Substorm-associated effects in the variations of low energy electron fluxes in the inner magnetosphere: Does the substorm's strength matter?

N. Ganushkina (1, 2), S. Dubyagin (1), I. Sillanpää (1), D. Pitchford (3)

(1) Finnish Meteorological Institute, Helsinki, Finland
(2) University of Michigan, Ann Arbor MI, USA
(3) SES ENGINEERING, Luxembourg

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 and by the European Union's Horizon 2020 research and innovation programme under grant agreement No 637302 PROGRESS

Unsolved Problems in Magnetospheric Physics Workshop, Scarborough UK, September 6-12, 2015

Why are we interested in low energy electrons (< 200 keV) 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.

- Chorus emissions (intense whistler mode waves) excited in the low-density region outside the plasmapause are associated with the injection of keV plasma sheet electrons into the inner magnetosphere.

- Surface charging by electrons with < 100 keV can cause significant damage and spacecraft anomalies.

- The electron flux at the keV energies is largely determined by convective and substorm-associated electric fields and varies significantly with geomagnetic activity driven by the solar wind – variations on time scales of minutes!

  No averaging over an hour/day/orbit!

It is not easy to model (nowcast) and forecast low energy electrons

• Following low energy electrons in large-scale **magnetic and electric fields:** Correct models for these fields are extremely hard to develop

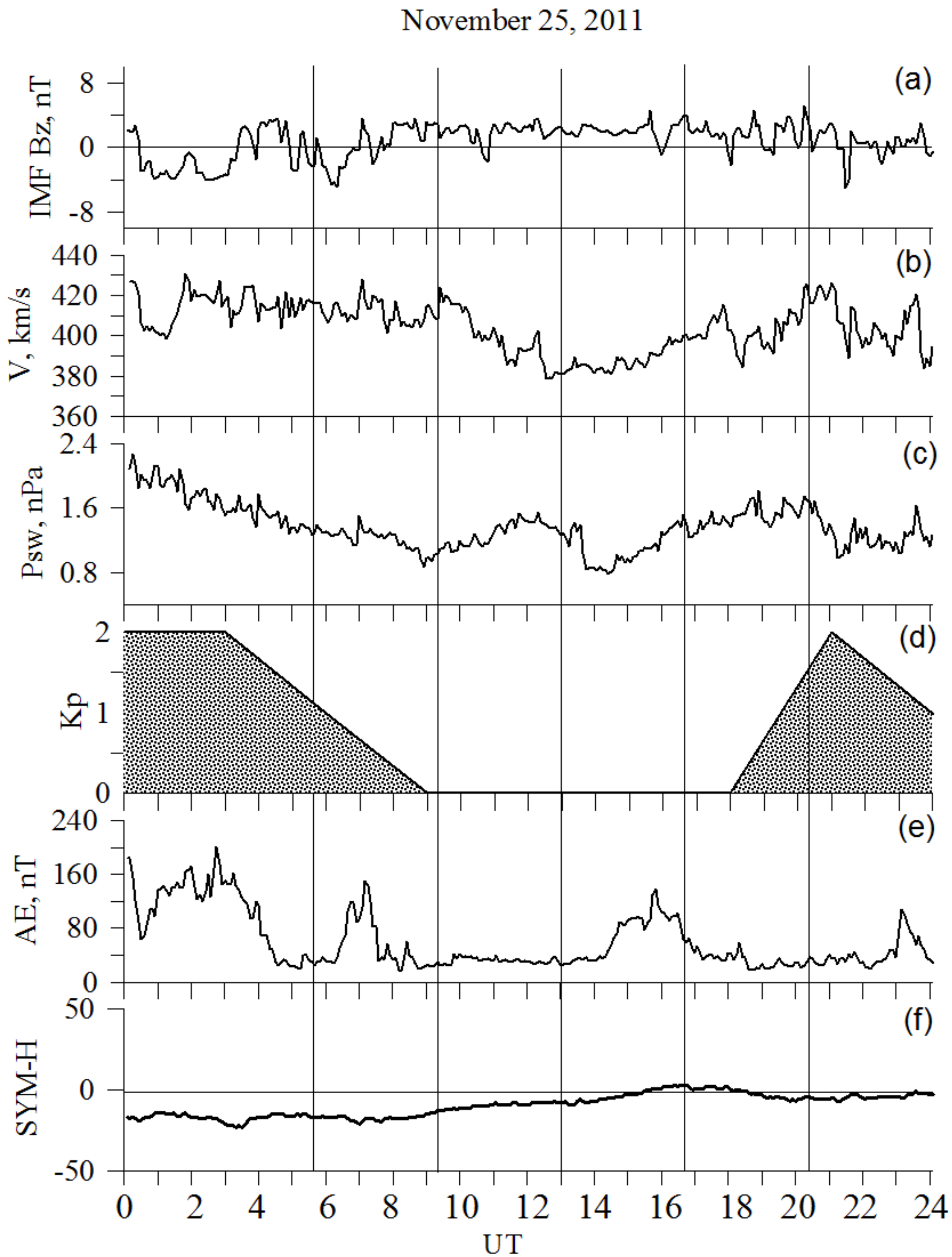
• Specification of a correct **initial conditions in the plasma sheet** is very nontrivial

• **Coefficients for radial diffusion** when electrons move from the plasma sheet (10 Re) to inner regions (<6 Re) are far from being exact.

• How to introduce low energy electrons' losses correctly? Electron lifetimes due to interactions with chorus and hiss, other waves, are they important?

•**MAIN FACTOR: SUBSTORMS**.

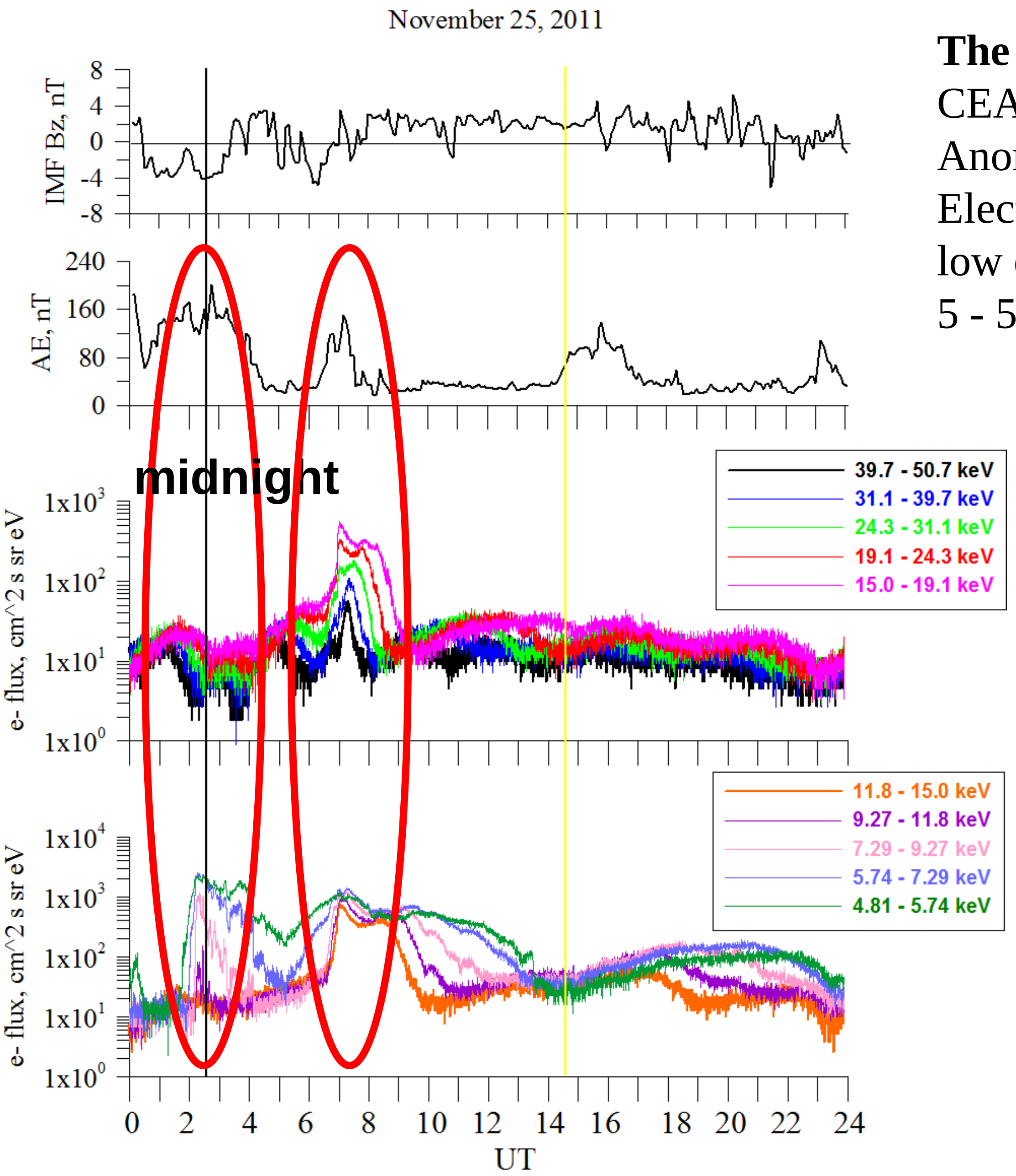
Substorms play a significant role in keV **electron transport and energy increase.** How to include them properly?



