Remote Sensing of Leaf Area Index and Primary Productivity
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Lecture - 13
RS of Primary Productivity - Process Based Models

Yes, welcome back. In the previous lecture number 12 we discussed about the Remote Sensing particularly the vegetation indices as an input to primary production estimation and the model following the radiation use or light use efficiency as a clue to primary production estimation; we discussed in the last lecture number 12.

So, here in the lecture 13, we are going to discuss more on the Process Based Model. So, friends as we understand primary production or primary productivity as we say, so, primary productivity is not that easy, in terms of understanding. So, it depends on many more variables many more factors.

So, understanding it in terms of all the processes is perhaps will give us as close as possible estimate of the primary production of an ecosystem or a vegetation community.

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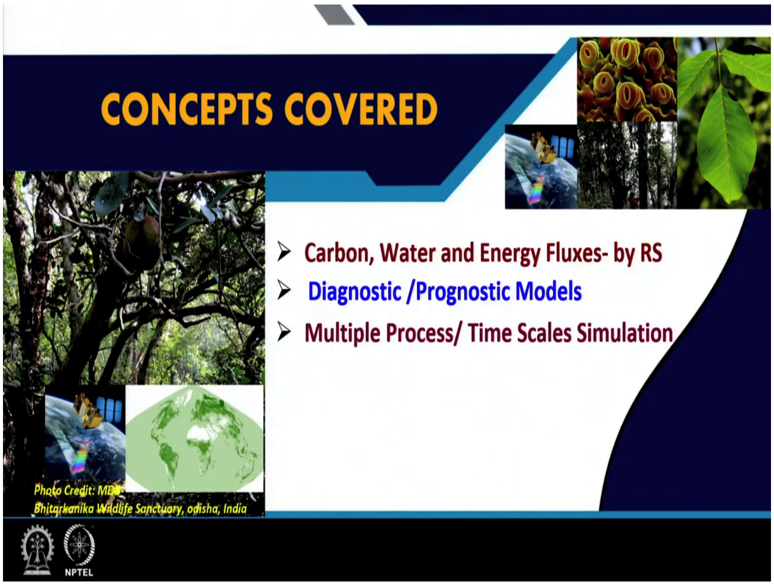

So, photosynthesis which we actually if we come back to the equation CO 2 plus H 2 O in presence of light. It gives us C 6 H 12 and O 6 that is a carbohydrate and H 2 O also one of the byproduct and oxygen also one of the byproduct. So, keeping the photosynthesis equation in mind we can say that many of these variables which are directly linked; are directly or indirectly linked needs to be considered in the model for assessing the primary production.

So, in that sense the photo the process based models, which accommodates many or you say many complexities in terms of relationship between and among many variables that could affect the photosynthesis or primary production is actually the need of the hour. So, that is how the process based production primary production models have been evolving.

So, we will in terms of concept we will touch upon carbon, water and energy fluxes by and how it is benefited in terms of information from remote sensing. And the models particularly if we divide them or put them under two categories like diagnostic and prognostic categories in terms of process based models.

And also we will see how the remote sensing benefits in terms of the model or the process based model that could have multiple processes integrated and multiple at multiple time scales in terms of simulations.

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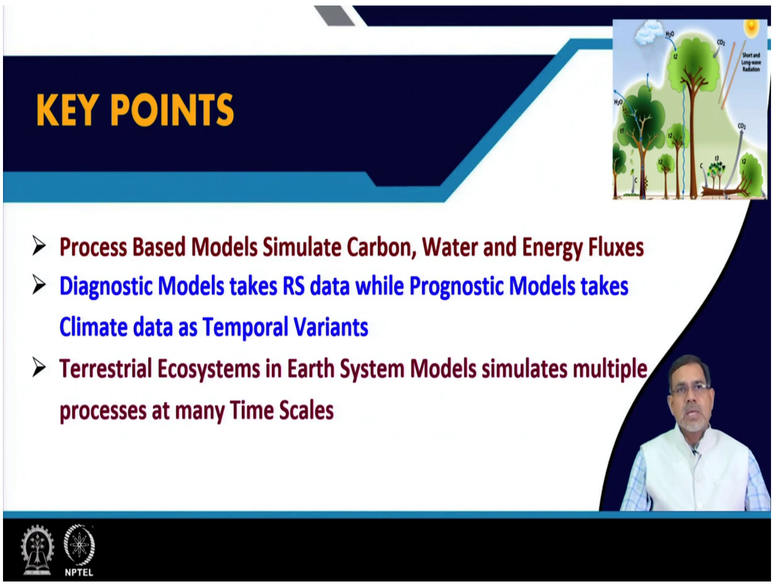

