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 - 09
LAI – Global Data Products

Welcome back. Let us move on to the 9th lecture on LAI. We will discuss mostly on the LAI based Global Data Products.

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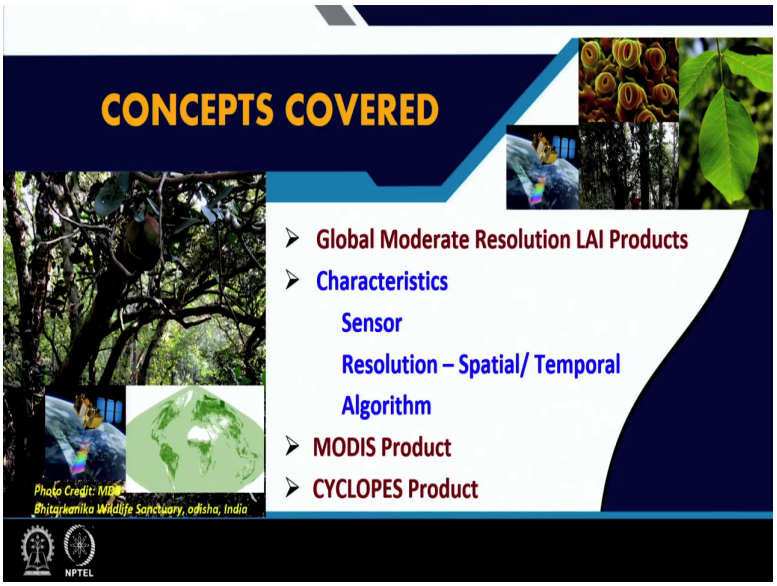

So, with respect to the concept that we will be discussing are the global moderate resolution LAI products, what are the different moderate resolution LAI products available at global scale. Then we will talk about the properties or different characteristics in terms of the sensor characters, in terms of the resolution, both spatial, temporal and also we will talk about the algorithm basis what kind of algorithm all the different products they follow.

As we have been discussing in our last two classes number 7 and number 6 and 7 we know that these are mostly based on the empirical functions or based on the radiative transfer. So, canopy reflectance function or transfer models. So, we will see what are the different basis of algorithm, but most of them use radiative transfer models and also some times as a back of

they keep the kind of empirical or vegetation index LAI based empirical equations in the as a back end support or back up support.

As an example we will also discuss about the MODIS based LAI products and we will also touch upon with respect to CYCLOPES which has been one of the old or you say starting in terms of its algorithm and a global product.

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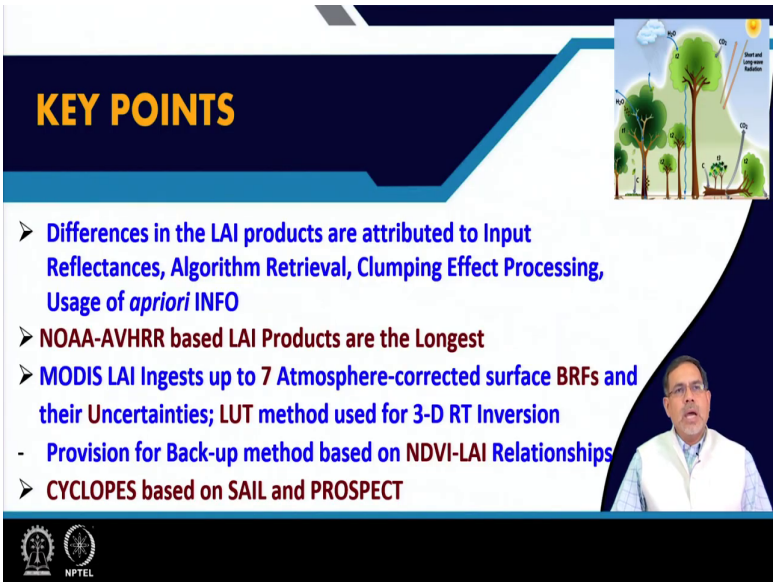

So, with this the key points we will be covering are mostly we will know that the differences in the LAI products are attributed to input reflectance, algorithm retrieval, clumping effect processing and how different products they use the information which is available them apriori basis.

