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The Influence of Solar Parameters on Lightning Activity over Northern India using Lightning Imaging Sensor (LIS) Data

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Abstract

Objective: This study utilizes data from the Global Hydrometeorology Resource Center (GHRC) and the Lightning Imaging Sensor (LIS) to explore the relationships between solar parameters, lightning activity, and space weather conditions in Northern India from 1998 to 2014. **Methods:** The analysis explores temporal variations in lightning flashes (LF) in conjunction with solar indices such as Sunspot Number (SN), Solar Radio Flux(10.7cm), Cosmic rays' intensity, and geomagnetic indices (Kp and Ap). Correlations with space weather dynamics are examined, and regional meteorological influences are considered to contextualize these relationships. **Findings:** Limited direct variation is observed between solar parameters and lightning activity. However, peak lightning activity coincides with solar cycles 23 and 24, during the monsoon and pre-monsoon seasons. Increased lightning occurrence during the pre-monsoon period is strongly associated with western disturbances—warm, low-pressure systems originating from the Mediterranean—and during the monsoon period, with deep convective systems driven by monsoonal circulation. **Novelty:** This study offers the first comprehensive spatial-temporal assessment of lightning activity in relation to solar parameters under diverse climatic regimes of Northern India. It highlights the significance of large-scale meteorological processes as primary modulators of lightning variability, providing deeper insight into the intertwined roles of space weather and regional meteorology.

Keywords: Sunspot number; Lightning flashes; Cosmic rays; Solar radio flux (F10.7cm); K_p & A_p index

1 Introduction

Every year, serious risks such as lightning and solar activity pose significant hazards to the population. A common occurrence is the release of electricity into the atmosphere, which is frequently accompanied by weather events including storms, hail, and heavy rain [(1)]. Lightning discharge into the atmosphere is a significant phenomenon that frequently occurs in conjunction with weather events, including storms, hail & heavy rain [(2)]. Cosmic rays have been linked to Lightning Flash Events (LFEs), which are flashes of light produced by the release of electricity in the atmosphere [(3)]. Elevated humidity levels can lead to strong lightning strikes because they enhance lifting speeds and hydrometeor concentrations [(4)]. According to [(5)]. There is a lot of seasonal variation of lightning activity in India. For example, during the winter monsoon (Dec-Feb), the northern segment of India saw the highest LFE. Lightning activity has increased by 0.096 fl $km^{-2}a^{-1}$ in the South Asia area [(6)]. When negative charge is retained in the atmospheric region of -10°C to -20°C while positive charge is distributed in deeper layers above the negative charge, lightning activity clouds are created. Cloud types affect the development of solar parameters and LFE, respectively. Clouds and Lightning activity are influenced by cosmic rays, which mostly come from the sun and go to Earth [(7)], [(8)]. The solar parameters as well as cosmic rays influence the lightning activity over northern India [(9)]. The primary distinction between solar parameters and LFEs, which are both outcomes of lightning activity, is reliance on updraft speed [(10)]. Based on the Lightning Imaging Sensor (LIS) and the Space Weather and Prediction Center (SWPC) dataset of the northern segment of India. This article's dynamic friction function, which has a minimum of 216 KeV/m at an electron energy of 1.23 MeV, solely accounts for energy losses from inelastic collisions. However, the impacts of electron momentum loss from elastic collisions must also be included in more relevant thresholds. An analytical estimate in the scenario [(11)]. The influence of solar parameters and lightning activity process is explained in this study. Initiating the process requires a primary energetic electron. Typically, cosmic rays are the source of such energetic electrons in atmospheric mediums. Even secondary (low energy) electrons can accelerate to relativistic energies under strong electric fields greater than the greatest frictional force. This phenomenon is a form of thermal runaway. In most instances, RREA avalanches proceed in the opposite direction to the electric field. Consequently, frictional forces take over, the electrons lose energy, and the process comes to a halt once the avalanches exit the electric field zone. Nonetheless, it is possible that the avalanche's photons or positrons will return to their starting point and potentially create fresh seeds for avalanches in the future. By bremsstrahlung, the high number of primary (energetic) electrons derived in RREA will result in the same large number of energetic photons. Terrestrial gamma-ray bursts are thought to originate from these photons. Rare but significant radiation doses to commercial aircraft flights may also be caused by massive RREA episodes in LFE. This phenomenon, which is currently being studied in this article by the American physicist Joseph Dwyer, was dubbed dark lightning. Umakanth asserts that the number of deaths caused by lightning and cosmic rays is increasing and that 75% of these deaths are linked to lightning activity in Kerala [(12)].Midya recently conducted a study on lightning over the region and discovered that there were over 30 lightning flash events per minute at the maximum wind speed of 50 km/h [(13)]. However, in a different study, he also discovered a strong association between lighting activity and cosmic ray rate density over northern India [(14)]. In addition to dust storms, which also greatly contribute to lightning activity, solar cycles 23–24 are related to SN, and variation in SN values to determine LFE in the northern segment of India dust events accounts for 30% of positive lightning activity (200 LFE/minute) [(15)]. The Earth's global warming also increases lightning activity and electrifying clouds due to rising surface temperature [(4)]. Lightning activities and solar parameters, as well as cosmic rays, are also influenced by the thunderstorms and therefore responsible for the increment in lightning activities over the northern segment of India [(16)]. The elevated count rate was continually recovered on a minute scale in an intermittent TGE that concluded with a lightning discharge, according to [(17)]. The scientific community has been interested in the gamma-ray glow process because of its extended persistence and the electric field it requires. RREA is a measure of the bifurcation force applying between primary accelerated electrons and secondary low-energy electrons, which play an important role in determining vertical updraft velocity. RREA is dominating over the northern segment in India as well; it is strongly impacted by the progress of the pre-monsoon [(18)]. In the Himalayan region, CAPE and surface temperature are responsible for the instability (50-60% relative humidity at 700 hPa) and lead to an ideal condition for intense lightning [(19)]. The satellite and model datasets are indicating that lightning activities are also governed by the aerosol concentration, and it is increasing with the aerosol concentration [(19)], [(20)]. The lightning activities also depend on elevation, the slope of mountains, and vegetation over the Himalayan region. Lightning activities are dominating over the dry higher terrain slope/elevation as well as the moist lower terrain slope/elevation in the northwest & northeast Himalayan region of India [(21)].

