Remote Sensing of Leaf Area Index and Primary Productivity
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Lecture - 18
LAI Applications: Indian Examples

Good evening and welcome back. So, today on our 18th lecture, let us discuss on few case studies with respect to LAI estimates from Indian sites.

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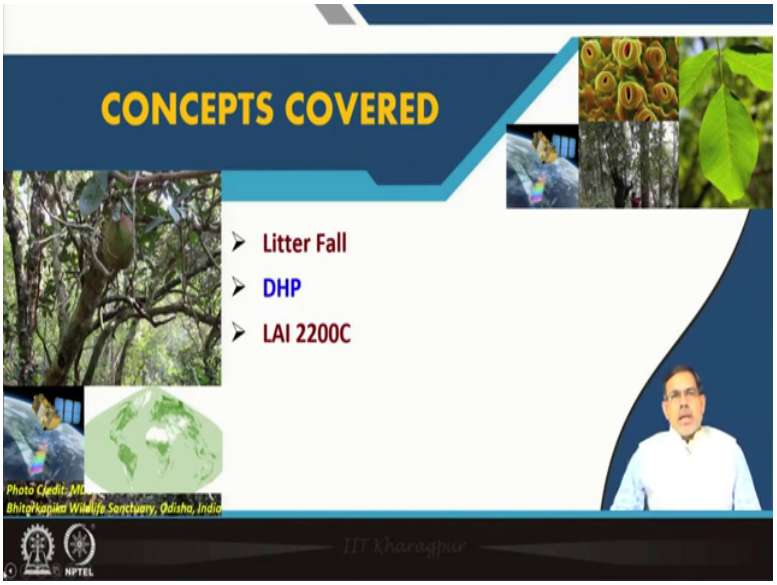

The concepts we are going to cover are the litter fall, the DHP based estimates, and the LAI 2200C equipment. Friends, as we have discussed in the week 2, several methods exist or have been had adopted in terms of estimating the leaf area index. Primarily, they could be destructive, non-destructive.

And in non-destructive, again you can use some of the equipments or instruments to take the measurements and measurements from ground and then come out with a LAI estimate. And also we have a kind of relationship we maintain in terms of empirical function or inversion or additive transfer based function RTM or RT radiative transfer models.

So, today what we are going to discuss are three, these three particularly we will see how litter fall which we have what you say estimated in terms of LAI using litter fall as a proxy

from one of the forests. Second, we will see how the digital hemispherical photography has been used or that principle has been used in a mangrove forest to estimate the LAI. And third, we will see the utility of LAI 2200C and particularly with respect to separating the LAI or discriminating what is the LAI range or how the LAI range varies between and among forest types that we will see in another tropical forest.

So, these three examples we have very carefully chosen as far as Indian sites are concerned. And there could be many more, but these three have been done by our team from the spatial analysis and modeling lab.

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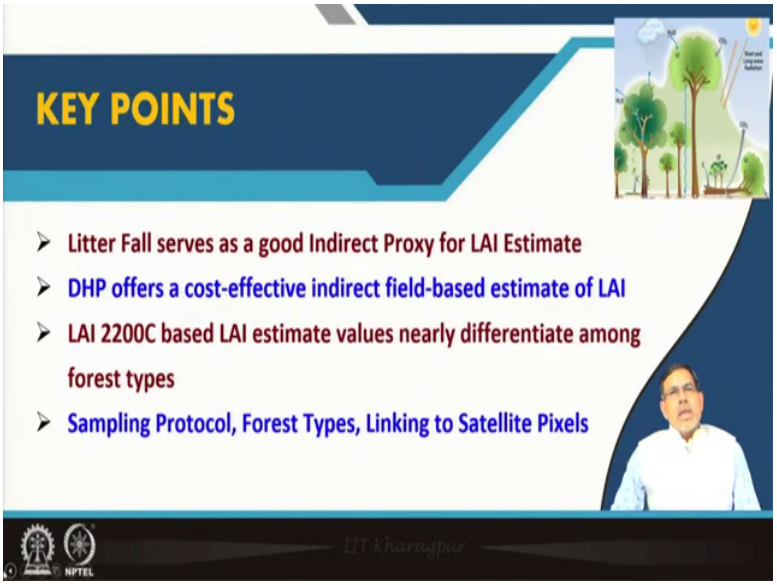

Coming to the key points, yes, we know and we will see here that litter fall serves as a good indirect proxy for LAI estimate. Second, we will see the digital hemispherical photography offers a cost effective indirect field-based estimates of LAI. And this LAI 2200C based estimation values they nearly differentiate the between or among different forest types.

And the third and fourth most importantly we will see that how different sampling protocols need to be adopted to make them suitable with respect to different forest types. And how different forest types let us say tropical, subtropical or you say evergreen, semi-evergreen or deciduous, they have different characteristics and that is why they offer different LAI as far as or across the seasons as we know, so how to estimate or how to account to that variation.

