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 - 12
RS of Primary Productivity - VIs and LUE

Yes welcome back. So, today we will be discussing on Remote Sensing of Primary Productivity and how we use the vegetation indices as a principle of empirical relationship or empirical function with respect to the ground based primary production and also we will see the next methodology, the second one is with respect to the light use efficiency.

So, we all have the understanding is that the primary production which is actually because of the process or the basic process of photosynthesis that measuring the primary production is not so easy. So, we have different methods and how remote sensing provides inputs in terms of assessing or estimating the primary production in a global scale or in a regional scale so that means, across different temporal and spatial scale.

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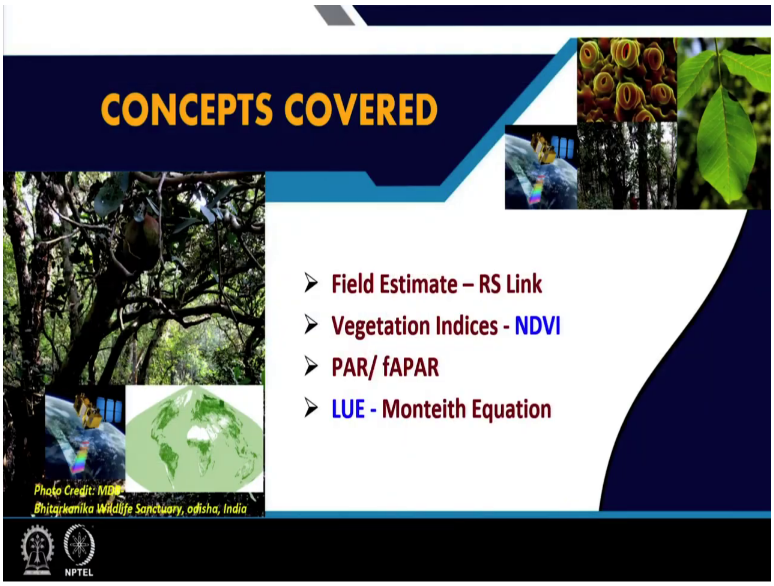

So, we will emphasize on these four concepts if I put them together. So, first one is the field estimate. So, what are the different field estimation methods are available? So, that we come out with a kind of empirical relationship with the remote sensing derived vegetation indices.

So, we will also know how the field estimation with respect to primary production of a vegetation or a vegetated area is usually taken care. Second as we already have been discussing there has been lot of vegetation indices and we will focus on few and most importantly on NDVI which is a very widely used and a universal index as far as vegetation indices are concerned.

And thirdly we will talk about the photosynthetically active radiation or the fraction of absorbed photosynthetically active radiation. And try to understand that in a kind of light use efficiency model or radiation use efficiency model based on the optimization principle when all other factors are kept constant, how the PAR or the fraction of absorbed PAR can be the determinant of primary production in for an ecosystem.

And fourthly we will elaborate our discussion with respect to the light use efficiency which takes inspiration or is based on the Monteith equation.

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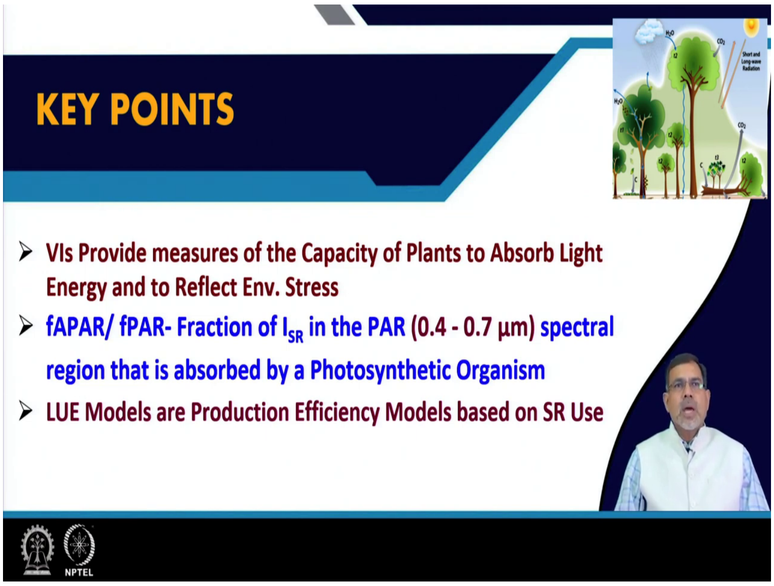

So, as we move on we will see these key points emerging out. Vegetation indices provide measures of the capacity of plants to absorb light energy and reflect environmental stress. Photosynthetically active radiation or fraction of photosynthetically active radiation which are defined as the fraction of incident solar radiation in the PAR range, the PAR is mostly the visible range. So, between 0.4 and 0.7 micron meter in general.

