Remote Sensing of Leaf Area Index and Primary Productivity
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Lecture - 08
LAI Estimation – LiDAR and Microwave RS Methods

Welcome back. So, in our lecture number 8, let us discuss on the LAI Estimation - LiDAR and Microwave Remote Sensing based methods. So, with respect to what we discussed in the lecture number 6, 7 or 5, 6, 7 are mostly optical remote sensing based methods because vegetation indices model inversions, we discussed in lecture 6 and 7. Now, in today in lecture 8, we are going to talk about the LiDAR and microwave based methods.

So, perhaps, many of you must be knowing what is LiDAR remote sensing; what is microwave or radar remote sensing or SAR and these days, we will also get to know lot of UAV based remote sensing; Unmanned Aerial Vehicles. So, UAVs are also becoming more and more prominent with respect to its use, its handiness, its friendliness and whenever you want to fly and where ever you decide it gives the user a lot of flexibility.

So, based on this, let us discuss how the LiDAR based, microwave based and also, the UAV based remote sensing estimates are methods are useful for LAI estimation.

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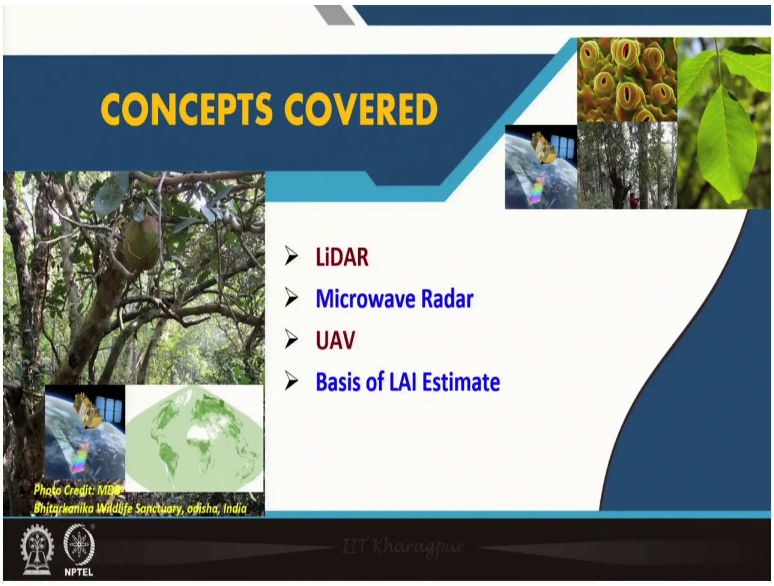

So, the concepts with respect to what we are going to cover are these four. The first one is LiDAR. So, LiDAR; second Microwave Radar and then, UAV and basis of LAI estimate. All of you know the expansion; laser detection and light detection and ranging, then you call it the LiDAR and microwave region, the reference if you are doing which is based on the most both passive and active.

So, and SAR also falls in this domain and the unmanned aerial vehicle and we will also discuss the basis of LAI estimate with respect to all the above three remote sensing methods or types.

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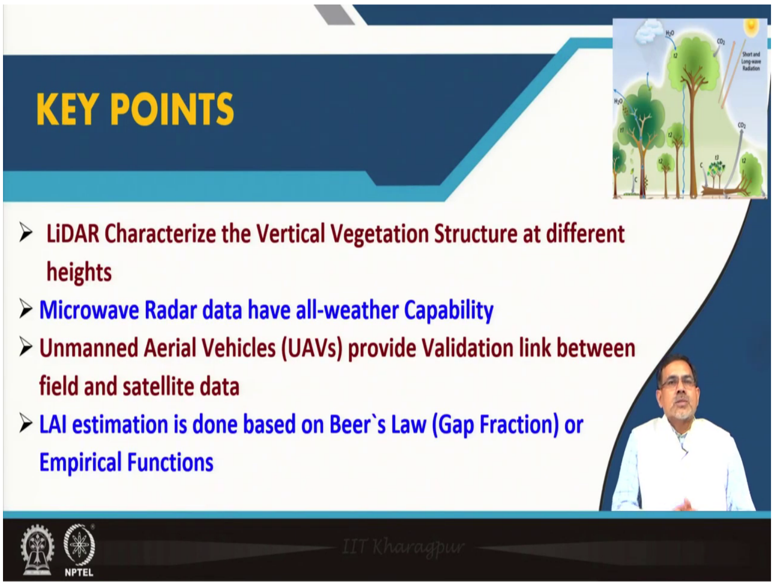

So, coming to the key points. LiDAR characterize the vertical vegetation structure at different height, unlike the optical remote sensing or unlike the passive remote sensing. Here, the LiDAR is a kind of optical remote sensing, it operates in optical remote sensing, which is in the active domain and microwave in the microwave range and these are these follow a kind of ranging principle.