We have discovered several significant gaps in the literature based on the previous study. The earlier research was based on an outdated dataset from 1998 to 2014 and only examined the spatiotemporal fluctuation of lightning activity variation with various solar parameters. There has been a 52.8% rise in lightning-related deaths during the last 17 years. Thus, we must take these concerns seriously, using the most recent LIS data sets, investigate solar parameters and lightning activity, and study different types of lightning formation (cloud-to-cloud and cloud-to-ground) in climatic regions in the northern part of India.

1.1 Site Descriptions:

In this article, we have studied the influence of solar parameters (SN, CR, RF, Kp & Ap Index) on lightning activity over northern India, shown in segment 1.1. We mainly focused on northern India (2,389,300 km^2), as shown in **Fig. 1**. The selected regions are parts of ten different states and Union Territories (UTs):Uttar Pradesh, Uttarakhand, Himachal Pradesh, Haryana, Rajasthan, Punjab, Chandigarh, Delhi, Jammu & Kashmir (J & K), and Ladakh. This study examines the impact of solar parameters (SN, CR, RF, Kp & Ap Index) on lightning activity in the northern region of India. The Indian map indicates that the northern region, central region, eastern region, southern region, and western region are divided into different colors (saffron, light blue, pink, green, dark blue, and brownish), respectively.

