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

Erin Gemelos

VLF Group
Stanford University

Dec. 12, 2010

Outline

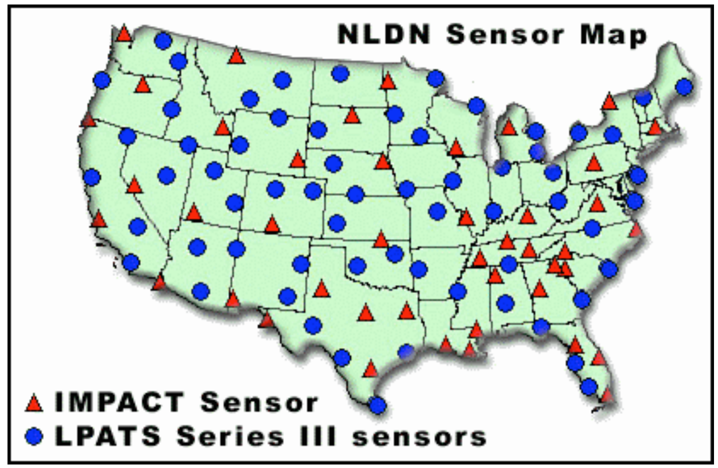
- Observations
  - DEMETER satellite
  - National Lightning Detection Network
  - Location for observations
  - Seasonal distribution
- Theoretical flux calculations
- Conclusions

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^2str
  - Has 4 second time resolution
  - Measures flux of electrons with energies from 72 keV – 2.35 MeV, with ~20 keV spectral resolution

Lightning data

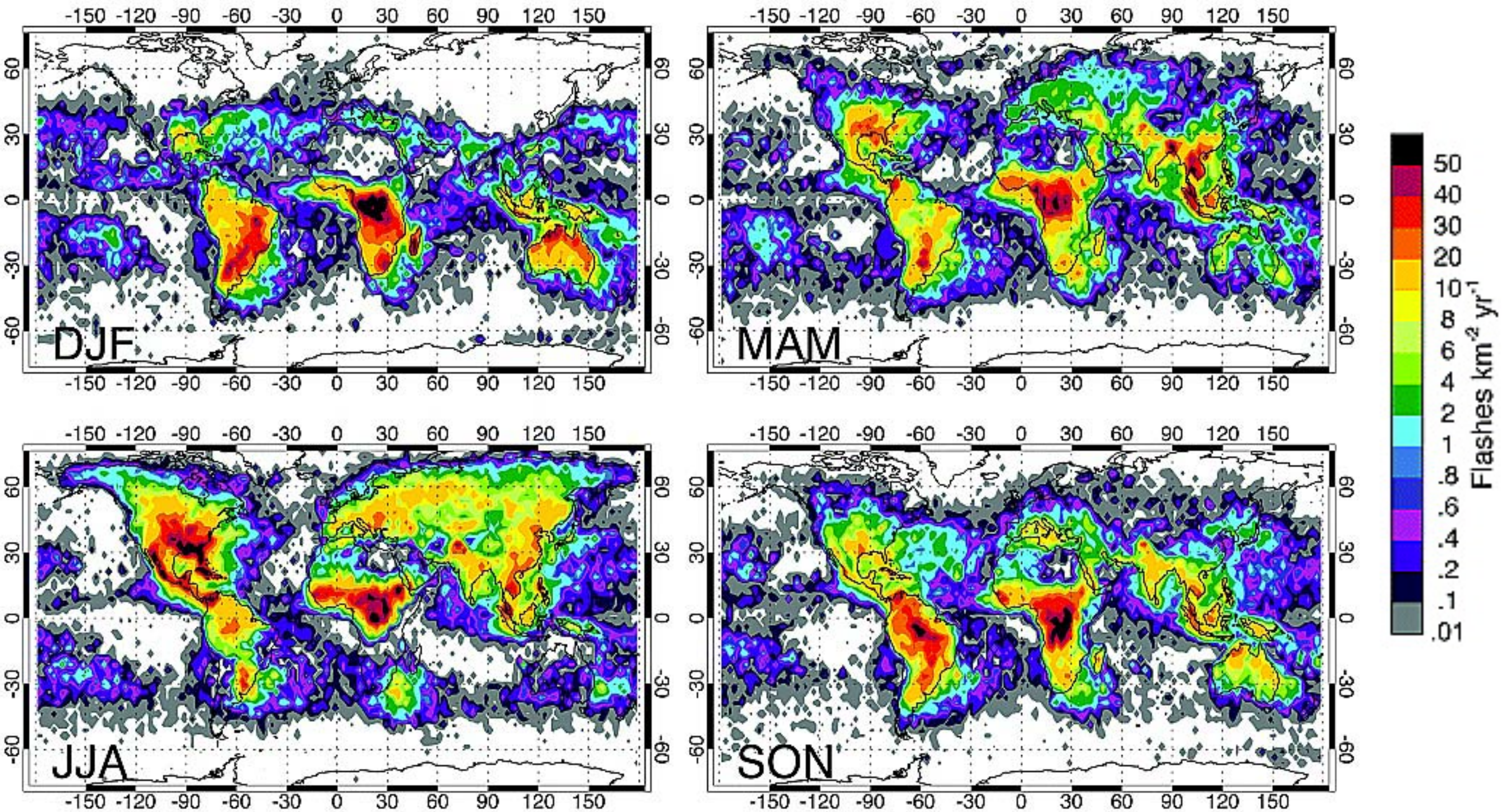
- US National Lightning Detection Network
  - >100 ground-based lightning sensors
  - Millisecond accuracy for cloud-to-ground flashes
  - Records location, peak current of lightning stroke



Source: [*Cummins, 1998*]

- Instrument Champ Electrique (ICE) on DEMETER
  - Electric field power spectrum measurements
  - 15 Hz – 20 kHz frequency range

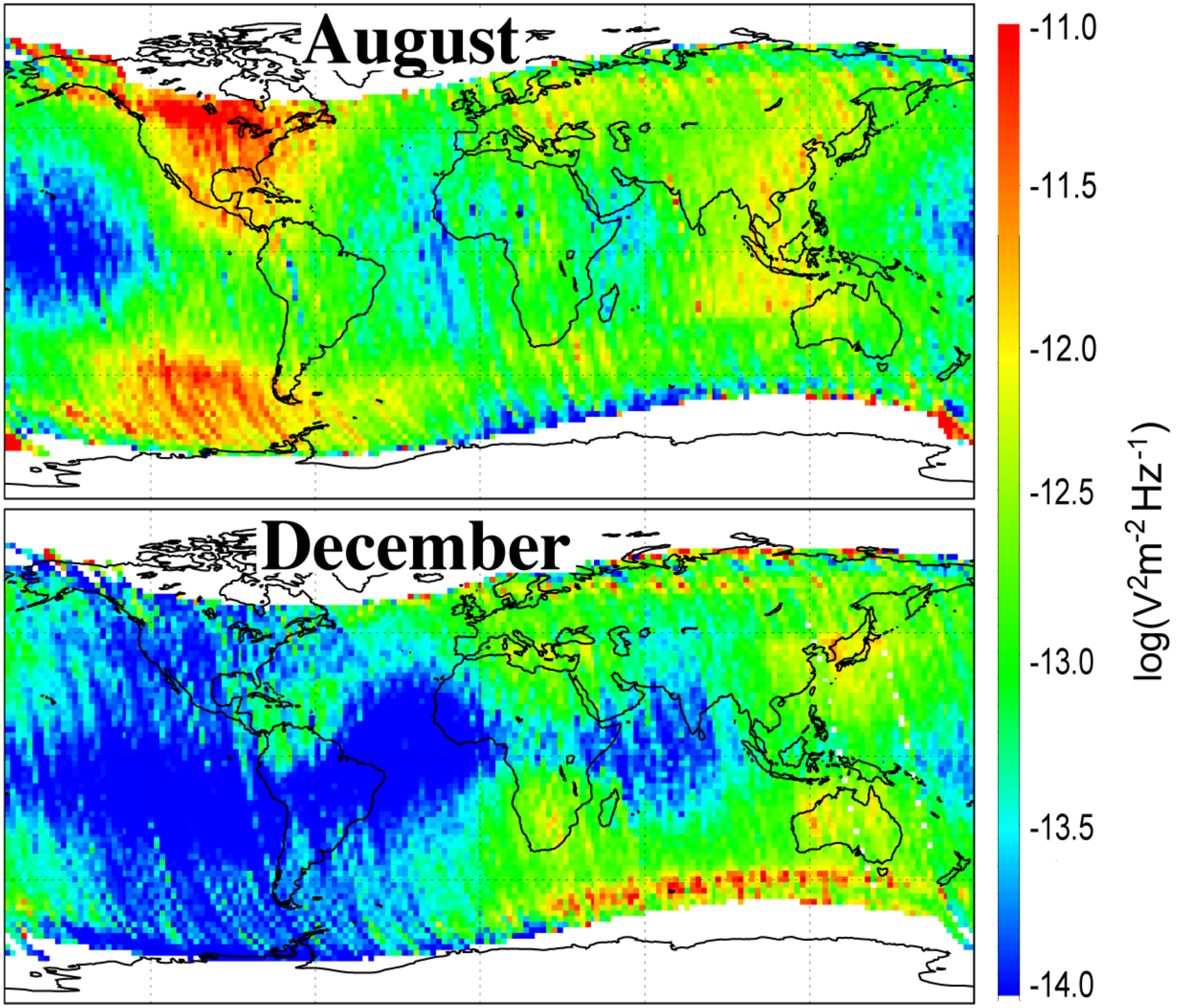
Seasonal Distribution of Lightning



Source: [*Christian et al, 2003*]

