Carbon Dioxide Emissions from Forest Biomass Burning in India

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Abstract

Biomass burning is an important source of greenhouse gas emissions, most importantly carbon dioxide (CO_2). In this study, we used burnt area estimates derived from the L3JRC product to estimate the CO_2 emissions from forests. The results suggested that an average of 2,414 sq.kms. is burnt annually. Of the different years, 2000-2001 recorded the greatest area burnt followed by 2003-2004, with the least during 2002-2003. Spatial patterns in the burnt area maps clearly revealed the greatest burnt areas were located in the Himalayan region. Over a period of seven years, closed needleleaf evergreen forest recorded the largest burnt areas (1087 sq.kms.) of the different forest types, followed by closed broadleaf deciduous forests (937 sq.kms.) and others. The total CO_2 emissions averaged across seven years were ~6.34 CO_2 Tg/yr from biomass burning of forests. Spatial variation in CO_2 emissions ranged from 2.37 to 3.85Gg CO_2/m^2 with a mean of 3.10 Gg CO_2/m^2.

Key words: burnt areas, CO_2 emissions, forest fires, India

1. Introduction

Fire is considered a key driver affecting earth system processes including the carbon cycle, atmospheric chemistry, the physical climate and human activities (Goldammar & Price, 1998; Crutzen & Andreae, 1990; Marlon *et al*., 2009). With respect to vegetation, fires may induce long-term changes in the floristic and physiognomic parameters of the vegetation through their impact on soil nutrients and physio-chemical properties. The response of vegetation to fires can be complex (Goldammer & Price, 1998; Nunes *et al*., 2005). The regeneration process is highly variable because of the large number of factors involved, including plant composition, topography, climate, soil characteristics, land-use history, wildfire severity, etc. (Dansereau & Bergeron, 1993; Ayanz *et al*., 2009). Biomass burning releases large amounts of trace gases and particulates into the atmosphere (Seiler & Crutzen, 1980). Sandberg *et al*., (2002) estimated that fires account for approximately one fifth of the total global CO_2 emissions. Tropical biomass burning has been estimated to release ~238 Tg/yr - 420 Tg/yr (Streets *et al*., 2003; Van der Werf *et al*., 2006). Using satellite derived fire counts together with a terrestrial biogeochemistry model, Van der Werf *et al*. (2006) estimated an average biomass burning emissions of nearly 2.5 Pg C $year^{-1}$ over the 1997-2004 period. The dominant contributors were Africa (49%), South America (13%), equatorial Asia (11%), boreal regions (9%) and Australia (6%). Recently, Mieville *et al*., (2010) attempted to ascertain historical biomass burning emissions. They estimated that until 1970 the emissions were ~7,400 Tg-CO_2 $year^{-1}$ but since the 1980s, they have increased rapidly and are currently about 9,950 Tg-CO_2 $year^{-1}$. They further attributed these differences to a decrease in fire emissions in the boreal regions due to fire suppression policies, and an increase in tropical regions, especially in South America and Indonesia, due to deforestation as a part of agricultural expansion. In addition to carbon emissions, a host of other gases such as carbon monoxide, methane, hydrocarbons, nitric oxide and nitrous oxide are released in the biomass burning process, which may contribute to global warming and ozone layer depletion (Sieler & Crutzen, 1990). To assess the atmospheric impact of biomass burning quantitatively, accurate emissions estimates of trace gases and aerosols are required. Crucial parameters in biomass burning emissions estimation include burned area, fuel consumption and the emission factor (EF) (Van der Werf *et al*., 2006).