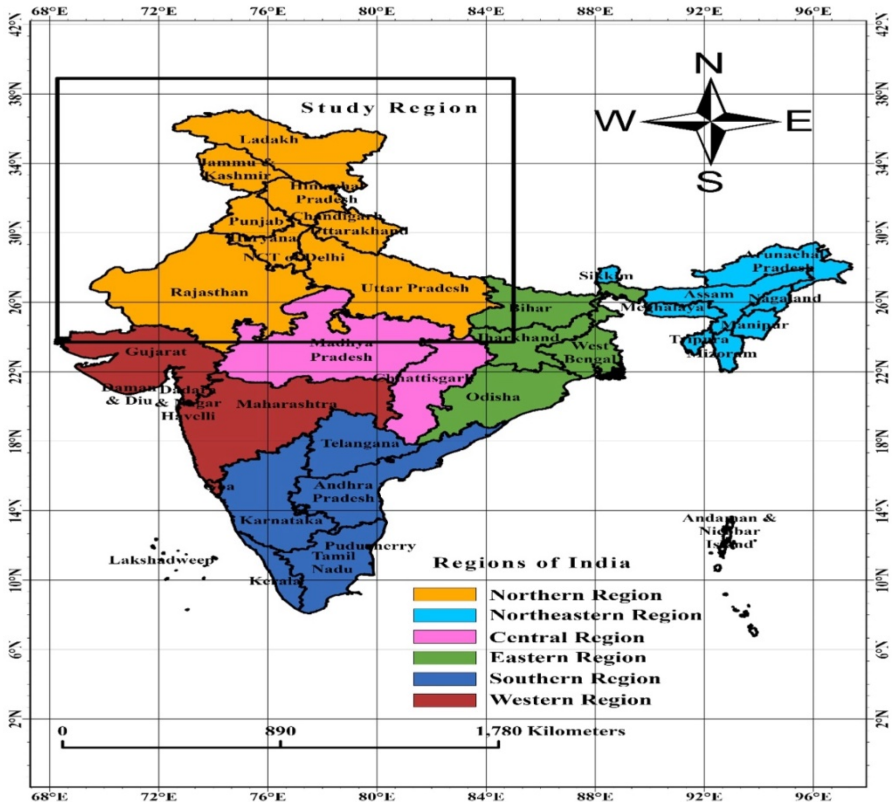

Fig 1. The Indian map indicates the northern region, northeastern region (25°N to 35°N latitude and 75°E to 90°E), central region, eastern region, southern region, and western region

Northern India, spanning approximately 25°N to 35°N latitude and 75°E to 90°E longitude, encompasses diverse terrain, from the Himalayan highlands to the Indo-Gangetic plains. This variability significantly influences the solar parameters on lightning activity. The study region (NR) is mapped with distinct zones—saffron (NR), brownish (WR), pink (CR), and green (ER)—to reflect regional differences.

Research focusing on the influence of solar parameter variation on lightning activity (1998–2014) aligns with existing studies on atmospheric conductivity and cloud electrification. Seasonal lightning activity peaks pre-monsoon, monsoon, and post-monsoon have been analyzed in relation to solar flux (10.7 cm) and cosmic ray (CR) activity. Data from the Lightning Imaging Sensor (LIS) indicates that pre-monsoon thunderstorms are more intense, whereas the monsoon season records higher total flash counts. Additionally, studies on global warming and lightning activity in India reveal an increasing trend in pre-monsoon lightning, correlating with surface temperature anomalies. The relationship between solar variability, atmospheric conditions, and lightning occurrences in Northern India is shaped by multiple factors, including solar flux, cosmic ray modulation, and terrain-induced convection. The Himalayan uplift plays a crucial role in lightning distribution by enhancing convective activity, moisture transport, and orographic lifting. Studies indicate that steep slopes in the northwestern Himalayas intensify convection, correlating with higher lightning flash densities, while regional variability shows distinct lightning patterns at different elevations. Seasonal influences further modulate lightning activity, with pre-monsoon peaks linked to strong surface heating and elevated CAPE, amplified by solar flux variations. In contrast, monsoon-season lightning tends to decrease despite high CAPE, likely due to cooling effects from increased rainfall. To refine the understanding of solar parameter variation (1998–2014), integrating terrain-linked convective enhancement into the analysis could provide deeper insights. This includes comparing lightning flash rates across elevations and assessing correlations between solar indices (F10.7 flux, cosmic ray) and terrain-induced convection.

The temporal resolution of solar parameter studies varies based on dataset and analytical approach: Monthly resolution captures short-term variability, useful for identifying seasonal trends. Seasonal resolution aligns with pre-monsoon, monsoon, and post-monsoon peaks, helping assess solar parameter influences on convection. Yearly resolution supports long-term trend analysis, detecting decadal-scale variations in lightning frequency and solar indices. These insights contribute to a comprehensive understanding of lightning variability, integrating solar activity, geomagnetic influences, and regional meteorological conditions to enhance predictive models for Northern India.

