Global Assessment of Precipitation of Radiation Belt Electrons by Electromagnetic Waves from Lightning

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Outline

- Observations
  - DEMETER satellite
  - National Lightning Detection Network
  - Location for observations
  - Seasonal distribution
- Theoretical flux calculations
- Conclusions
IDP on DEMETER

- 670 km sun-synchronous orbit
  - 10:30 or 22:30 local time

- Instrument for Particle Detection (IDP)
  - Detects particles with local pitch angles near 90° and has ~30° detector width
  - Has a large geometric factor of 1 cm$^2$str
  - Has 4 second time resolution
  - Measures flux of electrons with energies from 72 keV – 2.35 MeV, with ~20 keV spectral resolution
Lightning data

- US National Lightning Detection Network
  - >100 ground-based lightning sensors
  - Millisecond accuracy for cloud-to-ground flashes
  - Records location, peak current of lightning stroke
- Instrument Champ Electrique (ICE) on DEMETER
  - Electric field power spectrum measurements
  - 15 Hz – 20 kHz frequency range

Source: [Cummins, 1998]
Seasonal Distribution of Lightning

Source: [Christian et al, 2003]
2006-7 Seasonal Wave Power

5-10 kHz, Nighttime

August

December

log(\text{V}^2\text{m}^{-2}\text{Hz}^{-1})
Observations of Precipitating Electrons

Continental United States is an ideal location

- Predominance of VLF wave activity seen on DEMETER
- Geomagnetic conjugate region in the ocean
- Just inside the edge of the drift loss cone

Equatorial loss cone pitch angles at $L=2$ in 2008
Seasonal Variation

Nighttime IDP fluxes over the United States from 2006-8

Nighttime IDP fluxes in the conjugate region from 2006-8

Nighttime NLDN lightning flash rate over the United States from 2006-8
Resonant Energy

\[ \omega_H = \omega + k_z v_z \]

Resonant energy electrons versus \( L \) at five frequencies
Day/Night Variations

Nighttime

126 keV median flux vs. $L$ between $-100^\circ$ and $-80^\circ$ longitude

- August
- December

Nighttime

Ratio of August and December median fluxes

Daytime

126 keV median flux vs. $L$ between $-100^\circ$ and $-80^\circ$ longitude

- August
- December

Daytime

Ratio of August and December median fluxes

$L = 2.4$
Fluxes and Lightning

Median 126 keV fluxes

5 day average
1 month average

Lightning Flash Intensity

5 day average
1 month average
Outline

- Observations
- Theoretical flux calculations
  - Electron precipitation model
  - Expected precipitation at satellite location
  - Correlation between expected and actual fluxes
- Conclusions
Detailed Comparison of NLDN and IDP data

- Compare DEMETER precipitation data over the United States with precipitation expected from lightning recorded by NLDN
- Assume lightning creates a gaussian pattern of electron precipitation as quantified by Lauben et al., [2001]
- Determine relative amount of flux expected to be deposited at satellite location during each 4 second interval of DEMETER pass
Gaussian Precipitation Model
(from Plate 12 of Lauben et al., [2001])

- Precipitation occurs in broad region poleward of lightning source
- Model returns two-dimensional function of precipitation region
Gaussian Precipitation Model
(compared to Plate 12 of Lauben 2001)
Example Gaussian Model

Drift for 126keV

Drift for 304keV

Expected precipitation region
03:40:57

Lightning flash
03:31:53

DEMETER
03:40:57

Normalized Precipitation
Methodology

START

For every energy

For every orbit

For every time bin

Calculate drift period

For every lightning strike West/South of satellite within fractional drift period

Model precipitation region

Calculate where precipitation region is at time bin

OVER satellite?

yes

Scale normalized precipitation by peak current and add to relative expected flux

no

END lightning?

yes

no

END time bins?

yes

no

END orbit?

yes

no

no

no

END energy?

yes

no

no

Correlate IDP flux with relative flux expected from lightning

FINISH
Proof of concept: example

DEMETER ICE – Spectrogram of $E$-field on 06-Oct-2007

DEMETER IDP – Spectrum of Electron Flux

NLDN Lightning Activity

DEMETER trajectory

<table>
<thead>
<tr>
<th>UT</th>
<th>02:45:15</th>
<th>02:45:20</th>
<th>02:45:25</th>
<th>02:45:30</th>
<th>02:45:35</th>
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<tr>
<td>L</td>
<td>2.26</td>
<td>2.28</td>
<td>2.31</td>
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<td>35.29</td>
<td>35.56</td>
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<td>36.1</td>
</tr>
</tbody>
</table>
Proof of concept: results

- Expected fluxes agree well with IDP data up to ~300 keV over sample orbit shown on previous slide
Dependence on $L$

- Non-linear relationship with $L$ means we need to do a direct estimate of the conditional correlation
2007 Correlations

2007 Correlation of log(IDP flux) and log(relative flux expected from lightning)

Correlation coefficient

Energy (keV)
Seasonal Correlations: Spring

2006-8 Spring (MAM) Correlation of log(IDP nighttime flux) and log(relative flux expected from lightning)

Energy (keV)

Correlation coefficient

L
Seasonal Correlations: Summer

2006 - 2008 Summer (JJA) Correlation of log(IDP flux) vs log(relative flux expected from lightning)
Seasonal Correlations: Autumn

2006-8 Autumn (SON) Correlation of log(IDP nighttime flux) versus log(relative flux expected from lightning)
Seasonal Correlations: Winter

2006-8 Winter (DJF) Correlation of log(IDP flux) vs log(relative flux expected from lightning)
Outline

- Observations
  - Continental US ideal location
  - Seasonal variation of fluxes and lightning
- Theoretical flux calculations
  - Electron scattering model
  - Energy and $L$-dependencies
- Conclusions
Conclusions

- Discovered a seasonal variation in electron precipitation at mid-latitudes consistent with lightning as a major loss driver for electrons with energies of a few hundred keV.
- Identified the continental United States as the best geographic region for measurements of lightning-induced electron precipitation (LEP) at low Earth orbit.
- Quantified the relationship between electron precipitation and lightning activity, including dependence on energy and $L$-shell.