# SPATIAL AND SEASONAL CHARACTERIZATION OF TERRESTRIAL BIOSPHERIC CARBON FLUX OVER INDIA USING GOSAT DATA

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**ABSTRACT:**

Carbon plays a crucial role in determining the ecosystem balance and slight changes in its concentration in the atmosphere can have significant impacts. The launch of JAXA's GOSAT (Greenhouse gases Observing SATellite) in 2009 has started a new era of high accuracy $CO_2$ concentration and flux measurements from space borne sensors. This paper reports the spatial and temporal variability of terrestrial biospheric carbon fluxes over the agro-climatic zones of India derived using GOSAT data for the period June 2009 to October 2011. The country averaged biospheric carbon flux varied from -0.47 (October) to 0.37 (April) gC $m^{-2}$ $day^{-1}$. Maximum variability in fluxes was observed for the North-Eastern region (-2.18 to +1.38 gC $m^{-2}$ $day^{-1}$) whereas the dry region of Rajasthan showed extremely low values (-0.1 to +0.1 gC $m^{-2}$ $day^{-1}$). The temporal variation in flux values was compared to averaged NDVI for each zone and indicated that growing season corresponds to more sequestration of carbon from the atmosphere. We compared GOSAT derived biospheric flux with Carbon Tracker (CT) data and observed that the two values show good agreement for all months except June and July. This study provides new estimates of biospheric carbon flux using satellite data driven models to better understand the carbon dynamics associated with terrestrial biosphere over India.

## 1. INTRODUCTION

The study of terrestrial carbon sources and sinks is crucial for understanding key components of climate change. Regional carbon flux is important for monitoring the state of biosphere health and carbon exchange processes (Bonan 1995; Chen et al., 2000). Biospheric carbon flux is a critical indicator of climate and environmental changes (Schimel et al., 1995).

India is identified as one of the hotspots for carbon sequestration and its role in shaping the carbon budget of the world due to its diverse vegetation (Bhat and Ravindranath 2011). In recent years, many studies have been carried out to analyse the spatio-temporal variations in NPP (Net Primary Productivity) over India using different ecosystem models (Dadhwal and Nayak, 1993; Chhabra and Dadhwal, 2004; Panigrahy et al., 2004; Singh et al., 2011; Nayak et al., 2013). These studies focus on state of vegetation to estimate carbon fluxes and thus have the limitation of varying time scales and models / datasets (Dadhwal, 2012). Also, the model outputs can themselves be far off from the true values of flux. This calls for carbon flux estimation and monitoring using new and more advanced methods.

Existing carbon flux inventories, such as Carbon Tracker which is developed and maintained by the Earth System Research Laboratory (ESRL) at National Oceanographic and Atmospheric Administration (NOAA) (Peters et al, 2007), employs a modified version of Carnegie-Ames-Stanford-Approach (CASA) biogeochemical model (van der Werf et al.,2006) to estimate apriori fluxes (Valsala, 2013) and then constrain them using flux tower measurements. CASA model uses NDVI values obtained from space borne sensors and various other inputs to estimate the biospheric flux.

GOSAT launched in 2009 by JAXA, provides a unique platform to measure carbon dioxide concentration from space at very high resolution using its FTS (Fourier Transform Spectrometer) instrument (Morino et al., 2011). These observations act as input to inversion model which estimate carbon fluxes with unprecedented accuracy. This top-down approach of estimating carbon flux involves direct observation of the atmosphere and the accuracy of these measurements has been established using rigorous validation (Maksyutov et al., 2013).

A recent study (Valsala et al., 2013) has shown the intra-seasonal variability of terrestrial biospheric fluxes over India during summer monsoon using Carbon Tracker dataset. Different inversion models (Maksyutov et al.,2012 and 2013; Basu et al., 2013) have been used to estimate global carbon fluxes optimised at varying spatial resolutions. However, few studies focus on carbon flux estimation over India for a considerable period of time and there exists a gap in understanding the weather associated biospheric flux variations.

In this study, we present new estimates of biospheric carbon fluxes over India for the period of June 2009 to October 2011 using GOSAT data. This paper reports the spatial analysis of carbon flux over the agro-climatic zones of India followed by the temporal variations over these regions highlighting the time of year when a region behaves as a source or sink of carbon. Validation of GOSAT derived flux values was carried out using Carbon Tracker dataset. Future work will involve decoupling the influence of regional weather parameters on carbon flux values.

