Remote Sensing: Principles and Applications
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Lecture-43
Passive Microwave Remote Sensing-Part-4

Hello everyone, welcome to the next lecture in the topic passive microwave radiometry. So, we are discussing the concepts about how a passive microwave radiometer will collect the signals from the ground, what that signal comprises of, and for a pixel what will be the total effect of the surface temperature and the sky temperature that will be reaching the antenna. And what will be the brightness temperature of a mixed pixel which contains more than one feature. So all these concepts we have been discussing.

In today's lecture we will get introduced to the concept of signatures in passive microwave radiometry. So, signatures here I mean how different objects will behave in passive microwave radiometry and what essentially are we looking to do with this data. So, just take an analogy of passive microwave radiometry with thermal infrared remote sensing. In thermal infrared remote sensing our major aim is to retrieve the surface temperature or the radiometric temperature and use it for various applications.

But in microwave radiometry we will be measuring the brightness temperature of the surface that is a product of true temperature and its emissivity. The antenna will measure the combined effect of surface atmosphere component that is reflected by the surface, direct emission by the atmosphere and some galactic effects, say what is coming in from the cosmos. All these things will combine and produce one single temperature in the antenna; this in turn will also be affected by the antenna pattern. So, all these things we have seen, so the final net temperature measured by the antenna comprises of the effects or includes the effect of surface, atmosphere, outer space and also the antenna pattern. The satellite data providers will remove the effect of antenna pattern and atmosphere and give us this antenna temperature. So, normally if you download a product from any microwave radiometry data, we will have the brightness temperature of the surface. So, this brightness temperature is after removing the effect of atmosphere and antenna pattern.

Effectively in a brightness temperature pixel, we will have the combined effect of emissivity and temperature of various features on the surface. We have also seen how they add up; within a pixel if there are more than one feature, the net brightness temperature of that particular pixel is more or less equal to the area weighted average of brightness temperature of each and every feature.

So, it is a simple relationship which we can keep in mind and imagine it easily. So, from this brightness temperature we will try to get meaningful data and use it for various applications. So, normally if you take example of usage of passive microwave radiometry for soil moisture estimation and all, for most of the applications we will not be interested in calculating the temperature of the surface. There is thermal infrared remote sensing to calculate the temperature of surface. Here from the brightness temperature we will try to get out or separate the effect of emissivity and temperature. Because the brightness temperature is a combination of emissivity and true temperature, we will try to remove this effect of temperature and see what is the net emissivity of that particular pixel. From that emissivity, we will try to infer some land surface information about the features.

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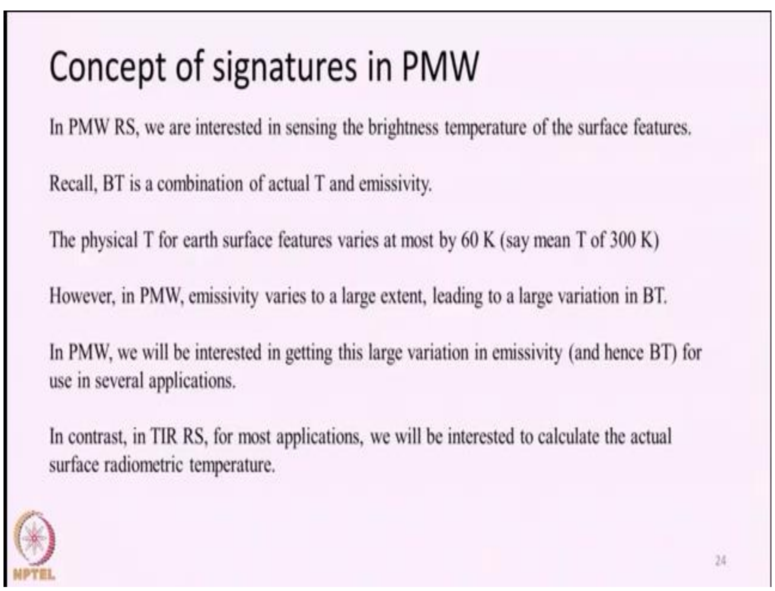

Say what is the soil moisture there or what is the snow cover information there, for such land applications, normally we will be interested in calculating the emissivity of that particular pixel and using it for different things. So, here in passive microwave radiometry for most of the applications our aim will not be calculating temperature rather it will be separating the effect of temperature and emissivity from the brightness temperature. And using that particular emissivity information, how to estimate several land surface features. So, essentially we are interested here in seeing how emissivity varies due to several conditions of the land surface. This is the major difference between what we do with the sensed temperature in TIR remote sensing and passive microwave remote sensing. Sometimes we will also be interested in stopping with emissivity but still for most of the applications we will be interested to calculate the temperature of the surface. So, this is how we use the brightness temperature data in passive microwave radiometry.