With respect to the area and the amount of biomass burnt in India, there are no clear estimates, in particular from forests. As per the recent state of the forest assessment report (SFR, 2009), the forest and tree cover of the country is 78.37 Mha (2007 year), which is 23.84% of the geographical area. The net increase in forest and tree cover between the latest and previous assessments (two-year data interval) is about 0.18 Mha. The decadal increase, *i.e.*, the increase in forest cover between 1997 and 2007 is estimated to be 3.13 Mha. Although, the forest cover increased during the two-year survey period (2005-2007), there seem to be significant spatial differences with respect to increases/decreases in different states and types of forests. For example, in the case of northeastern India, comprising seven different states, in Arunachal Pradesh, Assam, Nagaland and Tripura, the forest cover decreased nearly 119, 66, 201 and 100 sq.kms., respectively. In contrast, in the states of Manipur, Meghalaya and Mizoram the forest cover increased by nearly 328,116 and 640 sq.kms., respectively. Overall, in northeastern India, there was an increase of 598 sq.kms. of forest cover. Although the forest cover estimates from the State of Forest Report (2009) provide overall forest cover, it is unclear how much area was originally burnt or cleared for various purposes. There are no national level statistics available on burnt areas and carbon emissions. According to the 2001 State of Forest Report (SFR, 2001), about 50% of the forested areas in the Indian region were fire prone (ranging from 50% in some states to 90% in others). About 6% of the forests are prone to severe fire damage (IFFN, 2002). Considering the impacts of biomass burning on the environment, including the social, economic and environmental implications, fire statistics as well as estimates of the amount of biomass burnt are needed. To meet the international reporting commitments under the United Nations Framework Convention on Climate Change (UNFCCC), individual countries are required to estimate annual emissions and removals of carbon and non-CO_2 greenhouse gases. India is a part of UNFCCC and estimation of biomass burning emissions to date has been conducted mostly by empirical means. There is a stronger need to use satellite-derived products for calculating emissions from biomass burning.

In this study, we quantified the carbon released from the biomass burning of forests. integrating burnt area estimates derived from satellite data with the biomass, combustion efficiency and CO_2 emission factor to arrive at the total CO_2 emissions from the forest biomass burning. We also assessed the temporal variation in the amount of biomass burnt. In addition, we also compared the CO_2 emission estimates with the previously published estimates for relative comparison. Finally, we considered the implications of emissions affecting local and regional climates in addition to the need for developing high-resolution burnt-area estimates from the indigenous Indian remote sensing satellites.

2. Methodology

2.1 Forest types map

The forest vegetation in the country varies from tropical evergreen forests on the west coast and in the northeast to alpine forests in the Himalayas in the north. In between the two extremes, there are semi-evergreen forests, deciduous forests, sub-tropical broad-leaved hill forests, sub-tropical pine forests and sub-tropical montane temperate forests. Recently, the Forest Survey of India (SFR, 2009) mapped the forest cover of India using IRS-P6-LISS III data at 23.5 m resolution and 1:50,000 scale. The minimal mappable unit at this scale is 1 ha and the classification approach used was a hybrid combining visual as well as digital classification. In addition to the canopy cover classes of very dense (cover of 70% or more), moderately dense (40%-70%) and open forest (10%-40%), forest types were also mapped following the Champion and Seth (1968) classification system, at the same scale. However, these maps were inaccessible to the general public. With such a limitation, in this study, we have used the freely available land use/cover product from MEdium Resolution Imaging Spectrometer (MERIS) data at a 300 m resolution for characterizing vegetation types. Launched in 2002 onboard the ENVISAT satellite, MERIS is a wide-field-of-view push-broom imaging spectrometer measuring the solar radiation reflected by the Earth in 15 spectral bands from about 412.5 nm to 900 nm (Rast *et al.*, 1999) and a repetitivity of three days. The land cover product is derived by classification of a time series of MERIS full-resolution mosaics from December 2004 - June 2006. Its 22 land cover global classes are defined according to the United Nations Land Cover Classification System (LCCS) (Bicheron *et al.*, 2008). We used this product due to its high spatial resolution (300 m) compared to the other global land cover products. As we are interested in quantifying biomass burning emissions from forests, of the 22 classes, we have selected only six different classes pertaining to forest classes, *i.e.*, a) closed broadleaf deciduous forest; b) closed needleleaf evergreen forest; c) closed to open broadleaf evergreen/semi-deciduous forest; d) closed/ open mixed broadleaf/needleleaf forest; e) mosaic forest/ grassland/shrubland; and e) open broadleaf deciduous forest. Specifically, we used the burnt areas derived from the L3JRC product (Tansey *et al.*, 2008). The L3JRC algorithm makes use of a temporal index in the near infrared (NIR) channel to detect the burnt areas. The output is then post-processed to remove some over detections. Post-processing of the data is largely based on the land cover information provided by the GLC2000 product (JRC, 2011). We used the L3JRC derived burnt areas from 2000-2007. The data were overlaid on the MERIS vegetation map and analyzed for spatial variations.