No storm is needed for 2-3 orders of magnitude increase of low energy electron fluxes at geostationary orbit

Rather quiet event

5-50 keV electrons during quiet event



The data: AMC 12 geostationary satellite, CEASE-II (Compact Environmental Anomaly Sensor) instrument with Electrostatic Analyzer (ESA) for measuring low energy electron fluxes in 10 channels, 5 - 50 keV.

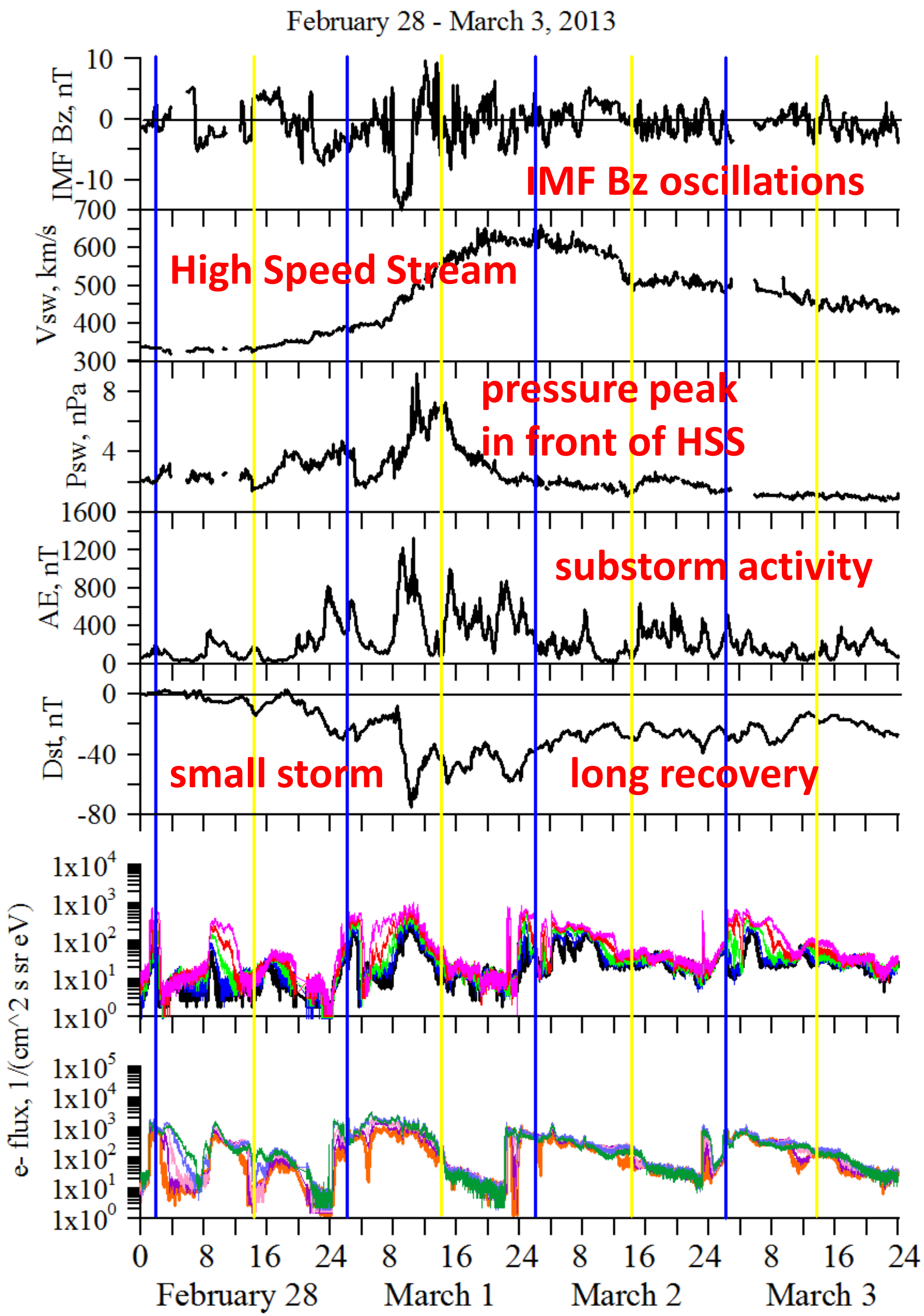
- **Flux increases** are related to **AE peaks** only (less than 200 nT, small, isolated substorms)

- The lower the energy, the large the flux

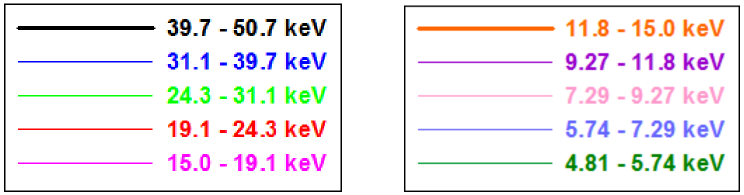
- Electrons of different channels behaves differently:
- 1st peak (AE=200 nT) at midnight seen for energies > 11 keV
- 2nd peak (AE=120 nT) at dawn, increase in all energies

