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

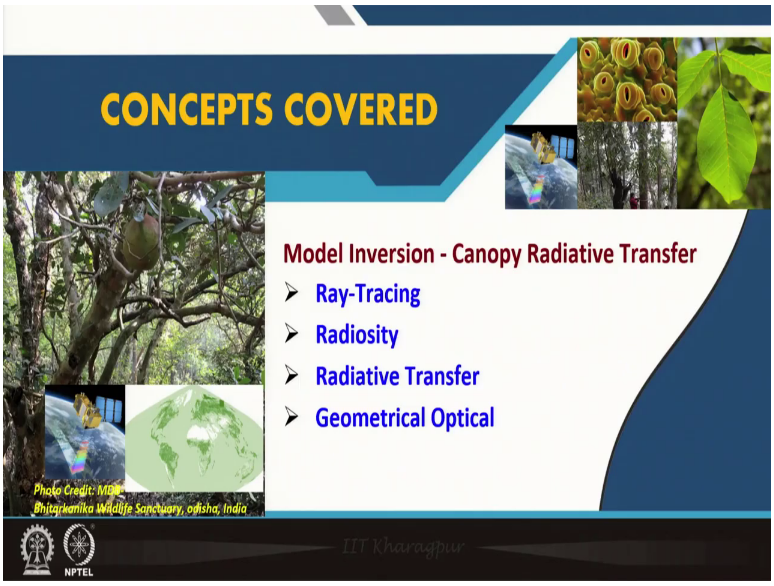
Lecture - 07
LAI Estimation- RS Methods: Model Inversion

Welcome back to the 7th lecture on LAI Estimation- Remote Sensing Methods and Model Inversion. Friends, all of you recall that in the 6th lecture, we discussed about the Estimation method. Particularly vegetation indices vis-a-vis remote sensing relationship, vegetation indices which are derived from remote sensing data vis-a-vis LAI relationship and previously, we also discussed about the field based measurements.

So, field based measurements are related based on the empirical relationship or some allometric equations to come out with a kind of what you say linkage between the vegetation indices and the LAI, Leaf Area Index. So, we discussed the drawbacks of these particular empirical functions.

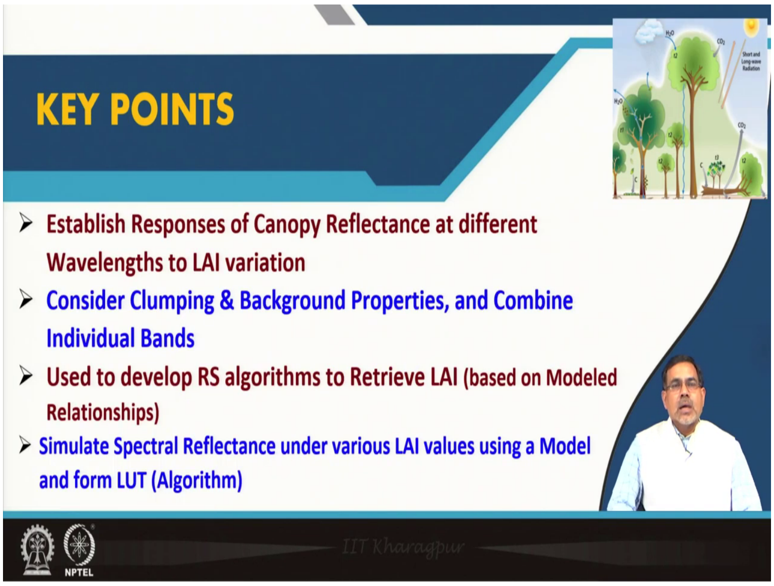
We also discussed that the major drawbacks of these relationships are these empirical functions with respect to VIs and LAI relationships vary with respect to different land use, land cover categories with respect to seasons. So, today we are here to discuss with respect to the model inversion.

(Refer Slide Time: 02:13)



So, coming to the concepts, we are going to cover or in terms of the model inversion, it is mostly the radiative transfer with respect to the leaf canopy the models types. We can categorize into four; one is the ray-tracing, second radiosity, third radiative transfer and fourth is the geometrical and optical called in short GO.