## 2. STUDY AREA AND DATA USED

Study was carried out over India extending from $8^oN$ to $37^oN$ and $68^oE$ to $98^oE$. With 329 million hectares of geographical area, the country presents a large number of complex agro-climatic situations. Planning Commission has delineated 15 agro-climatic regions/zones which were proposed to form basis for agricultural planning for the Eighth Plan, 1988. This sub-division is done on the basis of commonality of various factors like soil type, rainfall, temperature etc. Locations of the 15 agro-climatic regions in India are shown in Figure 1 and states located in the regions are given in Table 1. We have used a modification of this classification to understand the spatial variability of carbon fluxes over the country. The new region codes are mentioned in the last column of Table 1 (A-I), having merged few zones while retaining the others. Zone 15, comprising of islands and our data resolution being much lower than their size, was subsequently neglected for the purpose of this study.

The country experiences warm and humid climate during the southwest monsoon and receives more than 80% of the total annual rainfall during this season. The northeast monsoon is cold and dry; therefore southern parts of the country receive significant rainfall during this period. The two inter-monsoonal periods are mostly dry and moderately warm.

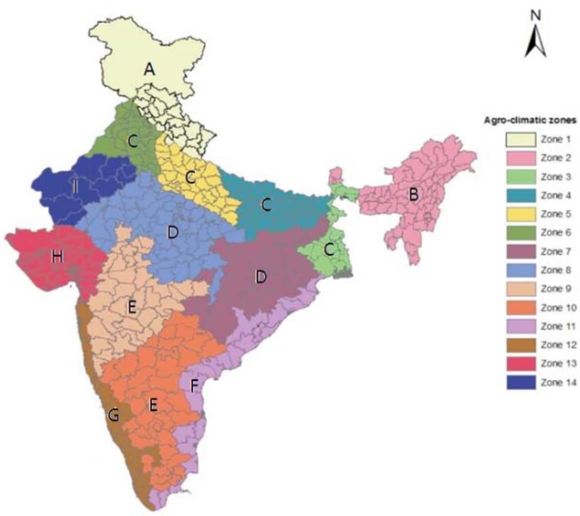


Figure 1. Agro-climatic zones and states/districts located in the regions Source: Khanna (1989)

GOSAT $CO_2$ flux level L4A 1°x1° gridded monthly global data was acquired for the period of June 2009 to October 2011 from GOSAT user interface gateway(GUIG; http://data.gosat.nies.go.jp). The details of data processing algorithms for generating the $CO_2$ fluxes from GOSAT TANSO-FTS SWIR Level 2 column-averaged $CO_2$ concentration are presented in Maksyutov et al. (2013). This dataset contains monthly imposed biospheric, fossil, biomass burning and oceanic $CO_2$ fluxes and the optimised total $CO_2$ flux.

NDVI (Normalised Difference Vegetation Index) dataset was acquired from MODIS at 500 metres resolution and Carbon Tracker (CT) dataset (developed by ESRL at NOAA) version 2011 for the period from June 2009 to December 2010 provided the optimised terrestrial biospheric fluxes which were used for comparison.

## 3. METHODOLOGY

Computation of imposed terrestrial biospheric flux utilises VISIT model (Vegetation Integrative Simulator for Trace gases), a prognostic biosphere model (Ito 2010, Saito et al., 2011) which simulates the carbon cycle in the terrestrial biosphere and is further optimised to match the GOSAT observations (Maksyutov et al., 2012, Saito et al., 2013). The total optimised surface flux ($F_{all\_optimised}$) for a given location 'x' and time't' can be represented as given in Eq. 1 (Peters et al 2007).

$$F_{all\_optimised}(x,t) = \lambda_1(x,t).F_{bio\_imposed}(x,t) + \lambda_2(x,t).F_{oce\_imposed}(x,t) + F_{fossil}(x,t) + F_{biomass\_burn}(x,t) \quad (1)$$

Where $\lambda_1$ and $\lambda_2$ are the optimisation coefficients generated after the inverse model was run. $F_{fossil}$ is the flux generated by the burning of fossil fuels, $F_{biomass\_burn}$ is the flux due to burning of biomass, $F_{bio\_imposed}$ is modelled biospheric flux and $F_{oce\_imposed}$ is the imposed oceanic flux. GOSAT L4A dataset contains all these components individually at regional as well as gridded formats. Using the above equation, the optimised biospheric flux can be computed for a given region on land by subtracting fossil and biomass burning fluxes from total optimised surface flux.

