Low energy electrons in the inner Earth's magnetosphere

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Why are we interested in low energy electrons (< 200 keV) in the inner magnetosphere?

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

- 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.

- 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 challenging to nowcast and forecast low energy electrons

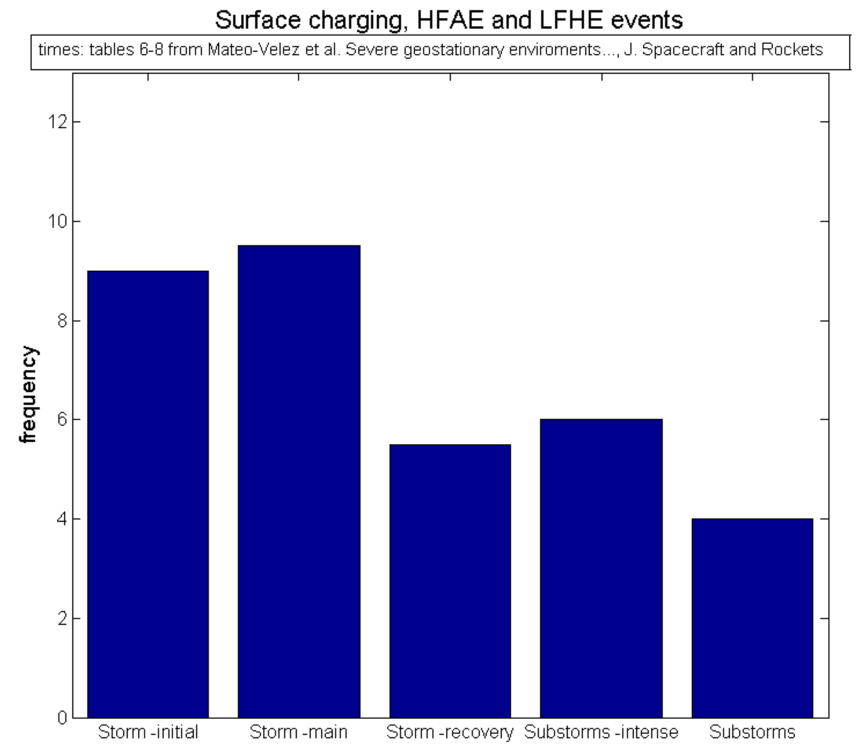
It is **NOT necessary to have even a moderate storm for significant surface charging** event to happen

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

No averaging over an hour/day/orbit!