So, in this spectral region this is absorbed by the light is absorbed by the photosynthetic organisms because of the presence of the chlorophyll in the chlorophyll pigment which is the green pigment in the chloroplast. Third, we will elaborate our discussion with respect to the light use efficiency model which is a production efficiency model. So, it is based on optimization principle and how satellite remote sensing helps or becomes useful in that effort.

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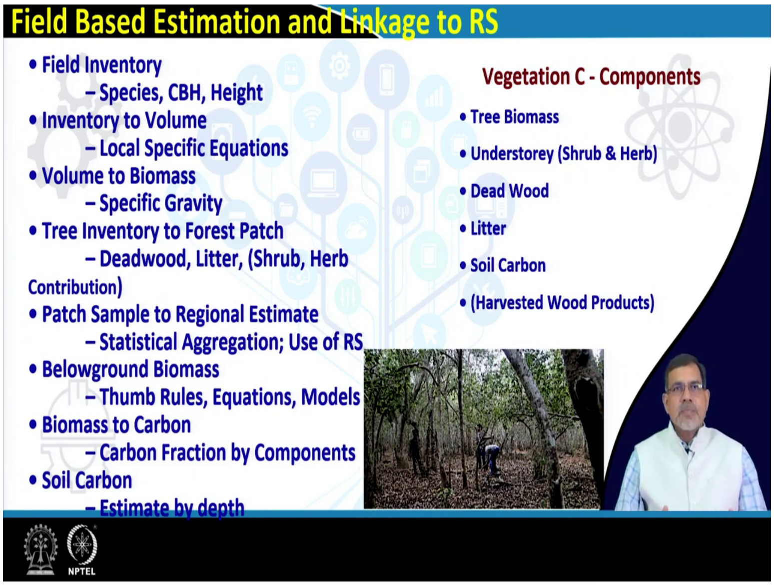

So, going back to refreshing our knowledge as far as the field based estimates is concerned. Look at a forest or a vegetated area or an ecosystem, it is actually difficult to really come out with the estimation of primary production. So, we have different methods and these methods are mostly or you say partly destructive and then you extrapolate it to the larger area. So, in that sense you make it non-destructive.

So, we have field inventory based. So, what we do? We go to field and measure the tree or the tree bole species wise take the CBH; circumference at breast height and the height. So, then this inventory to volume with respect to species with respect to community of the species or the group of species that we call community, we in extrapolate or transfer it to a kind of we use the volume based equation which are local specific and transfer volume to biomass based on the specific gravity.

So, finally, what we do? The tree inventory based data we convert. The data means, the primary productivity data we convert to forest patch label. So, we then integrate the other the other components particularly the dead woods because they have been produced or by the by the trees and have fallen or have taken the different course in terms of dead wood, litter or even if the back grounds shrub or herb whatever it is.

So, when we are talking about the forest ecosystem, so, all these matter. So, we also need to get information about these their inventory data along with the tree inventory. So, then we do lot of statistical aggregation and there perhaps in extrapolating we use remote sensing. And then we follow a thumb rule of 15 to 20 percent in terms of below ground linking to above ground and there are lot of equations and many equations are emerging out, so, in terms of linear regression non-linear regression and things like that.

So, then we convert this the biomass. The biomass is the oven dried weight. So, the biomass we convert to carbon and this carbon or the fraction we say that per meter square or per some area or unit area or per hectare what is the amount of carbon, we say. So, that is the vegetation carbon then we sometime means account or add the soil carbon component to that to make an estimate of vegetation plus soil. So, total carbon in that sense.

So, this is how we have been doing using the field based protocols. So that means, we come out with the carbon estimates from the tree biomass under story shrubs, herbs, the dead woods, the litter, soil carbon and even if the harvested wood products. So, together they give us a kind of estimates with respect to the carbon content and that is the primary production.

So, when we have one set of data in terms of the field based and on the other hand we have remote sensing derived output such as vegetation indices per se we try to link them using empirical equations. So, that is how the vegetation index based, what you say primary production estimation studies prosper.

