SPACESTORM

Low energy electrons (< 200 keV) in the inner magnetosphere during extreme space weather event

Natalia Ganushkina

Finnish Meteorological Institute, Helsinki, Finland/

University of Michigan, Ann Arbor MI, USA

Special thanks to: Dave Pitchford (SES) for AMC 12 CEASE electron data
Michelle Thomsen, Mike Henderson for LANL MPA data

The research leading to these results was partly funded by the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement No 606716 SPACESTORM

11th European Space Weather Week, November 17-21, 2014, Liege, Belgium

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
ONERA
THE FRENCH AEROSPACE LAB
SURREY
SPACE CENTRE
ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE
DH
CONSULTANCY

Low energy electrons (< 200 keV) in the inner magnetosphere during extreme space weather event

Natalia Ganushkina

Finnish Meteorological Institute, Helsinki, Finland/
University of Michigan, Ann Arbor MI, USA

Special thanks to: Dave Pitchford (SES) for AMC 12 CEASE electron data
Michelle Thomsen, Mike Henderson for LANL MPA data

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement No 606716 **SPACESTORM**

11th European Space Weather Week, November 17-21, 2014, Liege, Belgium

Low energy electrons in the inner magnetosphere

- The distribution of low energy electrons, the seed population (10 to few hundreds of keV), is critically important for radiation belt dynamics.

- Surface charging by electrons with < 100 keV can cause significant damage and spacecraft anomalies (*Purvis et al*., 1984; *Whipple*, 1981; *Garrett* , 1981; *Davis et al.*, 2008; *Frezet et al*., 1988; *Hoeber et al*., 1998; *Koons et al*., 1999).

- Simple corotation and convection electric field can describe rather well the average properties of transport for low energy electrons as Kp-dependent in the inner magnetosphere (*Korth et al*., 1999; *Friedel et al*., 2001; *Thomsen et al*., 2002; *Kurita et al*., 2011).

- Storm time dipolarization events result in strong radial transport and energization of radiation belt electrons (*Mauk and Meng*, 1983; *Kerns et al*., 1994; *Ingraham et al*., 2001; *Li et al*., 2003; *Mithaiwala and Horton*, 2005; *Miyoshi et al*., 2006; *Shprits et al*., 2009; *Liu et al*., 2009; *Glocer et al*., 2011).

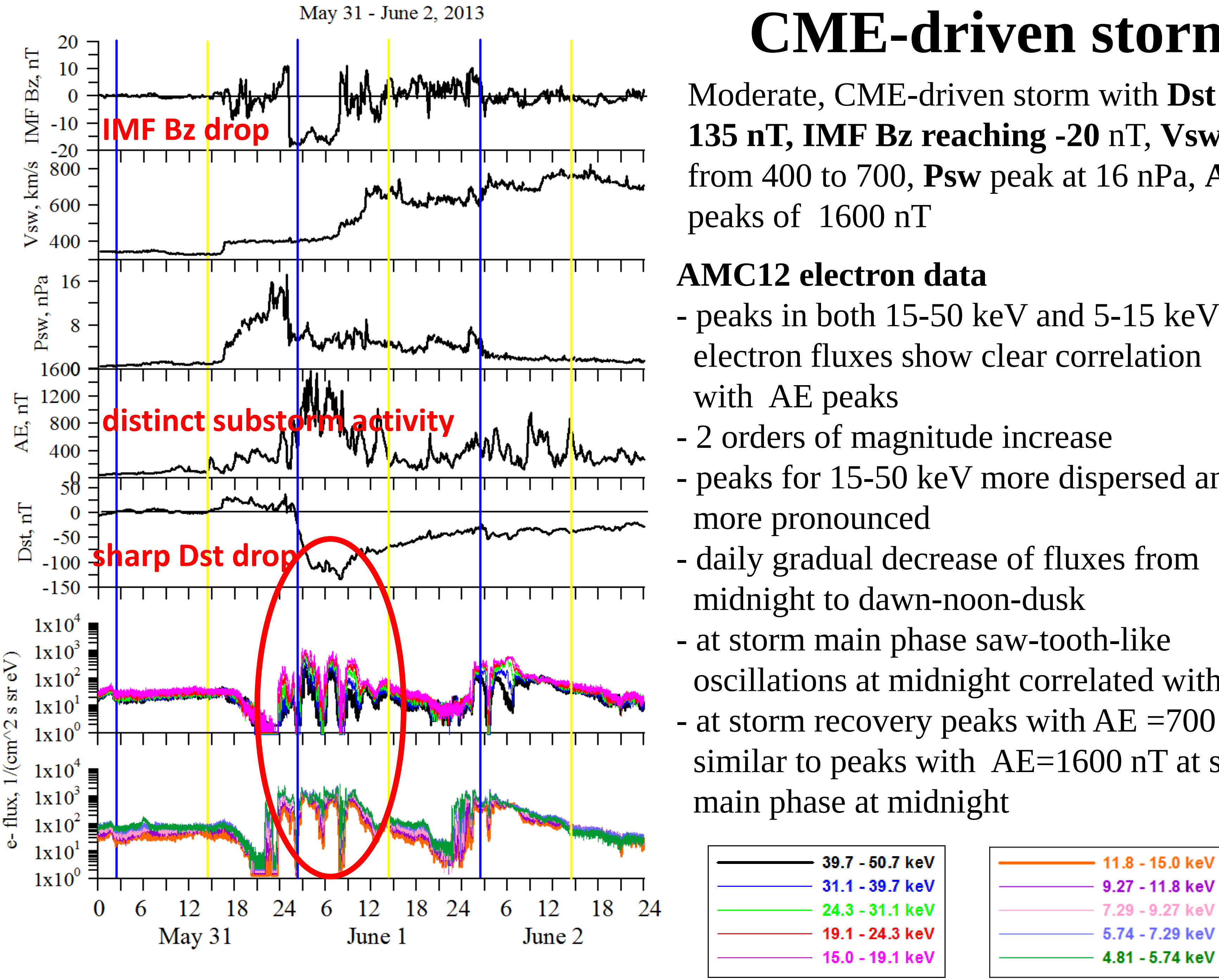
AMC 12 CEASE II ESA data

The data come from the AMC 12 geostationary satellite at 322.5 Deg E.