So, the key points: The key points are process based models simulate carbon, water and energy fluxes broadly. The diagnostic models takes remote sensing data while prognostic models takes climate data primarily as the temporal variants. So, the terrestrial ecosystems in earth system models simulate multiple processes at many scales. So, we will also see that these terrestrial ecosystems part of the earth ecosystem model how they simulate the multiple processes at multiple or many time scales.

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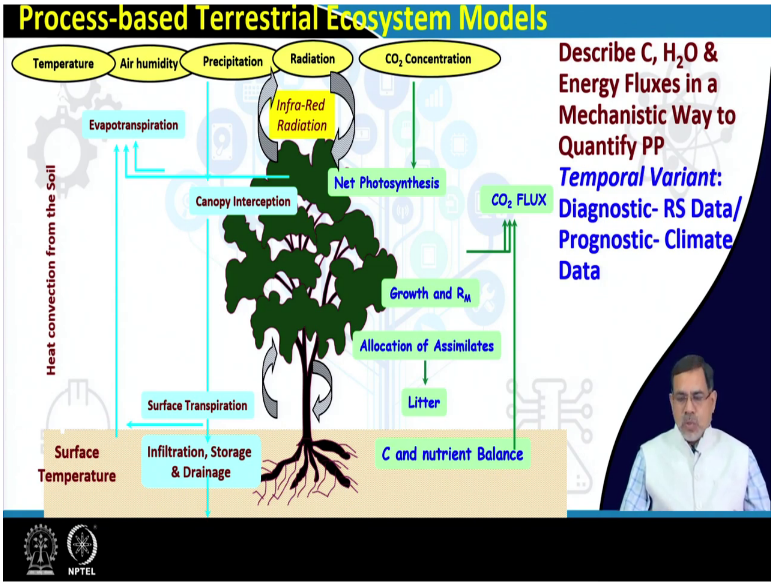

So, it is we need to understand it and with respect to understanding the remote sensing benefits for primary production estimates. Let us come to this particular graphics where a green tree has been shown and the upper row all the variables all the factors which actually affect the primary production in terms of temperature, air humidity precipitation, the solar radiation, the carbon dioxide concentration; all of them are very important or the dominant factors responsible for photosynthesis.

On the left hand side with sand colors and sand arrows, the water component in terms of canopy interception, surface transpiration, infiltration storage and drainage and evapotranspiration has been shown.

On the right hand side the vegetation processes particularly the net photosynthesis, growth and maintenance respiration RM. And once the carbohydrate is synthesized, how the allocation happens, so, that is also modeled in this process based models.

And the litter fall and carbon and the nutrient balance in terms of the soil or in the soil sphere. So, what we understand that these all which are directly regulating the photosynthesis or primary production we must have to bring them into concern into mind and try to derive or frame the algorithm accordingly and parameterize them in the model.

So, this is, this makes the process based models more and more complex as well as comprehensive. So, we can also understand that all of them need data. So, many of these data and how more of them we can get or collect using satellite based systems. So, that is what is the key, in terms of our understanding today.