2 Data Description and Methodology

Analyzing data from solar cycles 23 & 24 and lightning activity and solar parameters as well as CR-influenced lightning activity and RREA in the northern part of India. The efficient way to look at how solar activity impacts lightning activity in northern India. Specifically, during 1998 to 2014 solar cycles 23 and 24, this analysis will provide valuable insights into the relationship between solar phenomena and lightning flash events. The following websites were used to obtain the data: http://solarscience.msfc.nasa.gov/greenwch.shtml/,OMNIWebDataExplorer(nasa.gov), and http://celestrak.com/SpaceData/SpaceWxformat.asp. The information contained the solar radio flux (F10.7 cm), Ap & Kp index, CR, and SN on a monthly average. The following sources were used to gather data on the solar and lighting parameters: Lightning data sourced from Lightning Imaging Sensors (LISs) and solar parameters https://search.earthdata.nasa.gov. The ISS & LIS covers a large portion of the Earth's surface as the satellite revolves, detecting lightning strikes with a temporal precision of two minutes and a spatial resolution of 5 to 10 kilometers. The LIS achieves an impressive detection efficiency of nearly 90% uniformly throughout its field of view (FOV). It is capable of identifying both cloud-to-ground and intra-cloud lightning discharges, operating effectively during both day and night.

2.1 The variation of lightning flashes annually and per day in northern India:

Annual variation explanation in **Fig. 2** of per-day lightning flash count events and four solar parameters (Kp & Ap Index, Radio flux (F10.7cm), and CR) during 17 years (1998-2014) distributed over the northern region of India.

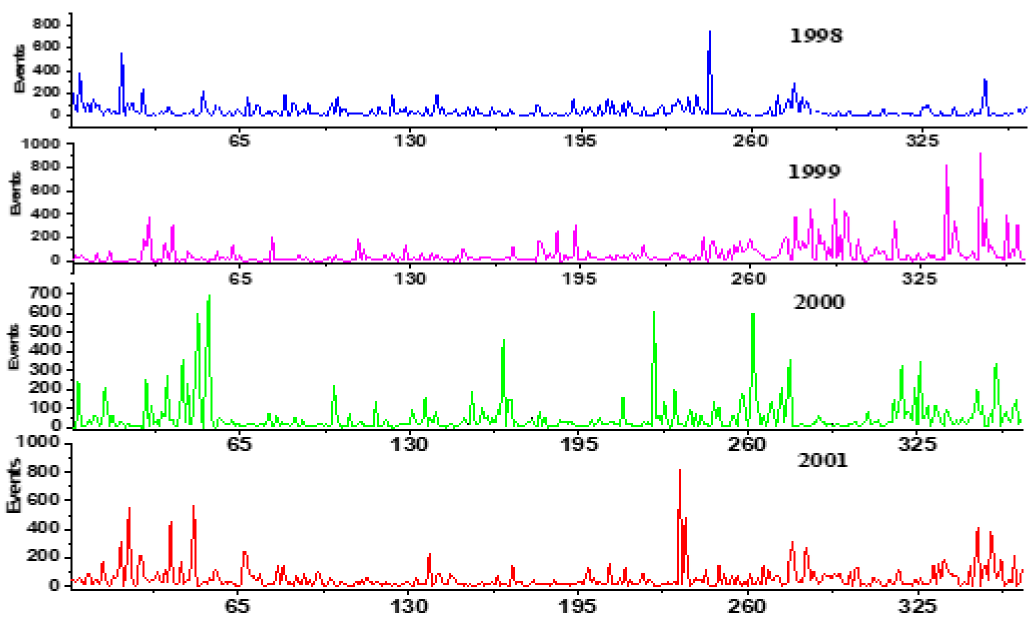

Fig 2. Yearly variation of lightning flash events from 1998 to 2001

Figure 2 provides an explanation of LF incidents on a yearly and daily basis, respectively, from 1998 to 2001. In 1998, the first LFE had a very high pulse on 20 days, 600 (events), which rose to 227.5 (D) LF events 650 and remained at a day pulse rate of zero as 65D > 130D > 195D. LF occurrences in 1999 began with pulse rate events of 275 and 250 on days 32.5 and 34, respectively. The remaining events (34–152.5) had zero LF events, then the pulse rate increased to 275 on days 19 and 5, with another increase (260–357) on days 400 and 1000. Since the LFE in 2000, which began with pulse rate events (200-700) lasting 0-60 days, was extremely high for the year 2000, the remaining occurrences lasted between 0 and 152 days.

