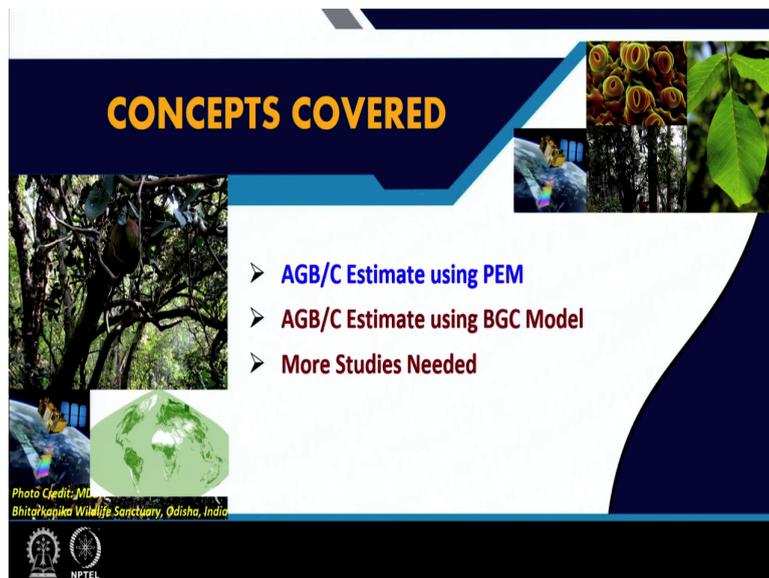


Remote Sensing of Leaf Area Index and Primary Productivity
Prof. M. D. Behera
Centre for Oceans, Rivers, Atmosphere and Land Sciences (CORAL)
Indian Institute of Technology, Kharagpur

Lecture - 20
Primary Productivity Applications: Indian Examples and Way Forward

Welcome back. So, today in the lecture 20 which is the last lecture of this particular course, we will continue about three-fourth of this particular lecture in terms of some more examples with respect to Primary Productivity Applications. Further, we will discuss and wrap up in last 5-10 minutes, what we discussed in the whole course and what are the ways forward.

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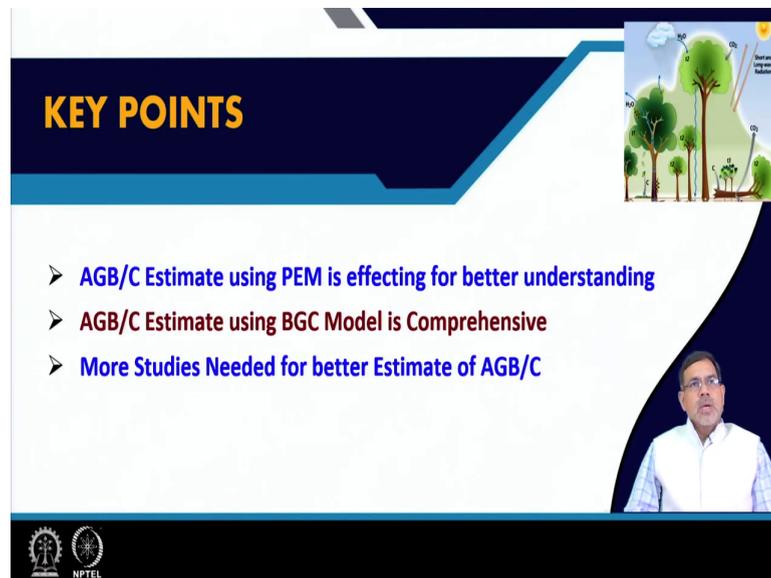
The slide features a dark blue header with the title 'CONCEPTS COVERED' in yellow. Below the title, there are three bullet points: 'AGB/C Estimate using PEM', 'AGB/C Estimate using BGC Model', and 'More Studies Needed'. The slide is decorated with several images: a tree with a large fruit, a globe, a satellite image, and a close-up of a green leaf. At the bottom left, there is a photo credit: 'Photo Credit: M. Bhitarkanika Wildlife Sanctuary, Odisha, India'. The NPTEL logo is visible at the bottom center.

With respect to the concepts covered, we will discuss in this particular lecture number 20, the above ground biomass and carbon estimate using production efficiency model. In the 19th lecture, we discussed about the data synergy, field-based estimates and also the use of machine learning. So, here, we will see two examples in terms of a light use efficiency model which we know means in terms of production efficiency.

And also a much comprehensive one, a biogeochemical model and what are the studies needed to come out with a more understanding as far as primary productivity or primary

production is concerned and also LAI. So, we will also discuss about that towards the end of this particular lecture.

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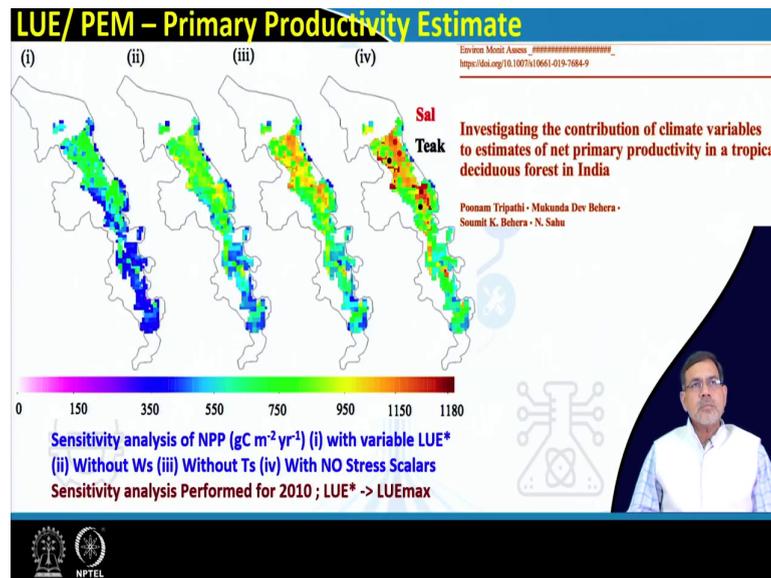
KEY POINTS