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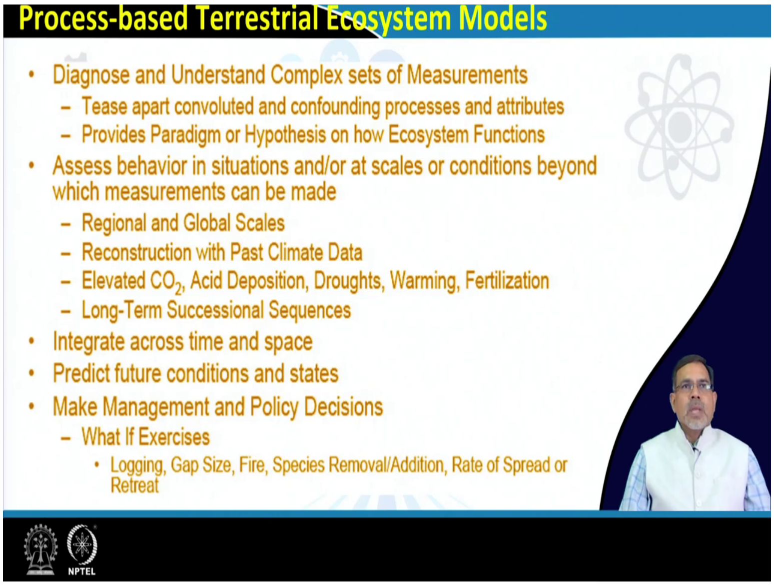

Yes, the process based models, they actually what they do? They diagnose and understand complex sets of measurements there we can tease apart convoluted and confounding processes and their attributes, and provide paradigms or hypothesis on how these system functions.

Also we can assess behavior in situations and or at different scales or conditions beyond which measurement can be made like regional and global scales, reconstruction of past climate data. We cannot make, but we can make the condition, we can simulate this with respect to past climate with a regional or a global scale or with respect to long term successional sequences.

And another important property what we can understand as far as the process based models are concerned the integration. The integration across time and space domain and once it is integrated, once it is integrated in time and space domain and then we have a pattern, then perhaps we can predict for the future. So, then it becomes a predictive model. So, future condition, future states can be predicted.

And, once it is predicted then it will be useful for policy decision for the managers. So, they can analyze if and what scenario, if our CO 2 constantly increase this much then these things are going to happen. So, preventive measures, mitigation measures, management activities will come up.

So, that is actually this, the beauty of the process based models, because you get to teach around many processes many attributes and if and what conditions gives inputs for to power for policy based implications or management implications.

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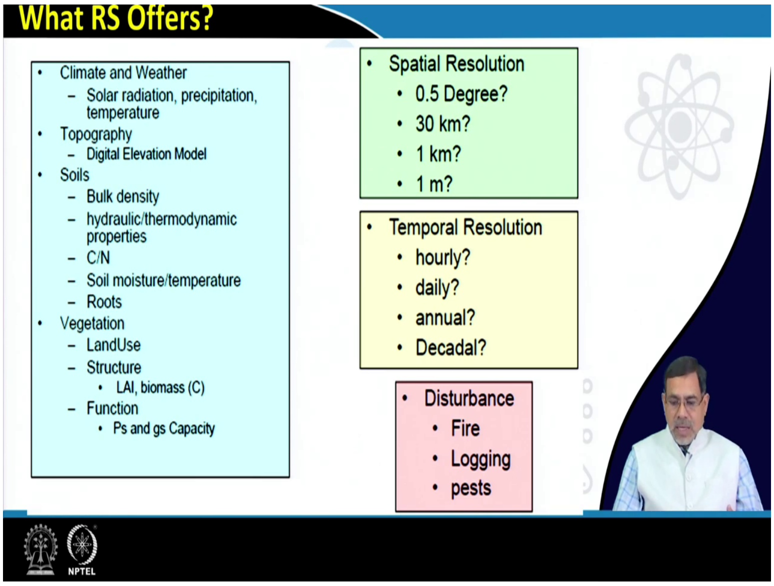

So, what a remote sensing can offer? In such activities like process based models remote sensing as we know have different spatial resolution, different temporal resolution. So, this can be harvested, this property of remote sensing is very important. We get the data or we get the estimation measurement in different spatial resolution starting from sub meter to half degree grids. So, that is very useful in terms of extrapolation and linking.

Then in terms of time yes we have daily annual decadal data. So, what is the need? So, that depends based on the processed based model or the algorithm what we have in that. And in terms of vegetation let us say land use the structure like LAI, biomass function like photosynthesis the stomatal respiration and stomatal conductivity many things we derive from the ground based measurements or field based measurements and then we link it and extrapolate it.

