Remote Sensing of Leaf Area Index and Primary Productivity
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Lecture – 17
RS of Primary Productivity - Uncertainties and Challenges – LUE

Welcome back. So, on today's discussion with respect to lecture number 17, we are going to talk on the Remote Sensing and Primary Productivity. And we will discuss we will focus our discussion on the Uncertainties and the Challenges particularly with respect to the Light Use Efficiency Principle.

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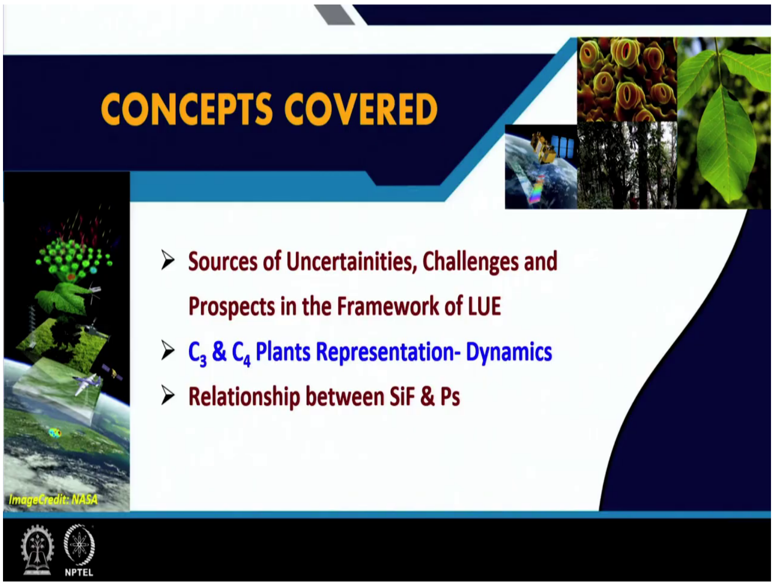

So, the concepts we will cover are the sources of uncertainties in terms of the challenges and the prospects in the framework of light use efficiency. The C 3, C 4 plant representation, I hope all of you understand what is the C 3 and C 4 plants and their differentiation with respect to or the specialization with respect to the photosynthesis activities.

And with respect to this C 3, C 4 representation, we will see how their dynamism have been taken into the primary productivity consideration or photosynthesis consideration. The third is we will discuss about relationship between the solar induced fluorescence and the photosynthesis.

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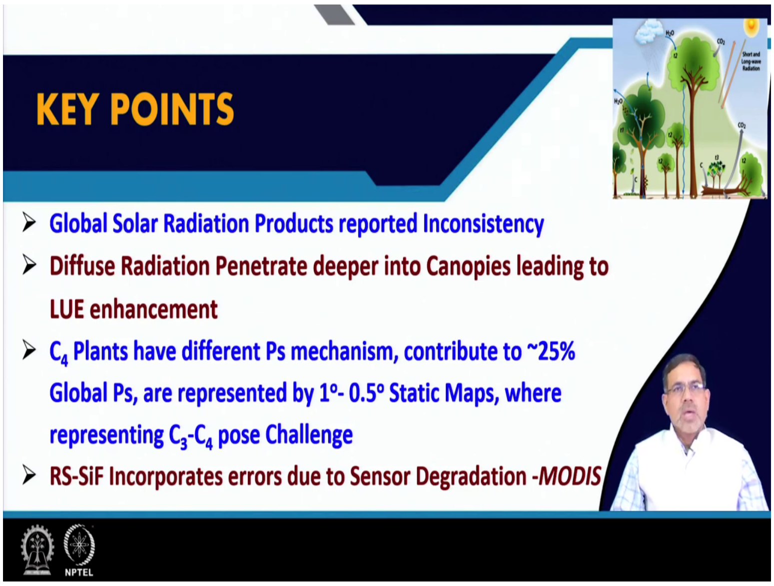

The key points what we will be covering are Global Solar Radiation products those have reported lot of inconsistency. We can understand it is bound to happen. So, we will see what are the different inconsistencies in terms of the solar radiation products that are global products and why they are. And what are the challenges so we face, and how some of them can be addressed that also we will be discussing.