So, accordingly, forest type wise sampling protocol needs to be carefully sorted out before the estimation or before the measurement. And the third point is more importantly linking to satellite pixels. If we are there on ground and this observation is going to be linked to the satellite pixel.

Then, we have to be very careful that the pixel size or the on ground the area or the we call it ESU, Elementary Sampling Unit or the quadrate. So, it has to have similar or the same dimension to that of the satellite pixel.

And you have to be careful or one has to be careful that the surrounding few areas on ground or the surrounding areas on ground also nearly reflect or could reflect. We are the same characteristics in terms of ground, so that it is well linked to the satellite pixel. So, that has to be very carefully taken care during the ground observation.

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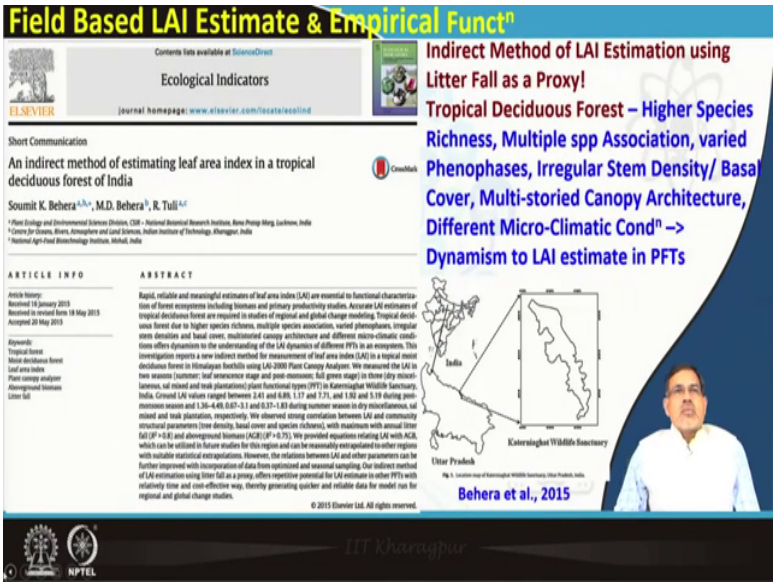

So, the three case studies. The first one is here the indirect method of LAI estimation using litter fall as a proxy. Here what has been done this particular study has been done in a tropical deciduous forest. As we know the tropical deciduous forest have higher species richness, multiple species association, varied phenophases as we know, different phenology based on your evergreen, semi-evergreen, deciduous that kind of forest are the leaf composition.

Then, here you can expect irregular stem density in tropical deciduous forest unlike the temperate or the conifer forest ok, also irregular basal cover. So, and also multi storied canopy architecture. We all know it, and I have discussed this again and again you can see multi storied canopy architecture.

So, all these adds to the complexity or the dimensionality of or you say the dynamism of the forest and along with different micro-climatic condition, soil background the estimation of LAI is very very challenging. And if we have different types or sometime we call from the their functional point of view we call them Plant Functional Types abbreviated as PFT. So, they offer different dynamism.

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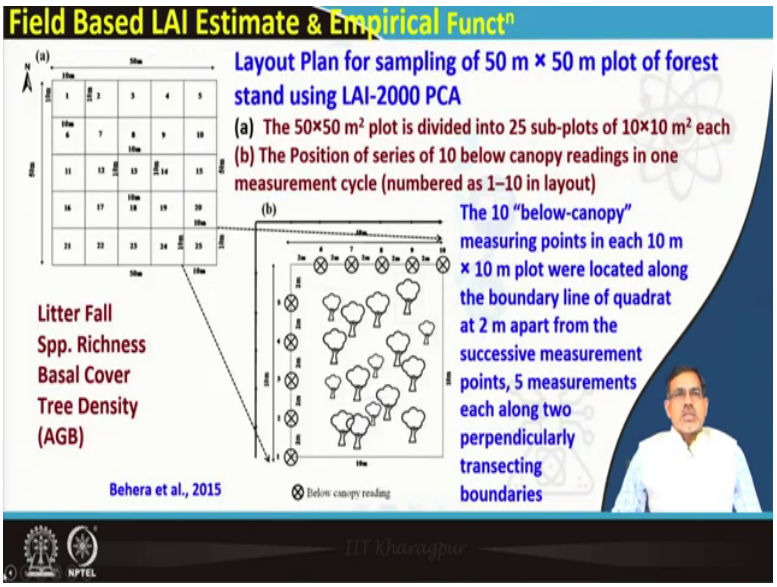

So, let us see as a case study. So, this as we have been talking, we have to design or come out with a fitting layout or the sampling plan. So, here what has been adopted a 50 meter by 50 meter plot of forest stand has been chosen, has been chosen. So, you can say in forest a 50 meter by 50 meter. So, we put about 50 meter by 50 meter plots across three different plant functional types.

And on the upper left that is a 50 meter by 50 meter plot, which has been again divided into 25 subplots and each of 10 meter by 10 meter square unit. And on the lower side which has

been zoomed with respect to one particular subplot of 10 meter square by 10 meter square, you can see that the arrangement of the trees could be like this.