CEASE-II (Compact Environmental Anomaly Sensor) instrument contains an Electrostatic Analyzer (ESA) for measuring low energy electron fluxes in 10 channels, 5 - 50 keV.

The measured low energy electrons are responsible for surface charging.

CME-driven storm



Moderate, CME-driven storm with **Dst of 135 nT, IMF Bz reaching -20** nT, **Vsw** from 400 to 700, **Psw** peak at 16 nPa, **AE** peaks of 1600 nT

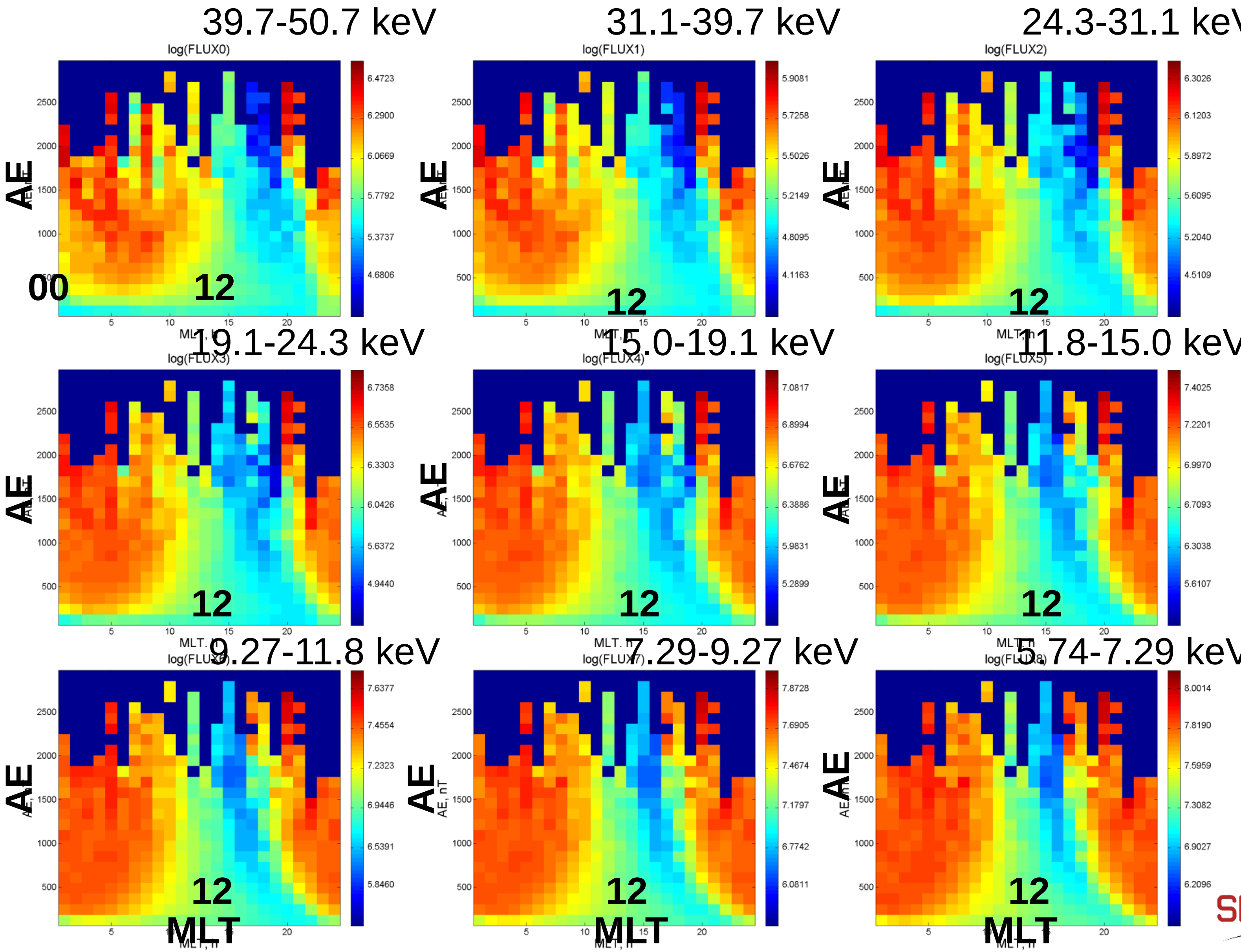
AMC12 electron data

- peaks in both 15-50 keV and 5-15 keV electron fluxes show clear correlation with AE peaks
- 2 orders of magnitude increase
- peaks for 15-50 keV more dispersed and more pronounced
- daily gradual decrease of fluxes from midnight to dawn-noon-dusk
- at storm main phase saw-tooth-like oscillations at midnight correlated with AE
- at storm recovery peaks with AE =700 nT similar to peaks with AE=1600 nT at storm main phase at midnight

Features in fluxes of low energy electrons

1. Peaks of **2 orders** of magnitude for **15-50 keV** and **1-2 orders for 5-15 keV**
2. Peaks are correlated with **AE index peaks**
3. Peaks’ **magnitudes are similar** for small (200-400 nT) and large (1200-1600 nT) AE
4. Peaks for **15-50 keV more dispersed** and pronounced
5. Daily **gradual decrease** of fluxes from midnight to dawn-noon-dusk
6. **Saw-tooth-like** oscillations correlated with AE during storm main phase

