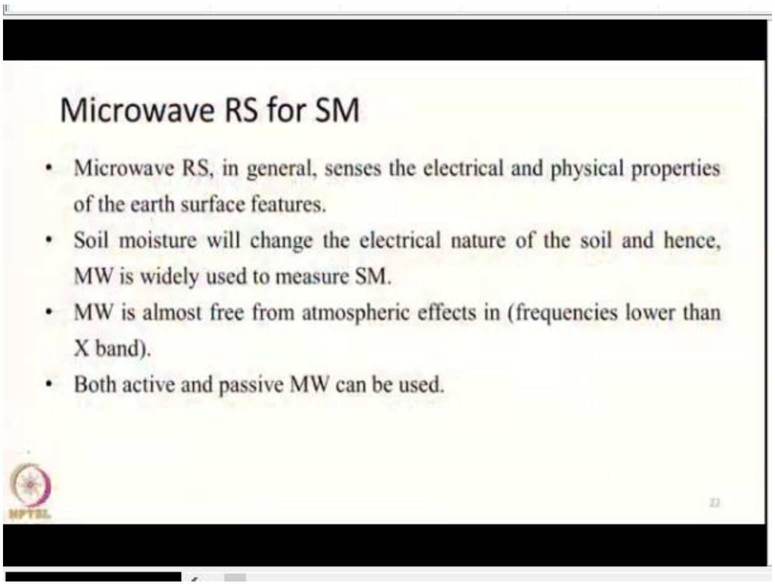

While discussing microwave remote sensing, both active and passive, I told that microwave signals react to the electrical and physical properties of the features on the earth surface. That means whenever water is added to the soil, it will change the electrical property of the soil which will be picked up by the microwave signals. Both active as well as passive microwave can be used for that purpose, we have seen some examples while dealing with those particular topics itself. So, here we will see the basic principles behind the estimation of soil moisture from passive and active microwave remote sensing.

First we will start discussing about the passive microwave radiometry for soil moisture estimation. We have already seen that passive microwave radiometers measures or observes brightness temperature. The brightness temperature depends on the actual temperature of the object and the emissivity of the object. T_b = emissivity × T in microwave wavelength.

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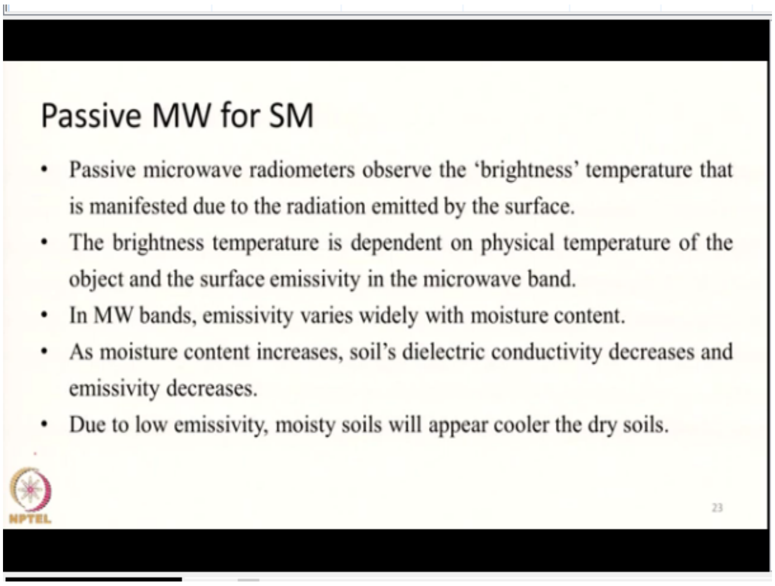

Whenever a soil is wet, the emissivity will change. For dry soils in microwave wavelengths, emissivity will be higher. When the soil gets wet, the emissivity will go down due to which the brightness temperature of wet soils will be lower than the brightness temperature of dry soils. Observing this particular difference is helpful in retrieval of soil moisture estimation from passive microwave radiometry.