So, they hit and go back to the sensor and divided by the time taken, we get information about the object of interest, where it the beam has hit. So, we call that the footprint. So, we study the footprint and the behavior of the footprint based on the signal has hit and come back and accordingly, we get the information and analyze it.

So, LiDAR characterize in that sense, the vertical vegetation structure based on where it hits. It hit the canopy, it hits the leaf, it hits the main branch or it hits the small branch or the major bowl. So, based on that, we get to know that how strong are the strength; where, I do not exactly say the strength of the value, we say we understand the strength actually and characterize the strength to get information about the vertical structure of the object.

For this case, it is vegetation and this is valid for both LiDAR and microwave. So, UAV; in case of UAV, one can put any kind of sensors and mostly, we are putting this result optical and hyperspectral sensors are the multi-spectral sensors. So, coming to the principle or the basis, similarly with respect to optical what we discussed in lecture 6 and 7, here also the LAI estimation is done based on the Beer's law particularly, the Gap Fraction based estimates and also, the Empirical relationship or Empirical transfer function based relationship.

Because LAI gives LAI perhaps gives us more confidence with respect to generate or with respect to get information on the gap fraction as far as the vegetation canopy is concerned.

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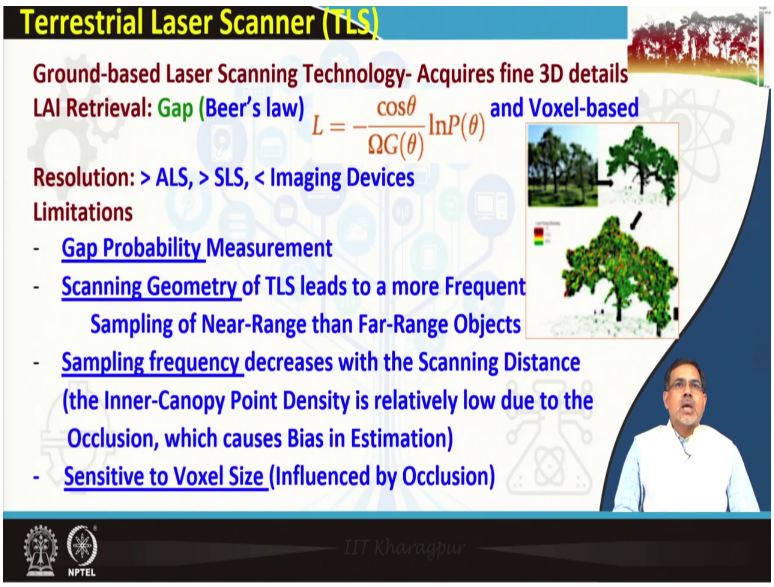

So, let us see the three types of laser scanner. So, the first one in that sense, I have taken with respect to the terrestrial laser scanner; the second one is with respect to your airborne and the third one is the space borne.

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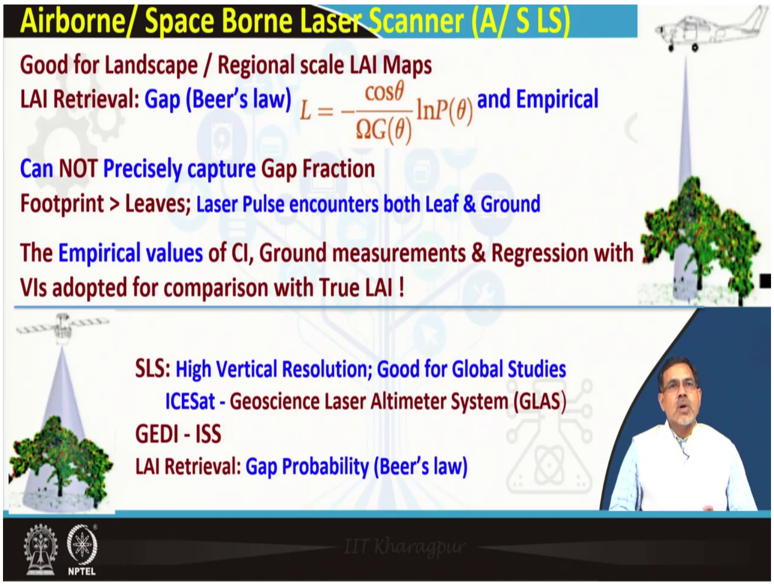

