Remote Sensing of Leaf Area Index and Primary Productivity
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Lecture - 10
LAI Products- Challenges and Future Prospects

Welcome back. So, today and the 10th lecture that is the last lecture of week 2, let us discuss on few more LAI products particularly the hybrid or the combination of different what you say sensors and even if a LAI based products. And we will see how they in the principle of synergy their accuracy has been improved.

And second, we will also talk about some of the hectometric that means, below 1 kilometer spatial resolution LAI products. And see they are of global or some regional spread are having the LAI from different continents. And then, we will discuss few things with respect to the challenges or the key issues as far as the LAI products are concerned and what are the future prospects or challenges before us to deal with them.

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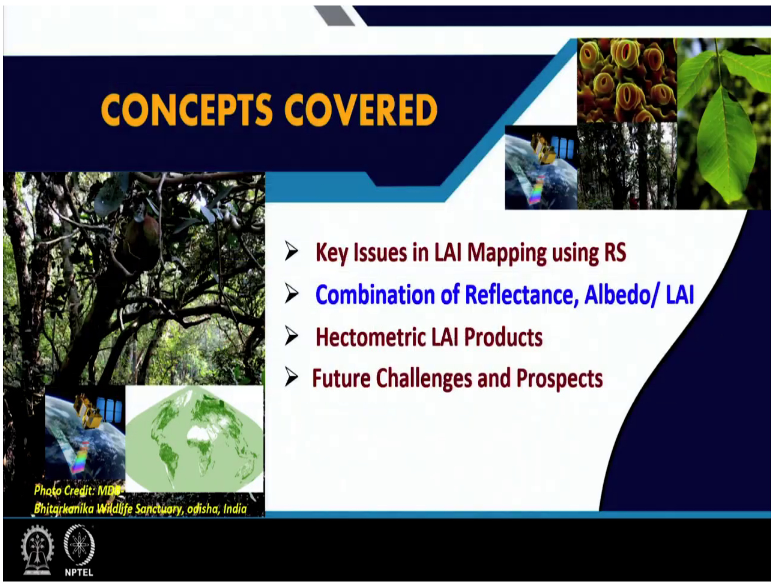

So, with this we are going to cover these 4 concepts like key issues in LAI mapping using the remote sensing, combination of reflectance, albedo and LAI, then hectometric LAI products, and future challenges and prospects.

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So, with respect to these 4 we will perhaps cover the following key points. First is we will know what are those several key issues that remain in LAI mapping as far as remote sensing is concerned. Second, we will also try to discuss with respect to the LAI products from a various combination of reflectance albedo or LAI that are particularly from moderate resolution satellite data. And we will see how with this combined effect the synergy is harvested and that leads to more accurate products.

And then we will see the below 1 kilometer resolution LAI products available particularly 250 to 500 meter range. And the what are the key challenges and future prospects are as far as LAI retrieval is concerned using set of algorithms or the data sets LiDAR, RADAR, UAVs and many more.

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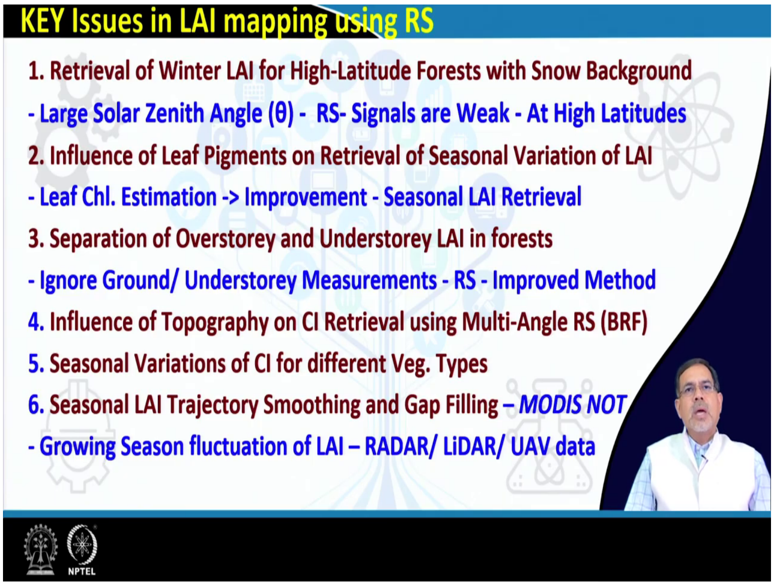

So, with this let us try to understand these 6 key issues in LAI mapping using remote sensing.