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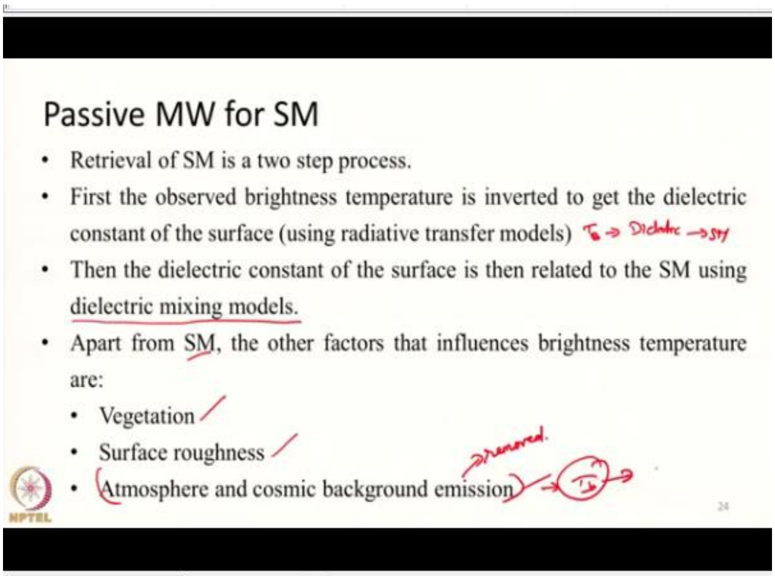

Retrieval of soil moisture is a two-step process. First the brightness temperature observed by passive microwave radiometers has to be inverted to get the dielectric constant of the surface. Dielectric constant is a property of the object which relates to its electrical nature. So, the first relationship is from T_b or brightness temperature. Scientists will try to retrieve the dielectric constant through radiative transfer models. So, the radiative transfer models will be able to simulate this and they will be trying to use this brightness temperature to retrieve the dielectric constant. And once it is done, using physical or empirical relationships people would try to connect this dielectric constant with the soil moisture. This is done using dielectric mixing models. So, first from the brightness temperature we get the dielectric constant and from this dielectric constant we go to soil moisture. It is kind of a two-step process.

Apart from soil moisture the brightness temperature is also influenced by vegetation, surface roughness, atmospheric and cosmic background emission. So, basically when we get brightness temperature the atmosphere and cosmic background emission effects will be removed or at least reduced to the great extent by the data providers. So, the brightness temperature what we get after processing can be assumed to be free from these effects. But still we have to account for the effects of vegetation and surface roughness while we are trying to retrieve soil moisture.

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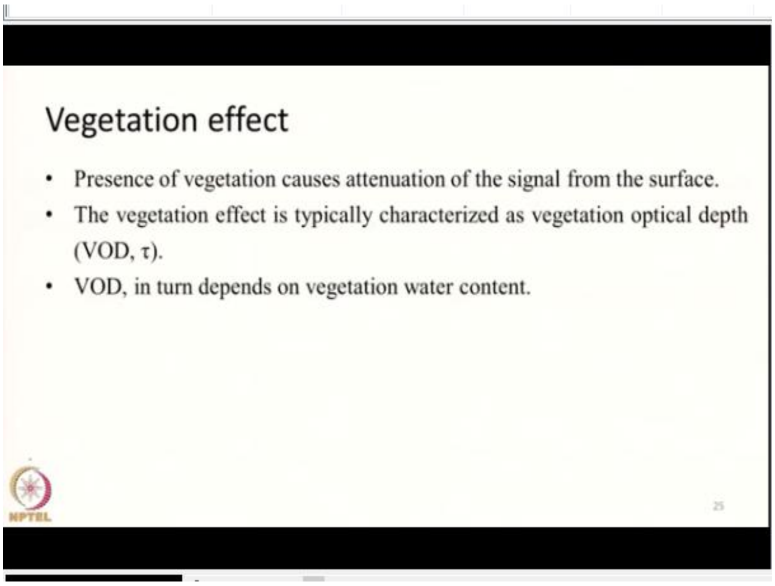

Presence of vegetation above the soil will attenuate the signals from the soil. So, whenever a microwave radiometer sees a land surface containing vegetation and soil together, then the microwave emission from the surface is going to be attenuated as it passes through the canopy. And we have also seen that longer wavelengths or shorter frequencies are capable of penetrating the canopy to a better extent than shorter wavelengths. Studies have proven that L band is suitable for soil moisture estimation that is why we have two dedicated missions SMOS and SMAP for soil moisture estimation operating in the L band. So, this vegetation effect is typically characterized as vegetation optical depth. Say there is a pixel, so whatever vegetation present over there, will have water content in different parts whether it is trunk, stems or leaves, vegetation will be present. Even in the case of recent rainfall the leaves on the top will contain a rain droplet that is again water present in the vegetation system.

All these things combined will affect the signals from the soil. So, the vegetation optical depth typically characterizes the vegetation water content. Say if you have a 2D pixel, imagine a 3D volume. So, whatever the water contained within that particular volume will affect the signals in the soil. So, it will be modeled or it will be obtained through some other ancillary measurements in order to remove the effect of vegetation.