(Refer Slide Time: 02:52)



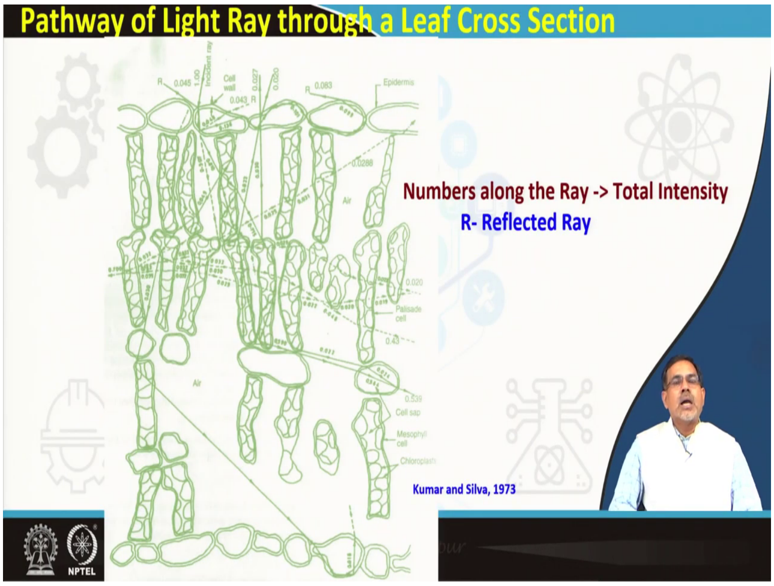
So, the key points we are going to cover are to establish responses of canopy reflectance at different wavelengths to LAI variation. This is actually different as far as what we have discussed as in terms of the VIs and LAI empirical relationship. Here, with respect to the model inversion, those are based on the canopy reflectance values.

They establish the responses of canopy reflectance at different wavelengths and with respect to the variation in the leaf area index and they also consider these indices; these inversion models. They consider clumping and the background properties, where in terms of the VIs are two bands, three bands indices and even if the single band indices such as NIR and R what we have discussed with respect to vegetation indices. So, those were missing.

So, in here, we will understand that how these kinds of canopy reflectance property relationship with a LAI variation, they consider the clumping and the background properties and combine with respect to the individual bands and these model inversions, they used to develop. They are used to develop remote sensing algorithms to retrieve LAI based on the model relationship.

So, this means this is going to be more generalization, this is going to be more and more universalization. So, in that context, it is going to give us a kind of global product and the fourth one is with respect to this is these models particular radiative transfer, transfer equations based models, they simulate spectral reflectance under various LAI values using model and accordingly, form the LUT lookup table based algorithm. So, our MODIS and other data products with respect to LAI, they are based on the LUT based inversion algorithms.

(Refer Slide Time: 05:18)

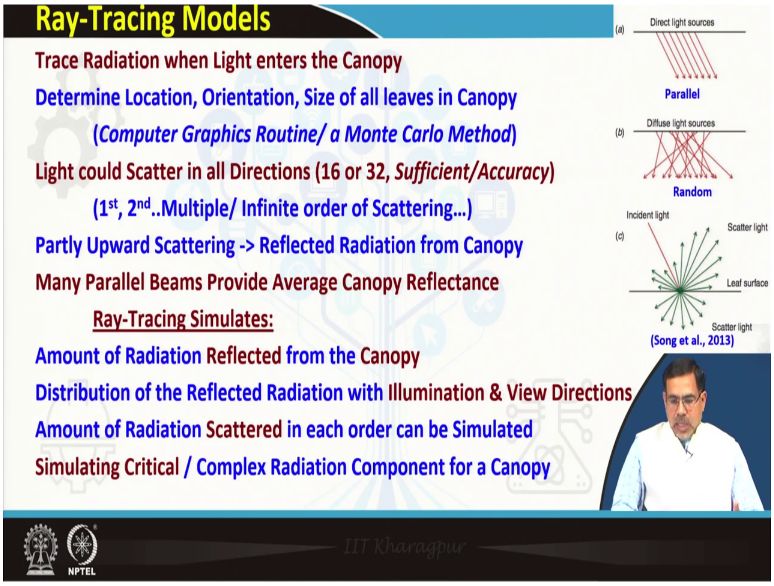


Coming to the first one with respect to the ray transfer, let us go back and understand this particular pathway of light through a leaf cross section. In our introductory classes, we discussed about the pathway of light in terms of the NIR reflectance, Near Infrared Reflectance.

So, here this is a cross section of a leaf projected and the solid arrow tells about the reflected ray and you can see there are number of arrows, dotted arrows, internal reflectance, diffraction, reflection all these things it is happening within the cell or the leaf within the leaf cells.

So, similar context, if we understand with respect to we if you project this, this with respect to the leaf canopy and imagine you have lot of leaves in a cube of canopy and the light ray takes different paths. So, if we can trace their paths, then perhaps, we can do some good thing in terms of simulating them and correlate them with respect to the LAI.

