Testing the Cosmic Ray-Lightning Connection Hypothesis

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Abstract

The proposed dependence of atmospheric electrical properties on the ionizing influence of cosmic rays has resulted in numerous attempts to obtain convincing correlations. While most of the studies remain largely theoretical, a few results indicate that there is a plausible link between lightning activity and cosmic ray ionization. Using global lightning and assimilated cosmic ray data, the present work suggests a correlation between simultaneous Forbush decreases and lightning activity.

1. Introduction

The proposed dependence of atmospheric electrical properties on the ionizing influence of cosmic rays has resulted in numerous attempts to obtain convincing correlations. While most of the studies remain theoretical, a few results indicate that there is a plausible link between lightning activity and the cosmic ray ionization rate. The controversial work of [1], for instance, reported a significant positive correlation between total cloud cover over the mid-latitude oceans and cosmic ray flux around the cosmic ray minimum of 1990. In an attempt to explain the above relation, it was proposed that cosmic rays influence the production of new aerosol particles in the troposphere, which may grow and eventually increase the number of cloud condensation nuclei. Some follow-up investigations claimed that galactic cosmic ray (GCR) intensity modulation influences thundercloud electricity and lightning activity [2]. The authors indicated that GCRs exert much influence on the Earth's atmosphere since many atmospheric processes (e.g. atmospheric electric current, cloud and thundercloud formation, concentration of heavy and light ions) are defined by their electrical properties. At certain altitudes (~3 to 35km), GCRs are believed to be the only source of atmospheric ionization and could be responsible for electrical conductivity of the atmosphere at lower altitudes. [2] found that ion production rate in the atmosphere and GCR intensity variations could account for atmospheric current and lightning occurrence at middle latitudes.

Should the proposed relationship between GCRs and lightning exist, [3] speculate that the sudden depressions in cosmic ray intensity called Forbush decreases (Fds) could result in a decrease in thunderclouds and lightning formation. The pioneering work of [4] suggested that thunderstorm electric field could accelerate cosmic ray secondary electrons to high energies. [5] claimed that showers of energetic particles produced by such high energy cosmic rays could provide a conducting path that initiates lightning. Besides thunderstorm electric field, a high-speed coronal mass ejection (CME) and its associated interplanetary shock (IP) might equally accelerate cosmic ray particles to very high energies during high solar activity period. Fast CMEs, accompanied by strong IP shocks, can simultaneously generate Fds and accelerate cosmic rays to tremendous energies. This might explain why Fds and lightning [6, 7 and references therein] are both taken as a proxy to severe space weather. However, the high-energy cosmic rays that make it to the Earth are also reduced due to the stronger shielding of geomagnetic field during high solar activity. There is thus a likelihood of a reduction in lightning activity during a Fd.

The present work uses data from the World Wide Lightning Location Network (WWLLN) and an array of cosmic ray stations to investigate the impact of Fds on global lightning. Previous studies [8] that attempted to test the validity of GCR-lightning connection either made use of local lightning station or isolated cosmic ray observatories. The availability of global lightning data from WWLLN, and amalgamated cosmic ray data from a global network of neutron monitors provides a good opportunity to study the relationship between cosmic ray variations and lightning occurrence on a larger spatial scale than was previously possible.

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2. Data and Analysis

WWLLN is a developing experimental lightning detection network that provides global data which is increasingly used for scientific, commercial and other applications. This steady improvement is attributed to increasing station number and a algorithm used in locating lightning [9]. The data overcome the limitations of satellite or regional lightning data and are of great interest to researchers investigating the global electric circuit, global tracking of severe storms as well as climate change.

