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 - 11
RS of Primary Productivity - Introduction and Overview

Welcome back to the 11th lecture of this course and the first lecture of week 3. So, let us discuss on the Remote Sensing of Primary Productivity and we will talk about the introduction with respect to the primary productivity vis a vis remote sensing data and the overview is what we will be covering in rest of the week in this and another four lectures.

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So, coming to the concepts covered; we will discuss about the different fluxes of carbon and how they are estimated using the remote sensing data. Broadly we will discuss today. And then the primary productivity with various carbon flux components.

Subsequently, today we will discuss about the primary productivity and carbon and carbon fluxes. So, that these two three terminologies has to be very clear in our mind. And then we will also see how this remote sensing methods are available for primary production and carbon flux studied studies in future

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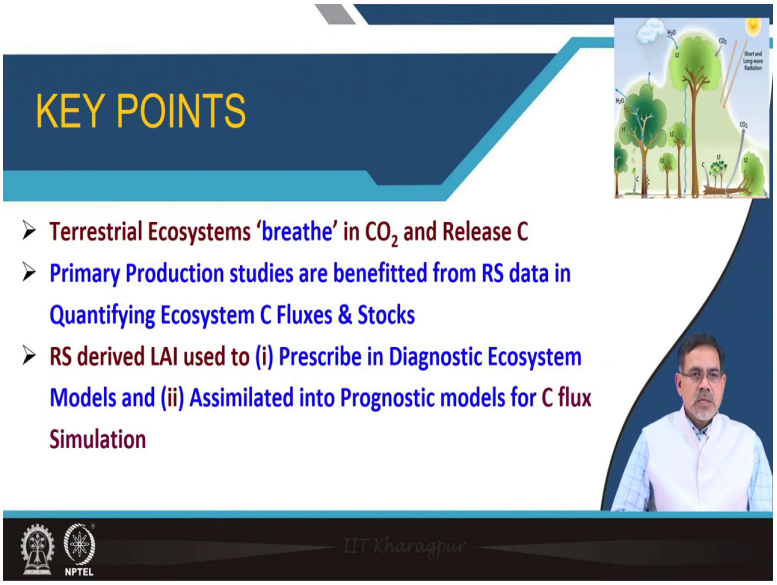

So, the key points to be covered are that all of us know terrestrial ecosystems they breathe using carbon dioxide through the process of photosynthesis and releasing carbon out in the process of respiration. So, we know it from the very beginning. So, it is very important to understand that in terms of carbon fluxes and more specifically with respect to the primary productivity through the plants and the vegetation material.

Then the second point is, primary production studies are benefited from remote sensing data in quantifying ecosystem carbon fluxes and the stock. So, this is what we will be discussing all through the week. And also with respect to the linkage between LAI which is derived as we have discussed over last two weeks, the LAI which is derived using satellite data.

They can be used in prescribing all these prescribed in the diagnostic ecosystem models and also in the assimilation process or get assimilated in the prognostic models for carbon simulation. So, LAI utility also we will be discussing subsequently which is again a RS derived product as we know. And how they play a particular role and what is the role they play in terms of the primary productivity are more generally carbon flux assessment.

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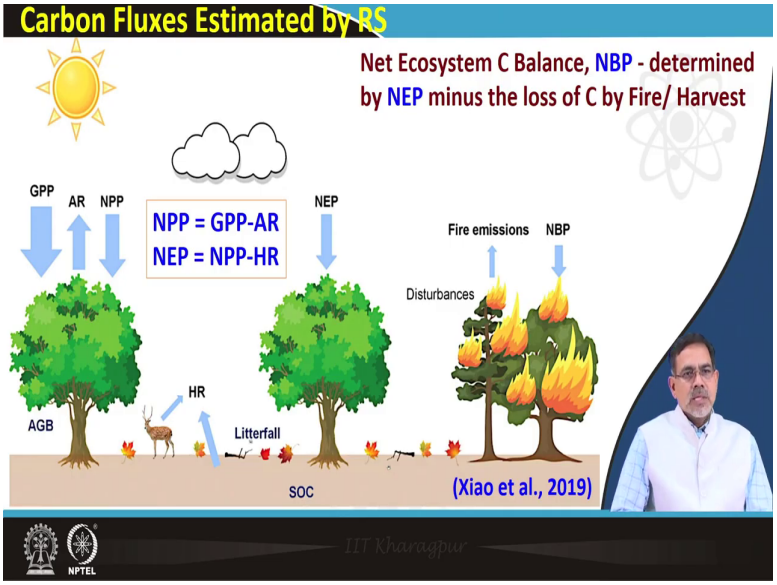

Let us get back to this particular figure. We all understand this I have picked it from the Xiao et al, paper. It is a very good diagram with the conceptual what you say terminologies. So, what it depicts? It depicts the carbon fluxes estimated by the satellite data or the remote sensing data.

