

Variability of lightning, convective rain and solar activity study over South/Southeast Asia during ENSO episode for the period of 1998-2010

Devendraa Siingh¹, T. Dharmaraj^{*1}, P. Ramesh Kumar², Rajesh Singh³, Sanjay Kumar⁴, G.R. Chinthalu¹, M.N. Patil¹ and R.P. Singh⁴

¹Indian Institute of Tropical Meteorology, Pune, India

²Department of Meteorology and Oceanography, Andhra University, Visakhapatnam-530003, India

³KSK Geomagnetic Research Laboratory, Indian Institute of Geomagnetism, Allahabad, India

⁴Department of Physics, Banaras Hindu University, Varanasi- 221105.

*Corresponding Author: dharam@tropmet.res.in

ABSTRACT

Analysis of monthly mean data of lightning and convective rain for the region 8° N - 35° N, 60° E - 120° E and for the period 1998-2010 show that lightning and convective rain are not significantly influenced by solar parameters such as sunspot number, total solar irradiance (TSI) and solar radio flux whereas CAPE anomaly and temperature anomaly have significant impact on the total lightning flash rate and convective rain during ENSO periods. Further no significant relation between cosmic ray flux and total lightning flash rate during La Niña period is obtained. On the other hand, for the El Niño period and for the total period, we get statistically some significant negative correlation between cosmic ray flux and total lightning flash rate. However, it is not possible to make any comment on the general relation between cosmic ray flux and total lightning flash rate due to contaminating global effects, regional effects and cloud microphysics. In the monthly variation of the parameters, temperature anomaly can be used as a proxy for the total lightning flash rate for the region under consideration. Most of the variation in ozone during the ENSO period is due to lightning. In the region considered here, role of aerosols in producing lightning and rainfall is quite comparable during La Niña period. On the other hand, aerosols contribute more towards production of lightning than producing rain during El Niño due to changes in cloud microphysics and cloud electrification.

Key words: El Niño, La Niña, Lightning flash rate, ENSO, Convective rain rate, Cosmic rays, Solar activity, CAPE, Aerosol optical depth.

INTRODUCTION

El Niño Southern Oscillation (ENSO) is roughly a global coupled ocean atmosphere phenomenon of the interaction between the atmosphere and the hydrosphere in the tropical Pacific Ocean. The southern oscillation refers to variation in the sea surface temperature of eastern Pacific Ocean. Warming leads to El Niño and cooling develops La Niña due to air surface pressure in tropical western Pacific. The warm/cold phases of ENSO is caused by anomalous heating/cooling of water from the equatorial east Pacific (Andreoli and Kayano, 2005; Kayano and Andreoli, 2007; Rampelotto et al., 2012). ENSO is represented by the Southern Oscillation Index (SOI), which is the standardized index based on the observation of the sea level pressure between Darwin (12° 27' S, 130°, 50' E) and Tahiti (17° 27' S, 149°, 26' W). Negative and Positive values of SOI indicate El Niño & La Niña phenomena. El Niño accompanies high air surface pressure in the western Pacific and the cold phase La Niña accompanies low air surface pressure in the eastern Pacific (Cane, 2005). The pressure and temperature changes

impact the global air circulation and the world wide climate ranging from floods to draughts. During El Niño events, the shift in convection from the western to the central and the eastern Pacific affect the response of rain producing cumulonimbus clouds and also influence the frequency and intensity of tropical storms and deep convective clouds (Williams et al., 1989; Williams, 1992; Stolzenburg and Marshall, 2008; Siingh et al., 2012). Lightning activity is also affected during El Niño period, because it is related to the stage of convective clouds development, the intensity of updraft (Lhermite and Williams, 1983), convective available potential energy (CAPE) (Williams and Renno, 1993; Siingh et al., 2011) and surface temperature (Williams, 1992; Price, 1993; Rycroft et al., 2000; Markson, 2007; Satori et al., 2009; Siingh et al., 2007, 2011). Ming et al., (2005) showed that lightning density remained higher for the El Niño event of 1997-1998 and the center of maximum density shifted from the south eastern China to the southern Indo China Peninsula. More lightning flashes have been reported during El Niño episodes in the tropical and extra tropical land regions (Satori et al., 2009; Kumar

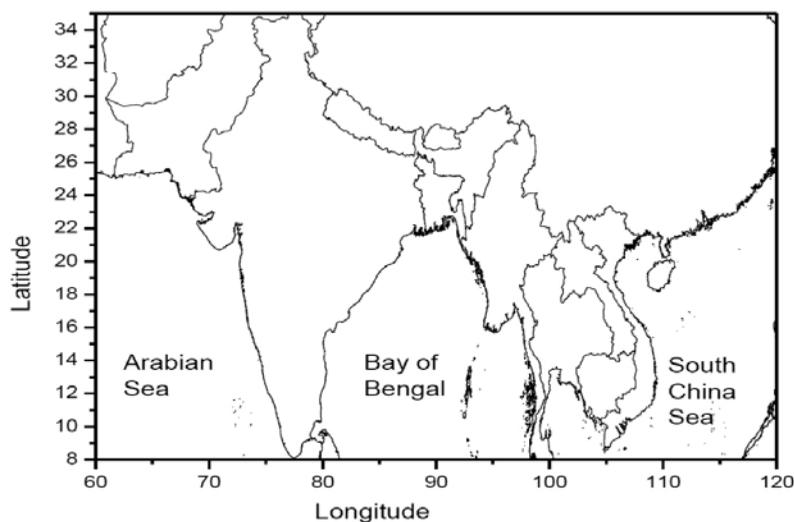


Figure 1. Map of South/Southeast Asia (8° N - 35° N, 60° E -120° E).

and Kamra, 2012). Harrison et al., (2011) examined the ENSO effect in the atmospheric electricity measurements made at Shetland (Scotland) and reported that the response is strengthened or weakened during El Niño or La Niña conditions, respectively.

The atmospheric circulation changes during ENSO events could possibly influence storm frequency and intensity (Williams, 1992) and lightning activity (Goodman et al., 2000). Analyzing Schumann resonance data, Satori and Zieger (1999) showed a southward shift in the global position of the lightning activity in El Niño years and northward shift in La Niña years respectively in African longitudes. During the intense ENSO events of 1997-1998, Goodmann et al., (2000) reported a 100% to 200% increases in the frequency of lightning days in the winter season along the Gulf Coast and adjacent waters. Hamid et al., (2001) showed that during the El Niño period and normal period the number of convective storms over the Indonesian ocean decreases or increases, while the number of lightning flashes remains low. Whereas, over land and coastal region during the El Niño period and normal period the number of convective storms decreases or increases, while the number of lightning flashes increases or decreases, indicating that convective storms are more intense during the El Niño period. The contrast in lightning activity during El Niño years over land/coast and ocean may be due to suppression of sea surface temperature and increase in air temperature over tropical lands. LaJoie and Laing (2008) analyzed lightning data along the Gulf Coast for the period 1995 - 2002 and showed the highest annual lightning count during the El Niño season of 1997- 1998.

The lowest lightning count was observed in 2000, which has mostly La Niña and neutral phases of ENSO. ENSO events modify sea-breeze and land-breeze circulations,

which triggered air mass thunderstorms. Comparing the results with the past studies, LaJoie and Laing (2008) suggested that the ENSO cycle impacts lightning activity through its influence on the storm tracks. Yoshida et al., (2007) showed that the lightning flash rate in the East/Southeast Asia shows a clear inverse correlation with the Southern Oscillation Index (SOI) i.e. the lightning activity increases during the El Niño period and decreases during the La Niña period. The moist air from the ocean is warmed over the land resulting into strong updraft in high pressure system over the oceanic area. As a result cumulonimbus storm develops over coastal area leading to frequent lightning activity. During the La Niña period, low pressure system over the land surface causes the increase of rainfall frequency with less lightning activity.

The surface winds converge into the regions of highest sea surface temperature, commonly known as “warm pool”. It shifts eastward during El Niño years. As a result the rain belt also shifts eastward leading to drought in the Indonesia and a number of other areas of the tropics and a drenching rain to the Pacific Islands and other areas lying close to the equator. In the La Niña years warm pool shifts westward reversing the rain trend in the Indonesia and other tropical regions. Rasmusson and Carpenter (1982) studied the impact of ENSO event in detail on Asian and Australian monsoon.

Yulishastin et al., (www2.ims.nus.edu.sg/Programs/.../Report_Swadhin%20Behera.pdf) had shown that ENSO and IOD (Indian Ocean Dipole) introduce varied impacts on the rainfall of Indonesia. A positive IOD event is defined when SST is anomalously warm in the western Indian Ocean, while it is colder than normal in the east (Saji et al., 1999; Yamagata et al., 2004; Yulihastin et al., (www2.ims.nus.edu.sg/Programs/.../Report_Swadhin%20Behera).

