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Amplified Fire Occurrences in Response to Drought and Vegetation Stress in the Western Ghats of India

By N. Kodandapani , posted on October 1st, 2013 in Articles, Earth Observation, Weather, Wildfires Theme

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ABSTRACT

There is uncertainty regarding the extent to which drought, fuel availability, and ignition sources contribute to the global fire regime. In 2004, a sharply increased fire activity followed a severe drought, highlighting the importance of drought-fire linkages in the Western Ghats hotspot of biodiversity. The spatial extent of drought and fire response to the drought was analyzed with 10-y remotely sensed MODIS NDVI and active fire data, respectively. Estimates of vegetation stress were made in terms of anomalies, as departures from decadal mean, standardized by the standard deviations. Anomalous fire events were estimated similarly. The average number of hotspots in the WG over the 10-y period analysed was 1024±615. About 23% of the total fire occurrences were from 2004, whereas it was 12% in 2007, and 15% in 2009. 86% of the hotspots during the 10-y period of analyses have occurred during the I quarter, 9% during the II quarter, 1% during the III quarter, and 4% during the IV quarter. During the 2004 drought the I quarter number of hot pixels (> 1σ) in the WG increased 47% in relation to the 2001-2010 mean, 35% of the hot pixels had negative NDVI anomalies > 1σ. The annual correlation analyses showed significant positive relationship between I quarter NDVI anomalies and I quarter hot pixel anomalies for the wet evergreen primary forest ($F_{1,8}$=7.06, R^2=0.46, p=0.02) and secondary moist deciduous forests ($F_{1,8}$=14.4, R^2=0.64, p=0.005). These anomalous events would have important implications for conservation of biodiversity especially in wet evergreen forests in the Western Ghats.

INTRODUCTION

The consequences of future warm and dry conditions on ecosystem processes such as forest fires have been the focus of several studies on global change (Bowman et al. 2009). In recent years many studies have reported an increase in the number of wildfires and the area burned in different terrestrial ecosystems across the globe (Westerling et al. 2006; Kodandapani et al.

2004; Dimitrakopoulous et al. 2011). There are uncertainties surrounding the global fire regime, especially the extent to which drought, fuel availability, and the presence of ignition source influence the occurrence of fire.

One of the many consequences of projected global climatic change is increase in the frequency, intensity, and the area affected by extreme drought (Breshears et al. 2005). Since the 1970s droughts in several tropical regions have been longer and more intense (Malhi and Wright 2004). The increased tree die-off, increased flammability (Nepstad et al. 2004), and increased carbon emissions from fires due to these droughts, have the potential to alter regional carbon budgets (Adams et al. 2009).

Although a few studies exist on forest fires in the Western Ghats (WG) (Kodandapani 2013), very little information exists on fires following droughts in the WG. In recent years, several remotely sensed vegetation indices have been applied to assess drought through time-series analysis methods (Bhuiyan and Kogan, 2010). Here, the spatial extent, intensity and impacts of drought were analyzed in terms of anomalies of NDVI. Detailed analyses of a sharply increased fire activity following a severe drought, was carried out highlighting the potential importance of drought-fire linkages. The objectives of the study undertaken in the WG are: 1) To estimate the magnitude and pattern of vegetation stress and fire occurrences. 2) To examine the relationship between vegetation stress and fire occurrences in the different forest types of the WG.

STUDY AREA

The WG region cover an area of 160 000 km^2 that stretch for 1600 km along the west coast of southern peninsular India, from (21°

Figure 1: Location of the study area in India.

N) to (8° N). In the coastal plain the annual rainfall is > 2000 mm, commonly reaching more than 5000 mm near the crest of the Ghats. Beyond the crest, a rapid diminishing of annual rainfall below 1000-1500 mm is observed within a distance of 10–50 km to the interior region. Correlating with the sharp decrease in rainfall beyond the crest of the Ghats, the length of the dry season rapidly increases in the west-east direction.

The WG is one of the 34 global hotspots of biodiversity (Mittermeier et al. 2005), simultaneously it is the hotspot with the highest human densities (Cincotta et al. 2000). The forests of the WG, are some of the best representatives of non equatorial tropical evergreen forests in the world (Pascal 1988). The WG cover only 5% of India's total land area, but contain more than 4000, or 27%, of the country's total plant species. Apart from plants, taxonomic groups such as reptiles, mollusks, and amphibians exhibit high levels of endemism, > 50% of species in these taxa are endemic to the WG (Gunawardene et al. 2007).

