Remote Sensing of Leaf Area Index and Primary Productivity

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Lecture - 16
LAI Applications: Phenology, Climate and LSMs

Welcome back. So, this week the 4th week or the last week for this particular course on Remote Sensing of LAI and Primary Productivity. Over 4 lectures from lecture number 16 to 20, we will be discussing on the challenges in terms of LAI and primary productivity estimation, the uncertainties, some of the applications, the historical and the future prospects and some applications, particularly with respect to the climate change because we all are living in a changing climate or a warming world.

With this, the today's lecture 16th lecture is on the LAI Applications. So, I would request you to recall what we have discussed in our week 2 in terms of LAI. So, we discussed the different definitions of LAI, then we discuss different technical instruments which are available for field based measurements. So, those mostly follow the non-destructive principle; but apart from that, we also have discuss the destructive methods of field based field assessment in terms of LAI.

Further, we try to link and discuss with respect to what you call the vegetation indices or the empirical relationship to estimate LAI and also, we discussed some inverse models to estimate a LAI from the remote sensing data and we also have discussed lot of remote sensing based products, LAI products.

Those are in different spatial and temporal resolutions and what kind of principles they follow and also, we discuss their pros and cons, accuracy, inaccuracy and why there are some kind of uncertainty exists. So, with this, what you say memory, let us move on to talk with respect to how the LAI which is estimated using remote sensing; how it serves the broad purpose or what are the different applications.

So, today, three applications we will try to focus on; one is the phenology and second one is on climate and third one is how it is utilized or applied with respect to different land system models, what are the different components or different variables or, what you say attributes with respect to these three different applications of remote sensing derived LAIs.

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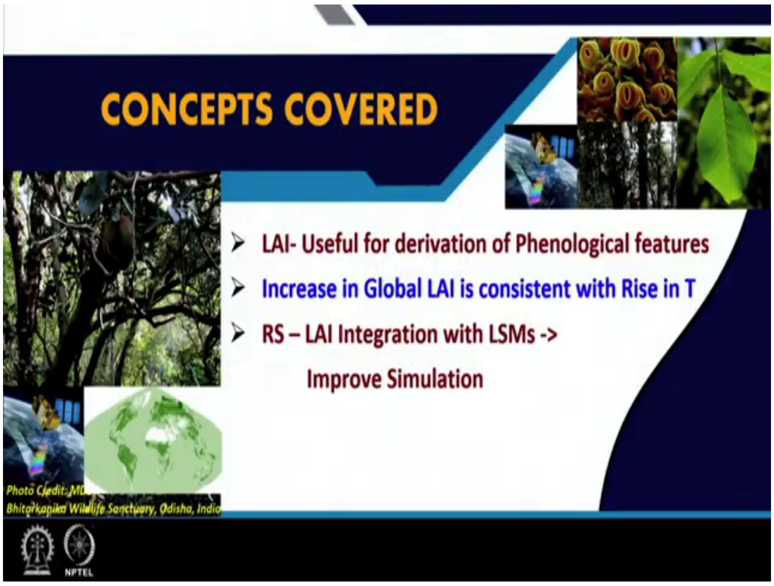

We will cover the concepts. So, in terms of the concepts, I try to put these three; one is the LAI is useful for derivation of Phenological features. So, friends, this term phenology is not new we have already discussed and you also may be knowing it. Phenology is in a general sense as we discussed, a simple phenotypical appearance of vegetation because we are here talking with respect to leaf or leaf canopy.

So, over a year over a season, you can see the vegetation appearance varies because of different stages of leaves starting from leaf up to leaf on and mature, you have flowering, fruiting and many phases. So, this gives rise to different phenological stages and so, LAI is useful to derive different phenological features, we will discuss on that. And then, the second concept is increase in the global LAI is consistent with rise in temperature.

So, this sounds interesting because the studies by different scientist have proven that the global LAI has means the LAI in a global sense or in a global distribution has increased more. So, the studies goes back to 20-30-40 years, but with respect to the satellite based; but other studies have been accumulated since 1850. So, 170 years back, since 170 years.

So, it has been seen that there has been a consistent increase in the global LAI. So, and that has a good corroboration with respect to rise in the temperature. So, rise in temperature is one of the key attributes of climate change. So, this is what is very consistently observed and LAI is playing a very important role in terms of what you say giving information with respect to climate change.

