IMPTAM verification and validation on GOES MAGED data for long-term variations of electron fluxes at geostationary orbit

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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

13th European Space Weather Week, November 14-18, 2016, Oostende, Belgium

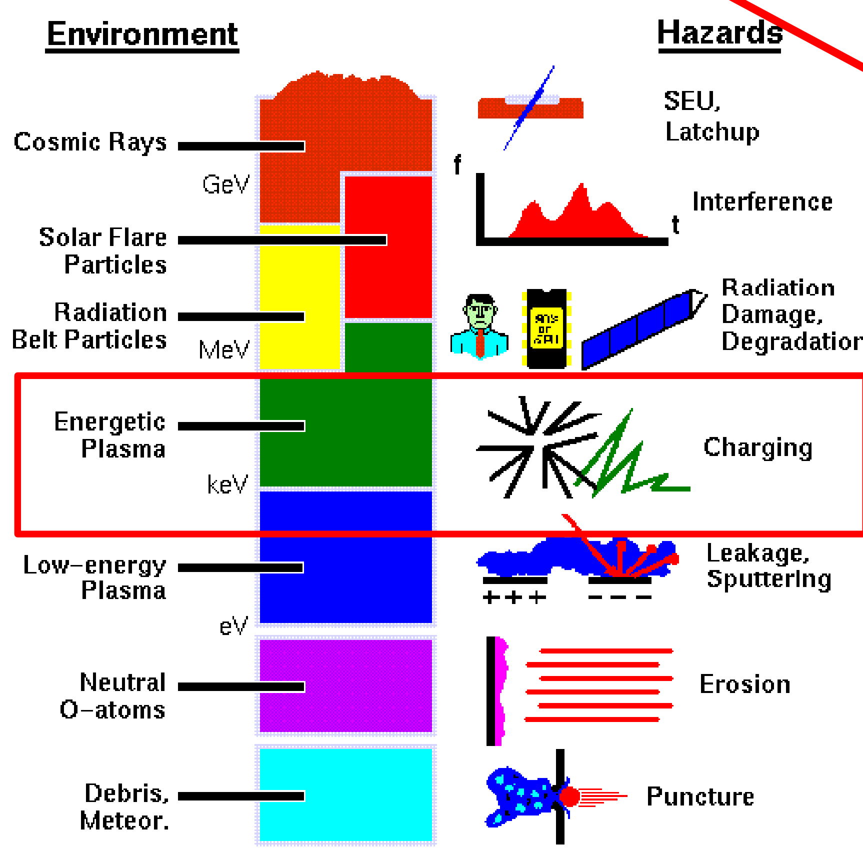
General definition of the effects of space weather

Where do the keV electrons come in?

Time-varying conditions in the space environment that may

- **be hazardous to technological systems in space or on ground**
- endanger human health or life

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



keV electrons for surface charging

Source: [European Space Agency, Space Environment and Effects Analysis Section]

Inner Magnetosphere Particle Transport and Acceleration Model (IMPTAM) for low energy electrons

(*Ganushkina et al., 2013, 2014, 2015*)

- traces **electrons** with arbitrary pitch angles from the plasma sheet to the inner L-shell regions with energies up to **300 keV** in time-dependent magnetic and electric fields

- traces a distribution of particles in the **drift approximation** under the conservation of the 1st and 2nd 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.

Near-real time IMPTAM model for low energy electrons (*Ganushkina et al., 2013, 2014, 2015*)

What do we present?

IMPTAM (Inner Magnetosphere Particle Transport and Acceleration model): nowcast model for low energy (< 200 keV) electrons in the near-Earth geospace, operating online at **http://fp7-spacecast.eu** and **imptam.fmi.fi**

Why this model is important?

Low energy electron fluxes are very important to specify when hazardous satellite **surface charging** phenomena are considered.

They constitute the low energy part of the seed population for the high energy MeV particles in the **radiation belts**

What does the model provide?

The presented model provides the low energy electron flux at all locations and at all satellite orbits, when necessary, in the near-Earth space.

What are the drivers of the model?

The model is driven by the real time solar wind and Interplanetary Magnetic Field parameters with 1 hour time shift for propagation to the Earth's magnetopause, and by the real time geomagnetic activity index Dst.

IMPTAM performance: Long-term variations of low energy electron fluxes: IMPTAM vs GOES 13