So, we now know this with respect to our discussion on the empirical based what you say functions empirical functions or with respect to the radiative transfer. So, these are the variations in terms of different models and we will see in terms of one or two list of tables how different recognize models they differ in all this for majorly with respect to all these four properties.

Then we will also know that NOAA-AVHRR because of their availability in terms of longest availability and producing the VI maps in regular basis they are perhaps the longest LAI

products. Though Landsat is available since 1972, but NOAA-AVHRR based LAI products are considered to be the longest available at global scale.

Then coming to the MODIS based LAI, friends we all know that yes before the launch of MODIS satellite sometime in 1999-2000 during that time both the sensors Terra and Aqua have been launched. So, during after that the photosynthetic products including the LAI have started coming up at a global scale. Before that also researchers have done this LAI based analysis, but as a product or a regular product based on satellite has perhaps came after the launch of MODIS satellites.

So, that actually goes back to almost two decades. So, MODIS LAI, what it does? So, we picked these two as an example and we will emphasize on MODIS based LAI. So, MODIS based LAI it ingests up to 7 atmosphere-corrected surface bidirectional reflectance functions and their uncertainties and the look up and they follow or they adopt the look up table based method and use for 3-dimensional radiative transfer inversion.

And, there also a kind of backup provision has been kept based on the method with respect to NDVI-LAI kind of empirical relationship and in terms of CYCLOPES we will understand that how a kind of SAIL and PROSPECT a kind of hybrid approach has been followed in terms of developing this CYCLOPES based LAI moderate resolution global data products.

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So, let us understand the variation with respect to LAI products. So, since past 2 to 4 decades, I made it 2 because the data products are available since mostly since last 2 decades; 4 because of the data availability which mostly goes back to 1980s or 81s when the AVHRR data have been used for this. And, the resolution varies; that means, the pixel size of LAI, which is available at this point of time in terms of moderate resolution scale vary between 250 meter and 7 kilometer.

So, they could be there could be many in terms of operational products; operational product means they are supported by a constant or a mechanize source of funding. So, then you can have an operational product data has to be available for use for free mostly these days.

And, many of them are experimental without any institutional commitment in terms of data guaranty or continuity discontinuity that. So, there is a disparity in terms of the data product availability from continuity point of view and which is also has a linkage with respect to funding.

Then coming to NOAA-AVHRR we it offers a kind of long term data with respect to LAI product and some of them based on different approaches could be means are written here in terms of AVH 15C1 C, GEOV 1, GLASS data, GLOBMAP, LAI3g and things like that and products like that.

And, let us see with respect to MODIS and GEOV1 which are mostly consistent, consistent in terms of their accuracy in terms of their data continuity also, but there are little differences or discrepancies with respect to their the type of algorithm they are using, the clumping effects how they process and the input reflectances.

But, the large discrepancies are also there and they are mostly because of three categories or three regions: one is this very dense canopies, which mostly are available with respect in terms of the broad leaf forest and mostly evergreen even if in deciduous. So, this broad leaf forest where the ecosystems follow lot of complexity; so, because of large density canopies we find lot of discrepancies with respect to the products in LAI products.

And, second is the contamination. So, the pixels and the satellite reflectance bands, so also the LAI are bound to be what you say contaminated with respect to frequent cloud and

aerosol. So, that is one of that contributes to large discrepancies with respect to the rainy and non-rainy season what you say attribution or with respect to the aerosol loading in atmosphere during the image or photo take.

Then coming to the non growing seasons in terms of if we bring in mind, the polar regions where mostly the needle leaf forest are there and they are on with respect to photosynthesis and all through for some part of the year, but for most of this it is it follows a kind of non-green season mostly in winter.

So, they also contribute to large discrepancies because when we are talking about the reflectance, utility in LAI calculation we can expect that it could lead to error because of the background reflectance which mostly are comes from this needle leaf forest there in winter season it comes from the background where mostly the snow cover is there and during the non winter season or the growing season it comes from the soil. So, there is a lot of variation. So, that contributes to the discrepancies.

