Statistical analysis of DEMETER satellite data and WWLLN lightning locations

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Motivation

Earth's magnetosphere is occupied by high-energy particles originating from the solar wind trapped within the Earth's magnetic field. The particle energies range from hundreds of keV to hundreds of MeV. Such energetic particles introduce a hazard for satellite instruments and astronauts. With an increasing number of satellites in the inner magnetosphere and potential tourists traveling to space, the need to understand the dynamics of respective environments is also increasing. In this work, we focus on the influence of lightning on electron precipitation from the Earth's magnetosphere.

Introduction

Lightning-induced electron precipitation

The particles are trapped within the Earth's magnetic field forever unless they interact, usually with waves. Such particle populations are called Van Allen radiation belts. One possible way of losing these particles is via lightning-induced electron precipitation (LEP) events.

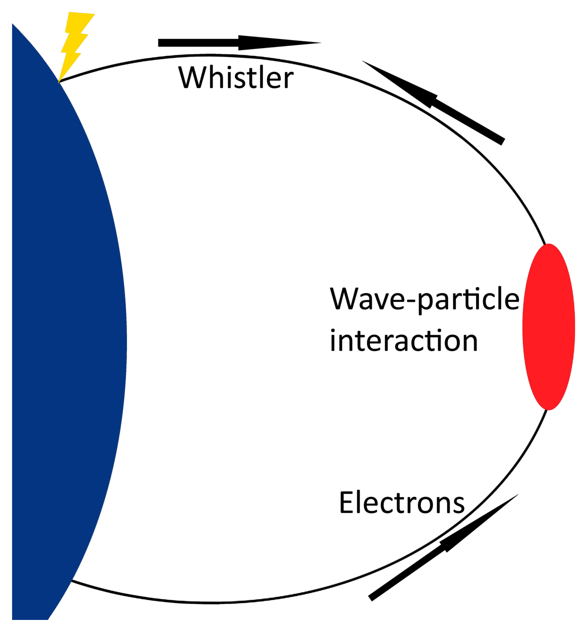

Figure 1. A systematic overview of the LEP event.

LEP event timeline

1. Lightning stroke
2. Whistler propagation
3. Wave-particle interaction
4. Decrease of the pitch angle
5. Lowering of the mirror point
6. Collision with neutrals in a dense atmosphere
7. Precipitation

Area of interest

We focus on the area above the U.S. (MLON 300°-360° and L-shell 2-3). This area is advantageous for two reasons:

- High difference between the Summer and Winter number of lightning strokes.
- The area is westward of the SAA, which should ensure that there are many electrons not too far from the loss cone.

DEMETER

- Satellite orbiting Earth between 2004-2010
- Orbit only during local Day/Night (10:30/22:30 LT)
- We use IDP and ICE-VLF survey data between 2006 and 2010
- IDP — electron flux in loss cone with energies between 70 keV and 2.34 MeV with 4 s resolution
- ICE-VLF — power spectral density of electric field fluctuations in the VLF range with 2.048 s resolution

WWLLN

- World Wide Lightning Location Network
- Global network of VLF sensors
- Time-of-arrival method => Lightning locations and times
- Non-stable detection efficiency

Geomagnetic activity

Averaged fluxes of electrons with energy of 230 keV measured by the IDP instrument over the U.S. region for low and high geomagnetic activity. White/black curves represent the number of lightning in each month.