The second; diffuse radiation penetrate deeper into canopies leading to light use efficiency enhancement. So, many times what happens this diffuse radiation we ignore or we do not consider it in our what you say LUE based primary production estimate. So, we will see that how their contribution is counted or missed in terms of its accounting.

The third in terms of C 3 and C 4 group of plants we will discuss have different photosynthesis mechanism, and how they contribute we know this C 4 group of plants they contribute about 25 percent of the global photosynthesis, and the rest 75 percent are contributed dominantly by C 3, CAM and other group of plants in terms of the photosynthetic activities.

And this C 4 group of plants, they are represented by static maps not dynamic maps, so that is a kind of inconsistency or we can say that it is improper because it is it will not address the issues properly. So, we need to introduce the dynamism with respect to the C 3 and C 4 plants representation in the maps.

Then this remote sensing derived solar induced fluorescence they incorporate errors. And we will see with respect to the example of MODIS the Tera and Aqua. So, how the degradation in the sensor has affected or have incorporated errors into this SIF Solar Induced Fluorescence products.

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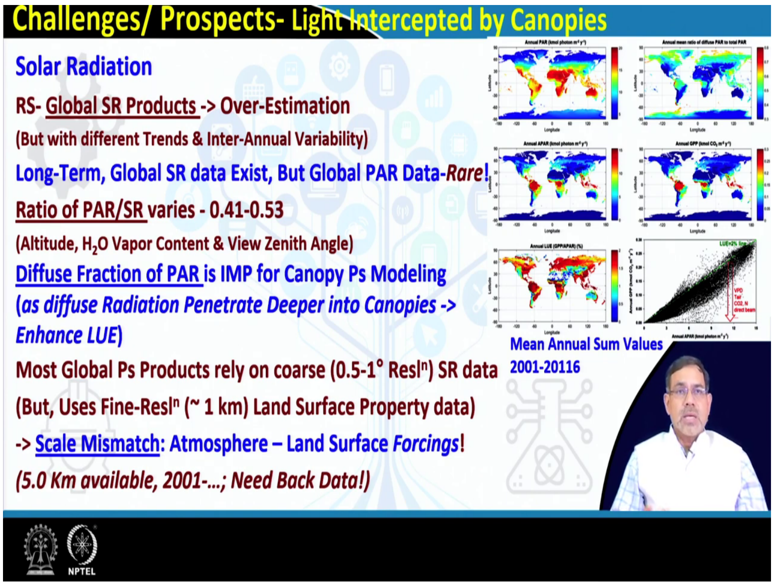

So, let us go one by one. We are here to discuss in detail today. The first one is solar radiation. And as we can realize that the remote sensing based solar radiation products are global, or I take it otherwise the Global Solar Radiation products have shown overestimation.

Overestimation because they are susceptible to different factors and this overestimation has been seen particularly with respect to inter annual variation or there are lot of internal variation in terms of the overestimation. And different trends also we have means have been seen with respect to the overestimation. So, this has to be kept in mind.

Second the long term global solar radiation data are existing, but in comparison to the PAR data – Photosynthetically Active Radiation data in terms of global data sets are very rarely exist; that means, we have very less amount of data in terms of the Global PAR as in contrast to the global solar radiation. So, the ratio of the photosynthetically active radiation in relation to the solar radiation, it varies; in general or in between 0.41 to 0.53.

And as you recall in our LUE discussion in week-2 or 3, we with respect to MODIS, we did remember that the MODIS takes 0.45 as a default value in terms of the PAR. So, 0.45 that means, almost 45 percent of the solar radiation it considers as the photosynthetically active radiation.

So, that is with respect to MODIS, but it varies between 0.41 to 0.53 as a property or because of the different altitudes, different water vapor content, or at different view zenith angle. So, the variation of the range goes between 0.41 to 0.53. And many of these data products or many of these models when calculating either the peaks are standardized some among this range.