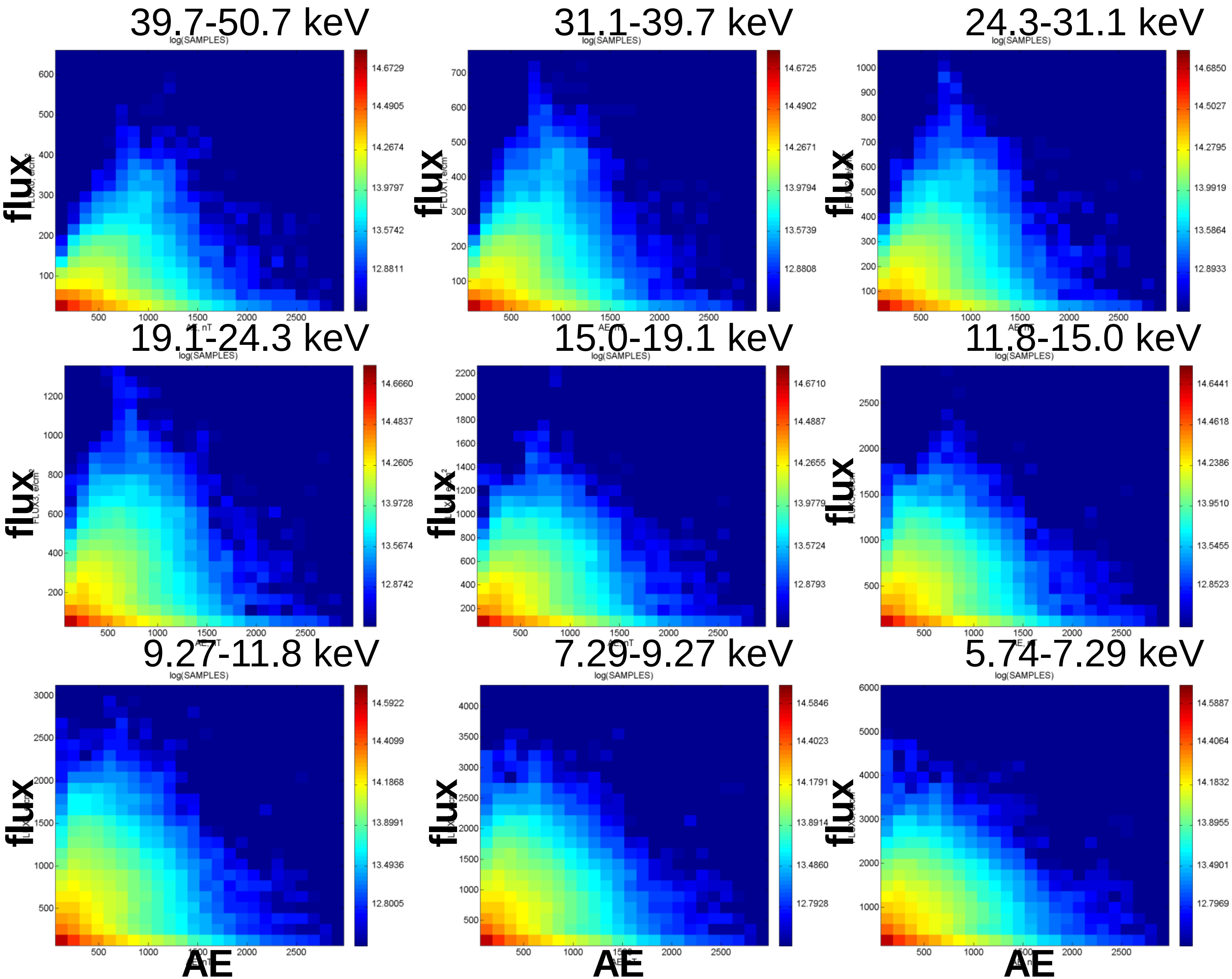
Dynamics of low energy (<50 keV) electrons in the inner magnetosphere: flux(AE-MLT) (1)



The higher the energy, the less distributed the flux peak

No distinct dependence on AE strength

Dynamics of low energy (<50 keV) electrons in the inner magnetosphere: flux(AE) (2)