2006-7 Seasonal Wave Power

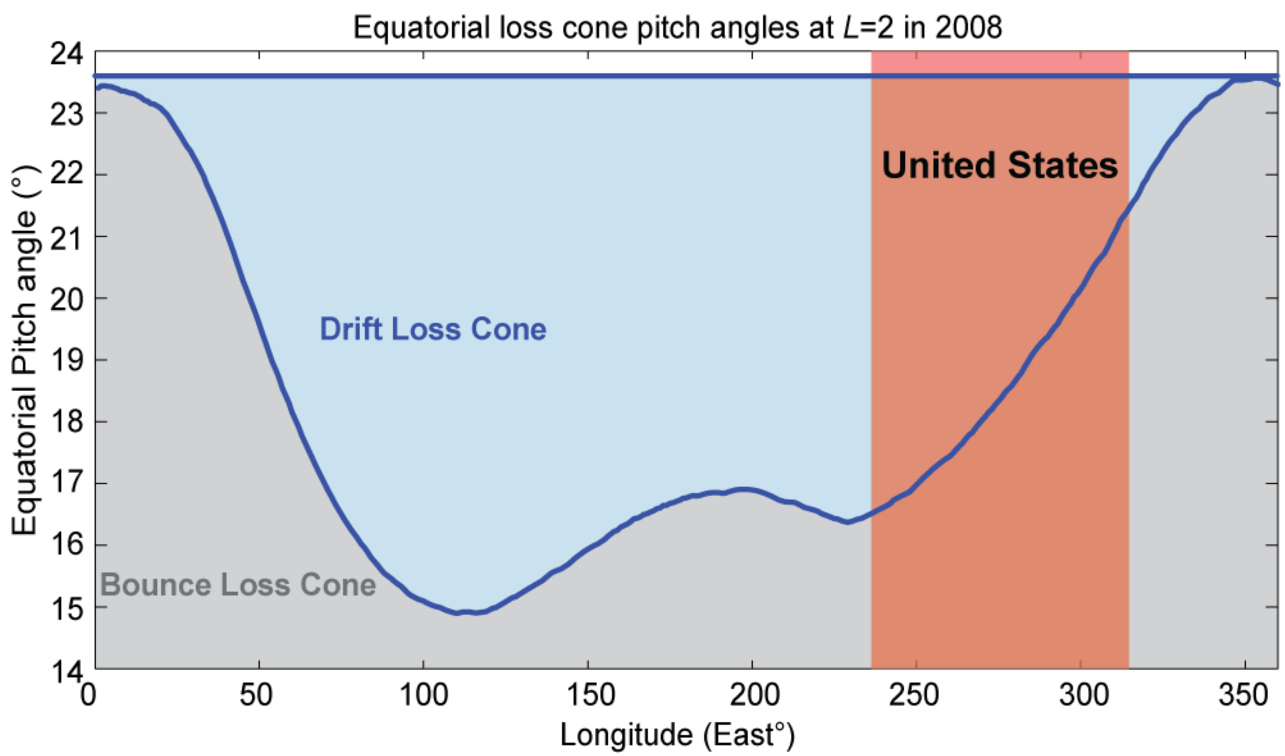
5-10 kHz,
Nighttime



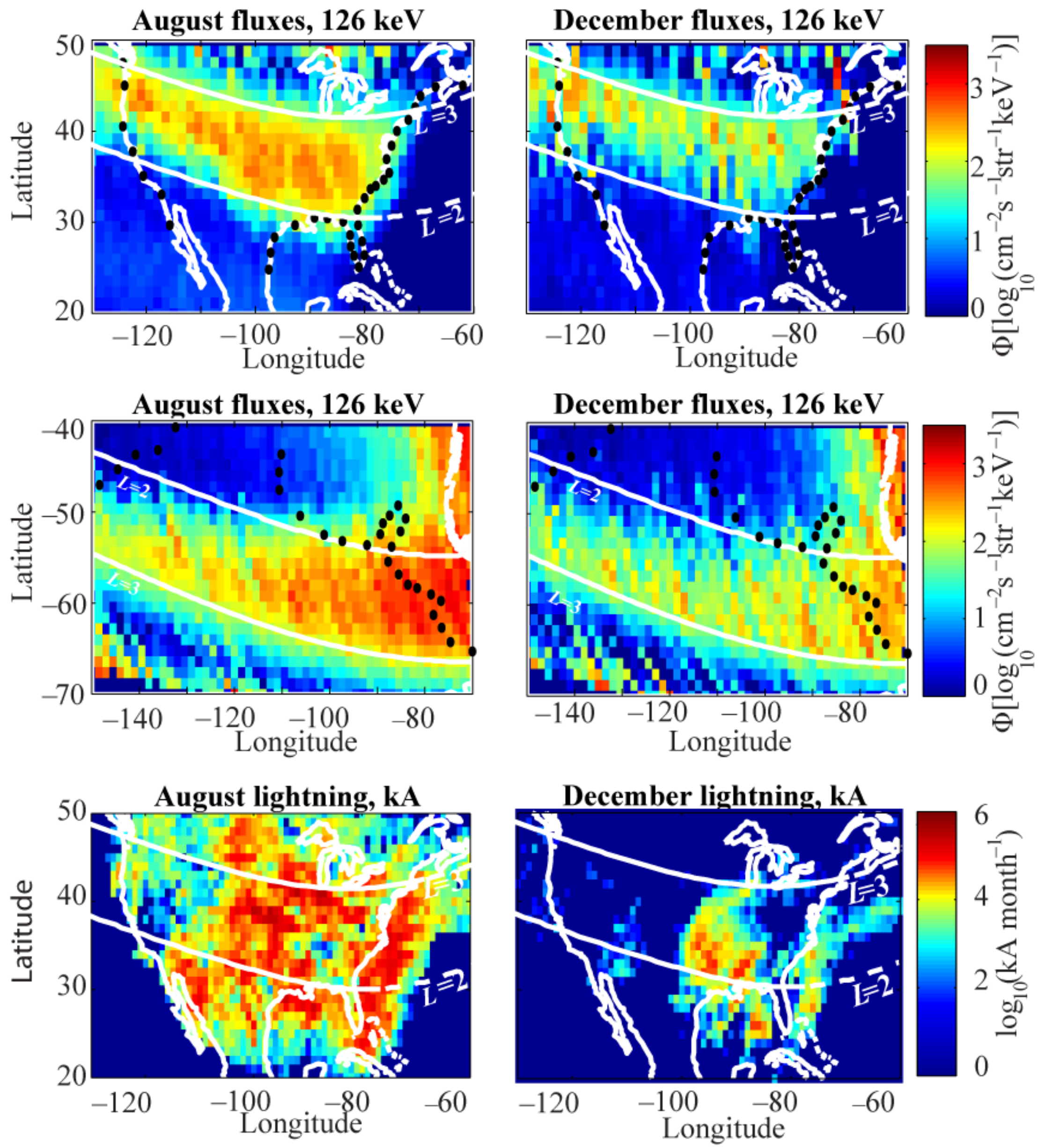
Observations of Precipitating Electrons

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



Seasonal Variation



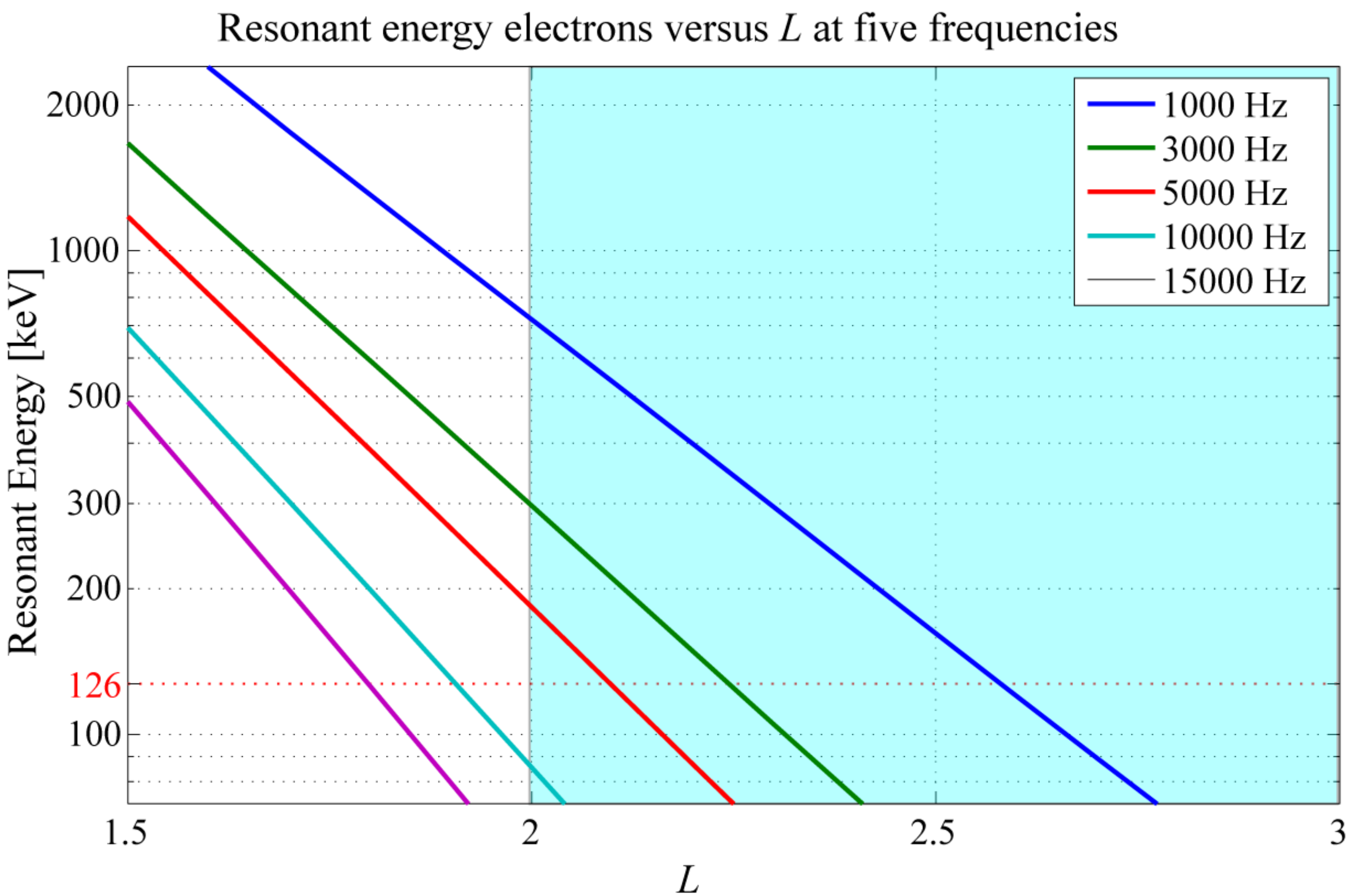
Nighttime IDP fluxes over the United States from 2006-8