Cosmic ray data were obtained from the World-Wide Neutron Monitor Network, (**http://cr0.izmiran.rssi.ru/common/links.htm**) which provides data for a large number of stations at a variety of locations. Fd dates were taken from the literature. However, for some events, the dates reported by authors using data from separate cosmic ray stations could differ by as much as 2 to 5 days. Such a wide range in Fd key days usually biases the results of composite studies leading to erroneous conclusions and thus, suggests a need for a better selection criterion for Fd dates. The differences in days of Fd at different neutron monitor stations might be attributed to the asymmetrical distribution of cosmic rays within the Sun-Earth environment [10, 11] as well as the variability in the manifestations of Fds. Fds are so variable that an event may appear in various forms at different locations of the Earth. What looks like a Fd at a given position and time, may reveal itself to be a small variation of the cosmic ray anisotropy, or as in increase in density at another position and time [12]. Recently, [11] reported that a multivariate analysis could be used to discriminate between globally simultaneous and non-simultaneous Fds. Similar approach is used in the present work. On average, the number of cosmic ray stations used to determine the global simultaneity of a Fd event is about 30 and covers a wide range of latitudes and longitudes. Superposed epoch analysis (SEA) was then performed using the days of simultaneous Fds as the key dates.

3. Results and Discussion

Using the days of simultaneous Fds as the representative days, SEA was performed on global lightning data, $-25° \leq \Lambda \leq 25°$, $25° \leq \Lambda \leq 60°$ and $60° \leq |\Lambda| \leq 25°$ latitude bands. Fig 1 is the SEA of lightning strokes related to Fd minimum. Fig 1 (a) shows that there is a significant reduction in lightning count a day prior to the minimum GCR flux on a global scale, 1(b) indicates that a reduction in lightning occurrence is likely to coincide with maximum depression in GCR intensity at Northern hemisphered while 1(c) suggests a decrease in lightning count two days prior to Fds at the Southern hemisphere. We do not find any discernible dependence of lightning activity on Fds at the equator. This result might be explained with the theoretical expectation of [3] that a decrease in the flux of relativistic electrons generated by GCRs during Fds could result in a decrease in lightning occurrence. The latitude dependent effects might be attributed to the shielding effects of the Earth's magnetic field on high-energy charged particles [13].

Following the indications of [14] that strong Fds are more likely to affect atmospheric processes, we next consider lightning signal and cosmic ray intensity variations during two cases of strong Fds. For each of Figs 2 and 3, (a) reflects the cosmic ray intensity variation during the Fd of January 19, 2005 and July 17, 2005 respectively while the corresponding lower panels, (b), are variations in lightning activity during the same period. The outline boxplot summarizes the distribution properties for each day's data. The thick line shows the median, the inter-quartile range is represented by the box edges, the ends of the vertical lines (whiskers) indicates the maximum and minimum values of the data while the points outside the ends of the whiskers are outliers. The daily average variation is subtracted in (a) and (b). The horizontal solid line indicates the daily mean intensity variation in each data. The zero day represents the day of minimum cosmic ray flux for each of the Fd event.

The Fd event of January 19, 2005 (Fig 2(a)) is one of the strongest events ever recorded since continuous monitoring of cosmic rays began. [14] assert that a Fd event of such magnitude (83%) is capable of affecting atmospheric processes. Fig 2 (b) shows the daily variation in global lightning activity for the same period. There are some interesting similarities and differences in the two plots. It can be seen from Fig 2 (a) that the GCR intensity varies significantly only at the time of Fd, while lightning activity varies greatly from day to day (Fig 2 (b)). The minimum lightning count happened on the same day as minimum GCR flux. It is apparent that the lightning count remains low from this time and recovers gradually with the GCR intensity. However, the onset of the Fd seems not to affect lightning occurrence. This could explain why reduction in lightning count started a day after the onset time of this event. This agrees with [15] who noted that onset dates of Fds may not have any relationship to atmospheric processes. Using the first Schumann resonance as an indicator of the global thunderstorm activity, [8] found that the amplitude of the first Schumann resonance decreased during the Fd event of January 2005.