The third is the integration of remote sensing derived LAIs with the land surface models. So, this actually helps in improving simulations of various what you say products, various intermediate products or intermediate steps.

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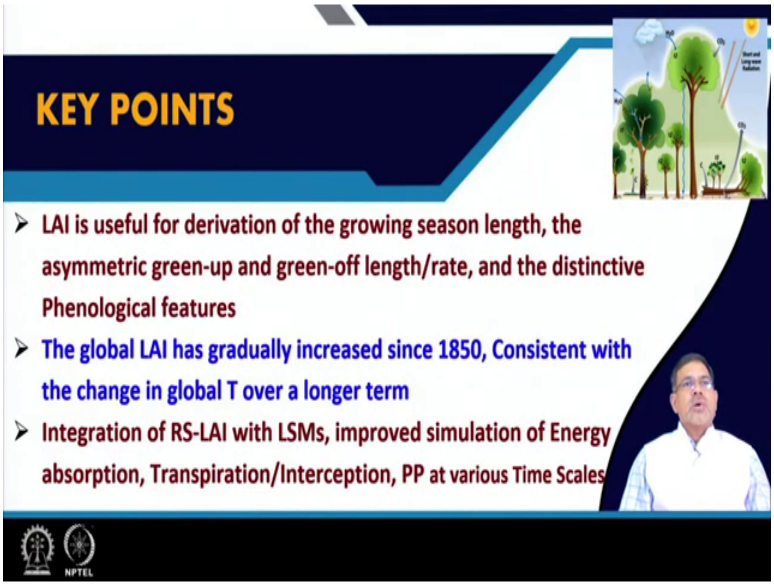

So, we will talk about these three. So, I have put accordingly the three overall sentences as our key points for 16th lecture. So, LAI is useful for derivation of growing season length. So, the length of the growing season is very important to estimate, to calculate many of the things including the carbon, the water and energy budget as far as vegetation processes are concerned.

So, and the asymmetric green-on and green-off length and also, the rate at which these processes or phenomena happens in terms of green-on and green-off and many other phenological features as we discussed. And the second point is the global LAI has gradually increased since 1850 consistent with the change in the global temperature over a longer term. So, 170 years since past, it is showing a good corroboration.

The third integration of remote sensing derived LAI is with land surface models improved simulations of energy absorption, transpiration, interception; interception in terms of solar radiation, in terms of the rainfall and primary productivity at various time scales; at seasonal, annual, decade also, this is very important and we will discuss more about this.

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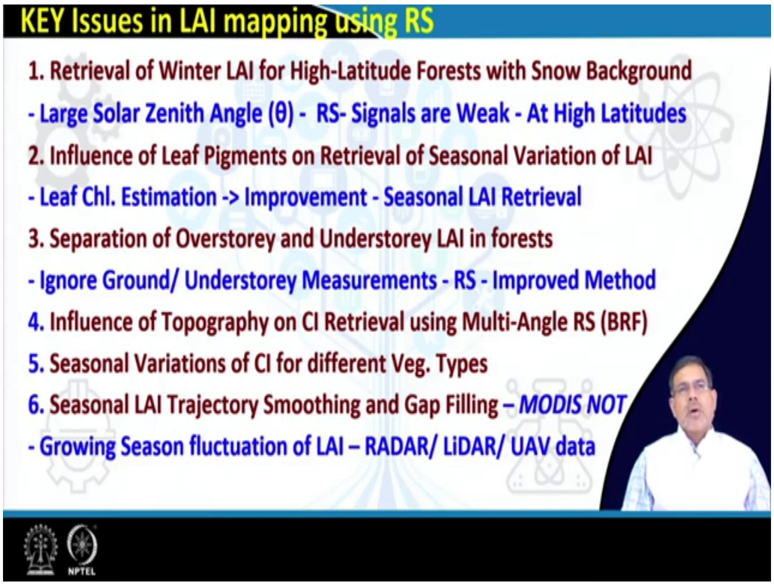

So, this 6 points particularly this slide I have once again repeated from our lecture 2 discussion. Friends, these are the 6 key issues we have discussed in terms of LAI mapping using remote sensing. So, just for our means call back memory, the first one is retrieval of winter LAI for high latitude forest with snow background.