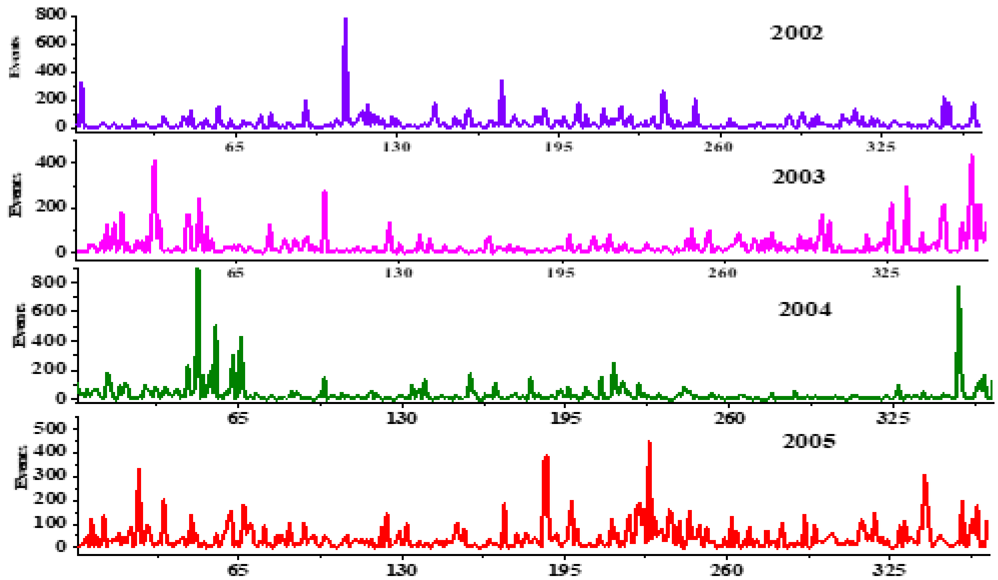

Fig 3. Yearly variation of lightning flash Events from 2002 to 2005

Figure 3 provides an explanation of daily and annual data of LFE from 2002 to 2005. The initial LFEs in 2002 included a very high event pulse rate on 800 days; the pulse rate drops over the next 100 days as follows: 100D > 130D > 195D > 260D > 325D. Likewise, the 2003 LFE, which began with 400 and 300 remaining events, respectively, based on 32.5- and 98-day pulse rate events, diminishes as 32.5D > 98D > 130D > 195D > 325D. This event is 800, and the others drop, respectively, since the 2004 LFE, which began on a 48-day pulse rate, was extremely high. Beginning with a 30-day event value of 350 and a 65,130-day event value of 400, the 2004 LFEs progressed to a 190-day.

Evaluate in Figure 4: The Lightning Flashes (LF) took place every year and every day from 2006 to 2009. The first LF event in 2006 had 500 impulsions over 65 days, each of which was significant. However, the frequency of impulsions gradually decreases as 130D moves up to 195D, then 260D, and finally 325D. Similarly, at the 2007 LF event, which started at a variable speed and lasted 27 and 195 days, 700 and 400 participants, respectively, were found, decreasing to 260D>365D. In 2008, the LF event, which takes place every 2.5 days, attracted 800 participants, but the other events saw a decline in attendance.

Figure 5 explains the LF incidents that occurred annually from 2010 to 2014 and daily. An extremely high pulse occurred on day 450 of the initial LF incidents in 2010; the remaining day pulse rate dropped to 125D > 180D > 260D > 325D, accordingly. Similar to this, the 2011 LFE began with 105- and 125-day pulse rate events, with 300 and 400 remaining events, respectively. These events then decreased as 32.5D > 98D > 130D > 195D > 325D. This event is 800, and the others drop, respectively, since the 2004 LFE, which began on a 48-day pulse rate, was extremely high. Beginning with 30-day events valued at 350 and 65-day events valued at 400, the LF events in 2004. Figure 6 provides explanations of the annual change in cosmic rays from 1998 to 2010.

Shockingly, from 1998 to 2004, in the years 1975, 1950, 1925, 1900, 1875, 1850, and 1825, the mean cosmic ray values steadily decreased. From 2004 to 2010, the mean cosmic ray values gradually grew in the years 2000, 2025, 2030, 2035, 2040, 2045, and 2250, with a rapid increase in the CR value of 3000 in 2010.