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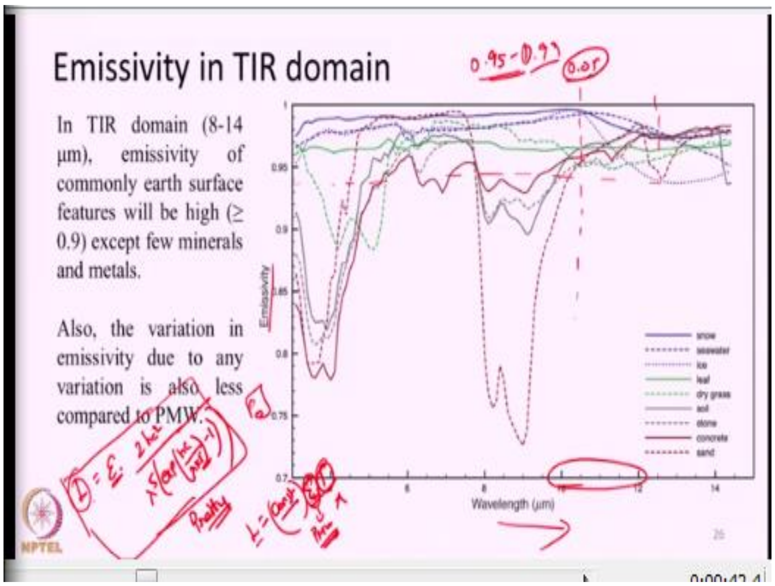

So, we will just take a look at variation of emissivity in TIR domain, we have already seen it in the TIR lectures but just as a quick recap I would like to recall it. Say this is a simple plot showing wavelength in x axis and emissivity of different features in the y axis. So, if you look at this 10 to 12 μm wavelength where we normally do our TIR remote sensing, we can see the emissivity of various features on the earth surface varies with a limited amount having a range of say 0.94 to 1 or we can even say 0.95 to 1. The variation is not much, just a 0.05 variation, not even like 1, it will be like 0.95 to 0.99 or something, no object is like a blackbody perfectly. So, the variation of emissivity is actually quite less in thermal infrared remote sensing between different features. And the effect of temperature will be very high in the total radiance produced by the land surface as said in Planck's law.

Planck's law tells us the total radiance emitted by an object is equal to product of emissivity into the Planck's equation times the temperature. Emissivity of different features does not vary much, temperature can vary say if you take within a pixel there may be house, there may be a water body etc. Water body may be at a different temperature, house may be at a different temperature and all these things will affect and produce a combined radiance. So, the influence of temperature on the total radiance is pretty high in TIR remote sensing. So, it is always better to calculate temperature from this particular wavelength, because whatever the radiation is produced the effect of temperature is more in comparison with the effect of emissivity.

Whereas in the passive microwave radiometry, the radiance produced is equal to a constant, say here the constant is 2 hc/λ^4, that constant multiplied by emissivity and T. So, here the radiance produced is a direct product of emissivity and T, so here the weightage that emissivity gets in controlling the radiance is pretty high, it almost has equal weightage with temperature. And in addition to this, emissivity of features will vary a lot in passive microwave remote sensing. So, this suggests that if you want to get some properties of earth surface, it is easy rather than concentrating on temperature it is easy for us to concentrate on this emissivity part and use it for understanding how emissivity varies with different land cover conditions.

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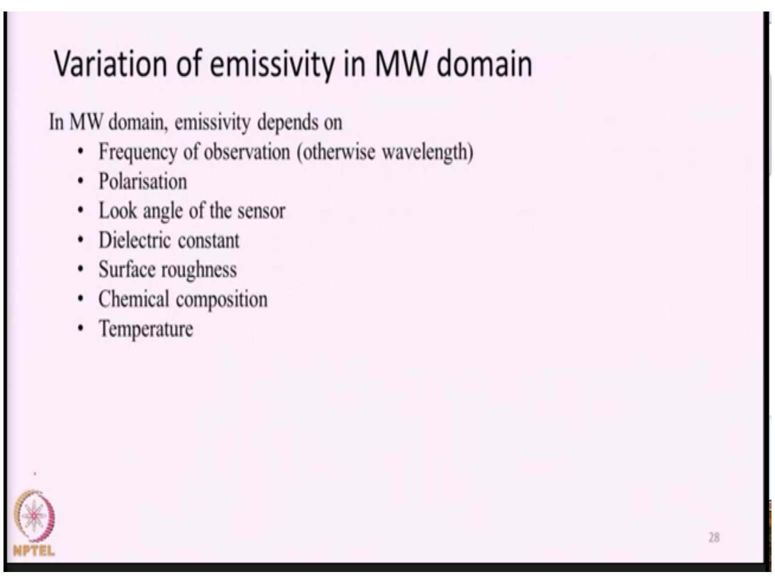