Nighttime IDP fluxes in the conjugate region from 2006-8

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

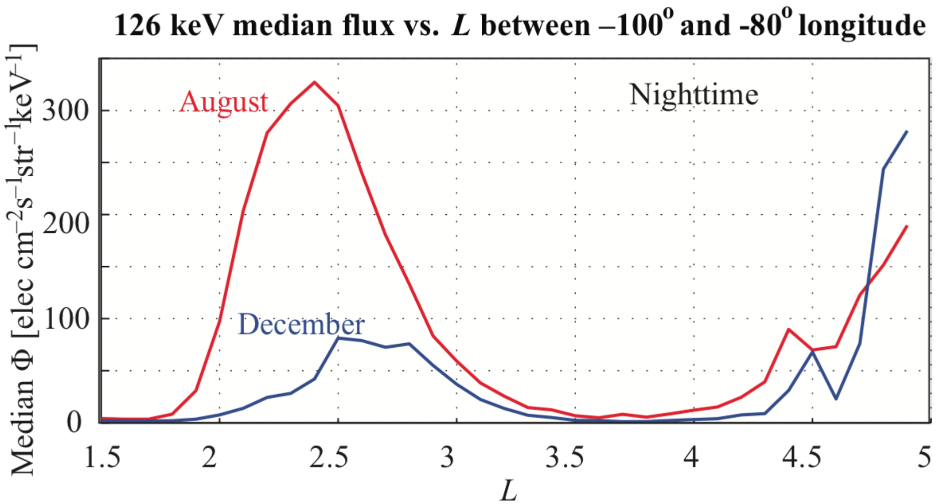
Resonant Energy

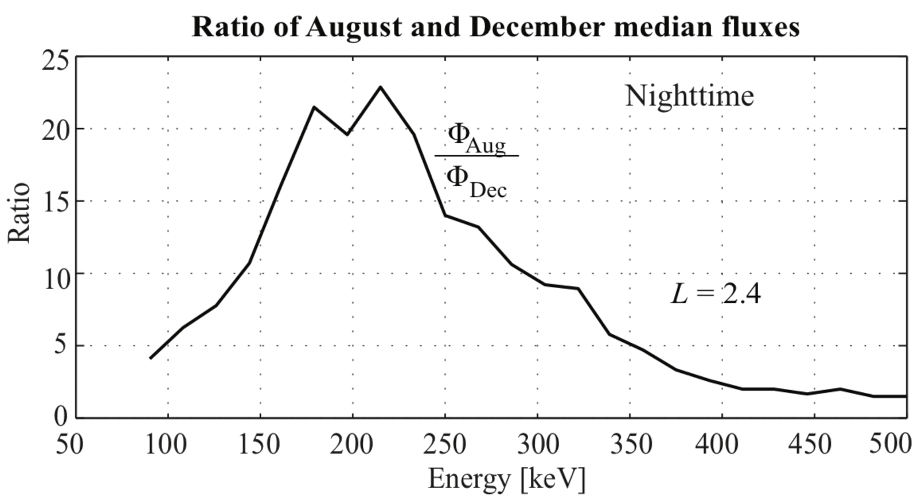
$$\omega_H = \omega + k_z v_z$$



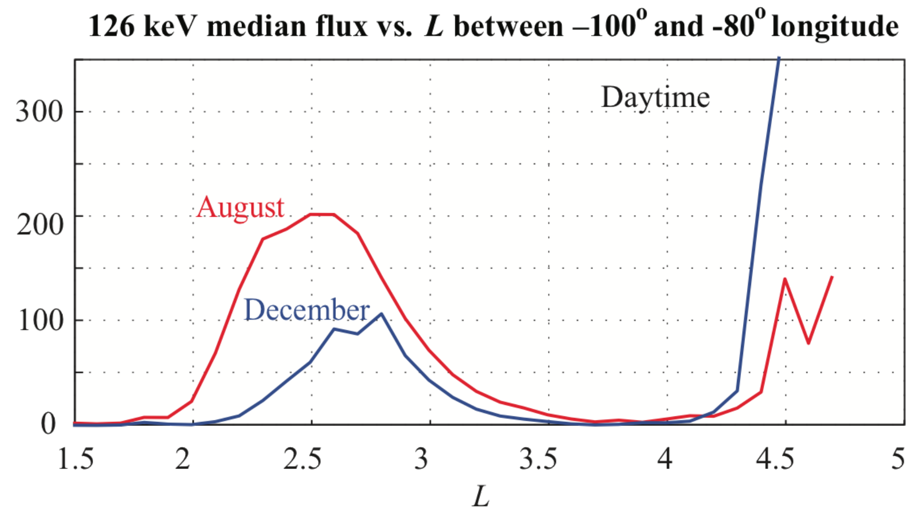
Day/Night Variations

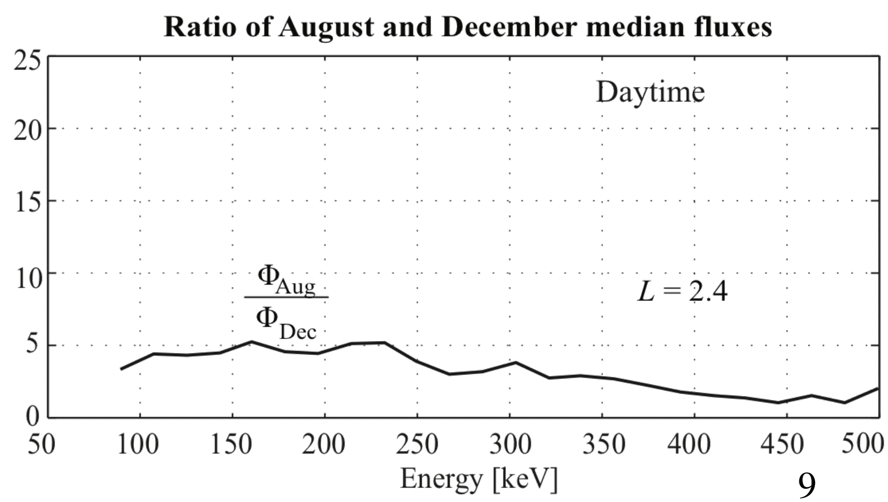
Nighttime



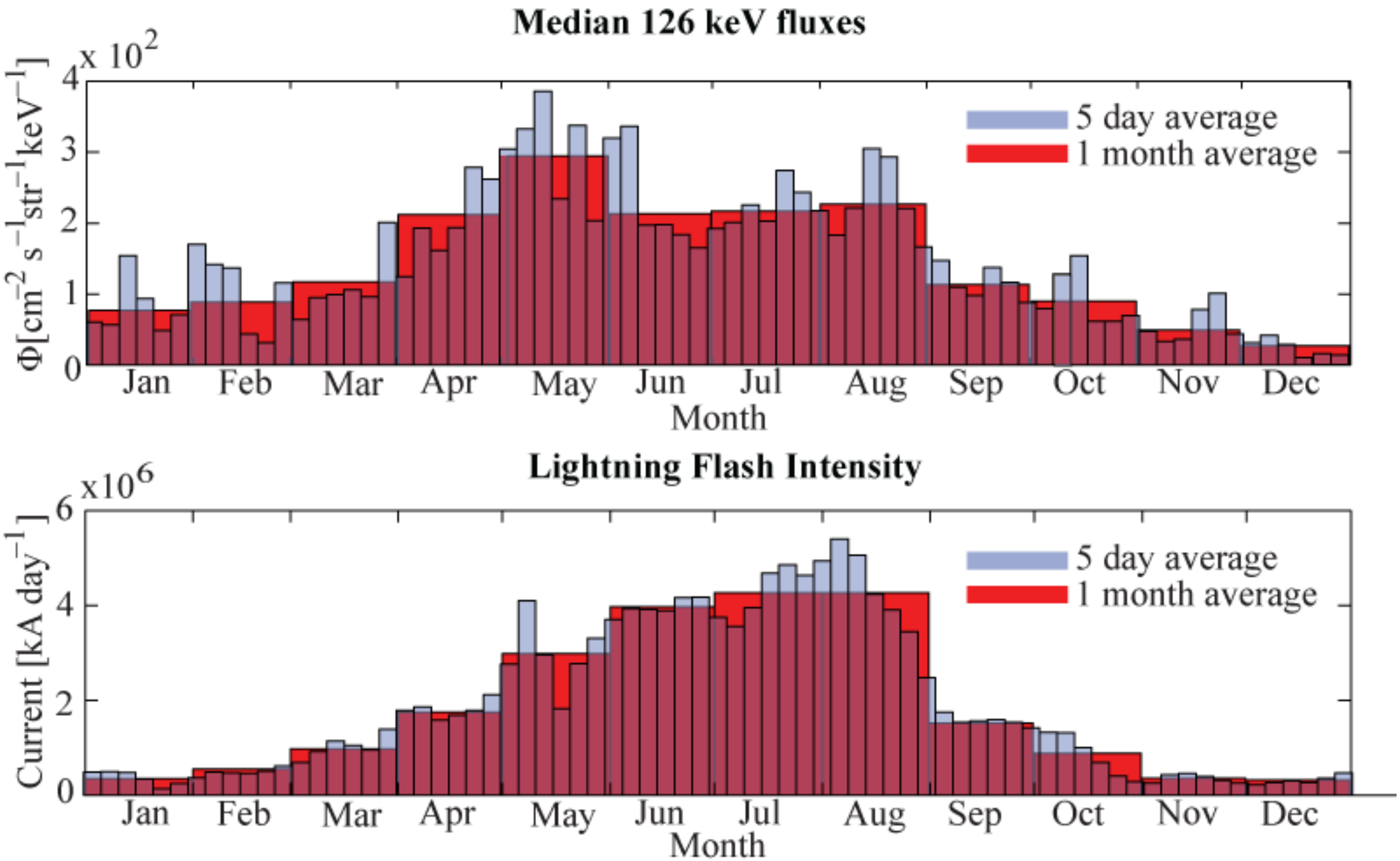


Daytime





