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The relation between lightning and cosmic rays during ENSO with and without IOD — A statistical study

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ABSTRACT

The relationship between the number of lightning flashes (NLF) and the cosmic ray flux (CRF) during the period of ENSO (El Niño/La Niña Southern Oscillations) with and without IOD (Indian Ocean Dipole) has been studied for the first time in the region of South/Southeast Asia (8°N–35°N and 60°E–120°E) to the authors' knowledge. Our analysis shows that the relationship is governed by regional meteorology and not by direct solar influence. Unlike on global scale, the data during ENSO are important for this relationship on regional scale. CRF and NLF are in statistically significant relationship only when CRF is significantly correlated with the meteorological parameters. CRF and NLF are significantly correlated during the period of ENSO with IOD (ENSO–IOD) but not during the period of ENSO without IOD (ENSO). The Aerosol Optical Depth (AOD), the positive temperature anomaly (TA) and an increase in TA may be responsible for this relationship during the ENSO–IOD period. On the shorter temporal/spatial scale, meso-scale meteorological parameters are responsible for the negative correlation between the CRF and the NLF. On the other hand, on the longer scale, an amount of Low Level Cloud Fraction (LLCF) is responsible for the positive correlation between the CRF and the NLF. Our partial correlation analysis shows that controlling for the AOD weakens the correlation between the CRF and the NLF but does not affect that between the 12 month running means of the same. Thus, aerosols are responsible during the total study period and during the IOD period for enhancing the significant CRF–NLF relationship. Solar radio flux $F_{10.7}$ cm ($SRF_{10.7}$) seems to be the main controlling parameter for the stronger relationship. We find that there is a distinct difference in the average magnitude of different solar and meteorological parameters between that during the ENSO period and the ENSO–IOD period which may be attributed to the difference in cloud types and aerosol properties between the two periods. The results of our analysis may be confirmed with longer data sets and more number of IOD events in the future.

1. Introduction

El Niño/La Niña Southern Oscillation (ENSO) is an important climatic phenomenon characterized by the seesaw in the sea level pressure between Tahiti (17.5°S, 150°W) and Darwin (12.5°S, 130°E) with positive/negative Sea Surface Temperature Anomalies (SSTAs) corresponding to El Niño/La Niña respectively in the Eastern and/Central Pacific Ocean. The Southern Oscillation Index (SOI) is a measure of the ENSO conditions. There are various studies on ENSO and lightning activity (e.g. Lhermitte and Williams, 1983; Williams and Renno, 1993; Price, 1993; Kumar and Kamra, 2012 with references therein). The global lightning is mainly concentrated over land and is highly dependent on the surface air temperature on the short time scale (Williams,

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1992; Price, 1993; Sekiguchi et al., 2006; Rycroft et al., 2000; Qie et al., 2003; Siingh et al., 2007, 2011, 2013, 2014; Markson, 2007; Sàtori et al., 2009; Yuan and Qie, 2008; Mach et al., 2011). Recently, Harrison et al. (2011) examined the ENSO effect in the atmospheric electricity measurements made at Shetland (Scotland). They found that the mean global circuit response to ENSO is characterized by the strengthening/weakening during the El Niño/La Niña conditions respectively. Yoshida et al. (2007) studied the contrasts in lightning flash rate and in the aerial distribution of its variation in the East/Southeast Asian region and in the western Pacific region respectively between El Niño and La Niña. Sàtori and Zieger (1999) reported that both the intensity and the position of the global lightning activity vary on the ENSO time scale. Further, their analysis showed more lightning activity in the tropical–extra tropical land regions during the warm El Niño episodes, especially in Southeast Asia.

The Indian Ocean Dipole (IOD) is another climate phenomenon which occurs on the inter-annual scale and is found to be responsible for the changes in the monsoon rainfall over India (Saji et al., 1999; Vinaychandran et al., 2009). All the above studies in lightning/global atmospheric electric circuit differentiate between the El Niño and La Niña periods but we do not find any study pertaining to the IOD period as per our knowledge. Similar to the SOI for ENSO events, IOD event is detected by the Dipole Mode Index (DMI) which is defined as the difference in SSTA between the western (50°E–70°E, 10°S–10°N) and the eastern (90°E–110°E, 10°S–0°) equatorial Indian Ocean (Saji et al., 1999). The IOD year is a year when the DMI is higher than one standard deviation for the period of 3–4 months in a year (Vinaychandran et al., 2009). When the difference between west and east (west minus east) SSTA is positive, it is called as the positive IOD and when it is negative, it is called as the negative IOD. Here, we examine the data during the years of ENSO without IOD (ENSO period) and during the years of ENSO with IOD (ENSO–IOD period).