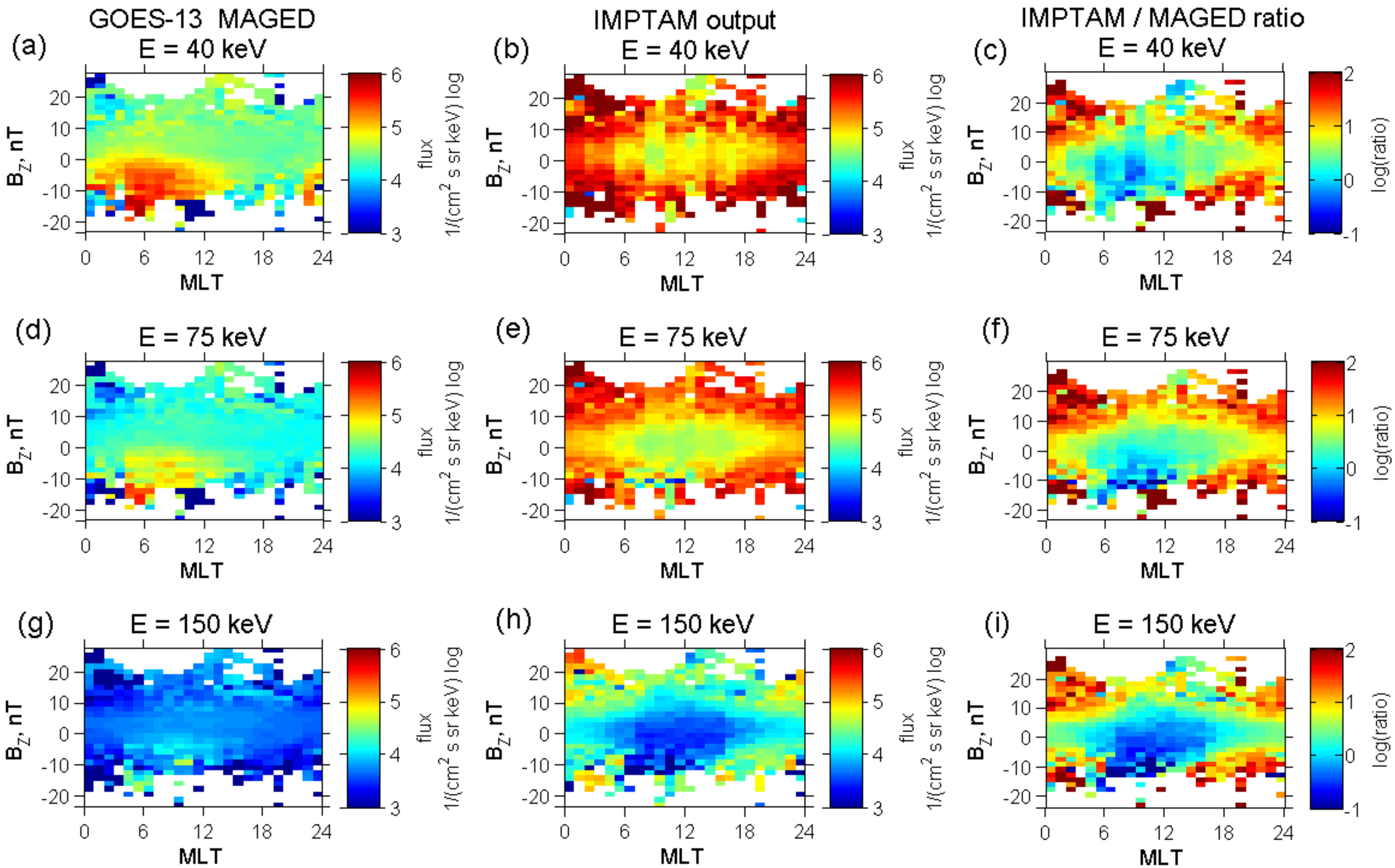
IMPTAM long-term output of omni-directional electron fluxes compared statistically to GEOS-13 MAGED fluxes for energies of 40, 75 and 150 keV.

GOES MAGED fluxes are the only available data on electrons with energies less than 200 keV which can be compared to IMPTAM output in near-real time.

Time period: September 2013 - March 2015.