So, remote sensing in that way helps us in extrapolating the ground based observation as far as the primary production is concerned, and also integration and linking.

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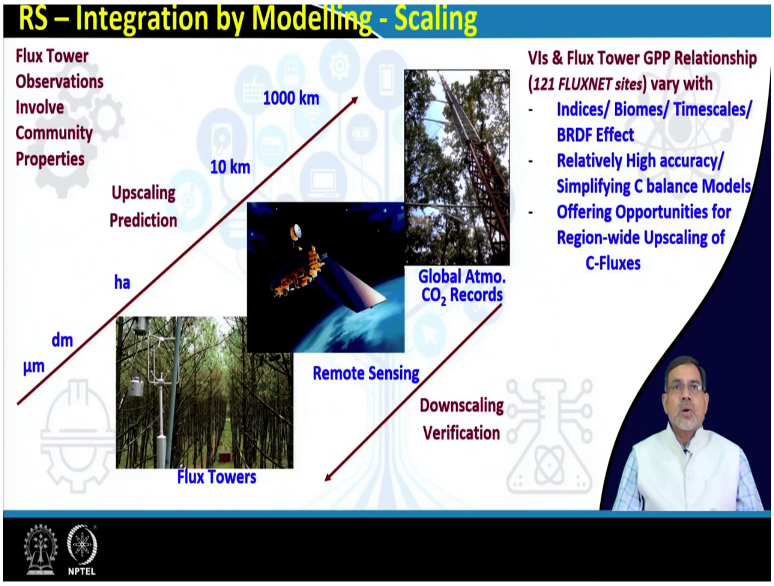

So, this particular three figures, three pictures with respect to the flux tower which we do at a point scale at a particular locality over a representing a particular ecosystem or community. And then you have the satellite based remote sensing based information which you get for your region based on the resolution or the scale. Then you can extrapolate it to the global level, what you say global scale like what is the global atmospheric CO 2 records or the profile.

So, when we move from local to global scale we do upscaling. So, upscaling we do for prediction. In vice versa we do the down scaling and the down scaling we do for verification or validation, ok. So, but these studies particularly the vegetation indices and flux tower based GPP star relationship for per se from 121 FLUXNET sites they vary with respect to different vegetation indices use different BIOMEs at different time scales and also the bio directional reflectance distribution function effect.

Relatively though they have high accuracy, but simplifying carbon balance models is means is required. Then offering opportunities for region wide upscaling of carbon fluxes.

So, this remote sensing being at the middle or intermediate it links, it links the local scale observation and extrapolates or upscales to the global level and vice versa in terms of the downscaling verification. So, it is there as the connecting link and does a good job in terms of integration by modeling.

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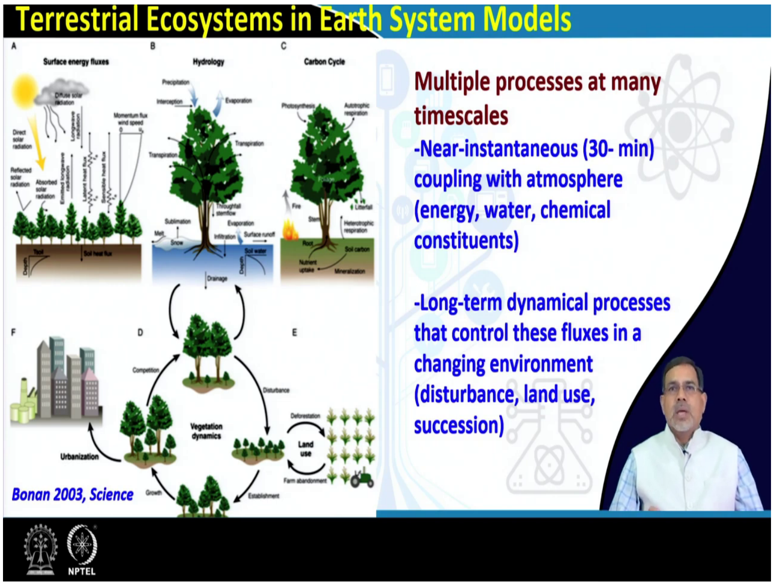

Then this particular representative diagram actually takes us little further in terms of understanding the different processes; the different processes which are increasingly considered in the earth's system models. So, this one published by Gordon Bonan in 2003 long back, I mean 17-18 years back in the journal science.

