**Remote Sensing of Leaf Area Index and Primary Productivity**
**Prof. M. D. Behera**
**Centre for Oceans, Rivers, Atmosphere and Land Sciences (CORAL)**
**Indian Institute of Technology, Kharagpur**

**Lecture - 19**
**Primary Productivity Applications: Indian Examples**

Welcome back. So, let us discuss about the Primary Productivity Applications and we will see it through some of the case studies and Indian Examples specifically. So, the title can go like this; Primary Productivity Applications. And as we have been discussing primarily, we are seeing how the remote sensing data we are utilizing along with field based and other approaches including, machine learning and other modelling approaches.

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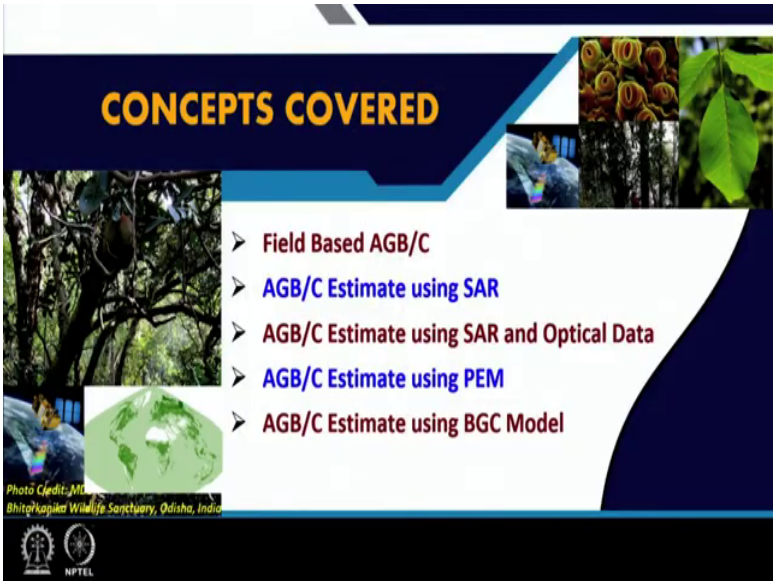


So, with respect to this; the concepts we are going to cover in today's discussion in lecture number 19 are a field based above ground biomass or carbon estimate. I know yeah we are already thorough with respect to biomass and carbon and their ratio or what you say thumb rule how we take it.

So, we will see it in terms of a case study from the same Katarniaghat Wildlife Sanctuary site, where we have done a very extensive field work and came out with above ground biomass and also estimated the above ground carbon. Second, we will see this above ground biomass

or carbon which we estimate in terms of the primary production of an ecosystem. We will see how the synthetic aperture radar or the microwave data used has helped in terms of accommodating the higher range of biomass or carbon or you say the primary production.

Third, the synergy, so we can integrate and we will see how the optical data along with the microwave data or SAR data can be integrated and also, in terms of the temporal and spatial resolution see here, we are where in the integration is targeted towards deriving synergy. So, SAR and optical; both of them act on different principle or as you know one is based on the backscatter another is based on the reflectance.

Then, they have different temporal and spatial resolution, but the temporal resolution also we will see how they could perhaps, be exploited to better estimate the AGB or the AGC above ground carbon. Fourth, we will talk about one model the production efficiency model as we have discussed. We will see in terms of an example in the same Katarniaghat site.

And seeing the LUE how the maximum light use efficiency has helped in imitating many of the intermediate processes are the teaching many things many variables also. And towards end, we will try to understand a biome BGC or you say biogeochemical model. We have a run on this using 16 variables from the model site. So, we will see how complex these models are to run and how data hungry these models are.

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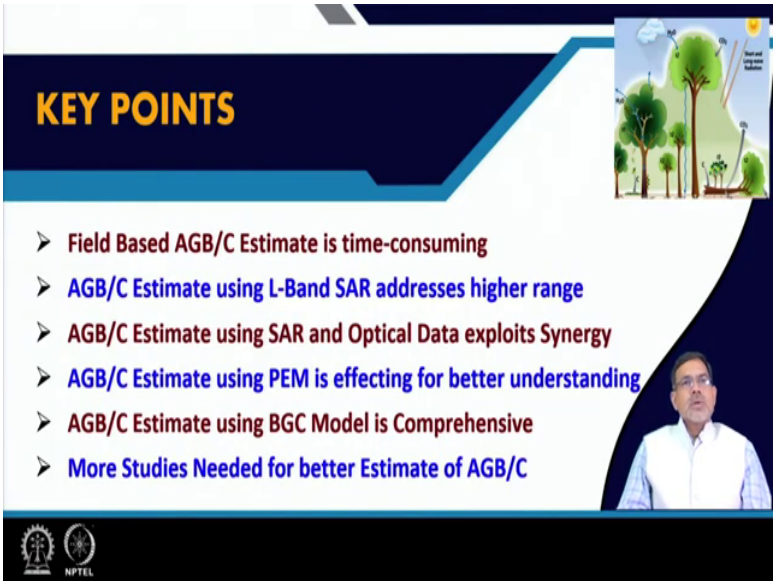