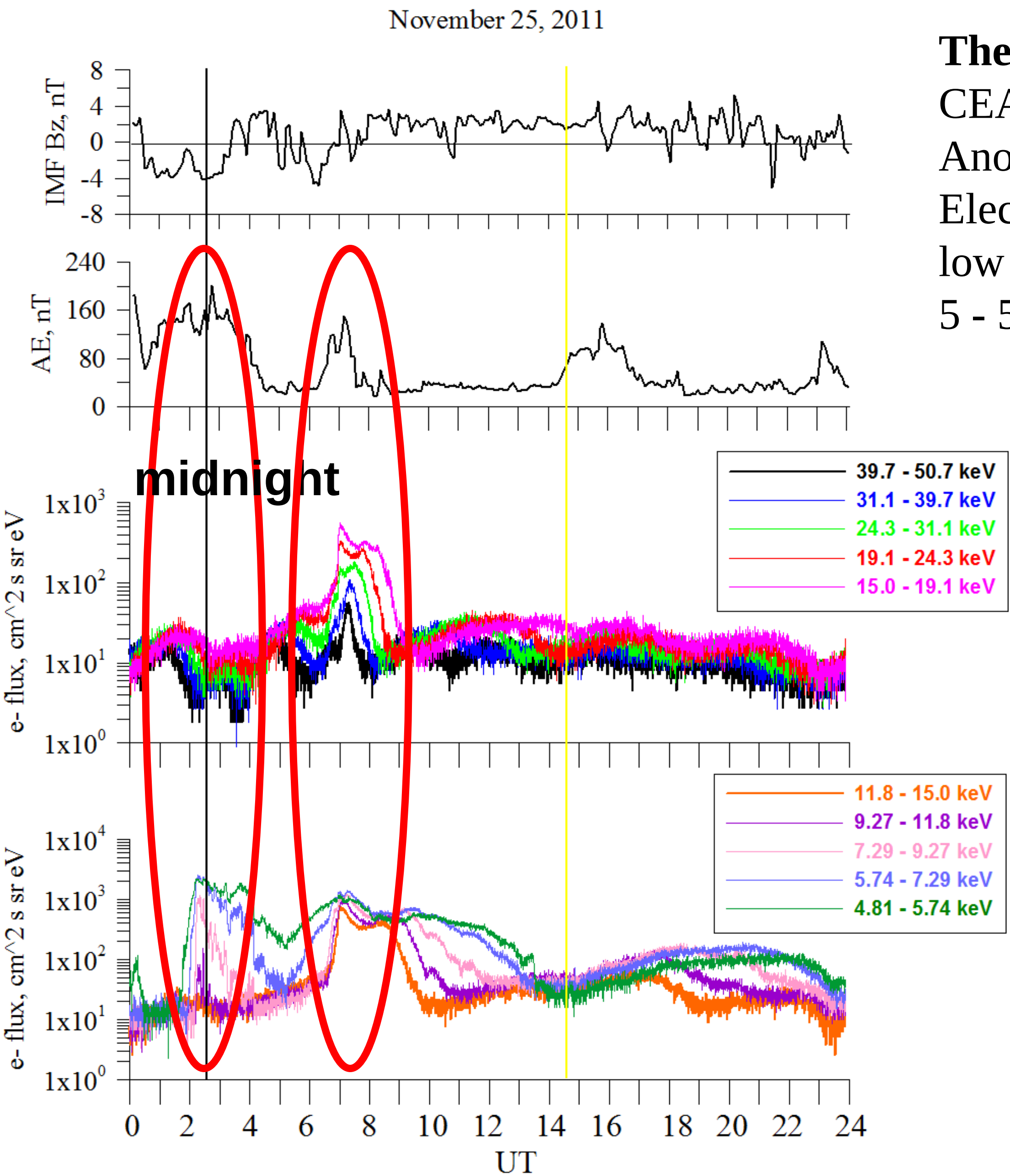
Correct models for electromagnetic fields, boundary conditions, losses are extremely hard to develop

Surface charging events vs. geomagnetic conditions



Matéo Vélez et al., Severe geostationary environments: from flight data to numerical estimation of spacecraft surface charging, *Journal of Spacecraft and Rockets, submitted, 2015*

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.