So, these are the broad what you say this means features with respect to the differences as far as the data consistency and is concerned with respect to LAI products.

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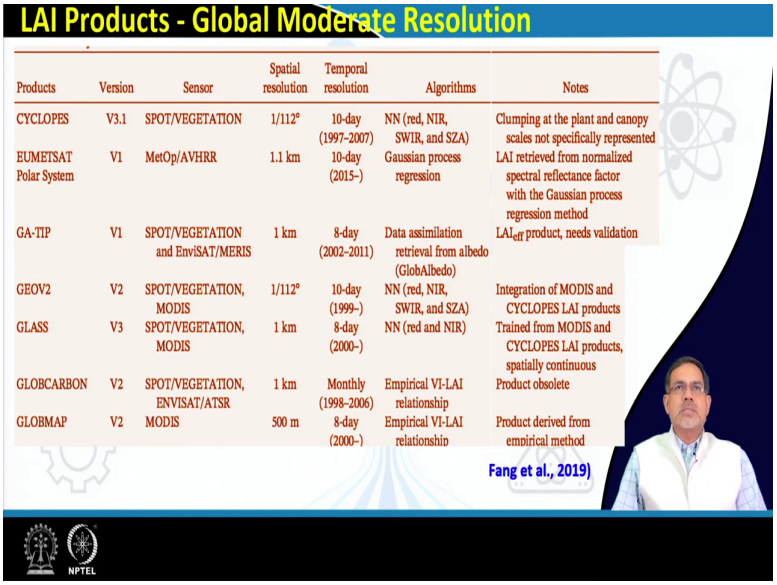

This and the subsequent slide I have. So, if we have taken two table one table in two slides I have tried to use for our discussion taken from the Fang et al. publications a very nice piece of document published in terms of a review paper on LAI products. So, look at the columns.

The first column talks about the products, the second one the version of the product because they all as we know in this era with respect to sub tier and all these things we go on improving the products, the output and in terms of algorithm what not. So, that we release with respect to our brand with respect to different version. So, the version numbers have been put here.

Then the third column talks about the sensors. So, these are the different satellite sensors data, which have been used for the LAI product generation or calculation then the resolution both with respect to spatial and temporal resolution. Here in this we can see there is lot of variation as well and in terms of the spatial resolution the variation goes between 500 meter up to what you say 1.1 kilometer range in terms of pixel size.

Coming to temporal resolution they could be what you say 8 days variation up to monthly variation in this particular group and in the next one we will see it varies between 1 day to 1 month. So, that kind of temporal resolution variation we have as far as the global scale LAI products are concerned.

And, the algorithm – mostly we will see with respect to the emergent models and also the empirical equations or empirical functions so, the all the algorithms that differ. In terms of algorithm the NN neural network it accommodates all as we discussed it could accommodate the deep learning, the machine learning, protocols including random forest, support vector machines and what not. So, all these are cumulatively shown in terms of neural network or abbreviated as NN.

And, then we have also if you come to the last, but one for GLOBCARBON it takes an empirical relationship based on simple vegetation and LAI relationship. So, this VI we have to go into detail for that particular product what kind of VI's they have taken, but the basis is the same.

So, let us emphasize on one by one on few of them. So, CYCLOPES the first one version 3.1 it has been processed using the SPOT based sensor that the name of the sensor is Vegetatio in French and in English we call it vegetation, but the sensor Vegetatio is which gives the what you say NIR and SWIR red all these kind of bands and you see the solar zenith angle also has been taken into consideration in a using the neural network algorithm.

And, as far as the notes or remarks is concerned clumping at the plant and canopy scales not specifically represented. So, in this the clumping is not specifically represented means this is perhaps this is perhaps what you say talking in terms of the true LAI and effective LAI. So, we have to see how good they are with respect to the true LAI.

Then, coming to the others like EUMETSAT, they are the Gaussian process algorithm or regression algorithm has been taken. Coming to GA-TIP higher lot of other means a merge of vegetation and EnviSAT, MERIS data has been taken. So, that gives the 8 day and spans between 2002 to 2011. So, the end date is closed and in terms of GEOV2 it also takes vegetation and MODIS. So, it is on at 11 at a 10 days interval since 1999 the day since MODIS started giving the first product from terra sensor.