So, (Refer Time: 3:59) we will cover this in terms of time, field-based estimates are time consuming and SAR and optical gives better estimate of higher range and their merging gives or exploits synergy. Then, the production efficiency models help in better understanding whereas, the biogeochemical models are very comprehensive and data hungry. And towards end based on the time, we will talk about the need for future studies and how to reduce the uncertainties and go for better estimate of the primary production.

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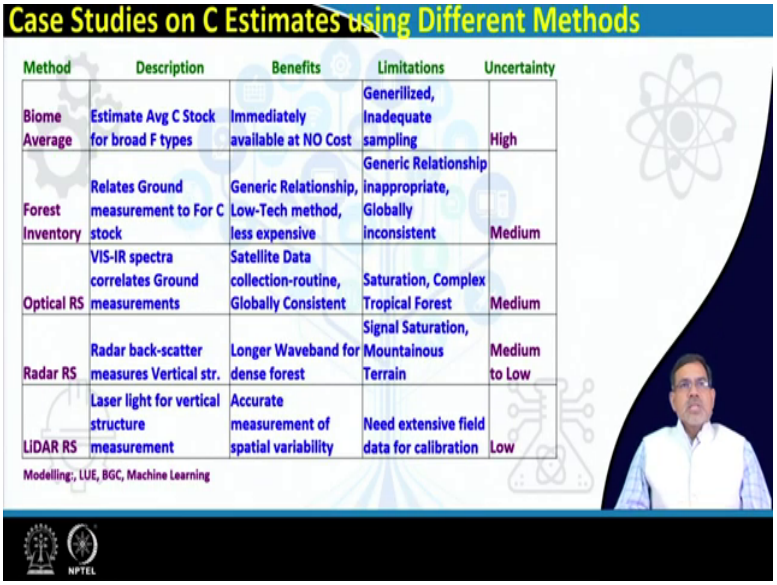


With respect to this, let us see the different methods what are available or broadly we have been discussing. So, in terms of the forest inventory that we are talking with respect to ecosystems or at landscape scale. So, inventory or we say the field-based estimates are in terms of certainty.

They have very medium level of uncertainty, but as you see with respect to optical data also the uncertainty is medium. Whereas, in terms of microwave or the radar remote sensing, it is medium to low, because we get good what you say proxy or signal, because it is based on the ranging it is based on the back scatter.

So, microwave or the SAR data Synthetic Aperture Radar data are very well used for primary production or you say, above ground biomass or carbon estimate. Coming to LiDAR, yes, we

know now that it gives us the vertical profile. So, with a very good accuracy, so that helps us in reducing the uncertainty.

So, uncertainty is very low; however, the modelling efforts in that helps us integrating many of these variables and in terms of others like, where the radiation or the solar radiation optimization principle is followed in terms of light use efficiency or detail in terms of biome or biome BGC or biogeochemical models and machine learning.

So, machine learning as we know, it optimizes by integrating many variables which are or which could be the correlates of AGB or AGC. So, let us see with respect to this some of the different methods and how they have yield different results and with respect to the same forest or the same community types.

Remember friends, throughout this particular course and this is the uniqueness of this course that we are discussing about the in terms of examples or in terms of the complexity we are heavily discussing with respect to the forest ecosystems, in contrast to the agricultural fields. As you know, the crop fields are very uniform in terms distribution and very simple they are the complexity is almost vary at a minimal at minimal level.

So, with respect to all our examples, we are relying on we are taking the examples from forest and more so from the tropical forest. As we know, in some of our initial classes the tropics they have different level or strata of the trees or plants including big trees then, shrubs or secondary trees then, shrubs then, herbs and the grass layers. So, it is a complex and also the background soil in terms of moisture and many other things. It is a very complex thing.