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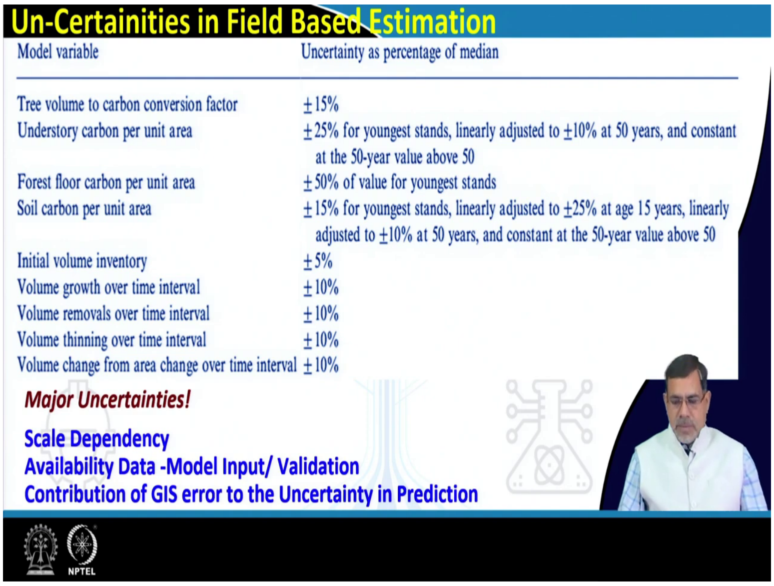

And some of the uncertainties, the uncertainties in terms of the field based estimates can be many fold in terms of plus or minus the percentage. So, tree volume to carbon conversion factor could give us underestimation up to our uncertainty up to plus or minus 15 percent.

So, underestimation, over estimation, uncertainty can happen at any point of time like understory carbon per unit area conversion, forest floor per forest floor carbon per unit area, soil carbon per unit area and in terms of the volume inventory volume growth over time interval volume removals over time intervals volume thinning over time intervals and volume change from area change over time interval.

So, all of them could contribute a kind of uncertainty from let us say plus or minus 25 percent to the tune of 10, 15 or 25 percent. So, there are uncertainties in the field base. So, we must understand the uncertainty.

So, we have to minimize the uncertainty here otherwise that will be carried forward when we try to match with respect to the remote sensing based pixels or vegetation indices or any other information to bring a kind of spatial and temporal profile of the primary production of the carbon content.

So, also in terms of relation like the major uncertainties scale dependent and available model, model input validation and also lot of errors with respect to the integration tool like GIS and prediction comes. So, all these uncertainties in terms of field based estimations are there which needs to be understood so that when we relate with respect to the vegetation indices we make a judicious inference out of them.

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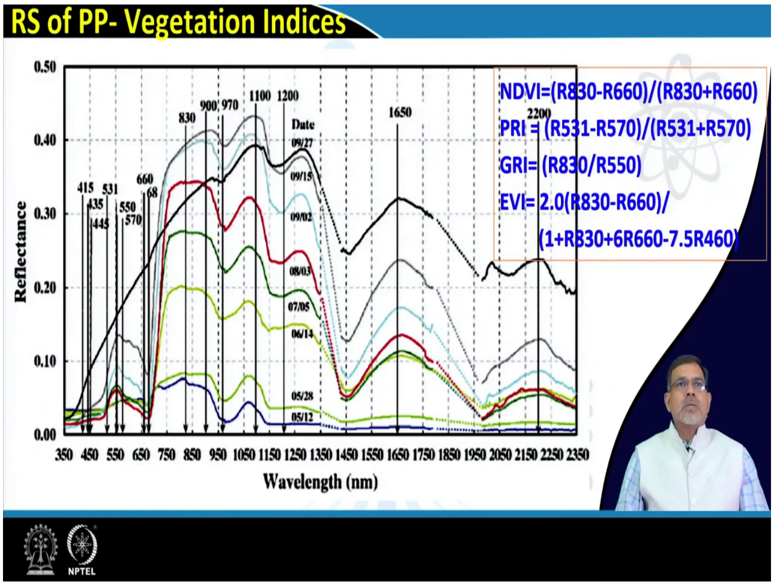

So, in terms of vegetation indices as we know most of the vegetation indices are two bands or three band ratios, so or having an additional or a coefficient or a constant factor. So, they actually take advantage of lot of absorption in the visible range and more importantly by the chlorophyll and the red edge or at the red edge. So, lot of absorption, but lot of reflection in the NIR.

So, this differential what you say reflectance pattern actually led to evaluation of evolution of lot of vegetation indices. So, some prominent among them have been listed here like NDVI, the perpendicular is ratio index PRI, green ratio indices GRI and enhanced vegetation indices EVI.