- **AGB/C Estimate using PEM is effective for better understanding**
- **AGB/C Estimate using BGC Model is Comprehensive**
- **More Studies Needed for better Estimate of AGB/C**

The slide features a dark blue header with the title 'KEY POINTS' in yellow. Below the header, three bullet points are listed in blue and red text. In the top right corner, there is a small diagram of trees with labels for 'Photosynthesis', 'Respiration', and 'GPP'. In the bottom right corner, there is a small inset image of a man in a white shirt. At the bottom left, there are logos for IIT Bombay and NPTEL.

As we continue, this production efficiency models are very effective in terms of better understanding of the primary production and the Biome-BGC are very comprehensive models and data hungry. And we will see why more studies are needed for reducing the uncertainty and thereby improving in terms of biomass estimation and also understanding the carbon or the primary production.

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So, here in this particular figure, you can see the sensitivity analysis of net primary productivity which has been shown in terms of grams of carbon per meter squared area per year ok with i, ii, iii, iv are in Greek, in Greek letter. So, with variable light use efficiency, which is shown in the maximum so, LUE max.

Then second one is without the water scalar. So, how the NPP will behave with respect to if it is simulated without the water stress or the water scalar. And the third one, how it will behave if it is simulated without the temperature stress and the fourth one is no stress scalars. So, what we can see very well seeing this is the beauty of these models, you can imitate, tease with the variables.

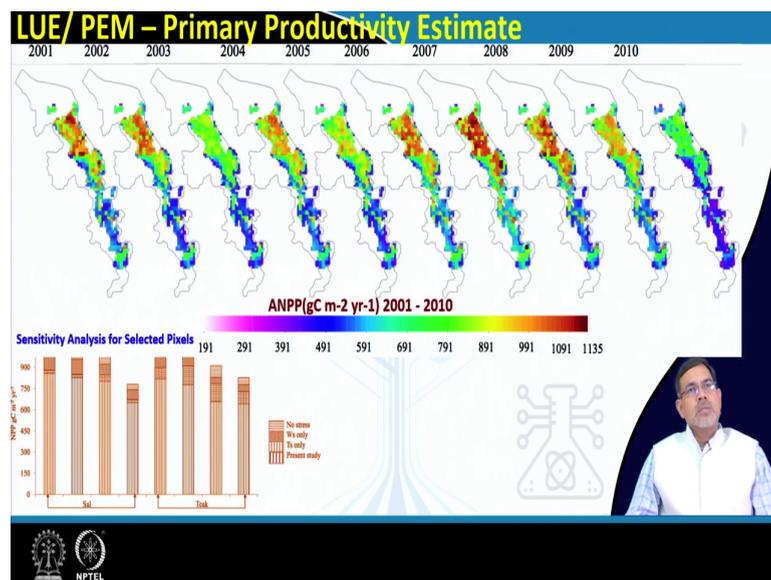
So, you see when only the light use efficiency is optimal and all others like water and temperature both are acting as a constraint, the left-hand side image shows very less primary production or NPP, net primary production. But the second one just the water scalar has been removed or the water stress has been removed, we are seeing more production. And the third one when the temperature scalar is removed alone, temperature scalar is removed; we are seeing more still more NPP or primary production.

So, looks like the temperature is having more control than the water here and then, when both are not as a stress factor so, your product production goes very high. So, that is how in terms

of a kind of production efficiency model based on the light use. We can simulate, we can tease around the various variables and see how an ecosystem, or how a landscape, or how a forest community will behave or could behave and that we can link to the climate change.

So, it has been already published in the journal and though the citation there it is shown and has because it was like an pre stage, but it is already published.

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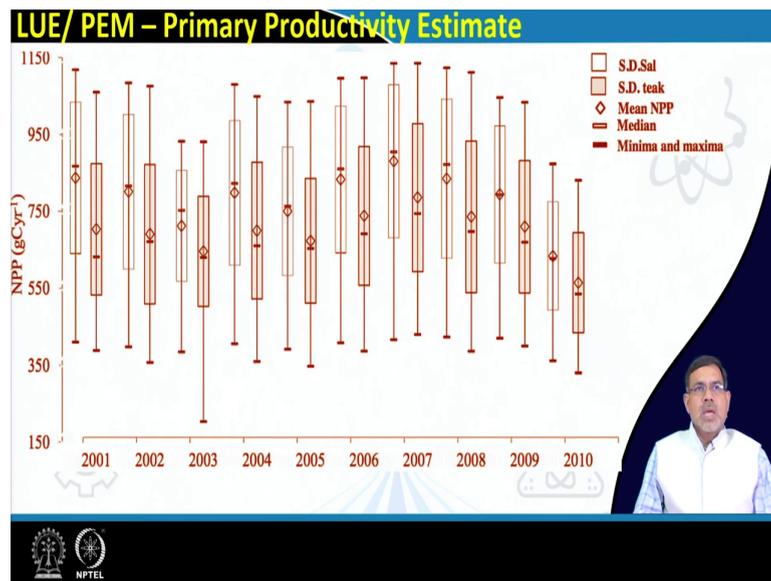
So, the same one when we have seen with respect to 2001 to 2010, now this is very interesting. Because as we know the various years, the fluctuation in terms of rainfall and temperature happens we get drought years, we get very hot year or warm years like that and that is also very well reflected in terms of the primary production.