Fluxes and Lightning



Outline

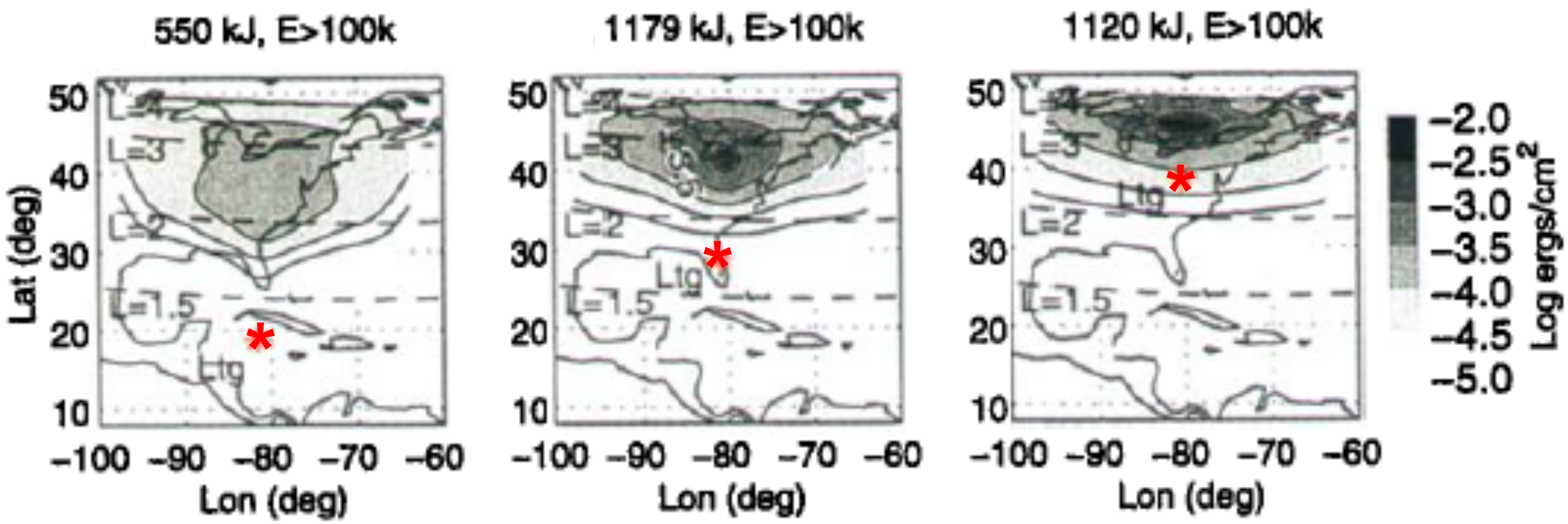
- Observations
- Theoretical flux calculations
  - Electron precipitation model
  - Expected precipitation at satellite location
  - Correlation between expected and actual fluxes
- Conclusions

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

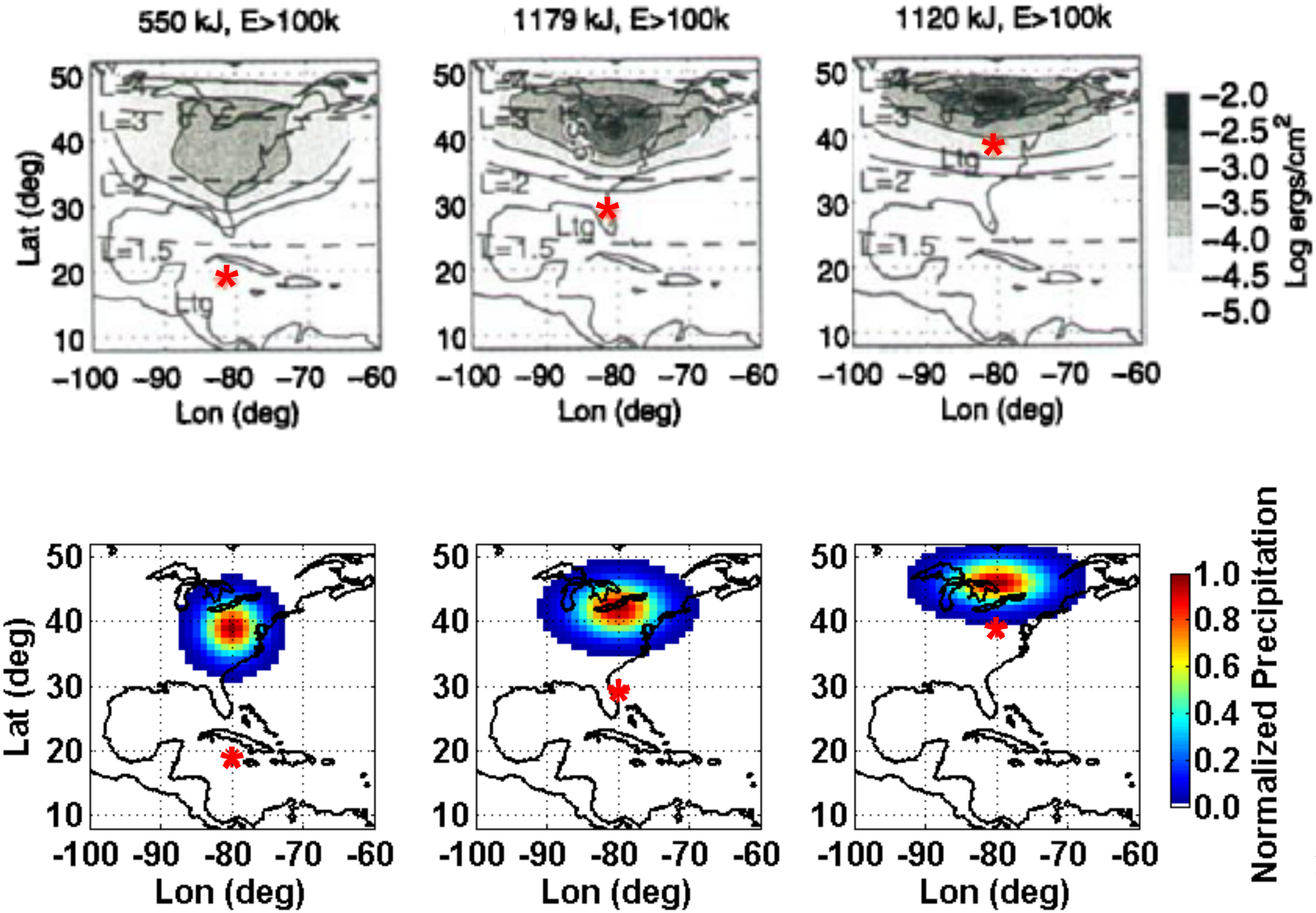
(from Plate 12 of *Lauben et al., [2001]*)