(Refer Slide Time: 06:47)



So, this particular kind of principle is applicable with respect to the ray-tracing models. On the right hand top corner, we can see three depictions. So, the first one talks about the direct light sensors, the middle one talks about the diffused light sensors and the third one talks about the scattering.

So, in case of direct, all these light beams they mostly travel in parallel mode; whereas, in case of the in random, the in case of diffuse, there these beams they cross over or they move they take a random function and in case of a scattering. You can see this is a property of the surface; you can say here, it is a property of the leaf surface and based on that, it can scatter in any direction.

So, this is actually we need to keep in mind. So, this trace ray, this ray-tracing models they actually with respect to the nomenclature, they trace the radiation when light enters the canopy. So, when the light enters the canopy, these models they start tracing or through this models. The rays or the light beams are traced to determine the location, orientation, size of all leaves in a canopy and it takes a kind of computer graphics routine; example, a kind of Monte Carlo method.

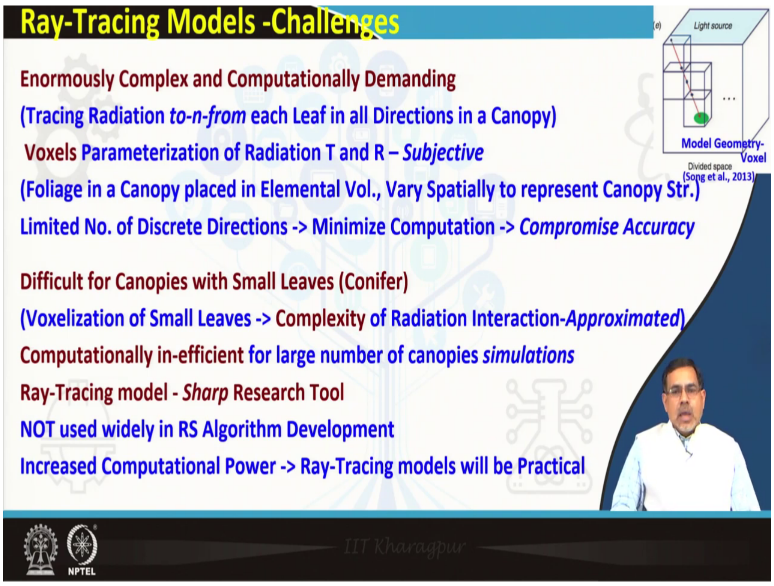
So, what we do in terms of the ray-tracing models, it determines the location, the orientation and size of the leaves in a canopy. So, that is very important because the individual light beams have to be traced. Second with respect to this, the light could scatter in all directions. It can have any or many directions. Then, coming to the model, how many we can have. So, many of these models they simulate kind of 16 to 32 directions. Then, comes the question of are they sufficient?

If they are not, then perhaps, we are compromising with the accuracy. So, with respect to that a kind of first order, second order, multiple order, it can go up to infinite order of scattering and partly also there could be scattering towards upward direction that could be compared with respect to a kind of reflected radiation from canopy. So, these all rays have to be traced.

So, what this a rate racing models they simulate? They simulate the amount of radiation that is reflected from the canopy; maybe from the top canopy, from the first order, second order canopy. Then, distribution of the reflected radiation with illumination and the view directions and the amount of radiation scattered in each order can be simulated using these ray tracing models and as we can understand with respect to the multiple order of scattering, the multiple order in terms of reflectance reflected radiations.

So, this simulation could be critical. It could be complex based on the radiation component of a canopy.

(Refer Slide Time: 10:26)



Coming to the challenges, when you have to track with respect to trace each leaf and the direction of its travel to and from within a canopy. Then it is going to be enormously complex and computationally, very demanding. So, you have to have a very high-end computation facility and you have to look for a very complex thing.

Because it is dealing with individual leaves and you have to trace the radiation in all directions, it could be infinite, it could be in multiple directions within a canopy. So, as you can see from the right hand top corner, graphics the three-dimensional pixels, we call it a Voxel. So, this three-dimensional pixel, we call the Voxel. Voxel parameterization of radiation, transmission and reflectance are subjective.

Many times, we have seen in terms of these models, they could be subjective because we cannot actually depict where all they could go, they can vary with the team where who are working or pursuing this kind of models. So, foliage in a canopy placed in elemental volume and varies spatially to represent canopy structure and they are limited. There is limited number of discrete directions means computation minimization.