In this article only the southern and central parts of the WG is considered, i.e. a study area of 73 784 km^2 between 74 to 78° E and 8 to 16° N (Figure 1). Land cover types range from wet evergreen to dry deciduous forest habitats in various stages of degradation, to mountain forests and grasslands, alternating with zones converted into agroforests, monoculture plantations and agriculture (Renard et al. 2012).

METHODS

Rainfall Datasets

The Tropical Rainfall Measuring Mission (TRMM) satellite provides satellite based rainfall estimates and is available from 1998. It uses a passive sensor TRMM microwave imager, an active precipitation radar, and a visible and IR scanner (VIRS) radiometer (NASA 2006). The microwave imager provides rain rates besides SST; the active precipitation radar provides various estimates of rain parameters. The rainfall data were obtained from a time-series (2001-2010) of the TRMM data (Tropical Rainfall Measuring Mission, 3B43-v6), at 0.25° by 0.25° (or 774.35 km^2) spatial resolution. The cumulative monthly precipitation was estimated in mm $month^{-1}$ considering a 30-day month.

NDVI Anomalies

The MODIS (MODerate resolution Imaging Spectroradiometer) NDVI 16-day composite grid data, C5, MOD13A2 was applied for the vegetation stress analysis. The intensity and duration of the drought across the WG were calculated in terms of NDVI anomalies, as the departure from the 2001-2010 mean ($NDVI_{2001\text{-}2010}$), normalized by the standard deviation (σ). NDVI surfaces were grouped into quarters to examine seasonal differences by computing the mean of images that correspond to each quarter. $NDVI_{anomaly}$ was calculated for each year and each quarter on a pixel-by-pixel basis. Thus NDVI anomaly calculation used quarters for each year and identical reference periods (i.e. 2001 to 2010), for which anomaly was estimated. Since the spatial resolution of the NDVI dataset was 1 km, it was resampled to 0.25° by 0.25° (or 774.35 km^2) spatial resolution to match the hot pixel anomalies.

Hot Pixel Anomalies

The MODIS thermal anomaly dataset, C5, MOD14A1, and MYD14A1 was applied for the fire analysis. Fire hotspots are recorded by the MODIS sensors four times in each 24 hour period. The daily MODIS thermal anomaly dataset, was downloaded from the MODIS Rapid Response System (available at http://maps.geog.umd.edu/firms/). Compared with other satellite systems, the MODIS hotspot detection system is the most accurate and reliable in terms of detection accuracy and completeness (Roy et al. 2008).

Hot pixel counts were derived from the original MODIS hospots by aggregating accumulated hot pixels at 0.25° spatial resolution. The quarter hot pixel anomalies were then calculated in terms of hot pixel density (accumulated number of monthly hot pixel counts), similar to the NDVI data. To explore the interactions between land cover and climatic conditions on fire patterns, differences in forest type were evaluated. To explore the relationship between the two variables, NDVI anomalies and hot pixel anomalies, linear regressions were conducted.

RESULTS

Inter-annual variability of hotspots in the WG

The number of hotspots in the WG showed strong variability between years. The average number of hotspots in the WG over the 10-y period analysed was 1024±615 (mean±standard deviation). Three years (2004, 2007, and 2009) during this 10-y (2001-2010) period witnessed elevated fire occurrences in the WG. About 23% of the total fire occurrences were from 2004, whereas it was 12% in 2007, and 15% in 2009. Under drought conditions, the total fire occurrences were 2 fold higher (2399) in 2004 compared to the 10-y mean. The fire response to the 2004 drought was large within forest types in the WG, fire occurrences were ~2 – 3 fold higher in the primary dry deciduous forest and degradation (220±126) and the primary moist deciduous forest and degradation (166±142) compared to the 10-y mean. Similarly in 2004, the fire occurrences were ~ 2-3 fold higher in the wet evergreen primary forest (52±30) and the secondary moist deciduous forest (123±93).