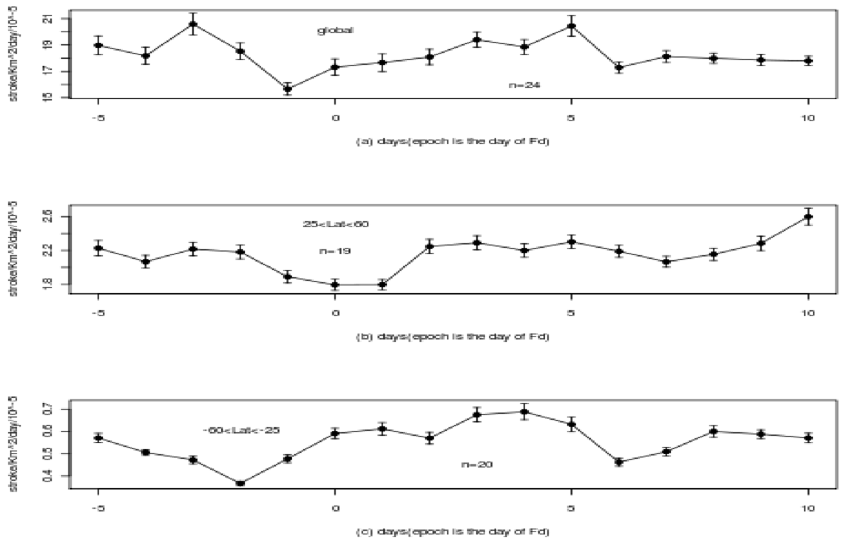

Figure 1: Superposed epoch analysis of lightning strokes related to Fd minimum for (a) the whole globe, (b) $25° \leq \Lambda \leq 60°$ and (c) $60 \leq |\Lambda| \leq 25$ latitudes. n represents the number of Fd events.

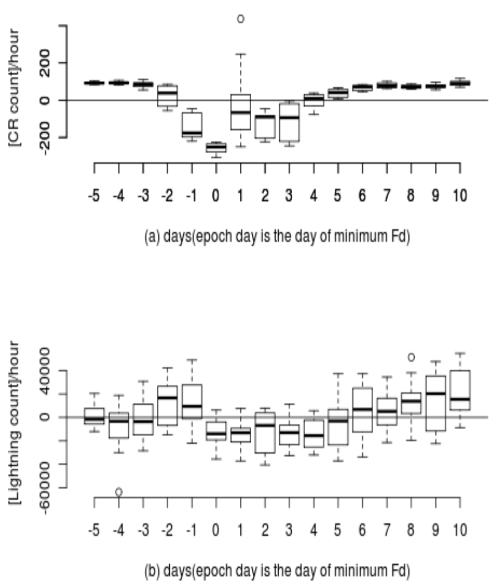

Figure 2: Comparison of (a) GCR amplitude deviation from hourly variation with (b) global lightning count deviation from hourly variation for January 19, 2005 Fd event.

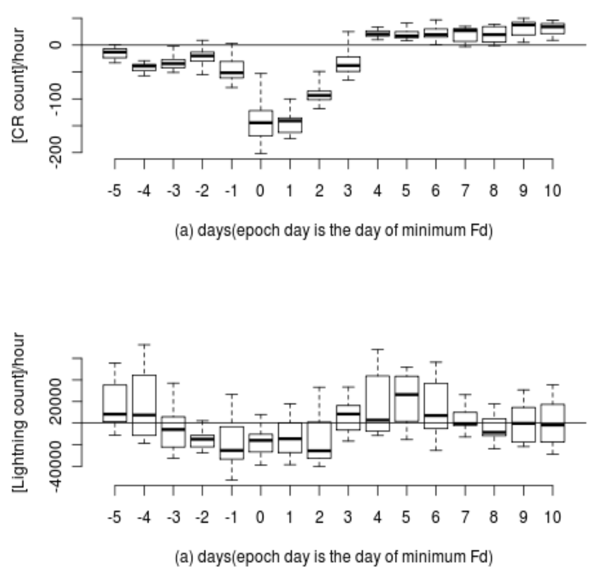

Figure 3: Same as Figure 3 for July 17, 2005 Fd event.

The result of another strong event is shown in Fig 3. A comparison of Fig 3 (a) and (b) indicates that a decrease in lightning count happened during the Fd. It can again be inferred that the onset of the Fd might not induce a reduction in lightning count. The onset of the Fd started over 5 days before the epoch day (July 17, 2005) whereas a reduction in lightning count started 3 days before the day of minimum GCR flux. Lightning activity also appears to recover gradually with the intensity of the cosmic ray flux.

4. Conclusions

The result presented indicates that there might be a link between GCR intensity variation and lightning formation processes. The cosmic ray-lightning connection might be latitude dependent.

5. References

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