2.2 Burnt areas

To assess biomass burning from forests, we used the L3JRC product described above. L3JRC burnt areas are reported at a resolution of 1 km for seven fire years (2000 to 2007). For creating this product, a modified version of a Global Burnt Area (GBA) 2000 algorithm was used. Burnt areas were derived from SPOT satellite data that has a revisit cycle of five days. A single algorithm was used to classify the burnt areas from global, daily, atmospheric-corrected SPOT VEGETATION reflectance data. The main processing algorithm makes use of a temporal index in the 0.83 μm near infrared channel for identifying burnt areas. The output is then post-processed to remove some over-detections. Post-processing of the data is largely based on the land cover information provided by the Global Land Cover-2000 product. It is assumed that a global fire year starts on the 1st of April of every year and that a surface cannot be burned more than once in the same fire season. For each fire year (*e.g.*, 2000-1, *i.e.*, 1 April 2000 to 31 March 2001) a binary product is available in geographic coordinates in addition to the ASCII text file for each fire year representing the geographic coordinate of the centre of each pixel that has been detected as being burnt (Tansey *et al.*, 2008).

2.3 Emissions

CO_2 emissions from biomass burning were estimated following Sieler and Crutzen (1980). The biomass burning emissions from forested regions of India were calculated as:

$$E = A \times B \times \beta \times EF$$

where E is the emissions (in CO_2 grams), A = total land area burned annually [m^2/yr], B = the average biomass/fuel load (kg/dry matter/m^2), β = the burning efficiency of the above-ground biomass, EF is the emission factor (mass of species per mass of dry matter burned in g/kg). The burnt areas were derived from the L3JRC product, and the biomass data from a wide variety of sources through a book-keeping approach. A literature review suggested that the above-ground biomass densities in Indian forests range from 12 to 230 Mg/ha, with a mean of 72.3 Mg/ha (Haripriya, 2003; Chabbra & Dadhwal, 2004; Kaul *et al*., 2009). For the different forest types derived from the MERIS data, we used the values of 3.64, 4.0, 4.76, 3.52, 2.94, and 2.7 kg dry matter/m^2 for closed broadleaf deciduous forest, closed needleleaf evergreen forest, closed to open broadleaf evergreen/semi-deciduous forest, closed/open mixed broadleaf/needleleaf forest, Mosaic forest/grassland/shrubland and open broadleaf deciduous forest respectively. These values were derived from averaging the dry matter values for different forest types reported in the literature (Haripriya, 2003; Chabbra *et al*., 2004; Manhas *et al*., 2006; Kaul *et al*., 2009). Further, we used a combustion efficiency of 40% in this study as this value seems to be a conservative estimate. Our previous studies on combustion completeness for tropical secondary dry mixed forests suggested values in the range of 28%-30% (Prasad *et al*., 2000; 2001). As the current study from the MERIS vegetation data also includes broadleaf deciduous forests in addition to mixed forest types, a conservative estimate of 40% seems justified. However, we also infer that more ground based studies are needed for assessing the error estimates. The CO_2 emission factor was derived from Andreae and Merlet (2001).