So, as one can see the terrestrial, it is handy and we do it and operate it at a very low height or close to the earth surface. The airborne as you can see on the upper right depiction, that these are at about 10 to 12 kilometer height because it has to be mounted on a airborne platform or a aircraft; whereas, the space borne is always few hundreds kilometers away because it is because these are mounted on the satellite platforms.

So, what happens? The in terms of the height one can also understand or guess that there will be differences in terms of resolution. If so, that means, the imaging devices, the imaging devices that they could have maximum resolution followed by this terrestrial laser scanners or TLS followed by the ALS or you call the airborne followed by the space, because it is always a function of the focal length.

So, what you what we understand with respect to the resolution between these four types of remote sense, four types of laser scanner based on devices or you say laser imaging devices, terrestrial laser scanner, airborne laser scanner and the space borne laser scanner is with respect to the resolution, it follows that sequence maximum for laser imaging devices, little less for the terrestrial laser scanner, then less for airborne, then for the space borne laser scanners.

So, these LiDAR's particularly, we are here talking in this slide with respect to the terrestrial laser scanner, they these are the ground based laser scanning technology acquires a kind of fine 3D details; try to put a depiction with respect to the laser scan of a forest. One can see the height varies from 0 to 45 meter and the imagination comes that yes, you can almost get very fine 3D details of the vegetation or the vegetation structure.

So, the LAI retrieval is based on using TLS principle or TLS images is based on either the gap fraction, where it follows a kind of where it follows the Beer's law as you know, we have discussed in our lecture 2 or 3 and also, it could be a voxel based or a three-dimensional pixel. So, what are the limitations of this terrestrial laser scanner? These limitations could be the gap probability measurement because in within a voxel, we sometime we need to measure the gap probability. So, that measurement is many times become a limitation.

Then, scanning geometry, look at this part with respect to the principle of the terrestrial laser scanner. As far as the scanning geometry is concerned, the scanning geometry of the TLS leads to more frequent sampling of the near range than the far range objects. So, what happens? Because of this the sampling frequency decreases with scanning distance understand. So, the because of the scanning geometry, the sampling frequency decreases with the scanning distance; that means, the inner canopy point density is relatively low, due to the occlusion, which can cause bias in estimation.

So, there is a slight variation between the near range and far range objects based on the scanning geometry and that gives rise to the inner canopy point density variation which is slightly different which or you could say low or high in terms of variation because of this occlusion. So, this could incorporate some bias with respect to the terrestrial laser scanner based images. So, what we understand that these TLS are very sensitive to the voxel size as you know voxel is a three-dimensional pixel along x, y and z plane.

So, coming to the next one the airborne and the space borne laser scanner. Airborne, we abbreviate it as ALS and space borne, we abbreviate it as SLS. So, in the upper half of the slide, I put with respect to the airborne. You can see the depiction on the upper right corner. So, the airborne laser scanners or ALS are good for landscape or regional scale. We need it over a district, over the country, it is very good.

But, the SLS space borne one is very good with respect to very high region or you say the country to country and to global scale and here, also this airborne based airborne laser based images, it follows in terms of the LAI retrieval, the gap function or the gap fraction based on the Beer's law and also, establish empirical relationship or follow empirical function as we have discussed in our in case of the optical. So, always this LAI retrieval is also following the same path as the gap fraction or the empirical relationship.

It cannot precisely capture the gap fraction because of these limitations in terms of the gap probability measurement. So, footprints in terms of the airborne laser scanner, it is higher than, or more than that of the leaves. So, laser pulse encounters both leaf and the ground. Look at the depiction on the right hand side; the footprint is more than the size of the leaf. So, that means what? That means, it will encounter both leaf and some part of the ground as you can see from the depiction.