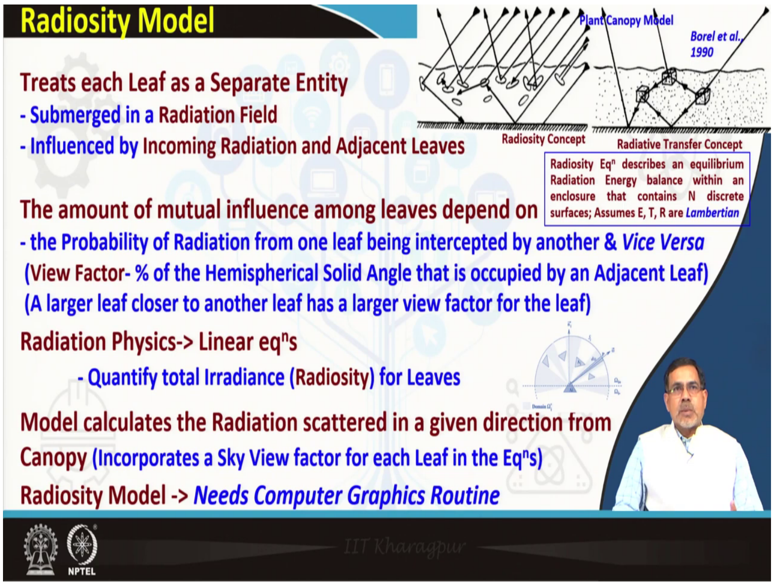
So, if computation is minimized, then some higher compromise with respect to a kind of the accuracy. So, it is actually a kind of compromise between the directions; how many directions one can simulate? 16, 32 as far as the models based on the experience, 16 to 32 people have gone. And then, if you are minimizing the computation, then perhaps you are somewhere compromising with the cup with the accuracy. So, these are the challenges one has to make a difficult balance.

Then, the diff the with respect to limitations, it could be very difficult for canopies with small leaves; particularly, the conifers leave. Conifer leaves which are very small leaves; because what happens within a 3D pixel, you call the Voxel. So, voxelization of this small pixel is very complex and then, complexity of this radiation interaction is approximated to a great extent. So, there we are inducing errors or we are compromising with the accuracy.

Then, it is computationally inefficient, if you are taking lot of small leaves with respect to conifer forest or conifer vegetation. Then, perhaps, it is going to become computationally very complex. Then, you if one is going to do it simple, or minimum, then somewhere there is a compromise with the accuracy.

Then ray-tracing model that is why it has become a very sharp tool in the sense, it has not yet taken a lot of practical applications as far as the ray tracing models are concerned. But, in these days with respect to super computer and high computational power, these ray-tracing models could do a better job and hold lots of promises in the future days.

(Refer Slide Time: 13:51)



Coming to the second category of model that is the Radiosity model. So, as we know in terms of the radiosity equations, they describe an equilibrium radiation energy balance within an enclosure that contain N discrete surfaces ok. So, one can compare it the surfaces with respect to different leaf surfaces within the vegetation canopy and these radiative models. They assume the emission, transmission and reflectance are diffuse; that means, there Lambertion in property.

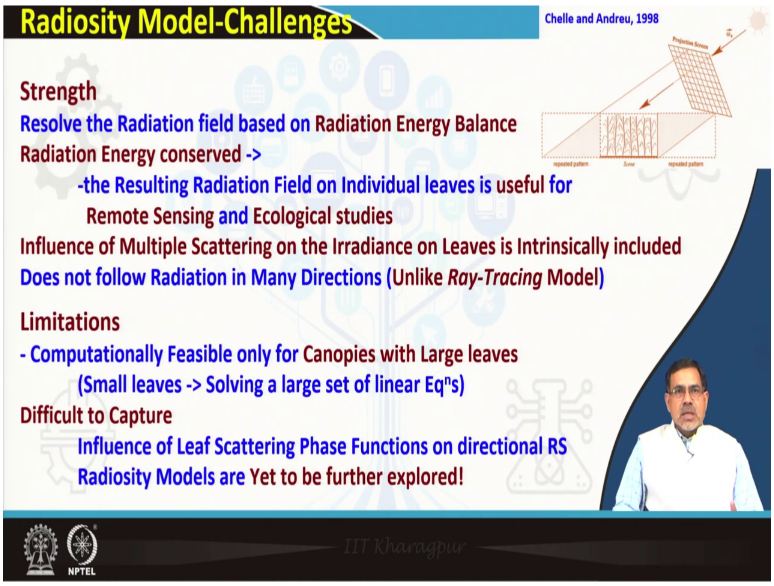
So, there these models, they treat each leaf as a separate entity. Imagine they could be submerged in a radiation field, influenced by incoming radiation and also, the surrounding or the adjoining leaves. The amount of mutual influence among leaves depends on mostly the probability of radiation from one leaf being intercepted by another and vice versa.