So, in turn there are several terminologies have or I mean so, we can recall. So, one is GPP, the other one is an AR and NPP. Friends this PP starts stands for primary production and if we are estimating it across time, so, we call it primary productivity in terms of monthly in terms of annual or decadal.

But in general it is the gross primary production, net primary production which takes the abbreviation as GPP and NPP. And in between we have the AR which is the assimilated respiration, as we understand that some amount of carbon or nearly 50 percent of the carbon what is fixed by the plants at the vegetation material which we call in in totality as GPP; gross primary production.

Out of that nearly 45 to 50 percent gets consumed or assimilated in the process of respiration that we call as assimilated respiration and which is abbreviated as AR. So, AR plus NPP, N stands for net. So, AR plus NPP gives us the GPP that is the gross or GPP minus ARR assimilated respiration gives us the NPP that is net.

So, coming to other two terminologies in terms of HR, which is the respiration by other animals what you say heterotrophic organisms. As we very well known the primary and secondary producers; the primary producers and others have the consumers.

So, this the other biota including the animals and other things I mean in terms of their respiration which we call it as heterotrophic respiration abbreviated as HR. They also release lot of carbon in terms of the respiration they used to do. So, that is abbreviated as HR.

So, NEP which is known as net ecosystem production is equal to net primary production minus HR, if we are considering with respect to an ecosystem where we have both primary producers and other consumers. So, again NEP is equal to NPP minus HR.

And apart from that these days we are experiencing and we are concerned with a lot of disturbances including forest fires and other issues like differences and things like that. So, if we deduct them then perhaps we are getting the net carbon or we call it that net ecosystem carbon balance which is abbreviated as NBP; that is determined by the net ecosystem productivity minus the loss of carbon by other activities are like harvesting or fire or things like that.

So, these are the basic terminologies we should call back. So, I will again summarise a GPP is equal to NPP plus AR and NEP is equal to NPP minus HR and NBP is equal to NEP minus the carbon loss with respect to fire and harvest. So, in total if we consider the primary production of an ecosystem we perhaps consider, we perhaps need to understand all these terminologies per se.

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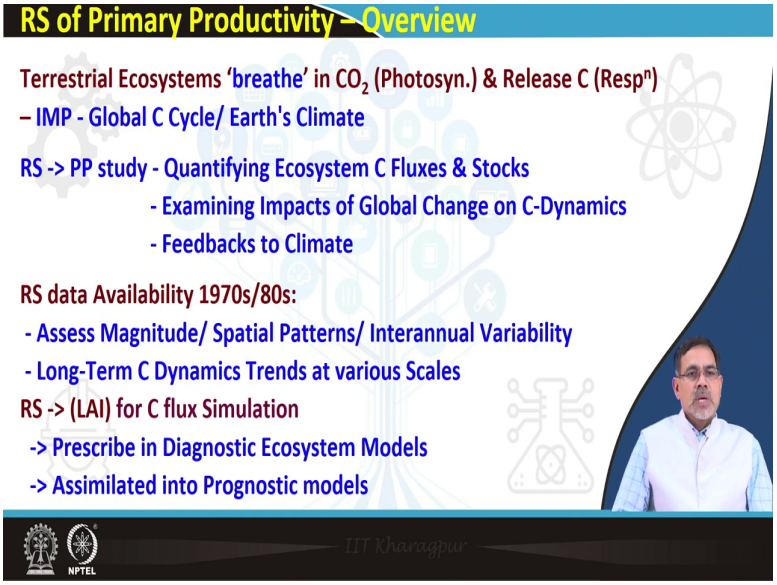

And let us see with respect to the remote sensing data utility as far as primary productivity is concerned what are the major understanding in the domain. The terrestrial carbons as we know within carbon dioxide breathe in carbon dioxide here through we call it photosynthesis and release out the carbon that is the respiration.