So, the first as we know retrieval of winter LAI for high-latitude forest with snow background. Though we have touched upon these things partially with respect to our discussion on the VI based and also the relative transfer based LAI estimates, but coming to more specifically in terms of the space key issues the one, the first one is the snow background effect.

So, as all of us know in terms of high latitude particularly alpine or the polar region forest, we receive lot of reflectance because of the background snow and that happens mostly for 3 to 4 or over 3 to 4 months period of an year.

So, large solar zenith angle which is experienced at high latitudes means the solar zenith angle is very large at high latitudes, but RADARs, the remote sensing signals are very weak. So, that is why this snow, the background snow is a key issue in terms of dealing the LAI estimate using satellite data.

Second, influence of the leaf pigments. The dominant one all of us know is chlorophyll. So, influence of leaf pigments on retrieval of seasonal variation of LAI. So, we need algorithms to improve the chlorophyll estimates as a dominant pigment, so that the seasonal LAI retrieval could be more and more accurate because the seasonal LAI retrieval is very important as far as the land surface models or vegetation dynamics models in between many other models including the primary productivity are very important because the seasonal LAI has to be very well estimated and fed into the model.

Third, separation of over storey and under storey LAI in forests. So, what happens using the field based or ground based measurements, we mostly try to see up and look at the gap fraction or how much gap is there, but perhaps mostly we ignore the ground canopy.

So, that actually incorporates error. In the sense that, when you see the remote sensing data from 100s of kilometers away from the sensor takes records the whole of the reflectance coming from the canopy and including the background or if it is soil or if it is moist or if it is some ground vegetation.

But, we mostly ignore these understorey measurements when we go with a kind of ground or field based measurement. So, that has to be very carefully considered. And more importantly improved methods has to be there in a sense of thumb rule or in a sense of any kind of empirical relation should be there to improve, if there is any a miss with respect to ground based means measurement as far as the understorey vegetation LAI is concerned.

So, we need improved methods to account based on empirical or any other methods, so that could be integrated or could be very well taken care along with the over storey measurement. So, as to accommodate or account in totality for comparison or linkage with respect to remote sensing data.

The fourth is influence of topography on the clumping index retrieval using multi-angle remote sensing. See, for mountainous region it is very very difficult and lot of influence comes from the topography or the background physiognomy or the undulation.

So, that has to be very well taken care otherwise the error will be there in terms of CI or clumping index. So, good BRF models, bidirectional reflectance function along with the topographical reflex what you say consideration from the DEM should be very well accounted to come out with a good estimation or error free estimation.

The fifth is seasonal variations of the clumping index for different vegetation types. As we know the vegetation they grow and come if we take example of this deciduous forest vegetation, which have a phenology in terms of setting the leaves for 3, 4 months of an year.

So, look at the pattern starting from its generation, starting from its leaf on or leaf generation up to the maturity and then senescence phase. So, this actually becomes very very critical in terms of accounting to the seasonal variations of clumping index for different vegetation types across the globe.

And sixth is seasonal LAI trajectory smoothing and gap filling. Like with respect to our example as far as the MODIS based estimates is concerned that follows an LUT based algorithm for inverse modelling. So, we discussed that the MODIS, they do not go for any smoothing or accounting in terms of gap filling. If there is a contamination because of atmosphere or because of cloud, so it is left like that as a blank or a gap.

So, we need to address that and particularly to account to the seasonal fluctuations. We need to get information or complementary information to fill the gap from RADAR observations particularly or others like LiDAR, UAV, and things like that. We have already discussed with respect to microwave LiDAR and UAV based of LAI estimates.