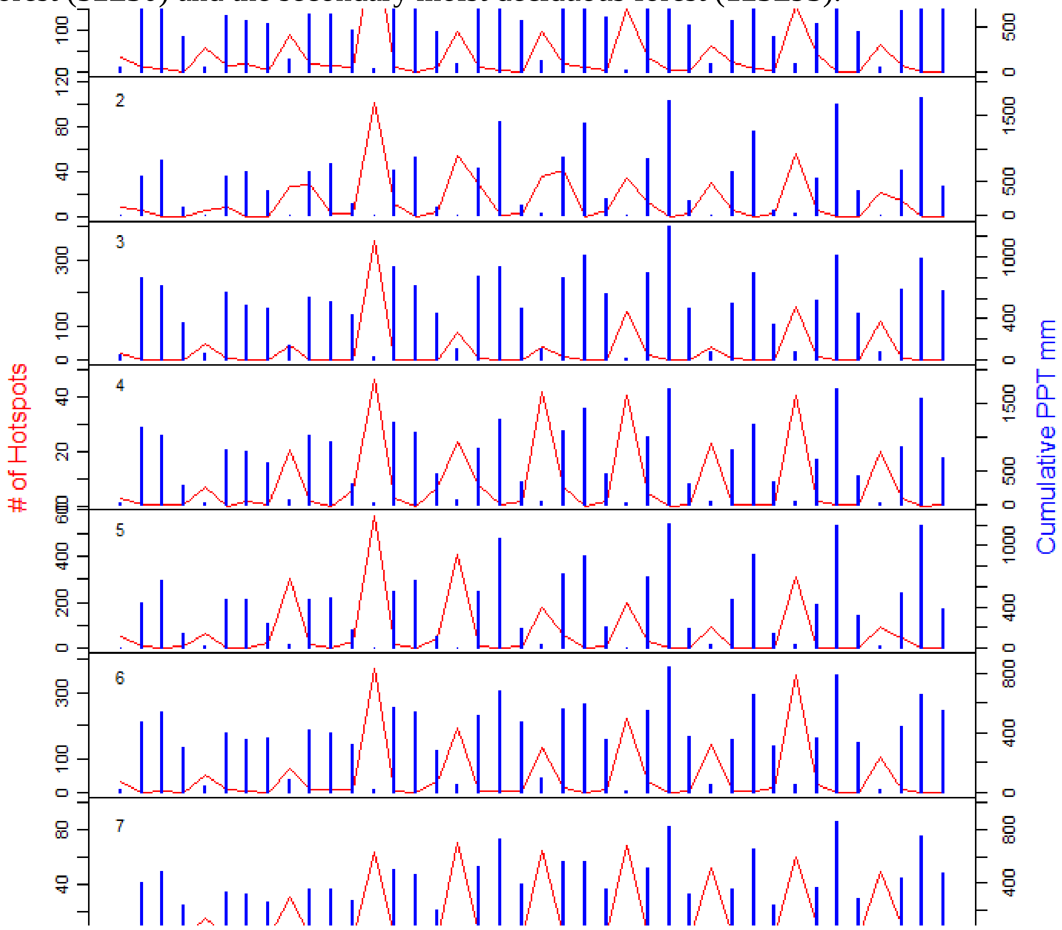

Figure 2: Time-series of 3-month number of hotspots detected (red line-Primary Y-axis) and cumulative rainfall mm (blue bars-Secondary Y-axis) in seven major forest types of the WG for 10-y. 1. Wet evergreen primary forest; 2. Wet evergreen secondary or disturbed forest; 3. Secondary moist deciduous forest; 4. Degraded formation in the potential area of wet evergreen zone; 5. Primary moist deciduous forest and degradation; 6. Primary dry deciduous forest and degradation; 7. Tree savanna to grassland in dry zone.

Seasonal pattern of Rainfall and hotspots for the WG

The (2001-2010) cumulative seasonal rainfall and number of hotspots also showed considerable variations, figure 2 shows the seasonal variations in both across the major forest types in the WG. In the I quarter the rainfall varied from 13 to 147 mm, it is 297 to 1115 mm in the II quarter, much higher rainfall occurs in the III quarter (232-1550 mm), rainfall declines again in the IV quarter (135 to 724 mm). Similarly, the cumulative seasonal hotspots also showed variations, the I quarter hotspots varied from 203 to 2229, it is 33 to 179 in the II quarter, much lower fire occurs in the III quarter (3-30), it marginally increases in the IV quarter (6-103). The average number of hotspots during the dry season (I quarter) in the WG over the 10-y period of analyses was (880±596), during the II quarter (94±50), during the III quarter (15±10), and during the IV quarter (35±30). The year having the highest number of hotspots was 2004 (I quarter), with 2229 and 2001 (I quarter) was the year having the lowest number of hotspots (203). 86% of the hotspots during the 10-y period of analyses have occurred during the I quarter, 9% during the II quarter, 1% during the III quarter, and 4% during the IV quarter.