So, the upper right hand side which is the carbon cycle, which is depicting the carbon cycle are linked to others in terms of hydrological cycle, in terms of the surface energy balance or the surface energy fluxes. And also many more like deforestation impact how it is impacting the primary productivity, the urbanization impact.

So, the essentially what I mean to say that the earth system models, they consider the terrestrial ecosystems as means, for multiple processes at multi at many time scales. For modeling, but many things are considered. So, the process based models offers us an opportunity to include many things including surface energy flux, hydrological component, urban and also the other deforestation or activities, ok. So, disturbance activities.

That means, there are processes let us say respiration conductance, this could have a near instance instantaneous; that means, 30-minute coupling with atmosphere in terms of energy, water and chemical constituents.

So, think of the time scale 30 minutes coupling with the atmosphere whereas, the long term dynamical processes like disturbance, land use, succession change of one state or forest state to another that could happen in terms of decades in terms of half centuries or in terms of century term.

So, we have, so that is what is at many time scale. So, 30 minutes time scales to the decadal time scale. So, this needs to be integrated in the earth system models and they do a good job in that. So, primary production which are explained based on the process based models are very comprehensive and that is why they are bound to be complex.

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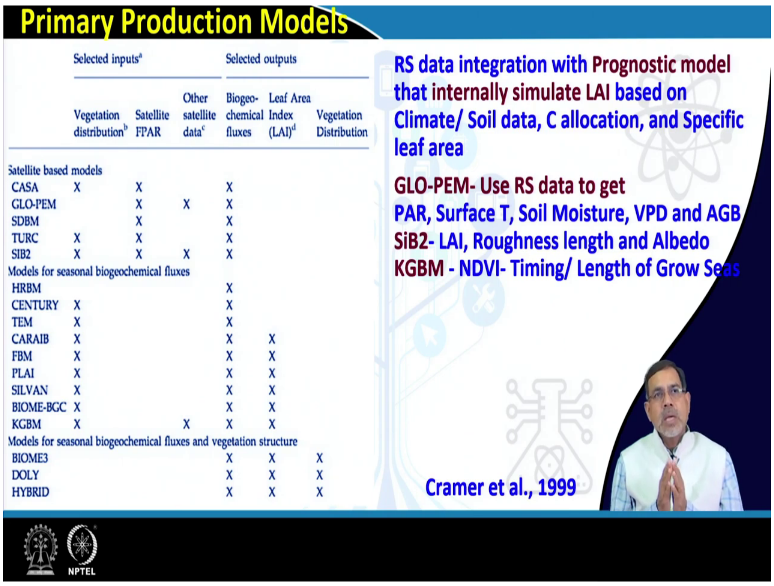

	Selected inputs[a]			Selected outputs		
	Vegetation distribution[b]	Satellite FPAR	Other satellite data[c]	Biogeo-chemical fluxes	Leaf Area Index (LAI)[d]	Vegetation Distribution
Satellite based models						
CASA	X	X		X		
GLO-PEM		X	X	X		
SDBM		X		X		
TURC	X	X		X		
SIB2	X	X	X	X		
Models for seasonal biogeochemical fluxes						
HRBM				X		
CENTURY	X			X		
TEM	X			X		
CARAIB	X			X	X	
FBM	X			X	X	
PLAI	X			X	X	
SILVAN	X			X	X	
BIOME-BGC	X			X	X	
KGBM	X		X	X	X	
Models for seasonal biogeochemical fluxes and vegetation structure						
BIOME3				X	X	X
DOLY				X	X	X
HYBRID				X	X	X

So, in this particular table what we need to understand? There are n number of models and here I have picked this particular table from a great job done by Cramer et al., long back at the initial stage when really remote sensing based things were coming up; remote sensing based process models were coming up. But we have I have picked it for our discussion to understand two-three very basic things.