So, as we move in the first decade of this 21st century between 2001 to 2010, we can see there is very less production in 2010 followed by maybe 2003, but you have a very good production in 2007, 2008, 2001, 2002, 2004.

So, what it simply tells? Yes, because here only the light use efficiency has been taken into consideration and the water and temperature has been simulated in terms of stress. So, this is clearly a reflection of the water and the temperature stress on this on the primary production in this particular area.

So, this is very important to understand, or it helps us in understanding and we can also see that how the climate in terms of change in temperature, precipitation could affect the primary production or the carbon flux in future particularly, the vegetation or the forest vegetation in specific.

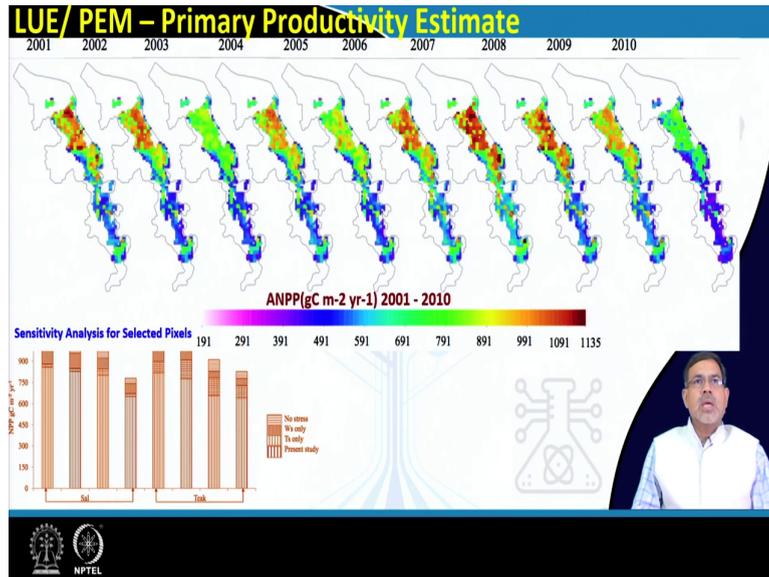
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So, same thing if we try to plot in term with respect to Sal and Teak. So, we are here focusing more with respect to two species because these two species are very dominantly found in that particular forest. So, that is why these two species has been taken for the simulation.

So, you can see there is a little variation as far as the Sal and Teak are concerned and the corresponding what you say standard deviation, minima, maxima and the median has been shown. So, there are years where you have less production, there are years where you have high.

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So, 2003, you have very less primary production which is also reflected in the image and also in the histogram. So, these are very interesting to see how the temperature and precipitation as an index or proxy of or T-stress and W-stress act as limiting factor for primary production.

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Bio-Geochemical Model – Primary Productivity Estimate

| Parameter | Type | DM | SM | TP | Source |
|---------------------------------------|-------------------------------------|---------|----------|----------|---|
| Year day to start new growth | Day of year | 102,000 | 105,000 | 90,000 | Present study |
| Year day to end litterfall | Day of year | 364,000 | 150,000 | 122,000 | Present study |
| T_p | Prop. | 0.450 | 0.450 | 0.450 | Singh and Kaulwala (2003) |
| m_s | Year ⁻¹ | 0.700 | 0.700 | 0.700 | White et al. (2005) |
| m_l | Year ⁻¹ | 0.085 | 0.085 | 0.085 | Default value of DRF biome |
| m_f | Year ⁻¹ | 0.001 | 0.001 | 0.001 | Present study |
| FRILC | Ratio | 1.000 | 1.000 | 1.000 | Default value of DRF biome |
| Allocation of SCLIC | Ratio | 2.200 | 2.200 | 2.200 | Default value of DRF biome |
| Allocation of LWC/TWC | Ratio | 0.300 | 0.300 | 0.300 | Default value of DRF biome |
| CRSIC | Ratio | 0.250 | 0.250 | 0.250 | Default value of DRF biome |
| Allocation current growth proportion | Prop. | 0.500 | 0.500 | 0.500 | Charavoll and Raghunathi (2011) |
| CM_{N} | kg Chg N | 26,370 | 29,800 | 46,390 | Present study |
| CM_C | kg Chg C | 64,400 | 67,200 | 74,600 | Present study |
| CM_N | kg Chg N | 48,200 | 49,200 | 43,200 | Tripathi and Singh (1992) and Raghunathi (2008) |
| CM_N | kg Chg N | 78,300 | 78,300 | 78,300 | Tripathi and Singh (1992) and Raghunathi (2008) |
| CM_N | kg Chg N | 442,000 | 442,000 | 442,000 | Default value of DRF biome |
| Leaf litter labile proportion | DEM | 0.280 | 0.280 | 0.280 | Singh (1990) and Singh and Singh (1991) |
| Leaf litter cellulose proportion | DEM | 0.470 | 0.470 | 0.470 | Singh (1990) and Singh and Singh (1991) |
| Leaf litter lignin proportion | DEM | 0.250 | 0.250 | 0.250 | Singh (1990) and Singh and Singh (1991) |
| Fine root labile proportion | DEM | 0.300 | 0.300 | 0.300 | Default value of DRF biome |
| Fine root cellulose proportion | DEM | 0.400 | 0.400 | 0.400 | Default value of DRF biome |
| Fine root lignin proportion | DEM | 0.250 | 0.250 | 0.250 | Default value of DRF biome |
| Dead wood cellulose proportion | DEM | 0.760 | 0.760 | 0.760 | Default value of DRF biome |
| Dead wood lignin proportion | DEM | 0.240 | 0.240 | 0.240 | Default value of DRF biome |
| Canopy water interception coefficient | LAI ⁻¹ day ⁻¹ | 0.041 | 0.041 | 0.041 | Default value of DRF biome |
| k | DEM | 0.800 | 0.800 | 0.800 | Present study |
| LAI_{max} | DEM | 5.000 | 5.000 | 4.000 | Present study |
| SIA | m ² kg C ⁻¹ | 30.000 | 30.000 | 30.000 | Default value of DRF biome |
| SIA_{max} | DEM | 2.000 | 2.000 | 2.000 | White et al. (2005) |
| N_p | DEM | 0.080 | 0.080 | 0.080 | Default value of DRF biome |
| k_{min} | m ³ | 0.083 | 0.154 | 0.274 | Present study |
| k_{in} | m ³ | 0.000 | 0.000 | 0.000 | Default value of DRF biome |
| R_0 | m ³ | 0.011 | 0.011 | 0.011 | Present study |
| IRP ₁ | Mpa | -0.600 | -0.600 | -0.600 | Default value of DRF biome |
| VPI ₁ | Pa | 681,000 | 551,000 | 355,000 | Present study |
| VPI ₂ | Pa | 267,000 | 2174,000 | 2485,000 | Present study |

