INCREASING TREND IN NET CARBON FIXATION BY INDIAN AGRO-ECOSYSTEM ESTIMATED USING NOAA—AVHRR BASED GLOPEM MODEL

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KEYWORDS: Remote Sensing, Net Primary Productivity, Agro-ecosystem, Carbon Fixation, Climate Change, Biogeochemical Cycle, NOAA-AVHRR, SPOT-VEGETATION.

ABSTRACT:

The monitoring of terrestrial carbon dynamics is important in studies related with global climate change. This paper reports the inter-annual variability of Net Primary Productivity (NPP) from 1981-2000 derived using observations from NOAA-AVHRR data using GloPEM model. The GloPEM model is based on physiological principles and uses the production efficiency concept, in which the canopy absorption of photosynthetically active radiation (APAR) is used with a conversion "efficiency" to estimate gross primary production (GPP). NPP derived from GloPEM model over India showed maximum NPP about 3000 $gCm^{-2}year^{-1}$ in west Bengal and lowest up to 500 $gCm^{-2}year^{-1}$ in Rajasthan. The India averaged NPP varied from 1084.7 $gCm^{-2}year^{-1}$ to 1390.8 $gCm^{-2}year^{-1}$ in the corresponding years of 1983 and 1998 respectively. The regression analysis of the 20 year NPP variability showed significant increase in NPP over India (r=0.7, F=17.53, p < 0.001). The mean rate of increase was observed as 10.43 $gCm^{-2}year^{-1}$. Carbon fixation ability of terrestrial ecosystem of India is increasing with rate of 34.3 TgC annualy (t= 4.18, p < 0.001). The estimated net carbon fixation over Indian landmass ranged from from 3.56 PgC (in 1983) to 4.57 PgC (in 1998). Grid level temporal correlation analysis showed that agricultural regions are the source of increase in terrestrial NPP of India. Parts of forest regions (Himalyan in Nepal, north east India) are relatively less influenced over the study period and showed lower or negative correlation (trend). Finding of the study would provide important input in understanding the global change associated with vegetation activities as a sink for atmospheric carbon dioxide.

1. INTRODUCTION

Net primary productivity (NPP) is an important component of the global carbon cycle because it provides a measure of the amount of CO_2 removed from the atmosphere through photosynthesis and respiration (Bonan, 2008). NPP is a key component of the terrestrial carbon cycle and forms the fundamental process in biosphere for assessing the carbon balance at the regional and global scale (Nemani et al. 2003, Knapp & Smith 2001). Accurate estimation of NPP is required to understand the carbon dynamics within the atmosphere–vegetation– soil continuum and the response of terrestrial ecosystem to future climate change (Fang et al. 2001).

Field based NPP measurements have been conventionally carried out using long tem ecological monitoring of biomass in selected ecological site. Most frequently, peak-standing biomass is assumed to measure NPP in grassland ecosystem. Methods to measure forest productivity are more diverse than those of grasslands. Biomass increment based on stand specific allometry plus litterfall is used to estimate NPP. *In-situ* NPP measurements are limited by its spatial distribution, which are difficult to upscale for understanding the global carbon balance. Satellites remote sensing provides a valuable source of information on the global distribution as well as inter annual variations in NPP (Sabbe & Veroustraete 2000).

The various ecological models (ZhiQiang & JiYuan 2008, Running and Coughlan 1988, Nemani et al. 1993) have been developed by many ecologists or researchers, among which Biogeochemical (BGC) models are most preferred. Three BGC models widely used in the Vegetation/Ecosystem Modelling (VEMAP 1995) are CENTURY model, Terrestrial Ecosystem Model (TEM) and BIOME-BGC model. BIOME-BGC (Thornton, 1998, Running and Gower 1991) employs biochemical model of photosynthesis, environmentally regulated stomatal conductance, and explicit calculations of respiration for various plant pools to calculate NPP. Such modeling uses a large set of input parameters, some of them hardly available or measurable on a regional or continental basis. Quite often these models become complex to cope with the validation realities imposed by field measurements. The gap between stand scale measurements and regional scale modeling, can be bridged by the use of observations from earth observing platforms. GloPEM models use moderate number of inputs observable from satellite data and can be implemented at landscape to global scale. Present analysis is based upon the annual NPP products derived using NOAA-AVHRR data (1981-2000) using GloPEM technique (Prince & Goward, 1995).