So, basically in microwave domain the emissivity of a particular feature depends on the wavelength or frequency of our observation. The polarization in which we are observing, the look angle of the sensor whether at nadir or at some angle away from nadir etcetera. That these 3 are basically the system properties or the sensor properties, wavelength, polarization and look angle. If you remove the system properties and if you look at the object properties then the emissivity of the object will vary based on its dielectric constant. So, dielectric constant is like dealing with the electrical nature of an object, so how good an object can conduct or not**.** So, based on the variation in dielectric constant the emissivity of the objects will vary, if an object is a good conductor of electricity or if an object is a good conductor in general, its reflectance in microwave wavelengths will be very high and by virtue of this the emissivity will go down. So, dielectric constant will influence emissivity to a large extent. Similarly surface roughness, whether a surface is smooth or rough that will influence the emissivity, the chemical composition of the surface and the temperature of the surface.

So, the major 2 factors which play a role in controlling the emissivity of the surfaces is, its dielectric constant and surface roughness. So, in most of the applications of passive microwave radiometry like estimation of soil moisture, ocean salinity and all these things, scientists will be interested in finding out the relationship between the emissivity and dielectric constant. And from that dielectric constant how to get the surface properties whether it is soil moisture or ocean salinity or snow cover area whatever. So, just by looking at the brightness temperature, by getting the emissivity information out, we will be able to get information about the dielectric constant of the surface. And by using this dielectric constant of the surface we will be able to retrieve several properties of the land or ocean surfaces.

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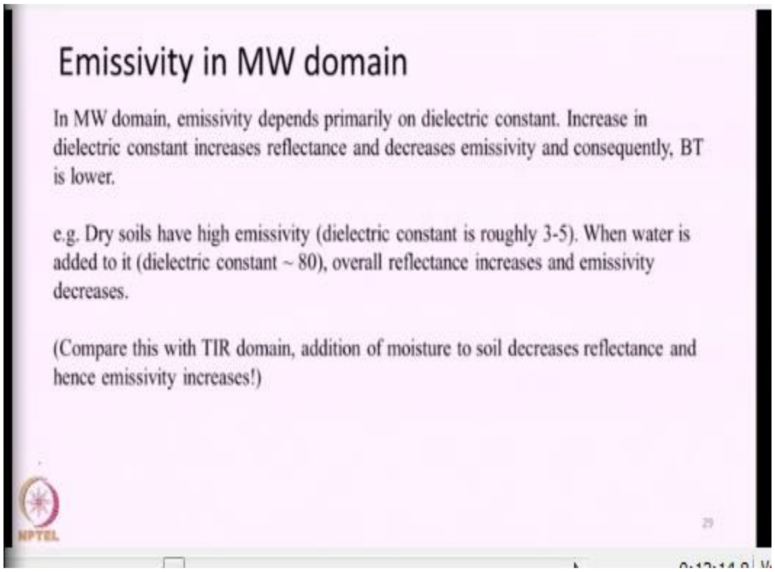

So, I told dielectric constant is like a major controlling factor. As the dielectric constant increases the reflectance increases and emissivity decreases. Say for example let us take dry soil and wet soil. For dry soil the dielectric constant will be in order of say 3 to 5 or 6 low dielectric constant, it will have high emissivity in microwave wavelength**.** But if you add water to it then the dielectric constant changes. Because water has a dielectric constant of about 80, but soil has a dielectric constant of 3 to 5, so that is a huge difference. So, when water is added to the soil and when the soil gets wet, the dielectric constant changes completely. The reflectance of soil in microwave wavelength increases and the emissivity decreases**.**

So, this is how emissivity changes with dielectric constant, a very simple example. Just compare this with thermal infrared remote sensing. Optical and thermal remote sensing goes together, just recall how the reflectance of soil will change. We have studied in detail about how reflectance of vegetation, soil and everything will change. When water is added to the soil its reflectance will go down, when the reflectant goes down emissivity will increase, emissivity = 1 – reflectance. So, wet soil will have high emissivity and low reflectance in optical and TIR wavelengths. In microwave wavelengths, it is like exact opposite, when water is added to soil due to change in dielectric constant, the reflectance increases and the emissivity decreases.

So, this is a huge contrast between conventional optical and TIR remote sensing and microwave remote sensing. In microwave remote sensing the signals are mainly controlled by the electrical nature of the earth surface and also the physical nature of surface. Surface roughness, the geometry and all those things will try to influence the signal that is emitted by the surface in passive microwave wavelengths. So, though the concepts are similar we have to be careful in understanding how objects behave in different, different wavelength. Behavior of same objects, say dry soil and wet soil are totally different when we observe in TIR wavelength or when we observe in microwave wavelengths, we have to be really cautious about it, in which wavelength we are working on**.**