So, our study and investigation and the discussion into this will help us in understanding more and more so that, we can do good job in terms of assessing the leaf area index or the primary production of our forest. And the examples that is why we have chosen from Indian sites, because from Indian sites, the examples are scanty.

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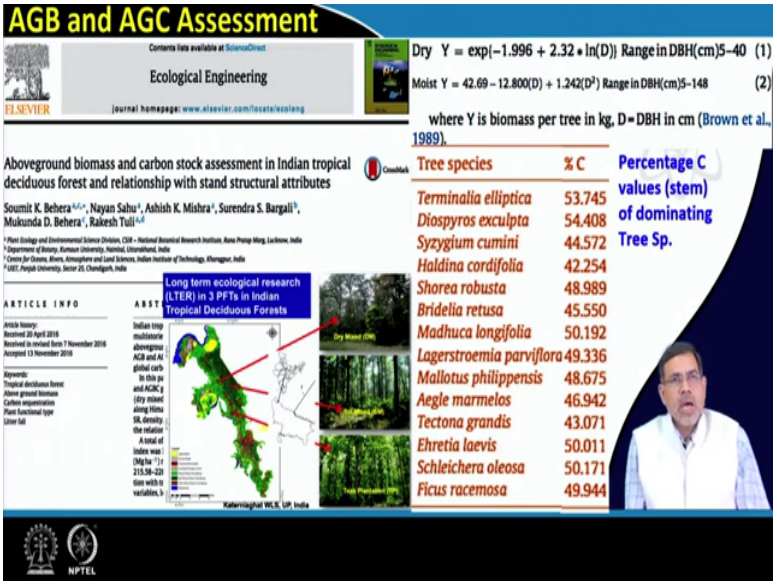


So, with this I have in this lecture number 19, what I have done on one side I have put straight way the first or the front page of the publications that will help you in locating the publication. And if you want to read then, you can do a good read with respect to that and you can get the details of this.

So, in this what we are trying to discuss or trying to pinpoint is the tree species vis a vis the percentage of carbon. Friends, all of us know the tree which is let us say of 100 kilo of that about 15 to 85 to 90 percent is just the moisture. So, it becomes like 10 15 kilo or 20 kilo is the biomass and out of that here, roughly 10 kilo is the carbon and that carbon is the carbon, which has been fixed during the process of photosynthesis. Let us see the whole thing about carbon and how to assess the carbon in the sense.

So, friends we have different regression equations, as you can see the one on the upper left corner one expression has been given in terms of dry forest and the moist forest. So, exponential of some number and log that D and DBH. So, these two D stands for here DBM means diameter at breast height or then, Y is the biomass per tree in kilogram.

So, with this kind of equations, we can. If we have the forest mensuration with respect to diameter and the tree then, we can come out with a kind of biomass with respect to different

forest communities, in terms of dry forest and moist forest, but you can understand the whole forest could be generalized, because you have variation in the species composition.

And coming to that, you can see this tree species vis a vis the percentage of carbon. In this particular forest site, I have also discussed on our 18th lecture, with respect to the Katarniaghat Wildlife Sanctuary, which is a tropical deciduous forest located in the Tarai region in Baharich district of UP Uttar Pradesh.

So, what we did we have tried to do the sampling in three different forest types. And as we discussed in 18th lecture, we tried to tell them or mark them in terms of PFT; Plant Functional Types, in terms of dry mixed sal and teak. So, in this we got different species and from literature, we found that the tree species as you can see fifteen tree species names have been given and vis a vis their percentage of carbon with respect to above ground biomass.

So, the above ground biomass of Terminalia elliptica have 53 point this percentage of carbon. So, if you see it varies from as low as 42.254, where Haldina cordifolia and goes up to your 54.408 that is Diospyros exculpta. So; that means, you have a variation of about 10 percentage to the range of or 50 plus or minus 5 in a broad sense. So, that kind of enumeration we must keep in mind, but if you take a thumb rule, it becomes for a community or for ecosystem it becomes about 50 percent of the AGB is the AGC or above ground carbon, that is why that is how you estimate or asses.

