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Q1 Identifying drought-induced correlations in the satellite time series of hot pixels recorded in the Brazilian Amazon by means of the detrended fluctuation analysis

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HIGHLIGHTS

- Correlations in satellite hot pixels recorded in the Brazilian Amazon are analysed.
- The most severe droughts coincide with maxima of DFA scaling exponent.
- The effectiveness of the DFA is shown in detecting drought events.

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ABSTRACT

In this work we study the long-term correlations in the satellite daily number of hot pixels recorded in the Brazilian Amazon during the period 1999–2012. While the highest peak in daily hot pixel frequencies occurred in 2007, coincident with a severe drought, for other intense droughts such as that occurred in 2005 (one-in-a-hundred year event for its high severity) and 2010, the corresponding number of hot pixels recorded was compatible or lower than that reached during e.g. 2004, with no reported severe drought. On the other hand, we find that the most severe droughts coincide with the peaks of the Detrended Fluctuation Analysis (DFA) scaling exponent of the time series of the daily anomalies in hot pixels. This finding is striking because it highlights the effectiveness of the DFA in disclosing that long-term hot pixel anomaly correlations are clearly associated with the drought events, that were not identifiable by examining hot pixel frequencies of the original time series. The dynamics of the time series of daily anomalies in hot pixels is, therefore, influenced by drought events. The coincidence of the peaks of the scaling exponent with drought events suggests the increase of the persistence of the hot pixel time series during the driest periods.

1. Introduction

Fires represent one of most important disturbance agents in natural ecosystems, with serious environmental consequences including soil erosion, destruction of vegetation cover, loss of biodiversity, and hydrological and geomorphologic

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changes [1–3]. They also influence climate by releasing black and organic carbon and greenhouse gases, which are important drivers of global warming [4]. Various environmental factors including vegetation cover, climatic conditions, topography of affected area and fire fighting methods contribute to process of initiation, propagation and suppression of fires, turning the modeling of this phenomenon into an extremely difficult task [5]. The development of adequate models of fire behavior in different ecosystems is crucial for understanding and modeling fire related phenomena that are important for efficient management of bioenvironmental resources, land use, and agriculture, and thus contributes to worldwide efforts to improve sustainable development and environmental protection. To include fires as disturbance agents in global ecological and climatic models, it is necessary to study the long-term records of global fire activity, which requires consistent global datasets that include information about temporal variation and spatial distribution of fires. Annual fire point datasets are available for some countries as U.S.A. and Canada, but the information from developing countries, in particular from tropics and subtropics are sparse so the worldwide historical survey is still lacking. Empirical studies based on forest and wild-land fire data from different countries have shown that (independently of geographic location, climatic conditions and type of vegetation) the frequency- burned area distribution displays power-law behavior which is a signature of Self Organized Criticality (SOC), the tendency of non equilibrium systems driven by slow constant energy input to organize themselves into critical states characterized by the energy released in bursts without typical size [6–9]. The fingerprints of SOC systems are power-law frequency-size distribution and spatial and temporal power-law behavior [10]. While frequency-size distribution of forest fires was extensively studied, much less is known about scale free behavior of temporal and spatial correlations of forest fires. Recent results that reveal temporal and spatial clustering of forest fire sequences, long-term correlations and relation with weather and vegetation parameters indicate the existence of fractal properties of spatial distribution and temporal variability of fires [11–15].

Recently, various global datasets have been constructed from Earth observing satellites [16–20]. Analysis of images produced by satellite sensors reveals so-called hot pixels with infrared intensity corresponding to burning vegetation. Depending on sensor resolution, a hot pixel may represent a single fire or be one of several hot pixels representing a larger fire. Although not all fires can be identified from satellite images, usually because of cloud cover, overpass time, and the fact that some hot pixels can originate from other heat sources (e.g. industry related or reflected light from the Earth surface, lakes, etc.), however, hot pixels may be used as a proxy to evaluate spatial and temporal patterns of fire activity and its relation with climatic and anthropogenic factors [19–21].

The Amazon rainforest is considered to be subjected to degradation processes in coming decades due to different factors, such as climatic conditions, conservation policies, agricultural expansion, development of new transport infrastructure, but also due to the increase of fire occurrences [22–24]. Recently various prediction models of deforestation were developed; but, even if they take into account many of these natural, anthropogenic and socio-economic factors [23,25,26], deforestation and future changes of land use and land cover in the Amazon are still poorly understood [27].

In order to provide complementary information that can help to improve these projections, we examined the long-term correlations of the time series of the daily counts of hot pixels in the Brazilian Amazon from 1999 to 2012.

A large number of hot pixels is detected annually by satellites in the tropical regions, mostly due to the widespread use of fire for land management [28]. In Brazil, in particular, the highest numbers of hot pixels detected every year are in *cerrado* (central Brazilian savanna) and in forest along the southern and eastern edges (Arch of deforestation) of the Amazon biome [29]. While *cerrado*is a fire-adapted and fire-dependent ecosystem, whose species are fire adapted, flammable and fire-maintained, tropical rainforests, such as the Amazon, instead are fire sensitive ecosystems [30]. Since tropical forest species are not resistant to burning, repeated fires severely affect tropical forests reducing the diversity of plant species, lowering the percentage of canopy cover and slowing forest growth and recovery [31,32]. As a consequence, the forest could shift (temporarily or permanently) to a different type of ecosystem, which is either a degraded forest or a savanna-like vegetation [30,31].

Most of wildfires in the Amazon are caused by human practices in clearing big forest areas for agriculture and livestock, and in managing agricultural crops such as burning residues [30]. Accidental fires that turn out to be large wildfires are common due to these practices, although natural factors such as drought, as in the case of severe droughts occurred in 2005, 2007 and 2010 [33–35], increase their chance of occurrence. During the 2005 drought (so severe that was classified as a one-in-a-hundred year event), the cumulative number of hot pixels in the Amazon was 33% higher than the 1999–2005 mean, while the deforestation in the Brazilian Amazon was 13% lower [33].

2. The method

The Detrended Fluctuation Analysis (DFA) was introduced by Peng et al. [36] as a method to detect and quantify correlations in non stationary time series [37,38] and successfully applied in physiology [39,40], environmental science [41] geophysics [42–45], climatology [46,47], econophysics [48,49] and music [50]. The DFA is implemented as follows:

(1) The original time series $x(i)$, $i = 1, \dots, N$ is integrated

$$X(k) - \sum_{i=1}^{k}[x(i) - \langle x \rangle], \quad k = 1, \dots, N \tag{1}$$

where $\langle x \rangle = \frac{1}{N}\sum_{i=1}^{N} x(i)$ is the average.