Biochemistry and Conservation
 biochemcon/10.1007/978-93-325-0104-4

ORIGINAL PAPER

Modeling net primary productivity of tropical deciduous forests in North India using bio-geochemical model

Sourabh Kumar Behara^{1*}, Poojari Tripathi^{2*}, Mukunda Dev Behara³, Rabeh Tull⁴

Received: 6 Aug 2018 / Revised: 21 February 2019 / Accepted: 11 March 2019
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Abstract
 The present work investigates the applicability of a vegetation bio-geochemical model (Biome-BGC) to simulate monthly net primary productivity (NPP) and leaf area index (LAI) of Indian tropical deciduous forests. We simulated the monthly NPP and LAI of three plant functional types (PFTs) (dry forest (DM), wet forest (SM) and tall grass (TP)) having distinct tree species composition, canopy structure, different nutrient availability rates and microclimate within a broad tropical deciduous forest during 2011–2012. The parameterization of 11 major eco-physiological parameters of Biome-BGC was performed from in-situ physiological measurements gathered from 9 long-term ecological research plots in diverse forest PFTs and PFT specific biomes were developed. Simulated results, with highest peak in September during summer and second peak in January during winter were observed for simulated monthly NPP in all three PFTs. Simulated NPP (gC/m²/year) values were 48.8 and 44.6, 176.8 and 162.8, and 322.5 and 318.2 during 2011 and 2012 in DM, SM and TP PFTs respectively. Observed NPP (gC/m²/year) values ranged between 48.2 and 61.1, 49.0 and 225.1, and 342.1 and 475.1 in DM, SM and TP PFTs respectively. Biome-BGC simulated NPP was in positive agreement with observed NPP in all PFTs (R²=0.82, 0.83 and 0.72 in DM, SM and TP respectively). In all PFTs Biome-BGC led to an underestimation of LAI. The current investigation evaluated the operational application of Biome-BGC in Indian tropical deciduous forest and opens scope for further improvement for LAI algorithms for forest in the LAI simulation.

Keywords Biome-BGC · Tropical deciduous forest · Leaf area index · Net primary productivity · Plant functional types

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So, with this, let us move to another example with respect to a biogeochemical model. So, here a Biome-BGC which has originally, been developed by University of Montana, Running's group, Steve Running or Steven Running group in University of Montana NTSC

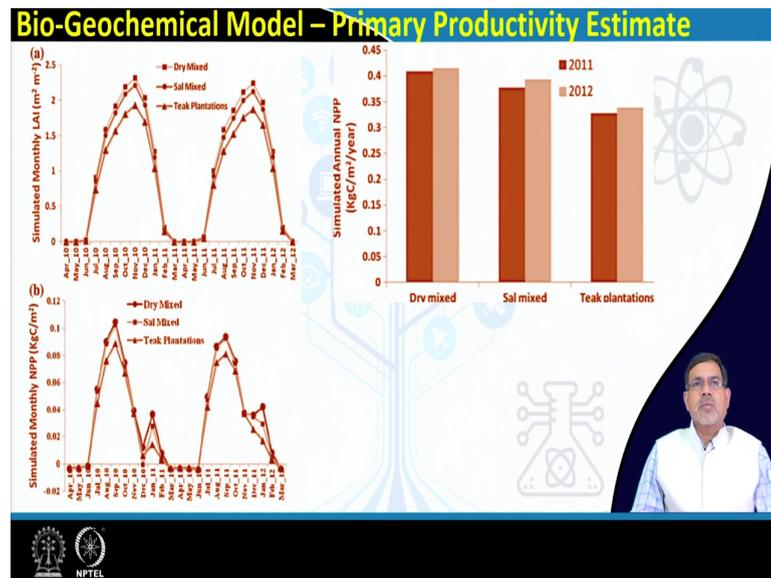
lab. So, that particular model has been used and you can see on the left-hand side, these are the parameters.

You have 32 different parameters and their specification with respect to type, days of the year or in terms of the temporally and what is in terms of the unit. And it has been paired in terms of the three different plant functional types or the forest types. So, dry mixed Sal and teak stands for DM, SM and TP respectively and corresponding sources. Friends, it is very important to understand that these biogeochemical models, they are really seem are very comprehensive.