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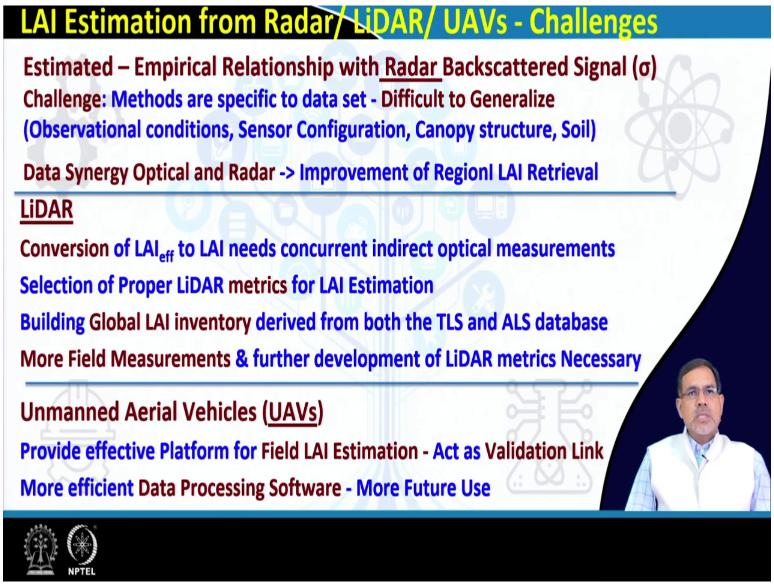

But let me just recall those important challenges as far as the use of what you say RADAR, LiDAR, and UAV is concerned. So, as all of us know this RADAR based protocol estimates based on a kind of empirical relationship that relates the RADAR back scattered signal that is sigma naught with respect to the LAI.

But the challenges are that it is very difficult to generalize because of observational conditions, sensor configuration, canopy structure and soil background including moisture, shadow and things like that. So, in terms of data merging like optical and RADAR data synergy can improve as far as the LAI retrieval is concerned both over regional or even if at global scale can be tried.

Next is LiDAR, as you know conversion of LAI effective or effective LAI to LAI the true LAI needs concurrent indirect optical measurements. So, selection of proper LiDAR metrices for LAI estimation is to be is to be guaranteed and more and more what you say, so methods and techniques has to come up.

But building the global LAI inventory derived from both the terrestrial LiDAR scanner and the airborne LiDAR scanner database is very important and more field measurements and further developments of LiDAR metrices are necessary.

And coming to the third that is UAV, Unmanned Aerial Vehicles, as we discussed they provide effective link or a kind of platform between the field estimation and also the remote sensing base. So, it sometime behave as a validation link, but we need more efficient data processing software, so that we can really exploit more and more as far as the UAV based images are concerned.

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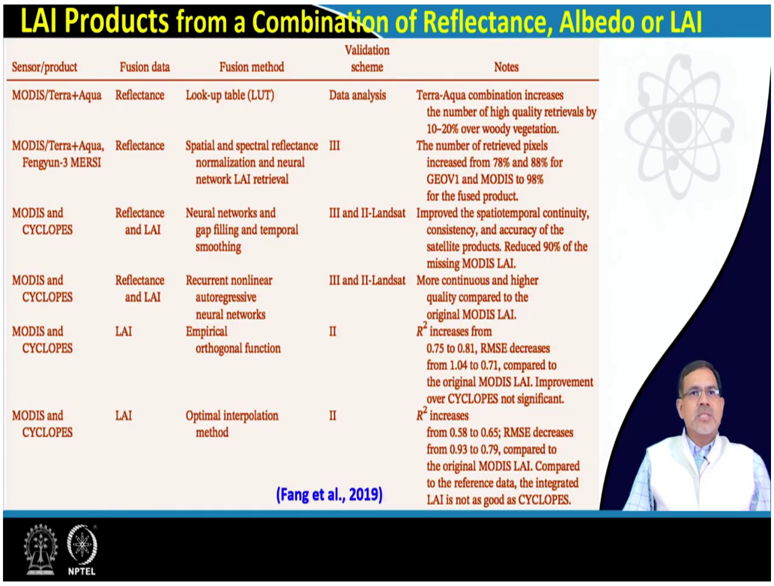

With this let us move forward as far as the two tables are concerned, I have straight away taken them from the Fang et al review paper on the LAI. And it is before us in this slide. So, on the first column the sensor products. So, here particularly in our 9th lecture we discussed about the coming, we discussed about lot of LAI products, but here we are trying to discuss with respect to combination of different reflectance, albedo and LAI that gives raise to the final LAI product.