And, it also follows the neural network algorithm using red, NIR, SWIR and the solar zenith angle. So, what it does it integrates the MODIS and CYCLOPES LAI product look at this. So, the MODIS and CYCLOPES LAI products have been merged and integrated together to derive synergy.

So, moving on we have the GLOBCARBON V2 version 2. So, that considers the vegetation from the SPOT image French satellite and ENVISAT the European satellite the sensor is ATSR and the monthly that resolution between 1998 and 2006, end date is closed. So, it followed an empirical relationship based on vegetation indices and LAI.

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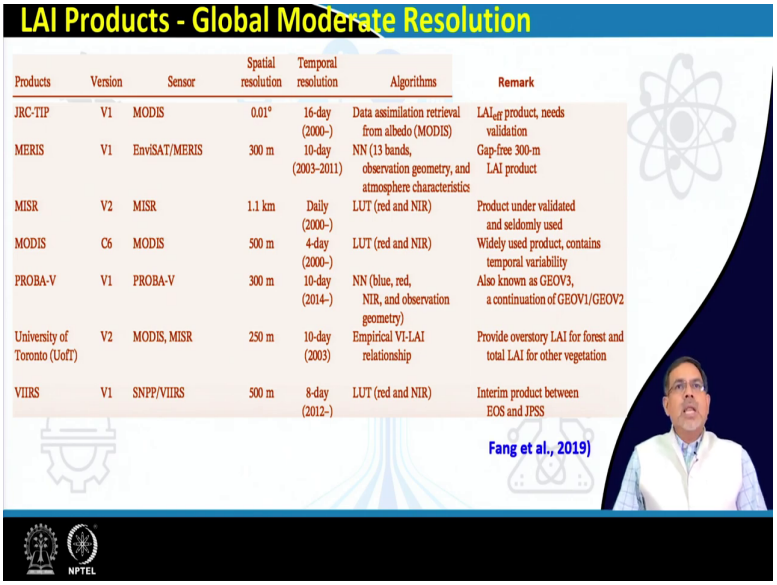

Coming to the next, the let us go to MERIS. MERIS this is between 2003 and 2011 and 13 bands observation geometry and atmosphere characteristics has been taken care here and the remark is gap free 300 meter LAI product. So, this is perhaps one of the finest products during 2003 to 2011 available.

So, now moving on to the latest sensors like SNPP and VIIRS that also offers at 500 meter 8 day frequency that resolution or say temporal resolution and is available since 2012 since the VIIRS launch and it also follows a LUT look up table algorithm based on the red and NIR reflectance. So, this is considered as one of the interim products between the EOS and JPSS.

So, just the before one is the University of Toronto released a V version 2 product based on the MODIS and the MISR data – Multi angle Imaging Spectro Radiometer data at the finest resolution of 250 meter. So, this what we see is available for 2003 as we have seen in one of the beginning slides we discussed that some of them have no continuity or no promise of getting continuity because these are all experimental.

So, given by University of Toronto for the year 2003 based on the empirical relationship of vegetation indices and LAI. So, they provide it is important they provide over story LAI for forest and total LAI for other vegetation. So, look at this. So, there is a very significant thing here for the forest only the over story LAI.

So, they did not talk about the understory or the sub story or secondary story call, but the total LAI for all the vegetation because they have very well thought that yes, perhaps if we go for the total LAI for forest also perhaps they will do they may do underestimation because it is because of the forest density.

So, for other vegetation they have considered the total and so, this is a very tricky and intelligent job this people have done, but what to take out of these two slides and the list of the global moderate resolution products are there are lots of LAI products available at global at moderate resolution and global scale.

They have used or they are using different data in terms of satellite data product data the regional bands and coming out with different resolution LAI products in terms of spatial and temporal and follow different algorithms.