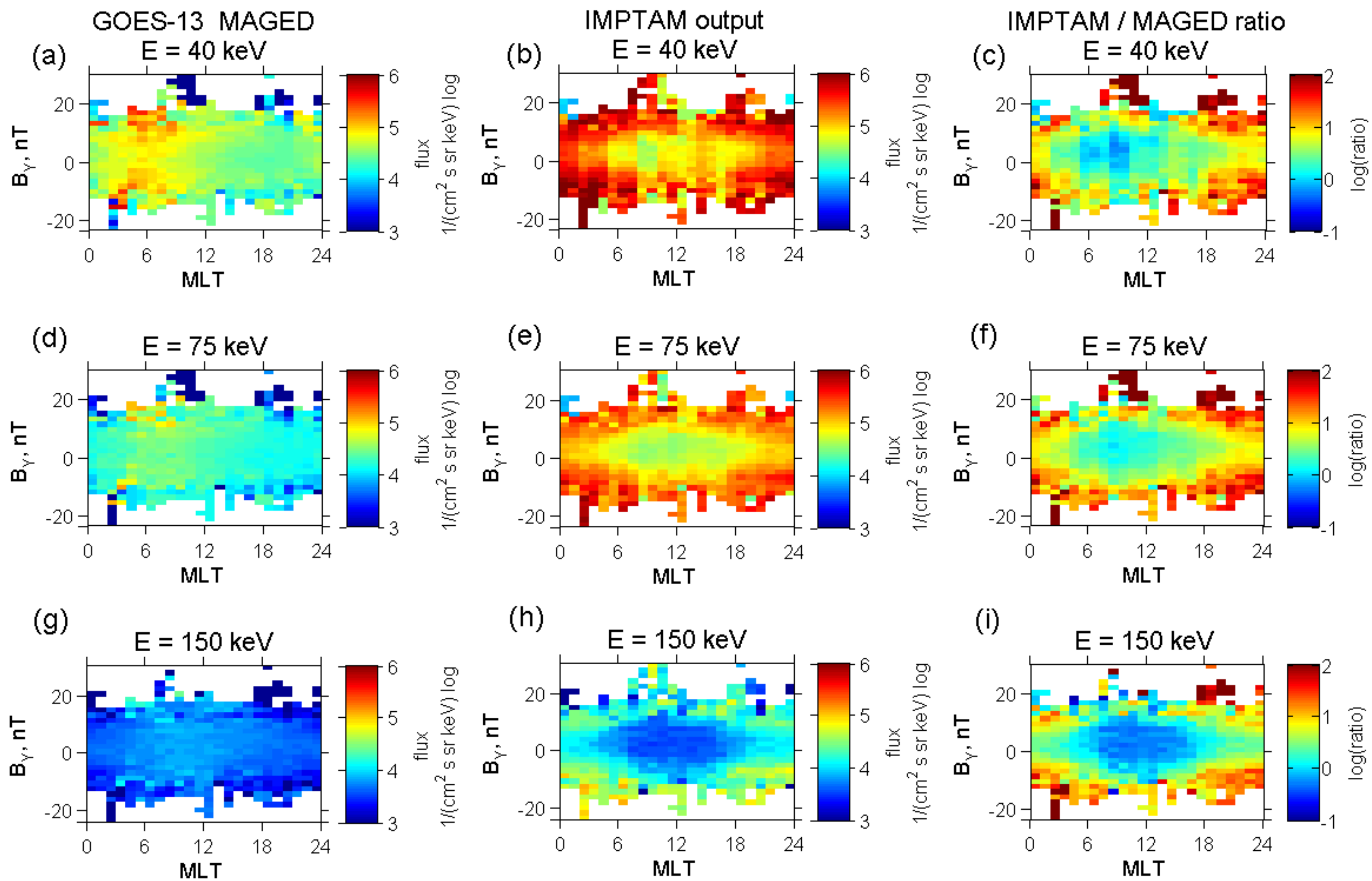
Magnetic field model: T96 (Dst, Psw, IMF By and Bz)
Electric field model: Boyle (Vsw, IMF B, By, Bz)
Boundary conditions: Tsyganenko and Mukai (Vsw, IMF Bz,Nsw)
Losses given as electron lifetimes: Kp, magnetic field
Strong diffusion (L=6-10): *Chen et al.* [2005]
Weak diffusion (L=2-6): *Shprits et al.* [2007]

IMPTAM vs GOES 13 MAGED: IMF Bz



Higher fluxes occupy larger MLT areas than observed. **Peak** shifted to **midnight.** Peak fluxes for IMF Bz < 0 at 00-12 MLT with maximum at 06 MLT are very closely reproduced: the ratio is close to 1 with no significant difference of orders of magnitude. High fluxes for **IMF Bz > 0** due to parameterization of electron lifetimes model.