Variability of lightning, convective rain and solar activity study over South/Southeast Asia during ENSO episode for the period of 1998-2010

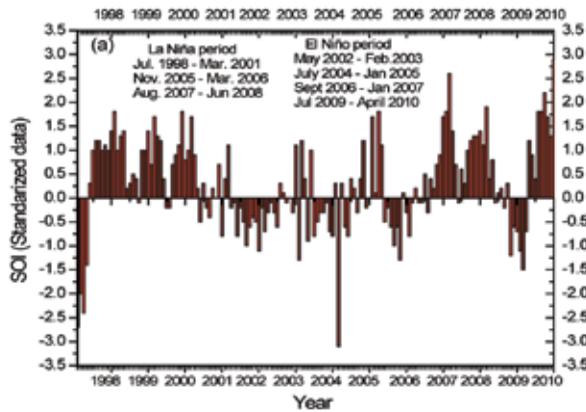


Figure 2 (a). Annual variation of SOI showing the period of El Niño and La Niña during 1998- 2010.

pdf) showed that a strong El Niño and a positive IOD simultaneously lead Indonesia to a longer dry season than normal. During El Niño years the walker circulation in Pacific becomes weaker, which suppresses the atmospheric convection. They further showed that when La Niña and positive IOD occurred together, precipitation was enhanced all over Indonesia except over western region (Java and Sumatra), which was affected by IOD owing to its closer vicinity. Yoshida et al., (2007) reported that during the La Niña period frequency and amount of rain increases in Southeast Asia and western part of Pacific regions as compared to the El Niño and normal period. During the La Niña period lower sea level pressure makes several low pressure systems and they increase amount and rainfall frequency and not lightning flash rate.

Both lightning flash rate and convective rain are influenced by changes in solar irradiance and galactic cosmic rays (GCR) (Rycroft et al., 2000; Kirkby, 2007; Siingh and Singh, 2010; Siingh et al., 2011; Singh et al., 2011), which depend on solar activity. The solar activity is indicated by the flux of 10.7 cm radio emissions from the Sun ($F_{10.7}$ cm), sunspot number, geomagnetic index, etc. The total solar irradiance increases significantly around the time when the sunspot number is at its maximum. Solar magnetic fields scatter GCR flux in the interplanetary space, hence GCR effects vary in the opposite sense to the other indices, i.e. maximum GCR flux corresponds to the minimum solar activity. The solar irradiance differentially heats the land and the sea surface and helps in development of convective systems. The deep and organized convective systems over the Bay of Bengal and South China Sea (SCS) lead to the onset of monsoons. Heavy monsoon rain develops over the west coast of India, the Bay of Bengal, the South China Sea and the Philippines and signifies the full establishment of summer monsoon in the entire tropical region (Lau and Yang, 1997).

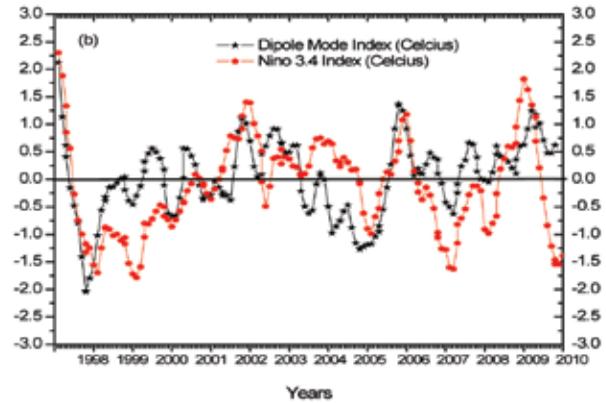


Figure 2(b). Same as Figure 2a but for Niño 3.4 Index (Celsius) and Dipole Mode Index (Celsius).

The purpose of this study is to summarize the general behavior of dependence of lightning activity and convective rain on various solar and meteorological parameters during the warm and cold ENSO episodes. Statistical analysis has been carried out for Asian continent containing India, Pakistan, Bangladesh, Burma, Part of China and Islands in Bay of Bengal as depicted in Figure 1 to examine the relationship between lightning and solar and meteorological parameters. The chosen area is densely populated and mostly dependent on agriculture. Hence, present study finds relevance. Satellite data for the lightning flashes, rainfall, solar parameters and relevant meteorological parameters are analyzed for the period 1998 – 2010. The dependence of lightning flashes and convective rain on the solar parameters such as sunspot numbers, cosmic rays, total solar irradiance (TSI) and $F_{10.7}$ cm solar radio flux have been checked statistically and discussed during the La Niña and El Niño period. Variability of lightning and convective rain anomaly with meteorological parameters such as temperature anomaly, CAPE anomaly, and aerosol optical depth (AOD) is discussed. Finally conclusions from the study are summarized.

DATA AND METHODOLOGY

Area of our investigation for the study of the spatio-temporal variations of lightning activity and convective rain comprises South/Southeast Asia ($8^{\circ}\text{N} - 35^{\circ}\text{N}$, $60^{\circ}\text{E} - 120^{\circ}\text{E}$), which is shown in Figure 1. This region has been chosen especially as it has three parts of different seas - the Arabian sea, the Bay of Bengal and South China sea. All of them have different meteorological characteristics in different seasons; land deserts (the great Indian Thar desert in west India); plains (the Central India and Southeast China); large river basins in the foothills of the Himalayas;

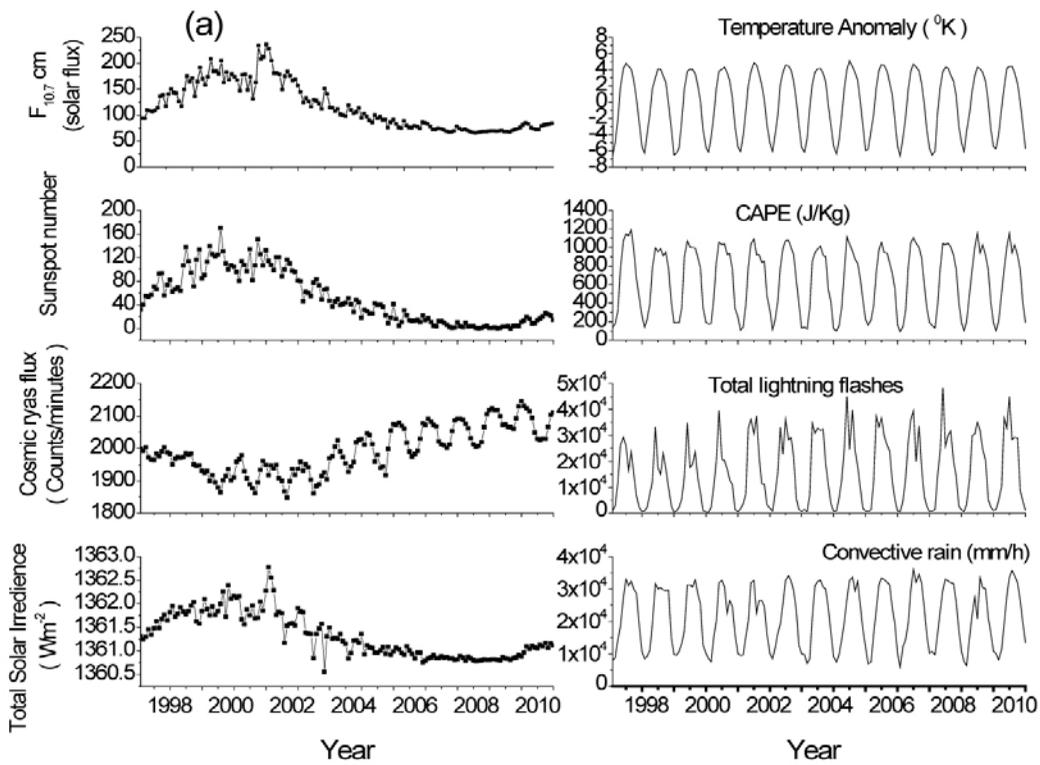


Figure 3(a). Annual variation of solar parameters, temperature anomaly, CAPE, total lightning flashes and convective rain during the period of 1998-2010.