The relation between the lightning and the cosmic ray flux (CRF) is not established yet (e.g. Schlegel et al., 2001; Dwyer et al., 2009). Siingh et al. (2013) studied the effect of the solar variability parameters and the meteorological parameters on the total number of lightning flashes (NLF) and the convective rain (CRain) for the two regions (8°N–35°N, 60°E–95°E — region 1 and 8°N–35°N, 95°E–120°E — region 2) in South/Southeast Asia. They found that only CRF and $SRF_{10.7}$ show significant low negative correlation with the NLF. The sun spot number and the Ap index do not correlate significantly with the NLF. Similarly, only CRF shows significant negative correlation with the CRain in both regions. However, with the meteorological parameters such as temperature variation, Convective Available Potential Energy (CAPE), convective cloud layer, total cloud cover and columnar total ozone, the NLF and the CRain are significantly correlated with the correlation coefficient between 0.5 and 0.95. Recent studies in CERN, Switzerland (Duplissy et al., 2010; Kirkby et al., 2011) using Cosmics Leaving OUtdoor Droplets (CLOUD) experiment support the major role of CRF in nucleation events. Thus, studying the association between NLF and CRF in two types of climate events is important as it is a topic of current research. Pinto et al. (2013) study a link between the thunderstorm activity and the solar activity using the thunder day data over Brazil by a method of wavelet analysis. In this paper we do correlation and partial correlation analysis of various solar and meteorological parameters to look for the relationship between NLF and CRF in the South/Southeast Asian region (8°N–35°N, 60°E–120°E) during the period of ENSO and ENSO–IOD events and try to give its possible physical interpretation.

2. Data analysis

The area of investigation for the present study comprises of South/Southeast Asia (8°N–35°N, 60°E–120°E) (Fig. 1). This area consists of the Arabian Sea, Bay of Bengal and South China Sea along with the desert of Thar in west India, plains in central India and Southeast China, and large river basins in the foot-hills of the Himalaya and the Tibetan plateau to the north of India. This whole region is impacted by the Asian monsoon due to differential heating over land and sea surface. Therefore, it would be interesting to investigate a selected region for the CRF–NLF relationship.

We have used datasets for the period 1998–2010. The monthly averaged data of sunspot number (SSN), cosmic ray flux (CRF), total solar irradiance (TSI) and solar radio flux $F_{10.7}$ cm ($SRF_{10.7}$) are downloaded. The details of the data sets are given in Table 1.

For the CRF data, we have used data from the nearest neutron monitoring station at Beijing (39.08°N, 116.26°E, altitude 48 m), China, operated by the Institute of Space Physics, Beijing for our primary analysis. We could not locate any other neutron monitoring station closer than this which was operational during the study period. Also, to confirm our conclusion we have used CRF data from two more stations Thule (76.5°N 68.7°W) and Kile (54°N, 10°E).

The NLF derived from the Lightning Imaging Sensor (LIS) aboard Tropical Rainfall Measuring Mission (TRMM) satellite encircling the Earth at an altitude of 350 km with an inclination of 35° have been used (Simpson, 1988; Simpson et al., 1988; Christian et al., 1992). As a result, the LIS can observe lightning activity between $+/-35°$ north/south latitudes, and detects both intra-cloud and cloud-to-ground lightning discharges during the day and night with a nearly uniform 90% flash detection efficiency within the field of view (FOV) of the sensor. The LIS detects and locates lightning with the spatial resolution of 5–10 km and with the temporal resolution of 2 ms over a large region of the Earth's surface along the orbital track of the satellite. The chosen area of the present study lies in the FOV of sensors which monitor storm system for 80 s. The monthly data have been downloaded with $5° \times 5°$ grid resolutions for the period 1998–2010 for the region of interest (Table 1).

The convective rain data are derived from the TRMM PR 3A25 data product with a spatial resolution of $0.5° \times 0.5°$ at 2 km height and it gives monthly mean rain rate (mm/h). The precipitation radar has a horizontal resolution of about 5 km at the ground and a swath width of 247 km (Simpson et al., 1988). It is able to provide the vertical profiles of the rain and snow from the surface up to a height of about 20 km. The radar is able to separate out the rain echoes for the vertical sample sizes of about 250 m when looking straight down and also detects fairly light rain rates down to about 0.7 mm/h. The details of the data are given in Table 1.

The Dipole Mode Index (DMI) based on the SST anomalies in the Indian Ocean as defined above and derived from the