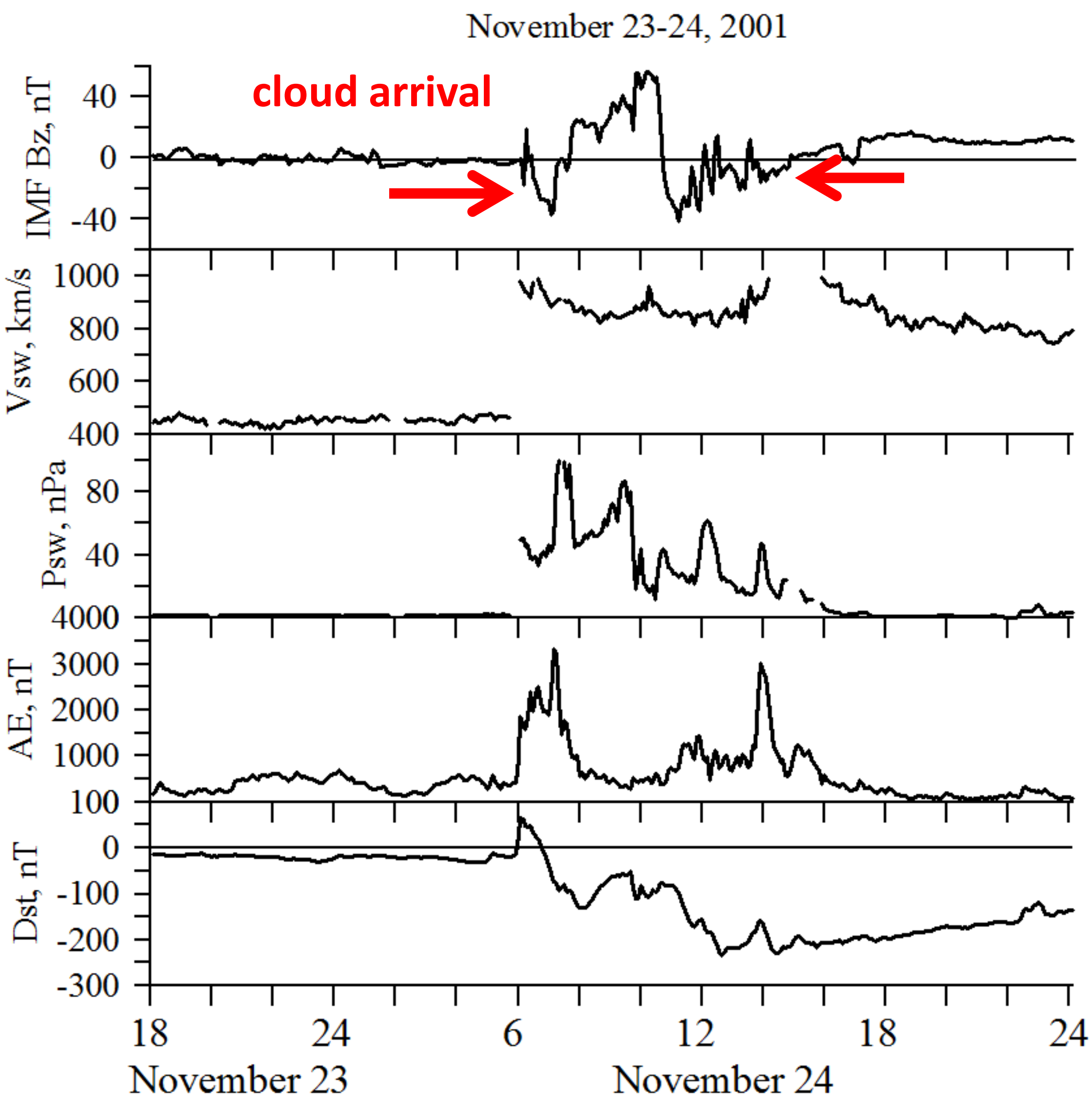


The higher the energy, the more clear the flux(AE) dependence

No distinct dependence on AE strength

SPACESTORM

Modeled Intense Storm Event: November 23-24, 2001



IMF Bz Nov, 24 reached 60 nT at 1014 UT and **−39 nT** at 1150 UT. Nsw of 79 cm−3 at 0742 UT. These disturbed conditions develop abruptly following **the arrival of a shock near 0600 UT and persist until 1600 UT.**

By 1600 UT, IMF Bz turns positive and remains for more than a day.

The IMF and SW data show the arrival of **a CME-induced magnetic cloud** over the Earth. The cloud arrived at around 1600 UT following a compressed upstream sheath-like region between 0600 and 1600 UT. **Several strong pressure pulses** between 0600 and 1600 UT.

The Sym-H index was **−234 nT** at 1237 UT.

Energy ranges for AMC 12 CEASE II ESA and LANL MPA

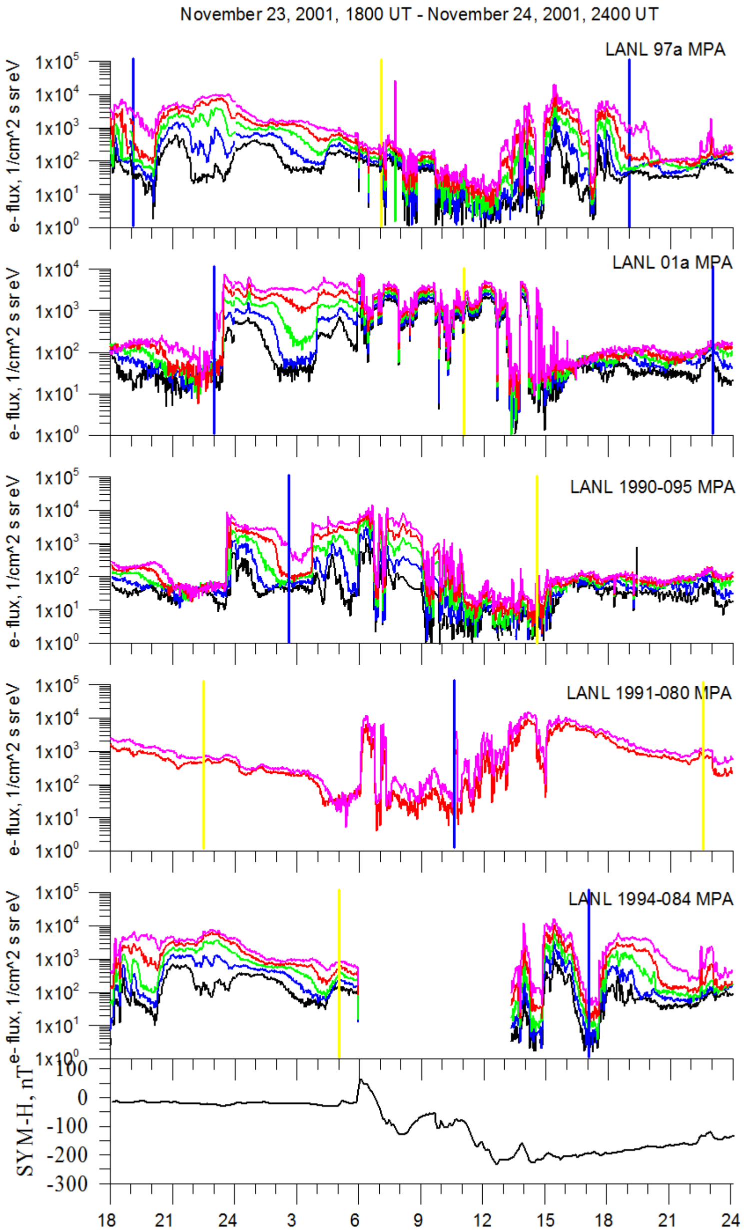
AMC 12 CEASE II ESA

39.7 - 50.7 keV	11.8 - 15.0 keV
31.1 - 39.7 keV	9.27 - 11.8 keV
24.3 - 31.1 keV	7.29 - 9.27 keV
19.1 - 24.3 keV	5.74 - 7.29 keV
15.0 - 19.1 keV	4.81 - 5.74 keV

LANL MPA

35 - 47 keV	9 - 12 keV
26 - 35 keV	7 - 9 keV
20 - 26 keV	5 - 7 keV
16 - 20 keV	4 - 5 keV
12 - 16 keV	3 - 4 keV