Global investigation of vegetation responses to climatic changes based on historical satellite data records have shown significant

increase in NPP significantly (P < 0.01) over 25% of the global vegetated area, with a mean rate of 6.3 g C m^{-2} year. There have been few, year specific studies related with assessment of carbon fixation over India using SPOT-VEGETATION NPP product. Chhabra and Dadhwal (2004) estimated monthly net primary productivity over India and its eight regions, using SPOT-VEGETATION 10-day NPP composites. Although many studies use calendar year for reporting NPP, they adopted an agriculture year (June 1998–May 1999) to better represent the effect of monsoon and the role of agroecosystem in controlling NPP over India. Total net C fixation of India was estimated as 2.18 PgC and highlighted that strong monthly variation in NPP across different regions of India with high net carbon fixation in winter as compared to monsoon season. In another study, Panigrahy et al. (2004) analyzed the spatio-temporal pattern of agricultural NPP in India using SPOT-VEGETATION 10-day composite NPP product for 2002-03 to 2004-05 agricultural years. They emphasized the dominant role of agroecosystem in Indian NPP scenario. Analysis of SPOT-VEGETATION NPP product showed that under normal monsoon performance (June 2004-May2005) the NPP of Indian landmass is 2519.13TgC. Agriculture account for a little more than 60 per cent of total NPP. Reduction of NPP in the monsoon deficit year (2002-03) in the agriculture and forest was of the order of 26 and 21 per cent respectively showing strong influence of precipitation on terrestrial NPP. The study could highlight strong seasonal variations among the crop rotations and year-to-year variation due to monsoon performance. Present study was aimed at analysing long term (20 years) satellite based records of NPP over Indian region generated using NOAA-AVHRR data. Spatial variability, decadal change and inter annual trend in NPP was analysed using 1981-2000 data.

2. STUDY AREA AND DATA USED

Study area is located between 65° E to 100° E and 5° N to 40° N covering Indian landmass. Study area consists of irrigating cropland, rainfed cropland, evergreen broadleaved, evergreen needle leaf, deciduous forest, mixed forests, woody savannas, savannas, open shrubland, barren/sparse vegetation and water bodies. Figure 1 shows the land cover map showing different vegetation type in India. Vegetation in Indian terrestrial ecosystem is generally controlled by weather and soil type. Different soil type with different climate has different abundance of natural vegetation and agricultural system. Large variation in climatic regime in India has given rise to various ecosystems containing evergreen, semi evergreen, deciduous forest system with broad leave and needle leaf architectures varying with different specific leaf areas. The NPP estimates from 1981 to 2000 were derived from NOAA-AVHRR sensor data using GloPEM approach.
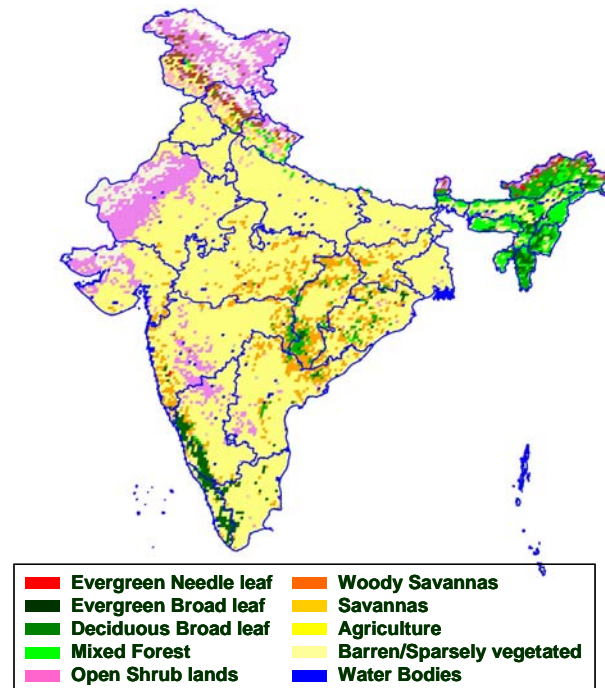