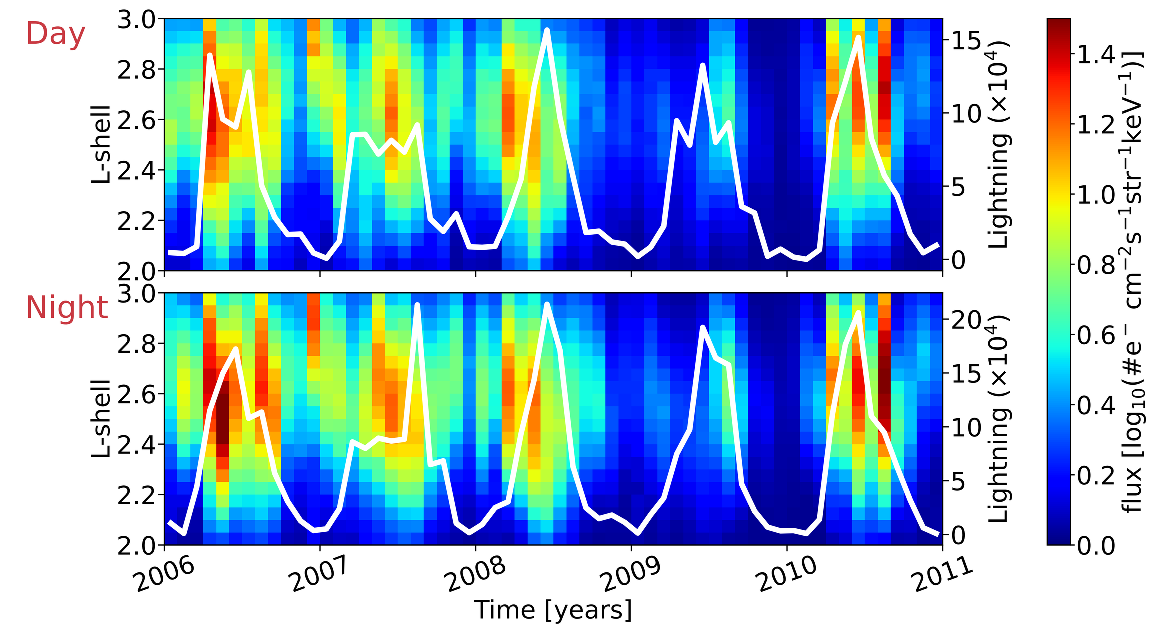

Figure 2. Monthly averaged electron fluxes during Dst > -20 nT.

Low geomagnetic activity

- Clear distinction between summer and winter fluxes
- Lightning occurrence peaks well corresponds to flux peaks

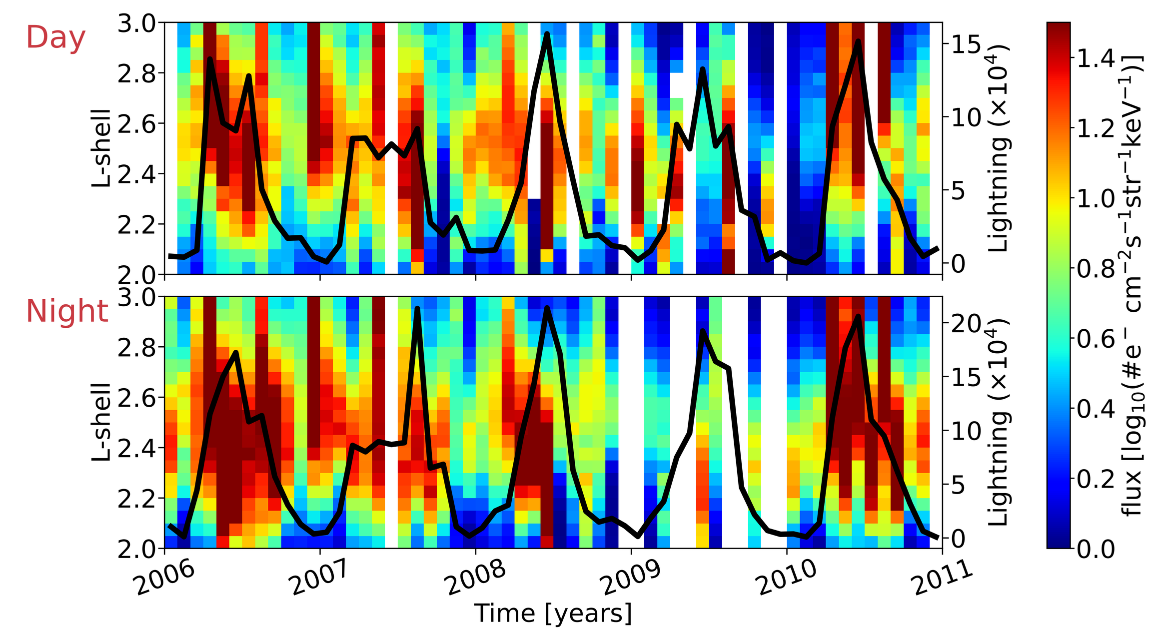

Figure 3. Monthly averaged electron fluxes during Dst < -20 nT.

High geomagnetic activity

- Flux peaks are not clear and poorly related to lightning occurrence.
- Lightning-related effects are not dominant, so we further focus on low geomagnetic activity.

Energies of precipitating electrons

Only measurements during low geomagnetic activity are included.

- Clear seasonal variation, but Day/Night situations are comparable.
- Enhancement over broad energy range.