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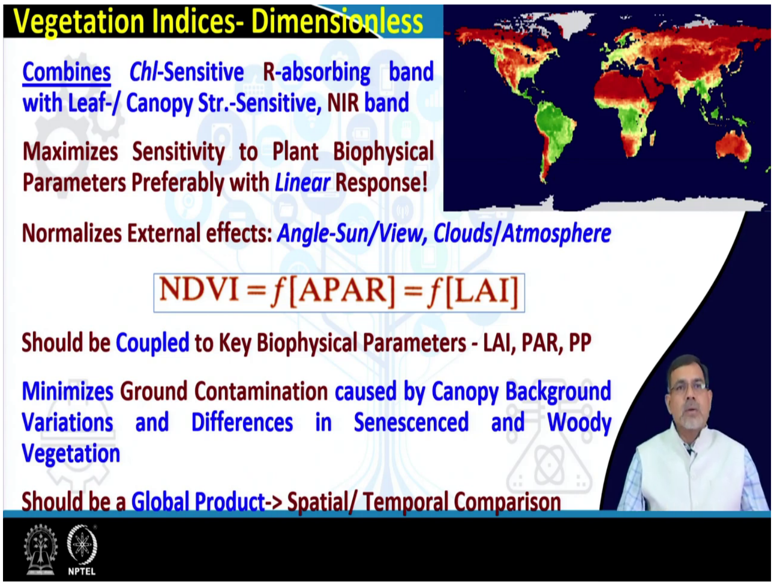

So, as we already know that these vegetation indices are dimensionless and as we just discussed, they primarily combine the chlorophyll sensitive red absorbing band with the leaf or canopy structure sensitive NIR band.

So, as we know this R band the red band is chlorophyll sensitive whereas, the NIR band reflectance is canopy structure sensitive. So, that comes mostly from the inter-cellular structural arrangement in the NIR band or the NIR region. So, this actually gets what you say combined or accounted in the vegetation indices.

So, what happens? All the vegetation indices they maximize the sensitivity of the plant biophysical parameters such as fAPAR, LAI and many more preferably in a linear response. Yes, if we do it more non-linear then perhaps extrapolation and many other problems happen. So, we try to prefer to take a kind of linear response between the vegetation indices and the other biophysical parameters.

And this they normalize the vegetation indices they normalize the effects of sun angle, viewing angle, clouds and also the atmosphere, so, because it is based on a ratio and difference. So, the ratio actually cancels out these because this sun angle effect and viewing angle effect in turn also the cloud and atmospheric effect are common to both the bands or to all the bands. So, that gets cancelled out. So, it is so, the vegetation indices normalizes the external effects.

So, another property very important property of this vegetation indices that they are coupled to the biophysical parameters. So, as I mentioned here NDVI can also be co related with respect to fraction of absorbed photosynthetically active radiation. We are going to see more detail what is the PAR and APAR and also it can be related with respect to a kind of function of LAI.

So, all these vegetation indices they also minimize the background or the ground contamination which is down below or at the background. So, that comes from differences in the senescence and woody vegetation. And one very important property of this indices per se and vegetation indices in specific they have to be global products that means, they have to be a kind of universal or generalized product so that the spatial and temporal inter comparison could be possible.

So, what is the NDVI or the vegetation strength of Amazon with respect to the Western Ghats? If you have a number and that is universal then we can compare and in terms of temporal interval or like with respect to season, year and decade.

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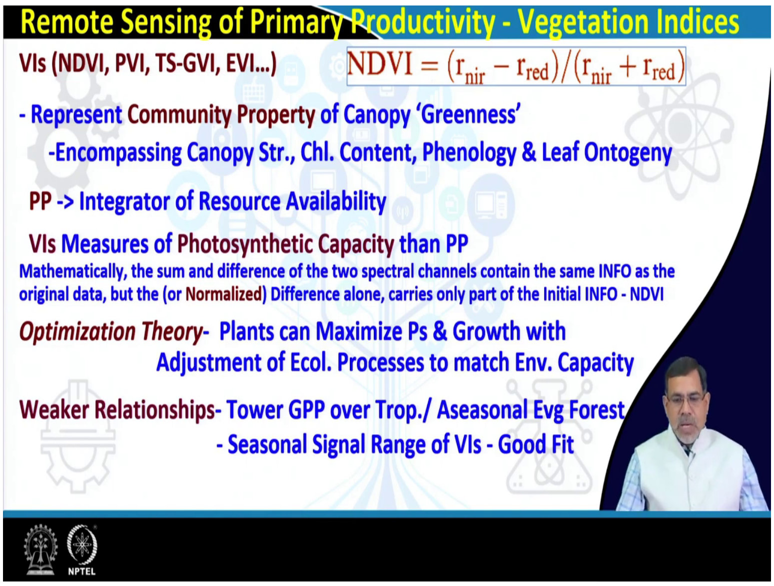

So, those are the very important or important properties of the vegetation indices. So, now, how this vegetation indices are linked or benefits the study of primary productivity as far as remote sensing is concerned? So, vegetation indices they represent the community property the group or the canopy ok the group of leaves or the canopy in terms of the greenness by encompassing the canopy structure, chlorophyll content, phenology and the leaf ontogeny.