Then with respect to the diffuse fraction of photosynthetically active radiation, this is very very important because of the canopy photosynthesis model. So, as we know the diffuse radiation penetrate deeper into canopies it leads to enhanced light use efficiency or light use efficiency gets enhanced.

So, diffuse fraction of PAR is very important. And in many of these models or calculations or data products, we perhaps do not appropriately consider this. So, diffuse fraction of PAR is very important, and needs to be appropriately incorporated in the PAR data or the data product.

So, most global photosynthesis products rely on coarse resolution data. So, coarse resolution you can see earlier we have been receiving at 1 degree, now we have started getting at 0.5 degree. So, with respect to let us say the solar radiation. So, the solar radiation that are available up to 0.5 degree resolution. But when we integrate with other models, so we integrate with many other data let us say the land surface property data that is at a very high resolution at 1 kilometre we have or less than that.

So, there comes the scale mismatch. You have a solar radiation data which is at half degree grid resolution, whereas you have the land surface property data at 1 kilometre resolution. So, it is means what you say mismatch with in terms of the scale the spatial resolution. So, this actually leads to a kind of the forcing between land surface and atmosphere, these forcings are not appropriately matched. So, we that is one of the challenges, and also in terms of prospect we need to bring out or we need to improve the resolution as per the solar radiation data is concerned.

So, now up to half kilometre, what you say resolution data have started coming up, but it dates back up to 2001, but we need to go back perhaps 1980s because we have the corroborated data coming from the AVHRR. So, more back data if we have. So, you have continuous 40 years or 3, 4 decade data for good what you say PAR and good solar radiation and good PP estimation of the photosynthesis study.

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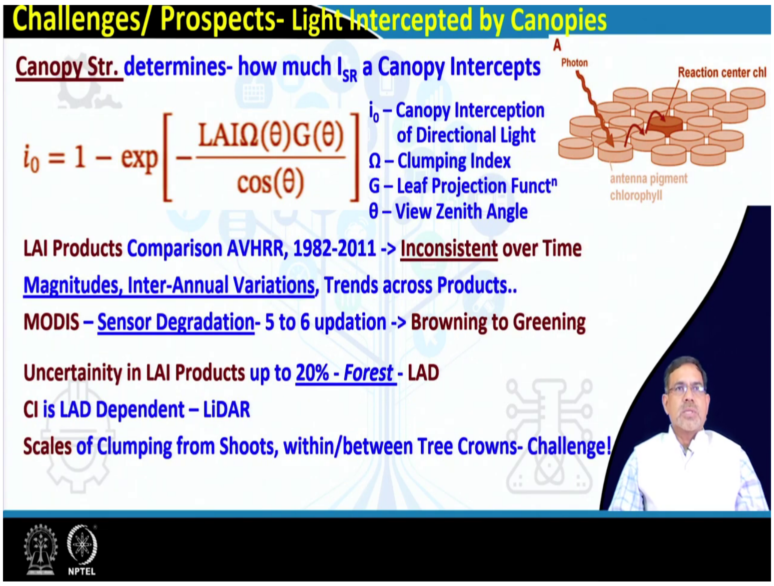

So, next is about the canopy structure. The canopy structure determines how much of the incident solar radiation a canopy intercepts. Friends, we have discussed in our previous class with respect to the antenna pigment chlorophyll, the photon, and all these things.

So, with respect to this the canopy interception of directional light which is represented in terms of i o is expressed in this with this formulae, where omega – the clumping index, G – the leaf projection function, theta – the view zenith angle. So, LAI products comparison particularly with respect to AVHRR based that dates back from 1982 to 2021. So, a comparison study of AVHRR, LAI products for the period of 1982 to 2011 has revealed very inconsistency over time.

So, this inconsistency are in terms of the magnitude, in terms of inter annual variation, and the different varieties of trends across varieties of products. So, as we also this means initiated our discussion in the key points. So, MODIS in terms of sensor degradation, the terra and aqua sensor have started suffering some degradation.