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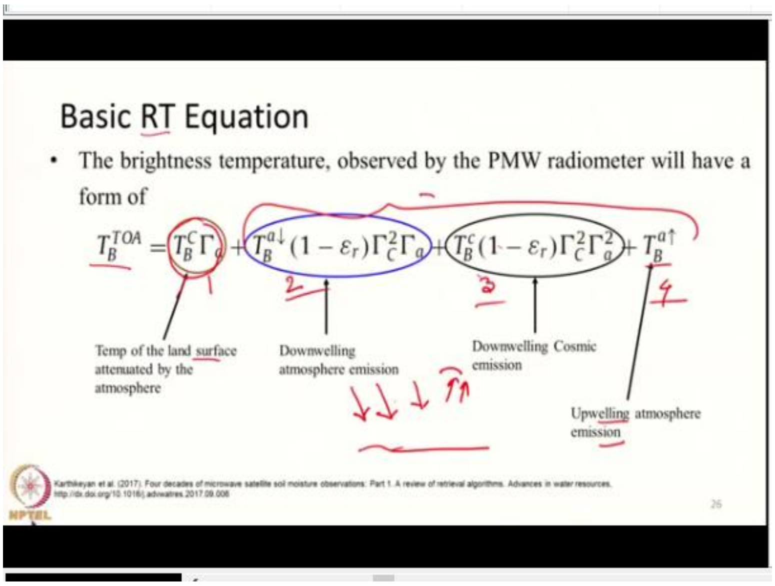

So, the basic radiative transfer equation that has the brightness temperature observed by the satellite sensor majorly comprises of 4 different components. The first thing is temperature of the land surface that is the brightness temperature of the land surface attenuated by the atmosphere. This is component number 1. The downwelling atmospheric emission that is, if there is a land surface, some part of the particular land surface will receive emission from the atmosphere. That is component number 2. Similarly we have also seen the cosmic emission that is the emission from the outer sky may influence their measurements. So, that is component number 3 and component number 4 is upwelling atmospheric emission. So, the upwelling atmospheric emission is what is going towards the sensor directly from the atmosphere. So, among the brightness temperature components, components 2, 3, 4 are actually atmospheric and outer space components which are kind of unwanted things to us. So, once we remove it then essentially we will be left with the brightness temperature from the land surface which we can use further in order to deduce soil moisture.

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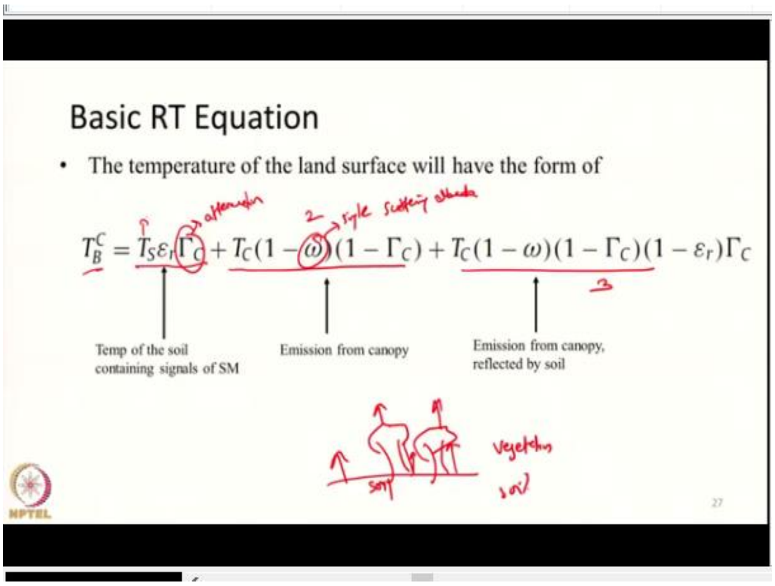

And this brightness temperature from the land surface again comprises of different, different components. Even the land surface has several components within it, there can be soil, there can be vegetation standing over the soil or some other features. If we assume that the land surface is comprised of vegetation and soil, then the brightness temperature can be split into the first component, temperature of the soil which contains the signal of soil moisture. So, T_s is the thermodynamic temperature of soil and ε is the emissivity, then emission from the canopy, because canopy also has its own temperature that will do some emission. Then the emission from the canopy towards the soil that gets reflected that is third part.

So, in the three parts we have one, the direct emission from the soil that is attenuated by the canopy, it has to pass through the canopy if something is present. Then the direct emission from the canopy and the third part is the emissions from the canopy in the downward direction reflected by the soil. So, among these things, again we have this parameter what is known as the attenuation parameter by vegetation. Then we have what is known as the single scattering albedo and so on. So, there are several variables involved but for the sake of simplicity we will not discuss all these things in detail here.