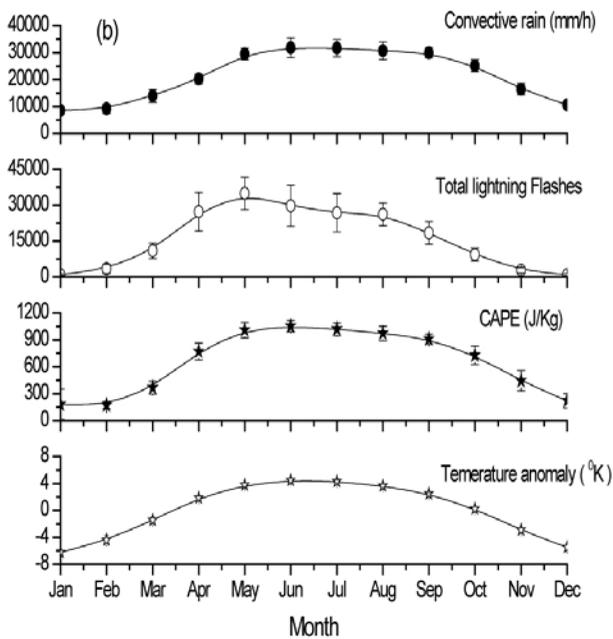


Figure 3(b). Average monthly variation of convective rain, total lightning flashes, CAPE and temperature anomaly for period of 1998 – 2010. Error bars show the standard error.

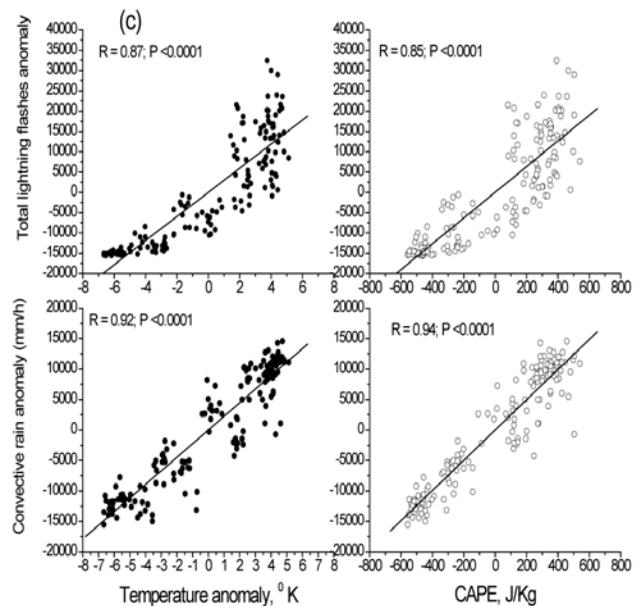


Figure 3 (c). Scattered plot of lightning flash anomaly and convective rain anomaly with temperature anomaly and CAPE anomaly of the whole study region for the period 1998 - 2010.

peak mountains and world's highest plateau of Tibet to the north of India. With these diverse features, the chosen area experiences large range of spatio - temporal variability in weather and climate conditions. The extreme weather conditions in different regions of the area widely differ in both space and time. In spite of such a diversification, the area has one common feature on climate scale and is impacted by the Asian monsoon.

The southern oscillation Index (SOI) time series data obtained from the United States National Geophysical Data Center (<http://www.ngdc.noaa.gov>) is shown in Figure 2a for the period of 1998 - 2010. The period of El Niño and La Niña are May 2002 – February 2003, July 2004 – January 2005, September 2006 - January 2007, July 2009 - April 2010; and July 1998 - March 2001, November 2005 - March 2006, August 2007 - June 2008, respectively. Niño 3.4 index and dipole mode index are plotted in Figure 2b. The data are taken from the website: (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml). El Niño period is characterized by negative Niño 3.4 index and dipole mode index and positive value of SOI and that of La Niña by positive (negative) values of SOI respectively. It is seen that dipole mode index does not follow Niño 3.4 index. During some years, it is in phase with Niño 3.4 index and during other times it is out of phase. A positive IOD suppresses convection process by weakening Walker circulation over the Maritime continent (Yulihastin et al., www2.ims.nus.edu.sg/Programs/.../Report_Swadhin%20Behera.pdf).

To understand the possible link of solar activity influence on lightning activity and convective rain during the El Niño and La Niña periods we analyze relevant data for a solar cycle period (1998 - 2010). Monthly averaged data of sunspot number, cosmic ray flux, total solar irradiance (TSI) and solar radio flux ($F_{10.7}$ cm) are downloaded from the following websites :<http://solarscience.msfc.nasa.gov/greenwch.shtml>;<http://lasp.colorado.edu>; <http://celestrak.com/SpaceData/SpaceWx-format.asp>.

Cosmic ray flux data is taken from the nearest neutron monitoring station at Beijing (39.08 °N, 116.26 °E, altitude 48 m), China, operated by the Institute of Physics, Beijing. Any other station closer than this was not operational during the reported study period. Cosmic ray flux slightly varies with latitude and longitude due to rigidity cutoff, caused by the geomagnetic field and tilting of rotation axis of the Earth (Smart and Shea, 2005; Siingh and Singh, 2010; Singh et al., 2011). However, the change is small and trend in variation remains almost the same.

The lightning data (number of flashes) derived from lightning imaging sensors (LIS) aboard Tropical Rainfall Measuring Mission (TRMM) satellite have been used (Simpson, 1988; Simpson et al., 1988; Christensen et al., 1992). The LIS instruments can observe lightning activity between $\pm 35^\circ$ north/south latitudes. The LIS detects and

locates lightning with the spatial resolution of 5 - 10 km and temporal resolution of 2 ms over a large region of the Earth's surface along the orbital track of the satellite. The LIS has a nearly uniform 90% flash detection efficiency within the field of view (FOV) of the sensor, and could detect both intra-cloud and cloud-to-ground discharges during the day and night conditions. The chosen area in the present study lies in the field of view of sensors, which monitor storm system for 80 s, a period long enough to obtain a measure of the lightning flash rate in these storms. LIS has a sampling rate slightly greater than 500 frames per second. The monthly data available in the grid resolution of 5 deg \times 5 deg for the period 1998 – 2010 were downloaded from the website (<http://ghrc.msfc.nasa.gov>) for the region of interest.

The convective rain data are derived from the TRMM PR 3A25 data product with a spatial resolution of 0.5 deg \times 0.5 deg at 2 km height. The precipitation radar operating at 13.8 GHz and having a horizontal resolution at the ground of about 5 kms and a swath of ~ 247 kms provide three - dimensional maps of storm structure (Simpson et al., 1988). One of its most important features is its ability to provide vertical profiles of the rain and snow from the surface up to a height of about 20 kms. The precipitation radar is able to detect fairly light rain rates down to about 0.7 mm/hour. Effective correction has been incorporated in the data processing method for attenuation effects during intense rain period. The precipitation radar is able to separate out rain echoes for vertical sample sizes of about 250 meters when looking straight down. The data are downloaded from the website (www.daac.gsfc.nasa.gov).

The meteorological parameters such as surface temperature, CAPE, AOD (aerosol optical depth), atmospheric columnar total ozone with 2.5 degree grid resolution from Climate Forecast System Reanalysis (CFSR) data developed by NOAA's National Center for Environmental Prediction (NCEP) (http://nomadl.ncep.noaa.gov/ncep_data/index.html) have been used.

RESULTS AND DISCUSSION

Figure 3a shows monthly average of solar radio flux ($F_{10.7}$ cm), sunspot number, cosmic ray flux, total solar irradiance, temperature anomaly, CAPE, total lightning flashes and convective rain for the years 1998 - 2010. Data derived from the grid points are averaged for the whole region shown in Figure 1. From Figure 3a, it is noted that solar radio flux ($F_{10.7}$ cm), sunspot number and total solar irradiance vary in phase having almost similar annual variation. As expected cosmic ray flux is in opposite phase to these parameters. Average monthly variation of temperature anomaly, CAPE, number of total lightning flashes and convective rain are shown in Figure 3b. Temperature anomaly, CAPE and convective rain show similar monthly variations. Lightning

flash rate shows a maximum in the month of May. It may be noted that in the Indian region monsoon starts in the month of June whereas in the South China Sea and adjacent region, monsoon starts in the month of April/May. However, pre-monsoon showers are expected in May in Indian region. Thus the maximum lightning flash rate in the month of May is not unexpected. The correlation statistics using linear regression analysis and Fisher's transformation formula are shown in Figure 4a, 4b for El Niño, La Niña for the period of 1998 – 2010, respectively. In all the figures confidence level (CL) of correlation coefficients is at 95 % and R^2 is coefficient of determination given in each panel. Sători et al., (2009) have studied global lightning activity on ENSO time scale based on the Schumann resonance data at Nagycenk (Hungary) and OTD/LIS satellite data. They found more lightning in the tropical/extra tropical land regions especially in Southeast Asia during El Niño episode.