IMPTAM vs GOES 13 MAGED: IMF By

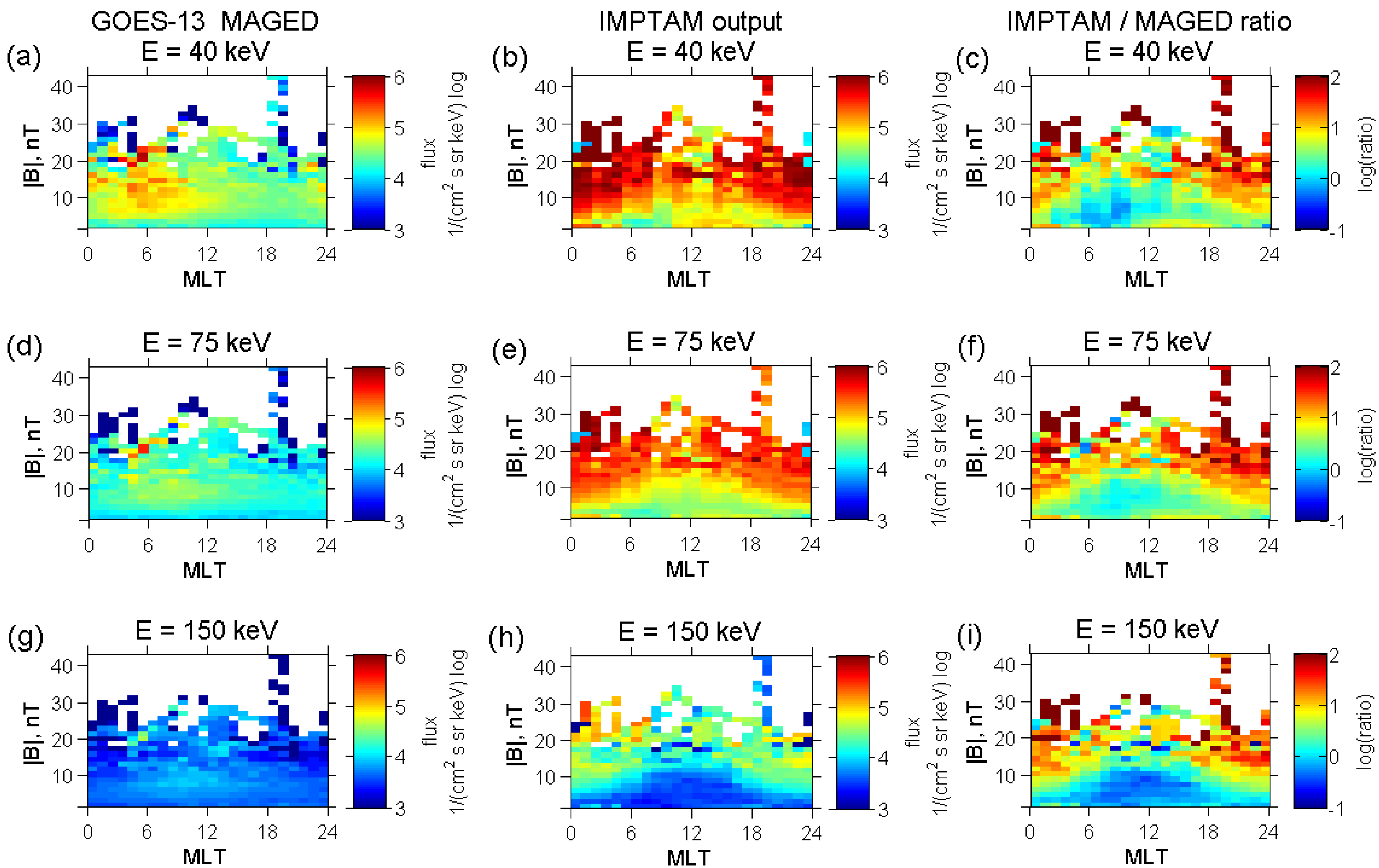


Higher fluxes occupy larger MLT areas than observed

Peak shifted to **midnight** instead of being at dawn as observed

BUT: Very **similar pattern, in general**

IMPTAM vs GOES 13 MAGED: IMF B

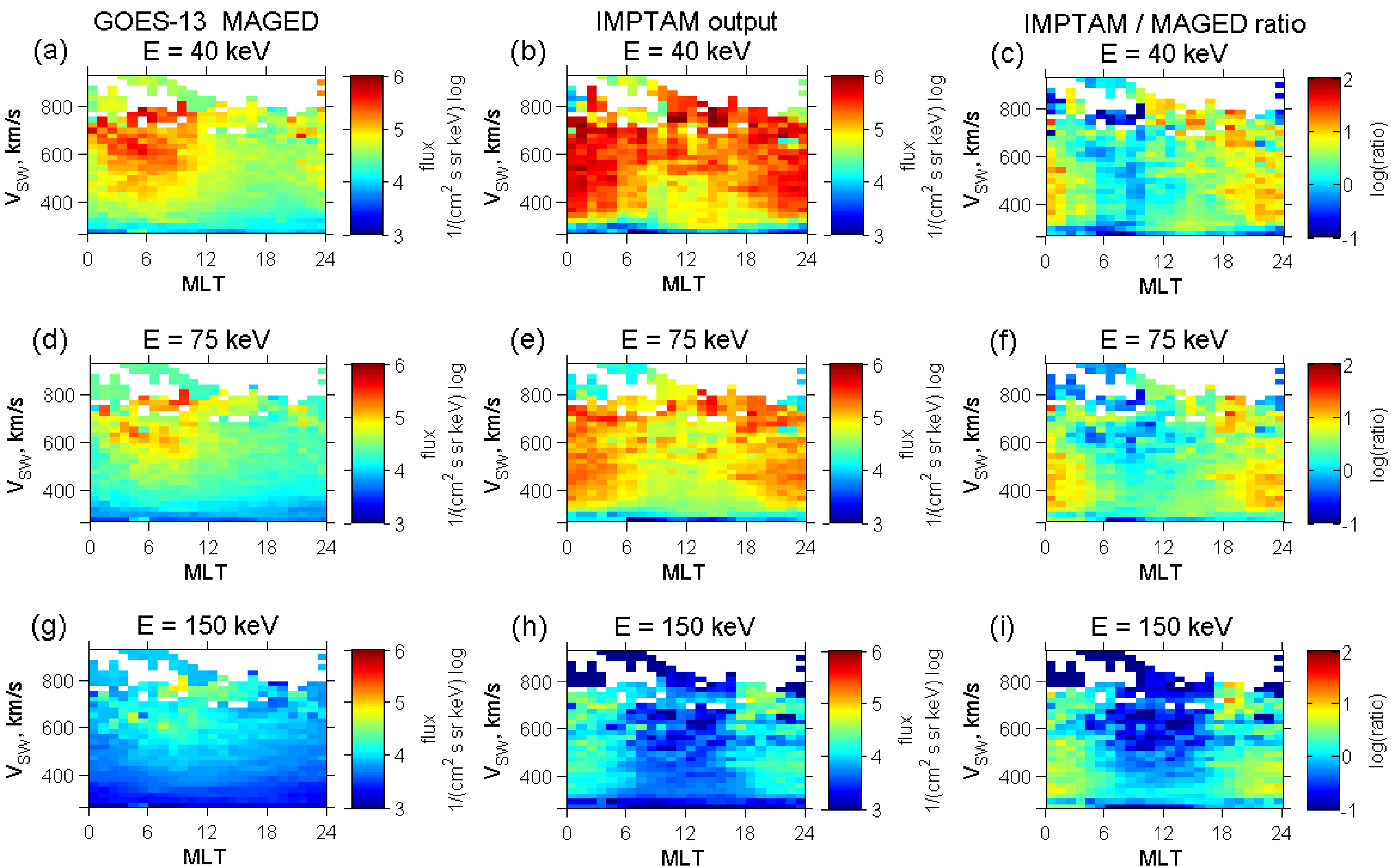


Higher fluxes occupy larger MLT areas than observed