Biospheric $CO_2$ fluxes for the months ranging from June 2009 to October 2011 were generated at a spatial resolution of 1°x1°. The regions of Andaman and Nicobar Islands and Lakshadweep were not considered for this study as their size was in the sub-pixel level. The regions mentioned in Table 1 were subset from the flux images for performing the spatio-temporal variability analysis of flux values. An error term of $\pm 1\sigma$ (standard deviation) was associated with the values of biospheric flux.

Biospheric fluxes for same months of different years were averaged and monthly averaged flux maps were generated for the country at $1^o$ resolution to represent the spatial variability. To represent the temporal variations, NDVI values averaged for each region (A-I) was plotted along with the biospheric flux and its one standard deviation range was represented using the shaded error bar.

All along this paper, we move with the convention that negative values of fluxes indicate a net uptake of atmospheric $CO_2$ by the biosphere, whereas positive values indicate release of $CO_2$ to the atmosphere. These values have the units of g C $m^{-2}$ $day^{-1}$. Average flux values for each month were generated for every pixel within the study area.

Validation of GOSAT $CO_2$ biospheric fluxes was carried out using Carbon Tracker (CT) v2011 dataset obtained for the period from June 2009 to December 2010. CT data consists of optimised biospheric fluxes at 1°x1° grids at a global scale. CT flux is available in mol $m^{-2}$ $sec^{-1}$ which was converted to gC $m^{-2}$ $day^{-1}$. Country averaged biospheric carbon fluxes derived from both these datasets were plotted along with their individual standard deviations as error bars. Future study will focus on understanding the influence of regional weather parameters on these flux values.

| Zone No. | Agro-climatic regions/zones | States represented | New Region |
|---|---|---|---|
| 1 | Western Himalayan region | Himachal Pradesh, Jammu and Kashmir, Uttarakhand | A |
| 2 | Eastern Himalayan region | Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, West Bengal | B |
| 3 | Lower Gangetic plain region | West Bengal | C |
| 4 | Middle Gangetic plain region | Uttar Pradesh, Bihar | |
| 5 | Upper Gangetic plain region | Uttar Pradesh | |
| 6 | Trans Gangetic plain region | Chandigarh, Delhi, Haryana, Punjab, Rajasthan | |
| 7 | Eastern plateau and hills region | Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Orissa, west Bengal | D |
| 8 | Central plateau and hills region | Madhya Pradesh, Rajasthan, Uttar Pradesh | |
| 9 | Western plateau and hills region | Madhya Pradesh, Maharashtra | E |
| 10 | Southern plateau and hills region | Andhra Pradesh, Karnataka, Tamil Nadu | |
| 11 | East coast plains and hills region | Andhra Pradesh, Orissa, Pondicherry, Tamil Nadu | F |
| 12 | West coast plains and hills region | Goa, Karnataka, Kerala, Maharashtra, Tamil Nadu | G |
| 13 | Gujarat plains and hills region | Gujarat, Dadra& Nagar Haveli, Daman & Diu, Rajasthan | H |
| 14 | Western dry region | Rajasthan | I |
| 15 | Island region | Andaman & Nicobar, Lakshadweep | Not used |

Table 1 Details of the agro-climatic zones and the new Regions created by merging them.
Source: Planning Commission (Khanna, 1989)

## 4. RESULTS AND DISCUSSION

### 4.1 Spatial and temporal variability of biospheric flux

The optimised mean biospheric flux for the study region varied between -0.47 (October) to 0.37 (April) gC $m^{-2}$ $day^{-1}$, where negative sign indicates a net uptake of carbon from the atmosphere and positive sign denotes release of $CO_2$ to the atmosphere by the terrestrial biosphere. This is in accordance with the high vegetation cover during the monsoon season leading to more uptake of carbon, whereas the hot and dry conditions during summer months result in release of carbon to the atmosphere. Maximum variability in fluxes was obtained for north-eastern region (region B:-2.18 to +1.38 gC $m^{-2}$ $day^{-1}$) of India followed by the Western Ghats (region G:-1.55 to 1.24 gC $m^{-2}$ $day^{-1}$). The dry region of Rajasthan (region I) showed extremely low variability with values ranging from -0.1 to +0.1 gC $m^{-2}$ $day^{-1}$.