But just as an overview the brightness temperature of the land surface observed by a passive microwave radiometer again comprises of 3 components, out of which only one component is of direct interest to us. So, the emission from the canopy component has to be removed from this and that is why scientists will always work towards this VOD vegetation optical depth as one of the parameters which contain information about vegetation.

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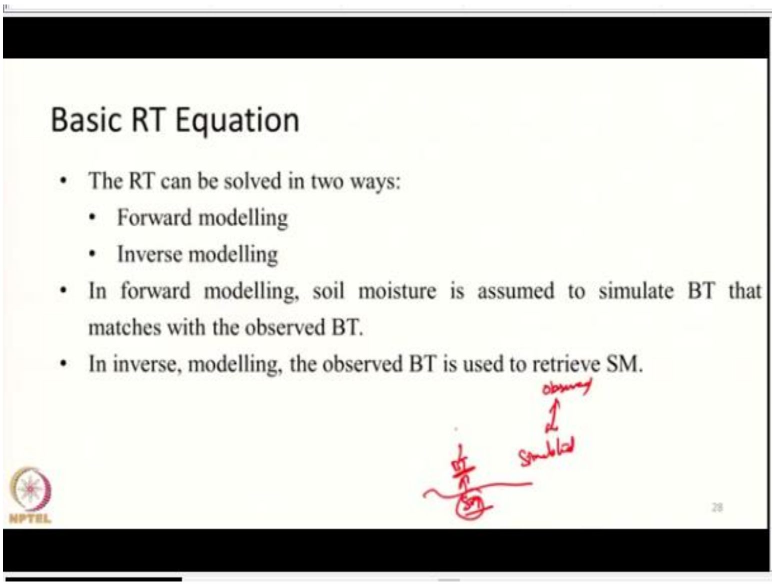

So, the basic radiative transfer equation what we have just seen comprise of 3 methods can be solved in 2 ways either in forward modeling way or in inverse modeling way. In the forward modeling, the soil moisture is assumed as given a particular value, so that the brightness temperature will be simulated and it will be matched with the observed brightness temperature. That is due to some effects of soil moisture, the land surface will have a particular brightness temperature.

So, this particular brightness temperature will be simulated by feeding the model with soil moisture and this will be simulated and whatever is observed by the satellite will be compared with this and the errors will be minimized by playing with the parameter. So, this kind of modeling is called forward modelling. Assume an initial value of soil moisture and try to retrieve brightness temperature and match it. This is one way.

In the other way satellite has already observed brightness temperature. So, using that particular brightness temperatures, use the radiative transfer model in the reverse fashion, that is now I know what is the emission from the land surface. So, what caused that emission? so come in the reverse direction. That is called inverse modelling. So, soil moisture can be modelled in both the ways. Normally brightness temperature will be fed into radiative transfer models to estimate soil moisture. That is how normally the satellite based retrievals will work.

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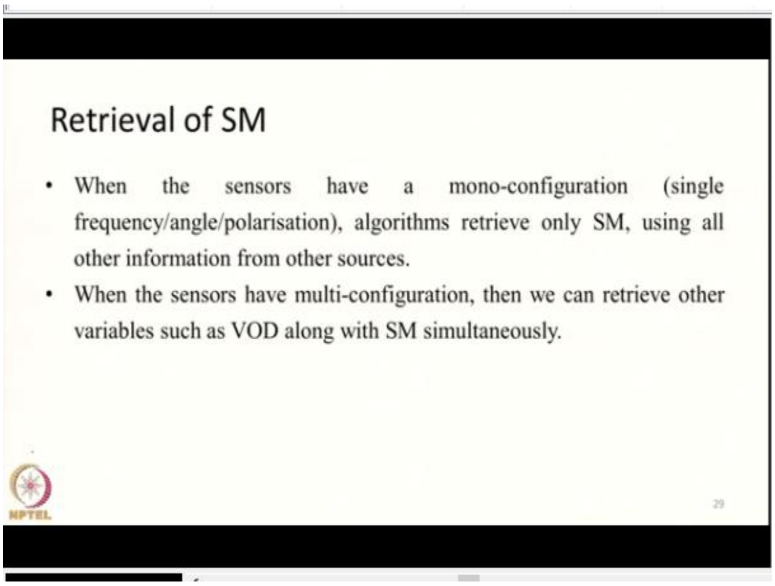

So, again we need to account for vegetation parameters as well as surface roughness parameters. There are different classes of algorithms exist based on the sensor characteristics. If a sensor has a mono configuration which means a single incidence angle, single frequency or a fixed polarization, everything is fixed without any change, then the algorithms that are developed to retrieve soil moisture has to depend upon other ancillary datasets in order to estimate vegetation and surface roughness properties.