Peak shifted to **midnight** instead of being at dawn as observed

BUT: Very **similar pattern, in general**

IMPTAM vs GOES 13 MAGED: Vsw

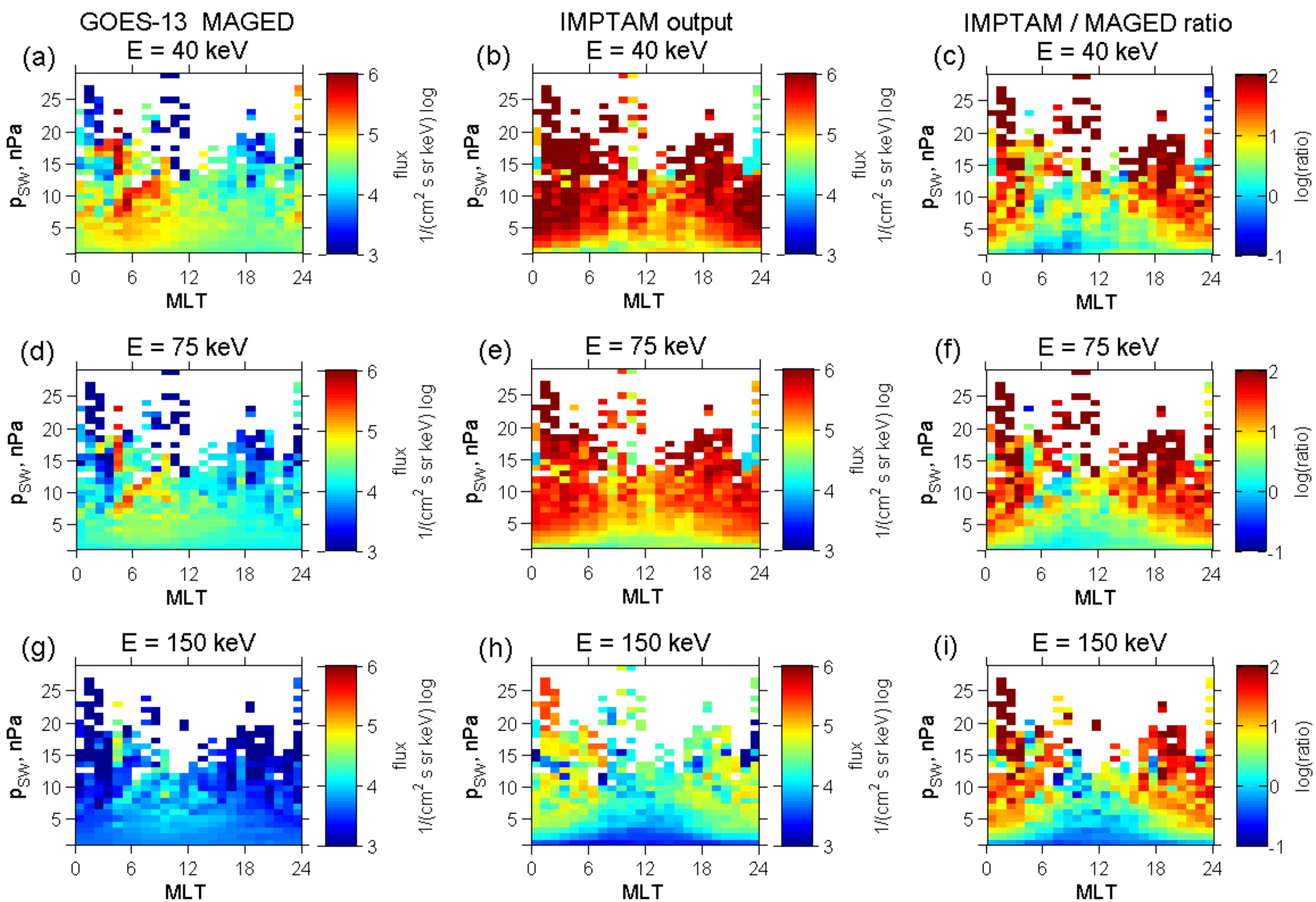


Higher fluxes occupy larger MLT areas than observed

Peak shifted to **midnight** instead of being at dawn as observed

BUT: Very **similar pattern, in general**