Figure 1. Land Cover Map (IGBP Version 2.0) Showing Different Vegetation Types in India (IGBP Source: http://edcdaac.usgs.gov/glcc/globdoc1_2/html)

3. METHODOLOGY

The analysis was carried out using 20-years historical records of global annual NPP values generated using GloPEM approach by University of Maryland USA (Prince & Goward, 1995). The Indian region was extracted from the global product. India specific aggregation of carbon fixation was estimated as well as pixel level linear trend analysis was carried out using geostatistical technique.

The pixel level temporal trend in annual NPP over Indian subcontinent was modelled as

$$NPP\ (gCm^{-2}year^{-1}) = m\ t + c \qquad (1)$$

where m is the slope, c is the intercept of the model and t represents years from 1981. The slope (m), intercept (c) and correlation coefficient (r) was estimated at each pixel of the study region. Decadal level relative deviations (RD) in NPP were also estimated between averaged 1981-190 and 1991-2000 data to identify the regions of increasing and decreasing vegetation activity.

Decadal Relative Deviation in percent (RD%) was estimated as

$$RD\ (\%) = 100*((NPP_{D1} - NPP_{D2})\ /NPP_{D1}) \qquad (2)$$

where d1 and d2 represent decadal period from 1981-1990 and 1991-2000 respectively. The positive value shows the increasing vegetation and negative values represent decline in vegetation. The difference in decadal mean (NPP_{D1} - NPP_{D2}) was considered for change detection to avoid the inter annual fluctuations in vegetation due to weather variability. The temporal correlation analysis and

relative deviation measure were compared to confirm the findings related with areas of increasing vegetation activities.

3.1 Global Production Efficiency Model (GloPEM)

GloPEM model (Prince 1991, Prince & Goward, 1995, Goetz et al. 2000)) utilizes the production efficiency concept (Kumar and Monteith, 1981) globally, in which the canopy absorption of photosynthetically active radiation (APAR) is used with a conversion "efficiency" or carbon yield of APAR for estimating gross primary production (GPP). The GloPEM model is based on physiological principles; in particular the amount of carbon fixed per unit APAR is modeled rather than fitted using field observations. Advanced Very High Resolution Radiometer (AVHRR) images at an 8 km resolution from the AVHRR Pathfinder Project were used in analysis. These data are radiometrically calibrated and cloud-screened but are not corrected for atmospheric attenuation. The amount of incident Photosynthetically Active Radiation (PAR) was derived from Total Ozone Mapping Spectrometer (TOMS) ultraviolet observations of cloud cover, which are used to modify incident PAR as derived from a clear sky model. Fraction of incident PAR absorbed by terrestrial vegetation (fAPAR) was estimated using spectral vegetation index (SVI). Surface radiometric temperature (Ts) and atmospheric column precipitable water vapor amount (U) are derived from thermal measurements in different spectral wavelength bands (the "split-window" approach). The regression relationship between a moving window array of SVI and Ts values (termed TvX) is used to derive an estimate of ambient air temperature (Ta) by extrapolating to a high SVI value (~0.9) that represents an infinitely thick canopy. It is assumed that canopy and air temperature are equivalent at this point. The atmospheric water vapor amount (U) was extrapolated to the surface and used to estimate surface humidity and dew point temperature. When combined with Ta this was used to calculate vapor pressure deficit (VPD). The potential amount of carbon fixation per unit Absorbed PAR is calculated from the quantum yield of photosynthesis and a climatological mean air temperature to differentiate between photosynthetic pathways (C3, C4). Potential carbon fixation is reduced by "stress" factors related to plant physiological control (i.e., Ta, VPD, soil moisture) to derive actual carbon fixation in the form of gross primary production (GPP). Respiration related to the growth and maintenance of biomass is subtracted from GPP to derive global net primary production (NPP).