So, primary productivity actually integrates or is the integrator of the resource availability. So, this is where the key point is. How the primary productivity takes a clue because all these vegetation indices which encompasses the canopy structure, chlorophyll canopy, chlorophyll content then phenology leaf ontogeny and things like that.

So, primary productivity actually integrates like acts as an integrator of these resources which is available. So, vegetation indices measures of the photosynthetic capacity. So, all these VIs they primarily measure or more. So, they measure the photosynthetic capacity not exactly the primary productivity in that sense.

So, it is more a measure of photosynthetic capacity by the vegetation indices ok. So and going to this in terms of the optimization principle or optimization theory plants can maximize the photosynthesis and growth with adjustment of ecological processes to match the environmental capacity. We will highlight more on this with respect to the LUE.

But what happens as we mentioned the VIs they measure the photosynthetic capacity more so than the actual primary production. So, this can be estimated or captured using the optimization principle where the plants you say can maximize or optimize photosynthesis and growth with respect to adjustment with any other or many other ecological processes.

But there have been also some weak relations been noticed with respect to tower or flux tower based GPP estimates mostly for the what do you say the evergreen forest which are not deciduous or as seasonal. Because what happens in case of the deciduous forest what we all know that they shed their leaves what you say over a year cycle.

So, like if we start with leaf on then leaf mature then the senescence phase and the leaf fall and you have a gap period of about three to four months depending on the species and for and the place where it is located. The deciduous forest they take a full cycle; that means no leaf to a full bloom leaf condition.

So, what happens? This particular cycle actually allows a range or a bigger range of VIs. So, if you are having NDVI. So, it could vary from 0 to let us say 0.7 or 0.72 or something like that. In contrast with respect to a broad leaf evergreen forest or as seasonal we say evergreen forest the NDVI range could vary between let us say 4 to 6 sorry 0.4 to 0.6.

So, if we are getting a full range then we have a better chance of getting a good relationship as far as empirical relationship is concerned. So, this is important to understand.

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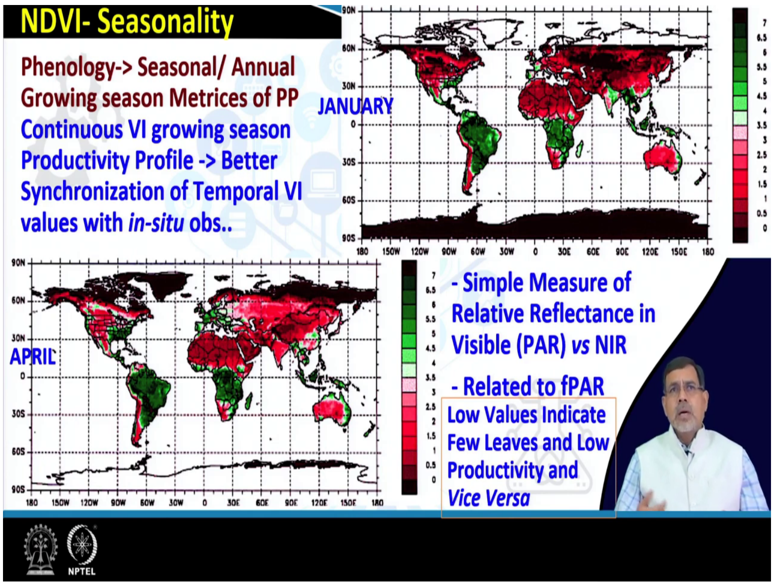

So, then coming to this in terms of the seasonality, which we discuss in terms of phenology. So, these two images in terms of upper right and lower left they depict the January or the winter season. April or the summer season vegetation in terms of NDVI. So, what they imply?

They imply that yes in the winter season you have in the in the polar region you have no vegetation, so, which is reflected in the NDVI whereas, in April you have lot of vegetation. So, this actually the low values indicate few leaves and low productivity vice versa. So, direct relationship with respect to NDVI to primary production. So, that is very important.

Now, we will move to understand the PAR that is the photosynthetically active radiation, but here this NDVI as we know it is a simple measure of relative reflectance in the visible or the PAR range versus the NIR. So, it is very well related to the PAR or the fraction of PAR.