We understood this because as you go to high latitudes, you receive solar, the solar zenith angle is large. So, that gives a very weak signal as far as remote sensing is concerned. So, that is a problem in terms of getting the LAI maps with respect to the tropic and the high latitudes.

Second, the influence of leaf pigment. So, this pigment as we know the dominant one is the chlorophyll. So, there is a kind of what you say seasonal variation. So, we have discussed that this has to be estimated properly, there has to be improvement in terms of the retrieval of the seasonal LAI as far as the chlorophyll or the pigment concentration is concerned or variation is concerned.

The third one is the separation of overstorey and understorey LAI in forest. So, many times, we ignore both below ground or understorey measurement, so that needs to be improved we discussed as far as the remote sensing based LAI is concerned. The fourth, fifth, sixth are in terms of the BRF, the seasonal variation and the gap or the gap filling exercise.

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Now, the challenges or the future prospects in terms of the LAI estimate as far as the LAI satellite derived LAI products are concerned are vegetation indices with snow background, sometime underestimate LAI because of many things as we know when with respect to the background of snow.

So, it will definitely underestimate because you get many other signals which goes back from the snow background, which is a brighter one in comparison to the other or a typical non-snow background or a forest background. So, the primary productivity better related to a LAI surrogate during the growing season. So, we also need to consider that in terms of the primary productivity estimation.

And many other meteorological and hydrological applications, we discuss on that and out of that we have selected three and we are going to elaborate on that. So, separation of seasonal

LAI from seasonal leaf and background greenness variation in terms of surface albedo, snow and rainfall interception, radiation absorption by canopy and soil.

And as far as this photosynthesis and transpiration as you say the CO 2 and water vapor exchange is concerned, the utility of LAI means the utility of FAPAR or fraction of absorbed photosynthetically active radiation does better than the LAI. So, these are some of the future challenges or prospects, also the clumping index integration needs to be accurately done to separate the sunlit effect from that of the sun shadowed leaves effect.

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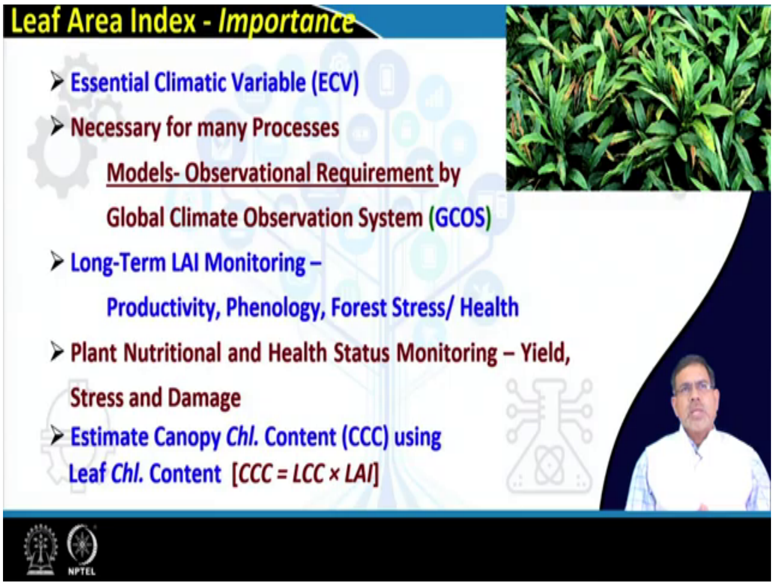

So, next is the importance. So, this importance, we have discussed with respect to the essential climate variables as far as compliance of various international negotiations or treaties are concerned. It is a necessity now for many protocols particularly as far as the GCOS has to what you say expectation is concerned like Global Climate Observation System stands for GCOS.

So, model observational requirements is needed for this. Then, long term LAI monitoring; yes, we need to understand the primary productivity that is what we have been discussing.

So, in terms of long run to understand how much of carbon or what you say water or the related things are getting exchanged. So, in terms of productivity, more probably, we are concerned with respect to the carbon removal from the atmosphere. Then, phenology; yes, then we are concerned about that and there is the different phenological variables or the structures needs to be monitored as far as long term LAI is concerned and also, the plant nutritional and health status in terms of monitoring.