And importantly through this primary productivity it is very important in terms of understanding, because it provides inputs or feedback as far as the understanding of global carbon cycle is concerned and also tune to the earth's climate system.

So, remote sensing benefits the primary productivity study or intern the primary productivity study gets benefit from the satellite remote sensing. As we have already been discussing in our first classes, because of obvious reasons with respect to spread, magnitude, spatial patterns, inter-annual variables and things like that.

So, the primary productivity study using satellite data. What it does? It quantifies ecosystem carbon fluxes and the stock. So, flux which is in constant or dynamic kind of entity and the stock which is a kind of storage. So, it quantifies. So, in terms of primary productivity study using satellite data, it helps us in estimating the quantification as far as the ecosystem level carbon flux and the carbon stock or storage are concerned.

Then it provides or it facilitates examination of the impact of global change on carbon dioxide vis a vis its feedback to climate or climate change in general, because all of us are living in a climate change world where lot of things are happening around us in every moment.

And coming to next, see as we have already been discussing the satellite or remote sensing satellite, data is available since 1970s. 1972 the first satellite earlier known as ERTS and now renamed as Landsat 1. So, that is available since 23rd July 1972. So, that means, the data we are surrounded by data with us since last nearly 50 years or half century as far as data is concerned.

So that means, we have access to the spatial pattern, the magnitude and we can also come out with inferential variability studies as far as inter annual inter seasonal patterns are concerned. So, long term carbon dynamics trends at various scales as far as 50 years or half century we have the data. And that is why the utility of remote sensing for primary productivity is very important which can give us very precise; what you say pattern trend as far as the half century is concerned.

Coming to the cognition with respect to LAI which is derived from satellite remote sensing, this helps us in carbon flux simulation as we also highlighted in our key points in terms of diagnostic and prognostic models.

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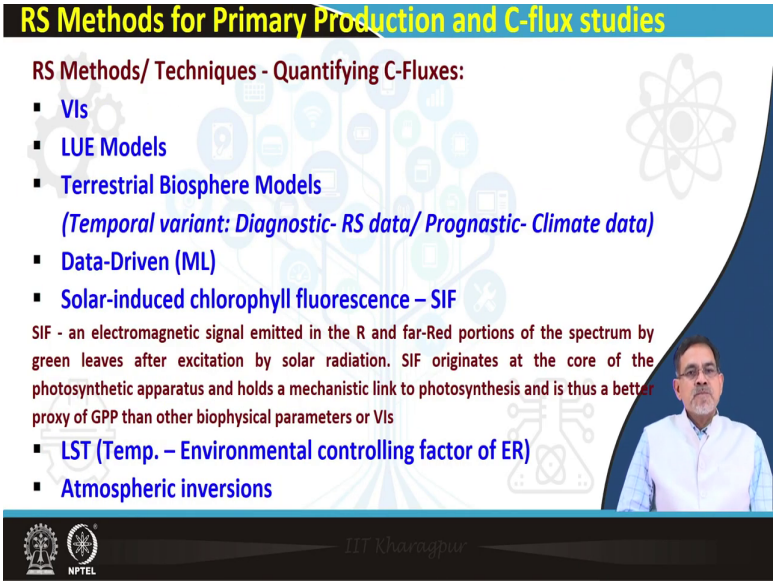

Coming to the different methods and techniques in terms of quantifying the carbon fluxes. These methods we are going to cover in detail in our discussion over next four lectures. So, as we discussed in terms of LAI, the vegetation indices based studies or vegetation indices based empirical function studies are very prominent as far as the optical even if the microwave or LiDAR based satellite data is concerned with respect to the carbon.

And the component of this primary production it can have the biomass in terms of above ground. Biomass abbreviated as AGB very frequently and BGB is the below ground biomass, soil carbon and many other things. So, the vegetation indices starting from NDVI, the EVI, the transform vegetation indices say TVI and many more in the series are in the list.

So, they are linked to the ground based measurement with respect to AGB as we know. 50 percent of AGB or 45 to 50 percent as a thumb rule is the carbon. So, we relate it in that way as far as the empirical equation is concerned. So, that is very important in that sense.

And coming to the LUE models. So, the next lot of methods which are mostly the LUE models are light use efficiency based models. So, these light use efficiency based models they are used in terms in the MODIS based NPP and GPP calculations. So, we will see how this; if we go back to the basic photosynthesis equation, the basic photosynthesis equation utilises light.