At small temporal and spatial scales, lightning and precipitation are positively correlated for individual thunderstorms (Petersen and Rutledge, 1998; Price and Federmesser, 2006) and at large temporal and spatial scales, they are negatively correlated (Price, 2009). Figure 3c shows the scattered plot of lightning anomaly and convective rain anomaly with surface temperature anomaly and CAPE anomaly (sum of whole region for the period of study). It is seen that both (lightning and rain anomaly) have almost similar trend. Rainfall and lightning are both related to the microphysics and dynamics of deep convective clouds (Williams et al., 1989). Drier climate produces vigorous thunderstorm with more intense lightning activity (Williams and Sători, 2004; Williams et al., 2005) and relatively lesser rainfall. Since the region considered here is in South/Southeast Asia having maritime climate, a direct relationship between rainfall and lightning activity is expected. The correlation coefficients of lightning flash rate anomaly, convective rain anomaly with temperature anomaly and CAPE anomaly are 0.87, 0.92 and 0.85, 0.94, respectively and the correlations are statistically significant (Figure 3c). A good correlation shows that lightning activity may be used as a tool to assess/predict the convective rain; the same was earlier discussed by Chronis et al., (2004).

Figures 4a and 4b show correlation statistics of total lightning flashes and convective rain with sunspot number, cosmic ray flux, solar radio flux (F10.7 cm), total solar irradiance (TSI), temperature anomaly and CAPE anomaly during El Niño and La Niña period, respectively. CAPE anomaly and temperature anomaly have statistically significant high positive correlations with total lightning flashes and convective rain during El Niño as well as during La Niña periods. It is interesting to note that cosmic ray flux has statistically significant negative correlation (~ -0.41) with lightning flashes and

convective rain during El Niño but no significant correlation during La Niña period. From this, explained variance in the total number of lightning flashes is about 17% due to linear relation with cosmic ray flux during El Niño. For the whole period from 1998 - 2010 we see statistically significant negative correlations of cosmic ray flux with total lightning flashes and convective rain with smaller correlation coefficients (-0.20 and -0.30) at more than 98% level of significance (Figure 4c) than those during El Niño period. The explained variance is lowered appreciably and for lightning flashes it is about 4% only. The observed small negative correlation with no statistical significance suggests that not all the lightning flashes are initiated by cosmic ray flux and may be only a few selected flashes are initiated depending upon suitable meteorological conditions. Dwyer (2003) and Dwyer et al., (2009) have pointed out that cosmic rays favor lightning through the process of runaway mechanism. Contrary to this, our analysis for the total period and for the El Niño period do not show any positive effect of cosmic rays on lightning flashes; rather negative correlation is obtained. This is in accordance with the findings of Schlegel et al., (2001). They obtained a significant negative correlation between cosmic ray flux and lightning frequency. Also, they point out that the correlation coefficient between sunspot numbers and thunderstorm frequency is varying throughout the globe, within a short distance. This variation may be attributed to the mechanism of transmission of solar signal by planetary waves to the lower levels of the atmosphere.

Our analysis does not show any dependence of lightning on cosmic rays during La Niña period. Statistically significant negative correlation of cosmic rays with lightning in case of El Niño period and for the total period (1998 - 2010), and no significant correlation during La Niña show that lightning flashes are dependent more on environmental conditions and not on cosmic ray flux. Further, as the considered region is located near the equator, the cosmic ray flux mostly consists of relatively lower energy particles. They may not be effective in nucleating clouds with sufficient charge separation so as to result in lightning flashes. As the major impact of El Niño and La Niña on meteorological conditions is through the changes in global circulation and in the location and strength of convection, it is quite likely that these may be the main factors responsible for the variation of lightning frequency and for the distinct behavior of correlation during El Niño and La Niña periods, respectively.

According to Schlegel et al., (2001), as cosmic ray flux is reduced, the atmosphere becomes less conductive and therefore high electric fields can build up causing more lightning and altering the global distribution and occurrence frequency.

One possibility of getting opposite relationship in our case may be as the number of ions with increase in cosmic

Variability of lightning, convective rain and solar activity study over South/Southeast Asia during ENSO episode for the period of 1998-2010

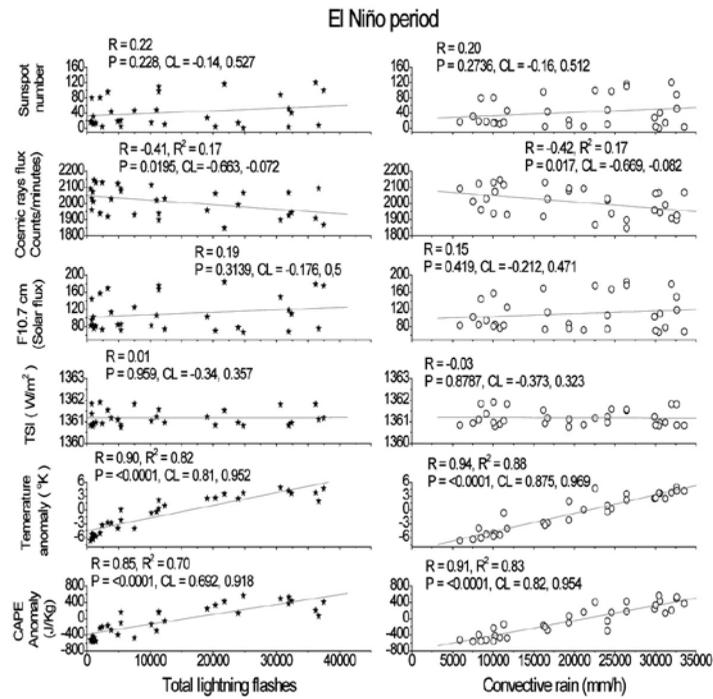


Figure 4(a). Scattered plots show correlation statistics of total lightning flashes and convective rain with different meteorological parameters and solar parameters for El Niño period. Value of correlation coefficient, coefficient of determination, confidence limits (CL) of correlation coefficient at 95% level of confidence using Fisher's transformation and significance level of the correlation (probability P) using linear regression analysis are given in each panel. The coefficient of determination R^2 is given only when correlation is statistically significant and which is a measure of explained variance.

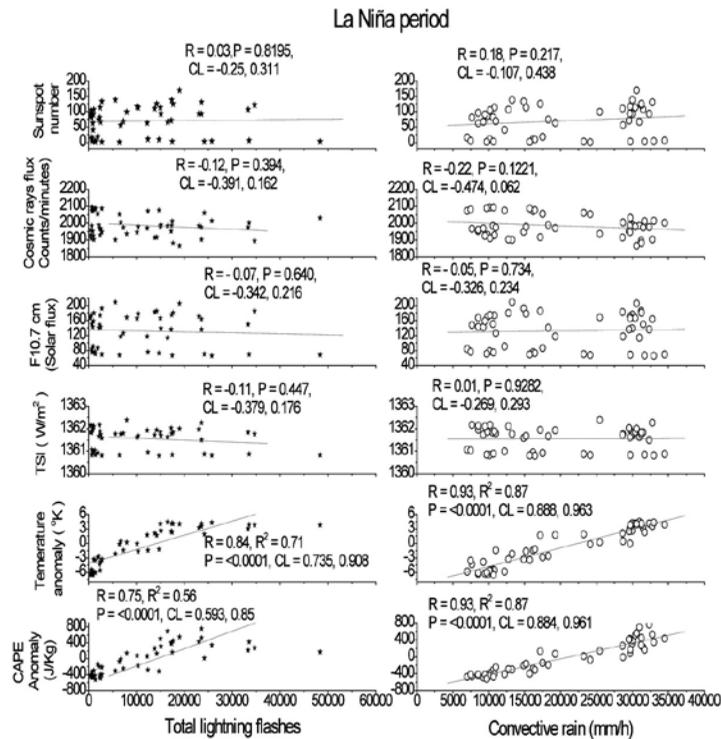


Figure 4 (b). Same as Figure 4a but for La Niña period.