LANL MPA data on November 23-24, 2001

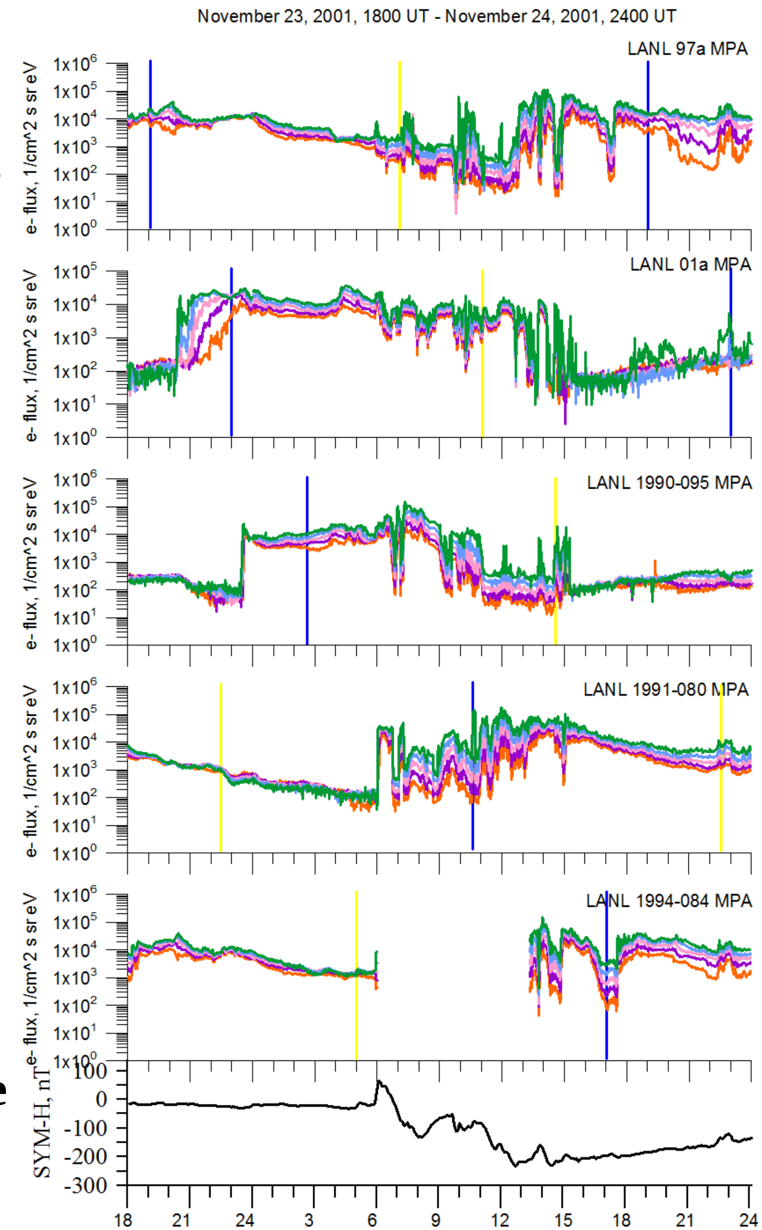


1. Peaks **3 orders** for **15-50 keV** and **2 orders for 5-15 keV**

2. Peaks for **15-50 keV more dispersed** and pronounced

3. Daily **gradual decrease** from midnight to dawn-noon-dusk

4. **Saw-tooth-like** oscillations



Inner Magnetosphere Particle Transport and Acceleration Model (IMPTAM) (*Ganushkina et al., 2005, 2012, 2013, 2014*)

- traces **ions and electrons** with arbitrary pitch angles from the plasma sheet to the inner L-shell regions with energies up to **hundreds of keVs** in time-dependent magnetic and electric fields

- traces a distribution of particles in the **drift approximation** under the conservation of the 1st and 2^{nd} adiabatic invariants. Liouville theorem is used to gain information of the entire distribution function

- for the obtained distribution function, we apply **radial diffusion** by solving the radial diffusion equation

- electron losses: convection outflow and pitch angle diffusion by the **electron lifetimes**

- advantage of IMPTAM: can utilize any magnetic or electric field model, including self-consistent magnetic field and substorm-associated electromagnetic fields.

IMPTAM for online nowcast

Magnetic field model: *Tsyganenko* T96 (Dst, Psw, IMF By and Bz)

Electric field model: *Boyle et al*. (1997) (Vsw, IMF B, By, Bz)

Boundary conditions at 10 Re: kappa distribution with number density and temperature given *by Tsyganenko and Mukai* (2003) model (Vsw, IMF Bz,Nsw)

Radial diffusion with diffusion coefficients D_{LL} (*Brautigam and Albert*, 2000)

$$D_{LL} = 10^{0.056Kp - 9.325} L^{10}$$

Losses: Kp, magnetic field
Strong diffusion (L=10-6):

$$\tau_{sd} = \left(\frac{\gamma m_0}{p}\right)\left[\frac{2\Psi B_h}{1-\eta}\right]$$