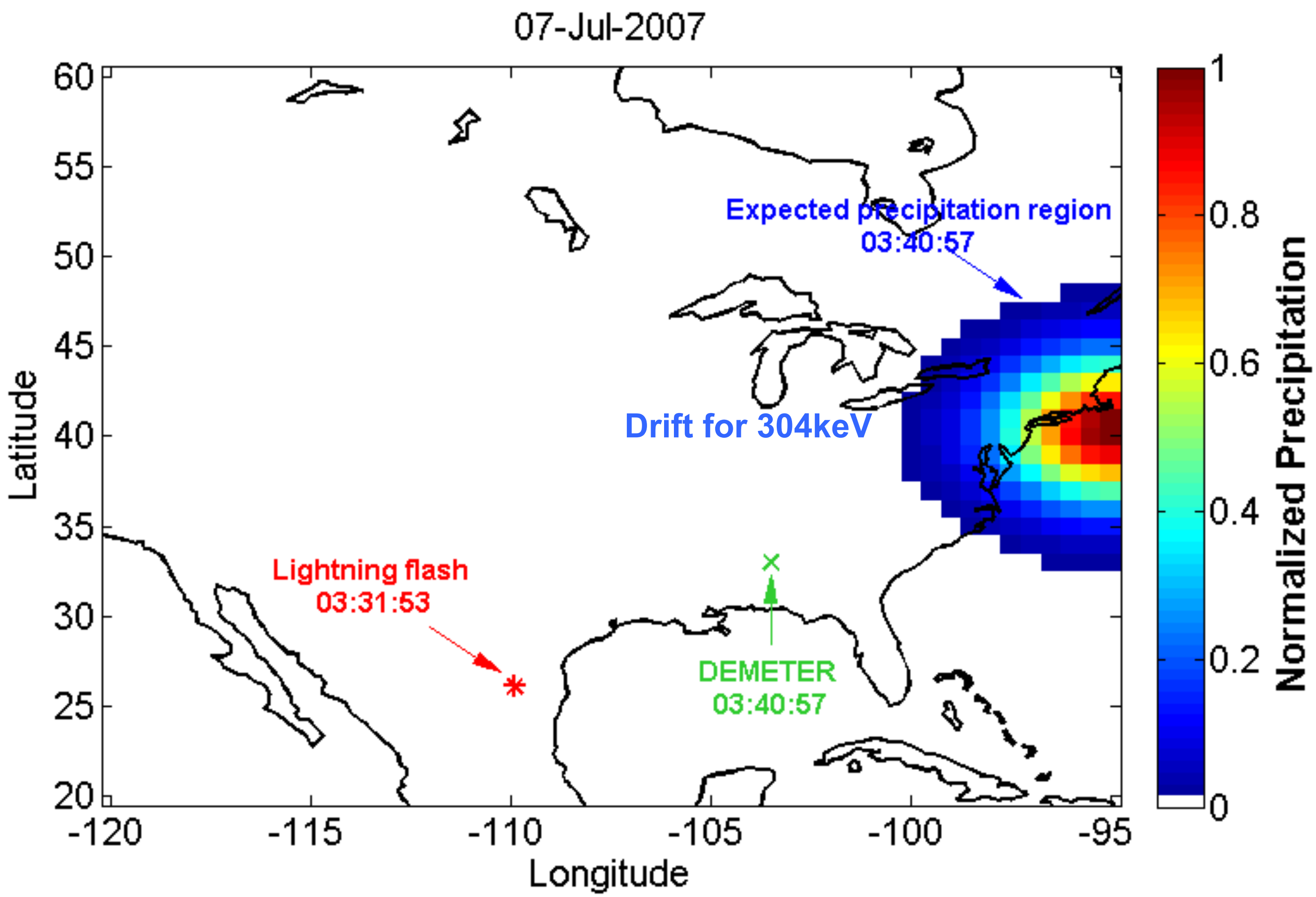
- Precipitation occurs in broad region poleward of lightning source
- Model returns two-dimensional function of precipitation region

Gaussian Precipitation Model

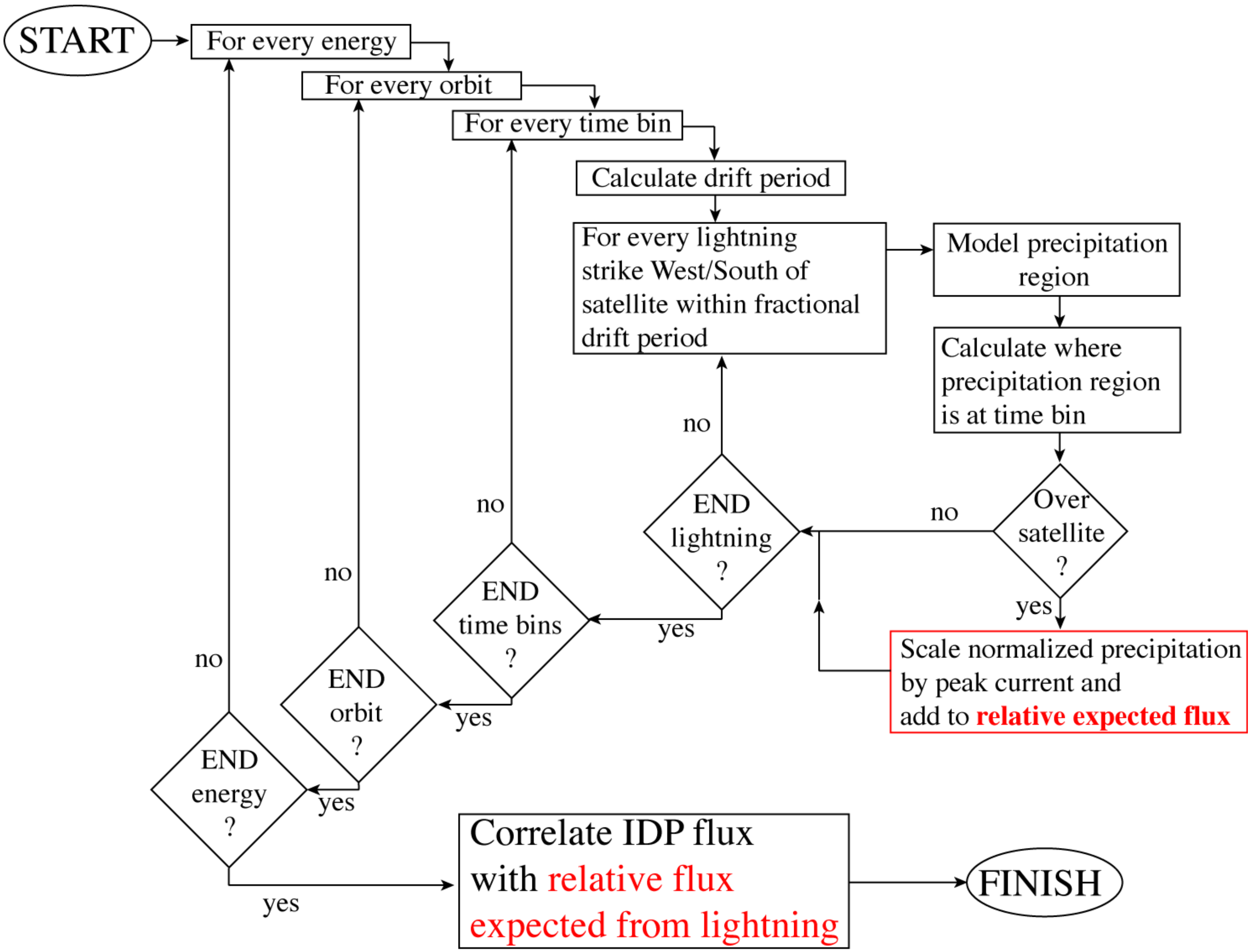
(compared to Plate 12 of *Lauben 2001*)