So, the first one is MODIS Terra-Aqua sensor. It is a fusion based with respect to reflectance following the LUT. And what happens? And the nodes if you see the Terra-Aqua combination, that terra for terrestrial, aqua for aquatic, but both the sensors are from MODIS platform.

So, Terra-Aqua combination increases the number of high quality retrieval by 10 to 20 percent over the woody vegetation, but either could not do so. So, that is the important point when both the sensors are merged. So, high quality retrieval by is in increased by 10 to 20 percent and more so particularly for the woody vegetation or high biomass vegetation.

So, coming to the next with respect to biomass the with respect to MODIS Terra plus Aqua along with one Fengyun-3 MERSI, MERSI instrument. So, when we see it in terms of fusion method spatial and spectral reflectance normalization and neural network based LAI retrieval algorithm has been followed.

But in terms of the improvement the number of retrieved pixels increased from 78 percent and 88 percent for GEOV 1 and MODIS to 98 percent. So, almost a kind of 10 to 20 percent improvement in the in terms of the pixel or it is a retrieved pixel. So, that is the advantage. So, 10 to 20 percent improvement is we are getting when we are combining two sensors.

So, now coming to two data like MODIS reflectance data and as we discussed CYCLOPES LAI data. So, one is reflectance data, another is try to another LAI data. So, when we merge them with a using a kind of NN based fusion approach and adopted a gap filling approach for temporal smoothing. So, what happens? It improves the spatiotemporal continuity consistency and accuracy of the satellite products and reduce 90 percent of the missing MODIS LAI.

What you say, the LAI values which is which was earlier missing in the MODIS data is almost filled. So, 90 percent gap filling has happened. So, look at this. Gap filling which we have we have discussed as one of the major drawback. So, this kind of approach in terms of combined, combination products actually helps in that.

And then, we can go to the last, but one like MODIS and Cyclopes. And yeah, when using a kind of empirical orthogonal function the R square, the relationship between LAI and the reflectance increases from 0.75 to 0.81. These are all statistical basis. But what happens?

Improvement over CYCLOPES is not significant, but over MODIS is LAI is very significant. So, using the statistical estimates also we can know that how the LAI estimates performs better in terms of combination of one or more reflectance albedo or LAI products or bands.

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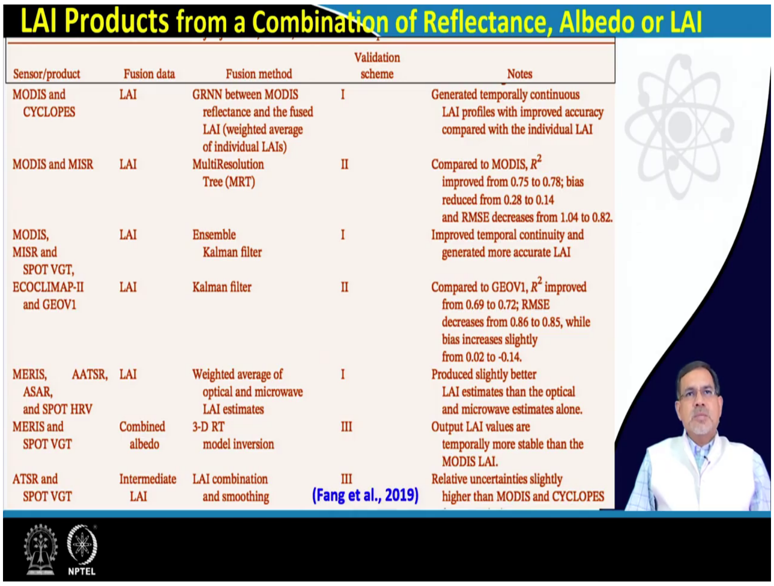

Then coming to the next in continuity with respect to the second one let us say MODIS and MISR meter. So, multi-resolution tree fusion method has been adopted. And compared to MODIS in terms of statistical sense R square improved from 0.75 to 0.78, but bias reduced from 0.28 to 0.14. So, there is improvement.