The first set of models like, the satellite based models; CASA, GLO-PEM, SDBM, TURC and SiB2, so, and the second set that is the models for seasonal biogeochemical fluxes, they model them. And the last three like BIOME3, DOLY and HYBRID they modeled these are the models for seasonal biochemical fluxes along with the vegetation structure.

So, the first five like CASA NASA which or we say NASA CASA a kind of planned light use efficiency model as we discussed in the lecture 12. So, we will see in terms of the selected inputs and the outputs the vegetation distribution; yes, all take the distribution of vegetation as input.

I mean all take the vegetation distribution as input; means as we have discussed they need the land use land cover, they need what kind of vegetation is where. So, accordingly they will simulate. So, vegetation distribution is very important and goes as an input to them.

Then second set like the satellite fPAR. So, satellite derived fraction of photosynthetically active radiations are going as input for all the satellite based models. So, these are mostly a in terms of light use efficiency, they are including the radiation parameter or incoming solar radiation parameter into the model framework.

Third, the other satellite data also some of these models like GLO-PEM SiB2 have used. So, SiB2 which use the remote sensing data there to get LAI roughness length and Albedo. Whereas, the others like let us say KGBM they use remote sensing data to get NDVI that particularly to account for the timing or the length of the growing season.

So, remote sensing data integration with the prognostic models that internally simulate LAI based on climate, soil, carbon allocation and other specific and leaf area.

So, what in terms of the selected output; in terms of the selected output all the satellite based models CASA, GLO-PEM, TURC SiB2 they all give the output in terms of biogeochemical flux that means, the carbon the primary production. So, all of them they simulate the primary production.

But if we see others like the century the PLAI, so they simulate also LAI. So, LAI also I mean, as this course we also have been discussing on LAI. So, they also simulate LAI.

So, what I mean to say that; this is actually the process based models, they can teach or play around with many more outputs in if and what condition and also give many outputs in terms of in terms of the simulation result. So, some of those models they give vegetation distribution also as the output.

See this is a very important thing; the first set of models the satellite based models they take vegetation distribution as a input based on the satellite parameter like land use, land cover or the forest type map whereas, the models like BIOME3, HYBRID and DOLY they give vegetation distribution as an output which is based on the potential what you say climate or the climate available over that region. So, that is the difference.

So, one you are taking input where the other you are giving it as an output. So, we have to see this or we have to analyze this with respect to the remote sensing based; input and output and the different models available.

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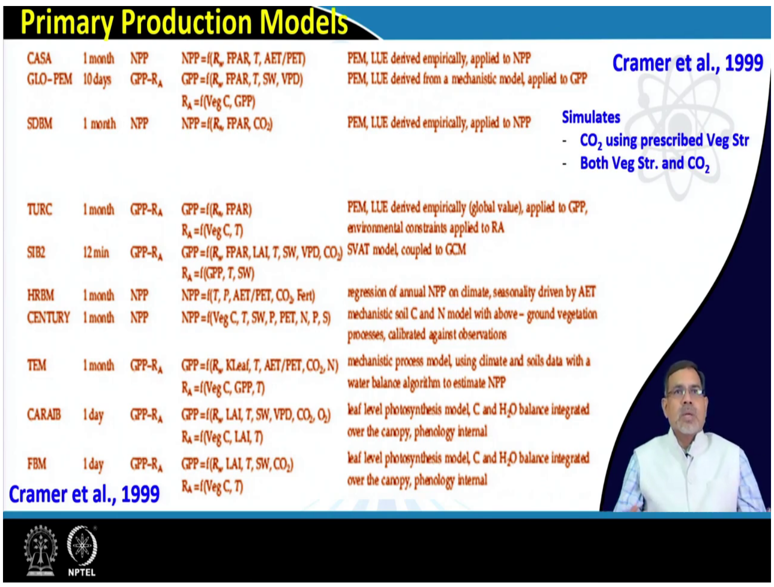

Now, coming to this particular list of detailed list with respect to the same set of process based models. So, NASA CASA as we know and have discussed in lecture 12, it is a light use efficiency model. So, all these 8 or 9 models what I have listed here for our discussion is that these models they simulate at different temporal scales.