Not a unique case

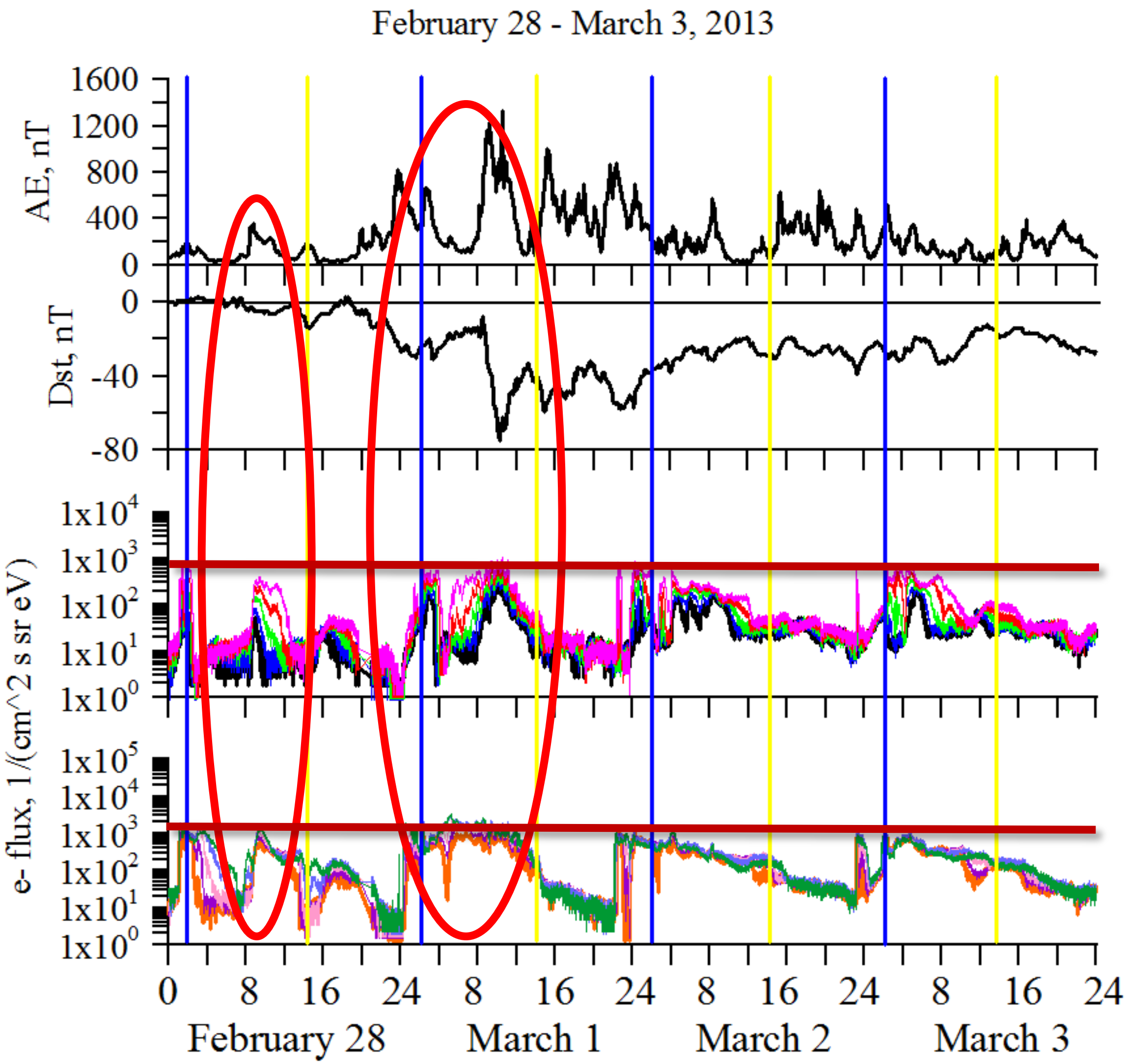
CIR-driven storm



Small, CIR-driven storm with
Dst of 75 nT,
IMF Bz of -5 -10 nT,
Vsw from 350 to 650 km/s,
Psw peak at 8 nPa,
AE peaks of 800-1200 nT



Similar increase in electron fluxes during AE = 400 nT and AE=1200 nT



AMC12 electron data

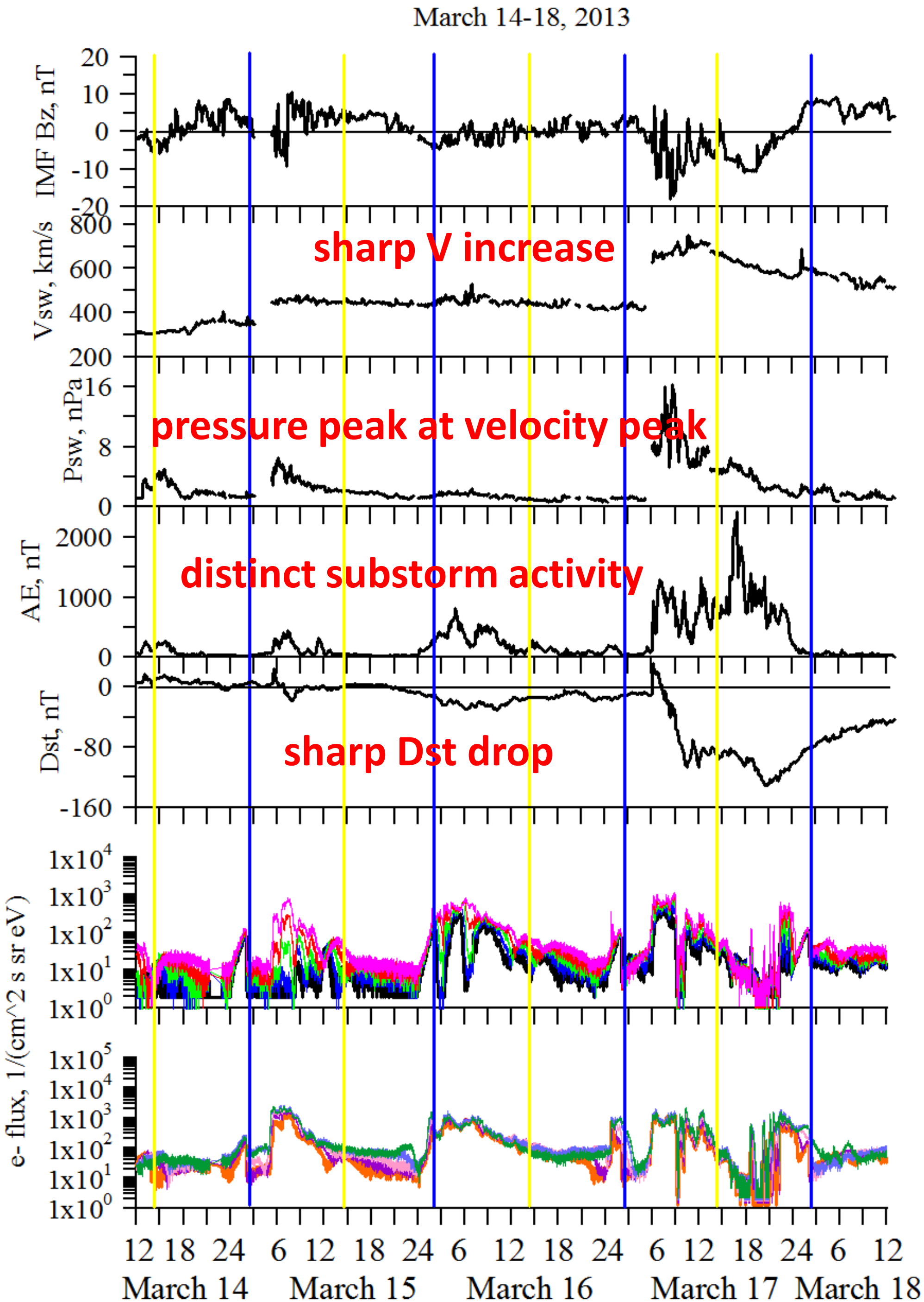
- peaks in both 15-50 keV and 5-15 keV electron fluxes show correlation with AE

- 2 orders of magnitude increase

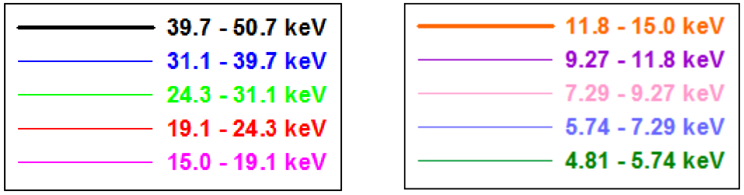
- all energies increase at midnight, when AE is only 200 nT