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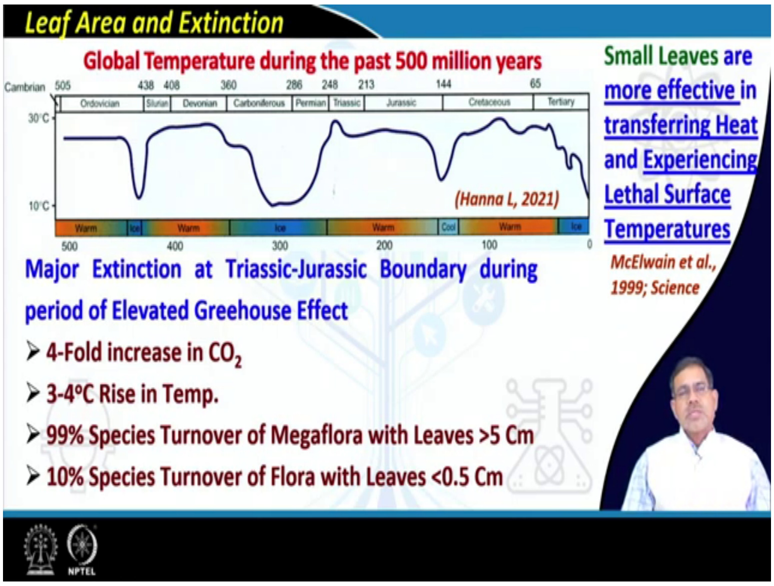

So, friends, the next one is with respect to the extinction and in terms of the long term or evolutionary framework. As far as we discussed earlier in our first lecture that our earth is 4.6 billion years old. In last 500 million years, it has received alteration in terms of ice and warm eras. So, during this, there has been 4-fold increase in the carbon dioxide, 3 to 4 degree rise in the temperature particularly during the Triassic and the Jurassic boundary.

But what was importantly we discussed that during this transition during this what you say major extinction events during the Triassic and Jurassic transition, there has been 99 percent species turnover of the mega flora which have leaves of more than 5 centimeter; but only 10 percent species turnover of the flora has happened which has leaves of less than 0.5 centimeter.

So, that indicates a very strong clue as far as the McElwain published in 1999 in the journal science, the indication is small leaves having less LAI value are more effective in transferring heat and experiencing lethal surface temperature.

So, we need to understand how or if this particular observation or hypothesis is true, then in this warming world, are we receiving or are our leaves are going to be smaller or so, we can make what you say hypothesis around this to see that, what could happen. So, this actually leads to a lot of what you say on revealing of science and for that, what we have discussed in terms of remote sensing based LAI products or the data products are going to help us or will play a major role.

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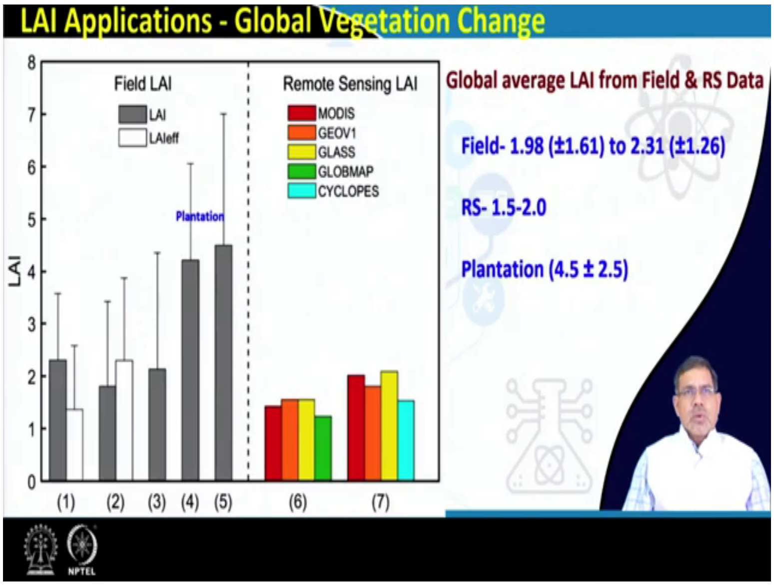

With this, let us come to the applications in terms of global vegetation change. So, this particular figure on the left hand side as we know in the black and white or the gray scale, it is the field LAI has been plotted. The first three as number below the x axis or in the x axis, 1 2 3.