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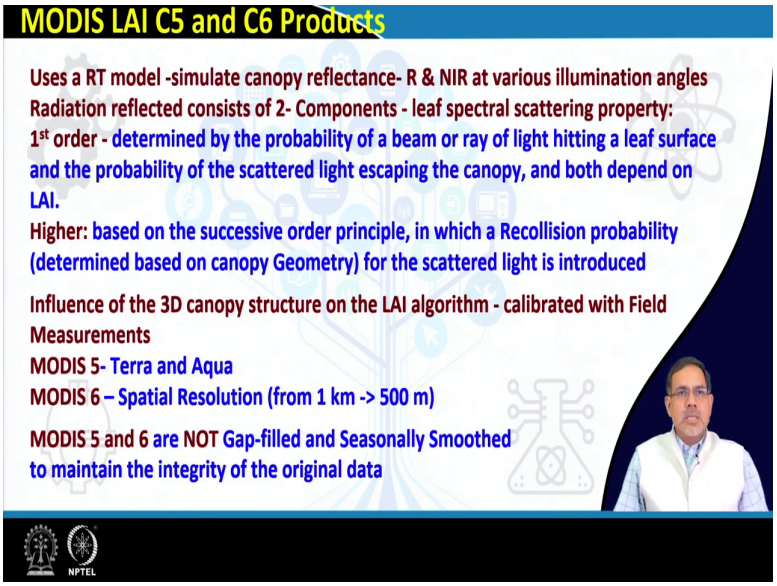

So, with this let us move on little bit more with respect to the MODIS LAI products and this C5 and C6 at the latest release. So, we will just have a mention with respect to C5 and C6 during the discussion. So, this MODIS LAI products use a RT model or you say the radiative transfer model.

And, to simulate so, using radiative transfer model they simulate the canopy reflectance using R in the red and NIR plane reflectance bands at various illumination angle and illumination

angle you can say with respect to sun angle with respect to the viewer angle. So, I will repeat this MODIS LAI products they use the radiative transfer based model to simulate canopy reflectance in the red and NIR plane ok.

So, this red and NIR bands they have been taken at different what you say illumination angle both with respect to sun and the viewer**.** And, the radiation reflected consists of two components ok. So, one so, these two components are could be 1st order and 2nd order. So, this radiation reflected consists of two components to accommodate the leaf spectral scattering property. So, with respect to the leaf spectral scattering property, it could be 1st order, it could be 2nd or higher order.

So, with respect to 1st order the 1st order scattering determines or is determined by the probability of a beam or ray of light hitting a leaf surface and the probability of scattered light escaping the canopy and both depend on the LAI ok. But, with respect to the higher order of scattering this higher order of scattering is based on successive order of principle order principle. So, that means, in which the recollision probability is there, ok.

So, it follows because as we discuss more number of leaf so, you have 1st order 2nd order. So, more than 1st order has been straightway consider as the higher order here for MODIS LAI. So, this follows the recollision principle or recollision probability that is determined mostly by the canopy geometry. So, we now know what the canopy geometry means. So, that gives the recollision probability for the scatter light ok which is introduced, ok.

So, in this MODIS LAI influence the 3D canopy structure and are calibrated with respect to field measurements. So, there are well what you say organized international field measurement data as far as LAI is concerned. So, people or scientist when they want to validate their product they use those data as the validation or the field or the field measure data to calibrate and validate their model and the model outputs. So, this is very well recognized. So, this MODIS LAI they also do that.

And, particularly the MODIS 5 it takes the images from both Terra and Aqua; that means, so the temporal resolution gets doubled. And, with respect to MODIS 6, so, this MODIS 6 or C 6 product here the spatial resolution goes from 1 kilometer to 500 meter. So, that means, a

shift in terms of spatial resolution so, 1 kilometer to 500 meter means it gone to a higher resolution from MODIS 6 product onwards.

So, MODIS 5 and 6 are not gap filled or seasonally smoothed. Why? Because to maintain the integrity of the original data. So, they the gap filling as not done or the seasonal smoothening is also not done in case of MODIS 5 6 to maintain the integrity otherwise there will be smoothing. So, original data will be lost, ok.