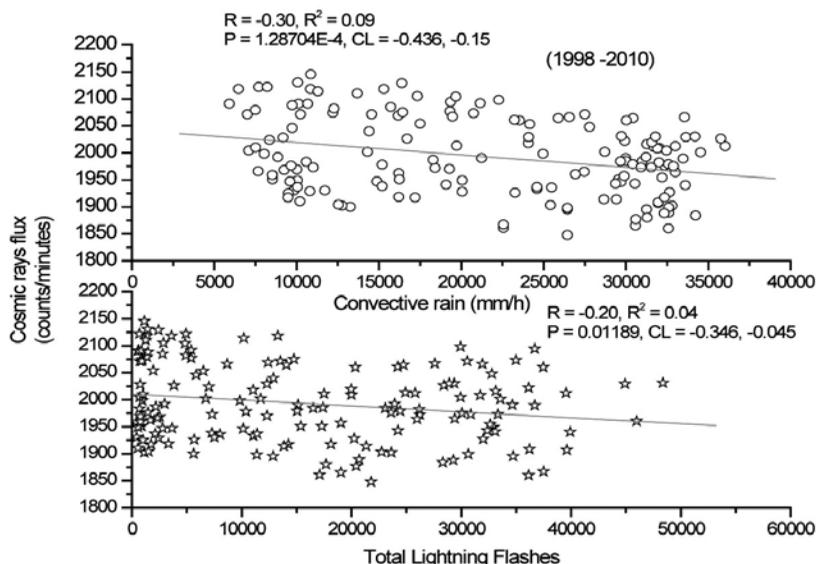


Figure 4(c). Scattered plots show correlation statistics of convective rain and total lightning flashes with cosmic ray flux for the period 1998 - 2010. Value of correlation coefficient, coefficient of determination, confidence limits (CL) of correlation coefficient at 95% level of confidence using Fisher’s transformation and significance level of the correlation (probability P) using linear regression analysis are given in each panel.

ray flux increases, they may attach to the oppositely charged particles instead of a neutral particle and get electrically neutralized. So, in effect, there is a decrease in number of charged particles even though cosmic ray flux is increased. This effect may be dependent on the type of aerosol, which differs from region to region. Due to the difference in global circulation between El Niño and La Niña events, the source region of air mass will be different during El Niño from that during La Niña. As a result, the type of aerosol during El Niño will be different from that during La Niña over the considered region. This may be the reason why we do not get any significant relation between the cosmic ray flux and the total number of lightning during La Niña period. Apart from cosmic ray ionization, there are other sources of ionization such as surface radioactivity and ionization due to radon gas, which vary with space and time (Siingh et al., 2013). The ions produced are carried up in the atmosphere by updrafts and are also involved in thunderstorm charging processes. Therefore, another possibility of getting negative correlation between cosmic ray flux and number of lightning may be due to other varying sources of ions. During La Niña phase, the average surface temperature decreases leading to weaker updrafts. As a result the upper portion of thundercloud may not reach freezing level altitude to have enough ice particles to initiate lightning processes.

If we compare the data set of figures 4a and 4b, then one finds that the scale for convective rain and lightning flash rates both for the El Niño and La Niña periods are almost of

the same order of magnitude. In fact as expected, based on previous studies (Goodman et al., 2000; Hamid et al., 2001; Satori et al., 2009; Kandagaonkar et al., 2010; Kumar and Karma, 2012), statistically a perceptible difference during the warm and cold phases was not visible. This may be due to the fact that we have averaged over the whole region for the period from 1998 to 2010. As the considered region is large, the other phenomena such as IOD may be more effective in part of the considered region. It is difficult to separate the IOD effect from the ENSO effect. However, qualitatively we may understand the role of IOD. It is in phase with the El Niño. IOD enhances El Niña effect and vice-versa. During the La Niña phase (July 1998 - March 2001), the value of IOD oscillated and remained in opposite phase for longer duration. Similarly, during the period August 2007-June 2008, IOD remained positive. During the El Niño of July 2004 - January 2005, IOD was negative. During these periods of opposite phase, the effect of IOD is to counter the effect of El Niño /La Niña. In order to understand this, we plotted the contours of lightning flashes and convective rain for the months of July and August during the El Niño, La Niña and normal periods. The results are shown in the Figures 5 a, b, c and 6 a, b and c, respectively. Comparing Figures 5 a, b, c one notices that the geographical distribution pattern of lightning flash rate remains almost the same except the magnitude. The location of peaks coincides.

The magnitude is largest during El Niño and minimum during La Niña periods. However, the difference is not large. This may be due to the effect of IOD, which is positive during both the declining phase of La Niña (July- August,

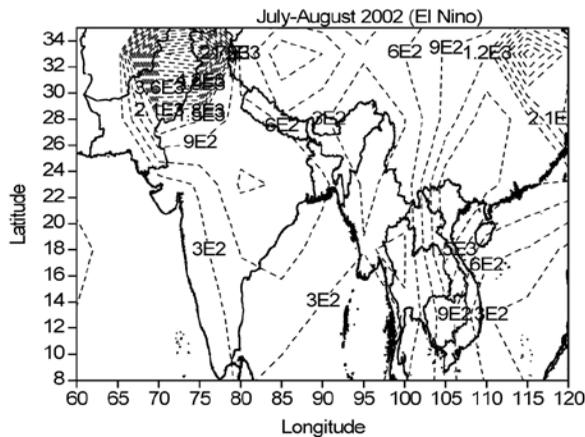


Figure 5. Distribution of total lightning flashes during the monsoon periods: (a) El Niño (July - August 2002)

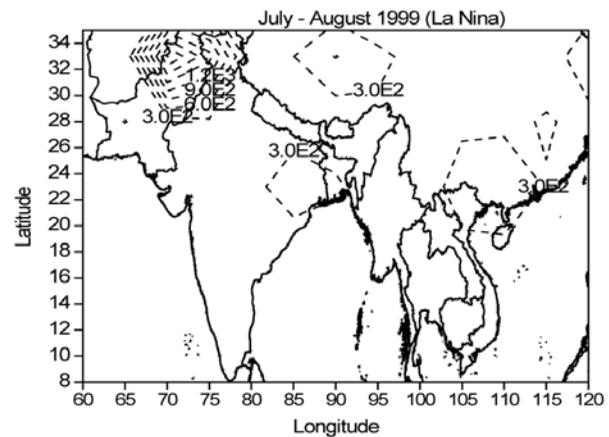


Figure 5 (b). La Niña (July - August 1999)

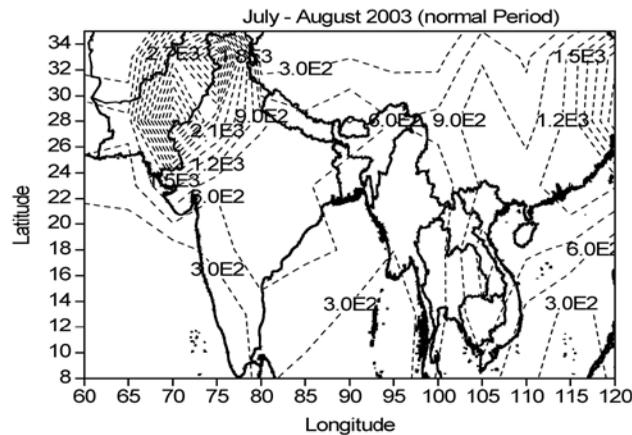


Figure 5 (c). Normal (July - August 2003).

1999) and normal (July - August, 2003) periods. Positive IOD has similar effects as El Niño (Yulihastin et al., www2.ims.nus.edu.sg/Programs/.../Report_Swadhin%20Behera.pdf). During the considered El Niño period (July - August 2002), IOD changes from negative to positive value. Negative IOD decreases the flash rate. Lightning flash rate distribution for the total period of individual El Niño is shown in figures 6 a, b, c, d, e. Figure 6a corresponds to short duration El Niño covering mostly winter season. Figure 6b belongs to the longer duration period covering monsoon season as well as winter season. In both cases El Niño strength was approximately the same. IOD was positive in both cases having almost similar duration, but slightly less pronounced. In both the cases we find more flashes on the land surface as compared to ocean surface. Further, there is a clear enhancement in flash rate (Figure 6b) along with emergence of secondary peak. The change in pattern of distribution shows that possibly lightning flash distribution during monsoon season is different to that of the winter season during the El Niño period. Figure 6c corresponds to the El Niño, which was

one of the strongest during the considered period of 1998 - 2010. IOD was also positive during this period. There is an intense secondary peak in the flash distribution. However, flash number in the remaining area has decreased. But in the Figure 6c, only part of the monsoon period is considered, which may explain the difference in distribution pattern. From these distributions, we notice that flashes depend on the duration and strength of El Niño. Flash distributions during the La Niña events are shown in Figure 6 d, e. Figure 6d shows contours of flashes for winter period. IOD was also negative from January 2005 to June 2006. Flashes are more concentrated in the region enclosed by the longitudes 95 - 108° E and latitudes 8 - 20° N. Figure 6e shows a different distribution when monsoon period is included in another La Niña events. The peak shifts to the region covering Pakistan and North-west adjacent part of India. Even the flash density increases. It was an intense La Niña, but IOD oscillated between positive (August - November 2007, April - June 2008) and negative values. In this case usual relation between ENSO events and lightning flashes breaks. Similar breaks

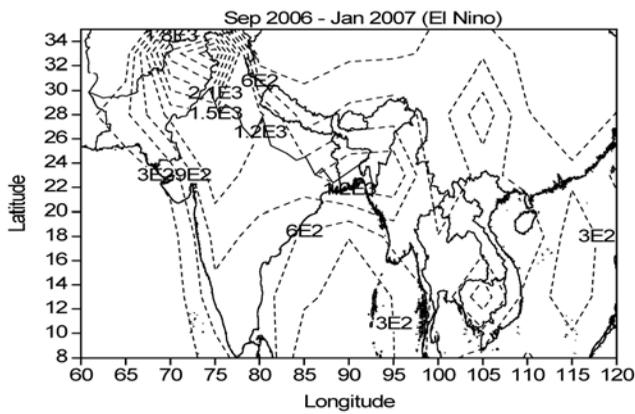


Figure 6. Distribution of lightning flashes for the complete ENSO events; (a) El Niño covering winter season (September 2006 - January 2007).