They say they simulate the photosynthesis or primary production by considering lot of variables in terms of carbon nitrogen ratio, in terms of light or the climate or the environmental variables, in terms of the soil variable, water variable, diffusivity, many things so, the list can be endless. But if you can see on the right-hand side or if you can ask yourself, how much of this data we can generate for the forest or for the ecosystem of our interest it is very difficult.

So, for this particular Katarniaghat side, we could manage to come out with 12; 1, 2, 3, 4, a 12 out of 32 based on our own experiment and in various measurements, but others we have gone with the default values. So, with that, we try to run the model to see first-hand impression of how the primary production behaves overseas in and among the forest types.

(Refer Slide Time: 10:39)



Just for our understanding, let us have a look at the two figures and the right; left-hand side. The left; upper left is the simulated monthly LAI; Leaf Area Index has been simulated because this BGC or Biome-BGC also simulates LAI as one of its intermediate output. So, LAI as we know in terms of it is a dimensionless, but per se we mentioned it meter square per meter square.

So, you can see in terms of the monthly simulation, we can very well see a trajectory that follows the seasonal pattern. Because it is a deciduous forest, and we may expect very less LAI as you can see during the deciduous or the summer sorry the summer months. So, between February and June, you have very less LAI whereas, in September, October, November, the post monsoon period you have the maximum LAI going up to 2.5.

But importantly, you can discriminate between and among these three different forest types, you can see that dry mixed have higher LAI followed by Sal and followed by the Teak plantation. So, they could be, they could have a link because they can be linked with the production or primary products are AGB or AGC. So, coming to the lower right ok so, sorry lower left, we can see the simulated NPP.

So, this NPP pattern and a LAI pattern, you can just try to link whereas, you have slightly mismatch between the range of a for the months of December to February where you have

slightly higher NPP which is not corresponding to that of the LAI and the and the upper figure. So, that is a mismatch, but we have reasons to these. So, the point to understand is yes because our course is on LAI and primary production estimates and remote sensing and many other thing.

So, here with respect to the Biome-BGC model, we can see there is a very good correlation between LAI and this and we can simulate it across monthly, seasonal, decadal whatever timescale we want using this kind of comprehensive models. And on the upper right, we can see the simulated annual NPP in terms of kg of carbon per meter square per year where the dry mixed forest is relatively higher than the Sal followed by the Teak.

So, this kind of graphs, curves helps us in understanding details with respect to the primary production, photosynthesis and many other biogeochemical behaviour of this particular groups of plants at the PFTs.

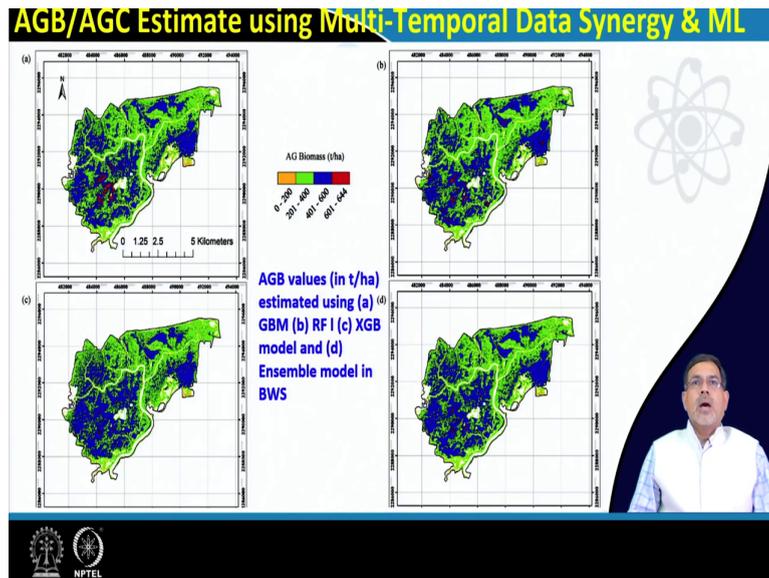
(Refer Slide Time: 13:50)

The image displays a flowchart and a research paper snippet. The flowchart, titled "AGB/AGC Estimate using Multi-Temporal Data Synergy & ML", details the process: Multi-Temporal Sentinel-1 Data and Multi-Temporal Sentinel-2 Data are processed through calibration, speckle filtering, terrain correction, and atmospheric correction. SAR backscatter image generation and vegetation indices (VI) image generation are then compared against rainfall and soil moisture. This leads to multi-temporal stack preparation from individual images, mean and percentile images preparation, and the use of RF, GBM, and XGB regression for AGB estimation. The final steps include validation of models and ensemble prediction, leading to AGB biomass map generation. The research paper snippet is from the Journal of Environmental Management, featuring a novel approach for estimating aboveground biomass (AGB) of a carbon-rich mangrove site in India. The authors are S.M. Ghosh, M.D. Behera, B. Jagadish, A.K. Das, and D.R. Mishra. The abstract discusses the use of multi-temporal Sentinel-1 and 2 data-derived variables to estimate AGB, comparing the results with field-measured AGB biomass.

So, with this, let us move on to one more study which is from a mangrove forest in the Eastern India in located in Bhitarkanika. So, here this is a novel approach has been taken where the x where the multi temporal property of both sentinel SAR, that is sentinel 1 data and sentinel 2 that is optical data has been exploited.