3. Results

Figure 1 gives the forest type map of India derived from the MERIS data at a 300 m resolution. Of the different classes, closed to open broadleaf evergreen/semi-deciduous forest dominated with 5.23% followed by closed broadleaf deciduous forests (3.75%), etc (Fig. 2). These four types of forests constituted 10.85% of the total geographical area of the country. As seen in Fig. 1, broadleaf evergreen forests dominated in the western, northern and northeastern parts of India, while open broadleaf forests were confined to central India. Figure 3 shows the burnt area estimates derived from the

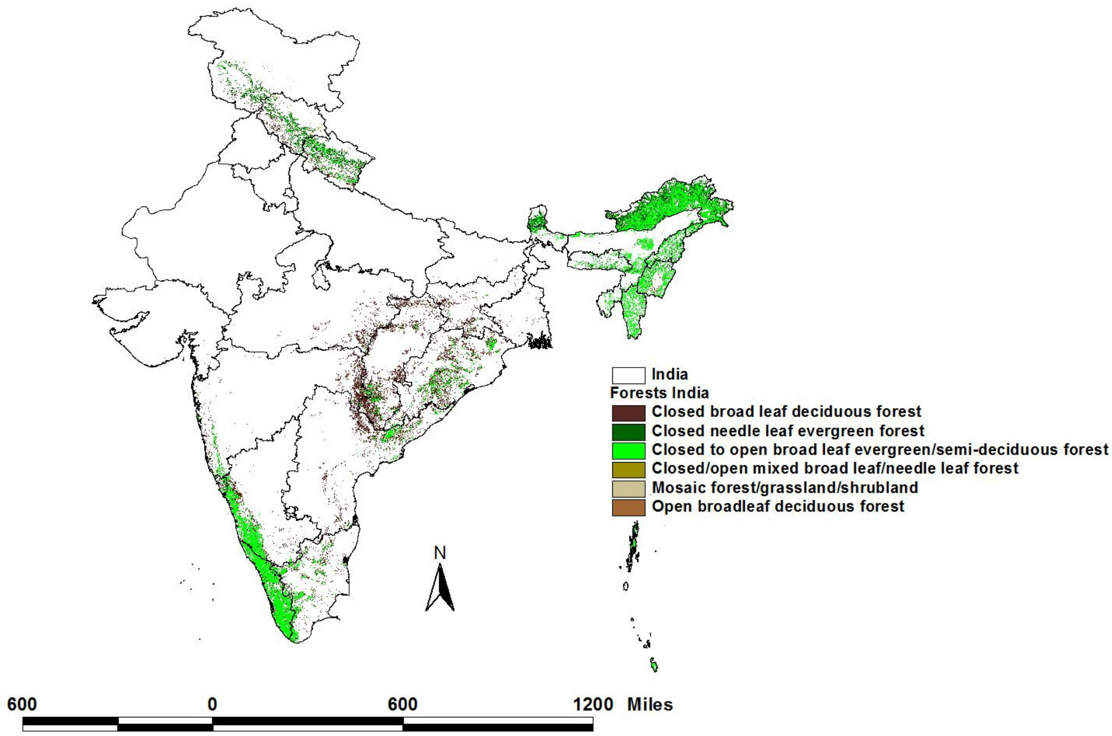

Fig. 1 Forest type map of India derived from the MERIS (300 m) product.

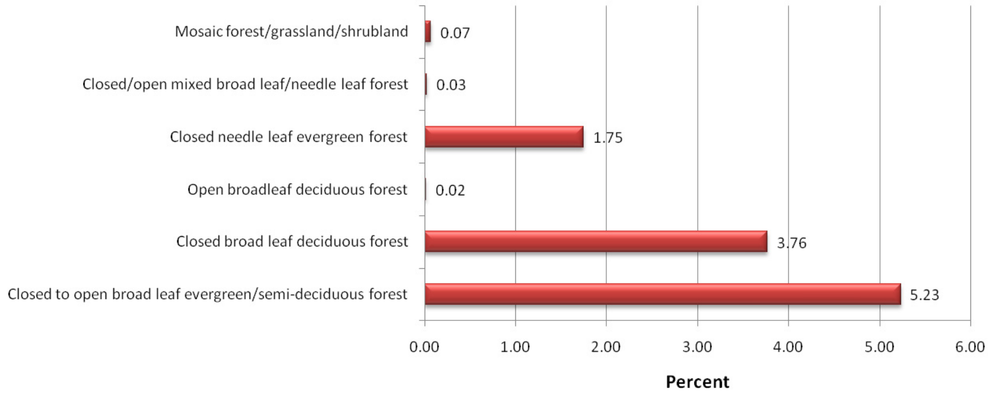

Fig. 2 Forest percent coverage derived from the MERIS (300 m) product.