Now, let us come to the last one with respect to ATSR and spot vegetation. So, which followed a kind of intermediate LAI fusion data. So, LAI combination with smoothing has given a kind of relative onsite, uncertainty has improved slightly higher than either of MODIS and CYCLOPES.

So, this is the advantage of combining reflectance albedo or even if LAI products of one or more sensors that helps in improving the LAI product in terms of accuracy in terms of gap filling. So, that is what is the take home message from these two slides from the table.

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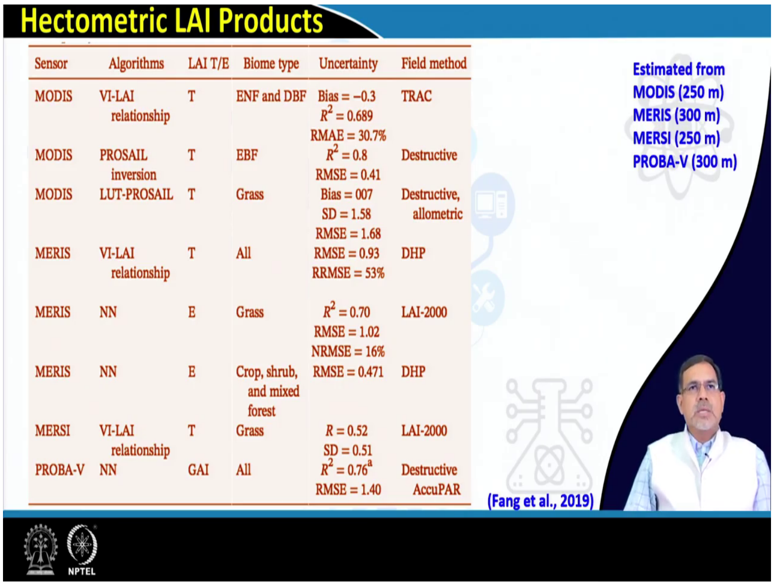

Sensor	Algorithms	LAI T/E	Biome type	Uncertainty	Field method
MODIS	VI-LAI relationship	T	ENF and DBF	Bias = −0.3 $R^2 = 0.689$ RMAE = 30.7%	TRAC
MODIS	PROSAIL inversion	T	EBF	$R^2 = 0.8$ RMSE = 0.41	Destructive
MODIS	LUT-PROSAIL	T	Grass	Bias = 007 SD = 1.58 RMSE = 1.68	Destructive, allometric
MERIS	VI-LAI relationship	T	All	RMSE = 0.93 RRMSE = 53%	DHP
MERIS	NN	E	Grass	$R^2 = 0.70$ RMSE = 1.02 NRMSE = 16%	LAI-2000
MERIS	NN	E	Crop, shrub, and mixed forest	RMSE = 0.471	DHP
MERSI	VI-LAI relationship	T	Grass	$R = 0.52$ SD = 0.51	LAI-2000
PROBA-V	NN	GAI	All	$R^2 = 0.76^a$ RMSE = 1.40	Destructive AccuPAR

And then let us have a quick look with respect to the hectometric LAI products. Friends, we have lot of satellite based products, let us say MODIS is offering 250 meter hectometric products; that means, below 1 kilometer resolution MERIS and MERSI, two different eco instruments. So, MERIS is giving 300 meter, MERSI is 250 and PROBA-V is giving 300. So, 250 to 300 meter resolution range LAI pixels we are getting in terms of products.

And among the listed one the PROBA-V that uses a neural network based approach and calculates the green area index and has a kind of global coverage. And many others like the first 3 let us go for the second one MODIS with PROSAIL that uses a PROSAIL based inversion as we know PROSPECT and the SAIL. So, for the evergreen broad leaved forest look at the R square and RMSE, and the statistical values and that has followed a kind of destructive approach like collection of the leaves using a trap method or other things.