4. RESULTS AND DISCUSSION

The figure 1 shows the land cover map showing different vegetation types and figure 2 shows the spatial variability of decadal mean NPP (1991-2000) were India. NPP derived from GloPEM model over India showed maximum NPP about 3000

$gCm^{-2}year^{-1}$ in agriculture region of west Bengal and lowest up to 500 $gCm^{-2}year^{-1}$ in arid region of Rajasthan. The NPP mostly varied from 1000 $gCm^{-2}year^{-1}$ to 2000 $gCm^{-2}year^{-1}$ in agricultural areas of indo-gangetic basin due to variation in irrigation and cropping intensity. The inter annual variations in average India NPP ranged from 1084.7 $gCm^{-2}year^{-1}$ to 1390.8 $gCm^{-2}year^{-1}$ in the corresponding years of 1983 and 1998 respectively. The year wise mean and standard deviation in average annual NPP of India is given in table 1.

Year	Mean NPP $(gCm^{-2}y^{-1})$	Std. Dev.
1981	1245.39	555.81
1982	1130.13	519.05
1983	1084.77	513.39
1984	1258.51	553.98
1985	1118.12	542.80
1986	1152.75	612.44
1987	1134.74	560.48
1988	1253.96	595.06
1989	1270.26	588.05
1990	1284.37	586.59
1991	1185.63	553.03
1992	1212.24	531.00
1993	1250.29	554.59
1994	1302.12	564.31
1995	1148.23	520.40
1996	1297.97	583.96
1997	1348.53	591.66
1998	1390.80	589.64
1999	1349.80	597.10
2000	1327.89	585.99

Table 1: Average Annual NPP Estimated for Indian Region Using NOAA-AVHRR Data

The regression analysis of the 20 year NPP variability showed significant increase in temporal trend of NPP over India (r=0.7, F=17.53, p < 0.001). The mean rate of increase was observed as 10.43 $gCm^{-2}year^{-1}$. Figure 3 shows the year wise variation in carbon fixation of Indian ecosystem. It can be seen from figure 3 that carbon fixation ability of terrestrial ecosystem of India is increasing with rate of 34.3 TgC annualy (t= 4.18, p < 0.001). The estimated net carbon fixation over Indian landmass ranged from from 3.56 PgC (in 1983) to 4.57 PgC (in 1998). Figure 4 shows the gridded map of correlation between NPP with respect to years. Every pixel (grid) in the image was independently analysed for arriving at increasing/decreasing vegetation activity. Grid level temporal correlation analysis showed that agricultural regions are the source of increase in terrestrial NPP of India. Parts of deserts (western Rajasthan) and forest regions (Himalyan in Nepal and North East India) showed decline in vegetation status over the study period and showed lower or some times negative correlation. Parts of eastern Rajasthan, western Madhya Pradesh, Maharastra

and Karnataka showed increasing vegetation trend (r > 0.5) as compared to Indo gangetic plain.

aslo confirmed by estimating the decadal level relative deviations from average of 1981-1990 and 1991-2000 period.
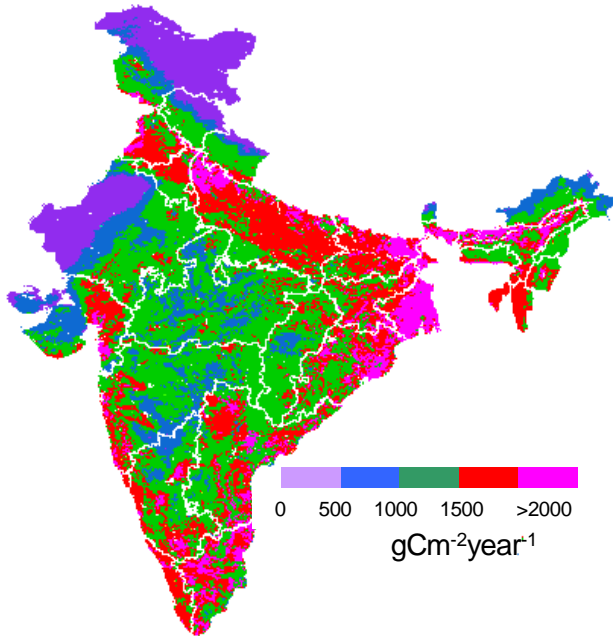