Then, coming to the empirical values, the empirical values of clumping index, ground measurements and the regressions with the VIs are adopted for comparison with the true LAI. So, this effective LAI and true LAI concept here show the empirical values of all three; clumping index, ground based measurement because that itself is what you say the absolute kind of near to absolute and the regression equations based on the VIs, all these are adopted to come out with a comparison to generate the true LAI.

So, now, coming to the space borne laser scanner SLS with respect to SLS high vertical resolution, as you can see on the lower left depiction. The high vertical resolution is good for global studies because you get very wide coverage. Examples are a very long run laser based LiDAR based satellite is ICESat and the sensor mounted on that is GLAS, Geoscience Laser Altimeter System and since last 3 years, we also have a sensor called GEDI; G E D I mounted on the ISS platform, the international space station which is orbiting the earth above 300 kilometer from the earth surface.

So, here in term in case of the space borne also, the LAI retrieval mostly calculates the gap probability following the Beer's law.

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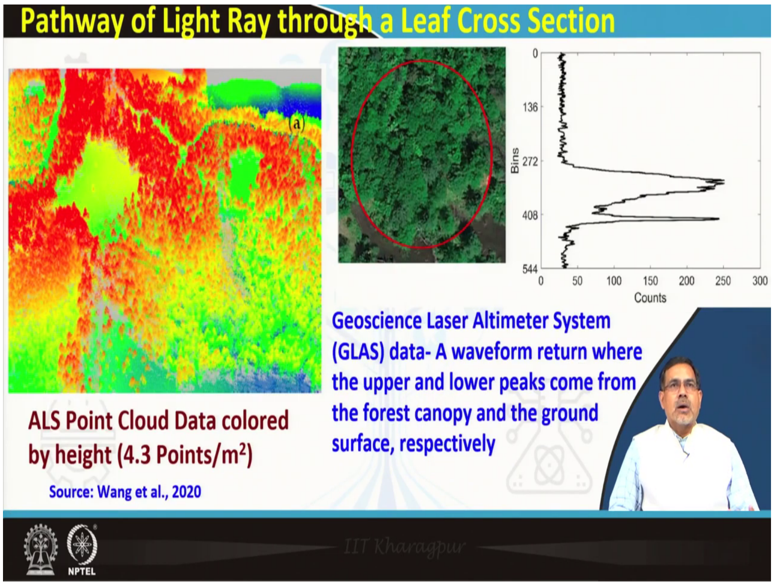

With respect to the pathway of the light ray through a leaf cross section, one can see on the left hand side, the ALS point cloud data colored by height. So, at a rate of 4.3 points per meter square area. So, in one by one meter square area you can have 4.3 points cloud or the point cloud and on the right and extreme right hand side, one can see the waveform. So, this has been plotted means has been taken from Wang et al publication and which has been plotted using the GLAS data.

The GLAS data, you see the waveform return, where the upper and lower peak come from the forest canopy and the ground surface and accordingly, can see the waveform which is shown in terms of the counts and the bins in the x and y axis. So, how well it is depicting the forest canopy and the ground surface in terms of the LiDAR waveform? I am sorry.

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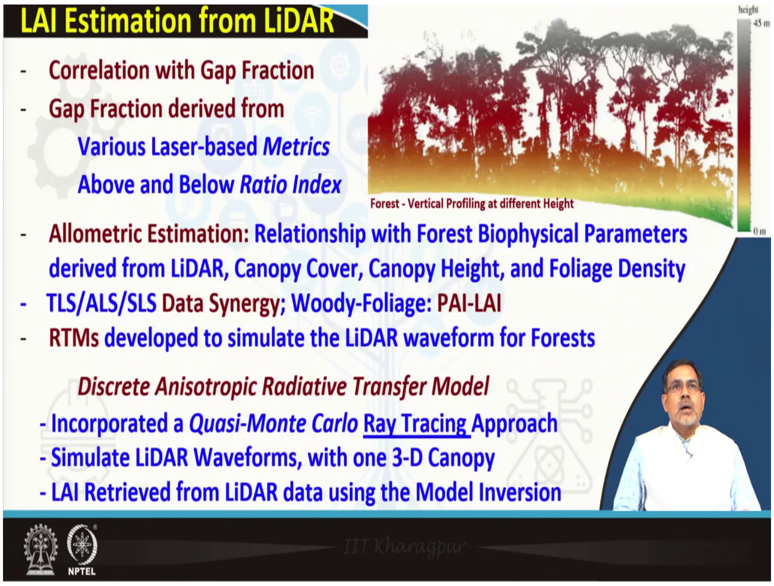

Then, with respect to LAI estimation from LiDAR. So, correlation with gap fraction, gap fraction derived from various laser-based metrics and based on the ratio index with respect to above and below. So, you can see the depiction with respect to forest vertical profiling at different heights and the as we saw the allometric estimations in terms of a the LAI relationship with forest biophysical parameters derived from LiDAR, canopy cover, canopy height, foliage density.