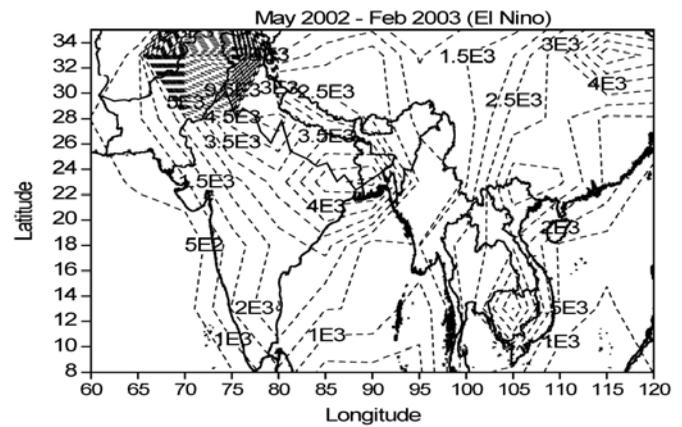


Figure 6 (b). El Niño covering monsoon and winter season (May 2002 - February 2003).

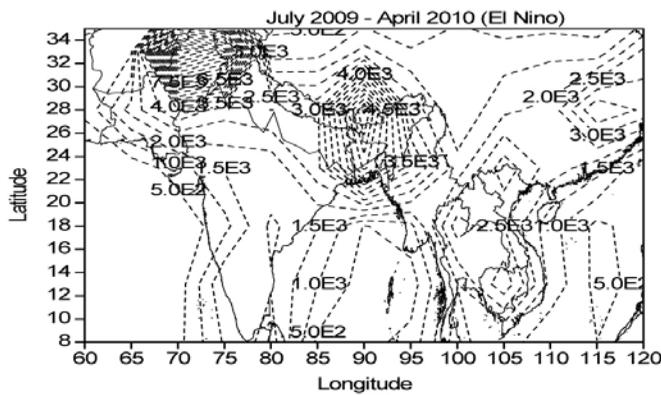


Figure 6 (c). El Niño covering partly monsoon and winter season (July 2009 - April 2010).

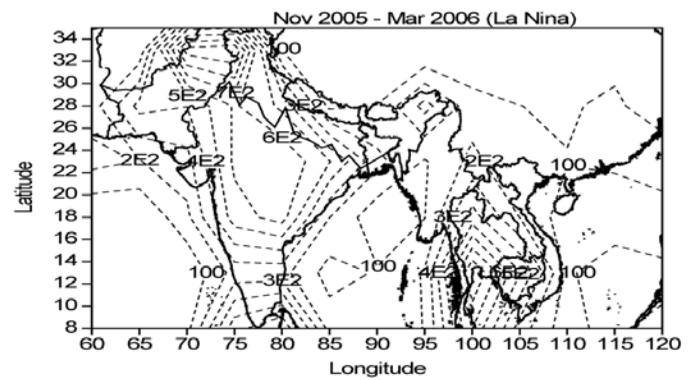


Figure 6 (d). La Niña covering winter season (November 2005 - March 2006)

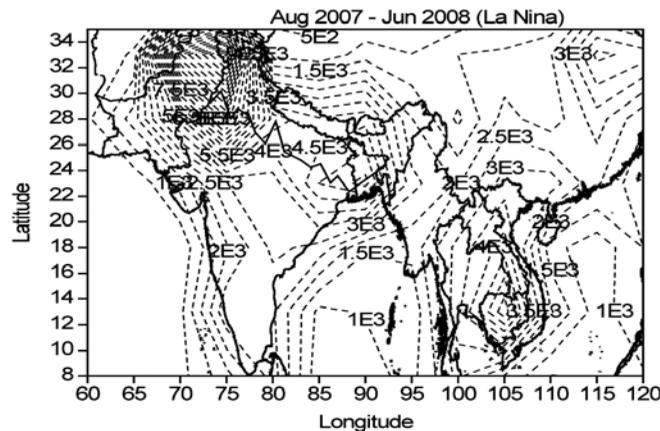


Figure 6 (e). La Niña covering partly monsoon and winter season (August 2007-June 2008).

in the relation were also reported by Kumar and Kamra (2012). This is an example, which is difficult to understand based on convection processes. There may be some other climatic variable playing the role. Detail study is required to understand this behavior of lightning flash distribution.

Figure 7 a, b, c show convective rain during the monsoon month July - August for the El Niño, La Niña and normal period, respectively. In the figure 7a the maximum range of convective rain rate during El Niño period (July - August, 2002) is 25 - 40 mm/h along the foothill of Himalayas, Bay

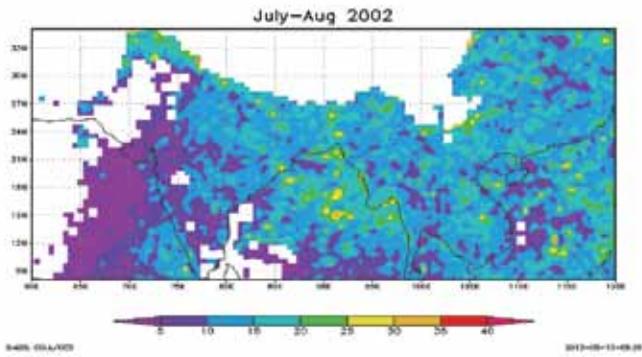


Figure 7. Distribution of convective rainfall rate (mm/h) during the monsoon periods: (a) El Niño (July - August 2002).

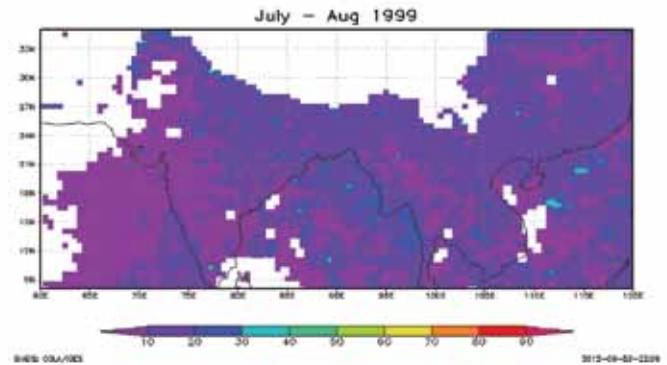


Figure 7 (b). La Niña (July - August 1999)

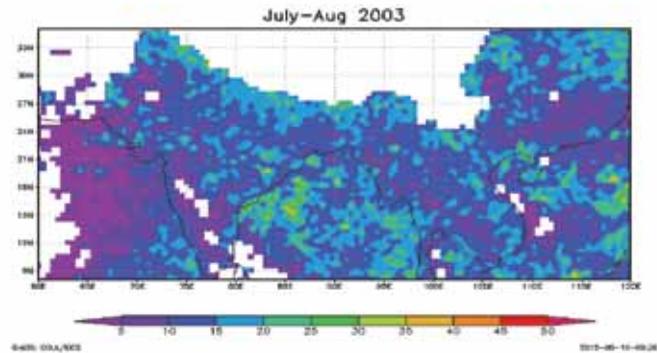


Figure 7(c). Normal (July - August 2003).

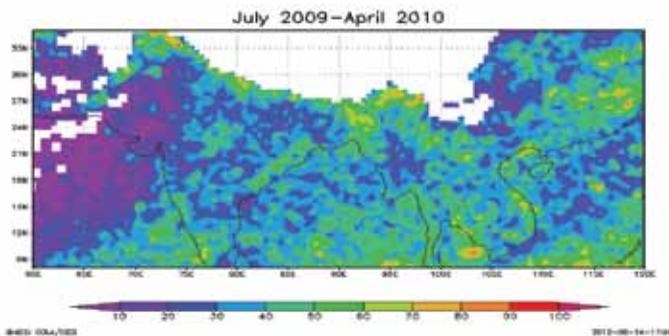


Figure 8. Distribution of convective rainfall rate (mm/h) during the periods: (a) El Niño (July 2009 - April 2010)

of Bengal, East China and South China sea region, whereas in Arabian Sea it is < 5 mm/h and maximum along the coast line of southern Peninsula. In La Niña period (July – August, 1999) maximum range of convective rain rate is 20 – 30 mm/h along the foothills of Himalayas, Bay of Bengal, East China and South China sea region, whereas in Arabian Sea it is < 10 mm/h (Figure 7b). For the normal period (July – August, 2003) maximum range of convective rain rate is

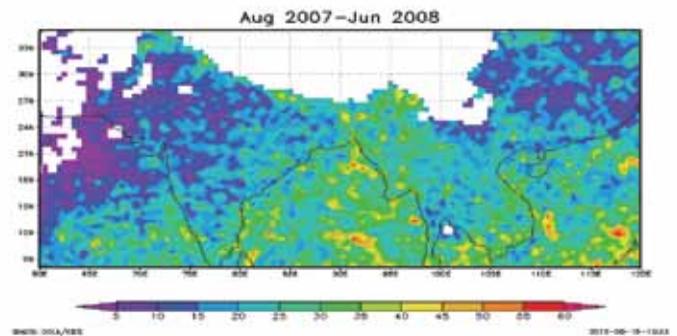


Figure 8 (b). La Niña (August 2007-June 2008).