IMPTAM vs GOES 13 MAGED: Psw

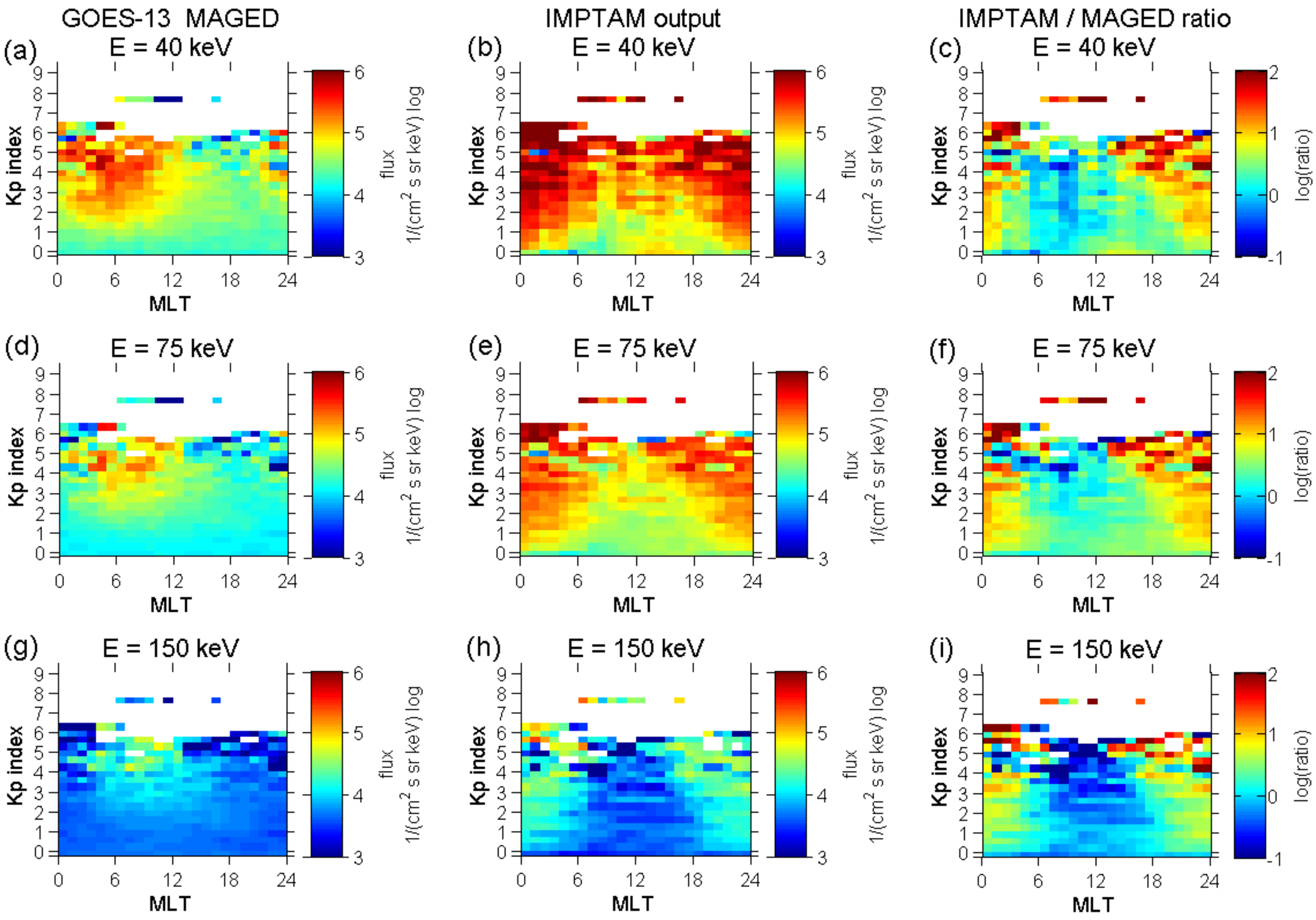


Higher fluxes occupy larger MLT areas than observed

Peak shifted to **midnight** instead of being at dawn as observed

High fluxes for **Large Psw** due to parameterization of models inside IMPTAM

IMPTAM vs GOES 13 MAGED: Kp

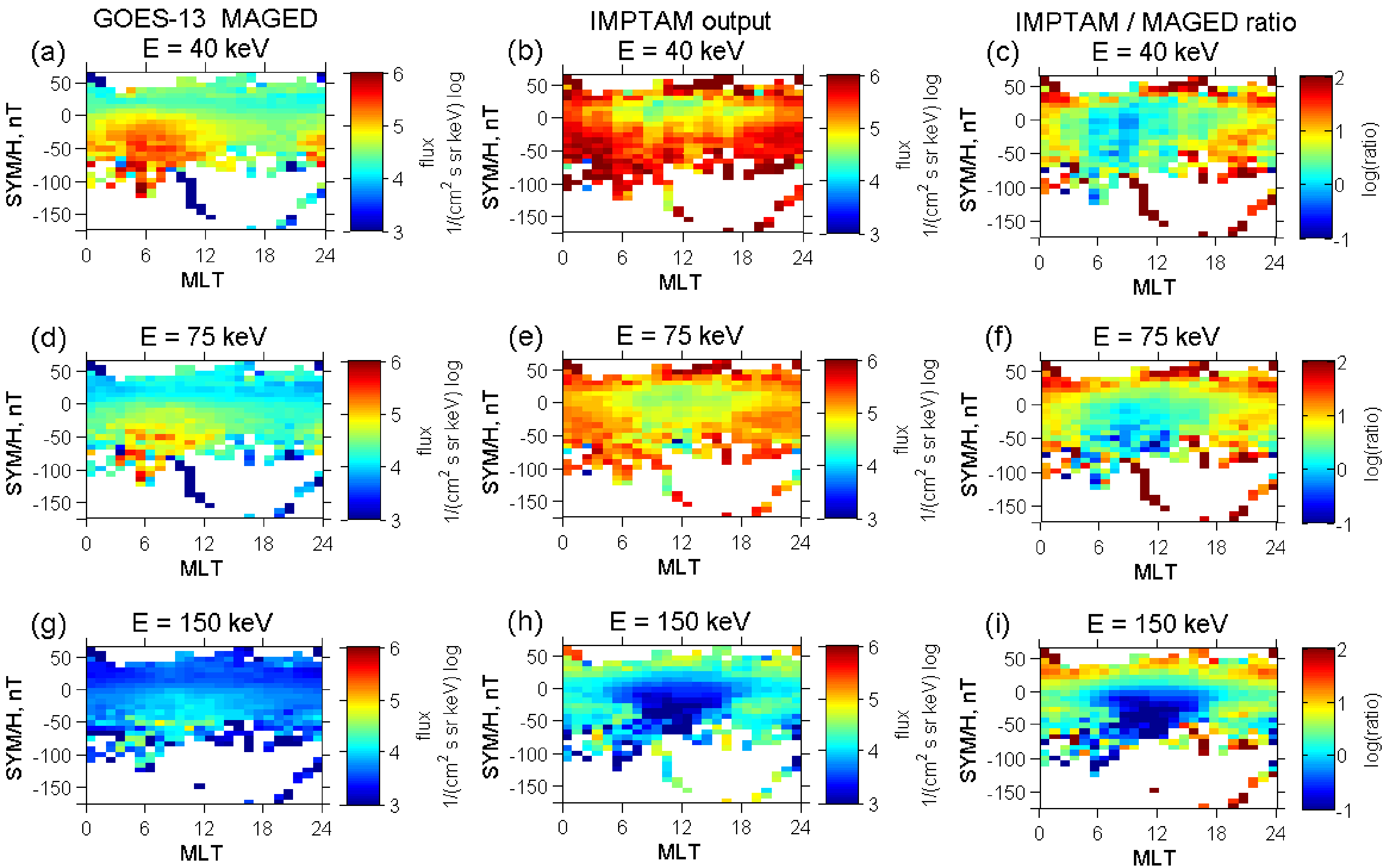