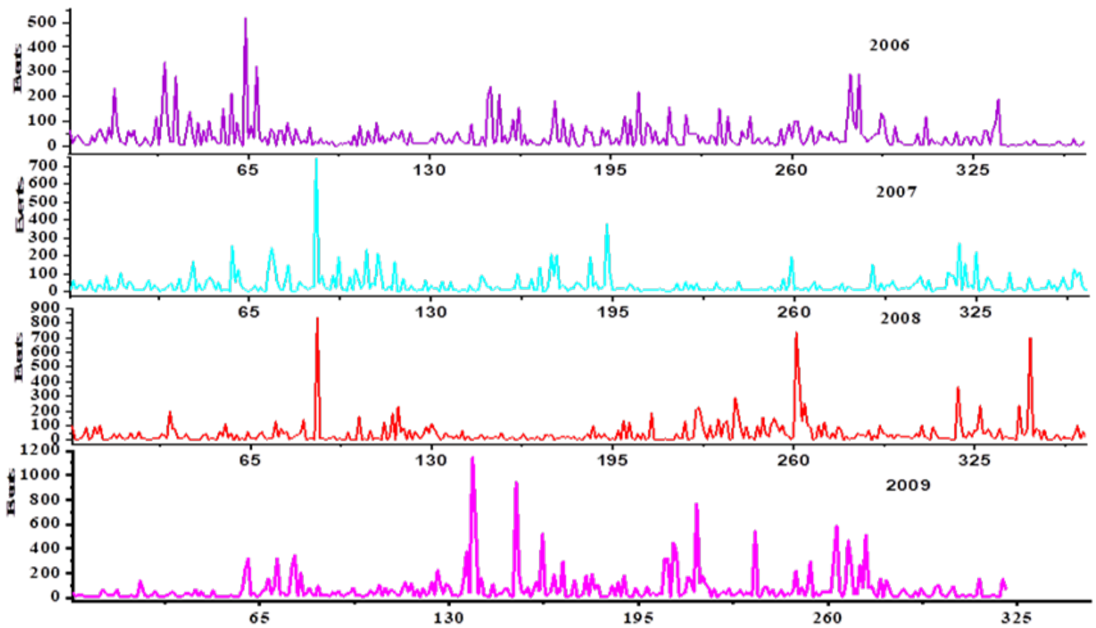

Fig 4. Yearly variation of lightning flash Events from 2006 to 2009

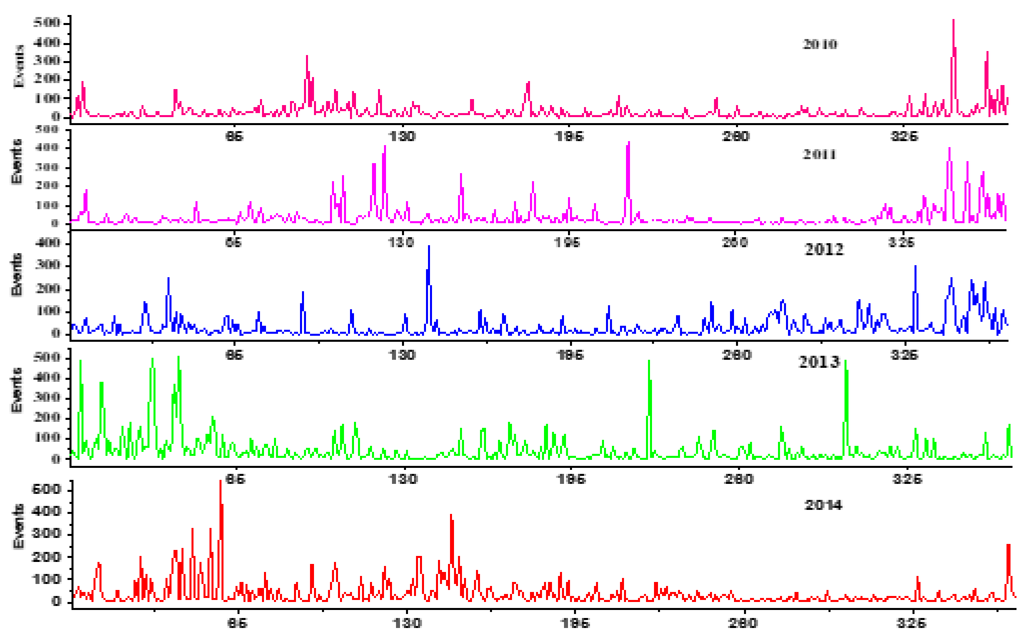

Fig 5. Yearly variation of lightning flash Events from 2010 to 2014

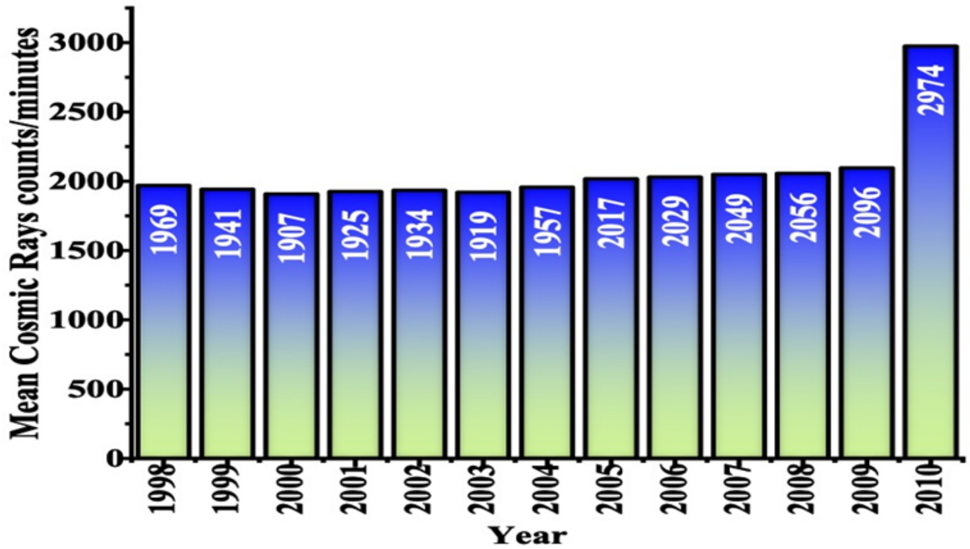

Fig 6. Yearly variation mean of cosmic rays from 1998 to 2010

2.2 The variation of solar parameters Kp and Ap, radio flux (F10.7), & SN in northern India:

In the present research work, the graphs represented by **Fig. 7** depict the variation of solar parameters, viz. radio flux (F10.7), Kp & Ap index, and sunspot number (SN), in the northern part of India during the time from 1998 to 2014. The upper part of the graph highlights changes in radio flux (F10.7), Kp & Ap indices, while the lower panel focuses on the sunspot number in the given period. Observing the radio flux (black line), we noticed that it generally follows the 11-year solar cycle, which shows prominent peaks around the years 2000 and 2014. The obtained peaks correspond to periods of heightened solar activity, which is known as the solar maximum. In contrast, we obtained a decline in radio flux between 2002 and 2007 with a notable depression around 2008-2009, indicating a solar minimum phase in those particular years. The obtained cyclical pattern in radio flux is a well-established indicator of fluctuating solar output over time, influencing the radiation levels that reach the Earth. Further, the data of the Kp index, which is represented by the red line in the upper part of the graph, indicates geomagnetic activity and exhibits frequent peaks and valleys over time. These variations reflect episodic geomagnetic disturbances, which are