- same order of increase for AE = 800 nT and even for 1200 nT

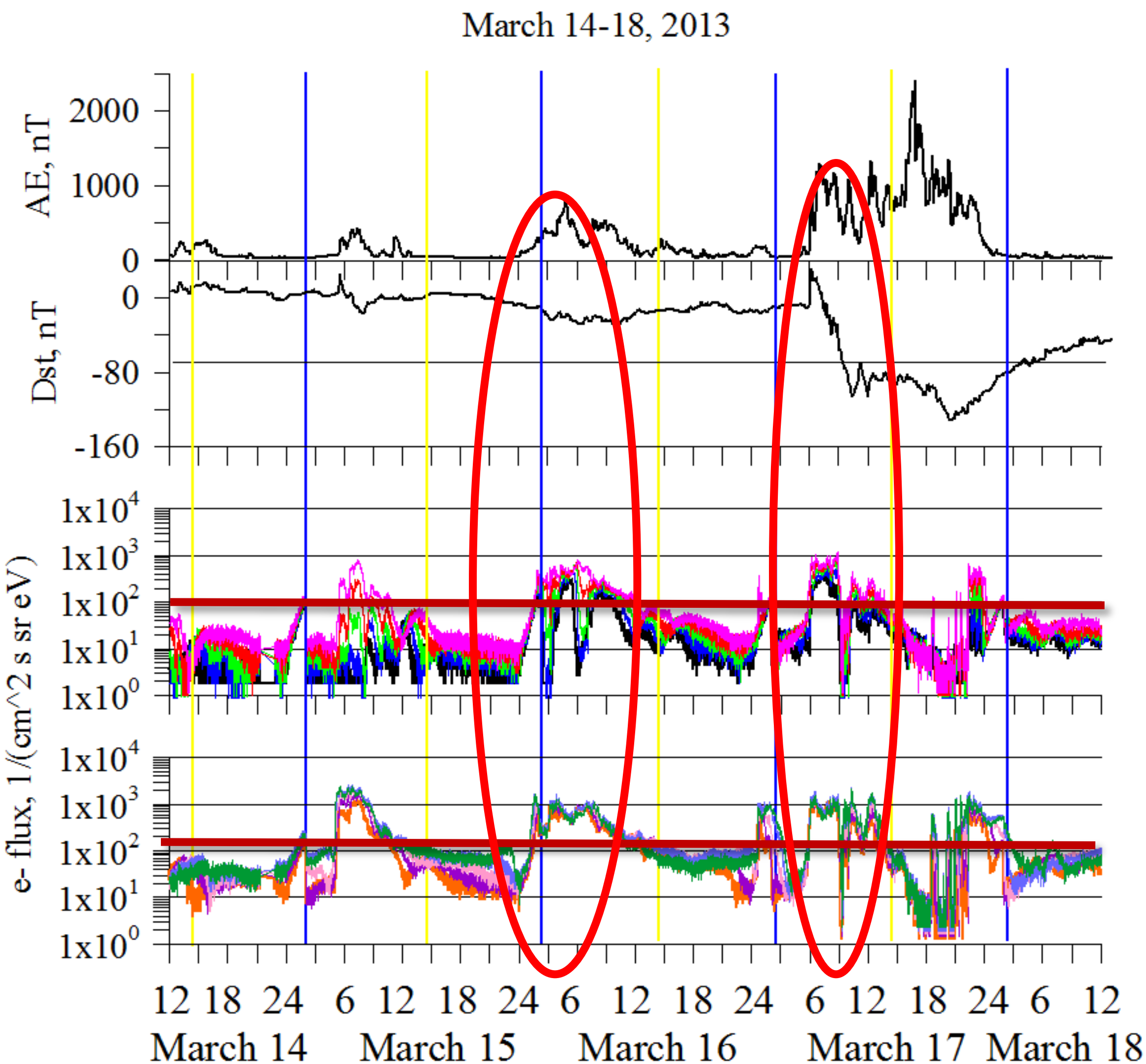
CME-driven storm



Moderate, CME-driven storm with **Dst of 130 nT,**
IMF Bz reaching -20 nT,
Vsw from 400 to 700,
Psw peak at 16 nPa,
AE peaks of 1000-2500 nT



Similar increase in electron fluxes during AE = 500 nT and AE=1500 nT



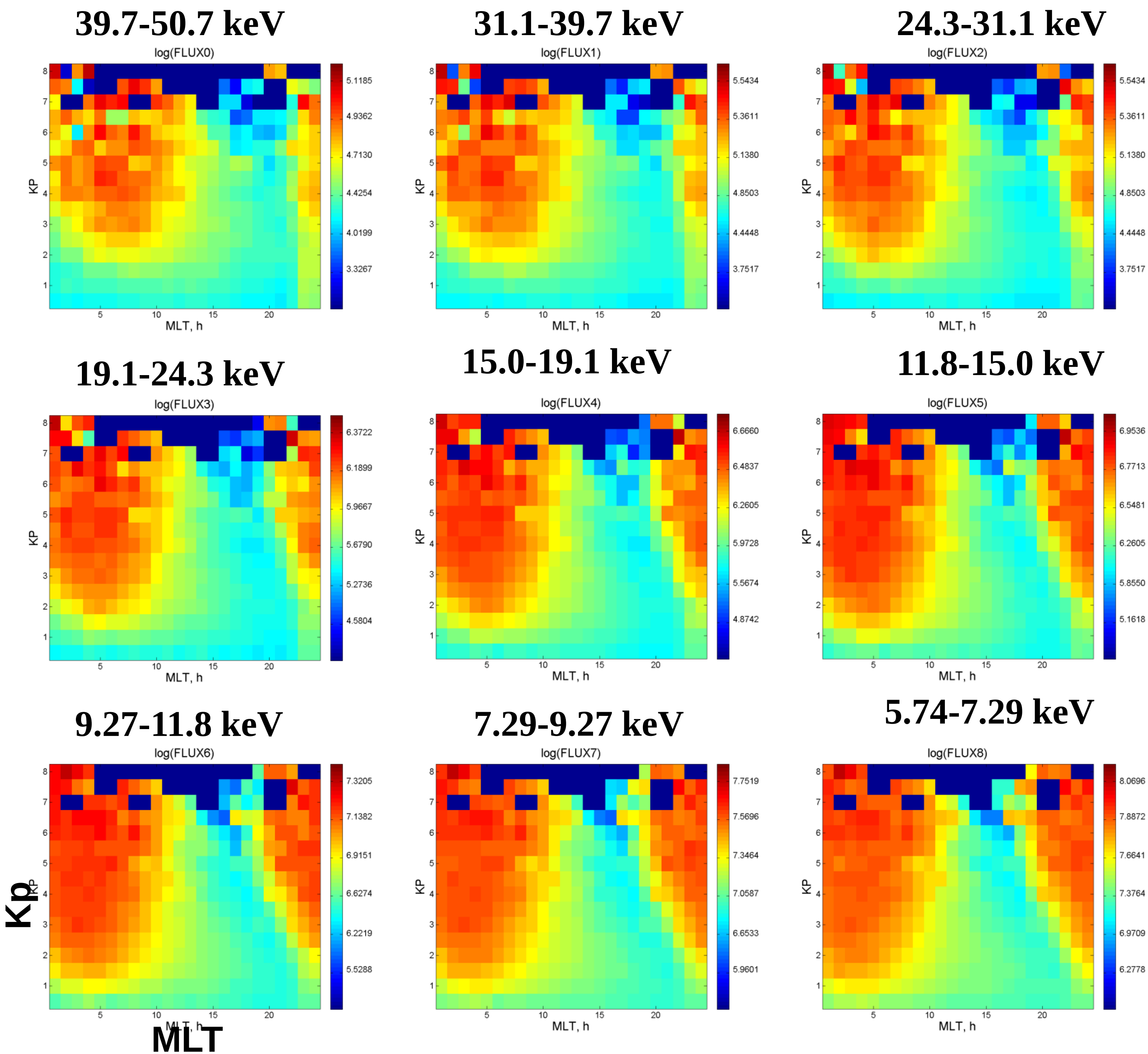
AMC12 electron data

- peaks in both 15-50 keV and 5-15 keV electron fluxes show clear correlation with AE peaks