And the ML that means, the machine learning has been used and that has given a very good estimate of the above ground biomass and we know the ratio now with respect to above ground carbon. And then, above ground carbon means the ratio between above ground and below ground carbon, we also know that is almost 80 to 20. So, if 80 is the above ground carbon, then below ground could be 20 and the total could be 100.

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Now, coming to the output yes, we have got good outputs with respect to these four for four different model outputs in terms of AGB which is simulating a higher range, look it is 644 is a good range, but this is not the last. But what I mean to say that when we use the multi-temporal data and from different sensors both SAR and microwave; SAR and optical, then we integrate them using machine learning.

Then perhaps we are deriving maximum synergy as possible as best possible to get a good estimate of above ground biomass. So, the experiment is integrating the models, integrating the variables can be analysed. And anyone can do any number of studies to get more and more means clear or better estimate of AGB or AGC as far as forest is concerned.

(Refer Slide Time: 16:09)

| Forest Vegetation C Estimate - India | | | | | | |
|--------------------------------------|-------------|----------------------|--------------|-------------|---------------|---------------------------|
| Year | Area (M ha) | Vegetation Component | Biomass (Mt) | Carbon (Mt) | Carbon (t/ha) | Reference |
| 1980 | 52.6 | Ag + BG | 5748.88 | 2587 | 49.2 | Hingane (1991) |
| 1980 | 51.73 | Ag + BG | 6919.74 | 3117 | 60.2 | Dadhwal et al (1998) |
| 1982 | 64.2 | Ag + BG | 8142 | 3663.9 | 57.07 | Dadhwal and Shah (1997) |
| 1984 | 63.9 | W | 2398.5 | 1085.16 | 16.98 | Manhas et al (2006) |
| 1985 | 64.2 | Ag + BG | 4432 | 1994.4 | 31.07 | Dadhwal and Nayak (1993) |
| 1986 | 64.01 | Ag + BG | 8358 | 3761.1 | 58.77 | Ravindranath et al (1997) |
| 1988 | 63.9 | Ag + BG | 7742.4 | 3484.08 | 54.52 | Chhabra et al (2002a) |
| 1993 | 64.01 | Ag + BG | 8683.7 | 3907.67 | 61.06 | Chhabra et al (2002b) |
| 1993 | 63.96 | Ag | 5867.6 | 2640.42 | 41.28 | HariPriya (2000) |
| 1994 | 63.3 | Ag + BG | 2395.4 | 1083.81 | 17.12 | Manhas et al (2006) |
| 1995 | 63.96 | Ag + BG | 4503.8 | 2026.71 | 31.72 | Lal and Singh (2000) |

Now with this, let me go to the general discussion as far as the total course is concerned. Friends, as far as forest or Indian forest is concerned, the carbon estimate studies vary or fluctuate a lot. So, using non-remote sensing based, using what you say non-remote sensing based studies, there have been the figure is vary is means varying between you can say about how much carbons in terms of tonnes per hectare.

It is varying from 17.12 in 1990 for estimate by Manhas et al where we have taken the above ground and below ground carbon. Whereas, it is going as high as about 61.06 by Chhabra et al published in 2002, where they have taken both above ground and below ground. So, look what I meant to tell in terms of the last, but one column, the carbon per carbon with respect to tonnes per hectare for the whole country.

So, this is the total carbon we are suggesting for India which is very difficult to digest because the range is fluctuating a lot. So, because we cannot to go into detail, but I can throw the limelight that yes, there has been lot of approximates, a lot of mismatching, lot of left out, lot of many many means we are perhaps not done with a good estimate of forest vegetation carbon as far as India is concerned.

So, that is why my request to all of you to do more and more studies based on whatever knowledge we receive; we got through our discussion over 20 classes in this particular course.

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Forest Vegetation C Management - India

Tropical Ecology (2020) 61:168–171
https://doi.org/10.1007/s42965-020-00075-9

International Society
for Tropical Ecology

DISCUSSION ARTICLE

India's contribution to mitigating the impacts of climate change through vegetation management

J. Dash¹ · M. D. Behera² · C. Jeganathan³ · C. S. Jha⁴ · S. Sharma⁵ · R. Lucas⁶ · A. A. Khuroo⁷ · A. Harris⁸ · P. M. Atkinson^{1,9} · D. S. Boyd¹⁰ · C. P. Singh¹¹ · M. P. Kale¹² · P. Kumar¹³ · Soumit K. Behera¹⁴ · V. S. Chitale^{2,15} · S. Jayakumar¹⁶ · L. K. Sharma^{3,17} · A. C. Pandey^{3,18} · K. Avishek¹ · P. C. Pandey^{2,19} · S. N. Mohapatra²⁰ · S. K. Varshney²¹

Received: 12 December 2018 / Revised: 10 October 2019 / Accepted: 11 November 2019 / Published online: 13 March 2020
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Abstract
The changes in natural ecosystems provide opportunity to increase vegetation carbon sink capacity and thereby contribute to mitigation of climate change impacts. The Indian tropics and the large ecological variation within the country afford the advantage of diverse niches and offer opportunities to reveal the role of biotic factors at different levels of organization from populations to ecosystems. The last 4 decades of research and development in the Indian space science community has been primarily application driven in response to the government space programme for national development. The expenditure in R&D over next 5 year suggest that scientific research is higher on the country's agenda. The Indo-UK Terrestrial Carbon Group (IUTCG) comprising both Indian and UK scientists, funded jointly by the Department of Science and Technology, India and the Department of Business, Innovation and Skills organised a workshop to explore ways in which Earth observation data can be effectively utilised in mitigating the impacts of climate change through vegetation management. Effective integration of field observations, collected through various monitoring networks, and satellite sensor data has been proposed to provide country-wide monitoring.