This 1, 2, 3 are from three different studies carried or undertaken by different scientists as far as the field based LAI observation is concerned and look they have and the line represents above this represents the standard deviation and the box represents as you know the value so, or the mean value.

So, the mean and standard deviation, you can very well see that it is varying between something like 1.98 plus or minus 1.61 to 2.31 plus or minus 1.26. So, what I mean to say this field based LAI, where I have means based on the LAI based on the field observation is following this range; whereas, on the right hand side, the colored bars so which are remote sensing derived so that the variation is between 1.5 and 2.0; that means, 1.5 to 2.

So, there is in general, a kind of match between the field LAI and the remote sensing LAI. So, that is the configuration factor. But if you see the fourth and fifth studies, particularly I have mentioned, there has the plantation, there the LAI values goes up to 4.5 and with a standard deviation of 2.5. So, in that sense, it is almost close to double which is coming from the plantations. So, the global average of LAI from field and RS data, they agree to some extent, but they also differ. So, this is very important to understand.

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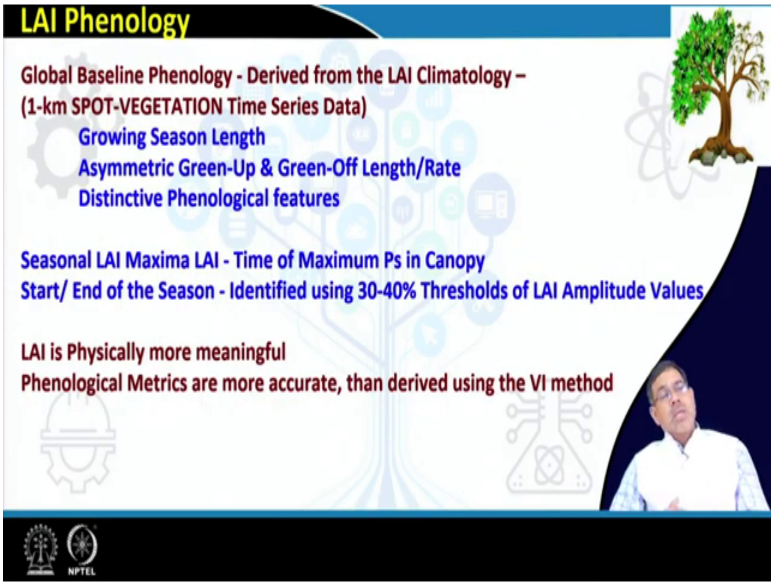

And now, let us see the three applications. The first one is with respect to phenology. The phenology global baseline phenology gives or is derived from the leaf area climatology, particularly using lot of data sets as we have discussed. So, one of them is or could be like for example 1 kilometer spot vegetation time series data.

So, which gives the global baseline phenology derived from the LAI or LAI climatology you say in long run. So, what it indicates? It gives us information, this long or the long term climatology of LAI, it gives us information about the growing season length.

So, if the growing season length is changing or is extending, it shifting or what is the rate of that change if it is, so we get information or good information as far as the LAI climatology data is concerned. Then, coming to the next one is the asymmetric green-up and green-off length and also the rate because different vegetation or different forest types, they will have different what you say growing season length.

So, which will be reflected in terms of the green-up timing and the green-off; that means, the leaf on and leaf off or the leaf fall timing, the length and the rate, so that will vary. So, it is very important to understand and capture this as far as this phenology from the LAI climatology.

The third is many other distinctive features as we can see or correlate because of different phenomena, because of the drought because of the many other stress factors in terms of water stress in terms of any other. So, this actually helps in terms of LAI phenology study as you get a kind of long term climatology in terms of LAI from the satellite data.

Then, the seasonal and the LAI maxima. So, what happens? With respect to this, you can correlate or one can correlate with respect to the maximum photosynthesis, where and when it happens over a year or the minimum photosynthesis at canopy level or whatever level you fill it. So, what happens? The seasonal LAI maxima I mean gives us the timing or information with respect to the photosynthesis, what you say phases, stages or optimum, maximum, minimum or whatever you say.