Higher fluxes occupy larger MLT areas than observed

Peak shifted to **midnight** instead of being at dawn as observed

BUT: Very **similar pattern, in general**

IMPTAM vs GOES 13 MAGED: SYM-H



Higher fluxes occupy larger MLT areas than observed

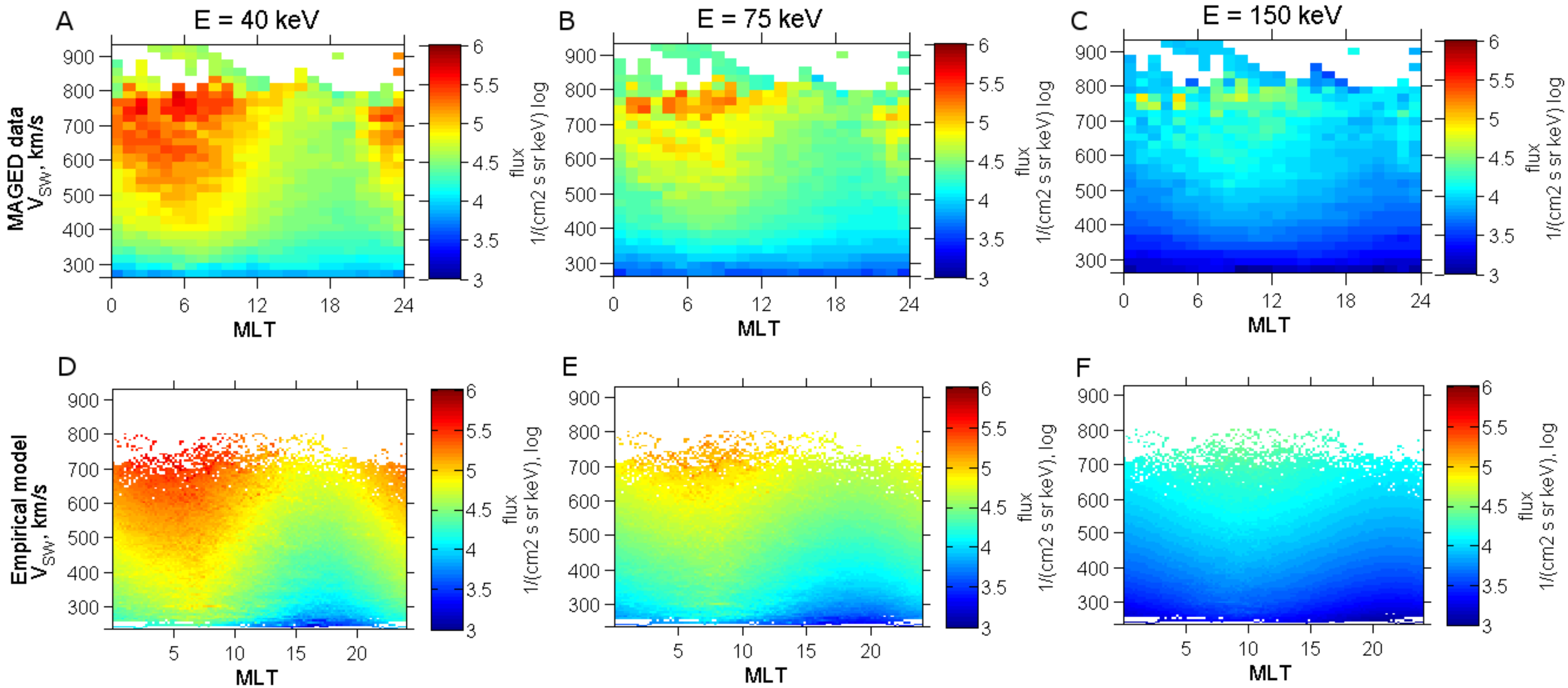
Peak shifted to **midnight** instead of being at dawn as observed