So, it is left to the user to do whatever smoothing or gap filling is required, but as far as the MODIS 5, 6 products are not gap filled or seasonally filled to maintain the original or integrity of the data.

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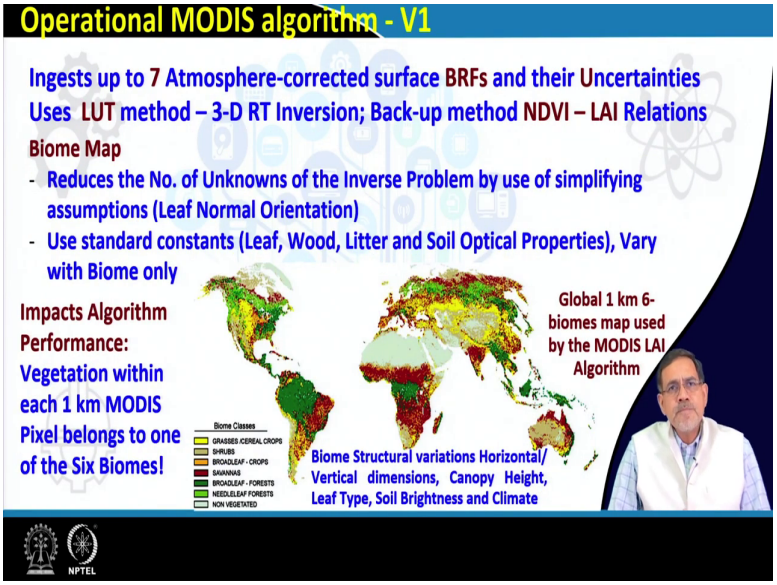

So, let us try to understand with respect to the basis of this MODIS algorithm because from their things started. So, as we have seen this particular MODIS algorithm they ingests up to 7 atmosphere-corrected surface bidirectional reflectance factors and their uncertainties ok. And, they use the lookup table method and follow a 3D based radiative transfer inversion and also take this NDVI and LAI relations as a backup method.

So, now coming to the map what they use for this global representation. So, for global representation this MODIS algorithm, they follow a kind of 1 kilometer; now, we have seen

up to 6 product it is half kilometer, but as till 5th it was 1 kilometer. So, global 1 kilometer biome map has been used. So, what does it mean?

So, that means, the biome map has 6 classes or the whole globe has been divided into 6 biome categories. So, it is a simplification. It is a simplification to reduce the number of unknowns of the inverse problem, ok in terms of leaf orientation in terms of the leaf, wood, litter, soil optical properties and many more. So, that is now kept constant with respect to 1 biome. So, you have 6-biomes. So, for 6-biomes you have 6s set of the variations with respect to this.

So, that actually introduces a kind of simplicity and reduces the unknowns in turn gives a symptom in model inversion. So, as far as the MODIS as far as the vegetation is concerned with this pixel because it is 1 kilometer resolution the biome map. So, within 1 kilometer what you say pixel the impact of what you say the vegetation within that 1 square kilometer pixel belongs to 1 of the 6-biome. So, in turn it could impact the model or the algorithm performance.

So, this is what with respect to the biomes or 6 biomes, but has been considered for simulating the whole globe.

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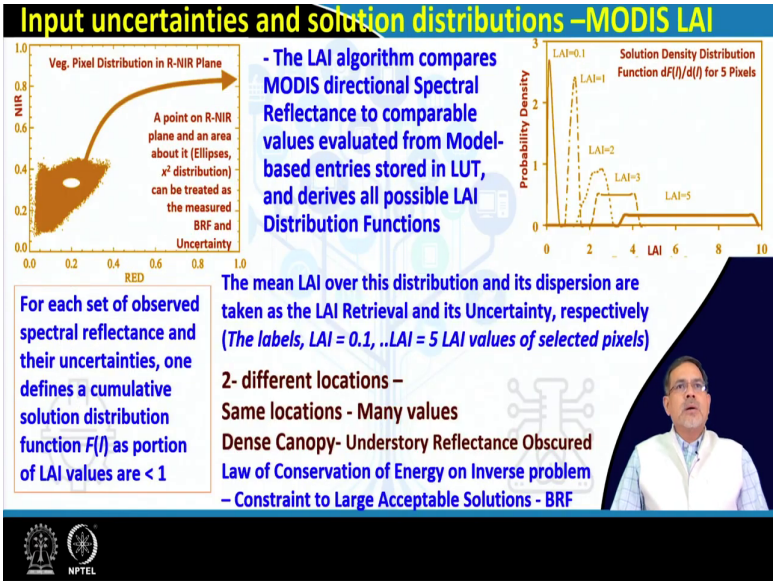