So, this is very important. And also, you can see the start and end of the season are identified using particularly the start of a season, we usually identify using 30 percent threshold of amplitude values and the end of the season, we use to identify by taking a kind of 40 percent threshold of the LAI amplitude values. So, that is how it is usually done methodologically.

So, LAI is physically more meaningful than others like the vegetation based method. So, what we mean to say that the phenology study using LAI is more meaningful physically than the studies using the other indices like vegetation indices and others. So, that is one very important factor because the LAI climatology actually gives more information from physical point of view.

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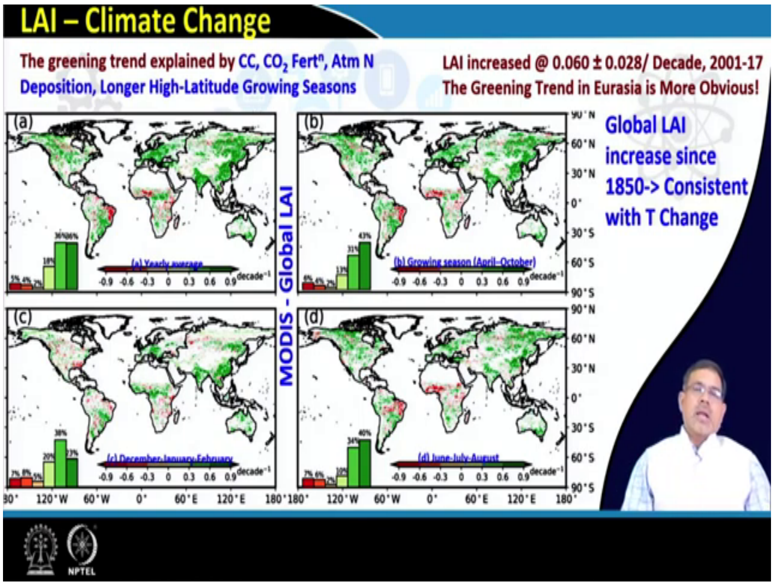

The second one is the climate change. Yes friends, as we have been discussing the global LAI has been observed to increase since 1850 and it has a good corroboration; that means, consistency with respect to rise in temperature which we take temperature variation, we take as one of the important variables of climate change. So, temperature change has been seen as having a good corroboration with respect to the LAI increase look at the 4 figures shown here. They are the MODIS global LAI.

So, a, b, c, d; a represents the yearly average, b represents the growing season average, particularly for April to October month and c represents the growing season average for the average during December to January that is mostly the winter or non-growing and the d represents June to July, June-July-August a what you say pocket within the growing season. So, different bars, they talk about in terms of the percentage of LAI in total. So, if you sum them, it will be 100.

Now, the point is if we see with respect to the b that is the growing season LAI map, we can see there is 43 percent or you say having the higher; that means, the LAI value for means the growing season year. So, you get more that means, 43 percent. So, with respect to the growing season period in April to October. So, this green, this trend the greening trend can be explained by also many more what you say phenomena like climate change because it is consistent with temperature rise.

Second is we also discussed about the CO 2 fertilization or the carbon dioxide fertilization, where the concept is if we have more CO 2 available in the atmosphere, then it is a behaving as a fertilizer or its giving a fertilizer effect as far as the photosynthesis is concerned and so, that is what also can be related and the atmospheric nitrogen deposition or the deposition of nitrogen or atmospheric nitrogen is increasing day by day because of anthropogenic activities.

And also, the growing seasons are becoming longer on higher latitude that is also one of the, what you say characteristic or the reflection with respect to the climate change. So, what happens? at high altitude, the growing season gets longer. So, to give an example, if you earlier you are getting 120 days in at 45 or 50 degree, what you say north latitude, now perhaps you may be getting instead of 120, you may be getting 122 days.

So, that is because of the rise in temperature. So, more and more area are becoming productive. So, we say that the growing seasons are getting longer at the higher altitude. And coming to the rate, the LAI increased at the rate of 0.060 plus or minus 0.028 in terms of standard deviation per decade between 2001 and 2017. So, this evidently has come from the remote sensing based LAI climatology.

So, look at this that LAI has been increasing relatively it has increased relatively in last 2 decades and more so, this increase or the greening trend of the LAI is more obvious or more reflected in the Eurasia which are the higher latitude areas, it is more prominently observed. So, these are very important because this LAI climatology helps us in understanding different climatology ok. So, this is very important.