It is bound to happen because sensor after they are what you say after they are placed in the space, they start they are prone to many variables many factors. So, gradually they start malfunctioning. So, we call them sensor degradation. So, in MODIS product 5 as far as the canopy structure representation, it was shown browning. So, that was actually because of the sensor degradation.

The signal coming from the MODIS was affected because of the sensor degradation. So, in product 6, it has been updated. So, browning has been changed to greening. I know I hope you understand what is browning, what is greening. So, green, the green leaf are signals reflectance coming from the chlorophyll.

Browning is a kind of in the non-chlorophyll stage, that means, the non-green representation and the reflectance which is coming from the non-green plants including the branches, the foliage which is down below in terms of a litre or the bowl. So, that is since it looks like brown we call it brown wave. So, that is also called as browning.

So, in terms of uncertainty in the LAI products, we, I mean scientists have also reported it could go up to 20 percent. And this 20 percent, up to 20 percent are mostly for the dense forest areas where you have complex LAD; the Leaf Angle Distribution. And as we know in our week-1 discussion, the clumping index is LAD dependent. Because the arrangement of leaf in different angles we call phyllotaxy.

So, the clumping is dependent on the arrangement of the leaves in different angles. So, though it is taken care of to some extent lidar data is helpful, but that contributes to lot of uncertainty in the LAI product which can go up to 20 percent for forest areas.

So, scales of clumping from suits within and between tree crowns and all these things are a challenge. So, we have also discussed about this in our LAI class in terms of clumping. So, these challenges are being addressed and more and more of these are being scaled down.

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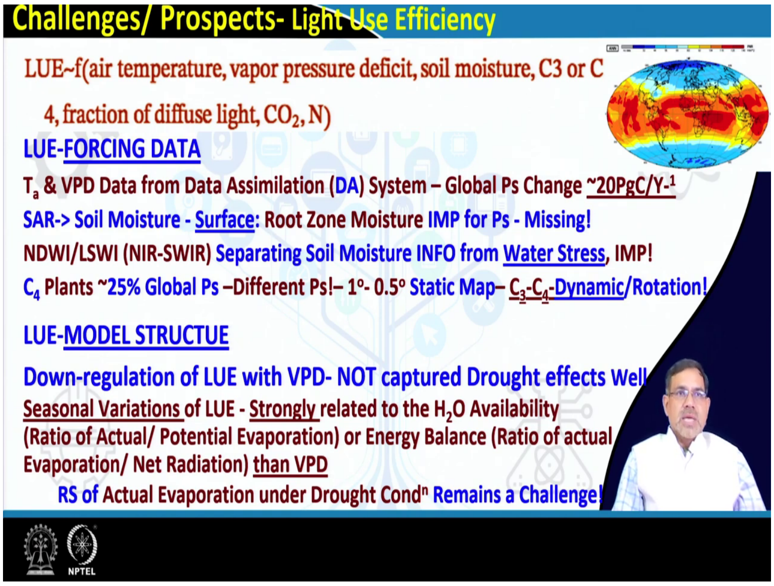

So, the next is with respect to LUE – Light Use Efficiency. So, as all of us know light use efficiency is a function of the air temperature, VPD – Vapour Pressure Deficit, soil moisture, and C 3 or C 4 means I purposefully introduced the C 3 and C 4 though we have not discussed this thing in detail in our previous class, but this is with respect to the challenges and prospects in terms of failure based estimation, I wanted to introduce it.

So, let us discuss and know what the C 3 and C 4 if we do not know it previously. So, and function of fraction of diffuse light, carbon dioxide, and nitrogen. So, LUE with respect to the forcing data, so in terms of the air temperature and the vapor pressure deficit whatever data we use in the model, so these come actually from different data assimilation systems or DA ok.