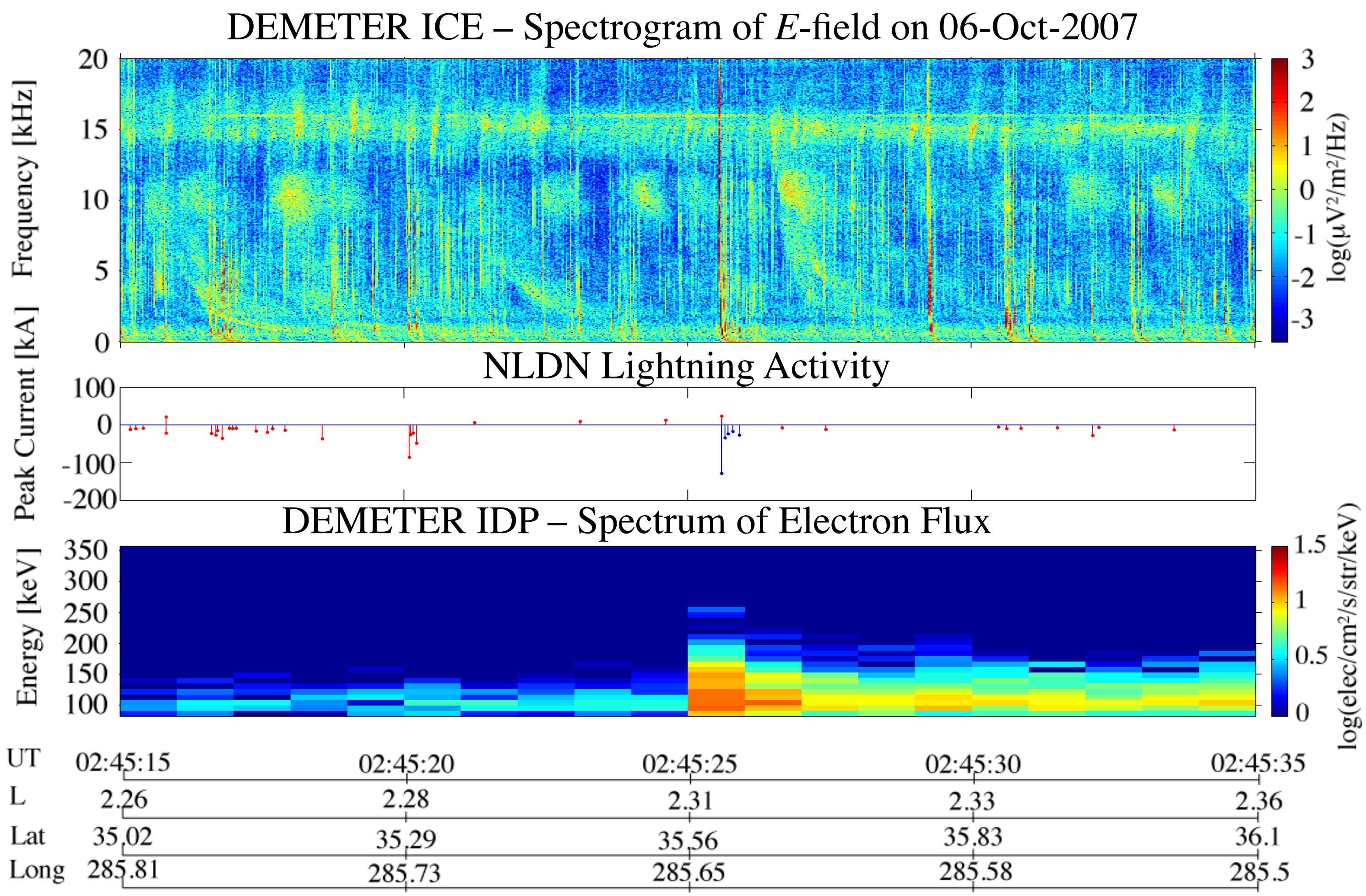
Example Gaussian Model

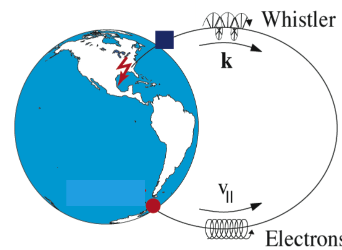


Methodology

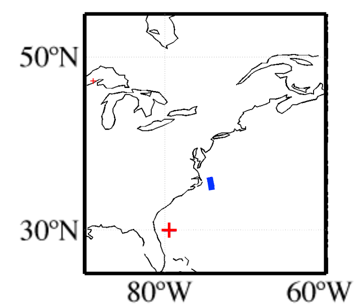


Proof of concept: example

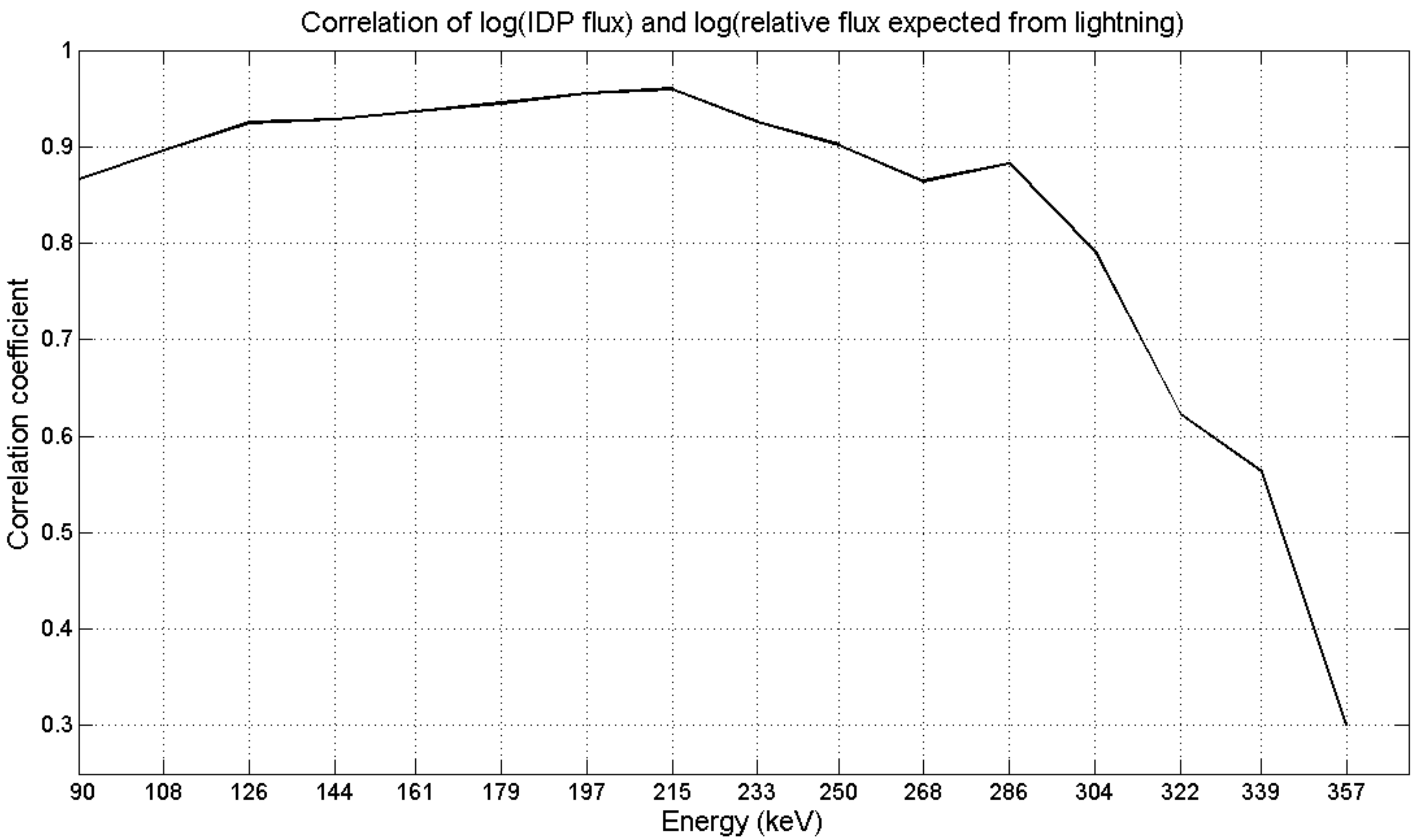




DEMETER trajectory

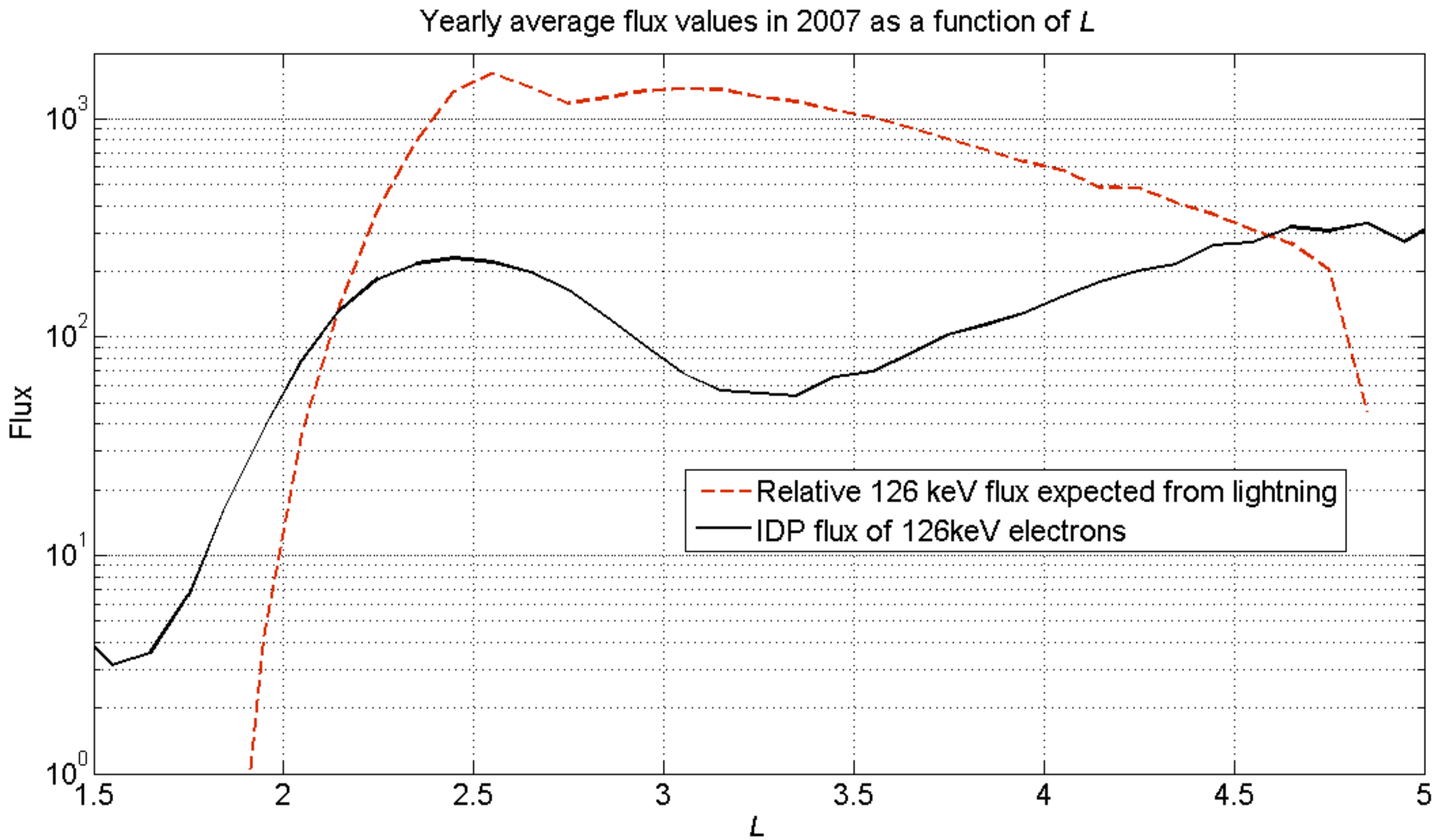


Proof of concept: results