ATBDs, algorithm theoretical basis documents of SMAP SM retrieval measurement or SMOS SM retrieval measurement are publicly available documents which has all the technical information about other ancillary data that are used by the scientist. If the sensors configuration is very simple and without much options available for us, then essentially the vegetation information or the surface roughness information has to be obtained independently.

So, some ancillary data sets has to be developed, but if the sensor has multiple configuration say a dual frequency or a dual polarization, then the algorithms can be suitably modified in order to retrieve soil moisture, VOD and a surface roughness simultaneously. So, normally if you take the SMAP soil moisture retrieval algorithms, we have both the single channel algorithm and dual channel algorithm.

In the single channel algorithm the vegetation properties or the VOD will be estimated using NDVI information available from optical datasets, whereas in dual channel algorithm the vegetation optical depth will be retrieved simultaneously along with soil moisture. So, based on the satellite configuration and the data available to us there are again variety of algorithms available to us.

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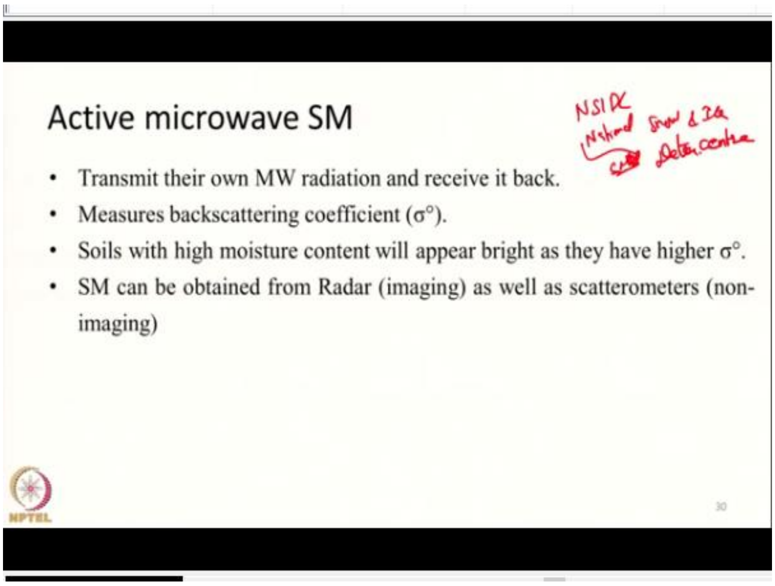

So, this is with respect to passive. So, the basic principle is from the brightness temperature observed separating the unwanted effects like first removal of atmospheric effects, then removal of canopy effects and surface roughness effects will lead us to the retrieval of soil moisture. This is the basic principle using which algorithms are being developed and operation data products are also available.

For soil moisture estimation we discussed about several data sources. So, this SMAP soil moisture data is available from what is known as the NSIDC national snow and ice data center which contains soil moisture data obtained from SMAP satellite. It is free downloadable, it is available at 36 km resolution, 9 kilometer resolution, at multiple temporal frequencies, different levels and so on. So, interested users can download the data which is available in HDF format.

Next we move on to the active microwave for soil moisture. So, similar concept addition of water to the soil will increase its back scattering coefficient. So, wet soils will appear brighter in active microwave images. But the problem with active microwave remote sensing is, in comparison with passive microwave active microwave remote sensing is highly influenced by surface roughness parameters and vegetation parameters. So, they have to be perfectly modelled or a ground measurement has to be taken care of in order to retrieve soil moisture from active remote sensing.

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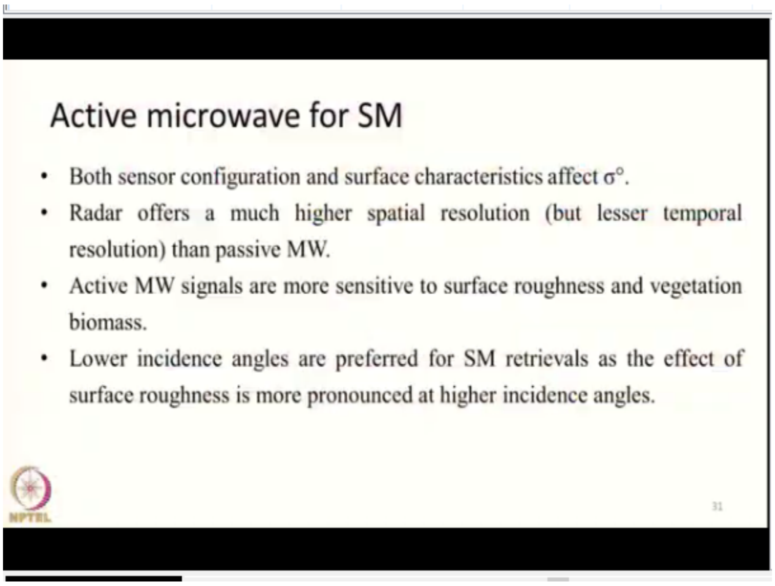