The flux values were minimum in regions B to I during the month of October and maximum in months of April-May. The pattern of change in biospheric flux during July to October matched with the onset and progress of Indian south-western monsoon. During winter months of December to February, biospheric flux was negative in most parts of the country which might be due to the growing season of Rabi crops.

This was followed by the hot and dry summer season where the flux was mostly positive except for the north eastern region. This can be attributed to senescence stage of most of the vegetation types, particularly agriculture crops and deciduous forest types. The microbial activity during this period also results in release of carbon to the atmosphere. Increased vegetation activity during south-west monsoon (June-September) was the reason for negative biospheric flux. The flux values were unexpectedly positive in the North-eastern states (Region B) during the months of July and August which may be due to various factors like errors in apriori estimation or lack of control over flux during the inversion process.

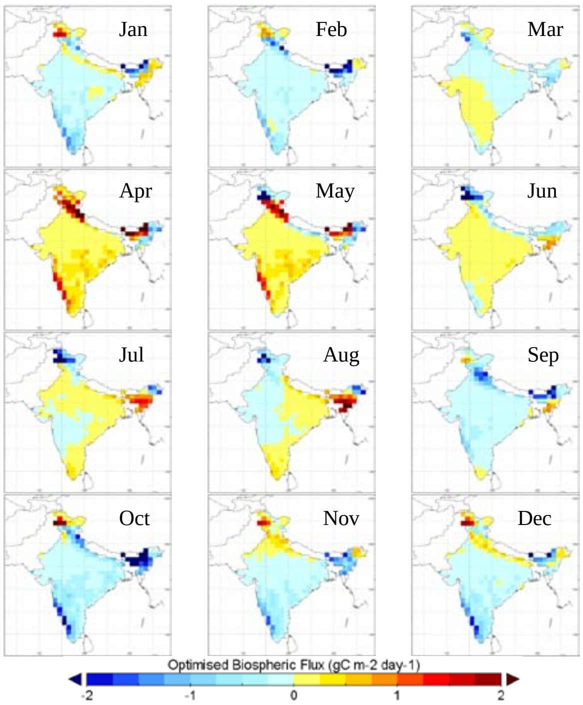


Figure 2. Monthly averaged biospheric carbon flux for the study region.