So, coming to the input uncertainties now we have put two graphs on left corner and upper left and right left corner on the upper left side we can see the vegetation pixel distribution over red plane in the x-axis and over NIR plane on the y-axis and look at what you say how they have been clustered. So, any point within this NIR plane.

So, a point on R-NIR plane and an area about a point and some area around this could consist of many more points, so, could be shown as a white eclipse in terms of x square distribution. So, these can be treated as the major bidirectional reflectance function and also the uncertainties, ok. So, for each set of observed spectral reflectance and their uncertainties one defines a cumulative solution distribution function that is function l as portion of LAI values are less than 0 less than 1.

So, what it says in general the LAI algorithm compares MODIS directional spectral reflectance to comparable values evaluated from the model ok. So, this evaluation from the model based entries are stored in form of lookup table and derives all possible LAI distribution function as shown on the right hand side graph.

So, look at this on the x-axis, the LAI from 0 to 10 for 5 pixels LAI 1 or 0.1, 1, 2, 3, 4, 3, 5. So, the mean LAI over the distribution as can be seen from the right hand side figure the mean LAI over this distribution and its dispersion are taken as the LAI retrieval and also its uncertainty respectively. So, the labels LAI 0.1, 1, 2, 3, 4, 5 all these values all these LAI values of selected pixels.

So, let us come to the uncertainties. There could be uncertainties at the pixel label or the biomes or the pixels for the same biomes. So, two different locations can have the same LAI. The same location can have many values in terms of LAI in a biome or in more than one biome and in terms of the dense canopy for the forest or vegetation with dense canopy the understory reflectance is obscured.

So, all these actually incorporates error or biasness like we have seen in a product of University of Toronto they have taken it separately they have clearly mentioned that for forest this is only for the top canopy because to avoid this kind of uncertainties for dense or the forest vegetation.

So, to constrain some of these a kind of law of conservation energy has been followed in this MODIS LAI approach. So, for or to deal with the inverse problem. So, this acts as a constraint to large number of acceptable solution and that actually is taken care with respect to the bidirectional means that actually takes care of in terms of the Bidirectional Reflectance Functions – BRF.

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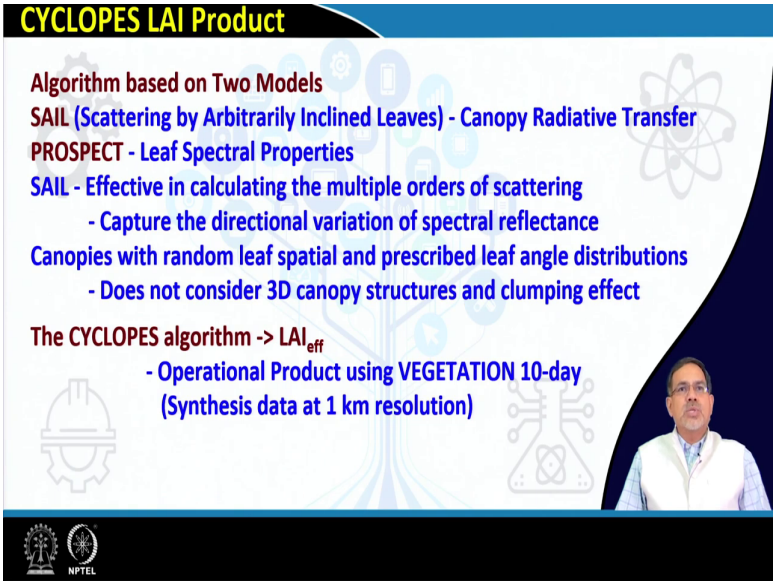

Now, coming to the CYCLOPES LAI product as we have we now know that this is one of the very longest serving one and it takes the two model or the algorithm merge. So, this CYCLOPES LAI product algorithm is based on two models as one is the SAIL and the PROSPECT.