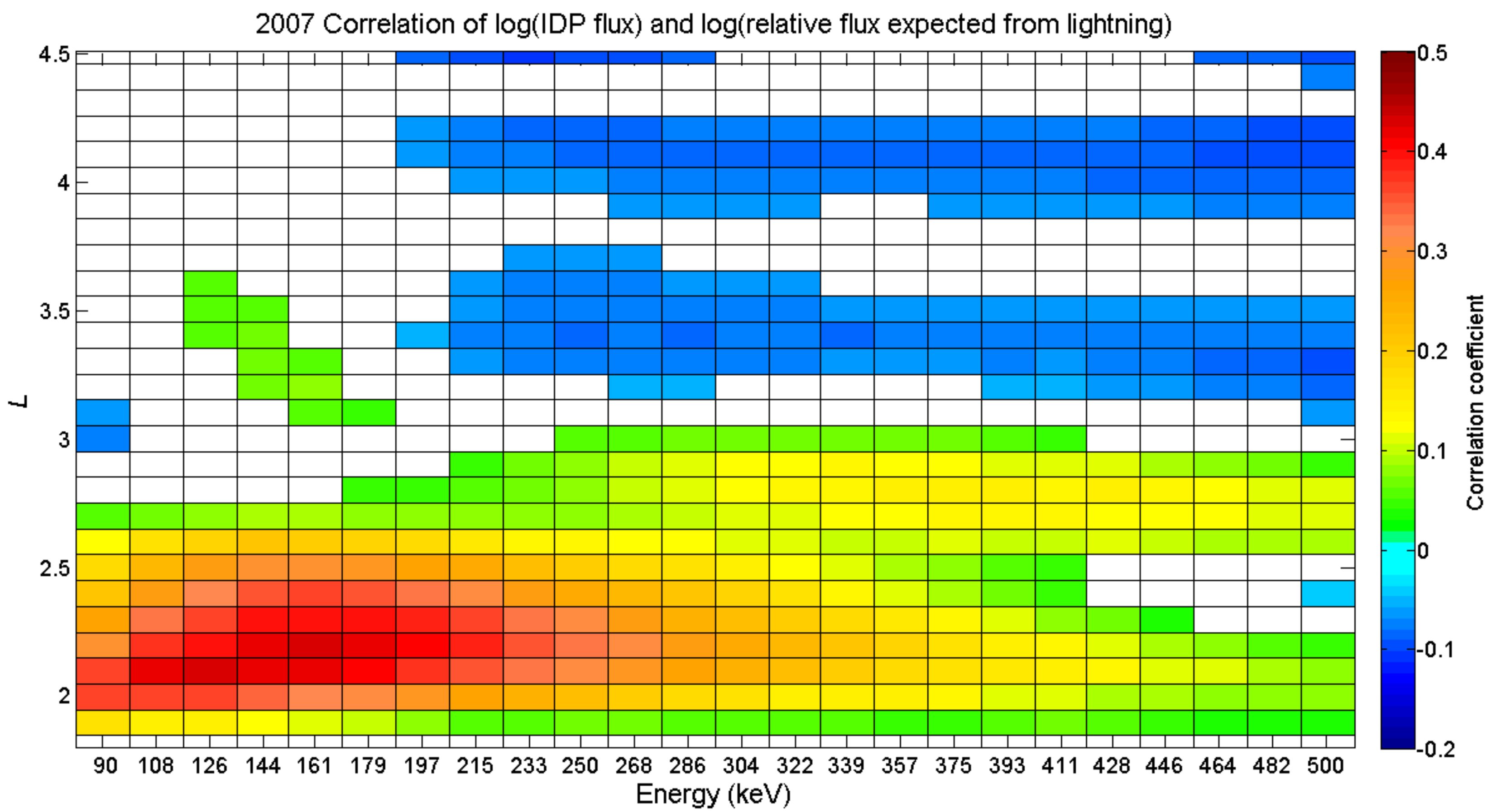
- Expected fluxes agree well with IDP data up to ~300 keV over sample orbit shown on previous slide

Dependence on *L*

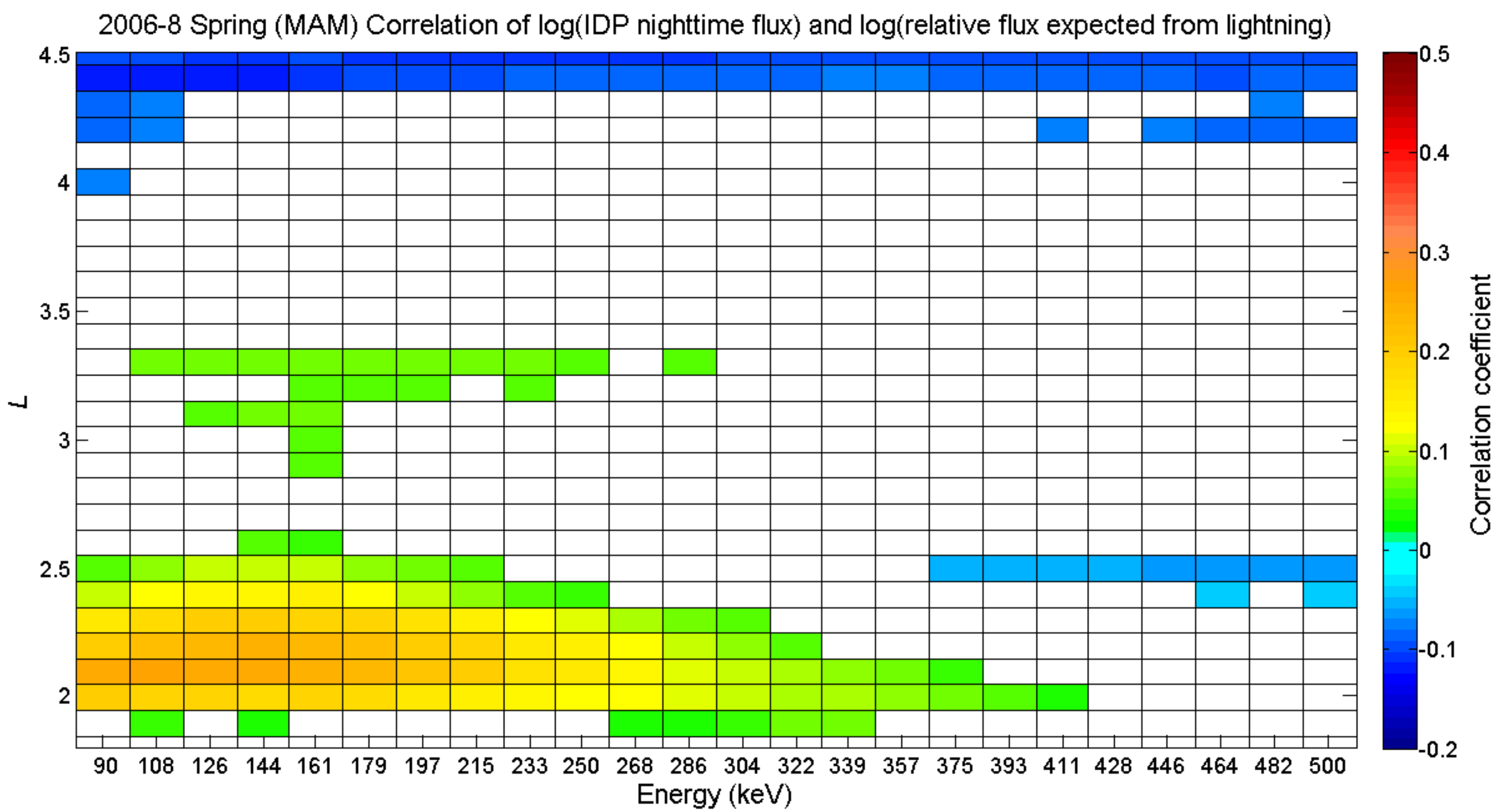


- Non-linear relationship with *L* means we need to do a direct estimate of the conditional correlation