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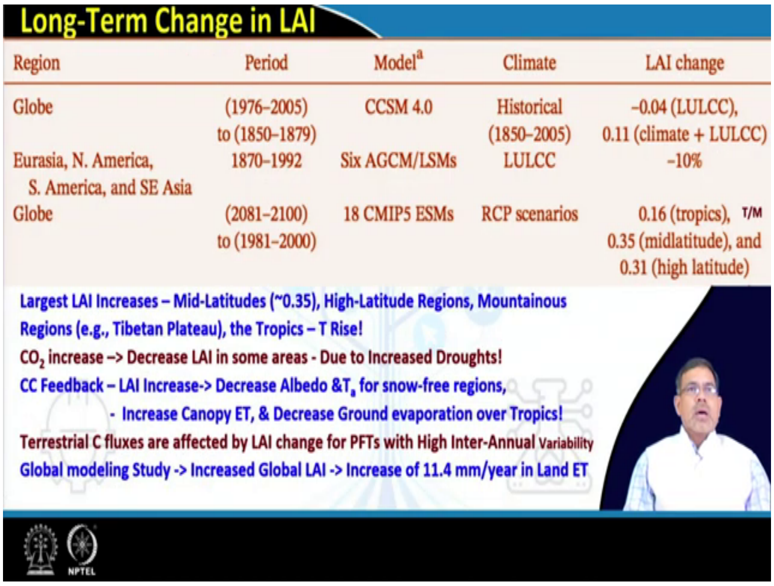

The long term change in LAI in terms of few model based outputs, we have seen from past and the current one that when as a kind of global sense, the largest LAI increase has happened with which is about 35 percent in terms of high latitude areas, which has been reported or in terms of mountainous areas and in tropics, it is about 0.16 percentage.

So, this can be linked with temperature rise and for tropics, it is also constant or related to moisture also. So, CO 2 increase leads to decrease in the LAI in some areas. So, a kind of stress factor in terms of drought and in terms of climate change feedback, the LAI increase leads to decrease in albedo and the air temperature for the snow free regions and also, increase in canopy above transpiration and decrease in the ground evaporation over the tropics.

So, what happens? The terrestrial carbon fluxes are affected by the LAI change for the PFTs are the Plant Functional Types with high inter annual variability. So, global modeling study leads to increase in global LAI and helps which has been reported in terms of increase of 11.4 mm per year in terms of land evapotranspiration.

So, these model outputs help us in understanding look at the first one in terms of global output, where it is mentioned the third means the on the right column and the third row it is mentioned 10 percent or minus 10 percent. So, this is what this explains that because of the land use, land cover change or the deforestation. So, the LAI or the global LAI has decreased by 10 percent, but as far as the RCPs are climate related is concerned.

So, at the high latitude there is 31 percent rise, mid latitude 35 percent; whereas, in tropics, it is 16 percent rise in terms of or increase in terms of LAI. So, these kind of model based outputs based on the LAI climatology helps us in understanding what is happening or how the response of LAI or vice versa, climate response to LAI or LAI response to climate change is actually easy to understand or gives us information to understand.

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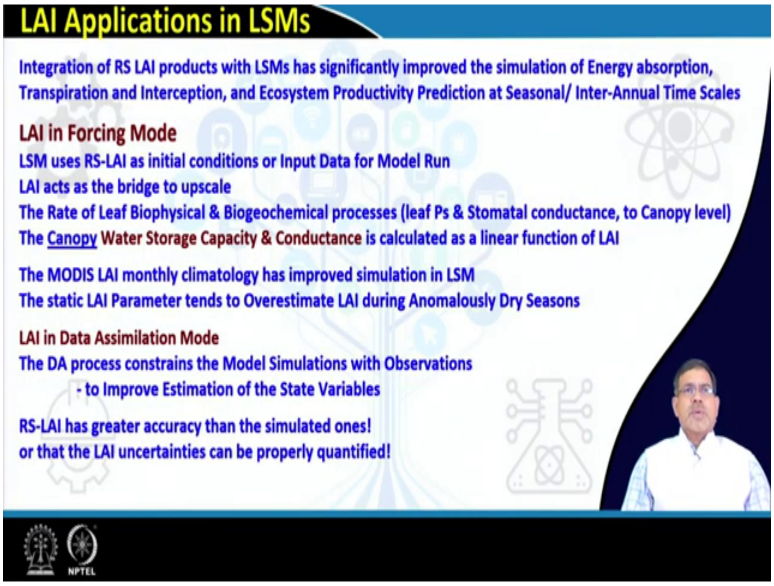