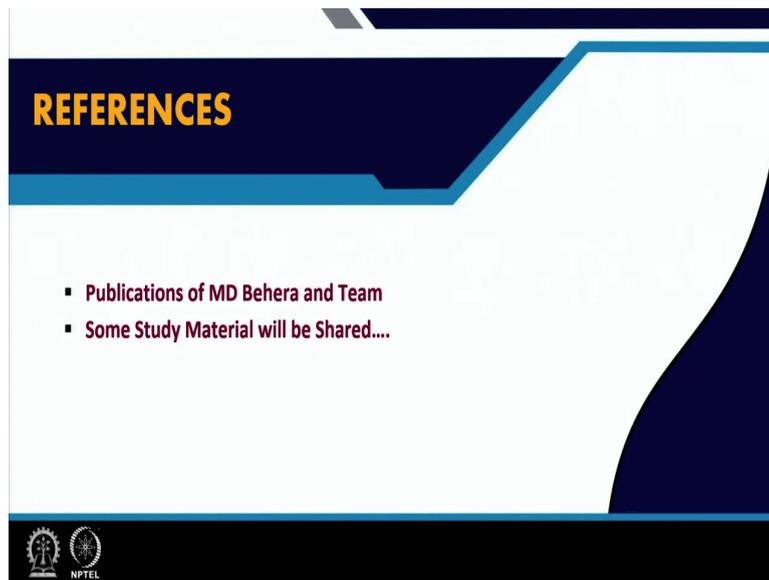
Keywords Carbon observation · Indian ecological observation network · Satellite remote sensing · Vegetation dynamics model

Effective integration of field observations, collected through various monitoring networks, and satellite sensor data has been proposed to provide country-wide monitoring

And we also discussed in a team based on UK and Indian experts picked who discussed with respect to the contribution in terms of India's contribution to mitigating the impacts of climate change through vegetation management that is the title. But we actually discussed the primary production, the terrestrial carbon and the primary production studies using satellite remote sensing in the end of 2012.

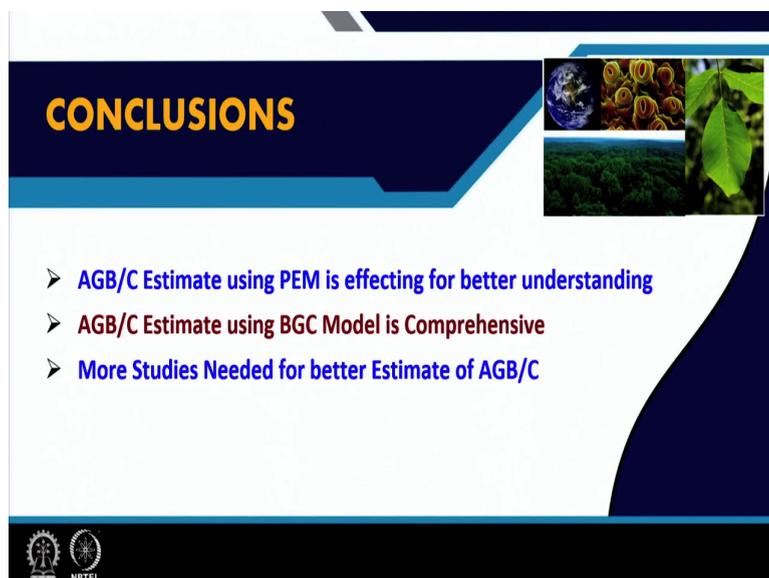
This particular discussion was supported by DST and UK so, UK and India signed team have discussed. So, what we found that effective integration of field observations collected through various monitoring networks and satellite sensor data should be proposed, we propose through this particular in deliberation so that the country wide, assessment, monitoring, a primary production or more importantly the carbon flux can be done.

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So, this particular references are there and we will also share some more study materials.

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Now coming to the conclusion of this 20th lecture at the same that we need to integrate many more data, many more variables into many more models to come out with a good assessment study and understanding of the leaf area of the primary production.

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RS of LAI and Primary Productivity - CONCLUSIONS

COURSE:

- Introduction to RS of LAI and PP
- RS of LAI - Forest
- RS of PP - Forest
- RS of LAI and PP- Applications, Prospects & Climate Change

Terms Ambiguity C-Flux/ PP
Satellite Data
Field Site
Techniques

The slide features a central graphic of a tree with various icons (gears, Wi-Fi, smartphone, laptop, etc.) as leaves. To the right is an atom symbol, and below it is a chemical flask with a circuit-like structure. The bottom left corner contains the NPTEL logo.

So, friends, let us come to our conclusion part of the discussion. This particular course has been as you know or have already gone through has been divided into four parts. And you now know that in the 1st week, we discussed, we introduced the course in terms of remote sensing technique though they are they are all very elementary or very preliminary. But I tried to do the best possible to give you a preliminary introduction what is the capability or potential of remote sensing.

Hope you will read more of remote sensing materials to learn many things in detail with respect to the satellite, the sensors, the resolution then their capability has concerned. Then, in the very 1st week we also discussed into two classes with respect to LAI and primary production. So, the photosynthesis and the leaf area index as you understand, they are very important in terms of understanding the carbon flux.

So, and leaf area index serves as a better proxy and can be very well estimated from the satellite data because satellite data gives us a very wide or the global coverage. So, seasonal and temporal what you say fluctuations we can capture and that can go into a model or study as far as the primary production is concerned.