So, this slider gives us these many biophysical parameters which can be derived from the LiDAR based images in terms of canopy cover, canopy height and foliage density which is very accurate or more accurate in comparison to other remote sensing derived products.

So, the if we relate them and we can very well establish or come out with allometric equations to estimate the relationship with LAI and there also people have researchers have tried with respect to data synergy including all three so that the synergy comes up; so, TLS, ALS and SLS data.

And another important thing is to differentiate the PAI from the LAI or the Plant Area Index which also includes the wood area index to the leaf area index could be differentiated because in the LiDAR based images, we can get information or more information with respect to the woody part of the canopy or vegetation and the foliage part. So, that actually helps in terms of differentiating the plant area index from that of the leaf area index.

And as we discussed in our previous classes, we know that these plant and leaf area indexes, these go differently or these have or specific importance as far as the models, input are concerned in terms of primary productivity and many other dynamic models. So, the RTMs Radiative Transfer Models developed to simulate the LiDAR waveform for forest. So, here also, we use that we give an example with respect to Discrete Aniso Radiative Transfer Model.

So, these models as example incorporate the Quasi-Monte Carlo Ray Tracing approaches, simulate LiDAR waveform with one 3D canopy and the LAIs retrieved from LiDAR data using the Model inversion method.

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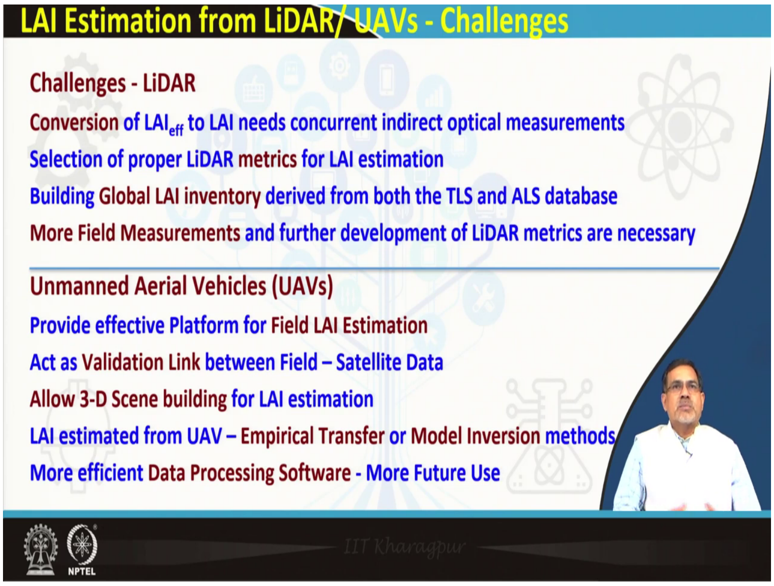

So, this is these are the challenges with respect to LAI estimation from LiDAR. Now, let us see it one by one the challenges in terms of LiDAR estimation, LAI estimation from LiDAR. Conversion of LAI effective or you say effective LAI to LAI need concurrent indirect optical measurement. So, we also need to be supported with other based other basis of optical measurements, which mostly should be suffix suffixed by the ground based measurements.

Then, selection of proper LiDAR metrics for LAI estimation. This becomes very important and to select the proper LiDAR metric. Building global LAI inventory derived from both the terrestrial laser scanner and the airborne laser scanner database. And we also need to do more and more field measurements to develop more LiDAR metrics so that confidence building will be there.

So, these are the challenges and the with many other satellite platforms like GEDI and even if the ICESat II, atlas data ALTAS data, this is coming of a as a major challenge and more and more studies are coming are definitely going to come in future with respect to this. Now, coming to Unmanned Aerial Vehicles UAVs, they provide a kind of effective platform for field LAI estimation.