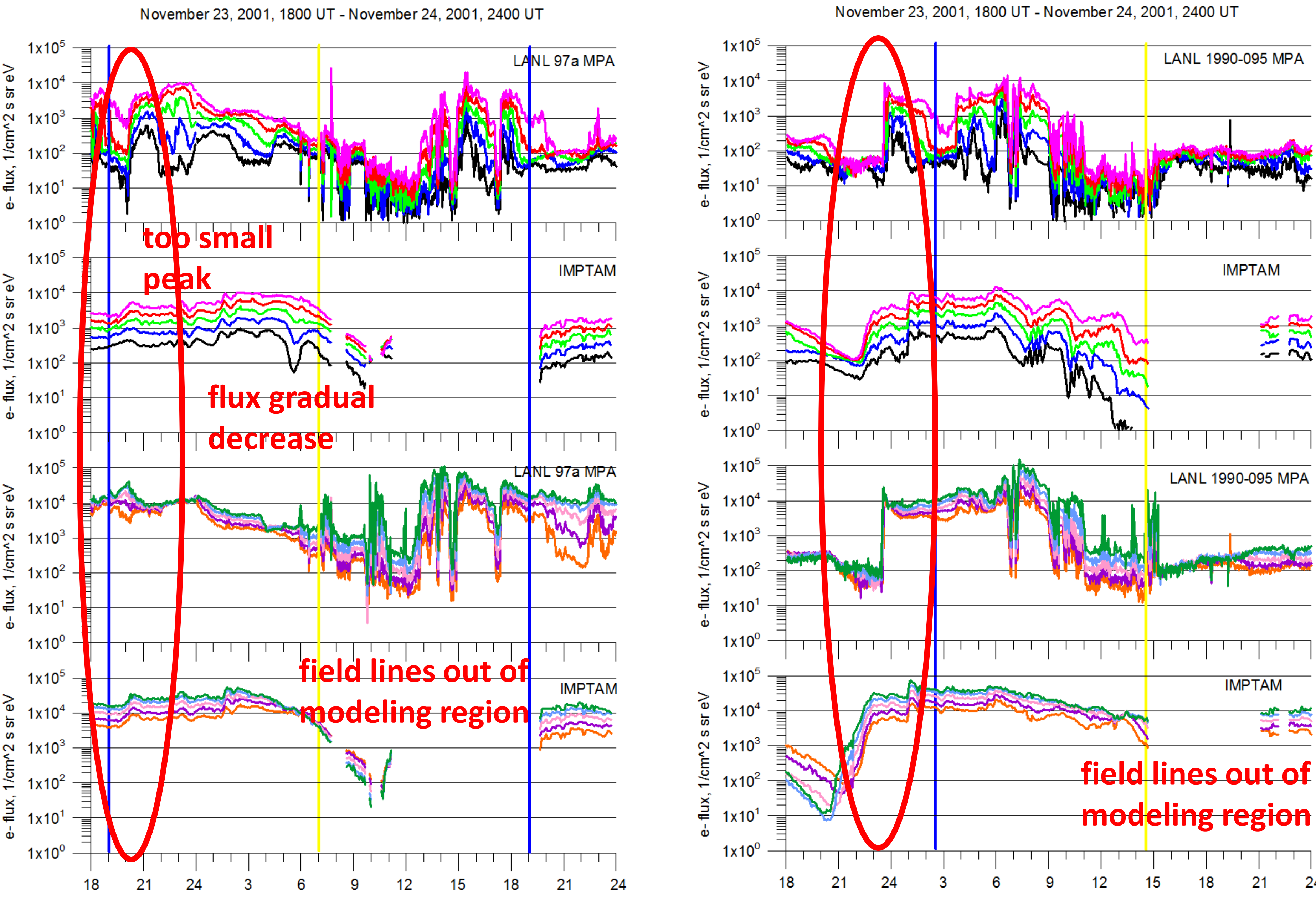
(*Chen et al*., 2005)

Weak diffusion (L=2-6):

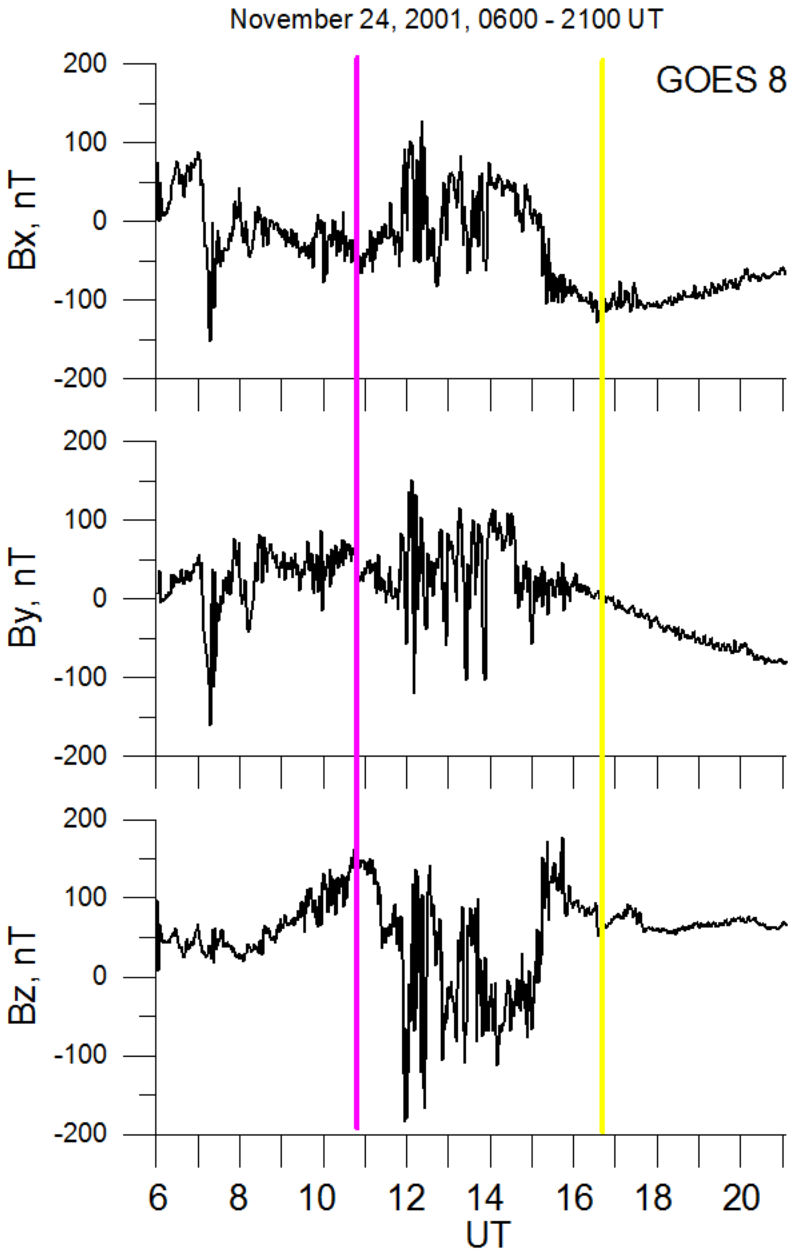
$$\tau_{wd} = 4.8 \cdot 10^4 B_w^{-2} L^{-1} E^2, \quad B_w^2 = 2 \cdot 10^{2.5+0.18Kp}$$