So, different data assimilation systems provides the temperature or air temperature and the vapor pressure deficit ok. So, what you say uncertainty or the uncertainty with respect to these data assimilation towards global photosynthesis change can go up to the tune of 20 petagrams of carbon per year. So, data assimilation alone can contribute or can give a kind of change or variation with respect to the tune of 20 petagrams of carbon per year.

Look at it. let us move to the next point is with respect to the soil moisture. Friends, as it is one of the important variables as far as the LUE estimation is concerned; the light use efficiency based models. So the SAR data as we know the microwave and synthetic aperture radar data.

They provide very good or reliable information on the soil moisture, but as we know this soil moisture or the signal or the emission that the back scatter whatever we are receiving and with respect to soil moisture using SAR or the microwave data are coming from the surface.

So, we miss the root zone moisture which is very important and important for the photosynthesis, so that is a miss in terms of the soil moisture. So, it is actually printing the surface soil and surface soil moisture and not the root zone moisture. And as we know for forest and other deep root trees the root zone moisture is very important as far as photosynthesis or the primary productivity is concerned.

And coming to a kind of separation of the soil moisture information from water stress. Friends, we have lot of models. So, based on the NIR and SWIR information, like NDWI – Normalized Difference Water Index, this land surface water index, and so these models they were good, but we need the separation of the soil moisture information from water stress.

So, probably the new set of data like Ecostress which we discussed in one of the classes from ISS platform can be a good source of data to separate the soil moisture information from water stress. Then coming to this C 3 and C 4. Friends, the C 3 and C 4 as the number is 3 and 4, this in terms of the photosynthesis pathway.

The C 3 for the C 3 group of plants a 3 carbon containing compound is the intermediate stable product; for the C 4 group of plants a 4 carbon containing compound is the intermediate stable product.

More generally the C 3 group of plants are actually the big and tall trees, But the C 4 group of plants, plants mostly their agriculture plants are the what you say the cereals, the grasses. So, this C 4 group of plants they contribute up to 25 percent of the global photosynthesis, and they have a different photosynthetic mechanism ok.

So, as far as the data availability is concerned with respect to the C 4 group of plants, we have data availability with respect to 1 degree or half degree, but they are a static data, what is the difference or the opposite of static is the dynamic. So, what is that? So, friends what we want to tell that yes in terms of the vegetation, the grass the you imagine a seven area where you have a mix of tree and the grasses down below.

You have a composition where you have grasses which is taken over by C 3 group of plants in a annual scale or in also to some extent in a seasonal scale. So, C 3, C 4 that is this dynamism or the rotation needs to be needs to be integrated in inter annual or seasonal scale.

So, static map availability with respect to C 4 plants are means do suffer or do provide lot of uncertainty to these. So, these are the challenges and prospects for us to come up with a dynamic representation of C 3, C 4 maps with respect to time.

Then coming to model structure, so the down regulation of LUE with vapor pressure deficit is not captured by drought effects well. So, seasonal variations of this LUE strong related to water availability. So, what is that the ratio of actual evaporation to potential evaporation or the energy balance than the vapour pressure deficit?

So, seasonal variation of LUE is strong related to water availability than the vapor pressure deficit. So, remote sensing of actual evaporation under drought condition always remains a challenge, and that in turn is the prospect for us to work on and sort out.

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Coming to the cloudy condition and the photosynthetic capacity with respect to light use efficiency. So, 70 percent approximately of the total photosynthesis or primary production comes from the vegetation which are present in tropics or the temperate areas ok.

But unfortunately these tropics and temperate areas or temperate vegetation, they suffer with respect to pervasive clouds, lot of clouds with respect to different depth and what you say deep means deep thick we call it thick clouds. So, it is well-known that diffuse light can penetrate deeper into the canopy. So, leading to enhancement in the photosynthesis in the shaded leaves in turn lead to increase in canopy level LUE.

So, this itself is a big challenge in the sense what happens in terms of the data, what we do? We do the wherever the cloud data are there, we just fill it with non-cloud data. So, then we miss the diffused light component which has an important contribution with respect to the photosynthesis. So, when the cloud data are gap filled using the non-cloudy data that leads to canopy level LUE underestimation.