30 - 35 mm/h along the foothills of Himalayas, Bay of Bengal, East China and South China sea region, whereas in Arabian Sea it is < 5 mm/h and the maximum convective rain rate of 40-45 mm/h is observed along the western coast line of Indian Peninsula (Figure 7c).

Figure 8 a, b show contours of total convective rain rate during the El Niño (July 2009 -April 2010) and La Niña (August 2007- June 2008) events, respectively. It is

noted that relatively there is more rain during La Niña events than the El Niño events. During the El Niño events precipitation is concentrated over ocean surface as compared to land surface. In the La Niña case convective rain precipitation is distributed approximately equal over the land and ocean surface. In both the cases convective rain is more concentrated in the Southeast Asian region as compared to South Asian region. In the case of Middle East, Price et al., (1998) showed enhanced precipitation during the winter season associated with El Niño years. These changes in ENSO and convective rain/lightning flash rate may be due to natural variability in the climate system or other factors related to global climate changes.

CONCLUSION

Our analysis of monthly mean data of lightning and convective rain for the region (8° N - 35° N, 60° E - 120° E) and for the period 1998 - 2010 show that lightning and convective rain are not influenced by solar parameters such as sunspot number, TSI and solar radio flux. CAPE anomaly and temperature anomaly have significant relation with number of lightning and convective rain during ENSO. This shows that meteorological conditions play major role in case of total number of lightning flashes. About 82% correlation with total number of lightning flashes can be explained by its linear correlation with temperature anomaly and about 70% by its correlation with CAPE anomaly during El Niño period. Similarly during La Niña period, these values are about 71% and 56%, respectively.

Earlier studies showed negative correlation between the El Niño phenomena and Indian monsoon rainfall (Pant and Parthasarathy, 1981; Parthasarathy et al., 1991; Kumar et al., 1999). We found more yearly rainfall during El Niño (July 2009 - April 2010) event than during La Niña event (August 2007- June 2008). Thus the negative correlation between El Niño event rainfall breakdown, Kumar and Kamra (2012) noted that the El Niño – Indian summer monsoon rain relationship broke down in the case of the 1997-1998 El Niño, which was associated with the southward shift in the Walker circulation.

We do not get any significant relation between cosmic ray flux and number of lightning flashes during La Niña. On the other hand, for the El Niño period and for the total period, we get statistically significant negative correlation between cosmic ray flux and number of lightning flashes. The explained variances are about 17% and 4%, respectively. It is difficult to conclude generally about the relation between cosmic ray flux and number of lightning flashes due to contaminating effects at the global and regional levels. Even cloud initiation by cosmic rays is not well established (Singh et al., 2011). Even solar influence and meteorological effects on convective processes in the

atmosphere are interwoven and these effects on convective rain and lightning flashes are not separated. So a data set for extended time period is required to separate out solar influence and meteorological influence. In the monthly variation of the parameters, temperature anomaly can be used as a proxy for the total number of lightning flashes for the region under consideration.

ACKNOWLEDGEMENTS

We acknowledge with thanks the NASA and NOAA for making the data available: global lightning, convective rain, solar parameter, cosmic rays and meteorological parameter. DS, PRK and TD are thankful to Dr. R. Nunjundiah, The Director, IITM, Pune for kind support and encouragement. This work is supported under the collaborative programme of IITM, Pune and BHU, Varanasi and also partially supported under CAWSES programme of ISRO (DS). Authors thank Dr. Upal Saha for his valuable suggestions during preparation of manuscript. The authors wish to thank the anonymous reviewer for his suggestions which helped to improve the paper. Thanks are due to Chief editor for proper editing and support.

Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

REFERENCES

- Andreoli, R.V., and Kayano, M.T., 2005. ENSO-related rainfall anomalies in South America and associated circulation features during warm and cold pacific decadal oscillation regimes. *Int. J. Clim.*, v.25, pp: 2017-2030.
- Cane, M.A., 2005. The evolution of El Niño, past and future. *Earth Plan. Science Lett.*, v.230, pp: 227-240.
- Christian, H.J., Blakeslee, R.J., and Goodman, S.J., 1992. Lightning imaging sensor (LIS) for the earth observing system, NASA TM-4350, Available from Center for Aerospace Information, P.O. Box 8757, Baltimore Washington International Airport, Baltimore, MD 21240, p: 44.
- Chronis, T., Anagnostou, E., and Dinku, T., 2004. High frequency estimation of thunderstorms via satellite infrared and a long-range lightning network in Europe. *Quart. J. Royal Meteorol. Soc.*, April issue Part B No. 599., v.130.
- Dwyer, J.R., 2003. A fundamental limit on electric fields in air. *Geophys. Res. Lett.*, doi:10.1029/2003GL017781., v.30, no.20, p: 2055.
- Dwyer, J.R., Uman, A., and Rassoul, H.K., 2009. Remote measurements of thundercloud electrostatic fields. *J. Geophys. Res.*, D09208, doi:10.1029/2008JD011386., v.114.
- Goodman, S.J., Buechler, D.E., Knupp, K., Driscoll, K.T., and McCaul, E.W., 2000. The 1997–1998 El Niño event and

Variability of lightning, convective rain and solar activity study over South/Southeast Asia during ENSO episode for the period of 1998-2010