So, this probability of radiation, which is also can be attributed with respect to the view factor. The view factor which is defined or could be understand in respect to the percentage of hemispherical solid angle that is occupied by an adjoining or adjacent leaf.

So, that means, a larger leaf could come closer or a larger leaf closer to another leaf has a larger view factor for the leaf and vice versa. So, based on this radiation physics, a set of linear equations could be framed. To quantify the total irradiance or we call it radiosity for the leaves in a canopy. So, a kind of the view angle the solid angle a depiction has been has been put in the slide. So, this radiosity model calculates the radiation scattered in a given direction from the canopy.

So, it incorporates the sky view factor for each leaf in the equation. So, imagine how complex it would be, when it is calculated in on the basis of submergence in a radiation field, which is influenced by the incoming radiation and the adjoining leaves in the canopy. So, the radiosity models, they also need the computer graphics routine, so computationally demanding in that sense.

(Refer Slide Time: 16:40)



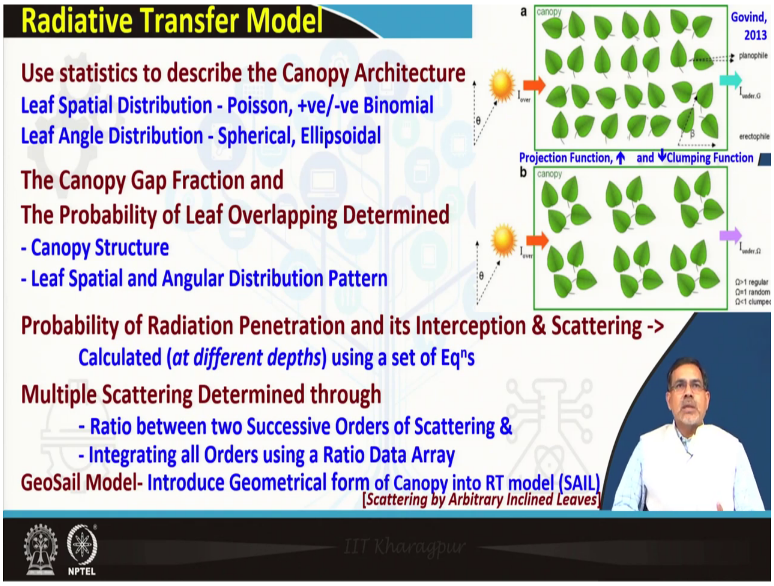
So, the challenges with respect to strength and limitations of this radiosity models. So, strength could be these models, they resolve the radiation field based on radiation energy balance. So, it is very important because once the radiation energy balance is conserve or we follow the conservation equation. That means, the resulting radiation field on individual leaves is useful for remote sensing and subsequently other ecological studies.

So, this is very important because it balances or it conserves the radiation energy. So, influence the other strength is it influences the influence of multiple scattering on irradiance and leaves are intrinsically included. So, it is very detailed, individual leaves irradiance is included. So, it is very what you say comprehensive the and another strength is unlike the tracing ray tracing models, it does not follow the radiation in many direction; instead, it influence the multiple scattering on irradiance and leaves which is very intrinsic.

So, the limitations could be as we can know that it talks about the individual leaves. So, it could be also the computationally demanding. So, computational feasibility only for canopies with large leaves; for small leaves like can the conifers, it should be solving a large set of linear equations. So, it could be computationally little, what you say demanding and difficult to capture particularly, with respect to the influence of leaf scattering phase functions on directional remote sensing.

And the radiosity models are yet to be further explored as we can; as we can understand because thus, because it imagines a kind of submerged submergence in a radiation field influenced by the incoming radiation and adjacent leaves, it could be very what you say intrinsic very complex. So, that is why these models are yet to be further explored; but as you can understand with respect to high computational facility coming up these days, the challenges are ahead and future will see more of this exploration.

(Refer Slide Time: 19:28)



Coming to the third category is the Radiative Transfer Model. So, with respect to radiative transfer model, what it does? It uses statistics. Like in ray tracing, it was tracing the rays; here, it was forming a radiation what to you say function kind of thing and here, in terms of the radiative transfer model, it use statistics to describe the canopy architecture.

So, in terms of the canopy architecture, the leaf spatial distribution and leaf angle distribution; the leaf spatial distribution could be calculated with respect to Poisson's both positive negative binomial equations or the Leaf Angle Distribution LAD could be spherical, ellipsoid and many other things as you can see the from the depiction on the upper right corner.