So, in active remote sensing both the sensor configuration that is which frequency it is observing, at what look angle it is collecting the data and what polarization is collecting the data, all these kind of sensor configuration and the surface characteristics especially the presence of surface roughness and vegetation characteristics will influence soil moisture estimation.

So, the advantage that active microwave remote sensing has over passive microwave is its spatial resolution. Say we have already seen that passive microwave radiometers will have a very coarse spatial resolution in the order of few kilometers and the soil moisture observing missions has spatial resolution close to 30, 40 kilometers. So, each pixel size will be roughly 30 kilometers or 40 kilometers or at best the disaggregated product itself will be available at say 9 kilometers and so on which is kind of extremely coarse for various applications for regional or local level applications.

But active remote sensing can provide data in the order of 100s of meters or sometimes satellites like Sentinel provides data around 10 meters or 20 meter resolution. So, if we can collect all the information required for soil moisture estimation, surface roughness and all, theoretically it is possible to retrieve soil moisture at 10 meter or 20 meter pixel size which is large improvement when we compare this with the passive microwave radiometry.

But as I told the surface roughness effect has to be removed and this surface roughness effect comes into picture to a larger extent when the satellite or the look angle changes like normally the lower angles are preferred rather than comparing with higher angles, like look angle and incidence angle. These 2 are relatively used or interchangeably used. So, normally lower incidence angles are preferred for soil moisture estimation because at higher incidence angle surface roughness effect is more pronounced.

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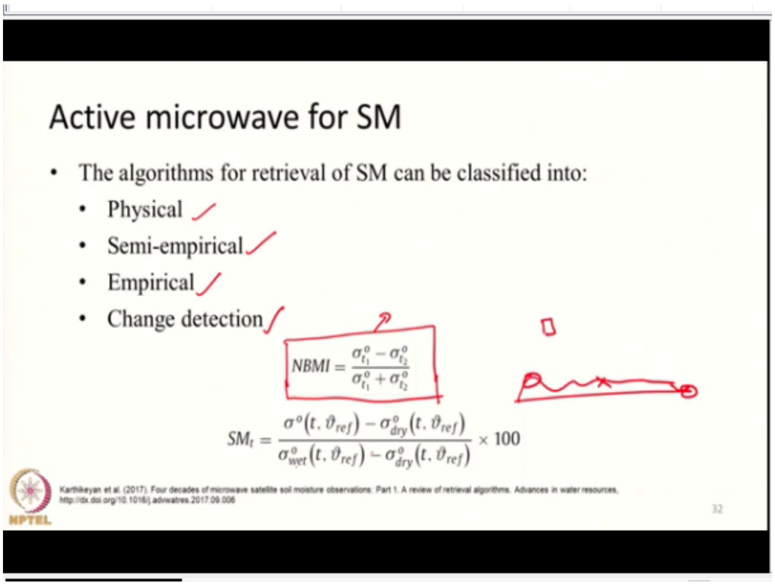

The different classes of algorithms available for the retrieval of soil moisture can be classified as physical models, semi empirical models, empirical models and change detection methods. So, physical models uses physics based equations relating backscatter coefficient to dielectric constant and then relating dielectric constant to soil moisture. So, these are physical equations.

The problem with physical equations is they demand a lot of data. If we want to remove surface roughness effect we need to know the surface roughness and also we should measure RMS height. So, there are some instruments called micro profilometry which we should take to field and then measure how the topography varies very minutely.

All these things we have to do, we have to calculate the RMS height and feed it or sometimes we may have to measure vegetation parameters carefully or we may have to measure even soil moisture at the time of satellite overpass. All these things may be required for physics based model. So, normally physics based models can retrieve high quality soil moisture provided we give all sort of data required by it.

So, that is one class of algorithm, then semi empirical model. So, they are kind of a balance between physics equation and what we measure in field really. There are like plenty of equations but just schematically speaking let us say there is an equation relating dielectric constant with the back scattering coefficient.