So, next is with respect to land surface temperature. So, this land surface temperature data are used to constrain the light use efficiency, but they are again not available for cloudy conditions, so that itself is again a challenge because it is not available for cloudy conditions.

So, we have to be very careful when we are dealing with the cloud condition or the pixels which are infested by the cloud.

The photosynthetic capacity, majority of the global ecosystems are nitrogen limited, so that means, they need to quantify both in terms of spatial and temporal patterns of the leaf nitrogen to improve the photosynthesis estimates. The canopy nitrogen contents scale with the NIR reflectance in temperate and boreal forest.

But what happens? Most direct absorption signals related to the protein and the nitrogen content are located in the short wave infrared region. So, that means, there is what you say very poor absorption signal or weak signal because they are masked by much stronger water absorption.

So, this is very, very hard to separate the direct absorption signal with respect to which is which is found or located in the SWIR region which are masked by the stronger water absorption is very hard to retrieve even if using the process based model such as radiative transfer model inversion studies.

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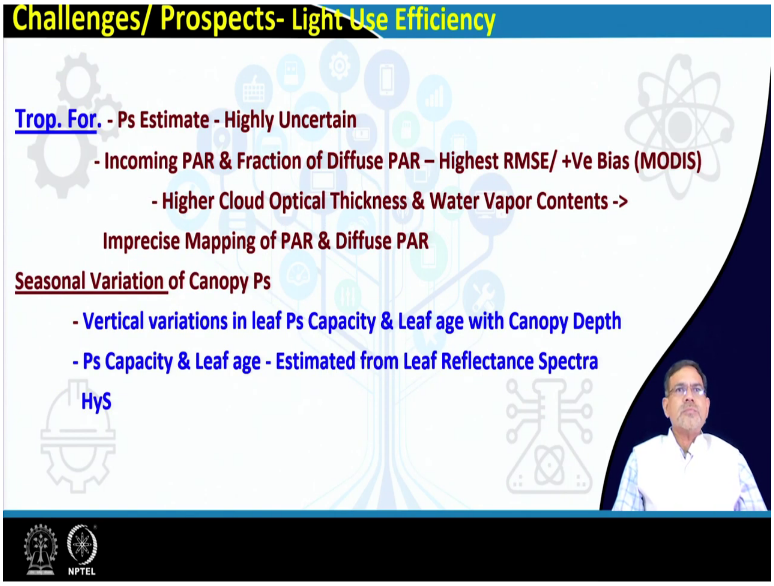

So, the tropical forest with respect to photosynthesis they estimate faster photosynthesis. As far as the tropical forest are concerned they have very high uncertainty because of the incoming PAR and fraction of diffuse PAR, so which also leads to or have been reported to show or have shown highest RMSE also very positive bias so as an example for MODIS data.

So, higher cloud optical thickness and water vapor contents are available or found in the tropical forest or the forest over the tropics, so that leads to imprecise mapping of the PAR and diffuse PAR. So, the PAR and diffuse PAR measurement or mapping becomes very very imprecise. So, that is also a challenge and also a future prospects to be to be addressed or taken care.

Then coming to the seasonal variation of canopy photosynthesis. So, vertical variations in leaf photosynthesis capacity and leaf phase with canopy depth, and photosynthesis capacity and leaf phase estimated from the leaf reflectance spectra. And perhaps for this you the hyperspectral remote sensing is a challenge means is the answer and a future prospect for us to address the seasonal issues.