- related winter time lightning variations in the Southeastern United States. *Geophys. Res. Lett.*, v.27, pp: 541-544.
- Hamid, E.F., Kawasaki, Z.I., and Mardiana, R., 2001. Impact of the 1997–98 El Niño event on lightning activity over Indonesia. *Geophys. Res. Lett.*, v.28, pp: 147-150.
- Harrison, R.G., Joshi, M., and Pascoe, K., 2011. Inferring convective responses to El Niño with atmospheric electricity measurements at Shetland. *Environ. Res. Lett.*, 044028, doi:10.1088/1748-9326/6/4/044028., v.6, p: 3.
- Kandalgaonkar, S.S., Kulkarni, J.R., Tinmaker, M.I.R., and Kulkarni, M.K., 2010. Land-ocean contrasts in lightning activity over the Indian region. *Int. J. Climatol.*, v.30, pp: 137-145.
- Kayano, M.T., and Andreoli, R.V., 2007. Relations of South American summer rainfall interannual variations with the Pacific Decadal Oscillation. *Int. J. Climatol.*, DOI: 10.1002/joc.1417., v.27, pp: 531-540.
- Kirkby, J., 2007. Cosmic rays and climate. *Survey in Geophys.*, doi:10.1007/s10712-008-9030-6., v.28, pp: 333-375.
- Kumar, K.K., Rajagopalan, B., and Cane, M.A., 1999. On the weakening relationship between the Indian monsoon and ENSO. *Science.*, v.284, pp: 2156-2159.
- Kumar, P.R., and Kamra, A.K., 2012. Variability of lightning activity in South/Southeast Asia during 1997–98 and 2002–03 El Niño /La Niña events. *Atmos. Res.*, v.118, pp: 84-102.
- LaJoie, M., and Laing, A.G., 2008. The influence of El Niño–Southern oscillation on lightning in the Gulf coast of the United States, Part I: Lightning climatology. *Mon. Weather Rev.*, doi: 10.1175/2007MWR2227.1., v.136, pp: 2523-2542.
- Lau, K.-M., and Yang, S., 1997. Climatology and interannual variability of the Southeast Asian summer monsoon. *Advances. Atmos. Sci.*, DOI: 10.1007/s00376-997-0016-y., v.14, pp: 141-162.
- Lhermitte, R., and Williams, E.R., 1983. Radar tests of the precipitation hypothesis for thunderstorm electrification. *J. Geophys. Res.*, v.88, pp: 10984-10992.
- Markson, R., 2007. The global circuit intensity: its measurement and variation over the last 50 years. *Bull. Amer. Meteorol. Soc.*, doi: 10.1175/BAMS-88-2- 223, (February issue)., pp: 223-241.
- Ming, Ma., Tao, S., Zhu, B., and Lu, W., 2005. The anomalous variation of the lightning activity in southern China during the 1997/98 El Niño event. *Science China, Serial D Earth Science.*, v.48, pp: 1537-1547.
- Pant, G.B., and Parthasarathy, B., 1981. Some aspects of an association between the southern oscillation and Indian summer monsoon. *Arch. Meteorology Geophysics Bioklimatol.*, Ser. B., v.29, pp: 245-251.
- Parthasarathy, B., Rupakumar, K., and Deshpande, V.R., 1991. Indian summer monsoon rainfall and 200mb meridional wind index: Application for long range prediction. *Int. J. Climatol.*, v.11, pp: 165-176.
- Petersen, W.A., and Rutledge, S.A., 1998. On the relationship between cloud-to-ground lightning and convective rainfall. *J. Geophys. Res.*, v.103, pp: 14025-14040.
- Price, C., 1993. Global surface temperatures and the atmospheric electrical circuit. *Geophys. Res. Lett.*, doi:10.1029/93GL01774., v.20, pp: 1363-1366.
- Price, C., 2009. Will a drier climate result in more lightning?. *Atmos., Res.*, v.91, pp: 479-484.
- Price, C., and Federmesser, B., 2006. Lightning-rainfall relationships in Mediterranean winter thunderstorms. *Geophys. Res. Lett.*, L07813. doi: 10.1029/2005GL024794., v.33.
- Price, C., Stone, L., Huppert, A., Rajagopalan, B., and Alpert, P., 1998. A possible link between El Niño and precipitation in Israel. *Geophys. Res. Lett.*, v.25, pp: 3963-3966.
- Rampelotto, P.H., Rigozo, N.R., da Rosa, M.B., Prestes, A., Frigo, E., Souza Echer, M.P., and Nordemann, D.J.R., 2012. Variability of rainfall and temperature (1912–2008) parameters measured from Santa Maria (29° 41'S, 53°48'W) and their connections with ENSO and solar activity. *J. Atmos. Solar. Terr. Phys.*, doi: 10.1016/j.jastp.2011.12.012., v.77, pp: 152-160.
- Rasmusson, E.M., and Carpenter, T.H., 1982. Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/El Niño. *Mon. Wea. Rev.*, v.110, pp: 354-384.
- Rycroft, M.J., Israelsson, S., and Price, C., 2000. The global atmospheric electric circuit, solar activity and climate change. *J. Atmos. Solar. Terr. Phys.*, doi:10.1016/S1364-6826(00)00112-7., v.62, pp: 1563-1576.
- Saji, N.H., Goswami, B.N., Vinayachandran, P.N., and Yamagata, T., 1999. A dipole mode in the tropical Indian Ocean. *Nature.*, v.401, pp: 360-363.
- Satori, G., and Zieger, B., 1999. El Niño–related meridional oscillation of global lightning activity. *Geophys. Res. Lett.*, v.26, pp: 1365-1368.
- Satori, G., Williams, E.R., and Lemperger, I., 2009. Variability of global lightning activity on the ENSO time scale. *Atmos. Res.*, v.91, pp: 500-509.
- Simpson, J., ed., 1988. TRMM – a satellite mission to measure tropical rainfall. Report of the Science Steering Group, NASA Goddard Space Flight Center, Greenbelt, MD.
- Simpson, J., Adler, R.F., and North, G.R., 1988. A proposed tropical rainfall measuring mission (TRMM) satellite. *Bull. Amer. Meteorol. Soc.*, v.69, pp: 278-278.
- Schlegel, K., Diendorfer, G., Thern, S., and Schmidt, M., 2001. Thunderstorms, lightning and solar activity — Middle Europe. *J. Atmos. Solar. Terr. Phys.*, v.63, pp: 1705-1713
- Siingh, Devendraa., and Singh, R.P., 2010. The role of cosmic rays on the Earth's atmospheric processes. *Pramana. J. Phys.*, v.74, pp: 153-168.
- Siingh Devendraa., Gopalakrishnan, V., Singh, R.P., Kamra, A.K., Singh, S., Pant, V., Singh, R., and Singh, A.K., 2007. The atmospheric global electric circuit: an overview. *Atmos. Res.*, Doi:10.1016/j.atmosres. 2006.05.005., v.84, pp: 91-110.
- Siingh Devendraa., Singh, R.P., Singh, A.K., Kulkarni, M.N., Gautam, A.S., and Singh, A.K., 2011. Solar activity, lightning and climate. *Survey in Geophys.*, DOI 10.1007/s10712-011-9127-1., v.32, pp: 659-703.

- Siingh Devendraa., Singh, R.P., Kumar, S., Kulkarni, M.N., and Singh, A.K., 2012. Discharges in stratosphere and mesosphere. *Space Science Reviews*, DOI 10.1007/s11214-012-9906-0, v.169, pp: 73-121.
- Siingh Devendraa., Gautam, A.S., Kamra, A.K., and Komsaare Kaupo., 2013. Nucleation events for the formation of charged aerosol particles at tropical station- Preliminary results. *Atmos. Res.*, DOI:10.1016/j.atmosres.2013.05.024., v.132-133, pp: 239-252.
- Smart, D.F., and Shea, M.A., 2005. A review of geomagnetic cutoff rigidities for earth orbiting spacecraft. *Advances Space Research.*, v.36, pp: 2012-2020.
- Singh, A.K., Siingh, D., and Singh, R.P., 2011. Impact of galactic cosmic rays on Earth's atmosphere and human health. *Atmos. Environ.*, doi:10.1016/j.atmosenv.2011.04.027., v.45, pp: 3806-3818.
- Stolzenburg, M., and Marshall, T.C., 2008. Charge structure and dynamics in thunderstorm. *Space.*, doi:10.1007/s11214-008-9338-z, v.137, pp: 355-372.
- Williams, E.R., 1992. The Schumann resonance: a global thermometer. *Science.*, doi:10.1126/science.256.5060.1184., v.256, pp: 1184-1187.
- Williams, E.R., and Renno, N.O., 1993. An analysis of the conditional instability of the tropical atmosphere, *Mon. Wea. Rev.*, v.121, pp: 21-36.
- Williams, E.R., and Satori, G., 2004. Lightning, thermodynamic and hydrological comparison of the two tropical continental chimneys. *J. Atmos. Solar. Terr. Phys.*, v.66, pp: 1213-1231.
- Williams, E.R., Weber, M.E., and Orville, R.E., 1989. The relationship between lightning type and convective state of thunderclouds. *J. Geophys. Res.*, v.94, pp: 13213-13220.
- Williams, E.R., Mushtak, V.C., Rosenfeld, D., Goodman, S.J., and Boccippio, D.J., 2005. Thermodynamics conditions favorable to superlative thunderstorm updraft, mixed phase microphysics and lightning flash rate. *Atmos. Res.*, doi:10.1016/j.atmosres.2004.11.009., v.76, pp: 288-306.
- Yamagata, T., Behera, S.K., Luo, J.J., Masson, S., Jury, M.R., and Rao, S.A., 2004. Coupled Ocean-Atmosphere Variability in the Tropical Indian Ocean. *AGU Book Ocean-Atmosphere Interaction and Climate Variability*, C. Wang, S.-P. Xie and J.A. Carton (eds.). *Geophys. Monograph.*, AGU, Washington DC, v.147, pp: 189-212.
- Yoshida, S., Morimoto, T., Ushio, T., and Kawasaki, Z., 2007. ENSO and convective activities in Southeast Asia and western Pacific. *Geophys. Res. Lett.*, L21806, doi:10.1029/2007GL030758., v.34.
- Yulihastin, E., Febrianti, N., and Trismidianto. Impacts of El Niño and IOD on the Indonesian Climate, www2.ims.nus.edu.sg/Programs/.../Report_Swadhin%20Behera.pdf.

Received on: 17.2.17; Revised on: 27.4.17; Accepted on: 2.5.17

Rain Quotes

- * The best thing one can do when it's raining is to let it rain.
- *Henry Wadsworth Longfellow (1807–1882) was an American poet and educator*

- * The three great elemental sounds in nature are the sound of rain, the sound of wind in a primeval wood, and the sound of outer ocean on a beach.
- *Henry Beston (1888–1968) was an American writer and naturalist*

- * Like a welcome summer rain, humor may suddenly cleanse and cool the earth, the air and you.
- *Langston Hughes (1902–1967) an American poet, social activist and novelist,*

- * Let the rain kiss you. Let the rain beat upon your head with silver liquid drops. Let the rain sing you a lullaby.
- *Langston Hughes (1902 –1967) an American poet, social activist and novelist*

- * Life is full of beauty. Notice it. Notice the bumble bee, the small child, and the smiling faces. Smell the rain, and feel the wind. Live your life to the fullest potential, and fight for your dreams.
- *Ashley Smith (1978--)an American author, speaker, and hostage victim*