- 2 orders of magnitude increase

- during quiet period before storm peaks with AE =500 nT similar to peaks with AE over 1000 nT at storm time

Log(flux)

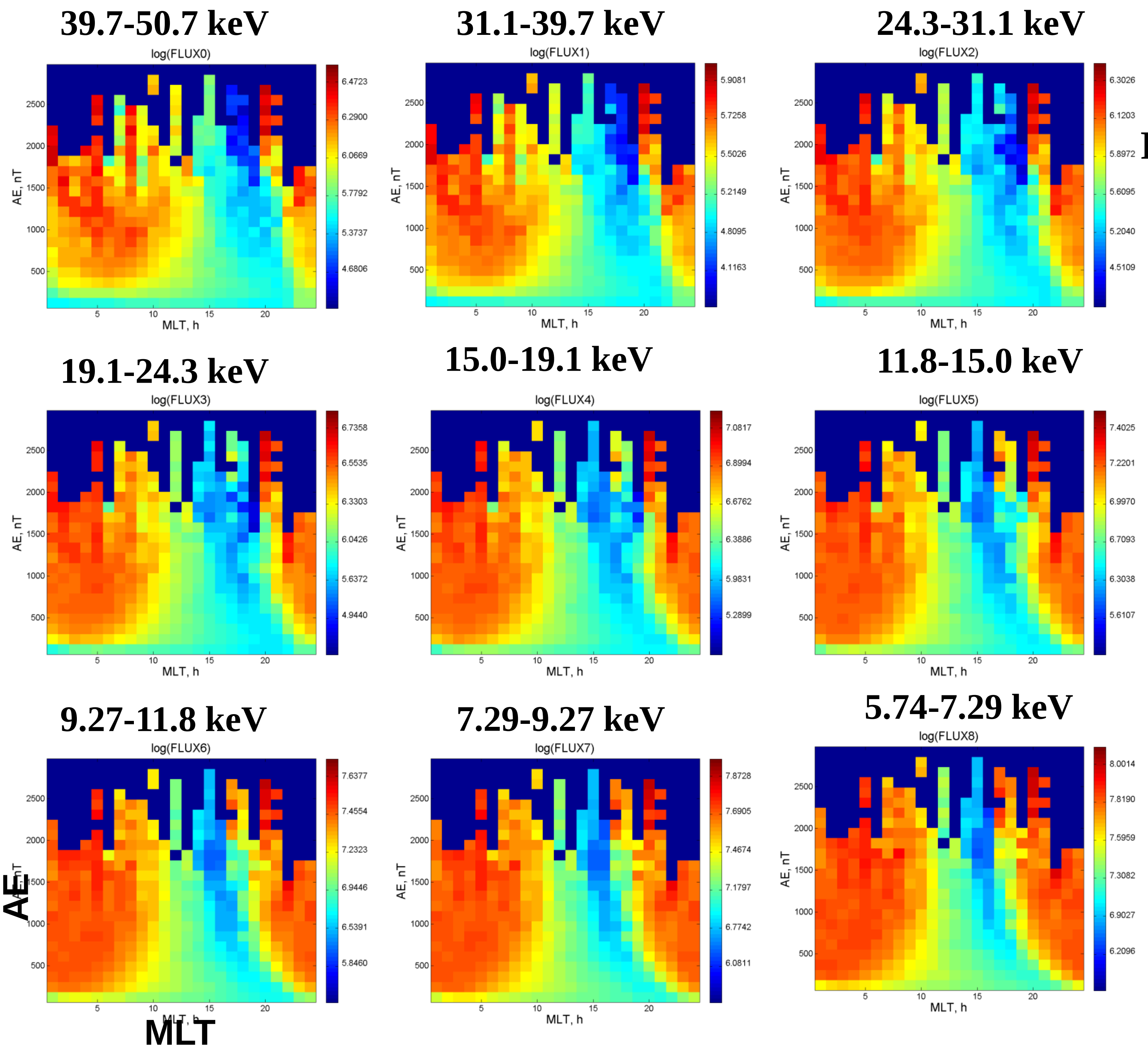


Flux(MLT, Kp)

Can we state that low energy electron fluxes are organized by Kp?

Kp:
3 hour index

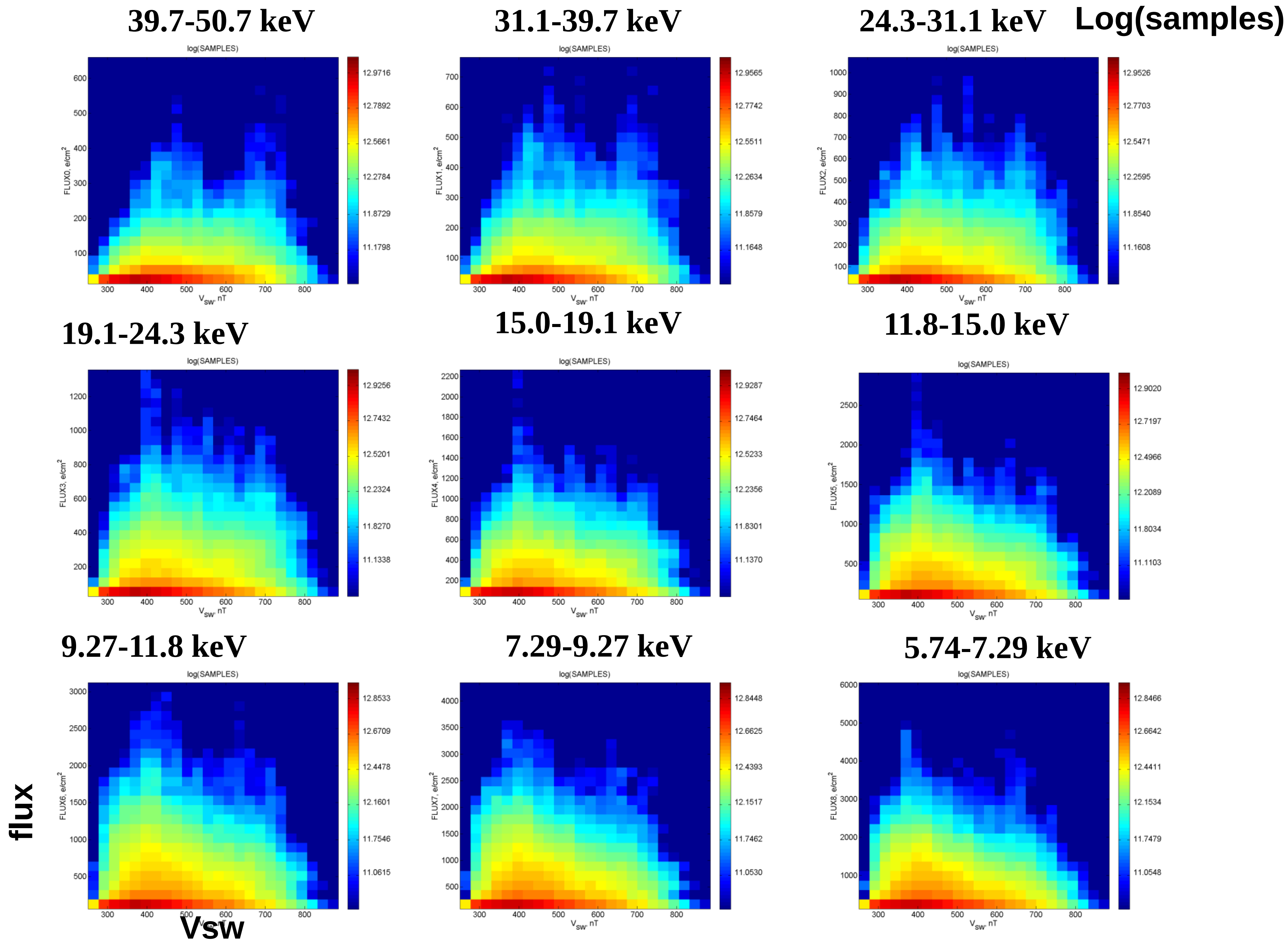
Log(flux)