And along the border some what you say circle with cross, so you can say cross circles have been put at a distance of 2 meter by 2 meter, so that means, 5 cross circles have been put. So, there the observations have been taken as far as the LAI is concerned means LAI instrument based observation is concerned.

So, now with respect to this 50 meter by 50 meter the litter fall has been collected, collected with respect to two different seasons. As we know, particularly for this forest the dry miscellaneous, sal mixed and the teak, these three forest are or we consider them very carefully as the plant functional types.

Though, some of you may not agree it, it cannot be like that. But, broadly we can agree on with respect to three different plant functional types with as far as the teak, sal, and the miscellaneous forest community are concerned.

So, the litter fall has been collected using litter trap method, as we have discussed in our week 2. So, that has been done during two seasons, ok, during leaf fall season and the leaf on season. And the species richness, so which can be as another proxy, so the species richness within this 50 meter by 50 meter plot has been accounted along with the basal cover and the tree density.

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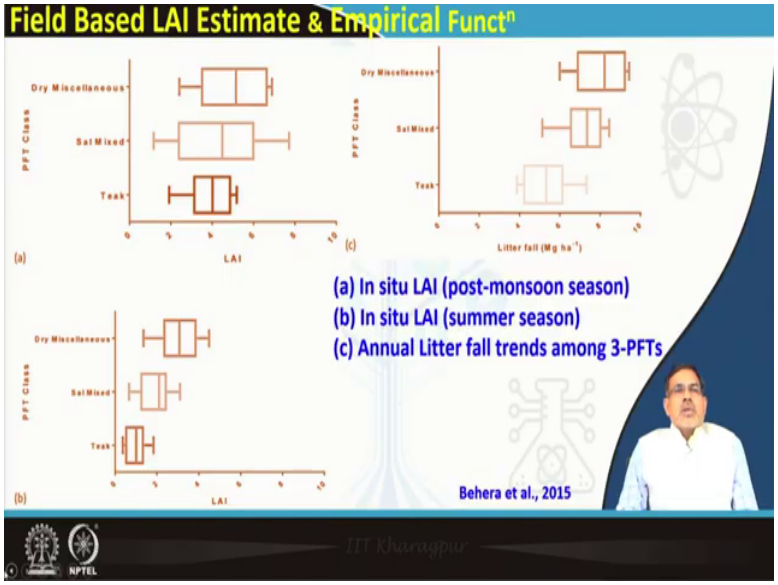

So, with this what has been observed? Yes, on the left hand two what you say histograms they say or they depict in terms of the upper left it is the in situ LAI, which is a kind of post monsoon season, and the down below is the in situ LAI of the summer season.

So, we can very well see that for this deciduous forest there is a large differentiation because the post monsoon you expect lot of leaves. So, that is why there is a seasonal variation your LAI is very high whereas, with respect to the summer season it is very very low, but it is high; among them if we compare it is very it is higher for dry miscellaneous because of the name you can expect some more species of secondary canopy having leaves.

And sal mixed having next to that, but teak have very less because most of the teak leaves are shedded during the summer season as you can imagine. Now, the upper right histogram it talks about the annual litter fall trends among the 3 plant functional types. So, if you see with respect to mean and their standard deviation values, this is higher for the dry miscellaneous followed by the sal mixed followed by the teak mixed. So, this has been calculated and shown in this figure per hectare.

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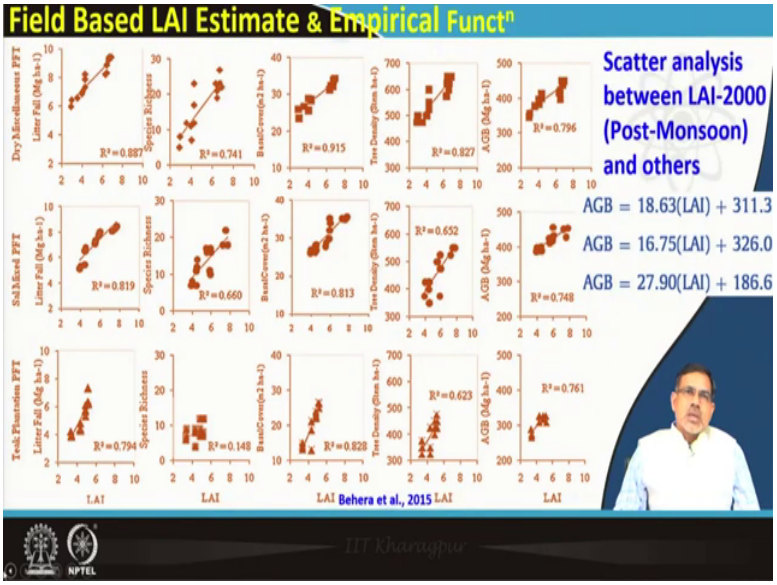

So, now these observations, like you have the litter fall, and also, as we discussed with respect to the species richness, the basal cover, the tree density, and all these have been used to calculate the above ground biomass. The above ground biomass using the volumetric equation as we have discussed in some initial classes in week 3.