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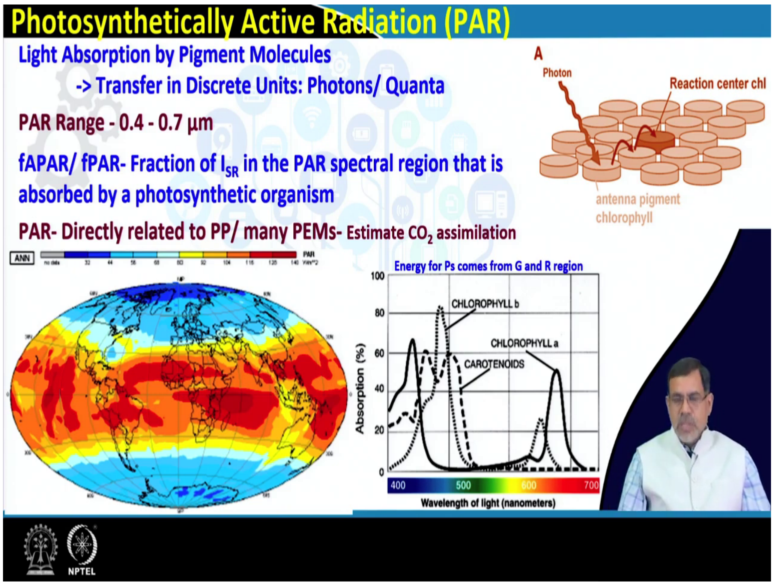

So, PAR as we know it is the photosynthetically active radiation PAR. So, light absorption by pigments on the right hand upper right. The depiction shows the antenna pigments which are excited because of the incident light energy or the photon or you say the quanta.

And so, this happens in the PAR range the photosynthetically active radiation range in the more importantly the visible range 0.4 to 0.7 micron meter. So, fraction of the incident solar radiation in the PAR spectral region that is absorbed by the photosynthetic organism the chlorophylls which are present in the chloroplast.

So, down below on the lower what you say lower left corner just a beautiful picture or an image of a PAR if that is a PAR image of the globe sometime during 1991 to 93 average. So, it actually depicts that what how much amount of PAR is available or available for utilization by the plants.

So, if you see it then in the tropics the PAR is more. So, availability in terms of watts per meter square is the represented and you have the color bar. So, that gives the impression that yes the tropics the lights the PAR available it is more. So, what it indicates? It straightway indicates that tropics are more productive.

So, tropics have higher or I would say the highest primary productivity in comparison to or in contrast to other subtropics temperature alpine sub alpine regions. Then the lower right diagram actually again reminds us the maximum absorption by the chlorophyll pigments in the green and the red region.

So, I repeat the maximum absorption by the chlorophyll pigments chlorophyll a, b and also the carotenoids have been shown. So, maximum absorption is happening in the in the green and the red, but more generally in the PAR region. So, this is what is very important to understand. In many models we will see particularly MODIS based GPP estimates they take PAR as a kind of 0.45 percent or 45 percent of the incoming incident solar radiation 45 percent of that.

So, if we quantify that then perhaps we are through with respect to a kind of light use efficiency based model.

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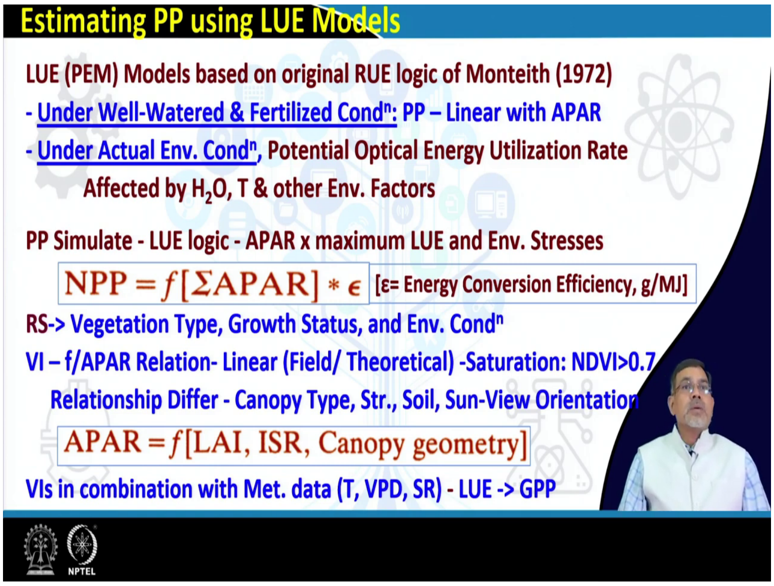

So, let us understand that in sense of the light use efficiency model which takes the radiation use efficiency logic given by the great scientist Monteith almost 50 years back. So, what it does? It says that under well watered and fertilized conditions, so; that means, if all the other environmental conditions are optimum or fine then the primary productivity is just what you say function or a linear function as far as the APAR is concerned, the absorbed photosynthetically active radiation is concerned.

But that is not the case. Actual or in reality or in actual environmental condition the potential optical energy utilization rate is affected by water or we say water stress, temperature we call temperature stress and many other environmental factors. As we know photosynthesis is not that simple, it depends on many more things.