So, SAIL gives the canopy radiate information on the canopy radiative transfer whereas, the leaf spectral property comes from the prospect model, ok. SAIL as you know and we discussed yesterday in our 7th lecture is on scattering by arbitrarily inclined leave abbreviated as SAIL.

So, SAIL model is effective in calculating the multiple order of scattering and capture the directional variation of spectral reflectance. Canopies with random leaf spatial and prescribed leaf angle distribution, but it do not consider the 3D canopy structure and also does not

consider the clumping effect. So, if it is not considered the clumping then probability is giving us what you say effective LAI not the true LAI. So, that is.

So, this CYCLOPES algorithm which gives the effective LAI so, it is a operational product using the vegetation data from spot and at 10 day interval. So, which also could be are synthesized at 1 kilometer resolution in terms of temporal.

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So, coming to the references, yes, these two review papers have been used consistently for understanding for our discussion with respect to LAI or satellite based LAI Fang et al paper in 2019, a very good publication review work and Chen's paper published in one book chapter as a book chapter.

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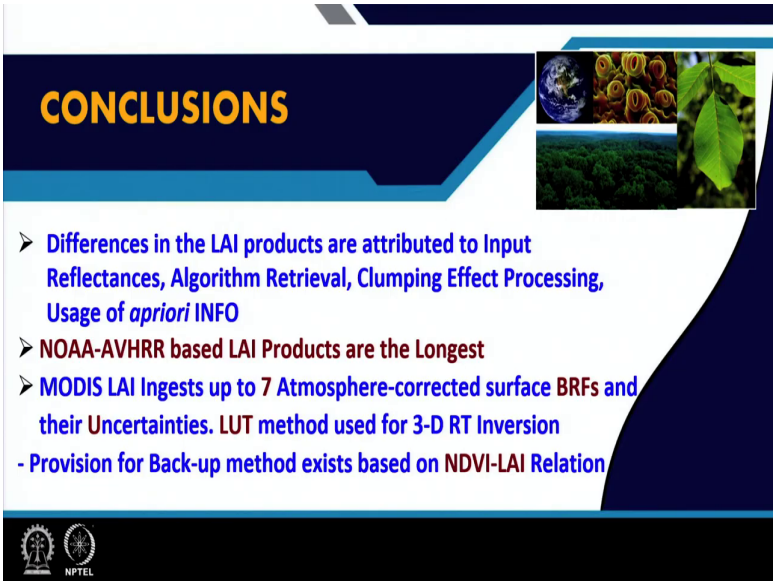

And, then the conclusion I repeat difference in LAI products are attributed to input reflectance, algorithm retrieval, clumping effect processing and usage of apriori information and as far as we know that NOAA AVHRR based LAI products are such the longest one.

And, MODIS LAI ingests up to 7 atmosphere-corrected surface bidirectional reflectance functions and their uncertainties and also follow a kind of lookup table method to do the inverse modeling in terms of a 3-dimensional radiative transfer. And, also as a backup model as a backup it uses a kind of empirical equation based algorithm, which is based on NDVI-LAI relationship.

So, with this we got a fair idea with respect to the different techniques how the LAI is derived based on the empirical relationship and based on the radiative transfer. But, lot of models or the data products LAI products are generated by either or both, because you derive the synergy.

And, many of them are operational products having a good and constant funding support, many of them are experimental best, but it is I would say it is still the beginning of many things because yet as we discussed yesterday in our 8th lecture yet the potential of microwave the potential applied on which is very good which is offering a very good information pool as far as the clumping or the CI clumping index.

So, there are many more the future is more promising with respect to a LAI algorithm development and remote sensing based LAI products. So, let us discuss in our 10th lecture what are the challenges in terms of the LAI products and what are the future scope with respect to that.

Thank you very much.