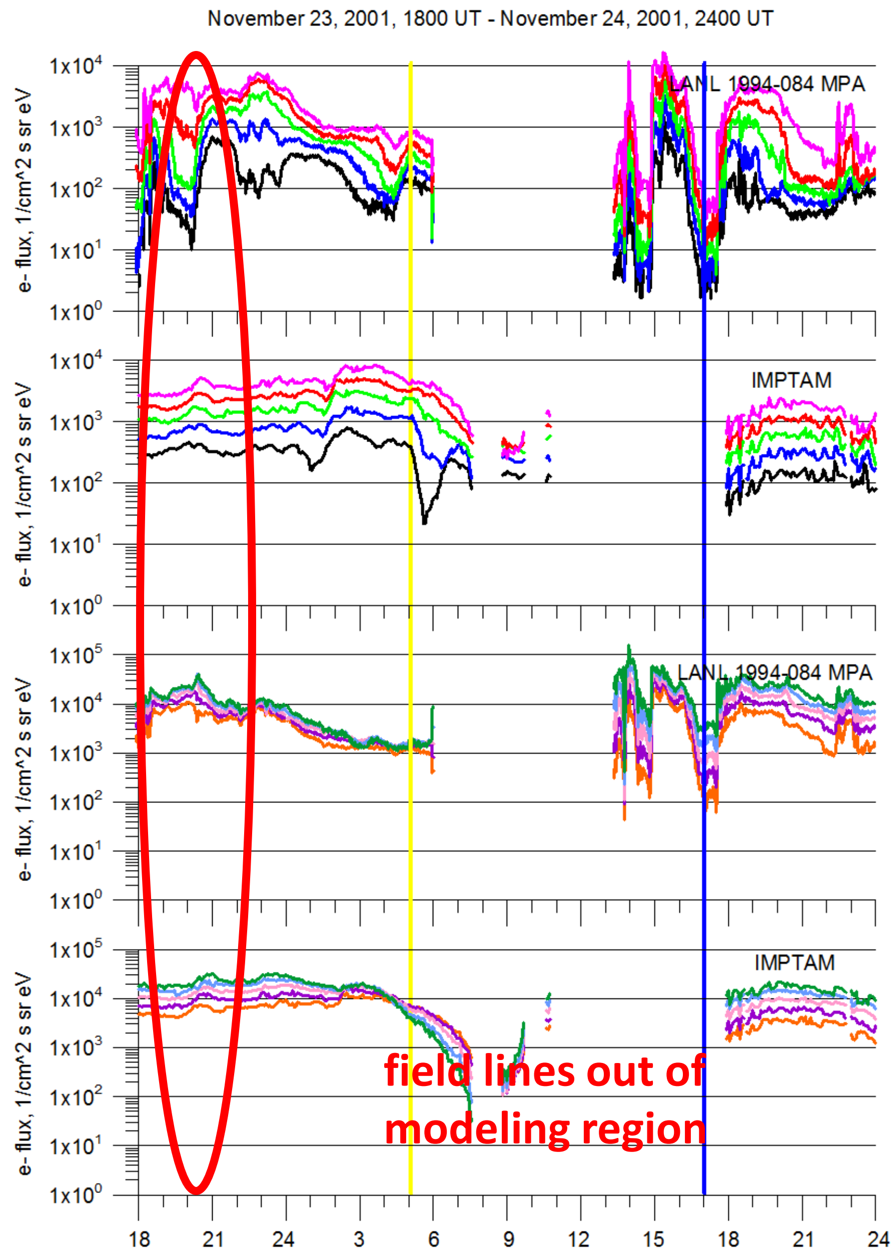
(*Shprits et al*., 2007)

November 23-24, 2001 storm: Modeling results (1)

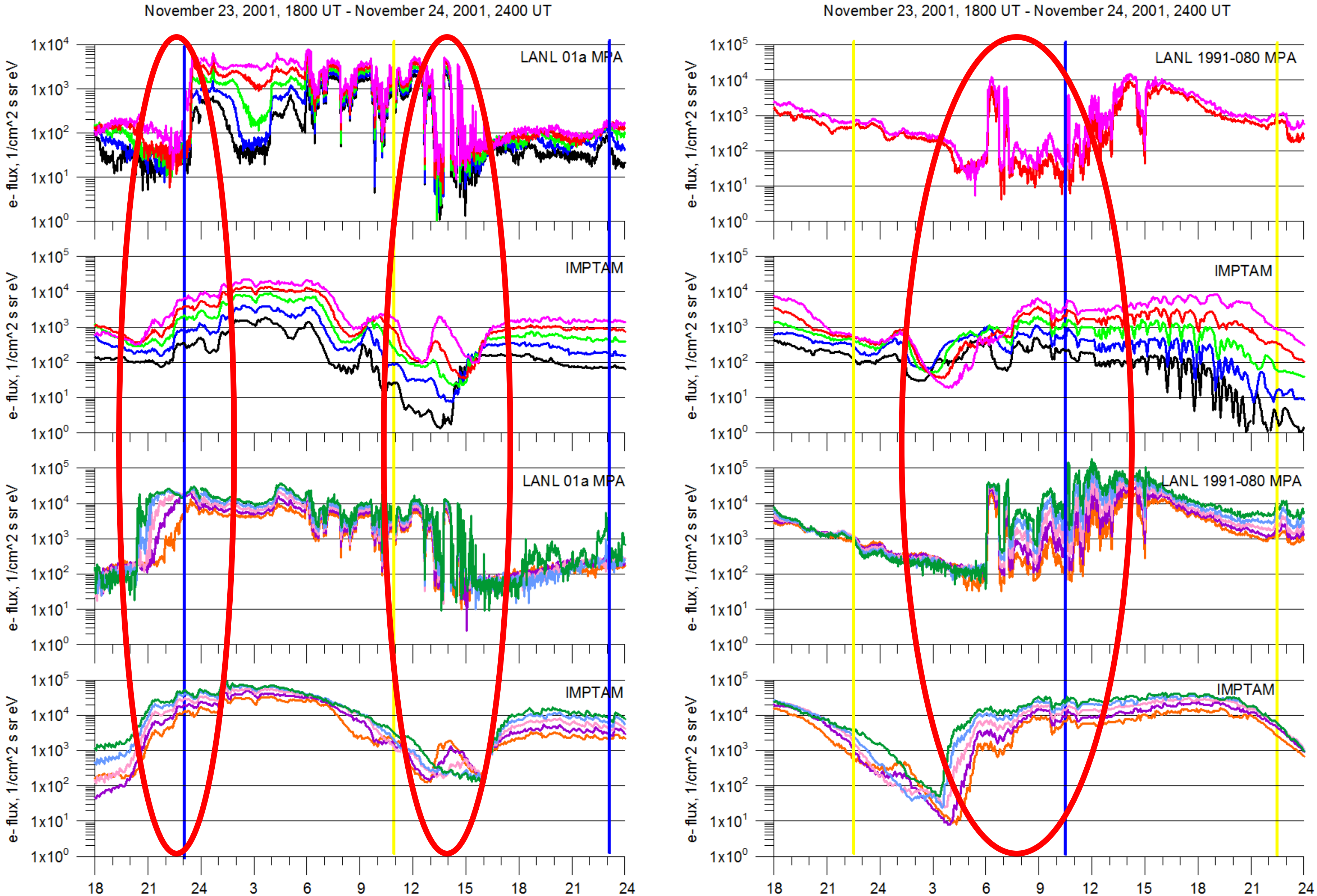


November 23-24, 2001 storm: Modeling results (2)