So, then, what has been done? A kind of empirical relationship has been tried to establish. Now, we can see the simple linear relationship has been established and we got very high R square values for the litter fall and for many others also.

So, the left column all these histograms they show the relationship between litter fall and the LAI. So, R square is very high all are close to 0.8 or more than that, or 0.8 to 0.9. So, it is a very high correlation with respect to litter fall. So, accordingly, this scatter plot based on this scatter plots the allometric or regression equations can be derived and those has been proposed with respect to a relationship between AGB and LAI. So, these equations are very useful to extrapolate for similar forest types.

So, let us say this particular area is the Katarniaghat Wildlife Sanctuary which is in the Shivalik Himalayas. So, across the Shivalik Himalaya or you say the TAL, Terai arc or the Terai landscape these things can be extrapolated. And so, this is a field based LAI estimate and we try to see the relationship of litter fall and the empirical functions.

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Now, let us move to another case study which is from a very interesting site of mangrove forest located in the Eastern India. So, this particular four photographs, you can see from field will give us the feeling of the field based mensuration or observations, where on the upper left it is just on the brink of the sorry what you say and the adjoining to the creek.

You have the forest, and the moist area and you have the lot of pneumatophores, you find in the mangrove forest. And so, a researcher is taking observation using a digital hemispherical photograph camera. So, you can see the fish eye lens which was used is about 8 to 15 millimetre focal length.

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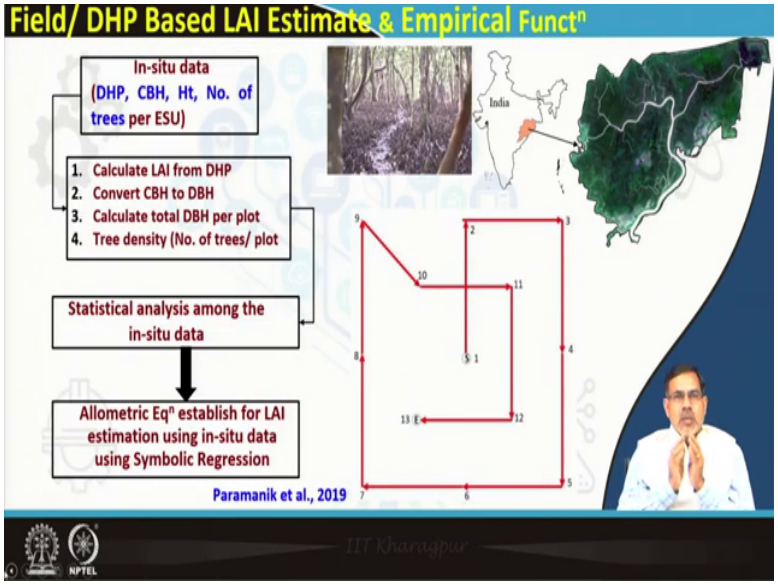

So, friends, we followed a definite ESU, as we know it is regarded as Elementary Sampling Unit. The middle depiction is for the ESU, where it is numbered S 1. So, you start taking the observation, one click in terms of digital hemispherical photograph, and then you move another 10 meter.

So, it is a 20 meter by 20 meter. So, when we move 1, 2, 3, 4, 5, 6, so accordingly, the whole 20 meter by 20 meter area is covered. So, this 20 meter by 20 meter corresponds to the sentinel pixel. So, that is where the design has been slightly changed with because our purpose or the link where we are going to do that is the sentinel pixel whose resolution is 20 meter.

So, the DHP based observation along with other forest mensuration including the CBH circumference at breast height, the height, and the number of trees per ESU have been calculated and they have been converted to get the DBH, CBH and the DHP.

So, LAI data this DHP based LAI data has been processed using CAN-eye a kind of freeware to come out with the LAI because as we have discussed in week 2, this DHP uses what you say the gap fraction basis to estimate the LAI. And then, we try to relate it and come out with a kind of allometric equation, try to establish for LAI using in situ data and also we try to do

the symbolic regression. So, this partially square regression and the symbolic regression we did and let us see what are the results.