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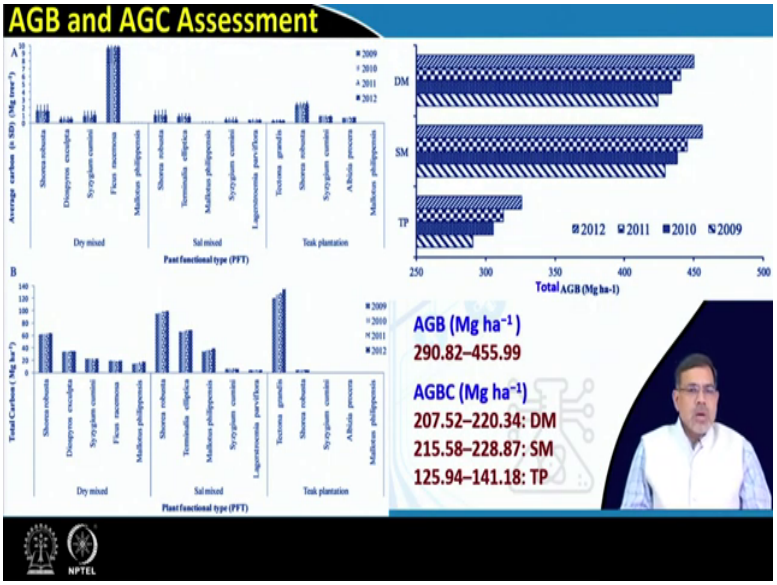


Now, let us move on. So, with respect to this assessment on the upper left and the lower right and what you say upper lower left, two histograms have been shown. The upper left shows on y-axis the average carbon in the and their standard deviation value in terms of mega grams per tree whereas, the lower one talks about the total carbon.

So, average and total has been shown with respect to three different plant functional types or you can say the communities or forest. And the dominant species which whatever has been seen. And on the upper and lower one you can very well see this is this enumeration or the measurement was between 2009 and 2012.

So, you can see there is slightly or very nominal increment in terms of the AGB vis a vis the AGC across the years or you say, in terms of annual increment. So, there is annual increment notice to it, but you can see it that vary from species-to-species and so also from forest type or from plant functional types to plant functional type.

on the upper right this has been shown in terms of the total above ground carbon and that ranges between 290.82 to 456 mega grams per hectare and half of that are in terms of the AGC. I am sorry it has been wrongly typed there. So, it is above ground carbon for different forest types also, has been shown that various and almost to the tune of 50 percent of their biomass range or above ground biomass range.

So, this is what I wanted to tell you friends, because when you will go for some kind of studies or assessment this must be in your mind that yes, AGB and AGC maintains a kind of thumb rule of 50 percent. And when you go for assessing for ecosystem, you take care of the major or the dominant species ok. And you see that how much they contribute for the total or of the total community or that for particular forest and you do the averaging.

If you see that yes, these 4 5 species contribute to 85 percent then, you just fill another 15 percent to make it 100 percent. So, that is how you do lot of approximation what you say addition and thumb rule-based extraction to come out with the forest or the ecosystem based above ground biomass vis a vis the above ground carbon assessment.

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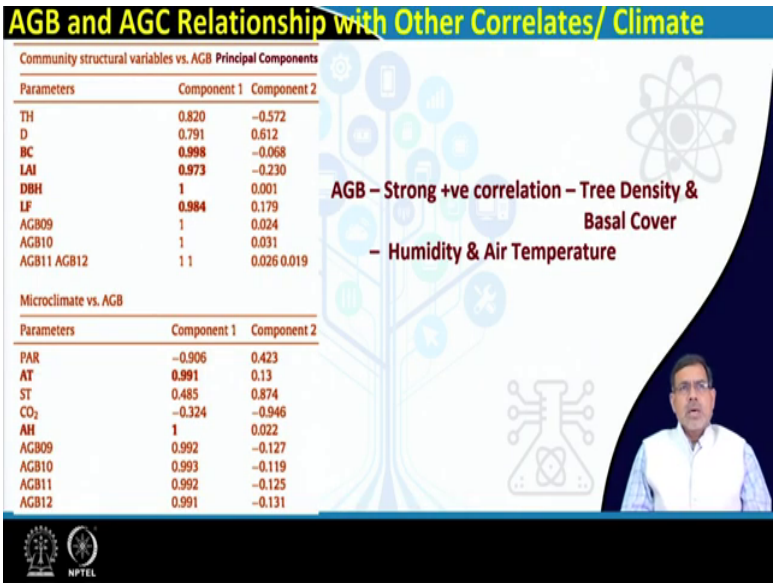


Here is the next one. In the same relationship, we try to see the relationship in a kind of statistically with respect to the principal component 1 and principal component 2 between AGB and the other variables. So, the different variables we have taken we try to put it under community structural variables and micro climate.