So, on the right hand side, extreme right hand side the different field based methods adopted for these have been mentioned using the track instrument, all the destructive, also the DHP that stands for the digital hemispherical photography LAI 2000 x equipment and also the AccuPAR. So, with this we have a good amount or number of products below 1 kilometer range and we can use it for initial analysis and take it for to earn early experience.

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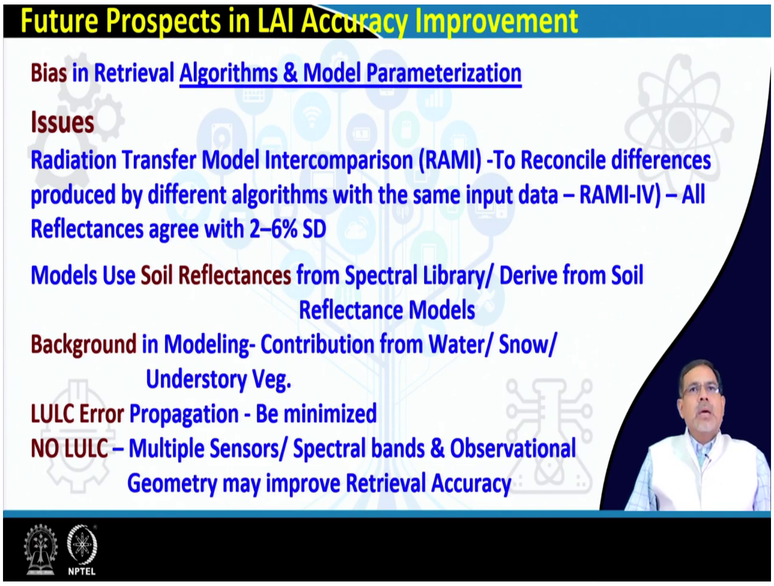

Now, let us move on with respect to the future prospects in LAI accuracy improvements. So, friends lot of bias in terms of LAI accuracy or LAI product comes with respect to the retrieval algorithm being used and the model parameterization.

So, I repeat the bias is mostly coming from the retrieval algorithm that is being used, you use any algorithm that is, that is definitely giving some amount of biasness and even if how you parameterize the model what are the parameters you are using, the algorithm bases and all these things.

Then coming to the issues in terms of the future prospects, one is if a kind of radiation transfer model inter comparison which is abbreviated as RAMI, mostly we use it RAMI. Using RAMI the reconciliation difference produced by different algorithms with the same input which has been tested using RAMI 4 version all reflectance agree with standard deviation of 2 to 6 percent.

So, it is a kind of inter comparison of many radiative transfer model. So, it is one of the possible ways to improve the accuracy using RAMI that use more than one transfer models and does the inter comparison using the same input data. So, that is one good thing to improve the accuracy using RAMI.

Second, as we know the models use reflectances from spectral library and derive from the soil reflectances, so the background, particularly the soil background and all this modeling that actually we can improve if we improve the contribution from individuals like the background soil, background water, background snow or even from the understorey vegetation.

So, the background material has to be very well accounted and the method has to be evolved that has to be what you say synchronized, so that the background value or inputs in the model has to be very very significantly accurate.

Then, if as we discussed like let us say the example of MODIS based LAI, so there as you discussed in the 9th what you say lecture that they use a kind of biomes or LULC which has 6 biomes. So, so the input like input in terms of land use, land cover, could have lot of errors and that error, and if you are using an error I means an LULC with error, then there could be propagation, the error could be propagated throughout.

So, we need to be very careful to minimize the errors if with respect to the land use or land cover or biome or the category of forest whatever we are using that has the spatial extent. So, because we are making many things or many of these variables uniform with respect to one set of biome or ecosystem or you say the forest type. So, that we have to very very careful.

And the models that are not using LULC, so they can also improve the retrieval accuracy using multiple sensors, spectral bands, and also variation in terms of the observational geometry. So, these are the improvement or improvement in the improvement scope before us as far as the LAI product or LAI algorithm is concerned.