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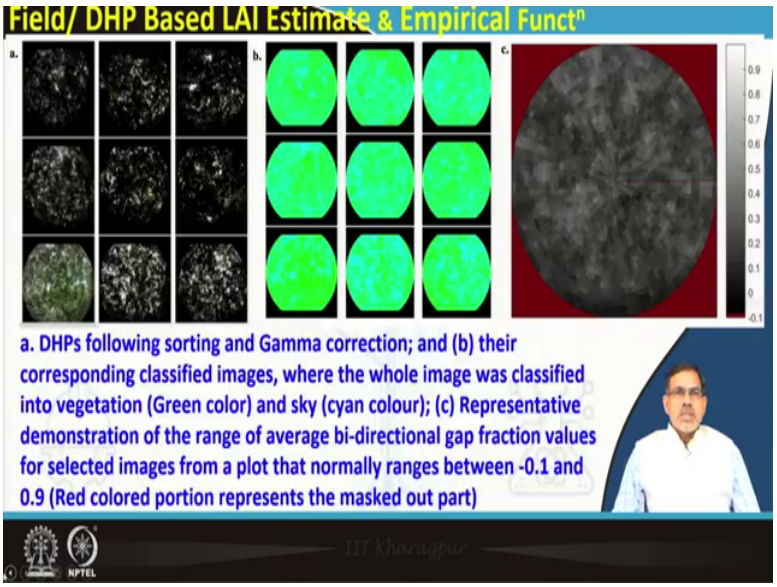

So, these particular figures they show the DHP or the Digital Hemispherical Photographs. And that 3 by 3 on the left hand side matrix, you can see the DHP is following sorting and gamma correction, and the middle they are corresponding classified images.

So, they have been classified where the whole image was classified into vegetation that is seen as green, and the sky portion has seen as cyan color. So, when some of you will work on this using a digital hemispherical photography principle or camera photography and then you may use or take it with any software. So, here cyan has been used.

So, then, you get this kind of images where you get the vegetation and the sky, so that means, you get the gap fraction. And on the extreme right, you see the representative demonstration of the range of average bidirectional gap fraction values for selected images from a plot that normally ranges between minus 1 and 0.9.

So, minus it is minus not 0.1, minus 0.1, so that minus is not correct, it is 0.1 to 0.9 or close to that, so above 0. So, red colored portions are the masked out portion. So, we can see how

the what you say the range of average bidirectional gap fraction values are shown on the image.

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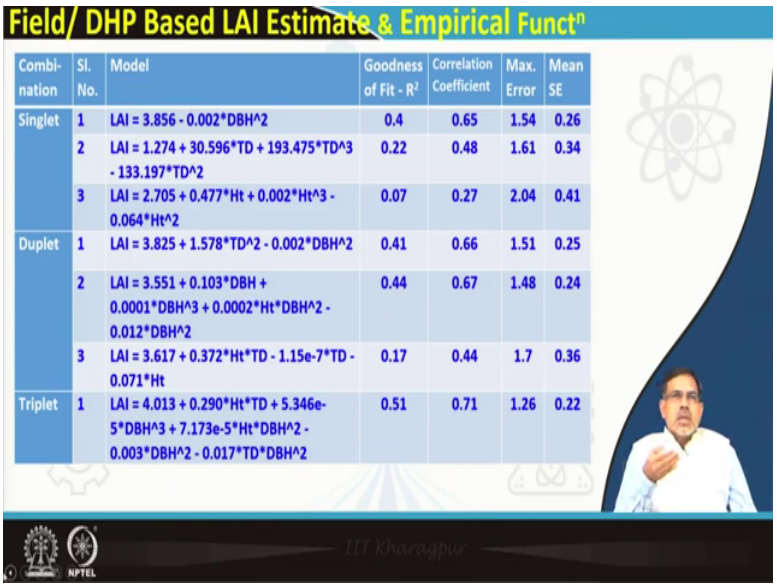

Combi-nation	Sl. No.	Model	Goodness of Fit - R^2	Correlation Coefficient	Max. Error	Mean SE
Singlet	1	LAI = 3.856 - 0.002*DBH^2	0.4	0.65	1.54	0.26
	2	LAI = 1.274 + 30.596*TD + 193.475*TD^3 - 133.197*TD^2	0.22	0.48	1.61	0.34
	3	LAI = 2.705 + 0.477*Ht + 0.002*Ht^3 - 0.064*Ht^2	0.07	0.27	2.04	0.41
Duplet	1	LAI = 3.825 + 1.578*TD^2 - 0.002*DBH^2	0.41	0.66	1.51	0.25
	2	LAI = 3.551 + 0.103*DBH + 0.0001*DBH^3 + 0.0002*Ht*DBH^2 - 0.012*DBH^2	0.44	0.67	1.48	0.24
	3	LAI = 3.617 + 0.372*Ht*TD - 1.15e-7*TD - 0.071*Ht	0.17	0.44	1.7	0.36
Triplet	1	LAI = 4.013 + 0.290*Ht*TD + 5.346e-5*DBH^3 + 7.173e-5*Ht*DBH^2 - 0.003*DBH^2 - 0.017*TD*DBH^2	0.51	0.71	1.26	0.22

So, with this we try to establish a kind of relationship, so using empirical functions. So, first a singlet combination has been taken; that means, whatever the mensuration in terms of DBH, three density, the height, ok. So, these three has been taken as far as the field measurement is concerned.

So, they have been taken one at a time, so single combination. So, all three 1, 2, 3, you can see the goodness of fit and correlation coefficient and the errors. And when we use the duplet combination, we took two at a time and try to correlate with the DHP based LAI, it the error has been slightly minimized whereas, the R square value slightly improved.