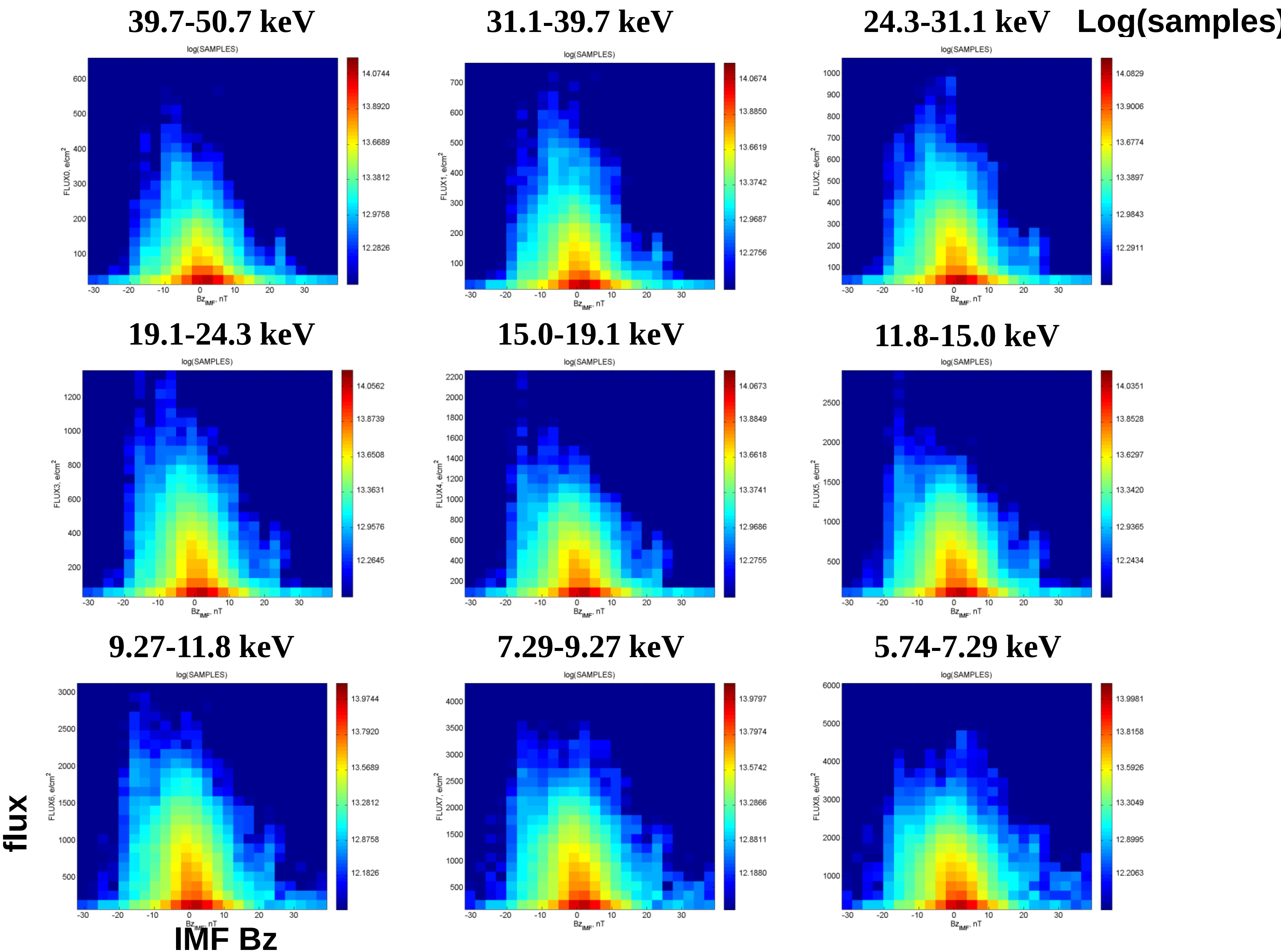


Flux(MLT, AE

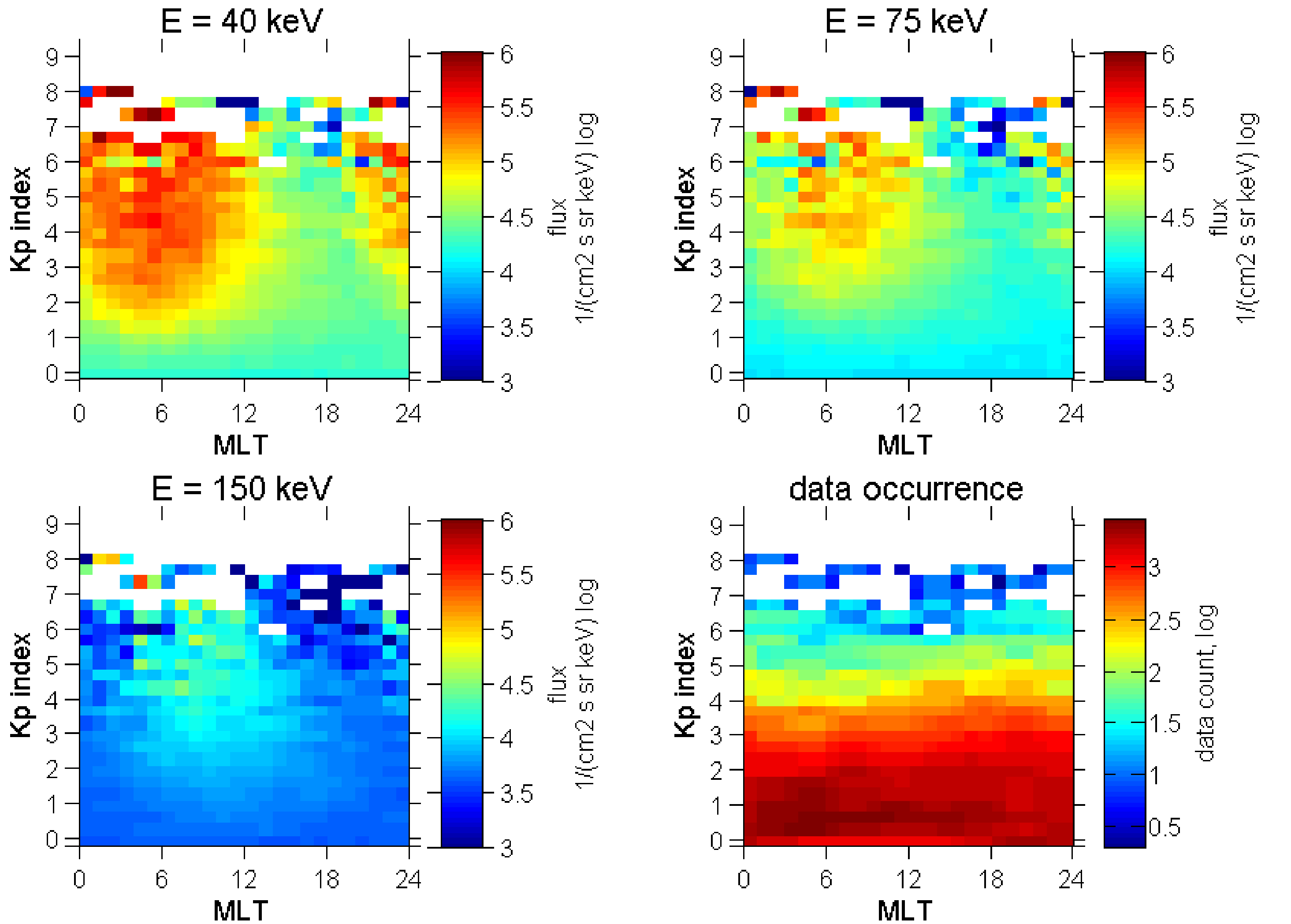
The higher the energy, the less distributed the flux peak