So, this equation is of highly physical which involves lot of parameters to measure. Can we model it by directly measuring soil moisture and can we relate back scattering coefficient to soil moisture? So, doing some sort of simplified assumptions and using ground measurements to substitute in the physics based equation is semi-empirical. So, it is a combination of field developed equations and vegetation parameters like NDVI or LAI. That may be valid for that particular region which can be used in the physics based equations. So, these kinds of models are semi empirical. Then comes empirical which is directly relating the back scattering coefficient with field observed value.

Say you have a region, we observe soil moisture at certain plots at the time of satellite overpass and we somehow try to develop a relationship between the soil moisture and the satellite backscattering coefficient. So, then using the back scattering coefficient at all other plots and using this relationship developed we can estimate soil moisture. So, the empirical models are extremely simple. But at the same time they can be applied only over the region where the relationships are developed and they are non-transferable and even non-scalable. Even if the satellite parameters changes then the equation will change and also measurements has to be taken at the time of satellite overpass which again may complicate the data requirements.

The final class of model is the change detection models. So, the change detection based models will not actually retrieve the true soil moisture value, but they do some sort of a relative level, the change between 2 time intervals. If we have some reference soil moisture, with respect to that reference how the soil moisture changed. So, we can always get to this relative change. So, the change detection methods works like a simple equation is given here. So, normally there are different, different ways in which it can be done. So, this is normalized radar backscattering moisture index which works based on the backscattering coefficients observed at time T_1 and T_2. This equation is developed based on having a reference dry and wet backscattering coefficient values for one particular pixel.

we need to have a large time series of data, say data within the time series like the minimum and the maximum and if this is in between backscattering coefficient value, how this changes? So, this is kind of relative measurement. So, basically change detection methods assume the vegetation characteristic and the surface roughness characteristic changes in a much slower way in compared to the soil moisture. That is we always compare the backscattering coefficient in time T_1 and T_2. If we assume the change in backscattering is only due to change in soil moisture then obviously we are assuming that surface roughness parameter has not changed much and vegetation parameter has not changed much.

So, these are again simplified representations of real world. These kind of change detection techniques may be applicable over crops which has longer seasonality where the vegetation growth takes place slower and the surface roughness may not change. Once crops start growing; farmer will not try to disturb the surface characteristics. So, under those conditions it can work or under a uniform vegetation canopy then these things may work. Under natural environments this may work. But again there are limitations but still change detection algorithms are one of the most widely used algorithm for soil moisture estimation.

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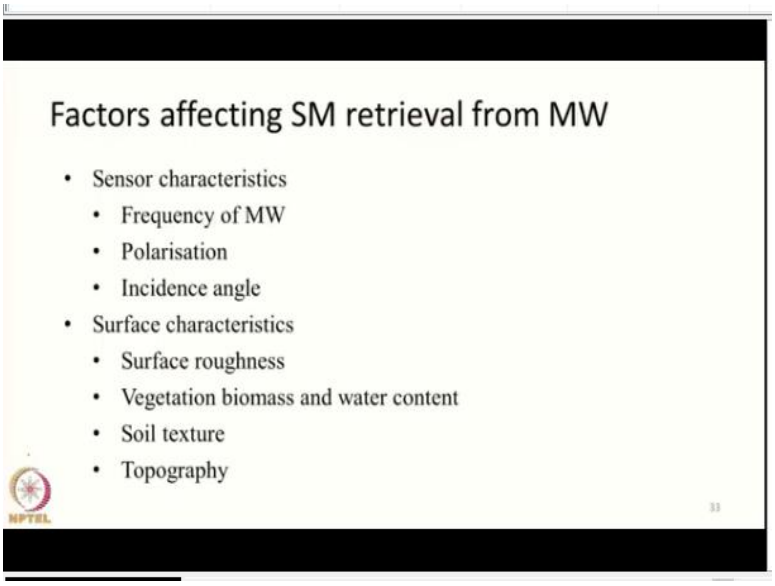

The different factors that affect soil moisture retrieval from microwave are the sensor characteristics, the frequency, polarization, incidence angle and the surface characteristics which includes surface roughness, vegetation biomass and water content, soil texture and topography. In active microwave remote sensing the overall backscattering coefficient can change based on the topography. Whether it is on a flat topography or the topography is facing outwards or away from the radar and so on. All these things will play a major role. So, essentially our aim is to remove all other effects apart from soil moisture for us to retrieve soil moisture from this particular method. So, on overall comparison between active and passive microwave methods, the passive microwave is actually highly related to soil moisture and hence the results are very much promising especially over bare soils and also they are not affected by clouds or daytime conditions. They provide high temporal resolution in the order of once every 2 days, once every 3 days or sometimes model based data comes every 3 hours once.