Friends, as our week 4, we are slightly trying to correlate with respect to the climate or the micro climate here, that is why I picked this example to discuss with you. So, in terms of the community structural variables, you can see the humidity the sorry the tree height the

diameter the basal cover the LAI the DBH the leaf litter fall and their relationship with respect to the principal component 1 and 2.

So, you can see DBH is very highly related with respect to P C 1 whereas, the LAI and basal cover and the leaf fall are also very highly related or correlated. Coming to the micro climate, we can see that at this air temperature represented by AT and atmosphere atmospheric humidity. So, atmospheric humidity is giving you a very high or strong correlation with AGB.

So, this is a very good test to see in terms of statistics yes, the AGB maintains a good correlation with these variables, because as we know the plants or the forest are what you say the reflection of whatever is available to that particular plant in terms of this. So, that is why very good relation and correlation. Now, we can see that with this kind of things, we can try to assess or how they could vary or they could change if there is any change with respect to climate ok. So, this is where we stand.

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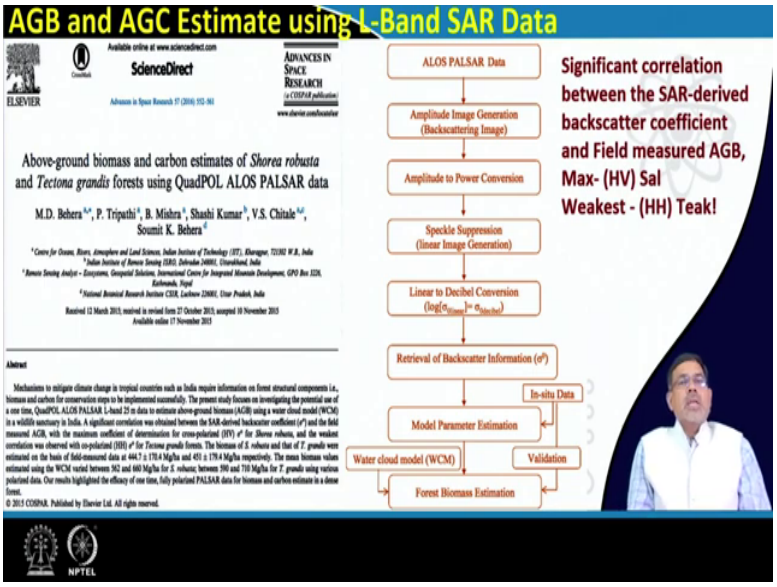


Now, let us move to the next example from the same site after of the Katarniaghat Wildlife Sanctuary. Here, what has been done, as you can see the QuadPOL ok the polarized what you say data with respect to L-Band, coming from the ALOS PALSAR; that is the name of the satellite sensor.

So, that has been used. So, L-Band data is supposed to give us a return more information as far as the higher range above ground higher range biomass or carbon is concerned. So, that is why this L-Band study I have chosen to cite an example.

So, the flow chart is there. You can find the detail in this particular publication. So, ALOS PALSAR L-Band data has been taken the amplitude image was generated. Then, the speckles the noise in the sense have been suppressed and linear image was generated. Then, linear to decibel conversion has done to retrieve the back scatter information that is sigma naught.

And then, using this in-situ data in terms of above ground biomass, the model has been parameterized and here, a kind of water cloud model has been utilized. So, I am not going into the depth of the water cloud model, but because it could be totally out of scope and the time will not permit us. So, then, it has been validated also with respect to the in-situ data that was collected from the field.

And part of that data has been separated for model prioritization 70 percent, as we have seen in terms of our theoretical discussion in previous classes and 30 percent were retained for validation. And then, we got a good forest biomass estimation and here we try to see with respect to two dominant species that is Sal Shorea robusta and Teak Tectona grandis; two particular species.