Effective platform, why? Because they act as validation link between field and satellite data. So, field you are on ground, satellite you are beyond 100 kilo few 100 kilometers up in vertical space and this is a kind of in between and it is more close when you want where and this is in this time, this place, you can fly and take a take the readings.

So, this is why it acts as a validation link because as you know in terms of remote sensing based any estimates, validation is a must to give or to come out with a confidence or accuracy of that particular product or the result. So, in that sense, it allows 3-D scene building for the LAI estimation and LAI estimated from these UAVs also follow empirical transfer or model inversion methods.

So, as we know these are the two broad methods one has to follow or any remote sensing based things has to follow in terms of empirical or inversion methods. So, more efficient in terms of data processing and definitely is going to have a better future.

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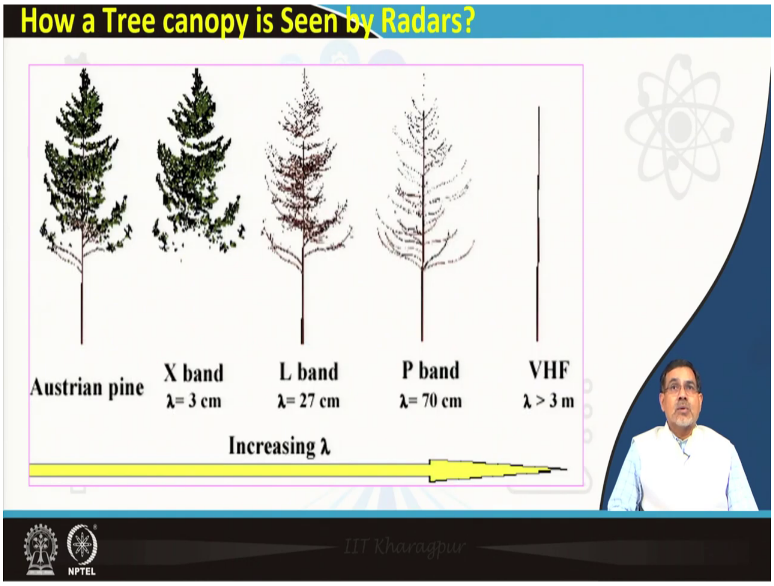

Now, let us come to the third component that is the microwave or the radars. So, radars, we have been knowing that these are the all weather images or the satellite data which we can take in all weather conditions. This we know in general. So, what does it mean? That means, we all mostly in the tropics we are in means the atmosphere, we have lot of floating clouds and many other things in the with respect to the cloud in the monsoon period or in the rainy season.

So, what happens? These that means, there will be data gap, if we are only focusing or concentrated with respect to the optical domain or the reflectance based remote sensing. So, microwave or these radars are there to fill the gap, but as you discuss they are based on the ranging principle. Now, this five what you say figures in terms of the depiction of a plant, a Austrian pine plant which actually on the left hand side is the full one and how it looks in the X band or by the radar how it looks and the L band and the P band and the VHF.

So, once we go move in terms of the increasing order of wavelength. So, accordingly, we get the information from those parts of the object which is of our interest because which is proportional to the wavelength ok. So, if you are using X band for microwave remote sensing, then perhaps we are getting information with respect to the leaves; L band the small branches; P bands the major branches and the VHF is probably giving information about the bowl.

So, imagine if we club them together, all four maps, we club them together, then perhaps, we get information about the PAI, the total Plant Area Index. If we take only the X band, then perhaps we are done with LAI max in that sense and little bit left and if we take L, P and VHF, then perhaps we are done with the wood area index. So, putting them together we can do a good job of estimating with respect to LAI.