The different types of leaves, they form different angles and the one which is beneath, you can see the arrangement or the spatial distribution is more a kind of what you say clumped. So, the different kinds of spatial distribution, and different kind of leaf angles. So, they are solved based on the statistics to describe the canopy architecture. The canopy gap fraction and the probability of leaf overlapping are determined by the canopy structure and both the leaf spatial and angular distribution pattern.

So, that is what is the major strength of these radiative transfer models because they account for the canopy structure as well as the leaf spatial distribution and leaf angular distribution.

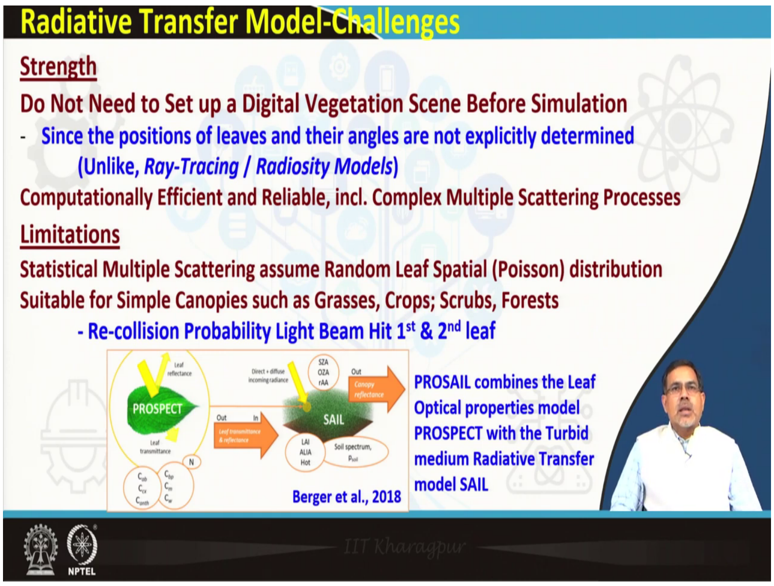
So, probability of radiation, penetration and its interception and scattering calculated at different depths using a set of equations. So, multiple scattering determined through ratio between two successive orders of scattering and integrating all other orders using a ratio data array.

So, in terms of multiple scattering, this ratio between two successive orders of scattering as considered which integrates all other orders using a ratio data arrangement and coming to the to spell out name of one or two models. So, SAIL is a model based on this radiative transfer or RT model expanded as scattering by arbitrary inclined leaves, scattering by arbitrary inclined leaves.

So, these models when included or when combined or when also added with the geometrical form of the canopy, then other models develop such as one like GeoSail. So, this GeoSail model is the name as an example I have put it here, introduce geometrical form of canopy into RT model. So, the different geometrical forms like rectangular, conical ellipsoid and many other geometrical forms.

So, those forms of canopy architecture are included into these RT models like SAIL and then this is better taken care with respect to the canopy architecture.

(Refer Slide Time: 23:15)



So, with respect to the challenges of radiative transfer model in terms of strengths and limitations. The strengths are they these RT models do not need to set up a digital vegetation seen before simulation unlike the ray-tracing or the radiosity models. Because the position of the leaves and their angles are explicitly determined by set of by statistics and also the canopy architecture.

So, one do not need to set up a digital vegetation scene before simulation for this RT model based simulation, unlike the previous two as we discussed the ray racing and the radiosity models. That means, it is computationally efficient and reliable because in radiosity model you are tracing you are taking care of individual leaf.

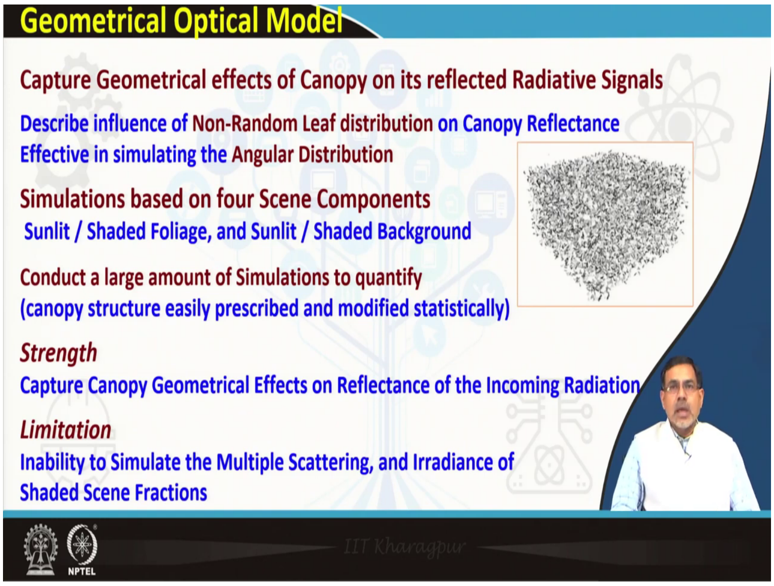
So, in comparison that RT models are computationally efficient because they are taken care with respect to the canopy architecture. So, including the complex multiple scattering processes. But the limitations could be the limitations could be statistical multiple scattering assume random leaf spatial or Poisson distribution.