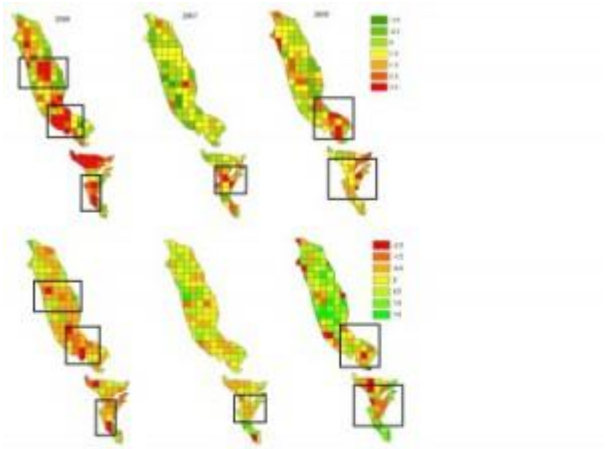

Figure 3: (top) Hot pixel anomalies for the I quarter in 2004, 2007, and 2009. (bottom) NDVI anomalies for the same three-month period in 2004, 2007, and 2009. The anomalies are the departure from the decadal mean normalized by the standard deviation of the time-series for each pixel (spatial resolution of 0.25°). Highlighted pixels share anomalies for both parameters.

Hot Pixel Anomalies and NDVI anomalies

During the 2004 drought the I quarter number of hot pixels (> 1σ) in the WG increased 47% in relation to the 2001-2010 mean. Throughout the I quarter, notable fire anomalies (> 1 σ) covered areas from the south to the far north of the WG in agreement with the NDVI anomalies of 2004, 35% of the hot pixels had negative NDVI anomalies > 1σ. In the year 2007, the I quarter number of hot pixels (> 1σ) in the WG increased 14% in relation to the 2001-2010 mean, 10% of the hot pixels had negative NDVI anomalies > 1σ. In the year 2009, the I quarter number of hot pixels (> 1σ) in the WG increased 32% in relation to the 2001-2010 mean, 14% of the hot pixels had negative NDVI anomalies > 1σ. Figure 3 shows the hot pixel anomalies and the NDVI anomalies for the I quarter in 2004, 2007, and 2009.

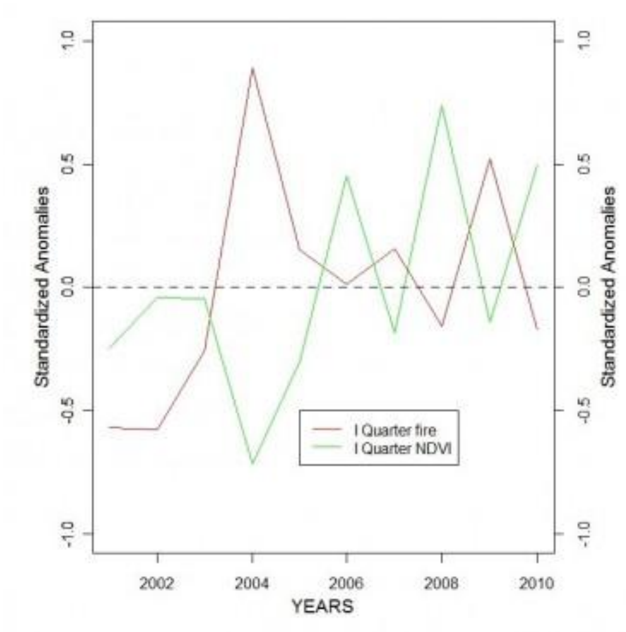

Figure 4: First-quarter pattern of standardized NDVI anomalies and fire anomalies averaged for the 10-year period of study.

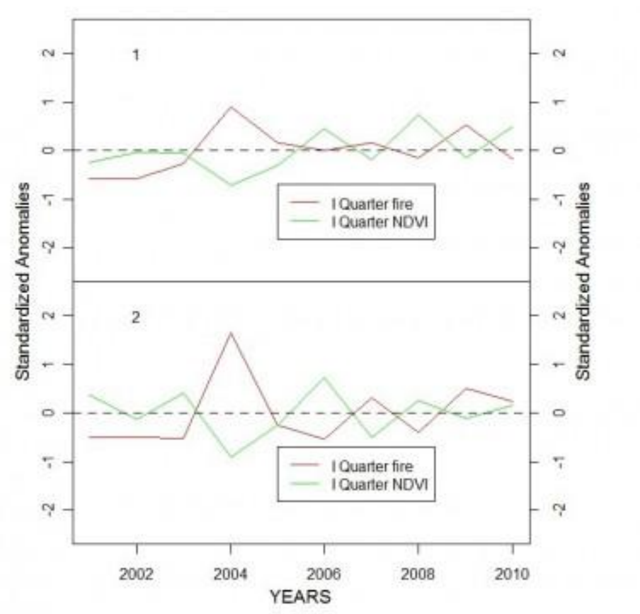

Figure 5: First-quarter pattern of standardized NDVI anomalies and the fire anomalies averaged for 1. Wet evergreen primary forest and 2. Secondary moist deciduous forest.