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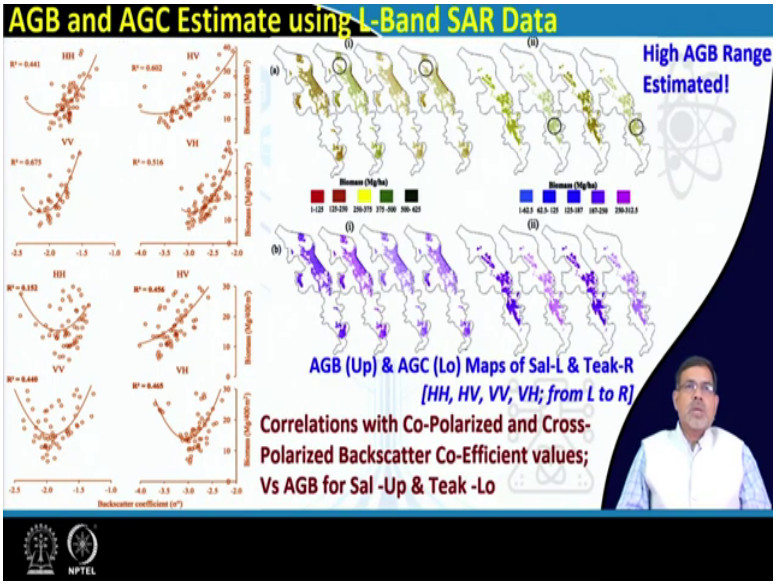

So, on the left-hand side, you can see the correlations with a co-polarized and cross-polarized. So, HH and VV are the co-polarized and the HV and VH are the cross-polarized backscatter coefficient values. So, backscatters. So, we see this in terms of the upper one is the Sal is for Sal and the lower one is for teak and R square is mentioned.

So, you can see the correlation for different polarized data. So, using that when the model has been run through the model, what we got is the is a very high above ground biomass or above ground carbon range we got, which could go up to very high range; that is, 600 plus.

So, 623 whereas, your ground data and other estimates based was almost less by 20 percent. So, the higher range could be picked and believe it. I am not saying that this is 100 percent right, but what I want to say that yes L-Band provides or overcomes the saturation effect. Because it has a longer penetration potential and using the co-polarized and cross-polarized, we can reveal it in a better way. So, with respect to the biomass and the corresponding carbon map which depicts it

So, the right side upper one is for the biomass, the left side of that is for Sal and the right side is for teak and whereas, in terms of the lower one you have Sal and Teak there, but that is the above ground carbon. So, just think of the map for two particular dominant species for the above ground carbon in terms of a spatial distribution. And you can see it across time across season and that is what we can analyze and understand.

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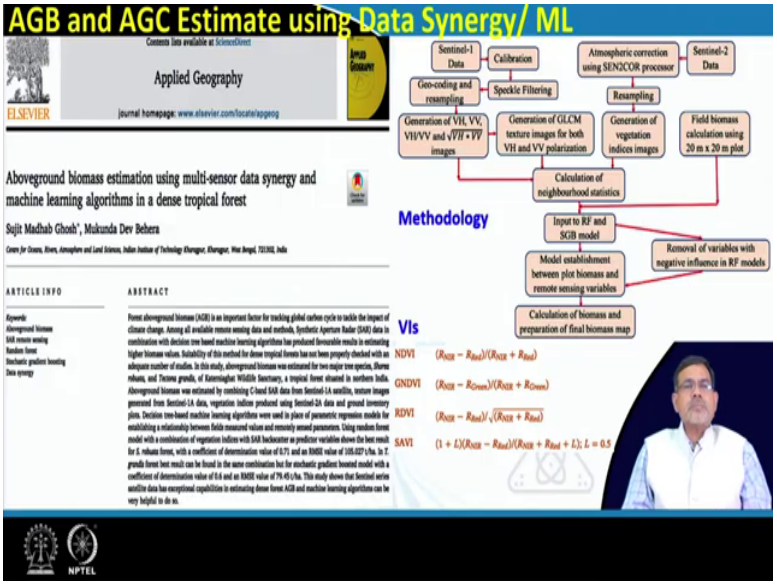


Now, coming to the next, with respect to the data synergy. So, as far as the data synergy is concerned. What do we mean by data synergy we, because we need to exploit or we need to extract best of two or many. So, in terms of the sentinel data here, the sentinel-1 and sentinel-2 data has been used. Friends, I am sure you remember that sentinel-1 is the micro microwave sensor and sentinel-2 is in optical.

So, when we merge in the principle of backscatter and reflectance, we expect synergy, because one gives lot of information with respect to the canopy in terms of reflectance, the other one gives lot of information with respect to the structure, geometry and also, the moisture content.

So, if we club them then, probably we can get or we can do a good job in terms of getting a getting good estimation of the biomass and that is what has been done here look at the methodology. So, sentinel-1 sentinel-2 data has been used and then, the input has been given to two models the RF and XGB.

So, the random forest and the gradient boosting model has been used. So, in that we will see that the model has been established between the plant biomass and remote sensing variables and then, the biomass has been calculated and the final map has been generated. So, here,

along with the sentinel-2 the sentinel derived vegetation indices has been used, not directly the reflectance band.