These models, these RT models, they assume that the statistical multiple scattering, they assume random leaf spatial distribution; whereas, in practice or in nature or in true sense, the leaf distribution is not random. It is non-random or we call clumped; there is clumping. So, that is one of the limitations. Second is suitable for simple canopies having less leaves such as grasses, crops; scrubs or a kind of open forest.

So, this is the major limitations; whereas, the re-collision probability light beams hit both 1st, 2nd and many orders of the leaves and the bottom try to put a depiction with respect to the hybrid or the margin merger of PROSPECT model with SAIL model to give us the process the PROSAIL model. So, PROSAIL combines the leaf optical properties of the model called PROSPECT. On the left hand side of the figure, one can see the model is depicting the optical properties ok, that is the Prospect.

On the right hand side, it is the turbid medium radiative transfer model called SAIL. As we know if we take advantage of both in a hybrid sense, the combined model is the one PROSAIL. So, many of the scientists are working on this kind of combined and hybrid models to exploit synergy. This one has been taken from the publication by Berger et al published in 2018.

(Refer Slide Time: 26:34)



Then, coming to another category the Geometrical Optical model. As one can understand from the title the name itself that these kind categories of models, they capture geometrical effects of canopy on its reflected radiative signals. So, based on this, these models describe influence of non-random leaf distribution on canopy reflectance.

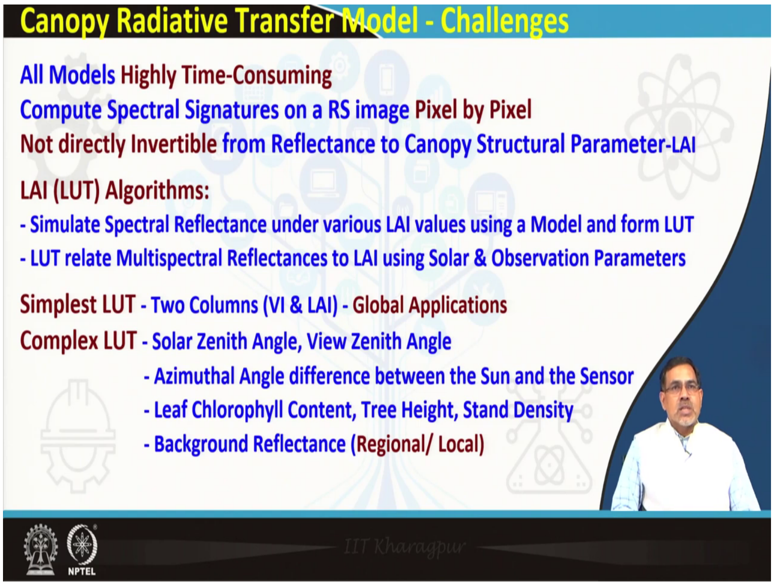
So, this non-random leaf distribution is very important because that is what is the reality; that is what is addressed to the clumping index and also, these models are effective in simulating the angular direction. So, clumping and angular direction are very well taken care also with respect to the geometrical optical model because the geometry is merged with the optics or optical phenomena as we discuss with respect to RT models.

So, simulations based on four scene components, based on the sunlit and the sun shaded foliage with respect to the leaf or the foliage and also, with respect to background sunlit and sun shadow or the shaded background. So, all these four scenes are simulated with respect in these categories of geometrical optical models.

So, these models they conduct a large amount of simulations to quantify canopy structure, which are easily prescribed and modified statistically. The strength and limitations to understand, the major strength is these kinds of models.

They capture canopy geometrical effects on reflectance of the incoming radiation; whereas, the limitation could be the inability to simulate multiple scattering and irradiance of the shaded scene fractions. Wherever the shaded scene fractions are there, it becomes difficult ok. So, a kind of a depiction is there on the upper left corner upper right corner.