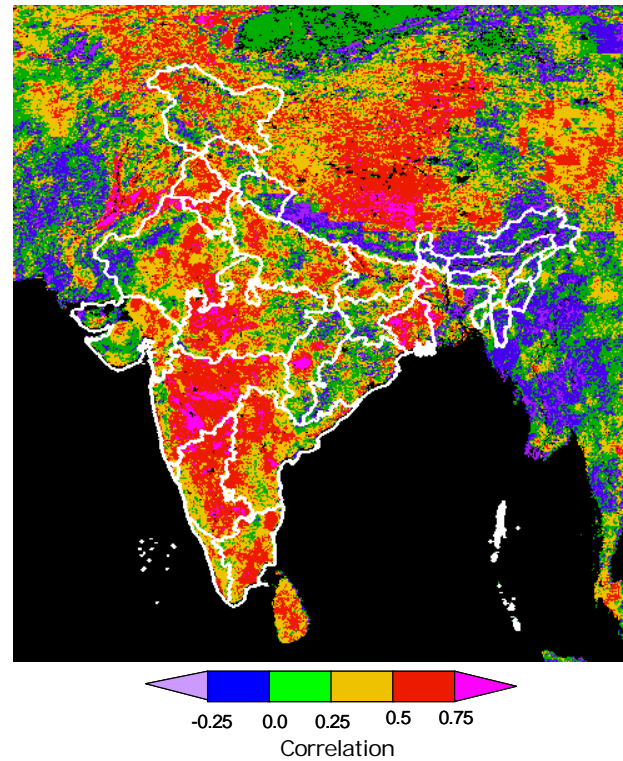Figure 2. Average NPP of India (1991-2000) Estimated Using NOAA-AVHRR Data

Figure 3. Inter Annual Variability in Carbon Fixation Ove India

Figure 4. Grid Level Temporal Correlation of NPP Over Indian Subcontinent

Figure 5a and Figure 5b show grid level coefficient of trend model viz. slope (m) and Intercept (c) respectively. It can be seen from the figure that rate of change (increase/decrease) of NPP per unit year varies approx. from –8 $gCm^{-2}year^{-1}$ (forested Himalyan region of north east India) to 40 $gCm^{-2}year^{-1}$ (Parts Maharastra and Karnataka). The avearge rate of increase in vegetation NPP estimated of total India was observed as 10.43 $gCm^{-2}year^{-1}$ which include response of arid, semi arid, forests and dryland and irrigated agricultural regions. Change detection in the NPP was
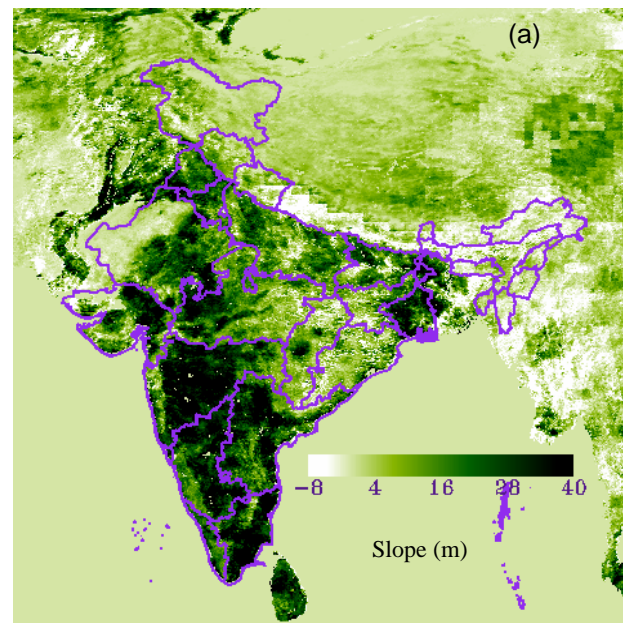
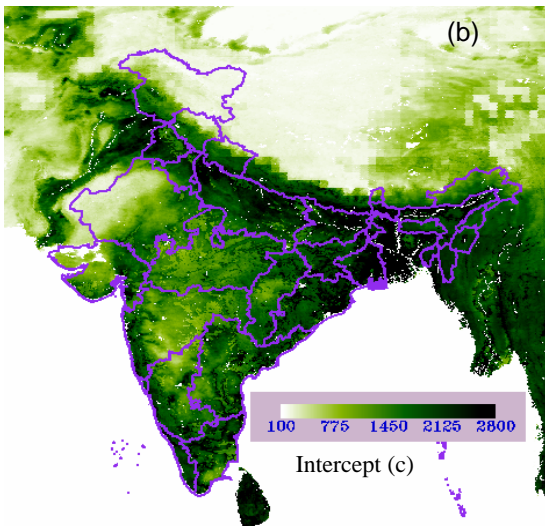Figure 5. (a & b). Grid Level Slope (m) and Intercept (c) of Temporal Trend Model (NPP ($gCm^{-2}year^{-1}$) = m t + c) Over Indian Subcontinent Where t is Years from 1981