So that means, they vary from 10 days to about sorry 12 minutes 10 days to about monthly time scale. So, temporal resolution in varies up to say 10 minutes to 1 month time scale. And these models they either simulate NPP or they simulate GPP. So, many of these models they simulate both GPP and R A that means, assimilatory respiration.

So, GPP minus RA they are simulating both; that means, 2 parameters GPP and RA and their subtraction will give us the NPP. So, the better see how they are simulating, how different models are simulating the NPP or the primary productivity or GPP or the assimilatory respiration.

As we discuss in terms of CASA the first one. So, it is simulating NPP or net primary productivity as a function of the incoming solar radiation as we know its light use efficiency model. Then from there it is taking the clue in terms of the par from the FPAR; that means, fraction of photosynthetically active radiation. And it is also considering the temperature scalar term.

And the water scalar term it is taking in terms of AET upon PET that is the actual evapotranspiration upon the potential evapotranspiration. So, what is the basis or the remark with respect to CASA? It is a production efficiency model as we have been discussing. The light use efficiency derived empirically and applied to bring out the primary production.

So, let us move to the GLO-PEM. The next one now which has a temporal resolution of 10 days and it calculates both GPP and the assimilatory respiration RA. And see GPP it similarly it is calculating GPP as a function of the incoming solar radiation, fraction of absorb photosynthetically active radiation, the temperature scalar and the soil water. You see SW.

So, water scalar it is taking in terms of the soil water and the vapor pressure deficit.

So, this is what actually the basis of variation in terms of algorithm from model to model. So, CASA and GLO-PEM they both of them they are taking incoming solar radiation FPAR and temperature scalar, but they differ in terms of in terms of in terms of how they are how the algorithm is taking in terms of the representation of water scalar. So, here soil water and vapor pressure deficit has been taken to account for GPP or the gross primary productivity.

So that means, it is and also the LUE derived from a more a kind of mechanistic model and then applied to GPP. And look at how it is calculating the assimilated respiration, it is as it is calculating from vegetation carbon and GPP. So, then GPP minus R A you get the NPP or the net primary production. So, this way it gives a kind of 10 days simulation data.

And let may come to some other I will skip the SDBM and let us discuss the fourth one that is the TURC and for then the SiB2. So, TURC which is also a kind of production efficiency model and based on light use efficiency principle, it is derived empirically with a kind of global value let us say 0.45 as modes is doing, and some value for LUE and applied to GPP and the environmental constraints applied to the respiratory respiration.

So, here GPP is simulated as a function of the solar radiation and FPAR. So, this temperature scalar and the water scalar terms have not been included here. And as far as the RA is considered here in comparison to GLO-PEM, the vegetation carbon and the temperature factor has been considered, because as we know temperature has a dominant what you say link or you say has a means a good relationship with respiration.

We will also see in our next discussion in the class in the lecture 14 that how using LST the respiration is simulated or estimated. So, here they have taken the vegetation carbon and temperature to account for the respiration or assimilatory respiration RA.

So, what I mean to tell you or what we need to understand is different models they are based on different premises, different assumptions, different theoretical understanding which are integrated into the algorithm and then the model parameterization. So, we need to understand this.

Then coming to SiB2 which simulates at 12 minutes came the temporal frequency is very high and it also stimulates both GPP and the respiratory assimilation; sorry assimilatory respiration. I am sorry.

So, here the GPP is simulated as a function of solar radiation incoming, the fraction of photosynthetically active radiation that takes care of about the light component or the radiation component. Here LAI has been considered which gives you more what you say more control with respect to the vegetation content or the leaf content or the photosynthetic material content is available, and then temperature scalar is also added.

And the water scalar is represented with respect to soil water and vapor pressure deficit, whereas, carbon dioxide is also integrated into this model. So, the carbon dioxide which is also on the left hand side of the photosynthetic equation that also has been considered here.

So, if we want to see the or alter or flicker try to teach the effect of carbon dioxide in the sense of understanding, the enhancement effect of carbon dioxide fertilization in primary production in terms of enhancement or change. So, this model could be useful because this takes carbon dioxide as a input variable.