So, now, coming with respect to the application to land surface models. So, the integration of remote sensing LAI products with land surface models has significantly improved the simulations of energy absorption, transpiration and interception and also, the ecosystem productivity prediction at various time scale.

You can keep it seasonal, annual, inter annual and things like that and this in terms of its integration in the land surface models, the RS products integration of LAI based or a RS based LAI products integration with the land surface models happens in two ways. It could happen as a forcing mode or it can happen as a data assimilation or DA mode.

So, though LSM, Land Surface Models use remote sensing derived LAIs as initial condition or input for model run and also, these LAI they act as a bridge or helps in off scaling from leap to canopy to ecosystem to a regional and global scale. So, LAI provides a basis. And the rate of leaf biophysical and biological processes such as leaf photosynthesis, stomatal conductance to canopy level, so the canopy water storage capacity and the canopy conductance is also calculated as a linear function of LAI.

So, look the LSM models how they use or how they parameterize the LAI to simulate lot of what you say leaf biophysical and biogeochemical processes including the stomatal conductance, the water storage capacity, the canopy conductance many, so many equations, they go as a linear function to make it more universal in terms of up scaling; but there are also complexities.

The MODIS LAI based monthly climatology has improved simulation in LSM. So, MODIS LAI which is there since 2000, so researchers they have taken it and found that the LSM outputs have improved or simulations have improved; but the difficulties, the static LAI parameter which goes mostly in terms of forcing mode or as input data for model run, sometime it tend to overestimate the LAI during anomalous dry season or I would say during anomalous season.

So, the other mode that is DA, the data assimilation mode helps in that. So, the DA process, it constrains the model simulations with observations and thereby, it improves the estimation of the state variables. So, remote sensing derived LAI has greater accuracy than the simulated ones or that the LAI uncertainties can be properly quantified in the LSMs.

So, the point here in this discussion is LAI is integrated or LAI remote sensing derived LAI products are integrated in LSM models so that there is improvement in the simulation of various steps that characterizes the energy absorption, transpiration, interception and also the primary production.

So, this is what we wanted to discuss as far as the important applications of the LAI in understanding various phenomena such as phenology, climate change and also, input or integration to the land surface models.

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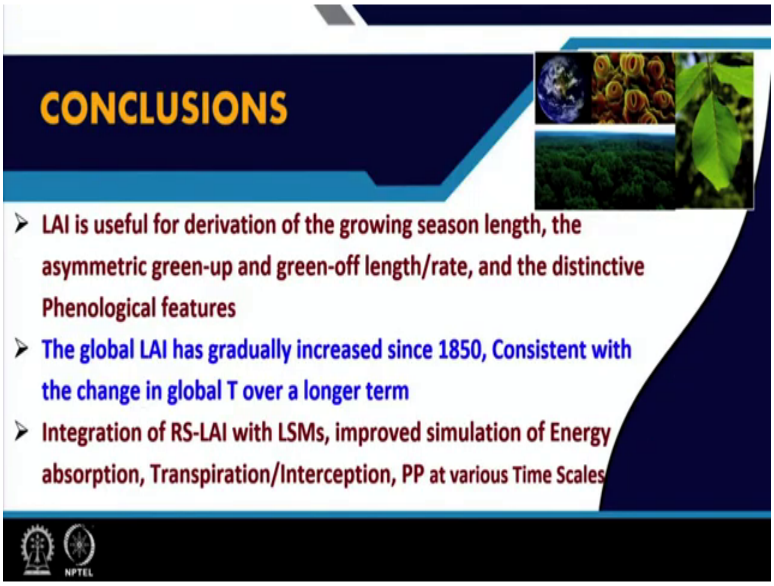

Thank you and then, we have the reference, the same, Fang's paper and I have taken the same three points as our conclusion.

Thank you very much.