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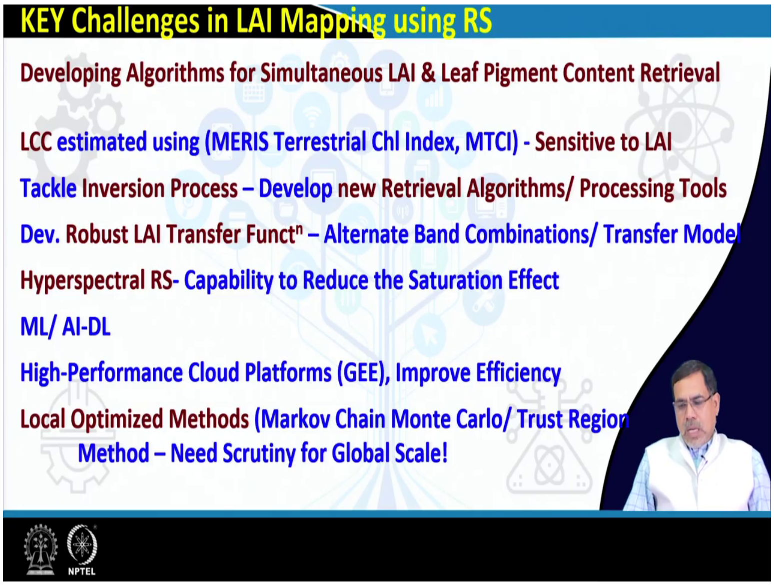

Now, coming to the challenges with respect to development. So, developing algorithms for simultaneous LAI and leaf pigment content retrieval is one of the ways are people or scientists are advocating in favour.

So, what is that is the simultaneous development of algorithm for LAI and leaf pigment, because as let us say chlorophyll has the dominant leaf pigment is very well related and very very very sensitive to LAI as has already been proven from the MERIS based terrestrial chlorophyll index MTCI, where the LCC, the leaf chlorophyll content has been related to LAI and found to be very very sensitive.

So, if similar algorithms are developed simultaneously for LAI and the leaf pigment content or chlorophyll content which is the dominant pigment, then perhaps the improvement in terms of LAI algorithm, I means LAI as a product could be better.

Then, tackling the inversion process. To tackle or to improve the inversion process we need to develop more and more new retrieval algorithms and also the processing tools need to be developed and improved on. And development of robust LAI transfer functions that takes or that could take advantage of alternate band combinations or different transfer models.

But we need to develop robust transfer functions. So, by combining different band combination, taking different transfer models, one can plan or see that how the transfer functions can be as robust as possible.

Then coming to the saturation effect of the bands. Friends, as we have been discussing that individual bands have a saturation effect with respect to LAI, with respect to EVI, with respect to NDVI with respect to EVI what we have discussed in the 5th or 6th class lecture.

So, what happens? Beyond certain point or beyond 2, 3 or 4 LAI level, level means the stack of layers one above other, then you do not have this kind of vegetation indices or individual bands also, they are saturated. They actually do not give the full what you say the maxima or I mean to say the actual reflectance or the information what it has.

So, in terms of that hyperspectral remote sensing that has very narrow spectral bands or channels are the champions. So, they have the capability to reduce the saturation effect. So, in terms of the vegetation index based or we say the empirical function based and the radiative transfer based models.

We also need to use more and more spectral hyperspectral bands and a flat more what you say the satellite based hyper spectral sensors are coming up and maybe one from ISS has is on orbit and many more are coming up. Then, but most of them are airborne till date.

And the other point is use of machine learning algorithms. As we also discussed with respect to the ray tracing model, with respect to the radiative transfer model, we know that if we use more and more advanced algorithms that takes clue from lot of other or other variables or proxies then perhaps we can come out with better LAI.

So, use of machine learnings including artificial intelligence, deep learning is one of the major, means can give major thrust to the LAI estimates. And also the improvement in terms of the HPC platforms, high performance computing, high performance cloud for cloud platforms like Google Earth Engine, Amazon and even if Microsoft has come up.