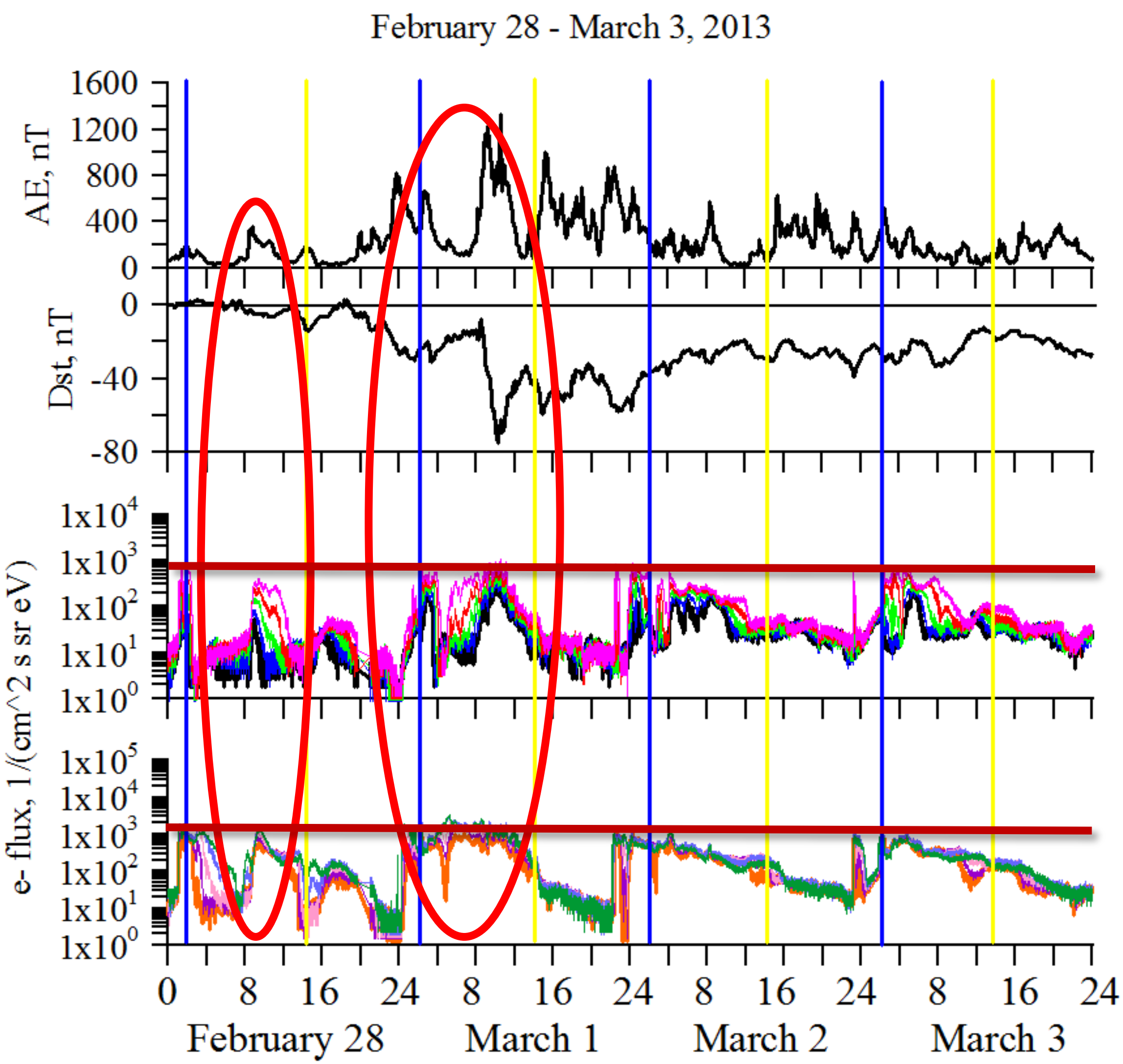
- **Flux increases** are related to **AE peaks** only (less than 200 nT, small, isolated substorms)

- 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

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



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

AMC12 electron data

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

- 2 orders of magnitude increase

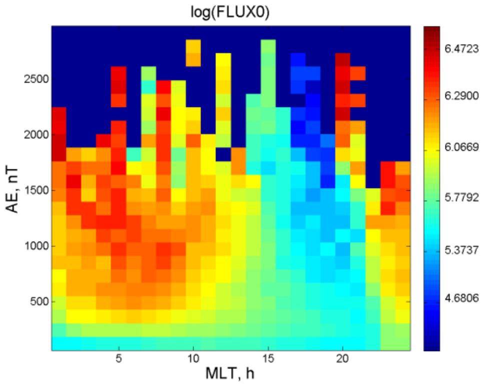
- all energies increase at midnight, when AE is only 200 nT

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

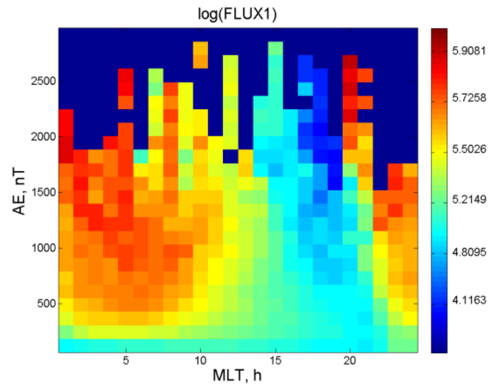
Log(flux)

Flux(MLT, AE)