No distinct dependence on AE strength

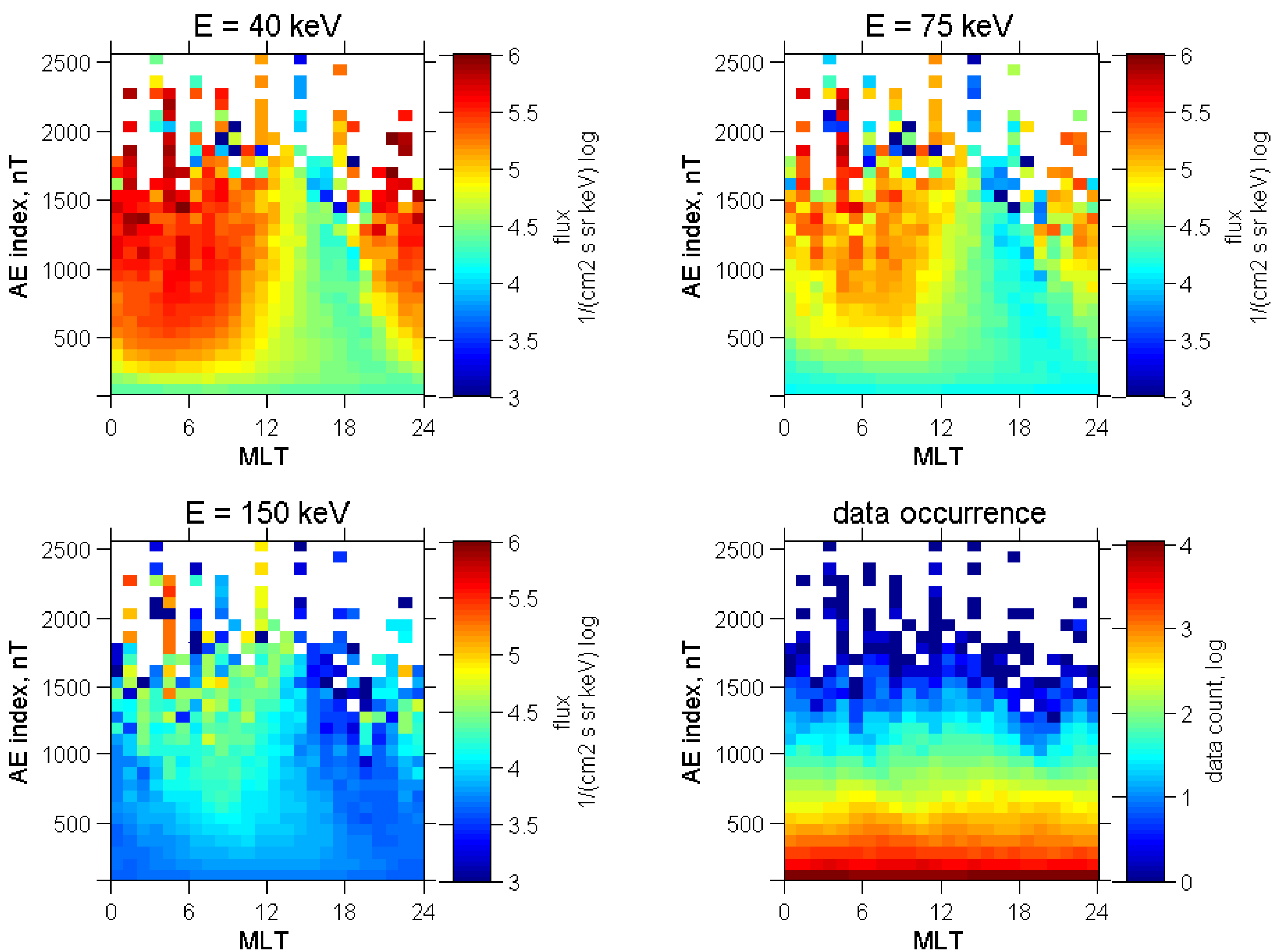

39.7-50.7 keV
31.1-39.7 keV
24.3-31.1 keV
Log(samples)
19.1-24.3 keV
15.0-19.1 keV
11.8-15.0 keV
9.27-11.8 keV
7.29-9.27 keV
5.74-7.29 keV
flux
Vsw


39.7-50.7 keV
31.1-39.7 keV
24.3-31.1 keV
Log(samples)
19.1-24.3 keV
15.0-19.1 keV
11.8-15.0 keV
9.27-11.8 keV
7.29-9.27 keV
5.74-7.29 keV
flux
IMF Bz