So, as we know and as we have discussed in some of our previous lectures that vegetation indices two band-based vegetation indices mostly are available. So, and few bands they also have some constraint like, you can see the SAVI the soil adjusted vegetation indices takes a coefficient or constant factor. So, these indices gives a better proxy or provides better proxy as far as the optical data is concerned.

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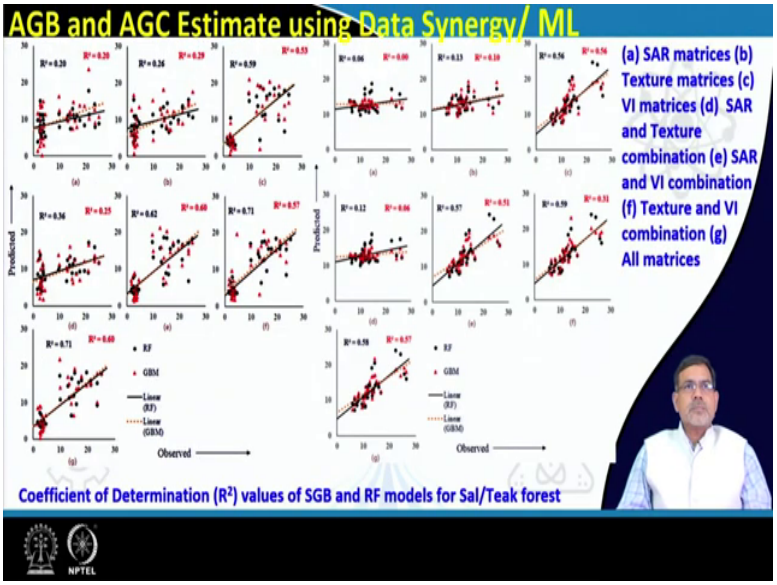


And then, we try to see what is the amount of correlation in terms of the coefficient of determination or the R square between the model and model for the Sal and Teak forest. So, on the left-hand side I mean figures or the correlation graphs are for the Sal and right-hand side for the teak.

And all the seven plots for each of them. The first one corresponds to a SAR matrix the synthetic aperture radar based. Second one, the derived texture. Third one, the vegetation matrices. All these four vegetation indices that we have discussed.

So, that have been used and then the fourth one is the SAR and texture combination look on the d, both combinations have been taken. In terms of e, the SAR and VI combination has

been taken and in terms of f, the texture and VI combination or vegetation index combination have been taken and at the end all the matrices have been taken.

You can very well see as we go for singlet; that means, one at a time, duplet; two at a time and more than two; that means, all matrices the coefficient of determination R square goes on increasing. As we can expect statistically, because they all based on a complementary kind of principle.

So, that is why we are getting a kind of improvement in terms of the coefficient of determination R square value. So, for both in terms of Sal and Teak; based on your data, we have got it up to 0.6 and 0.57. So, very good correlation R square that is for Sal and what you say for Teak is with respect to random forest and GBM gradient boosting modelling.

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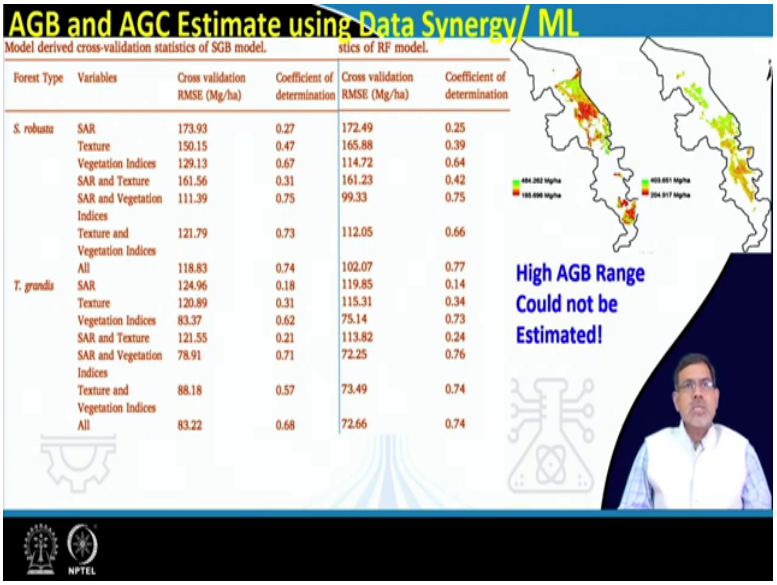


So. this data synergy using machine learning, Look here, we have used machine learning, but we have used the SAR which is in C-Band. C-Band has a smaller what you say wavelength than the L-Band or ALOS PALSAR derived L-Band.