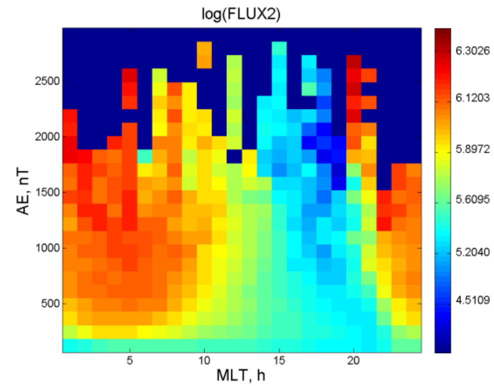
39.7-50.7 keV



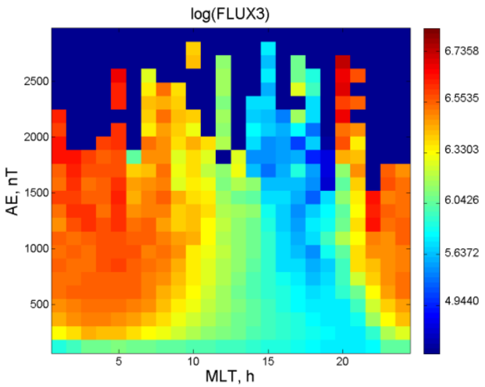
31.1-39.7 keV



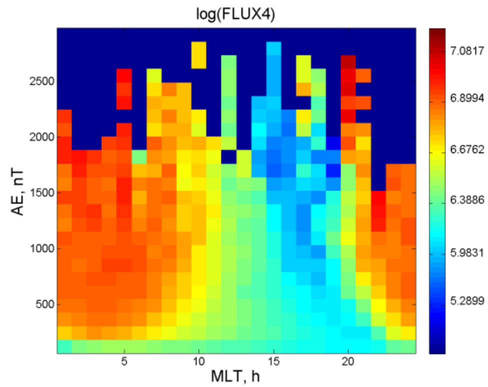
24.3-31.1 keV



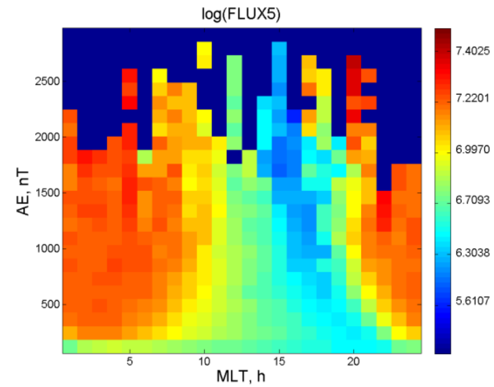
19.1-24.3 keV



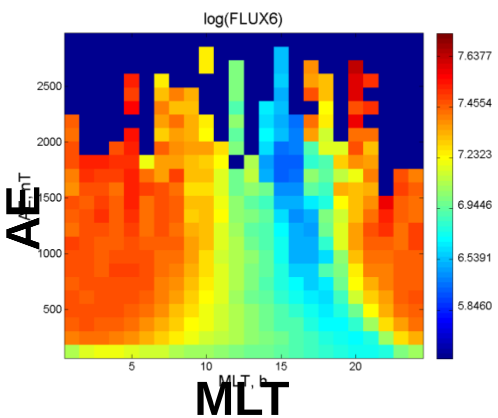
15.0-19.1 keV