But look at the third one, the triplet combination, where all three were considered at a time. So, we can expect based on the synergy or optimization principle the goodness of it. That means, R square has increased to 0.51 and the correlation coefficient increased to 0.71.

So, that can be considered as a good fit with respect to the empirical function between the field based mensuration measurements and the DHP based LAI measurement, so LAI vis-a-vis the field mensuration.

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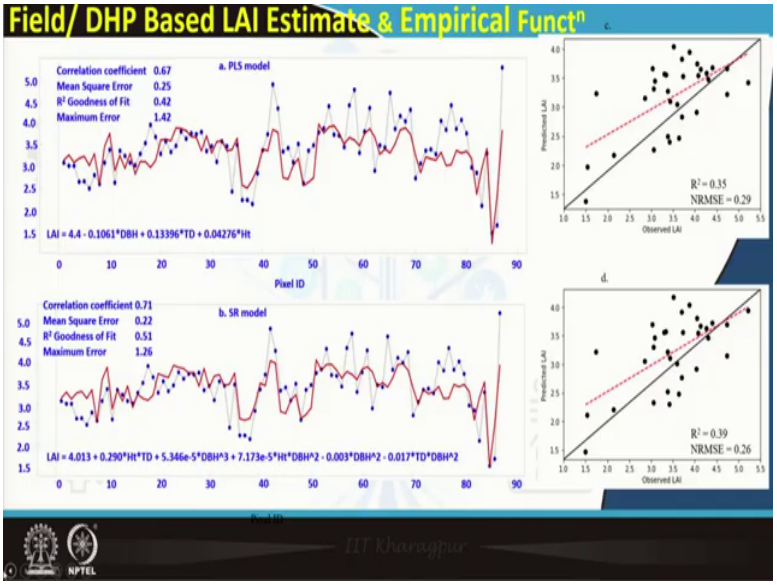

So, this is what, then finally, model using the partially square regression and the symbolic regression. So, here, this particular one looks like a good fit and we already discussed about the triplet combination. So, this is very interesting because these kind of regression equations are very useful and we need to develop more and more.

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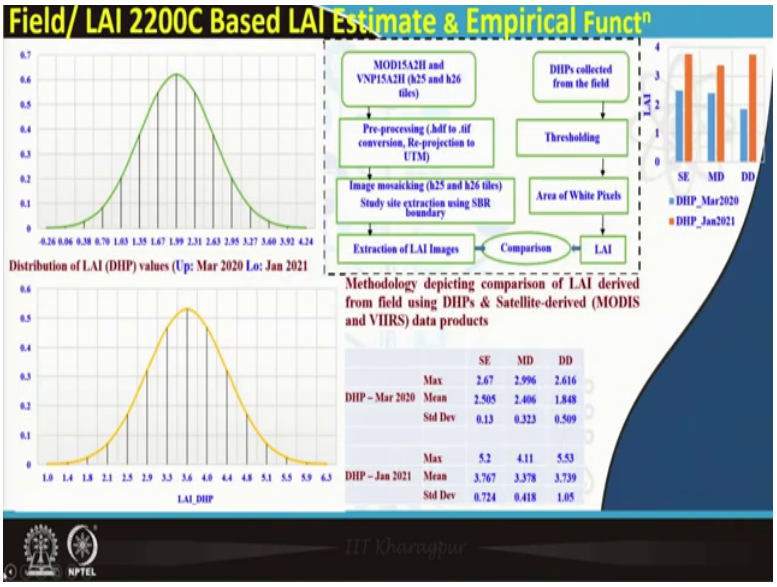

So, with this let us move to the next one. Let us move to the next one that is using LAI 2200 instrument. And in a tropical, again I will not say deciduous, but we have taken all three, again a tropical forest.

So friends, in this study we will try to see how they have been linked, and how they behave with respect to the satellite based images. So, friends what has been done here? This is from another forest site we have chosen. So, this is from Similipal Biosphere Reserve which is about 100 kilometre west of this particular place IIT, Kharagpur.

So, what we did? This is again we try to collect the DHP values, ok. So, DHP values and also we try to collect the LAI 2200C values. Look, the preamble here was since different forest types have different phenology, here particularly three different forest the semi-evergreen, moist deciduous, and dry deciduous has been chosen.

And the measurement has been taken during the post monsoon and the pre-summer. The pre-summer or you can say when the onset of summer begins. So, that is the beginning of summer season, we try to take the measurement.

The purpose was that let us see that can we get, what we expect theoretically, there we must have variation in terms of LAI observation across these forest types and across the seasons. So, we try to see that based on the DHP based measurement. And we also adopted the LAI 2200C to also have another set of measurement for comparison and contrast.

So, we visited ground we took the observation and took the measurements in three different forest types in two different seasons. And if just see on the right hand side, the values with respect to distribution of LAI, DHP the upper one is for March 2020 and the lower one is for January 2021. Since, we are working on this and there will be many more numbers, so one more season will be picked. So, this curve may slightly be fine tuned.