(Refer Slide Time: 28:45)



And let us try to understand the challenges of these inversion models or the canopy radiative transfer models. So, all these models, they are highly time-consuming; they take a lot of time. Because we as we feed them with lot of linear equations to address many processes, many relationship, they become complex and complicated. So, in the sense, they consume lot of time in terms of giving the model result.

So, all models are highly time consuming and they compute spectral signature on a remote sensing image pixel by pixel. So, for each pixel, there has to be a computation. So, pixel by pixel it computes. So, it has to be scanned through, it has to be addressed through individual pixels. So, that is why it is very computationally demanding. Then, these are all these models are not directly invertible.

So, as we talk about inverse models in this class, these all these models are not directly inverse or invertible from reflectance to canopy structural parameters. They have to be through some means. So, one is with respect to the LUT based algorithms, lookup table as we discussed. This algorithm why I put it? Because the MODIS data, LAI data has taken this kind of algorithm.

So, these algorithm through this, they simulate spectral reflectance under various LAI values using model and form a kind of lookup table and these lookup tables, they relate multispectral reflectance's to LAI using the solar and observation parameters. So, this is what we do in this inverse model. So, they are not directly, but it has to be through the LUT vis-a-vis using the solar and other observation parameters.

So, with respect to LUT, the simplest one could be two columns relationship. You take vegetation index and LAI and relate. So, it is very simple or we try to make it as simple as possible for a global or a kind of continental application with respect to LAI.

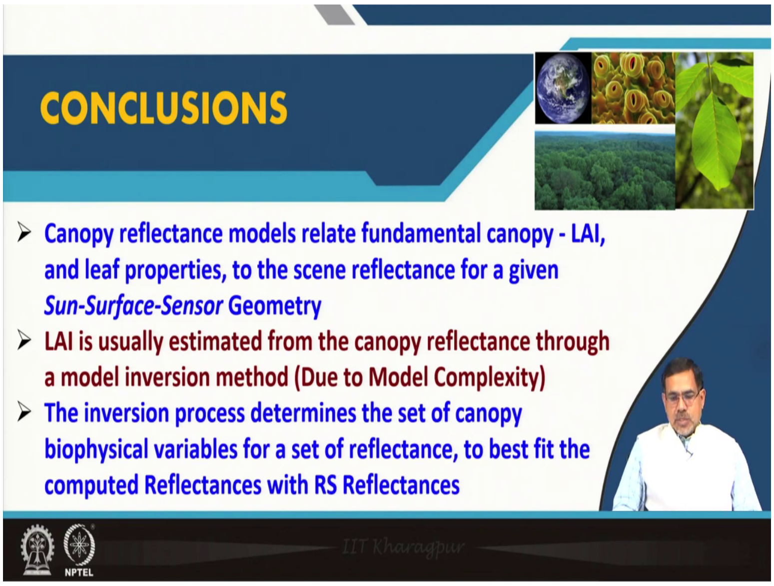
But as we integrate more and more variables, more and more columns including Solar Zenith Angle, Views Zenith Angle, Azimuthal angle difference between the Sun and Sensor, others like Leaf Chlorophyll Content, Tree Height, Stand density, Background Reflectance and the list can go on.

But believe me, when we integrate all these variables, all these columns to frame out with a relationship or inverse the relations with respect to LAI, they limit because of the complexity. The generalization became limited. So, they are more specific to local or regional scale.

(Refer Slide Time: 31:59)

These are the references, I have used to frame the slides and discuss with you.

(Refer Slide Time: 32:06)



And the conclusion, as we sum up the canopy reflectance models relate fundamental canopy that is leaf area index and leaf properties to the scene reflectance for a given sun surface sensor geometry. So, this is what is the trajectory you. Because we are talking here with respect to the optical remote sensing! So, you have the sun, you have the surface; the surface is the leaf or the vegetation canopy and the sensor which is there in terms of the satellite.

So, this is actually the link or the relationship, which is established. Then, with respect to LAI, LAI is usually estimated from the canopy reflectance through a model inversion method due to model complexity. As we know, it has to be through an inversion method. So, LUT acts as a intermediate step or we generate lot of LUTs in terms of you can go up to 1 lakh and then, take 52 to invert the model.

The inversion process determines the set of canopy biophysical variables for a set of reflectance, to best fit the computed reflectance with respect to remote sensing based reflectances. So, this is what is happening the researcher, research is going on and we are including more and by more biophysical variables to come out with better relation vis-a-vis better inversion; so, better equation and better LAI.

So, this is what we need to discuss with respect to the model inversion using the optical remote sensing based principle.

Thank you very much.