So, that is where the term is photosynthesis. So, something is synthesized in presence of light or photo or photon. So, we will see how the light use efficiency or the efficiency of light use has been taken as the clue to calculate or simulate or estimate the primary production and how remote sensing gets input or when you benefit in that regard.

Then let us come to the third one which is mostly the terrestrial biosphere models. So, lot of developments has happened in this. These all dynamic vegetation models we integrate many more mechanistic things physio- ecology physiological things. So, this we are going to discuss in detail in another lecture.

But coming to a very broad way in terms of the diagnostic and prognostic based terrestrial biosphere models. So, in terms of the diagnostic models the remote sensing data goes as the temporal variant whereas, in terms of the prognostic models the climate data goes as the temporal variant. And now with respect to data driven algorithms or methods.

So, these days lot of statistical models including the advanced ones like machine learning, artificial intelligence, neural networks and all these are very important and are clubbed under the data driven models for primary production estimates. So, we will discuss about them in more detail, because these are advancing very fast and giving us different results as we can integrate many more proxies or many more proxies or primary production into the estimator the methodological calculation algorithm.

Now, coming to the fifth one, yes this particular sun induced chlorophyll fluorescence. It is very important and is utilized dominantly. So, sun induced fluorescence and electromagnetic signal emitted in the red and far red portions of the spectrum by green leaves after excitation by the solar radiation. So, SIF that is sun induced chlorophyll fluorescence is defined as an electromagnetic signal which is emitted in the red and far red portions of the spectrum by green leaves.

So, let us remember the red and far red portions of the spectrum by the green leaves after the excitation of the solar radiation. So, that is why the SIF originates at the core of the photosynthetic apparatus. We will see in details with respect to and the; and with respect to a few schematic diagrams how the excitation of this what you say spectrum or why the solar

radiation, and how these things mean; we will get it clarified with respect to a schematic diagram.

So, SIF originates at the core of the photosynthetic operators and holds a mechanistic link therefore, to the photosynthesis. And that is why it is known to be a better proxy of gross primary production assessment than any other biophysical parameters or the vegetation indices per se.

Now, the sixth one people are using is the land surface temperature. So, many of these satellite sensors have the temperature; means they measure the temperature also as one of the entities. So, this gives us the land surface temperature. And the basis is that see temperature acts as a dominant controlling factor as far as the environmental controlling factor is concerned it is very dominant in terms of the ecosystem respiration.

So, picking that as the clue or the proxy the LST can be in utilized, which is derived from satellite data can be utilized for the study of the ecosystem respiration. So, which again gives linked to the NPP and then to GPP. So, LST serves as a very good environmental controlling factor as far as the ecosystem respiration is concerned.

Now, the latest and one in research and mode is research and studies is the atmospheric inversion. Many other things are there into as far as the carbon is concerned in the atmosphere. So, we will also discuss about how the atmospheric inversions are useful in terms of understanding the primary production vis a vis the carbon fluxes.

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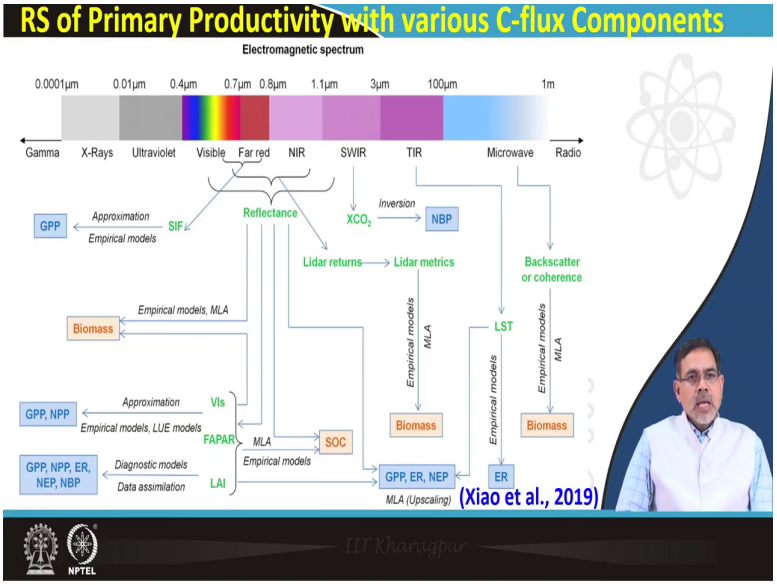

Then let us look at this particular diagram which has been again picked from the Xiao et al, paper 2011 which has been given in the references. So, remote sensing a primary productivity with various carbon flux components as you can see. And the upper part the electromagnetic spectrum in terms of increasing order of wavelength has been shown and the visible range and the far red also has been very prominently marked as far as the; as far as our understanding in terms of the SIF is concerned.