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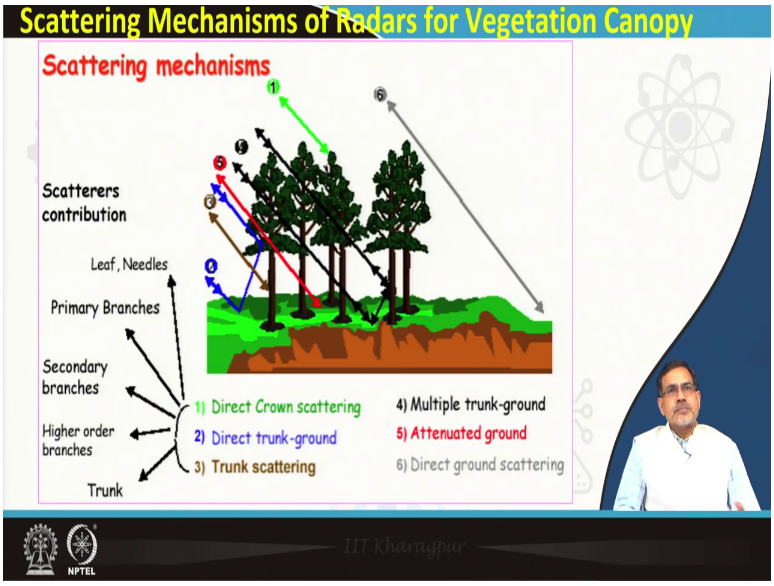

So, as far as the basic scattering mechanism is concerned of radars for vegetation canopy, we know these six types of scattering happens and in the forest and they can be understood with respect to 1, 2, 3, 4, 5, 6 depicted with in different colors. So, direct crown scattering is shown in green color; in blue, the direct tree direct trunk ground.

So, trunk to ground, then only trunk scattering is 3; multiple trunk ground scattering is shown number 4 with a kind of black color, then attenuation from the ground, remember that is very important because we are also getting the attenuation or from the background soil or whatever metal is there in the background and the sixth one is direct ground scattering. So, these are the various scattering mechanisms can be expected in terms of the vegetation canopy or the surrounding ground or the background.

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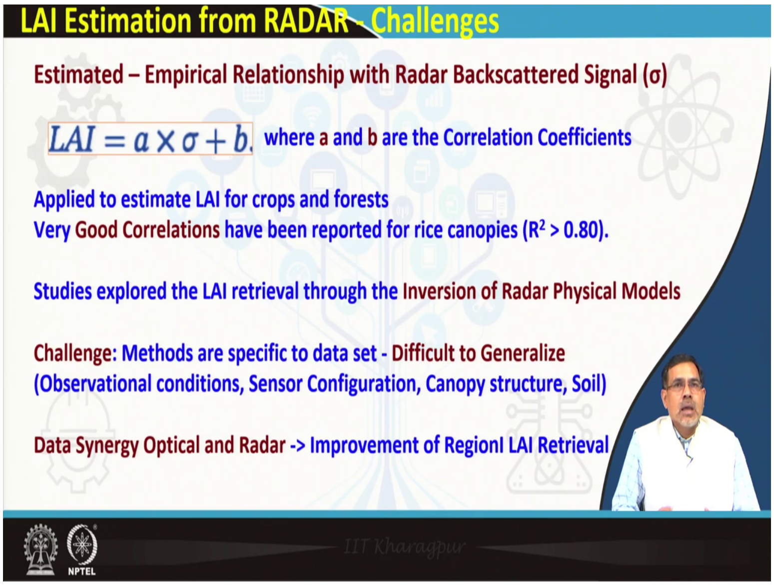

So, this is what we need to keep in mind with respect to the microwave scattering mechanism. So, now, coming to the LAI estimation from the radar and the challenges, it this SAR or the microwave radar estimates empirical relationship with radar backgrounds, what you say back scattered signal or we say it sigma naught. So, as the equation LAI is equal to a, the sigma naught plus b; where, a and b are the correlation coefficients.

So, it is always a kind of empirical relationship with the radar backscattered signal or you say backscattered coefficient sigma naught. So, these are applied to estimate LAI for crops and forest and with respect to correlation, people have reported correlation going up to for R square to the tune of or more than 0.8 for rice and other canopies. But they could be little less for forest.

Studies explored the LAI retrieval through inversion of radar physics models or physical models. So, challenges; methods are specific to data set and very difficult that is why to generalize. So, what kind of data you are using, which band data, what polarimetry we are using, so based on that, it is very difficult and complicated to generalize.

So, and also that is again linked with respect to the observation condition, sensor configuration, canopy structure and even if the background soil; but the study is promising with respect to the synergy because optical you are getting all the reflectance based radiance or the and in the radar, you are getting all the backscattered coefficient. So, if the both of them can be merged, then probably there could be improvement in terms of the regional LAI retrieval. So, always this kind of synergy or deriving synergy is being explored and more and more studies are coming up.