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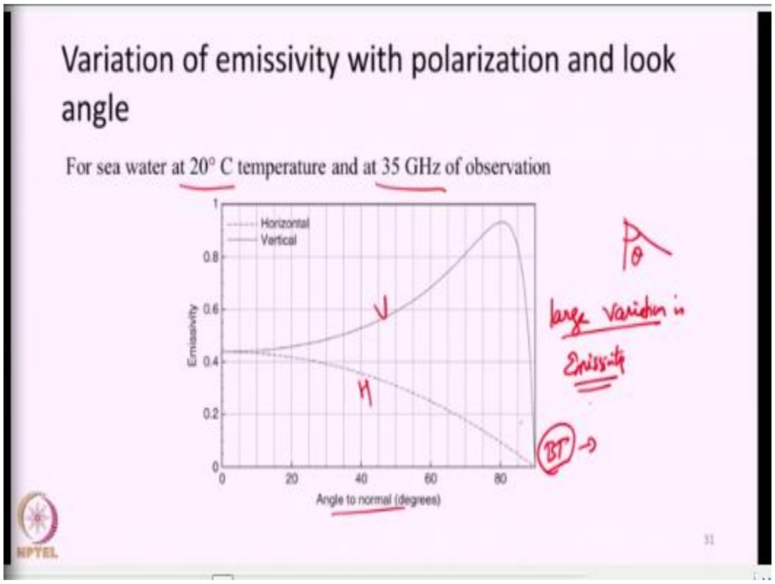
This particular curve will tell us how the emissivity of a surface changes. So, this is for sea water at 20 degree Celsius at 35 gigahertz of observation.



You can see that with change in angle, with change in the emissivity of the surface changes drastically, so the emissivity varies very widely with respect to polarization and angle. And similarly emissivity will also vary with different features. And because of this large variation in emissivity, we will get a very large variation in brightness temperature in the microwave signals. And using this information we will be able to get several other land surface properties.

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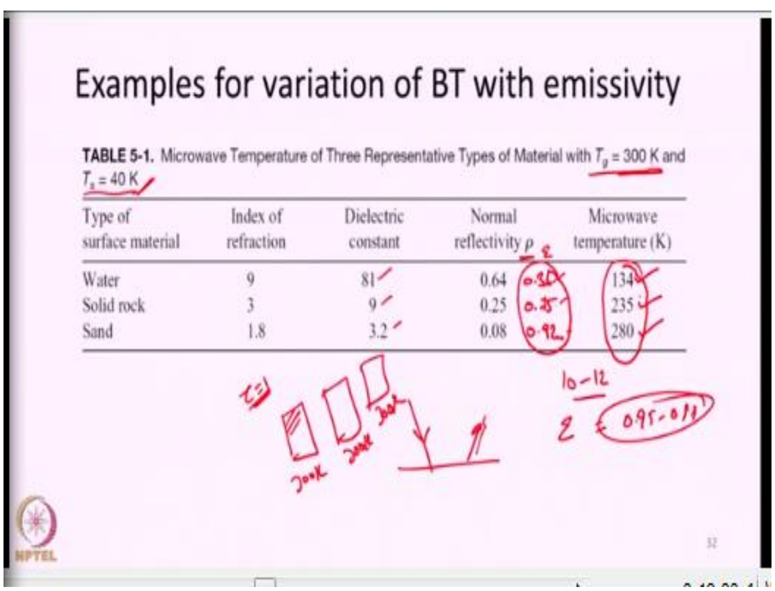

TABLE 5-1. Microwave Temperature of Three Representative Types of Material with T_g = 300 K and T_s = 40 K

Type of surface material	Index of refraction	Dielectric constant	Normal reflectivity ρ	Microwave temperature (K)
Water	9	81	0.64	134
Solid rock	3	9	0.25	235
Sand	1.8	3.2	0.08	280

Say this table will give us microwave temperature of 3 different materials theoretically calculated. The surface has a temperature of 300 Kelvin; the atmosphere has a temperature of 40 Kelvin. So, assuming that atmospheric transmissivity is equal to 1 and neglecting the effects of atmosphere including only the surface effect, atmospheric reflection on the surface and surface emission.

Just including these 2 effects we are going to estimate how the brightness temperature changes**.** So, ground temperature is 300 Kelvin, atmospheric temperature is 40 Kelvin. So, this is the dielectric constant of different features, water, solid rock and sand. Based on which there are equations to calculate reflectivity, so that is from dielectric constant we can calculate reflectance roughly and then relate it with emissivity.

So, here what we are doing is, we are having information about reflectance. For water the reflectance in microwave wavelength is roughly about 0.64, so the emissivity is 0.36. Here I write for solid rock reflectance is 0.25, emissivity is 0.75. For sand reflectivity is 0.08, emissivity is 0.92. So, you can see the emissivity of the object changes drastically.