So, with respect to this we can see that there are reflectance whereas, carbon what you say LiDAR returns, there are backscatter coherence and the sun induced fluorescence in terms of the green letters and the carbon dioxide concentration columns in terms of xCO_2. So the, and the LST, all the all of them have been shown very prominently in in the green colour text.

So, they are useful in terms of GPP, NPP, NBP and all these estimates. So, and the various intermediate variables like VIs vegetation indices the fAPAR, the fraction of absorbed photosynthetically active radiation and LAI, how they are used in terms of the diagnostic models data assimilation. And also the empirical functions provision including the LUE, light use efficiency models for GPP and NPP or you say the gross primary or the net primary production estimates.

And also the ecosystem respiration in terms of ER and the biomass also have been mentioned. And the linkage are very clear as far as in which part of the electromagnetic spectrum how the and what variable is used for what kind of primary production or primary production component assessment and studies.

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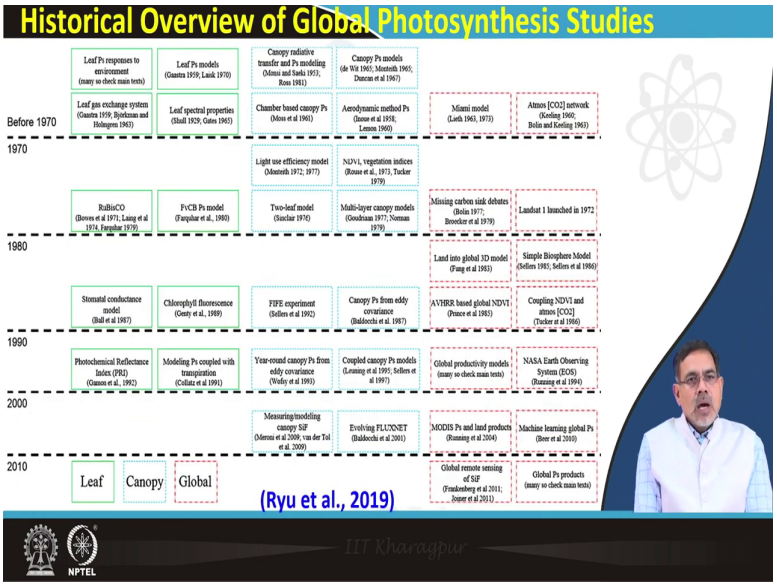

Now, with respect to a historical overview this text are very small here, but you can go and refer the Ryu et al, paper. It is very important publication as far as the photosynthesis studies in terms of historical context and till date is concerned using remote sensing data.

But, we want to take home from here are the historical overview of the global photosynthesis. See before 1970s during 1970s to 80s, 80s to 90s, 90s to 2000 and 2000 to 2010 and 2010 beyond. So, the left hand boxes with green boundary green colour boundary middle one with blue colour boundary. And the right ones with red at a red colour boundaries are with respect to your leaf photosynthesis canopy photosynthesis and a kind of global photosynthesis studies.

And if we see them, then perhaps we will see before 1970s all of them were mostly the measurement based and even if the canopy models were based on that canopy transformation transfer functions. But, as we move on when the satellite data are integrated we moved to

more and more kind of global studies including; I mean using many methodologies what we just discussed overall.