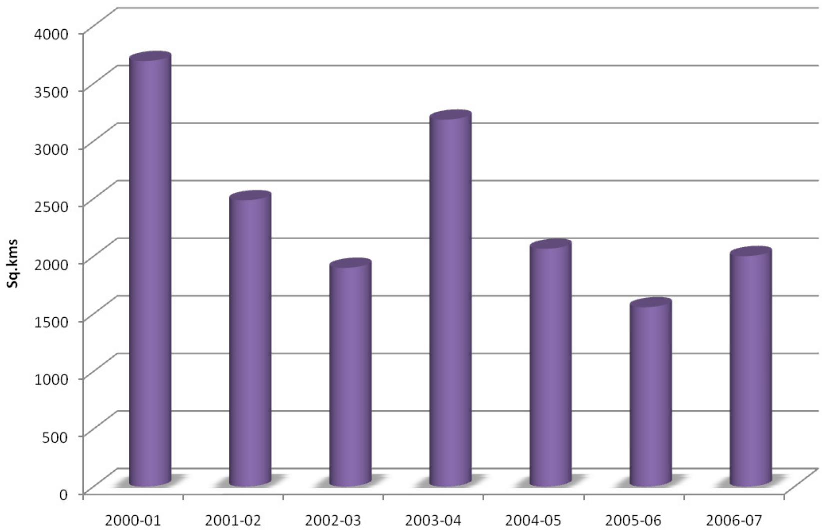

Fig. 3 Temporal variation in burnt forested areas derived from the L3JRC product.

L3JRC product for the seven years. An average of 2,414 sq.kms. has been estimated to be burnt annually in the forested areas. Of the different years, 2000-2001 recorded the greatest burns, followed by 2003-2004, with the least during the year of 2002-2003. On an annual basis, the total area burnt for all of India derived from L3JRC was about 30,603 sq.kms., of which forest biomass burning constituted 2,414 sq.kms., nearly 7.8% of the total area. Figures 4 a-g show spatial and temporal variability in burnt areas of forest classes for the seven years. These spatial patterns clearly suggest the greatest burnt areas are located in the Himalayan region. Further, considering the huge spatial and temporal variability of burnt areas, understanding the causative factors of fires in the Indian region need further exploration. Figure 5 gives the amount of area burnt for each of the forest types class and Fig. 6, the average annual area. Over the seven-year period, closed needleleaf evergreen forest recorded the greatest burnt areas (1,087 sq.kms.) among the different forest types, followed by closed broadleaf deciduous forests (937 sq.kms.) and others (Fig. 6). Figure 7 shows spatial variation in the CO_2 emissions (in Gg/m^2) among the burnt areas. The values ranged from 2.37 to 3.85 with a mean of 3.10 Gg CO_2/m^2. A total of ~6.34 CO_2 Tg/yr of emissions has been estimated resulting from forest biomass burning.

4. Discussion

Air quality issues in India are a matter of great concern. Emissions from forest fires may cause substantial releases of CO_2 emissions and there is a need to address this issue through effective fire policies and management. A variety of forest types exist in India, from the tropical evergreen forests of Kerala and Assam to the conifers of the Himalayan region, and from the tropical deciduous forests of Madhya Pradesh and Orissa to the thorny scrub forests of Rajasthan. In India, current knowledge of the contribution of forest fires to the total CO_2 emissions is insufficient. The current study has been undertaken to fill such a gap. Further, most of the studies relating to burnt areas conducted in the Indian region are highly localized, and national level mapping efforts on burnt areas have yet to be undertaken. Since there are no national level