So, see the middle part with respect to the methodology. The methodology depicting comparison of LAI derived from field using the DHPs and satellite derived MODIS and VIIRS data products. We have discussed with respect to different global data products and as all of us know by now this MODIS are the pioneers. So, since 1999 or you say 2000 onwards,

we have the MODIS based LAI data available at a global scale at different temporal and spatial resolutions mostly 250, 300, 500, so in a hectometric range.

So, we did this field work and then try to come out with a LAI estimate. Same way we process the DHP Digital Hemispherical Photography data to come out with the LAI. Believe me they all take lot of time and our research students, particularly the PhD students, they do a good job in this. And with respect to max the statistics a kind of minimum, maximum, mean, standard deviation, we all calculated this.

So, and try to see that how is the variation on the upper right if you see, upper right corner the semi-evergreen, moist deciduous, and dry deciduous. One very significant distinction we can see that this March 2020 which is shown in blue histogram or blue in terms of blue histogram is showing a lower value than the January 2021.

Because the January 2021 is slightly what you say beyond your post monsoon. We should have ideally taken a kind of November or December. But there in this particular forest till you say December end, early January we have good leaves or all the leaves are there.

So, after around towards end of January the leaf fall starts. So, we have captured almost the post monsoon or the full leaf condition as far as the January 2021 concerned, the magenta or the orange color histogram shows that. So, that is having a higher value in comparison to the deciduous area, deciduous season. So, this is a very good indication and very clear indication and in the quantitatively here we got it what we tried to see or wanted to do.

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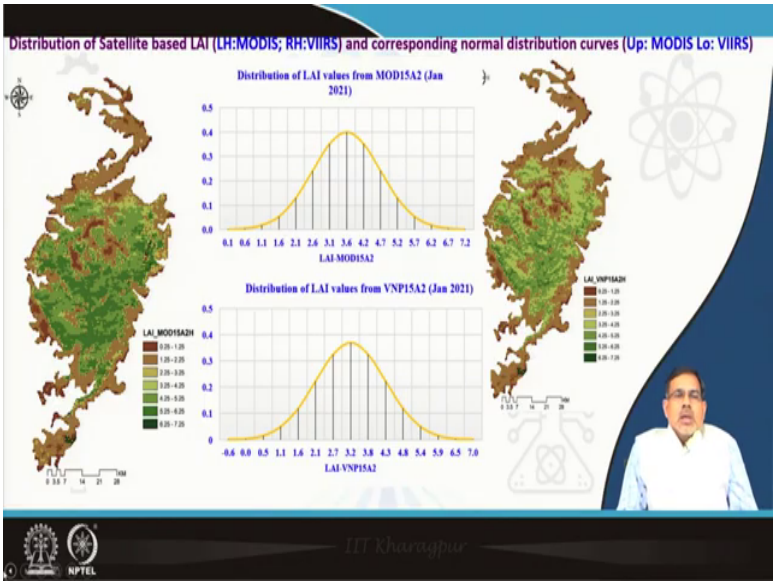

Now, after having this, we try to see how the MODIS and the VIIRS based LAI products look like over the Similipal biosphere reserve. So, on two sides, the size has been on the right hand side image has been slightly shrunken to match to what you say PPT protocol.

So, what we did? We just tried to show this between the range and try to see that the LAI, the MODIS range is varying between 0.25 to 7.25 on the left hand side whereas, on the right hand side it is going up to 7, ok. So, 0.1 to 7.2 for MODIS and for VIIRS it is the upper ends has been slightly lower what you say come down.

And with respect to the two histograms in the middle, those depict the distribution of LAI from this and we can see that how the with respect to the peaks, the ground estimates and how they vary in terms of the histograms. So, the upper one, the MODIS one, and the VIIRS one are nearly comparable whereas, the mode value in terms of VIIRS is slightly lower than that of the MODIS pixels.

So, this is a general observation. And what we have studied in our week 2, that yes different global products, LAI products though they behave similarly, but there are also differences. So, this is the evidence and what we have under what we studied, we got it also, we saw that also.

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So, after doing that we tried to compare these two values with respect to the ground based observation. So, we took it with respect to three different forest types. The upper left one is for the moist deciduous, the upper right one is for the dry deciduous and the lower left one is for the semi-evergreen forest. And you can very well see the LAI observation from the DHP, the LAI observation with respect to the MODIS and the VIIRS pixels.

In terms of the moist deciduous, we are seeing that the LAI values are higher, generally higher which are the field based LAI values whereas, in terms of other two, they are slightly what you say confusing or not following a significant pattern or we can say that the number of plots are less because with this much numbers we cannot conclude anything.

But, the indications are clear and we can interpret, that yes the semi-evergreen and deciduous, why these two forest they have more number of species those are either deciduous or evergreen nature. So, semi-evergreen accommodates more of evergreen species, whereas, the deciduous, dry deciduous it accommodates more of the deciduous species. So, it is a mixed composition, so that is why you do not get any pattern.