And as I just mentioned, that throughout the whole course, we have discussed or we have taken the example, citations from the forest and more so the complex tropical forest. Because

India is mostly having the tropic is a tropical country by virtue of its latitude, but by virtue of the altitude because it accommodates part of the whole Himalayas, it also accommodate some of the temperate and alpine subalpine forest.

So, with respect to that, we studied in terms of LAI and primary production and understanding our forest particularly the Indian forest is incomplete. So, we need to do more and more study as far as the leaf area index is concerned and try to link it with respect to primary products; production to understand the carbon flux of the forest.

Then our forests are complex in terms of its composition, in terms of its dynamics, in terms of its varieties from tropics to alpine and in terms of its phenology. So, we need to address them very well and remote sensing is a good tool or a very handy tool because these days we are getting lots of data available to us for free.

And there are many earth engines including Google, Amazon and many more are coming up and they support the data, you hire the algorithm, and you get the result. So, we have lot of options in terms of understanding or analysing our data with everything for free and India being a developing countries country, it helps us.

And particularly in student mode, it helps us in doing lot of trials, in terms of understanding, analysing the satellite based LAI and the primary production ok are the NPP or GPP. And friends, throughout the our discussion in week 3, we discussed about the primary production. As in the very beginning of the 3rd week, the 11th class, we talked about various terms in terms of gross primary production, net primary production, autotrophic respiration, heterotrophic respiration.

I hope these terms are very clear to you though there is little you says related ambiguity in terms of production productivity it has to be very clear in your mind. So, productivity is always in terms of the rate with respect to certain time. So, one the annual productivity, monthly productivity, production is the quantum or the total so, you say that and stock, carbon stock is the total carbon. Sink, source so, these terms has to be very clear in your mind and you should not be confused at all in them.

And then, the applications with respect to the prospects and more importantly the climate related applications. Friends, in our 2nd week and 3rd week, we have used lot of tables where we discussed the LAI, LAI global data products ok. And also, we talked about the lot of models in our week 3 where we talked about the different primary production or the NPP, GPP models based on different preamble. So, try to understand them, so, understanding them needs our basic understanding with respect to photosynthesis ok.

So, the primary understanding of photosynthesis will help us in knowing more with respect to primary productivity or NPP, GPP models. Then, we need to know that the linkage between satellite and LAI or GPP or NPP or primary production is not that straight. Because the satellite is somewhere up above 600 or 700 kilometre from the earth surface and the forest what we are measuring is down below.

And we have a interfering atmosphere and the forest what is looked by or seen by the satellite data or the satellite sensor is in terms of its reflectance or backscatter or we also discussed with respect to fluorescence, very less of the emitted radiation goes back. So, we need to understand it very well that, what are the limitations in terms of reflectance, backscatter, in terms of atmospheric hindrance back and the soil background.

So, these things has to be kept in mind, but believe me, we have started doing a good job with n number of data around us, we need to also keep doing good job with respect to field data, because they are the absolute. So, field data, good field data, more field data and when I say good, it has to cover all the heterogeneity in terms of temporal, spatial so that the linkage or the link to the model, it could be LAI, it could be primary production will be very well.

So, one has to be very careful with respect to the size, the field size or the elementary sampling unit ESU on the field has to match with the satellite pixel size otherwise, that is a mismatch. So, and then how many data, how much of the data, how to take care of the data in terms of good data, bad data or repetitive data so, we have to also understand lot of statistics for this.

And believe me, we are only talking about data and data science we are dealing with. And all these machine learning models, artificial neural networks, deep learning and a lot of models random forest XGB, gradient boosting many more, the list goes on, they are based on

different statistical preambles. So, let us understand that and an understanding this actually helps us in interpreting the results what we are getting.

So, we will get some result, but we can say that wow, the result is good in terms of LAI or PP or private production. But then at the end, we need to see or interpret it that this good or whatever the uncertainty in that believe me in whatever results you get, there will be uncertainty. But our job has to minimize the uncertainty so that the estimation or the output will be as accurate as possible or could be as accurate as possible.

So, there are many other sources of measurement in terms of the carbon flux coming from the eddy covariance flux. So, we also have the proximate and Indian Indo flux or Asian net so, lot of data is coming from these towers as far as the carbon flux is concerned over lot of the varieties of ecosystems. So, those also needs, those also act as a separate or independent data as far as the validation is concerned.

So, towards the end, let me summarize. Oh, we need to understand the principle of satellite remote sensing and the complexity of satellite remote sensing in terms of the resolution, in terms of the scale, in terms of what you say backscatter, reflectance, emitted radiance and the interfering things and also the BRDF, we did not touch that ok. So, those are the complexities we need to understand.

The field study has to be very meticulously planned and has to be linked and as possibly with respect to time, with respect to space, the linkage has to be as good as possible. And then, the techniques, there is no end to the techniques. Believe me whatever estimate you get with respect to LAI or linkage with respect to primary productivity, it may not be absolute, there are many techniques.

And with a lot of techniques, we are trying to minimize the errors and going doing a good job in terms of understanding the LAI and primary productivity. At the end, this course on remote sensing of LAI and primary productivity with this 20 lectures, half an hour each or slightly more than half an hour.

So, we tried to touch upon the things starting from the elementary to the advanced. But you to read more and more with whatever literature you get around.

And in many of these classes, I have picked from some of the review articles to give you a glimpse of the history, the developments and the future activities so that you have a capture of all the developments with you. And in terms of uncertainty also, I gave lot of emphasis because that becomes the scope or prospects for future studies. So, thank you very much once again for choosing this course.

Thank you very much and all the best. Bye.