And so, all these actually improve the efficiency, you get the data directly from there, from the platform, from the cloud platform and you put your algorithm and you do it there. So, it actually improves the efficiency in terms of computation and also the flexibility in playing with different data set without investing much in terms of your own resources.

Then, coming to local optimized methods like Markov Chain Monte Carlo, Trust Region methods. So, we need to really do lot of scrutiny to make these kind of local optimized methods to extrapolate them to global scale and make them competitive as a global product in terms of LAI.

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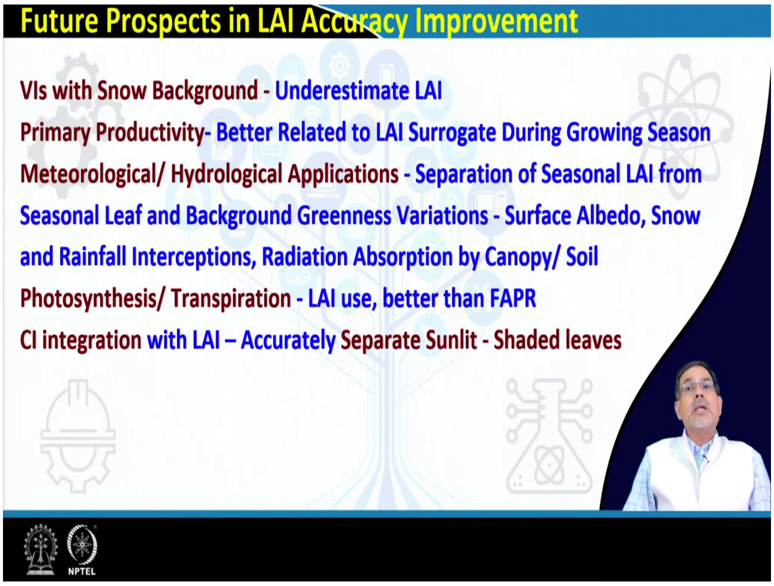

So, the future prospects like vegetation indices with snow background they underestimate LAI. So, we need to address them. Particularly, coming to primary productivity the LAI surrogates are better related during growing season. So, as far as primary property is concerned, it is perfect. But as far as the meteorological and hydrological applications are concerned, we need to be very careful in terms of separating the seasonal LAI from the seasonal leaf and the background greenness variations.

So we need to be need to be addressing the surface albedo snow rainfall interception radiation absorption by canopy or even soil or all of them individually, so that they could be better applied to meteorological and hydrological themes. And as far as the photosynthesis transpiration as concerned we know that both of them are kind of one to one; one is the CO_2

in and the other one is the H_2O out. So, for them LAI use is better than the use of any other proxies like the FAPR or upper or fraction of absorbed photosynthetically active radiations.

Now, coming to the clumping index. So, if we integrate the clumping index with LAI, then perhaps we have a better clutch or better hold in terms of accurately separating the sunlit and the sun shadow leaves. So, in a sense we get a better LAI. So, CI integration has to be very well carefully considered or has to be integrated carefully to LAI, so that very accurate estimation in terms of sunsets and the sunlit leaves are concerned.

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Now, coming to the references. Yes friends, for this whole week these two references as far as the review papers are concerned Fang et al and Chen et al are very important. And we have been consistently using these, and I will request you to go through them and to read or understand more of that.

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And then coming to the conclusions. Yes, we discussed about several key issues. And there are LAI products with different combinations of reflectance albedo and LAI that gives us better accuracy. And we have lot of products also available at 250 to 300 meter special range or the pixel dimension.

Yes, LAI retrieval using remote sensing holds lot of scope for the future. And that is why this particular week whatever we discuss in terms of ground based in terms of vegetation indices or you say empirical function based, radiative transfer based, even if LiDAR, microwave, and UAV based and in totality all the data products available.

So, this actually gives us a very good idea that where we stand as far as remote sensing based LAI estimates is concerned, what are the pros and cons, and what we have what we know till date, and what we need to know, and what are the scope for the future.

So, thank you very much. We will again continue meeting on the week 3 for our discussion with respect to remote sensing based primary productivity.

Thank you very much.