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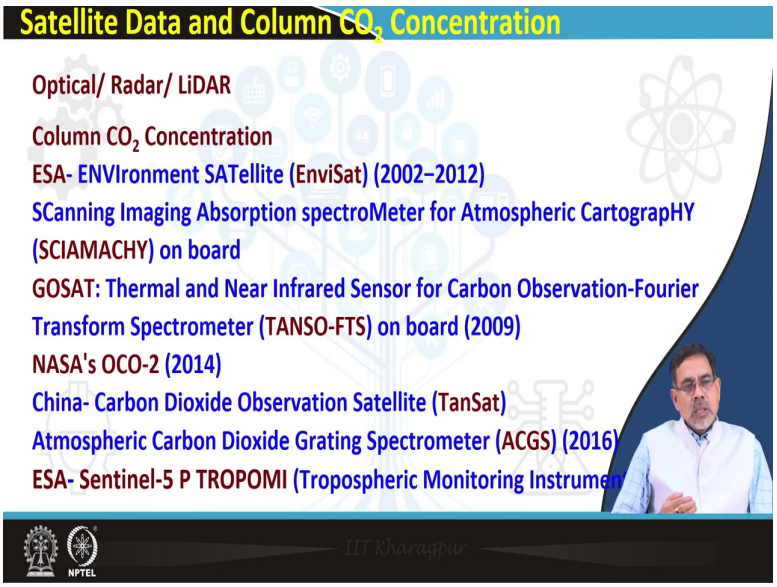

Now, with respect to the data types available with us as we have we now know it for sure that we have optical, LiDAR both in active passive and active domain, hyperspectral, optical domain and the Radar including SAR and then you have InSAR, TomoSAR and many more things are available.

So, and another important set of observation we get with respect to the column carbon dioxide concentration. So, we have about four or I means more than five satellites which have been giving us this information the column CO2 concentration since 2002 onwards like the one first one; one orbit from EnviSat sensor by ESA; European Space Agency here was the SCIAMACHY.

So, SCIAMACHY stands for Scanning Imaging Absorption Spectrometer for Atmospheric Cartography. So, this actually gives has given a lot of information as far as the column carbon dioxide concentration is concerned and it was an orbit for about 10 years between 2002 and 2012.

Coming to GOSAT, the GOSAT was particularly by the Japanese and the thermal and near infrared sensor for carbon observation Fourier transform spectrometer TRANSO-FTS on

board. Since 2009 and the NASAs OCO-2 since 2014, China's TanSat carbon dioxide observation satellite and the satellite which has the sensor ACGS since 2016 the atmospheric carbon dioxide grating spectrometer.

And ESA Sentinel-5 P TROPOMI since last two years is giving the TROPOMI data is very good in terms of resolution and accuracy as far as the column CO2 concentration is concerned and have been useful in lot of what you say carbon and carbon flux related studies.

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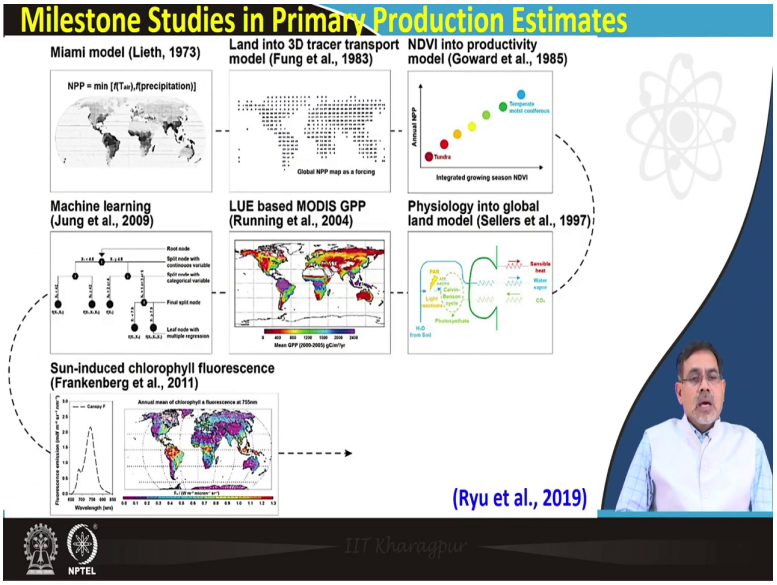

So, with this understanding let us see the milestone studies in terms of primary production estimates with respect to this 6 plus 1, 7 figures. They have been picked from different studies like the Miami model in 1973, where NPP was a where NPP as simulated as a function of the air temperature and the precipitation.

So, then coming to the Fung et al, 1983 where it was kind of means global NPP map as a forcing was used. And then coming to the next one Goward in 1985 where NDVI linked two production means primary production a model was curbed and that was a kind of empirical based on empirical transfer function.

Then coming next is the LUE based, means GPP model and before that also the machine learning models are there mostly statistical so that you can relate many more primary

production proxies to that. So, LUE based MODIS GPP has given first time by the Running et al, from University of Montana.