In thermal infrared remote sensing 10 to 12 μm wavelength, the emissivity of most of the features were in the range of 0.95 to 0.99, very less. In microwave the emissivity is varying drastically 0.36 for water, 0.75 for rock, 0.93 for sand. So, these 3 peaks features if they are present within 3 pixels let us say all these 3 features has same temperature 300 Kelvin. Then the net resultant microwave temperature of each pixel will be 134 Kelvin for water body, 235 Kelvin for solid rock, 280 Kelvin for sand. So, this tells us same brightness temperature, same atmospheric effect but just by virtue of very large variation in emissivity, the microwave brightness temperature varies drastically. This suggests that the influence of emissivity on brightness temperature is very large.

So, emissivity influences the brightness temperature to very large extent rather than the true temperature of object. And hence in passive microwave radiometry our aim is to use this very large difference in emissivity between different features. And from that emissivity difference calculate the dielectric constant of the objects, from the dielectric constant get its emissivity or reflectance and use it for various applications. So, this is a major difference how we think and work in TIR remote sensing and passive microwave radiometry. The physical nature of the signal or the concept behind the signal emission is same, but the way in which we use the data is extremely different**.**

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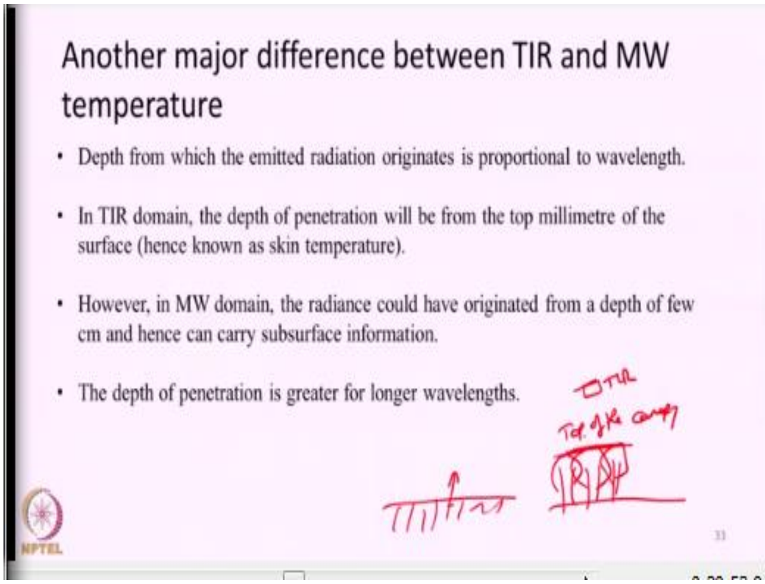

In TIR remote sensing, the temperature what we estimate we normally call it as surface radiometric temperature. But the other common name is skin temperature that indicates the temperature emitted by the surface is limited or whatever signals we get in TIR remote sensing is limited to very top one or two millimeter of the surface. So, whatever the signals we get in TIR remote sensing comes from may be top 1 or 2 millimeters. Let us say there is a very dense forest where we are seeing only the top of the canopy, you are not able to see the land surface itself. So, the temperature we are going to sense from the TIR radiometer is only the temperature of this dense canopy.

So, the temperature we are sensing is essentially the skin temperature, only the top 1 or 2 millimeters. In passive microwave radiometry the temperature signals or the radiance emitted by the surface will come from certain depth of the surface. Say if you observe in L band most likely the signals coming out will contain information about first few centimeters of soil say 3 centimeters or 5 centimeters. Whereas in TIR remote sensing it is in order of millimeters, 1 millimeter or 2 millimeters, so there is a huge difference in the depth from which the signals are going to come in passive microwave radiometry. So, in passive microwave radiometry we are going to get information from a significant depth of the surface in order of few centimeters.

This depth will vary with respect to the wavelength in which we observe and also the moisture content of the surface, increasing moisture content will decrease this penetration depth. Increasing or decreasing wavelength say L band to X band, if you are moving in decreasing wavelength the penetration also will go down. But whatever be the microwave wavelength, the total penetration we have got will be almost higher than the penetration we will normally get in TIR remote sensing.

So, the temperature what we collect in microwave signals will not be known by the name of skin temperature. Because the signals essentially have originated from certain depth below the surface. So, this is again one of the major differences between what we sense in TIR remote sensing and passive microwave remote sensing.

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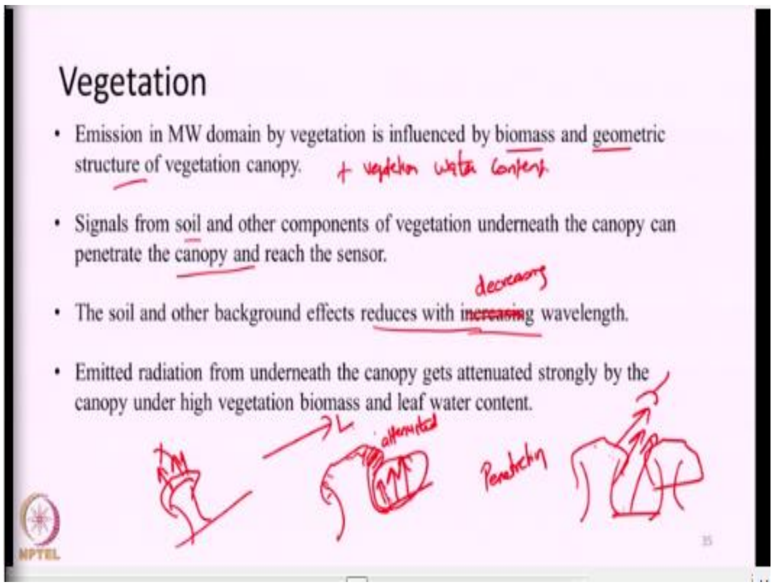