more intense around solar maximum years, i.e., 2000 and after 2012. Solar events like coronal mass ejections and solar flares typically trigger such disturbances[(22)]. During the solar minimum period from around 2006 to 2010, the Kp index remained relatively stable with fewer and smaller peaks, mirroring the decrease in solar activity during those periods. The blue line in the upper part represents the Ap index that aligns meticulously with the Kp index, showing a smoother variation as it represents daily average geomagnetic activity in the given period. The Ap index shows similar variation to the Kp index that gives higher values around solar maximum years, which reinforces the strong connection between solar and geomagnetic activity[(10)].

The lower part of the graph represents the sunspot number (SN), which measures direct solar activity, and the figure shows clear peaks around 2000 and 2014, corresponding to the solar maximum phases, and a minimum around 2008. The obtained pattern makes direct relevance with the trends observed in Radio flux (F10.7), Kp & Ap indices, representing the impact of solar cycles on geomagnetic conditions of the Earth. The sunspot number demonstrates the variation of solar activity through its rise and fall over approximately 11 years with implications for Earth-bound systems, including ionospheric conditions, satellite operations, and possibly even atmospheric dynamics. These parameters combined reveal a cohesive picture of the solar cycle driving fluctuations in the geomagnetic and solar emissions that significantly influence the effect of solar parameters on lightning activity and the environment of the Earth over northern India.