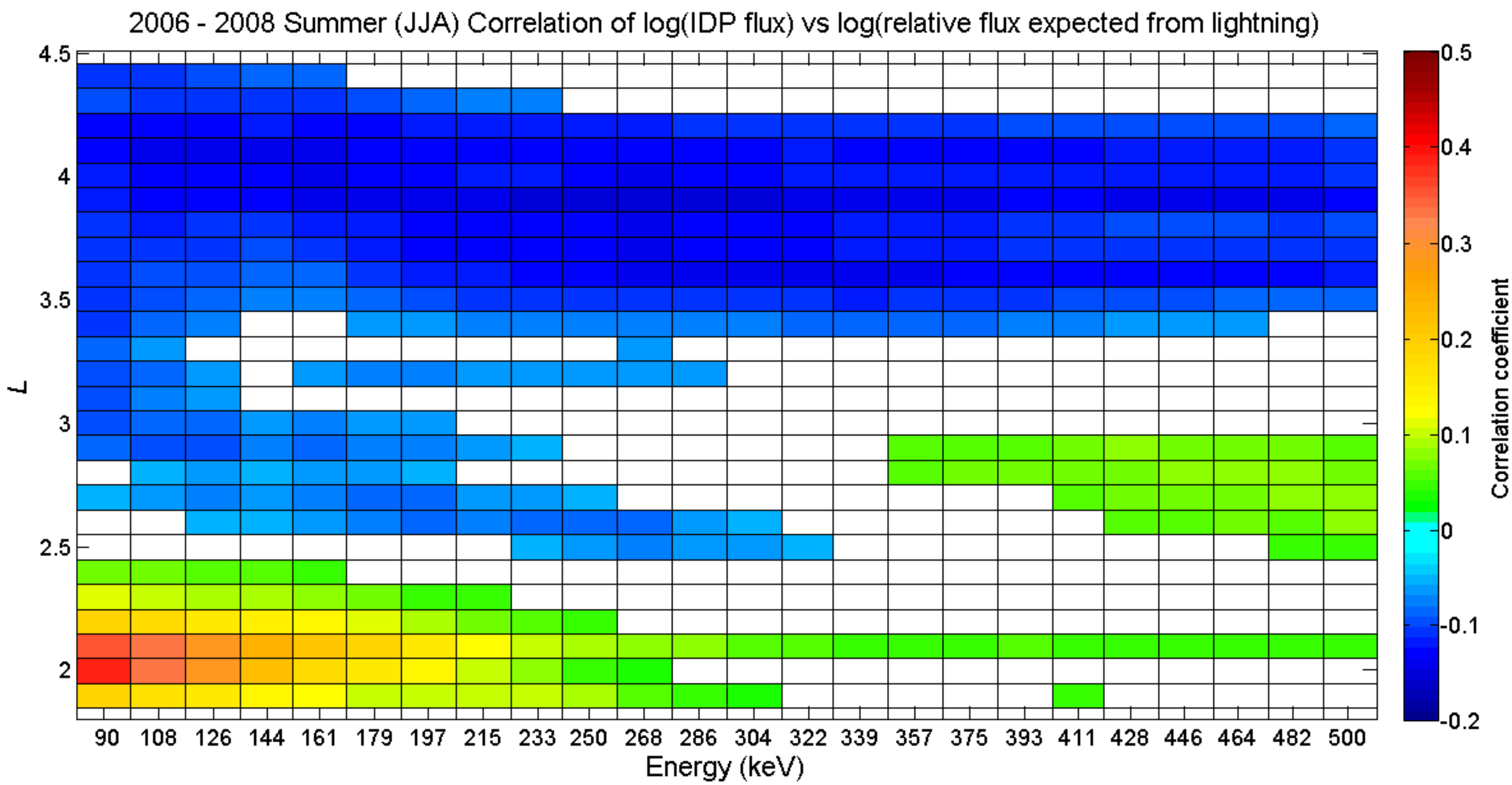
2007 Correlations



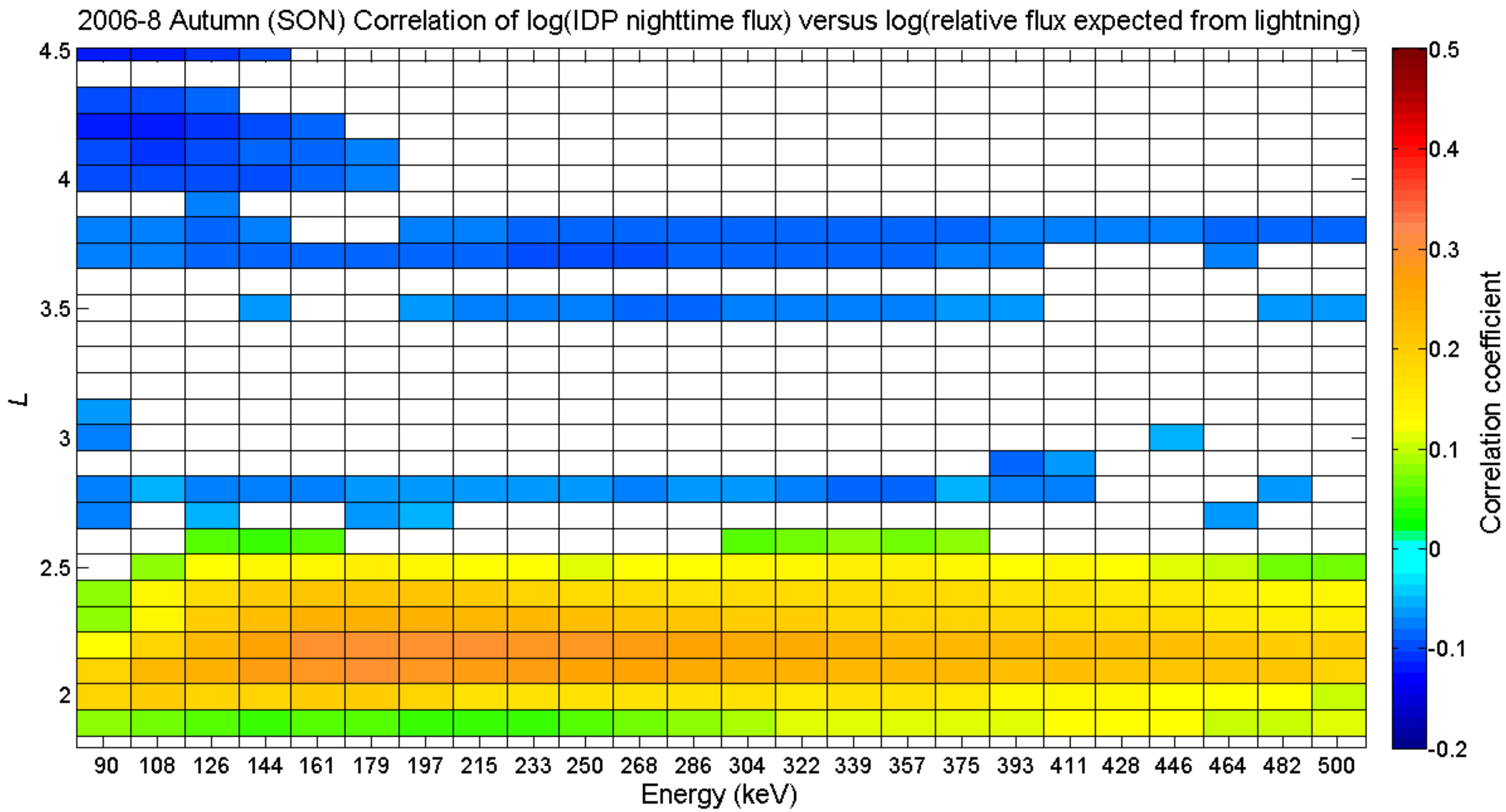
Seasonal Correlations: Spring



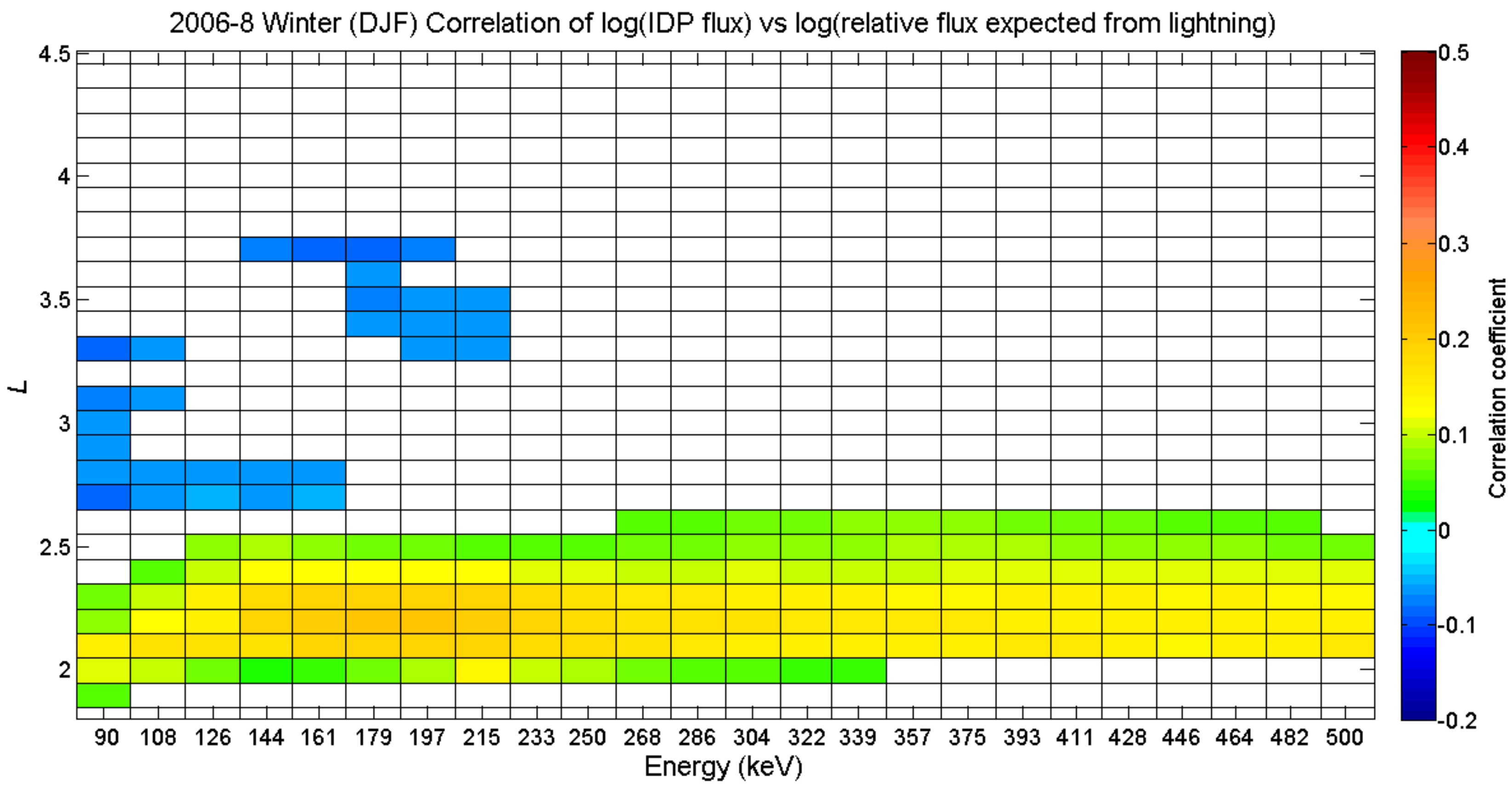
Seasonal Correlations: Summer



Seasonal Correlations: Autumn



Seasonal Correlations: Winter



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.