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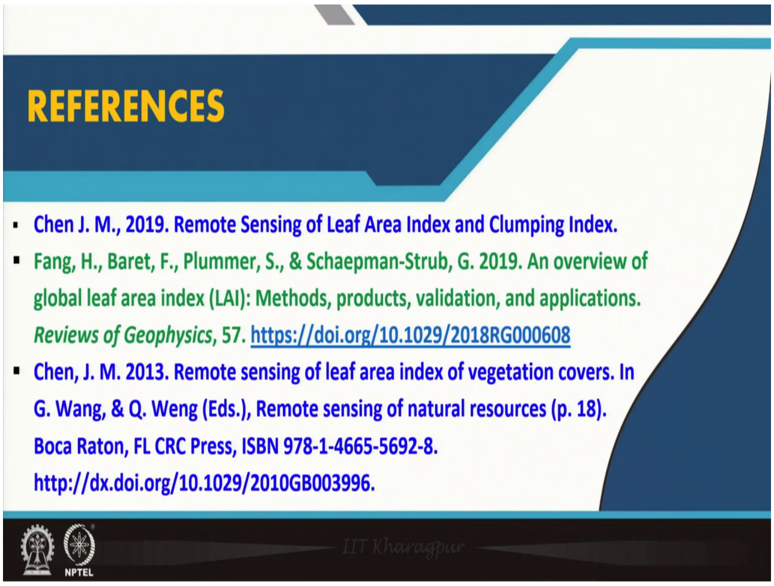

Coming to the references, these are the references used.

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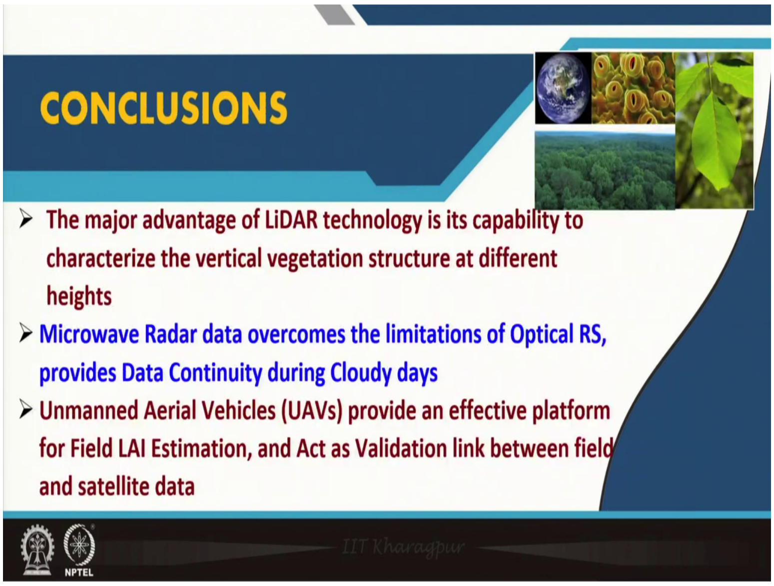

And we will summarize in terms of the conclusions. The advantages of all these three remote sensing protocols are in terms of LiDAR, microwave and UAV. So, the major advantage of LiDAR technology is its capability to characterize the vertical vegetation structure at different heights. With respect to microwave radar data, these data overcome the limitation of optical remote sensing and that is why I could provide data continuity during the cloudy days; whereas, the UAVs Unmanned Aerial Vehicles, they provide effective platform for field LAI estimation and that is where they act as validation link between field and satellite data.

So, friends, in this week with respect to lecture 6, 7 and this one 8th, we completed our discussion on the optical based that is the empirical function VIs relationship with LAIs. Then, the model inversion particular radiative transfer and in this class, we also talked about the other data set particularly the microwave, the LiDAR and the UAVs.

And in the subsequent two classes of this week, lecture number 9 and 10, we will cover the different global products and what kind of algorithm, they are used in terms of calculating the different global products and major one as we know, we always get it in terms of MODIS, in terms of VIIRS and few more which are derived based on the hybrid approach.

So, that is what we will cover in the lecture number 9 and the last lecture of this week number 10, we will try to go for the hybrid kind of approach and see the uncertainties, pros and cons and the challenges of these data products and what are the things needs to be done to improve the accuracy of this algorithms. So, look forward to discussing with you about the data products; particularly, the LAI global data products in next two classes of this week.

Thank you very much.