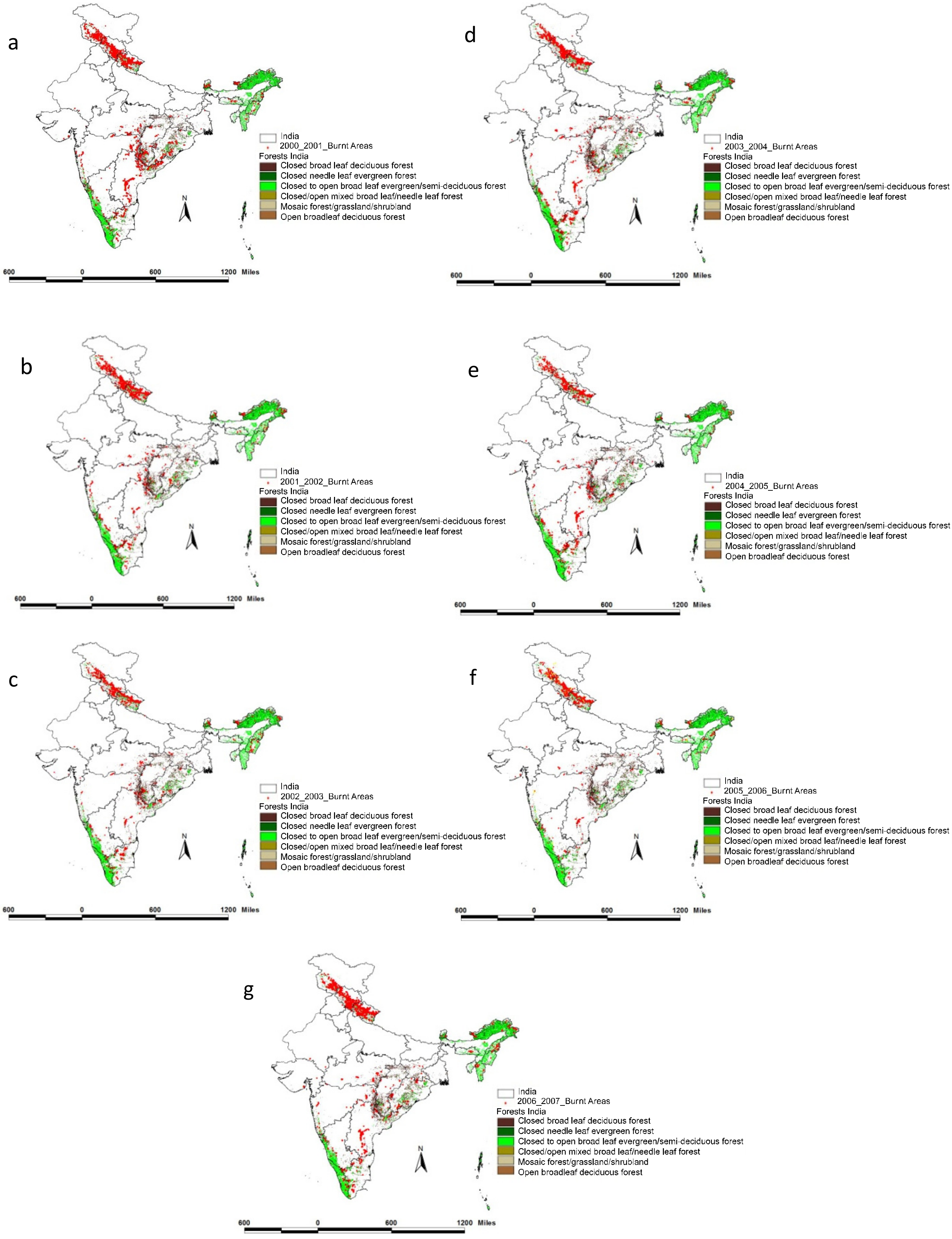

Fig. 4 Burnt forested areas derived from the L3JRC product shown as a red-colored area. Fire year is (a) 2000-2001, (b) 2001-2002, (c) 2002-2003, (d) 2003-2004, (e) 2004-2005, (f) 2005-2006, and (g) 2006-2007. See the text for details.