Now let us see how the signals of different features will behave in passive microwave wavelength. Similar to how we have discussed spectral reflectance of vegetation, water, soil, etc., here also we will see what factors will control the emission from vegetation, water and so on.

First we will start with vegetation. So, the emission from vegetation in passive microwave radiometry is influenced by biomass, the geometric nature of the vegetation and also the vegetation water content within the canopy. Normally for very dense healthy vegetation, the emissivity will be lower, it will appear much cooler. The brightness temperature will be pretty low. So, increasing biomass naturally indicates, there is a very large amount of vegetation and it may contain very good water content and hence will have a very low temperature. If you compare this with a dry bare surface, it will have high temperature or brightest temperature because of high emissivity.

So, the emission of vegetation in microwave domain is influenced by the biomass, the geometric structure of vegetation canopy plus the vegetation water content. So, signals from soil and other components of vegetation will also penetrate the canopy and reach the sensor. That is say if there is a tree canopy here and if there is a microwave radiometer located here, not only the signal from this canopy will reach, signals from this trunk, signal from the soil, underneath, all will reach.

Because of the penetration capacity of microwave signals, the signal from the ground, the signal from the other non canopy components also will reach it. So, this is a major difference between passive microwave and thermal infrared remote sensing. The soil and other background effect reduces with decreasing wavelength.

That is longer the wavelength say L band, you are going to get information about objects present underneath, from the soil also. But say you are looking at x band high frequency and low wavelength, you are going to get only the information about the canopy and maybe a small layer of the canopy. So, the soil and background effects will reduce when the frequency changes. Longer wavelengths will mean generally higher penetration**.**

So, the emitted radiation from underneath the canopy gets attenuated strongly by the vegetation biomass and leaf water content. Say if the vegetation biomass is very large, very high amount of vegetation and with very high water content, then the signals from this particular soil or whatever that is underneath the canopy they will be attenuated by this. Attenuated means reduced significantly by this canopy and we will not be able to sense or get any information about the soil or whatever feature present underneath the canopy. So, this is how the signals in general will vary from vegetation.

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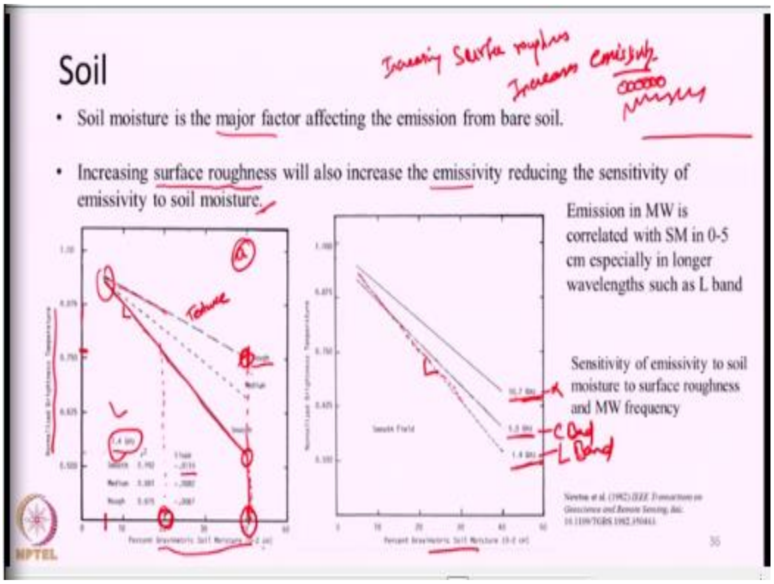

The next important feature or one of the major application for which passive microwave radiometry is used is estimating soil moisture, so how wet or how dry a soil is. For bare soil, soil moisture is a major influencing factor of emissivity, because we have seen as an example that there is a huge difference in the emissivity of dry soil and wet soil.

The dielectric content of dry soil is low, dielectric content of pure water is high when they mix together the reflectance of wet soil increases and emissivity goes down. And this particular behavior is a major factor to use passive microwave radiometry for soil moisture estimation. In fact, the global soil moisture monitoring mission SMAP and SMOS are effectively dedicated missions for measuring soil moisture, ocean salinity and so on, which are operating in L band.