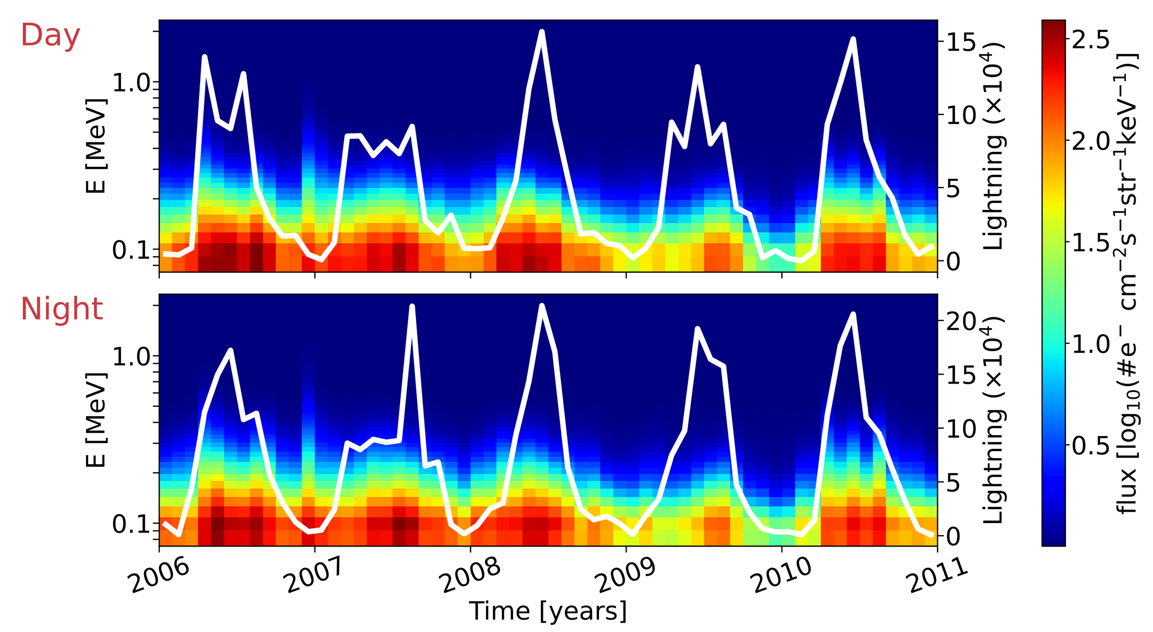

Figure 4. Precipitated electron flux measurements, averaged in monthly bins.

Wave activity

- Clear seasonal variations.
- Effect much stronger during Night due to lower trans-ionospheric attenuation.
- Compared to Figure 4, Day/Night difference is much stronger. (additional wave amplification at larger radial distances during the Day?).