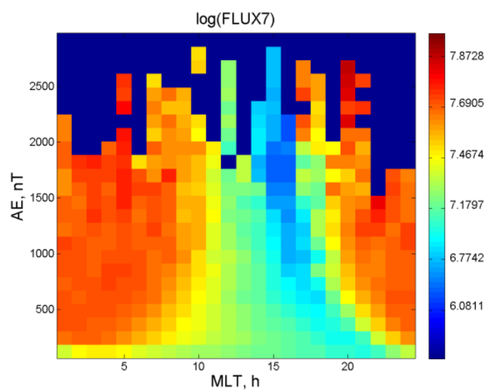
11.8-15.0 keV



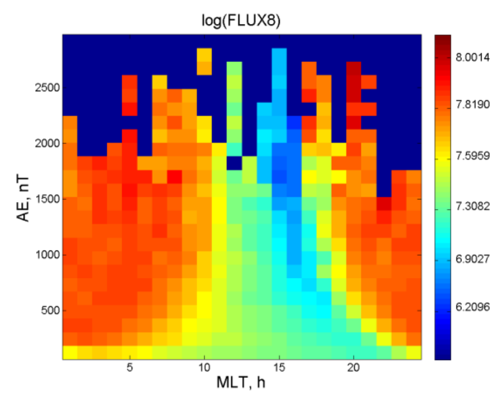
9.27-11.8 keV



7.29-9.27 keV



5.74-7.29 keV

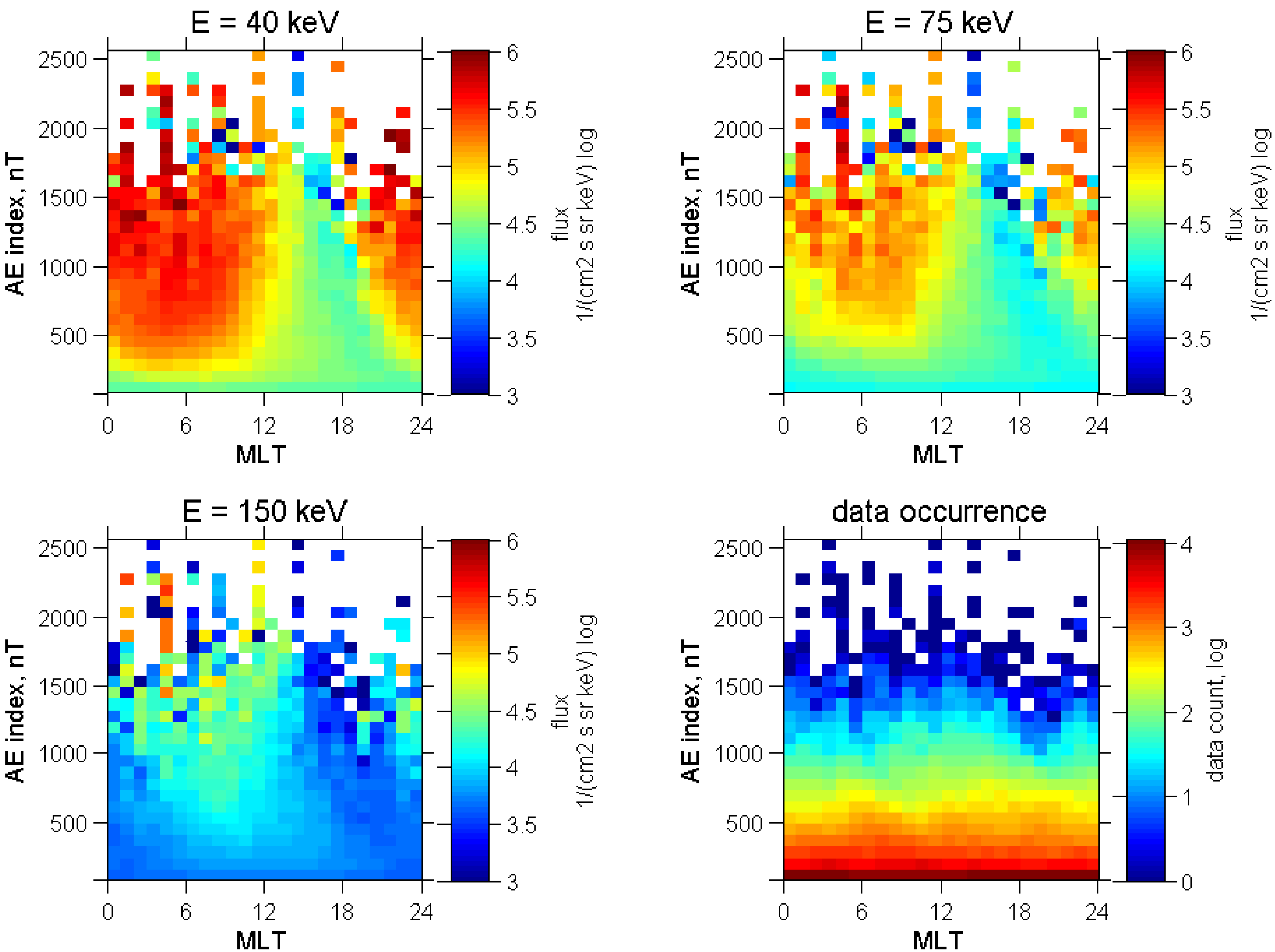


AMC 12 CEASE-II ESA data, 2010-2014

The higher the energy, the less distributed the flux peak