So, that is how the models, the process based models try to integrate more and more what you say variables that have a direct relationship with photosynthesis or production. So, the list goes up, goes on and more and more complexity are taken are included and as we knew from Bonan's study and many more studies that these are increasingly being included in the earth system models or and also the climate models.

So, many more things climate variables are also considered at a time. So, coming to the century 1, which people use we also have used in terms of simulation of the primary production it directly simulates the NPP; no two step it is straight to a NPP, so which is which it is simulating as a function of vegetation carbon, temperature, soil water, precipitation.

So, here you see in terms of the waters scalar it is accommodating precipitation and the potential evapotranspiration, these two terms are presenting the water scalar. And also in terms of the soil nutrient nitrogen, phosphorus and this, a sulfur have been considered. So, this is more a mechanistic soil, carbon and nitrogen model with above ground vegetation process.

So, it is calibrated against many observations. So, when when you need some teaching or some more detail analysis with respect to soil mechanical properties, then perhaps this model will do a good job in terms of giving a giving you the primary production.

So now, with this set of understanding it is very clear in our mind that the process based models are inclusive very comprehensive and that is why they are complex. And the challenge is how to incorporate many and many more parameters directly from the satellite data. So, that is what it you cannot have everything from the satellite, you have to have lot of from the ground based link it to satellite data. So, through empirical or any other linear or non-linear function.

So, then that goes there. So, integration and then modeling. Up-scaling also satellite data is there to help because in terms of the point based field observation is linked to satellite data and that gives you better control in terms of up-scaling. And as far as the global product or upscale product is there, you can also use back in terms of validation or verification again using your point based data. So, that we have to be very clear in our mind.

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So, more details can be read from this book by Gordon Bonan Ecological Climatology. And also the second one which is a very interesting publication are in terms of Comparing the Terrestrial Models of Global NPP appeared in a good journal Global Change Biology.

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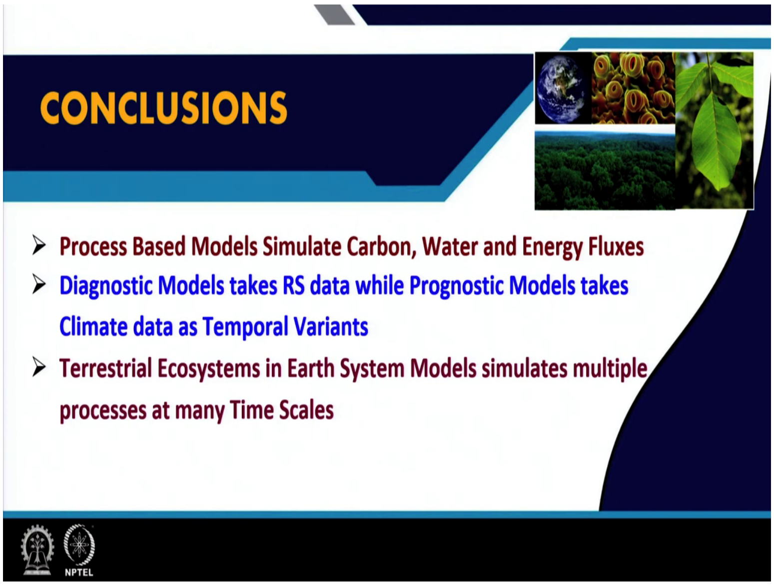

And coming back to conclusion, yes, the process based models simulate carbon along with water and energy fluxes. So, carbon is important for us because we are in discussion with respect to the primary production. The diagnostic models takes remote sensing data, while prognostic models takes climate data as temporal variants.

And increasingly the terrestrial ecosystem models are simulated within the ecosystem within the earth system models, because that takes the advantage of multiple processes at many time scales. So, this is what in terms of our understanding in of a process based models for primary production estimation.

So, moving on we will see many more as far as the data simulates the what you say data integration using lot of machine learning neural network algorithms are concerned. We will also see the SIF; solar fluorescence solar induced fluorescence based relationship, which are very important. And increasingly more and more studies are coming in terms of primary production estimation in our next class.

Thank you very much.