Correlation analyses

The seasonal (I quarter) pattern of NDVI and fire anomalies, averaged during the period 2001-2010 over the WG are shown in figure 4. The I quarter NDVI anomalies and fire anomalies, averaged over the WG are correlated, but not statistically significant ($F_{1,8}$=1.9, R^2=0.19, p > 0.1), the coefficient is -0.42. A similar analyses was conducted for the fire season (I quarter) for individual forest types in the WG, figure 5. In the wet evergreen primary forest, the I quarter NDVI anomalies and fire anomalies, averaged over the WG are significantly correlated ($F_{1,8}$=7.06, R^2=0.46, p=0.02), the coefficient is -0.55. In the secondary moist deciduous forest, the I quarter NDVI anomalies and fire anomalies, averaged over the WG are significantly correlated ($F_{1,8}$=14.4, R^2=0.64, p=0.005), the coefficient is -0.55.

DISCUSSION

Satellite data regarding seasonal NDVI, active fires, and forest types were used to study the climatic effect on burning activity in the WG. The results supported the idea that the pattern of burning and the inter-annual variability of fires were related to vegetation stress factors. For example, during the years 2004, 2007, and 2009 higher negative NDVI anomalies had a positive effect on fire anomalies in all land cover types, and especially in the wet evergreen primary forest and secondary moist deciduous forest and they coincided with the dry season (I quarter). The synergistic effects of future emerging threats to tropical forests, such as warming temperatures (IPCC 2007), increasing frequency of drought episodes (Williams et al. 2007), along with forest fragmentation (Kodandapani et al. 2004) could push the wet and moist forests of the WG towards an amplified fire prone system (Bowman et al. 2009).

A combination of drought and ignition sources from human activities and forest type characteristics combine to result in these elevated fire conditions (Kodandapani et al. 2008). While some forest types in the WG experienced amplified fire conditions in response to the vegetation stress of 2004, the effects of these wildland fires would be different between forest types, which could be important for conservation in the WG. In the wet evergreen primary forest, the increased occurrence of fires, especially in drought years could have important implications for the conservation of biodiversity as demonstrated in similar forests in other parts of the tropics (Cochrane 2003). Tree species in this forest type are not adapted to recurrent fires; drought and fires in this forest type could have impacts on diversity, structure, regeneration, and biomass of these forests (Daniels et al. 1995). In the secondary moist deciduous forest local rainfall variations are amplified as a result of largescale disturbances within these forest types (Pascal 1988). As a consequence, these two landcover types could be extremely vulnerable to fires during drought years; together they constitute about 20% of the forest area and habor high levels of biodiversity. The future consequences of drought, fire, and the resulting mortality of trees both due to fire and the drought (Phillips et al. 2010) could result in a positive feedback, contributing to frequent and more destructive fires in these ecosystems.

Although, the correlation between fire anomalies and NDVI anomalies for the combined forest types was not statistically significant, it nevertheless demonstrates the drought-fire linkages, through the signal obtained from the NDVI anomalies for the entire WG. The current study was conducted over a 10-y period, extending this study over a longer time period would increase sample sizes and provide more robust correlations between these two variables for the entire WG. The earth observation data such as the MODIS data used in this study are important from a management perspective, as any early warning system regarding fire prevention could be prioritized depending on spatially accurate information on drought and vegetation stress in ecosystems. In combination with in-situ observations of climate and vegetation stress, earth observations could be used to mitigate the magnitude of destructive fires around the globe.

CONCLUSIONS

The study demonstrates the importance of the intensity and severity of drought in contributing to the anomalous fire events, which is an important driver of global fire regimes. Increasing intensity, frequency, and area under droughts will have a large positive impact on fire occurrences in the WG. Given that several GCMs are projecting increasing probability of droughts in the tropics, the longterm effects of recurrent fires in the WG could have implications for the conservation of biodiversity in the 21st century. While these spatial and temporal analyses of fires response to droughts indicates vulnerability of all land cover types in the WG, particularly the primary wet evergreen and secondary moist deciduous forests would be particularly at risk.

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