No distinct dependence on AE strength

GOES 13 MAGED electron fluxes (MLT, AE) 2011-2015



No distinct dependence of electron fluxes on AE strength

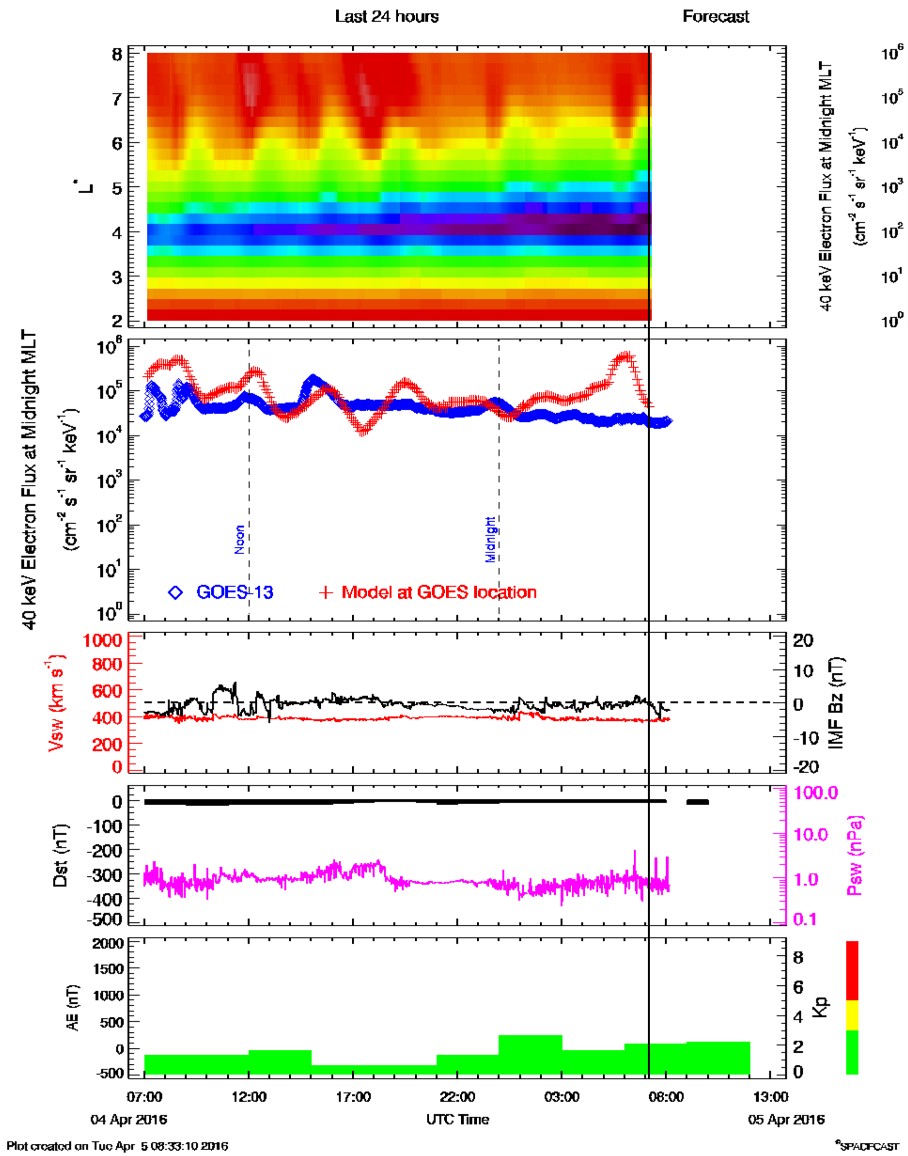
Inner Magnetosphere Particle Transport and Acceleration Model (IMPTAM) for low energy electrons