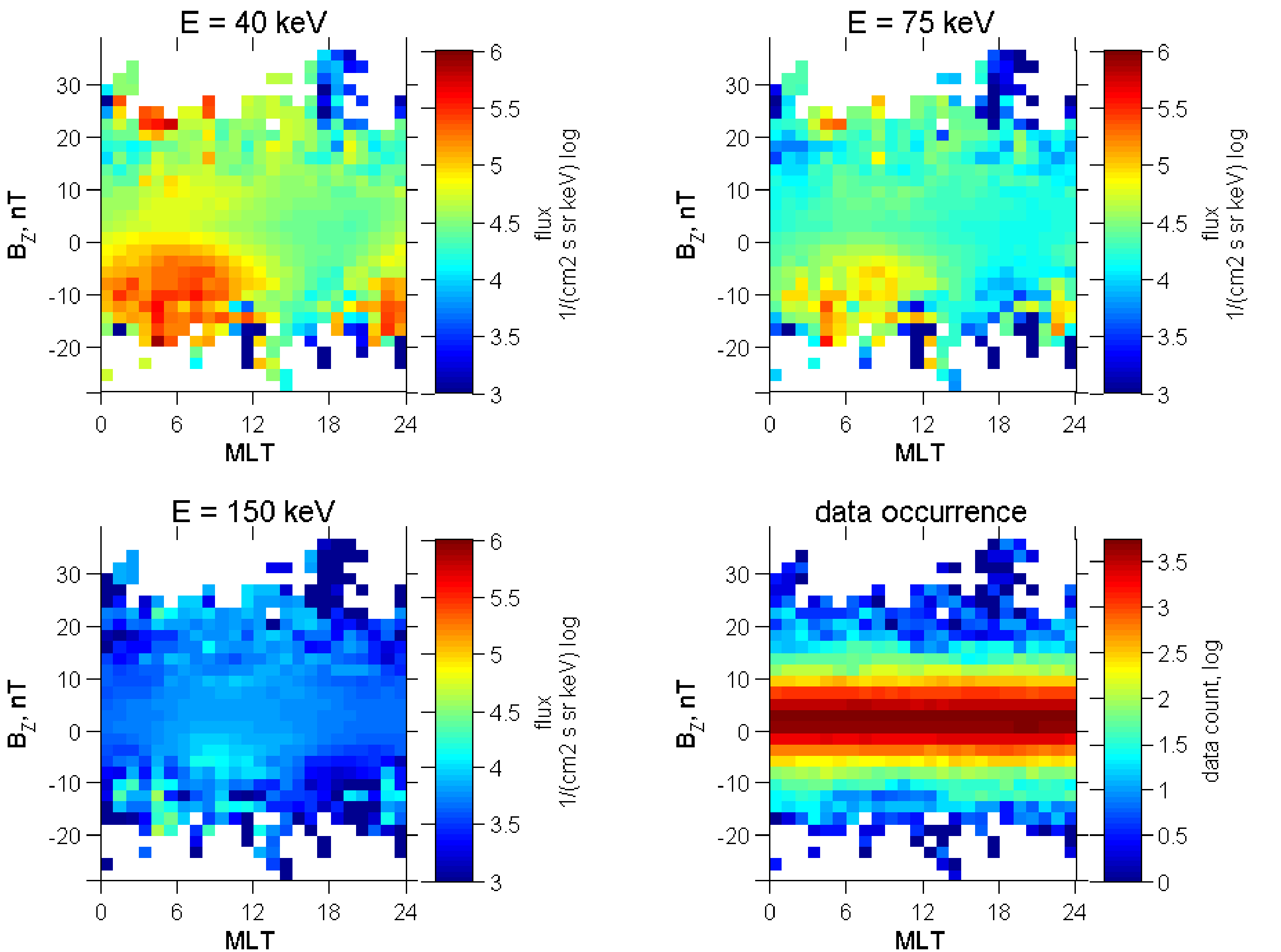
GOES 13 MAGED electron fluxes (MLT, Kp)



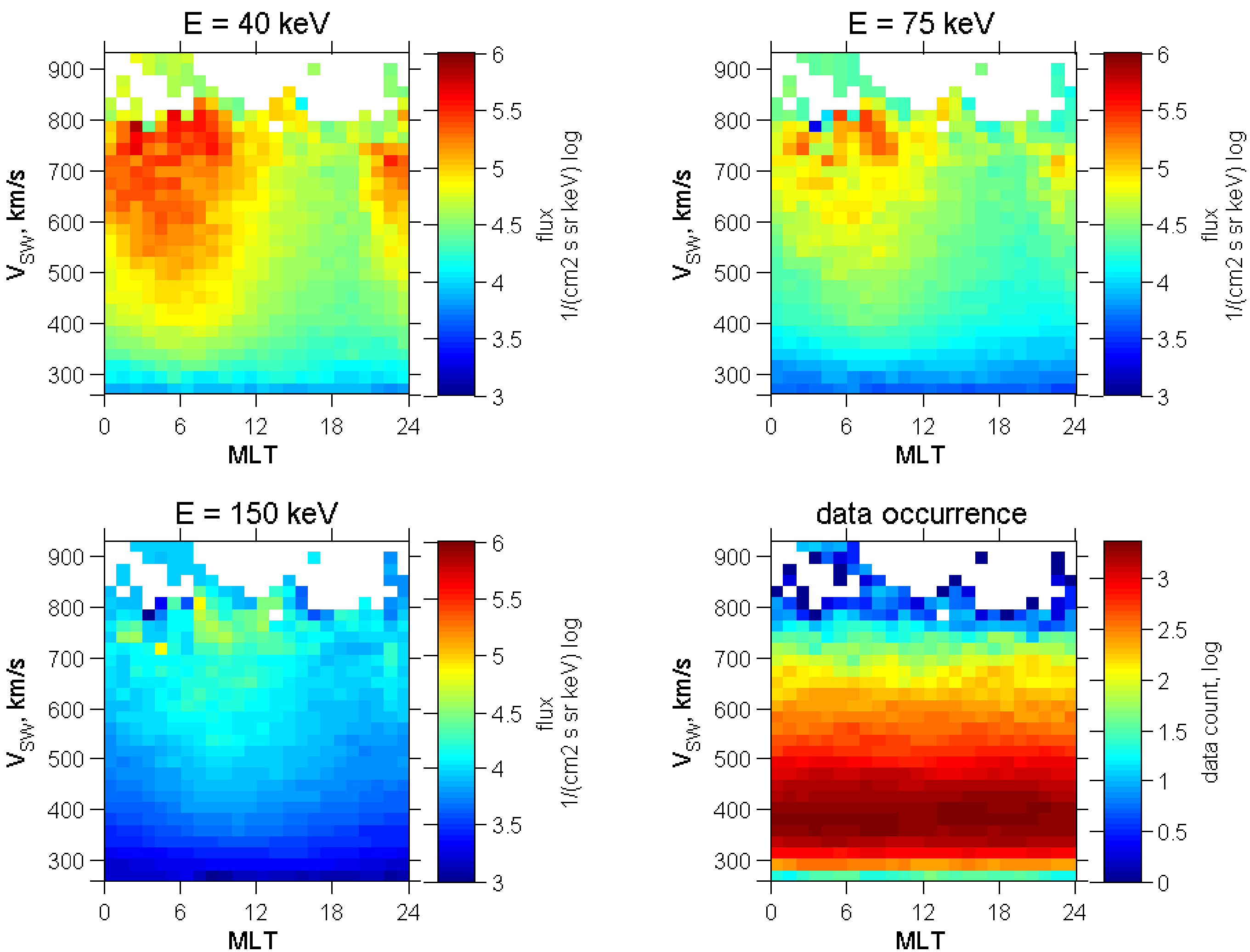
GOES 13 MAGED electron fluxes (MLT, AE)



GOES 13 MAGED electron fluxes (MLT, IMF Bz)



GOES 13 MAGED electron fluxes (MLT, Vsw)



GOES 13 MAGED electron fluxes, development of empirical model

$$q_{\mathrm{EMP}} = a1 \cdot 10^{V_{SW}} \cdot (a2 \cdot \mathrm{sMLT} + a3 \cdot \mathrm{cMLT} + a4) + b1 \cdot \exp\left(-\frac{|\mathrm{MLT} - b2|}{5} - (\frac{B_Z + 11}{6})^2\right) + c1 \quad (3)$$

Here

$$\mathrm{sMLT} = \sin(\frac{\pi}{12} \cdot \mathrm{MLT}) \quad (4)$$

$$\mathrm{cMLT} = \cos(\frac{\pi}{12} \cdot \mathrm{MLT}) \quad (5)$$

???

1. Electron (<200 keV) transport from the near-Earth plasma sheet to geostationary (inside) can not be modeled, even if particles move in IMF and SW dependent electromagnetic fields and boundary conditions, even during rather quiet times.

2. Need to include substorms. How?

3. Like electromagnetic pulse (great review given in Christine Gabrielse's talk)? What are the parameters? Most probably, not the amplitude. Location? MLT-width?

4. Do we need different representations for different types of substorms (isolated substorms, storm-time substorms?

5. Low energy electrons (at geostationary) are not organized by AE, KP-organization misses dynamics, IMF BZ and Vsw are main parameters. For specific events: See 1. Present IMF and SW dependent models fail to represent the observed peaks associated with substorm activity (?)