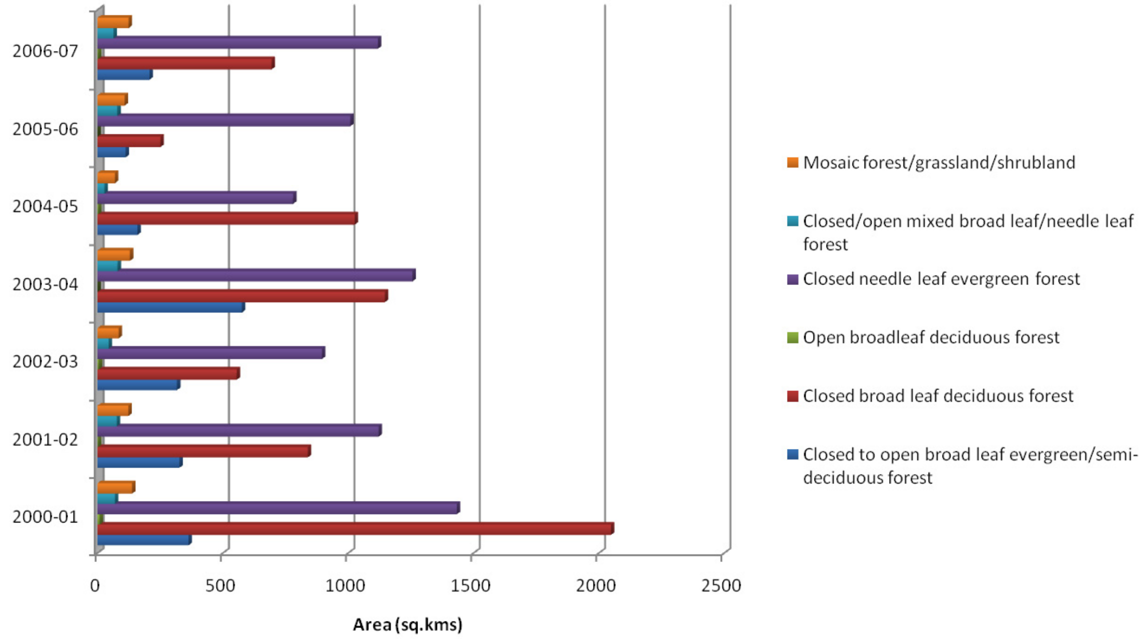

Fig. 5 Burnt areas in different forest types derived from the L3JRC product.

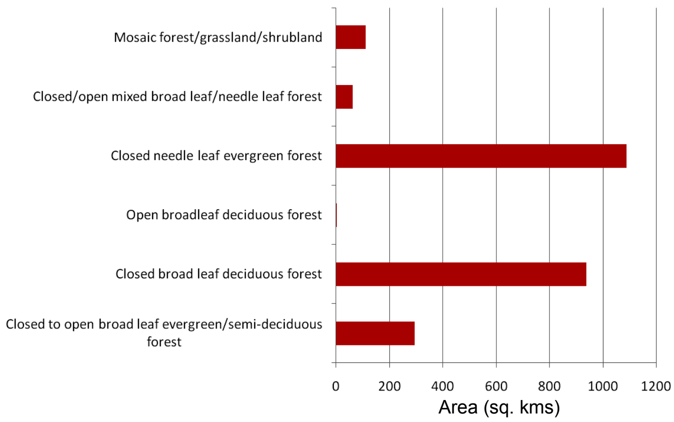

Fig. 6 Average annual burnt areas in different forest types derived from the L3JRC product.