But to be the simplest of the simple we try to understand here in terms of LUE, light use efficiency which is actually a production efficiency based model. So, it actually talks about what is the productivity in terms of in an optimal condition. So, the primary production simulate based on the LUE logic that takes a kind of equation like APAR into the maximum LUE and the other stress in terms of environmental stress here water stress and temperature stress.

So, which is shown in this equation. So, this varies with respect to place, type of vegetation, their growth stage and remote sensing data very well gives information with respect to the which vegetation type we are accounting, what is the growth status, what are the other environmental conditions. So, remote sensing becomes very useful in terms of giving this data or information in a spatial extent or spatial form of the image.

And vegetation indices which actually means has been shown or has been seen to give a kind of linear relationship with respect to field based what you say primary production estimate or based on the theoretical estimation. So, VIs and the PAR or the fraction of absorbed photosynthetically active radiation fAPAR they give mostly linear relationship with primary production.

So, VIs which we are deriving or we can derive from satellite data is almost linearly related to primary production. So, that is the key, but we have to remember the other negatives or the limitations of the VIs, VIs have the saturation effect. So, as an example NDVI more than 0.7 value, will no more vary linearly if you go on increasing the primary production.

So, that is the saturation. So, that means what? In high or very high forest or very thick dense forest or productive forest we say the VIs beyond certain range will not increase or show a linear relationship with GPP because it will be saturated. So, these are the things we also need to understand and there are many other factors there.

Even if indices like EVI, enhanced basis indices which just takes it little higher or elevates the saturation limit to little higher extent. So, studies are going on in that way. And coming to VIs in combination with other meteorological data like temperature, vapor pressure deficit, the solar radiation gives a good estimate of GPP or we say the primary productivity both in terms of gross or net based on the light use efficiency.

So, let me make it very clear light use efficiency models are the production are production efficiency model. So, they are explained with respect to an optimization principle.

So, if all other conditions are optimum or let us say optimal then the PP, primary production is a function or a linear function of APAR ok; absorbed photosynthetically APAR, which is or which can be expressed as epsilon, epsilon that is the energy conversion efficiency term which is which is explained in the LUE models.

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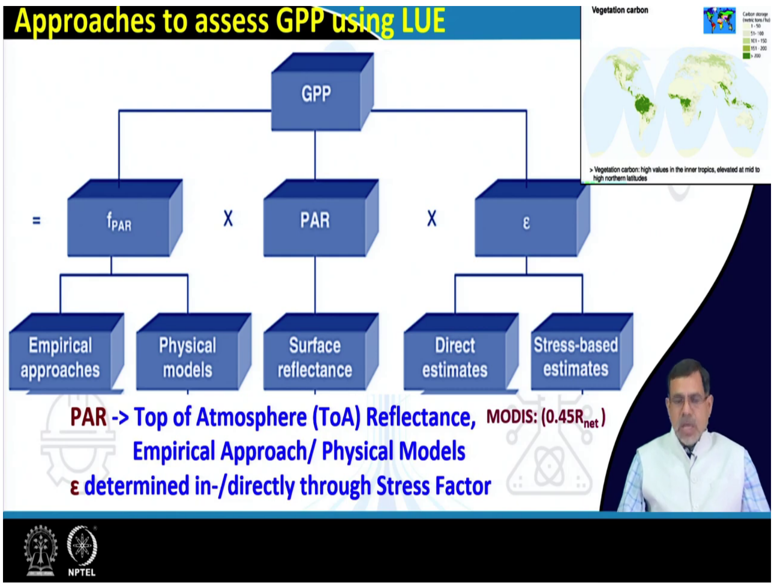

So, with respect to a kind of how people have been using, so, different approaches have been seen to assess the GPP using the light use efficiency model. So, as we know GPP is estimated like with as a factor function of PAR multiplied by means fPAR multiplied by PAR and epsilon.

So, this fPAR can be derived which is based on the empirical approach some people derive it with respect to physical models. PAR which is actually the top of atmosphere reflectance is mostly coming from the surface reflectance value and for MODIS we take a kind of 45 percent of the net what you say radiation falling and epsilon is also estimated directly or using some stressed stress based estimation.