But, what is very indicative and clear from here on the upper left in figure that the DHP based LAI which is field driven are means are having higher values in contrast to the satellite based. So, we can put it on the other side, that the MODIS and VIIRS, the satellite based MODIS

and VIIRS products do little underestimation of LAI which is evident in the moist deciduous forest more prominently over the Similipal biosphere reserve.

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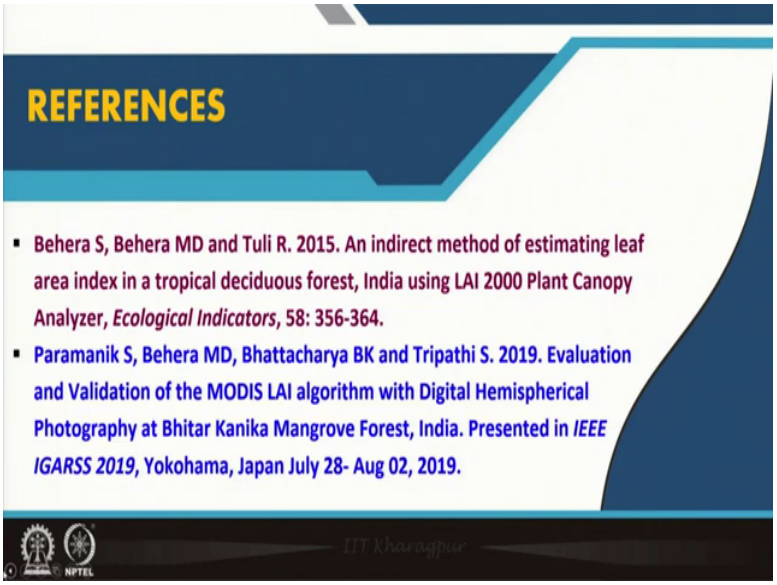

So, friends, with this we try to discuss the three different forest types. And these are the two references I have put before you, and for the last one for Similipal biosphere reserve we could not give the reference as some of the results are still under consideration for publication.

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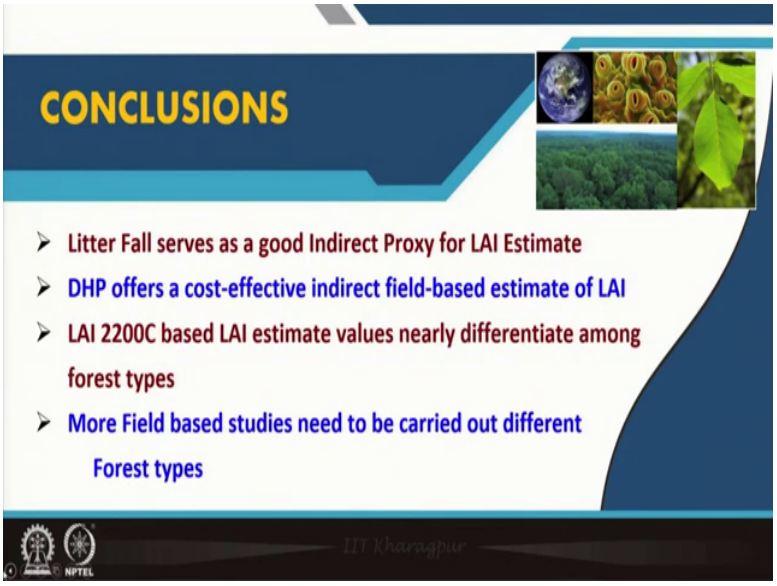

So, let us conclude. As we know, with respect to the first example in Katerniaghat based on the leaf fall that serves as a good indirect proxy which is a field based non-destructive method. It acts as a good proxy for LAI estimate.

And the second one, where we saw that the DHP based LAI estimate offers a cost-effective protocol for LAI estimate. And sometime please keep a watch on our publications because the next work I could not include due to paucity of time. We have linked it to satellite data particularly with respect to landsat and the sentinel pixels.

The third one, yes, the differentiation between and among the forest types in terms of LAI is nearly possible. And it is little difficult, if the forest types or the phenology or phenophases of different forest types are nearly similar.

But there could be some gap areas which we need to pick in terms of understanding the phenophases and the phenology with respect to this deciduous forest. The fourth one, as we mentioned more field based studies need to be carried out for different forest types.

Friends, in some of our, means 2nd or 3rd lecture we discussed India has many different forest types. It is very easy to come out with LAI estimates from homogeneous vegetation like agriculture or horticultural crops. For forests, it is very difficult because your background is totally different and your variation in terms of species composition, the topography, and whatever we have discussed till date with respect to this they all contribute and confuse with respect to your LAD, the leaf angle, how they are distributed, the clumping factor.

So, all this actually makes the LAI estimate from forest much more complicated. But I can really tell you that we are at the beginning of these studies. As far as India is concerned, we need to do more and more studies, so that we can come out with better what you say empirical relationship and better estimate the primary production.

Thank you very much.