So, soil moisture is the major factor that affects the emission from bare soil. Increasing surface roughness will also increase the emissivity by reducing the sensitivity of emissivity to soil moisture. Here we have 2 plots. This first plot is plot A. So here on the x axis we have the soil moisture, in the first 2 centimeter of the soil. And the y axis we have a normalized brightness temperature. All the brightness temperature are normalized between value of 0 to 1. We have 3 texture of soil plots, each one is like rough texture, medium texture and smooth texture. For a smooth surface the slope is very steep indicating that for a change for even a small change in soil moisture, there is a significant change in the brightness temperature. As soil moisture increases the brightness temperature decreases, that is the emissivity goes down basically**.**

So, larger the slope larger will be the change in soil moisture because of the change in brightness temperature. So, for a smooth surface as soil moisture changes, the brightness temperature changes to a significant extent. On the other hand for a rough surface the brightness temperature is always higher than the smooth surface. So, increasing roughness increases emissivity, this is one important point we have to remember. So, this means rough surface will have high emissivity and high brightness temperature. But for a smooth soil, the normalized brightness temperature is just above 0.5, for a rough surface the normalized brightness temperature is above 0.75. So, this suggests for a wet surface a change in surface roughness is going to increase the emissivity and increase the brightness temperature. So, this means if the surface is bare and smooth we will be able to get information about soil moisture in a better way.

Soil moisture will influence the brightness temperature to a large extent. If the surface is rough, the effect of surface roughness will add up which will try to increase the emissivity, we will get a mixed signal. Let us say we do not know whether the soil is rough or not and we may assume the surface has smooth or rough whatever. Let us say by mistake we assume the surface as smooth, but the signal is actually come from a rough surface**.** So, this will be the brightness temperature 0.75, and if we assume the surface are smooth then the 0.75 brightness temperature has occurred at around 20% soil moisture content.

So, instead of calculating the moisture as 40%, we will be calculating the moisture as 20%. So, this is a very huge error 40% moisture, 20% moisture we are making like 50% error in this 0.2 and 0.4 there is a huge error**.** So, when we try to estimate soil moisture from passive microwave signals, we should also know the surface roughness element, how rough or how smooth a surface is, because the surface roughness plays a major role. For a dry soil, rough surface and smooth surface will be at more or less close temperature. You can see around this 5% soil moisture content, the brightness temperature of all the 3 soils rough, medium and smooth are almost very similar. But as the moisture content increases the difference in brightness temperature becomes very huge. And at very high moisture content definitely we should know whether the soil is smooth or rough**.** Similarly let us have a look at the influence of frequency of microwave observation in estimating soil moisture. Same plot, but here we have 3 lines where each line is on different, different frequencies 10.7 gigahertz, 5 gigahertz, 1.4 gigahertz, 1.4 gigahertz is L band, 5 gigahertz is C band and this can be around X band, so 3 different bands are there. You can see the slope is steepest for the L band, so even a small change in soil moisture will produce a large change in the brightness temperature in L band. When you compare this with 5 gigahertz or 10.7 gigahertz frequency, the sensitivity of brightness temperature to soil moisture varies with wavelength of observation and also the surface roughness.

So, normally we will get better information about soil measure when we use higher wavelength say L band or so. So, that is why the 2 missions SMAP and SMOS effectively work in L band 1.4 gigahertz frequency. So, the signals coming out from soil is primarily influenced by soil moisture especially bare soil. But the frequency in which we observe and also the surface roughness is also going to play a major role in influencing the signals that are influencing the emission from the soil surface. So, this is one of the major factor about passive microwave radiometry and this behavior of soil and influence of soil moisture and brightness temperature is used very widely for global soil moisture estimation.

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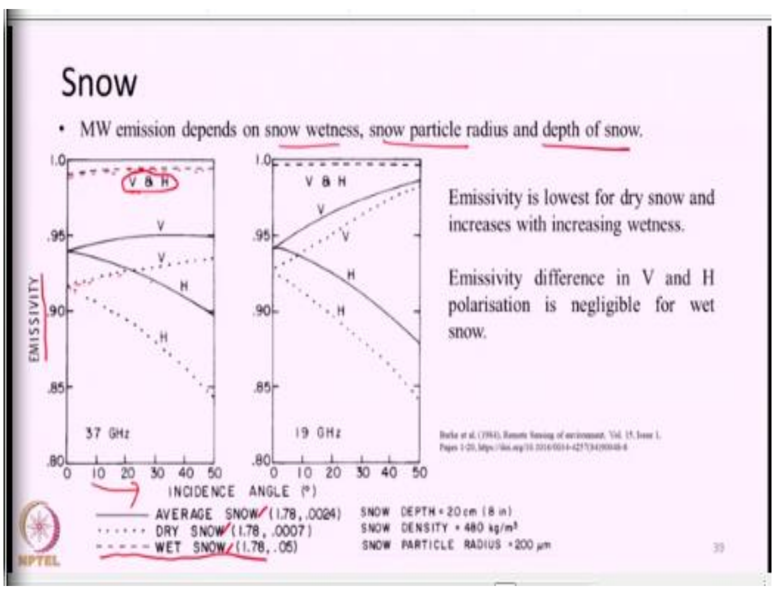

So, the next feature what we are going to see is snow, because snow also is one of the major cryospheric applications widely done using passive microwave radiometry. Normally the microwave emission of snow depends on the snow wetness, how wet or how dry snow is, whether it is pure snow or mixed with water, the snow particle radius and depth of snow.