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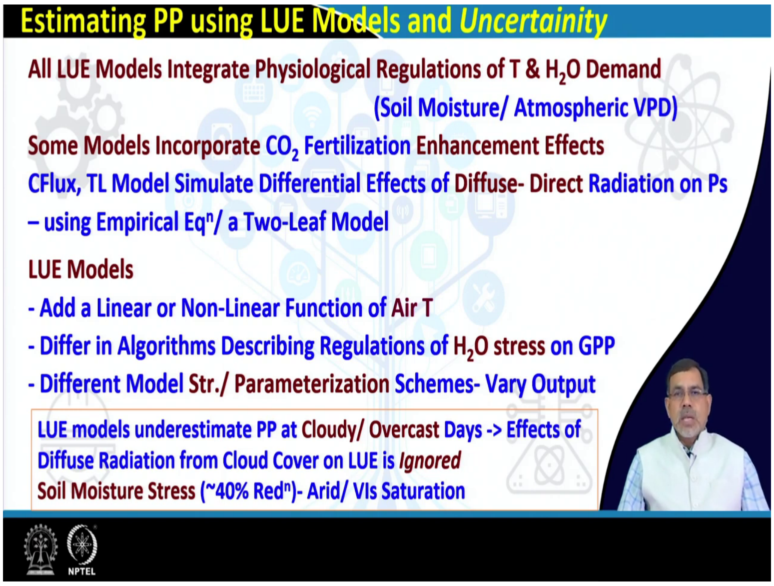

So, estimating primary production and the uncertainties; so, let us come that all the light use efficiency models. They integrate physiological regulation, such as the temperature, water demand and some models incorporate also the carbon dioxide fertilization enhancement effects.

So, almost all or most of the LUE models they incorporate temperature and the water scalar, earths stress. Many models have now started incorporating the enhancement effect of carbon dioxide fertilization. Friends as we know with respect to the to the increased concentration of carbon dioxide like let us say past half century and this now the carbon dioxide concentration has increased from let us say 360-365 ppm to 400-410 now.

So, this higher concentration of carbon dioxide in the atmosphere could be giving a fertilization effect that could be leading in terms of enhancement or increment in the primary production. So, many LUE models have tried to see the CO2 fertilization effect, enhancement effect in primary production. So, another few models like CFlux carbon flux and TL models they try to see the differential effect of diffuse and direct radiation on the photosynthesis using empirical equations or a two leaf model equation.

So, LUE models they add a linear or non-linear function of air temperature differ in algorithms describing regulations of water stress on GPP and different model structures parameterization schemes all these vary the output or results.

So, in terms of evolution of the LUE model the resources they try with a different algorithms describing or regulating the water stress temperature scalar factors different kind of model structure different parameters and scheme to come out with better estimates and better estimates of the primary production.

So, some are one or two very important limitations of this as they are mostly using the optical based remote sensing data, this VIs and VIs and all. So, LUE models underestimate the primary production at cloudy or overcast days and also the soil moisture stress. So, particularly with respect to arid semiarid region and means reduction in the primary production because of the soil moisture stress have been estimated up to 40 per cent.

So, we have to very careful in terms of incorporating this water scalar, temperature scalar and many others like soil moisture, cloud overcast days into the model algorithm and of course, the vegetation indices saturation impact has to be kept in mind.

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So, these are the references.

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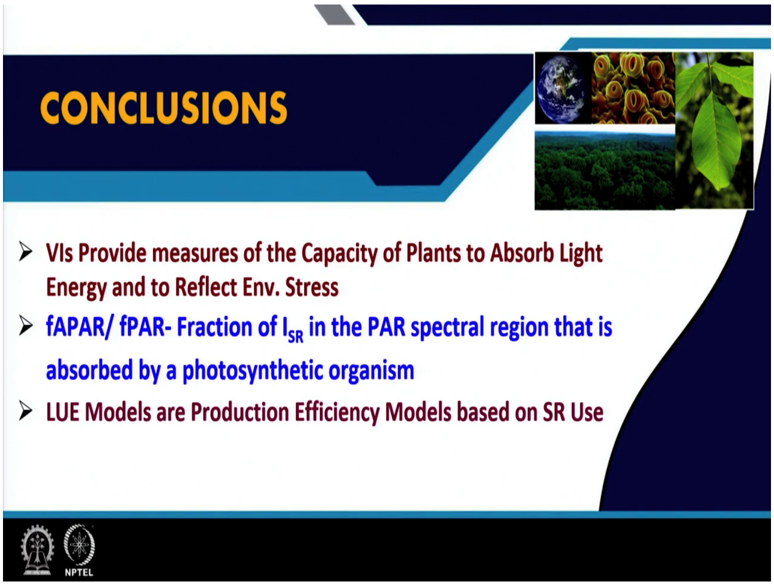

So, and what we conclude are the same three things as I mentioned in the key points. Vegetation indices provide measures of the capacity of plants to absorb light energy and to reflect environmental stress. The fraction of photosynthetically active radiation which is actually the fraction of incidence solar radiation in the PAR spectral range that is absorbed by the photosynthetic organisms, and LUE models are primarily production efficiency models.

So, here in the lecture number 12, we discussed about the vegetation index based or remote sensing based indices or vegetation indices how they are useful in estimating the primary production. And second the PAR or the light use efficiency model (Refer Time: 33:56) which is actually a production efficiency model and based on optimization principle.

Thank you very much.