BUT: Very **similar pattern, in general**

Empirical model for 30-200 keV electrons for geostationary orbits

Based on GOES-13 MAGED data analysis
5 years of data 2011-2015

Dependent only on MLT, B_Z and V_{SW}
with 1.5h time lag for B_Z and V_{SW}



Empirical model for 30-200 keV electrons for geostationary orbits

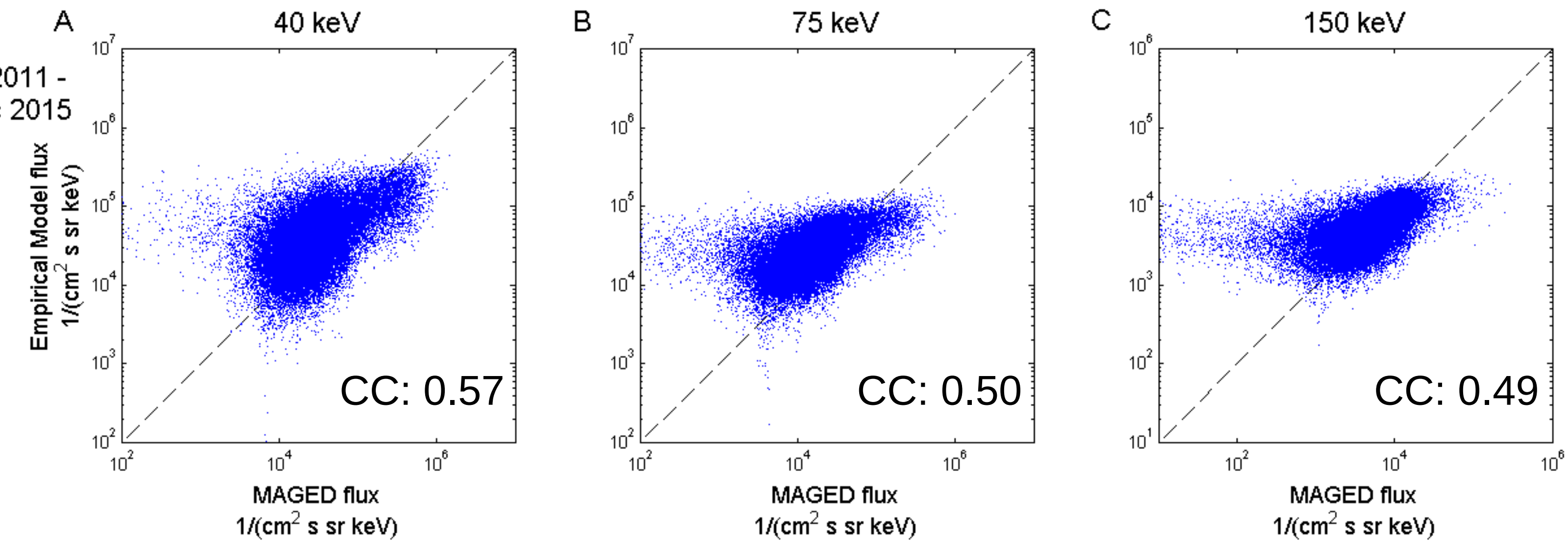
Dependent only on MLT, B_Z and V_{SW}
with 1.5h time lag for B_Z and V_{SW}

$$f_{\mathrm{EMP}} = a1 \cdot 10^{V_{SW}} \cdot (a2 \cdot \mathrm{sMLT} + a3 \cdot \mathrm{cMLT} + a4) + b1 \cdot \exp\left[-\frac{|\mathrm{MLT} - b2|}{b3} - \left(\frac{B_Z + 11}{8}\right)^3\right] + c1,$$

where

$$\mathrm{sMLT} = \sin\left(\frac{\pi}{12} \cdot \mathrm{MLT}\right)$$

$$\mathrm{cMLT} = \cos\left(\frac{\pi}{12} \cdot \mathrm{MLT}\right)$$



Summary

IMPTAM nowcast model for low-energy (< 200 keV) electrons in the inner magnetosphere operates online in near real time at http://fp7-spacecast.eu and imptam.fmi.fi.

Real-time geostationary GOES 13 or GOES 15 (whenever available) MAGED data on electron fluxes for three energies of 40, 75, and 150 keV are used for comparison and validation of IMPTAM in statistical sense by dependencies on IMF and SW parameters and activity indices.

Notes on model performance:

On average, the model provides reasonable agreement with the data, the basic level of the observed fluxes is reproduced.

For all dependencies: Higher fluxes occupy larger MLT areas than observed;

Peak shifted to **midnight** instead of being at dawn as observed;

Presence of high fluxes in contrast to observations due to parameterization of models in IMPTAM

BUT: Very **similar patterns, in general**