So, these particular figures give us how the emissivity of snow varies, with x-axis we have incidence angle, here in different plots we have different conditions of wetness, average snow, dry snow and wet snow. Say this dotted line is dry snow, this broken dashed line is wet snow, so for wet snow the emissivity is pretty high whereas for a dry snow the emissivity is pretty low and it varies a lot. Especially if you look with respect to polarization, one may be vertical polarization, one may be horizontal polarization the emissivity will vary a lot, whereas if the snow is wet the difference between vertical and horizontal polarization reduces drastically. So, as emissivity changes brightness temperature also will change.

So, in general wet snow will have a very high emissivity and dry snow will have a very low emissivity relatively. And also, the difference of emissivity between V and H polarization will be largely seen for dry snow when compared with wet snow**.** So, this is like one of the important things, we should realize when we do snow remote sensing. So, the next feature is ocean, how the ocean water emission will change?

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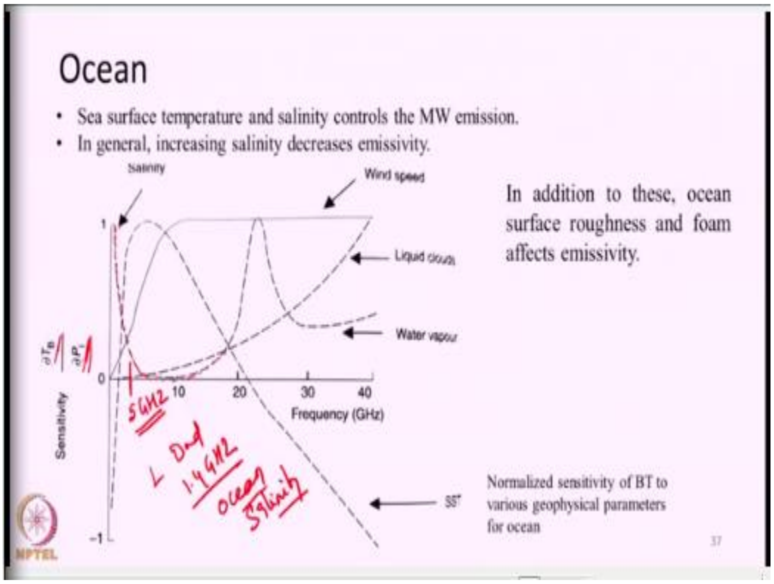

One of the major applications of passive microwave radiometry in ocean remote sensing is to estimate ocean salinity. Salinity will influence the ocean circulation which has a global implication in global climate system. So, it is always need to understand the ocean salinity and passive microwave radiometry helps us to estimate this ocean salinity.

So, the emission from the sea surface or sea water largely influenced by the temperature of the surface and also the salinity. So, in general increasing salinity decreases emissivity and also on this particular plot you can see the sensitivity of brightness temperature with respect to salinity**.** So, here if you look at this particular line where I am putting this red dash, you can see the y axis has change in brightness temperature with respect to different properties of ocean.

If we look only at salinity, we can see at very low frequencies say in the order of less than 5 gigahertz. There will be a large change in brightness temperature for even a small change in salinity because of this $\partial T_B/\partial$salinity is very high. So, this suggests the change in salinity of ocean will produce a large change in brightness temperature that is the emissivity will basically decrease thereby reducing the brightness temperature**.** So, not only ocean salinity there are other features or other factors such as any presence of oil slick or wind everything will influence ocean's emissivity. But as I said before our aim in this course is not to explain all the variation, all the features but just to give a glimpse and also like one example how it can be used**.**

So, just like a very broad or very brief explanation we have seen how the emissivity of soil will change, How the emission of vegetation will be influenced, How the emissivity of snow will change etcetera. So, this is just to give you a glimpse of variation in brightness temperature or emissivity with different surface features. So, with this we conclude the topic of passive micro radiometry.

So, in passive microwave radiometry we have discussed in detail about the basic physical concepts behind passive microwave emission, what sort of detector we use, like the antenna system, real aperture antenna, synthetic aperture antenna, the spatial resolution of passive microwave and sensors, what kind of signals we get. How those signals we use for our various applications and a brief discussion about how the emissivity will vary for different features. With this we end this lecture and also this particular topic.

Thank you very much.