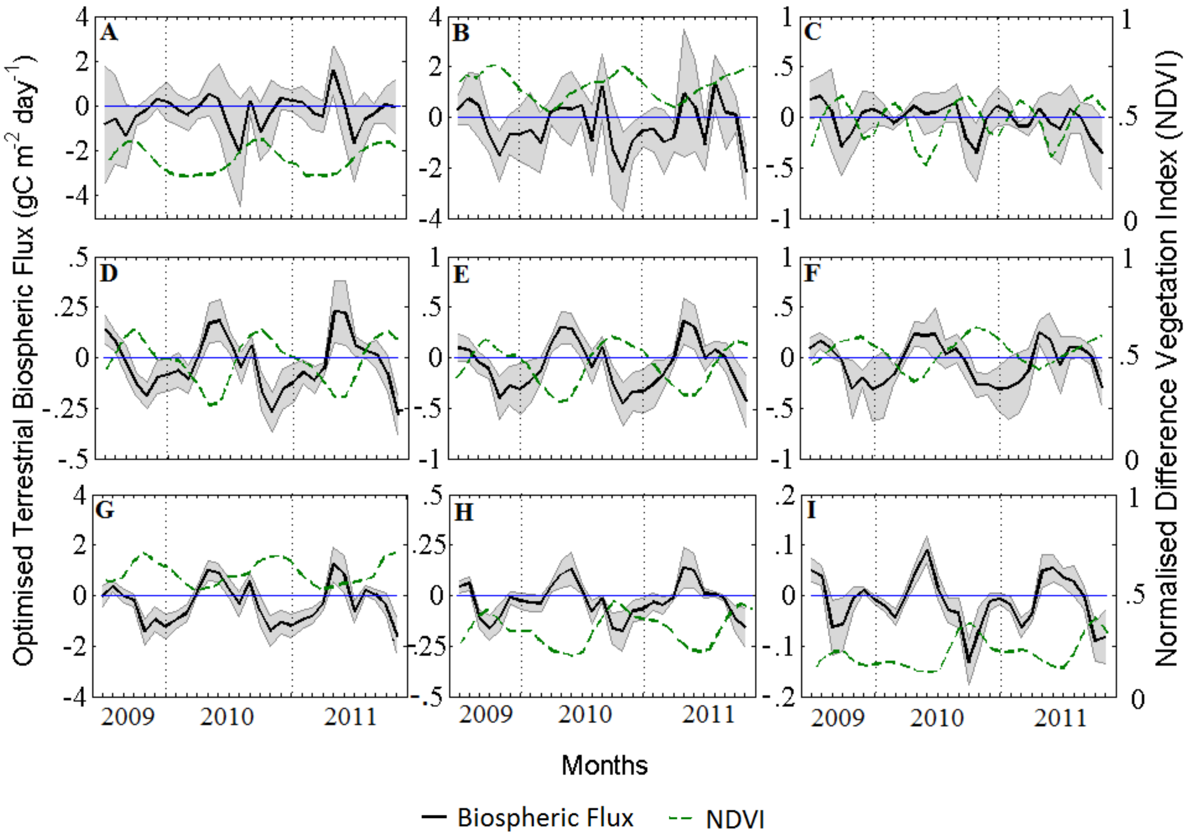


Figure 3. Seasonal variability of optimised terrestrial biospheric flux and NDVI in agro-climatic regions of India during June 2009 to October 2011. The solid line represents mean flux and the shaded region is 1 $\sigma$ error.

**4.2 Comparison between GOSAT and CT derived flux**

The optimised terrestrial biospheric flux obtained from Carbon Tracker (CT) v2011 dataset for India was compared to that derived from GOSAT, for the period June 2009 to December 2010. Figure 4 shows the comparison between the values with the error bars representing 1σ deviation. The two values seem to converge for the months of September to February indicating good agreement; however, for the months of June-July, we observe the maximum departure from the mean.

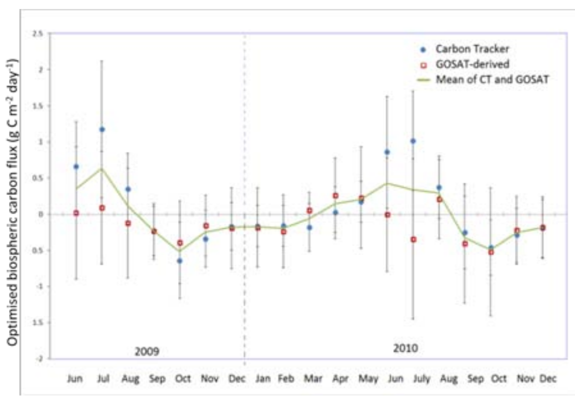


Figure 4. Mean optimised terrestrial biospheric flux for India obtained from Carbon Tracker plotted against that obtained from GOSAT for June 2009 to December 2010. The error bars represent ±1σ for each dataset.

Maximum difference in the two values was observed for the month of July 2010. This could be attributed to various factors like different models to compute fluxes, varying inputs for the two approaches, high deviation in the two values and lack of *in-situ* observations to control the model outputs.

## 5. CONCLUSION

Optimised terrestrial biospheric carbon fluxes were derived using GOSAT data and its spatial and temporal variability was studied over India for the period June 2009 and October 2011. The mean biospheric flux for study region varied between -0.47 (October) to 0.37 (April) gC $m^{-2}$ $day^{-1}$. North-Eastern region showed highest flux values whereas, the dry region of Rajasthan showed the least. Flux values became negative (indicating carbon sequestration) during the growing season whereas, it was mostly positive during the hot and dry summer season. GOSAT derived carbon flux was compared to that obtained from Carbon Tracker and these datasets showed good agreement except for the months of June and July. This study reports new estimates of biospheric carbon flux using satellite data driven models and rigorous validation is required using flux towers within India to further improve it.

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