So, these are the first global products satellite based global products available to the world from the MODIS platform. And this particular product has taken a LUE, the light use efficiency based algorithm which we will be discussing in more detail in lecture a 12.

Then of course, the bias here are the process based models they take a lot of physiology into account. So, physiology into global land transfer given by many models. So, those are interesting because lot of physiological and even if it is there is community based and a lot of other things are getting integrated along with the climate to these kind of biosphere process models.

Then the latest one as we have understood this SIF based models are very important since they give very important information which is actually a giving more clue as far as the mechanistic heavy heavier of the photosynthesis is concerned. So, the SIF based primary production estimate is very important and we will be discussing in one of our lectures later this week.

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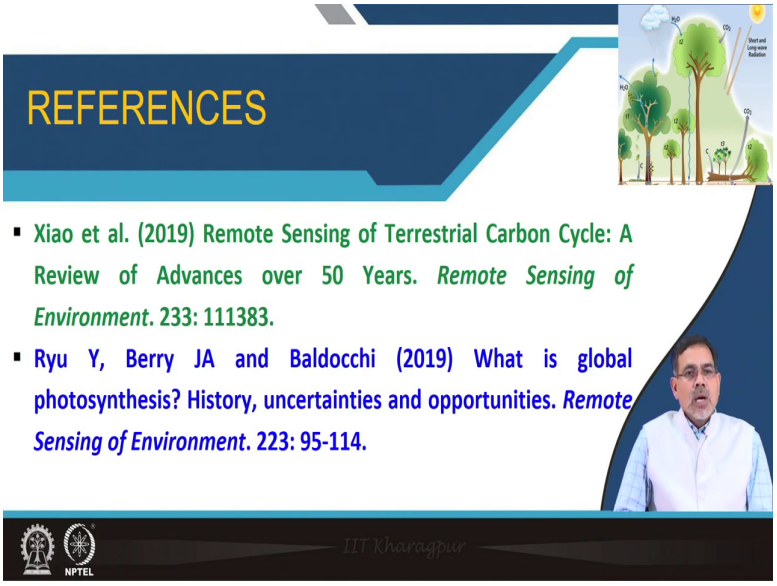

So, with these are the two references very important references has been picked in terms of references, I mean in terms of future reference for all of you. So, please go through this. This should be available for free download from web.

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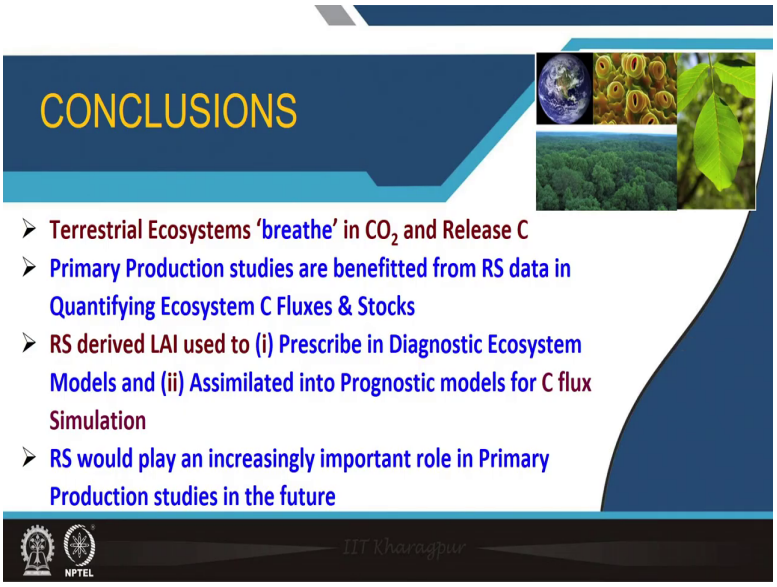

And we conclude with the same key points terrestrial. Ecosystems breathe in carbon dioxide and breathe out or release the carbon in terms of photosynthesis and respiration respectively. And primary production studies are benefited from remote sensing data in quantifying ecosystem carbon fluxes and stocks. Remote sensing derived LAI used to prescribe the diagnostic ecosystem models and assimilated into the prognostic models per carbon flux simulation.

And we are convinced that remote sensing would play an increasingly important role in primary production studies in future and look forward. With this we look forward to discuss more with you in next four classes as far as the different methods of primary production estimation are concerned using satellite data.

Thank you very much and see you soon.