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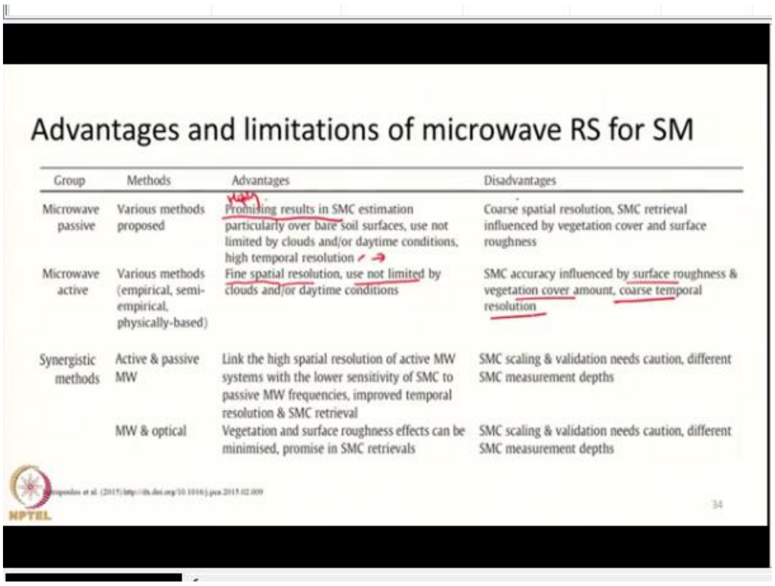

So, passive micro radiometers are the best ones at least now to provide soil moisture, but the major disadvantage with them is their coarse spatial resolution which is available in order of kilometer scale and hence we need to develop some sort of disaggregation or down scaling algorithms to bring this coarse resolution soil moisture to fine spatial resolution. So, active microwave again goes over this limitation, it provides us fine spatial resolution and it is not affected by cloud cover.

But at the same time it is highly influenced by surface roughness and vegetation amount and coarse temporal resolution. Say active microwave data from sentinel-1 and 2 combine we may get data once every 6 to 8 days as of now. But if you look at olden days data may be available once every 20 days and so on. So, the temporal resolution is bit coarser and the influence of surface roughness and vegetation cover is very high when we compare this with passive.

So, in order to overcome the limitations of passive, scientists are trying to combine optical data like thermal, visible, NIR data with passive microwave data for improving the spatial resolution and also both active and passive combinely are being used. Say the SMAP mission has a SMAP sentinel combined soil moisture product at 3 kilometer spatial resolution. So, that is combination of active and passive remote sensing.

So, this is kind of a trade-off, some characteristics of passive microwave will be taken, some characteristics of active microwave will be taken. Similarly thermal data is often integrated with passive microwave radiometry data in order to retrieve or in order to disaggregate soil moisture. So, this is also being carried out especially from the context of improving the spatial resolution of soil moisture observations.

So, again there are some advantages and disadvantages for these kind of synergistic methods especially when we discussed about the difference between passive microwave radiometry and thermal infrared. We discussed one important thing that is the depth of penetration. The thermal infrared remote sensing normally senses or observe only from the top millimeter of a surface, the skin temperature. So, essentially the soil moisture that we retry from it will have only the top surface soil moisture information, be it canopy, it will see only the canopy. If it is bare soil it will see only the top portion of soil, whereas microwave especially longer wavelengths will have certain penetration capacity. If there is a canopy standing over the soil, some sort of penetration would have occurred or if it is bare soil the depth of measurement may be few centimeters atleast say 4 or 5 centimeters. So, the depth of measurement of soil moisture observed by passive microwave radiometers and thermal infrared sensors are different.

So, when we try to combine them we should keep this difference in mind. So, we already know if the depth of measurement changes, the soil moisture amount may change or what we actually want for our application will be different from what is actually measured. We may be wanting root zone soil moisture, whereas thermal infrared measurements will only provide the skin soil moisture. So, this kind of differences will always come and we should keep in mind when we try to combine different wavelengths or different technologies of remote sensing together for improving the spatial resolution. So, this is a very broad overview of usage of microwave remote sensing for soil moisture estimation.

So, normally we cover this particular topic in a few weeks of lectures when we offer this as a part of course to the students here in IIT Bombay. But this is an introductory remote sensing course and I did not want to divulge more into the technical details and so I provided only a broad overview. There will be plenty of references in the slides which the interested users can always refer to. So, with this we end this particular lecture.

Thank you very much.