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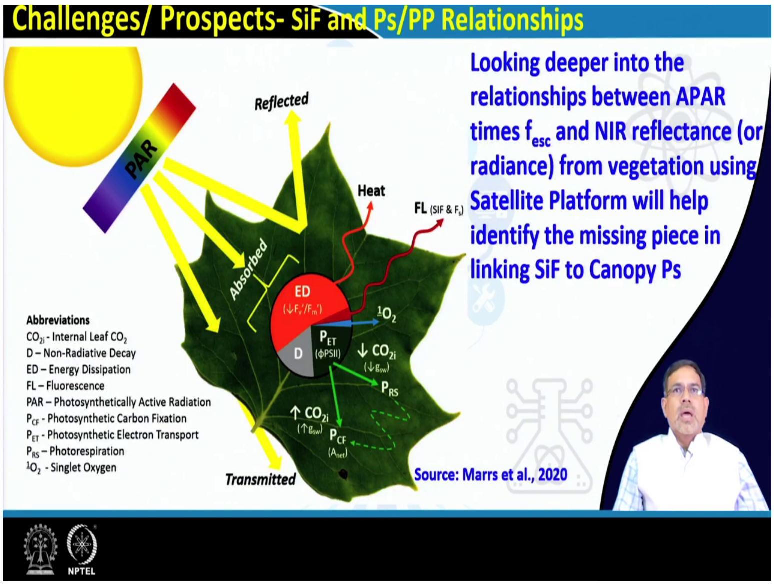

So, next is the third one in our discussion, let us move on to the solar induced fluorescence and the photosynthesis or primary production relationship. Friends, this particular diagram I have reinserted for our discussion or to just get back to our memory.

So, as we know the fluorescence the solar induced fluorescence is in terms of how much it is. So, it is a very less representation or a very little of the emitted energy is coming which we measure in terms of solar induced fluorescence. So, this particular slide just reminds us this.

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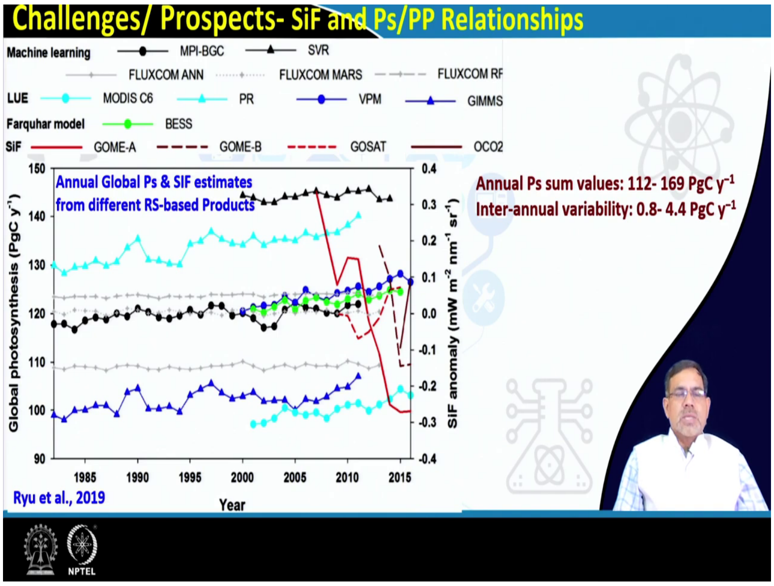

So, what happens in terms of the challenges? Then look at the figure which has been taken from Ryu et al. The global photosynthesis has been placed in x in the y-axis represented in petagrams of carbon per year; and in x-axis, the year between 1981 to 2015 or 16. Then what we are seeing this is the representation of the globe annual global photosynthesis and the solar induced fluorescence estimates from different remote sensing products.

So, as we can see in terms of the relationship between global photosynthesis are the primary production and the solar induced anomaly, there is lot of variation. Then, it is represented in terms of annual photosynthesis some values which varies as you can see here between 112 or 112 to 169 petagrams of carbon per year. And the inter annual variability could is has varied are varied between 0.8 to 4.4 petagrams of carbon per year.

And these are from different models which have been shown and written in terms of in the above. So, OCO 2, GOSAT, GOME 2, and all others can be read and understood. So, the take home message is there is lot of variation in terms of the annual global photosynthesis and the solar induced fluorescence estimates from different remote sensing based data products.