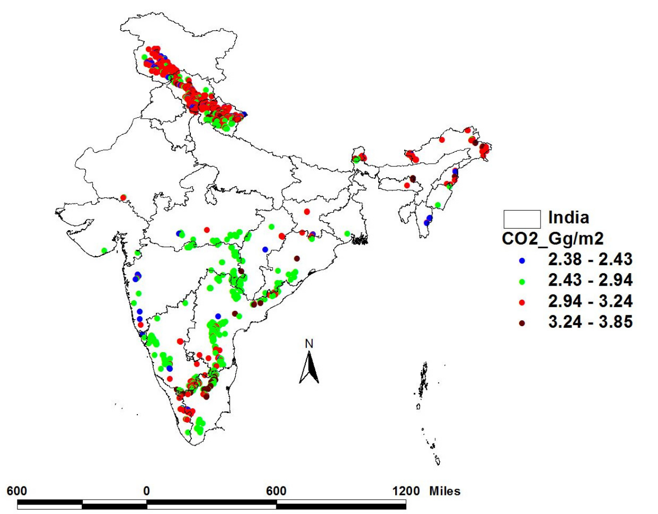

Fig. 7 CO_2 (Gg/m^2) released through biomass burning of forests. The results represent averaged amount from 2000-2007.

burnt area products, we have had to rely on the global L3JRC product for assessing the burnt areas and the resulting CO_2 emissions from forests. Regarding the L3JRC algorithm and burnt areas, Tansey *et al*., (2008) reported that the algorithm performs reasonably well for a number of different vegetation types, in particular, areas that have a relatively higher vegetation percent as compared to low vegetation cover areas (such as herbaceous and sparse herbaceous or shrub cover classes) where significant underestimation of burnt areas can occur (Tansey *et al*., 2008). Since our study is focused on the forested regions, we have used only the major forest type classes from the Globcover product. Thus, the burnt area estimates derived from the forested areas may have fewer errors, but validation is required to account for uncertainties. In addition to area estimates, fuel type, fuel load and combustion efficiency can also effect emissions calculations. In our case, we have used the MERIS 300 m Globcover map for delineating forested areas. The spatial patterns in the vegetation types (Fig. 1) reveal that the map represents broad vegetation types very well, although a better map with different floristic types and physiognomy would have helped to refine our current estimates. The biomass data have been obtained through a book-keeping approach. Overall, we infer that uncertainties in our emissions calculations resulting from the forest-type map as well as biomass were considerably less compared to the burning efficiency value of 40% used in this study. Our earlier studies, focusing on tropical dry deciduous and secondary mixed deciduous forests, suggested that the combustion factor could vary from 20%-30% during the initial phase of slash and burn agriculture (Prasad *et al*., 2000; 2001). Thus, there is a stronger need to validate the combustion factors from diverse forests of the Indian region. Despite these limitations, we have estimated annual CO_2 emissions of nearly 6.34 CO_2 Tg/yr from biomass burning of forests. This estimate is far less than the earlier estimate of 102-353 Tg/yr CO_2 from forests of India (Venkataraman *et al*., 2006). The discrepancies are mainly attributed to usage of MODIS-derived active fires for estimating the burnt areas. Since each active fire pixel with a spatial resolution of 1 km is considered a burnt pixel, the area estimates derived from such an approach may not be representative of the actual area burnt in the field. Relatively, the use of burnt area products for emissions estimations compared to active fires is considered highly effective (Tansey *et al*., 2008; Roy *et al*., 2008). We also infer the need for collecting data on fire-causative factors (both anthropogenic and biophysical data) at a variety of scales and geographic gradients. Accurate information on fire causes would help to reliably predict where, when, why and how many fires are likely to occur, information which could allow fire and landscape management to take on more proactive planning than a reactive process (Leone *et al*., 2003). Regarding emissions, although wildfires can be limited to a particular forest type or area, the emissions can be transported beyond the physical boundaries of the forested area through long-range transport. Depending on the meteorological conditions, the smoke plumes and haze layers can persist in the atmosphere for long periods of time with conditions prevailing (Badarinath *et al*., 2007; 2009). Thus, there is a stronger need to address fire management issues at a local scale.

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