November 23-24, 2001 storm: Modeling results

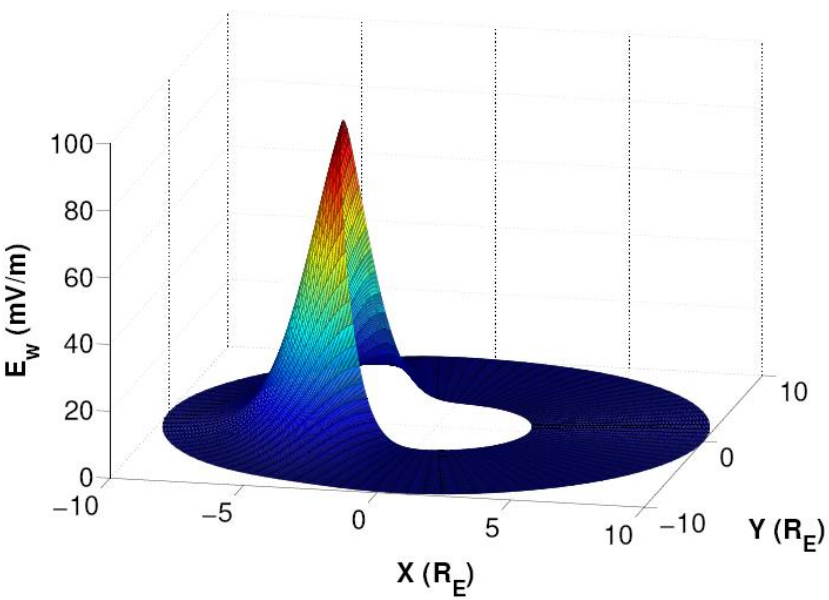


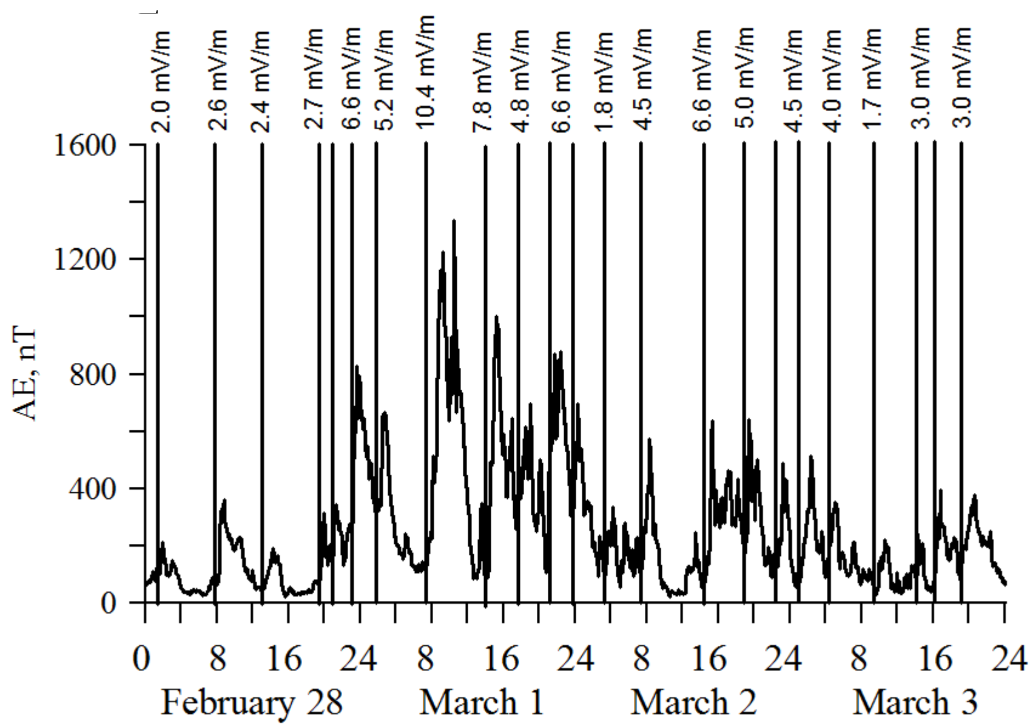
Electric field pulse model

Time varying fields associated with dipolarization in magnetotail, modeled as an electromagnetic pulse (*Li et al., 1998; Sarris et al., 2002*):

- Perturbed fields propagate from tail toward the Earth;
- Time-dependent Gaussian pulse with azimuthal E;
- E propagates radially inward at a decreasing velocity;
- decreases away from midnight.

Time-dependent B from the pulse is calculated by Faraday's law.





Summary

Low energy electrons (5-50 keV) data for period of moderate activity (2010-2013) from AMC 12 satellite and for period of intense storm (November 23-24, 2001) from LANL MPA instrument show quite similar features:

- Peaks of **2 (3) orders** of magnitude for **15-50 keV** and **1-2 orders for 5-15 keV**
- Peaks are correlated with **AE index peaks**
- Peaks' **magnitudes are similar** for small (200-400 nT) and large (1200-1600 nT) AE
- Peaks for **15-50 keV more dispersed** and pronounced
- Daily **gradual decrease** of fluxes from midnight to dawn-noon-dusk
- **Saw-tooth-like** oscillations correlated with AE during storm main phase

The variations of the observed fluxes for **5-50 keV electrons** were analyzed and reproduced by IMPTAM.
Question left open: How to incorporate the substorm influence into the modeling correctly? uniform representation of electromagnetic pulse scaled by AE value can not be used, flux peaks are not dependent on AE magnitude, pulse max at midnight is not correct etc.