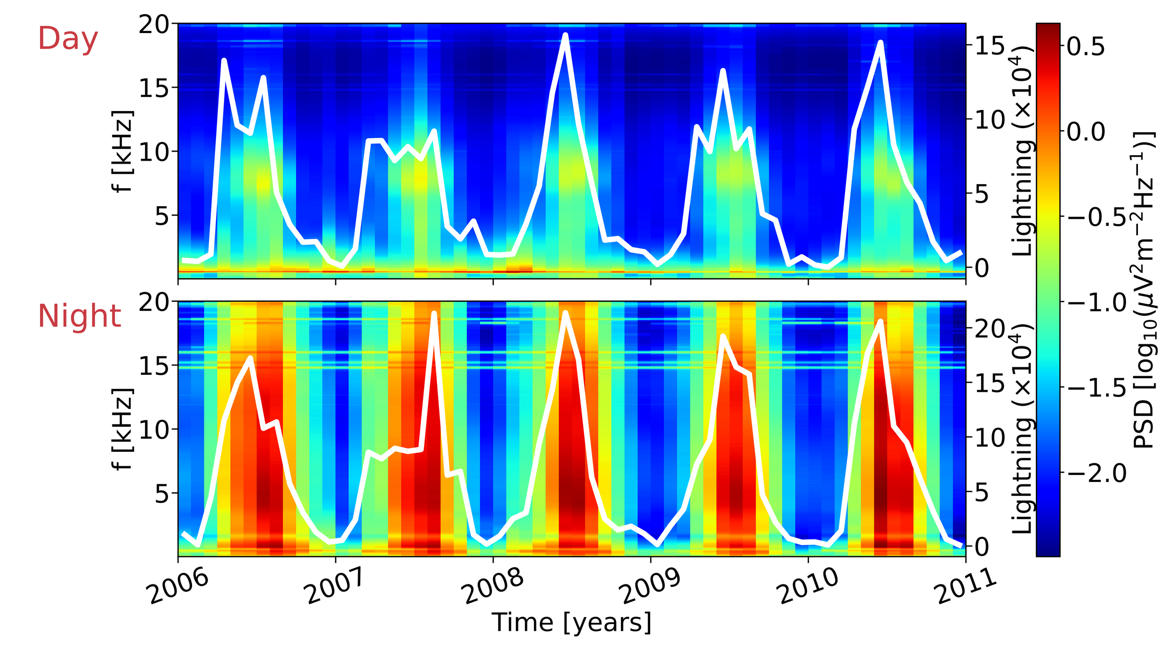

Figure 5. Averaged electric field PSD measurements.

Correlation analysis

To further investigate the energies of precipitating electrons, we computed the correlation coefficient between the number of lightning and averaged fluxes in each month as a function of electron energy.

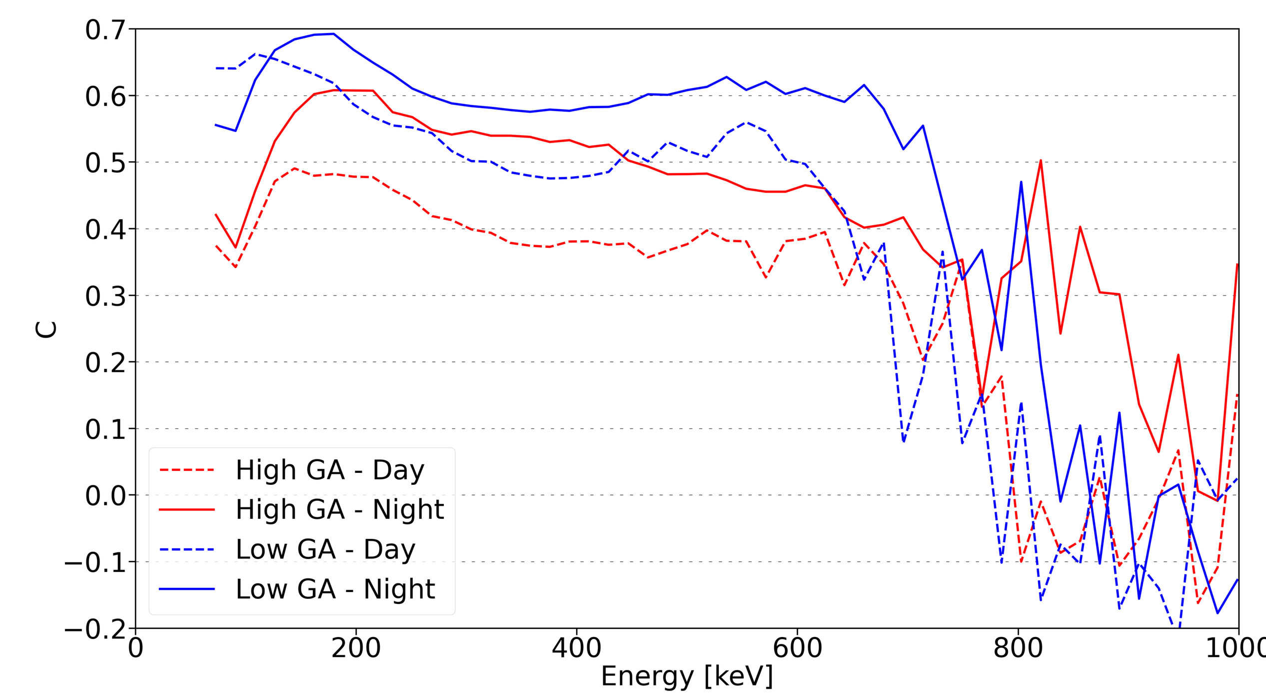

Figure 6. Spearman's rank correlation coefficient between lightning occurrence and electron fluxes as a function of electron energy.

Key takeaways

- Lightning plays a significant role in electron precipitation from radiation belts.
- During high geomagnetic activity, the lightning-related effects are less significant than other phenomena (Figures 3 and 6).
- The energy of precipitated electrons ranges from tens of keV to ∼ 700 keV (Figures 4 and 6).
- Other effects influence electron precipitation during Day since the wave diurnal variation at low altitudes (Figure 5) is much more significant than electron flux diurnal variation (Figure 4).
- Overall, the lightning-related effects are more pronounced during Night and low geomagnetic activity.

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