The figure 6 shows the raltive deviations in the NPP values in two decades. It can be seen from the figure 6 that relative deviations in NPP ranged from –10% to 40% at different regions of India. The forested region of the north east India was observed as region of decline in vegetation activity (-10%) wherase part of southern Maharastra and Karnataka showd highest increase in NPP (> 40%). Major agricultural belt of Indo gangatic plain showed moderate increase in NPP (< 20%) in two decades spaing 1981 to 2000. Overall it can be inferred that region with open shrubland and poor agricultural system showed significant improvent in NPP wheareas region which has already gone through technological improvements in agriculture (green revolution) showed relatively moderate increase in NPP in two decades of the study period.
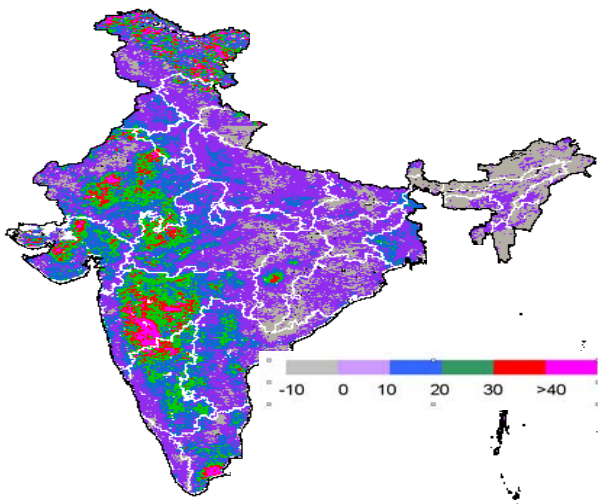

Figure 6. Decadal Changes in NPP Represented as Relative Deviations RD(%)=100*((NPP_{D1}-NPP_{D2}) /NPP_{D1}) where d1 and d2 Represent Decadal Period from 1981-1990 and 1991-2000 Respectively

CONCLUSION

The study was carried out to quantify the spatial and inter annual variations in NPP over diaserent ecosystems of India using NOAA-AVHRR derived NPP product (1981-2000). It was observed that NPP ranged from 500 $gCm^{-2}year^{-1}$ in arid region of Rajasthan to about 3000 $gCm^{-2}year^{-1}$ in irrigated agricultural rice cropping system of west Bengal in India. Overall average climatic (1981-2000) annual of NPP of India was estimated as 1237.32 $gCm^{-2}year^{-1}$. Significant increase in temporal trend of NPP over India (r=0.7, F=17.53, p < 0.001) was observed. The mean rate of increase was estimated as 10.43 $gCm^{-2}year^{-1}$. It was estimated that on the average 4.06 ± 0.29 Pg of carbon annually is fixed by vegetation in India. Parts of eastern Rajasthan, western Madhya Pradesh, Maharastra and Karnataka showed increasing vegetation trend (r > 0.5) as compared to Indo gangetic plain during 1981-2000. The forested region of the north east India was observed as region of decline in vegetation activity (-10%) wherease part of southern Maharastra and Karnataka showd highest increase in NPP (> 40%). There is further need to validate the findings from field measurements and other satellite based NPP products available during the study period.

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