3 Conclusions

The current analysis of lightning activity and solar parameters observed 17 years of data over northern India and provides a detailed interpretation of atmospheric and solar dynamics influence on regional space weather patterns.The data reveal distinct

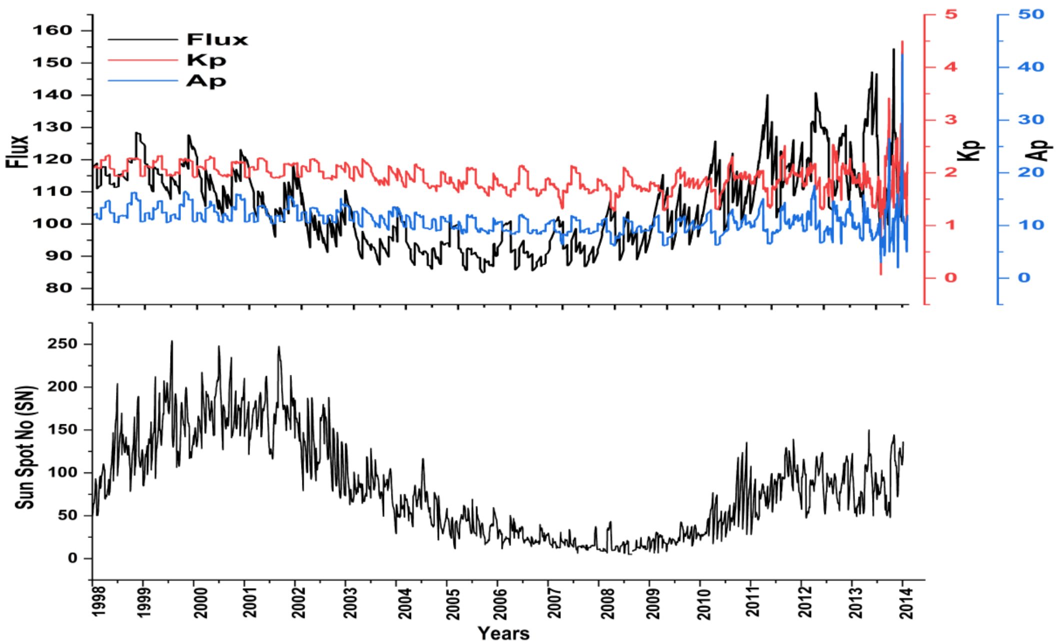

Fig 7. Annual variation of Kp & Ap, radio flux (F10.7) and SN for the period 1998 to 2014

annual and daily variations in the LFE and solar parameters. The solar parameters studied, RF (F10.7), SN, CR, Kp & Ap Index, exhibit expected cyclical patterns, aligning with the 11-year solar cycle with pronounced peaks around 2000 and 2014. These studies correspond to periods of increased solar output as well as CR influencing the solar parameters and LFE with CC and CG reaching Earth's atmosphere, as indicated by the Kp and Ap index alignment with the solar maximum periods. The present study highlights the relationship between variations of solar parameters and lightning activity, suggesting that the solar maxima and minima phenomenon during 11 years after that variation in sunspot number may amplify atmospheric disturbances. The findings contribute to understanding how solar phenomena influence lightning patterns and regional climate in the northern region of India.

4 Limitation of the study

1. The study is focused on the northern segment in India.
2. Only seventeen-year datasets are used in the research article.
3. Only CR, SN, Ap & Kp Index, and LFE are used in this study.

5 Future Scope

1. It is possible to expand this analysis to include the other Northern States.
2. Many parameters, such as dark lightning and avalanches with internal friction force between high-energy electrons and low-energy electrons, can be added in upcoming manuscripts.
3. Our findings will be useful in choosing the various solar parameters and lightning activities; therefore, this publication will be extremely helpful for novice researchers.
4. Understanding the many lightning activity zones and space weather over Northern India is made much easier by this document, which also helps with the creation of lightning safety and protection regulations.
5. Further study is necessary to comprehend TRMM and space weather change since LFE and solar parameters are two of the most important LIS, TRMM, and space weather factors.
6. More research is advised to fully comprehend how space weather processes influence the formation of sunspots (SN) and lightning activity.

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