So, here, the output AGB or AGC maps what we are you are seeing on the right-hand side upper right-hand side are the higher range is very less. It is going up to your 484 or 403. So,

that means, the longer wavelength data and a kind of cross-polarized or QuadPOL data gives us more information by overcoming the limitations.

So, the work is going ahead in terms of exploiting synergy from many and trying to use or integrate them, based on the different machine learning techniques to come out with a good AGB or AGC or the primary production maps or estimates.

So, on the right-hand side from the model derived cross validation statistics of XGB model and of the RF model. So, you can see the different figures with respect to cross validation and the coefficient of determination. So, this is with respect to the machine learning and the data synergy.

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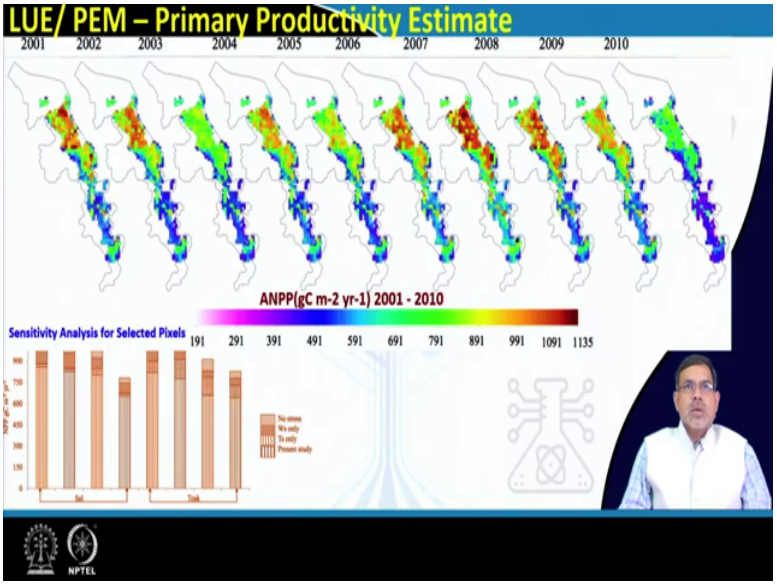

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So, with this we will come to the end of this 19th lecture; that is with respect to the references the publications are already shown there.

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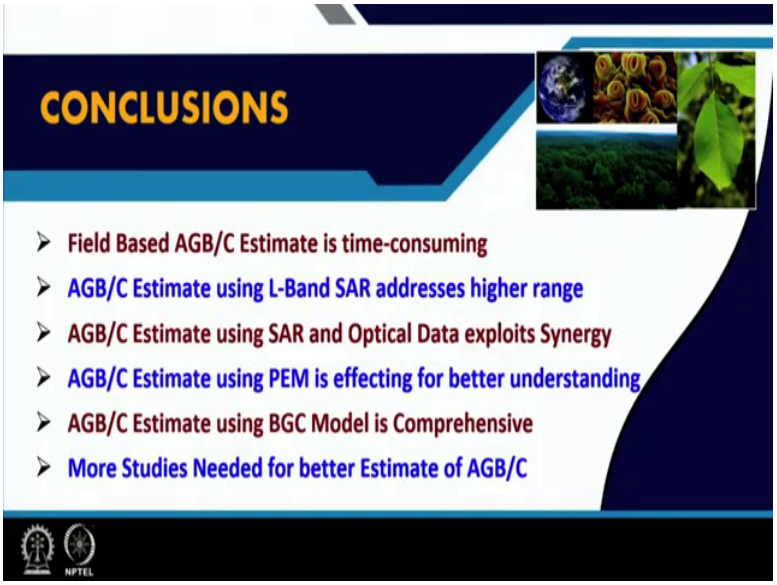


And the conclusions could for this are the first three; that means, we discussed about the field based it is very time consuming. We discussed about the SAR data and the L-Band L-Band quad PALSAR data gives or addresses the higher range.

And in terms of point three, the SAR and optical or microwave and optical; both exploit the synergy. So, use of what you say machine learning algorithm helps in better estimate of the above ground biomass or above ground carbon.

So, thank you very much for attending this lecture. See you soon.