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So, the challenges with respect to this are look the air and space borne instruments do not measure the total emitted solar induced fluorescence, but they only measure the solar induced fluorescence or SIF which is escaping from the canopy you know it. So, which you you can represent in terms of this equation SIF is equal to FPAR into LUE f that represent the LUE of fluorescence for the whole canopy and it escapes so that is the escape ratio.

So, escape ratio is the fraction of escaping solar induced fluorescence related relative or in relation to the total SIF which are emitted by the whole canopy. So, we can see from here if SIF maintains a kind of linear relation between canopy photosynthesis then the relationship will also be linear or must be linear for LUE minus LUE f into f escape. So, this is what we need to we need to keep in mind.

So, lack of appropriate methods to estimate f escape or the escape ratio. So, we have to there is this is the prospect we need to work on, and get more appropriate methods to estimate the escape ratio. Now, coming to the canopy scale, yes, the SIF; Solar Induced Fluorescence so and the means have a good canopy photosynthesis relationship that vary with respect to environmental variables and the vegetation types.

And as at the regional or global scale this remote sensing based SIF also show errors and that is again because of the sensor degradation. So, if you have sensor degradation, then there will be distortion or malfunctioning and that will be reflected with respect to the Sun-Target-Sensor Geometry. So, SIF is the radiance emitted from the vegetation which is essential to keep precise absolute calibration of the solar irradiance.

So, now if we look deeper into the relationship between FPAR and the times escape fluorescence or the escape ratio and the NIR reflectance or radiance from vegetation using the satellite platform. So, it will help identify the missing piece in linking the solar induced fluorescence to canopy photosynthesis.

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So, this is the same publication has been referred with respect to this particular lecture number-17 and coming back to conclusion.

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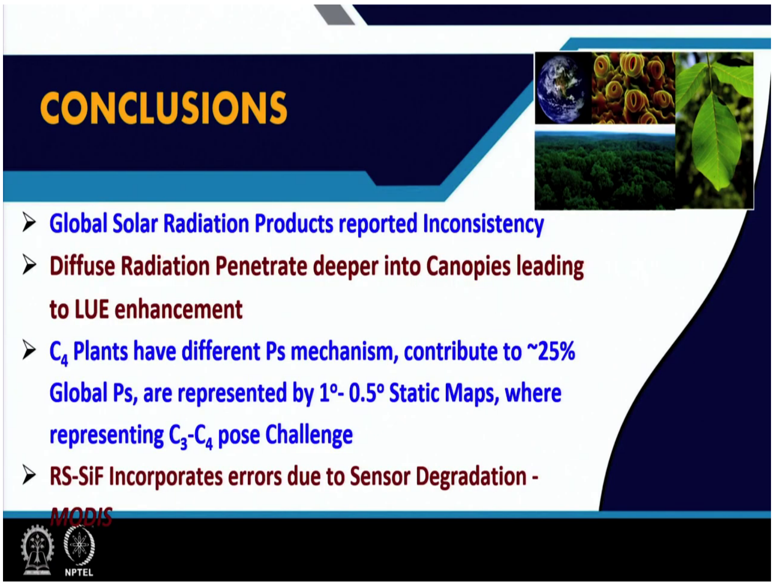

Yes friends, we discuss these four points. So, first; the Global Solar Radiation products have reported inconsistency. Second; the C 4 plants have different photosynthesis mechanism or primary productivity mechanism, and they need to be represented in dynamic maps in terms of their representation. So, static maps at coarse resolution does not solve the purpose.

And then the remote sensing based solar induced fluorescence they incorporate errors as we know because very less signals are what you say emitted or captured as far as SIF is concerned. So, this has to be very sensitive so as far as if there is any degradation in the sensor or sensor malfunctioning then there will be lot of errors will be incorporated in the SIF. So, the example could be MODIS which is already shown or evaluated by many scientists and researchers in past.

So, thank you very much. Now, with this we come to end of the 17th lecture.

Thank you very much.