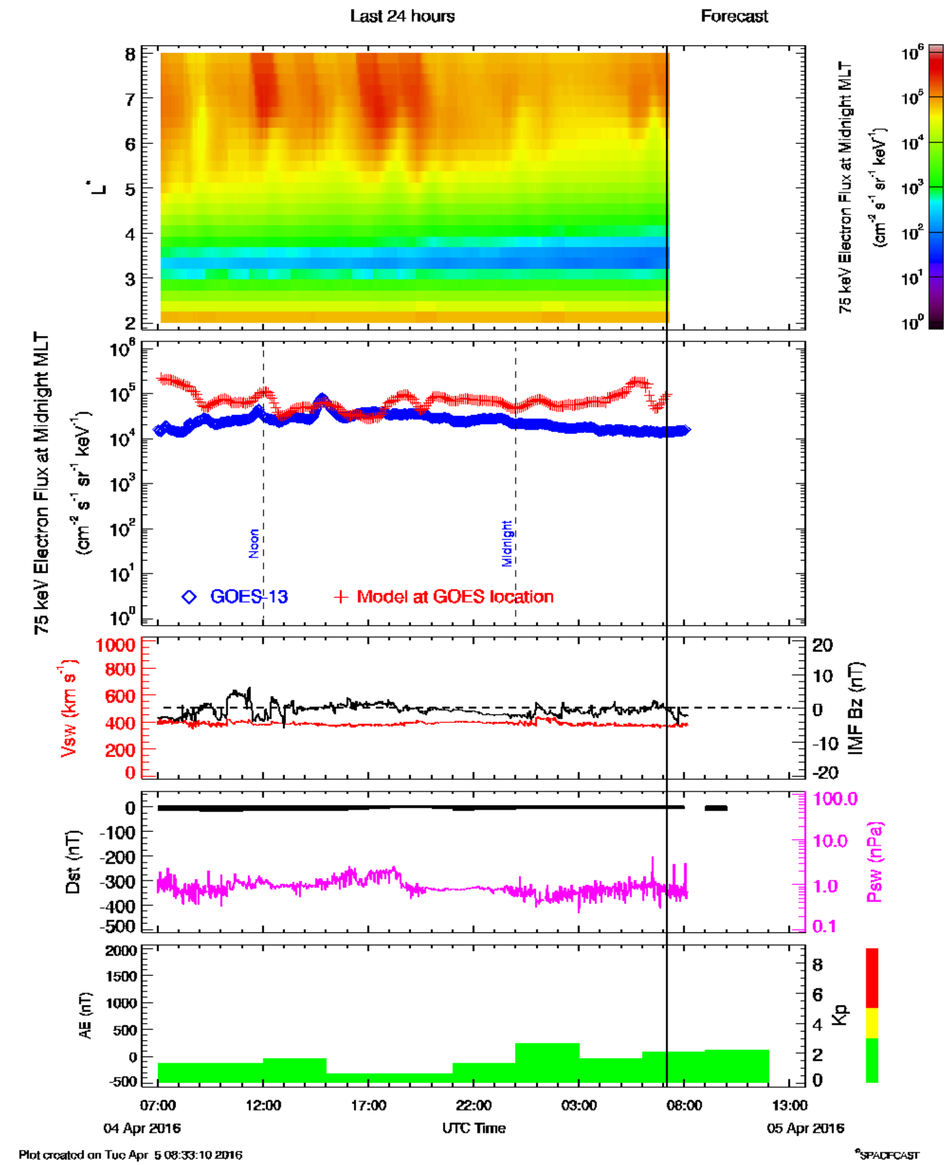
(*Ganushkina et al., 2013, 2014, 2015*)

- 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 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.

Run online in real time: http://fp7-spacecast.eu, imptam.fmi.fi, http://csem.engin.umich.edu/tools/imptam/

Current IMPTAM output compared to GOES MAGED 40 and 75 keV electron fluxes





Recent advances in IMPTAM for electrons

In order to follow the evolution of the particle **distribution function** f and particle **fluxes** in the inner magnetosphere dependent on the **position, time, energy, and pitch angl**e , it is necessary to specify:

(1) **particle distribution** at initial time **at the model boundary**;
Model boundary at 10 *Re* with kappa electron distribution function. Parameters are the number density *n* and temperature *T* in the plasma sheet given by **the new empirical model** at L=6-11 dependent on solar wind and IMF parameters **constructed using THEMIS** ESA (eV-30 keV) and SST (25 keV – 10 MeV) data during 2007-2013.

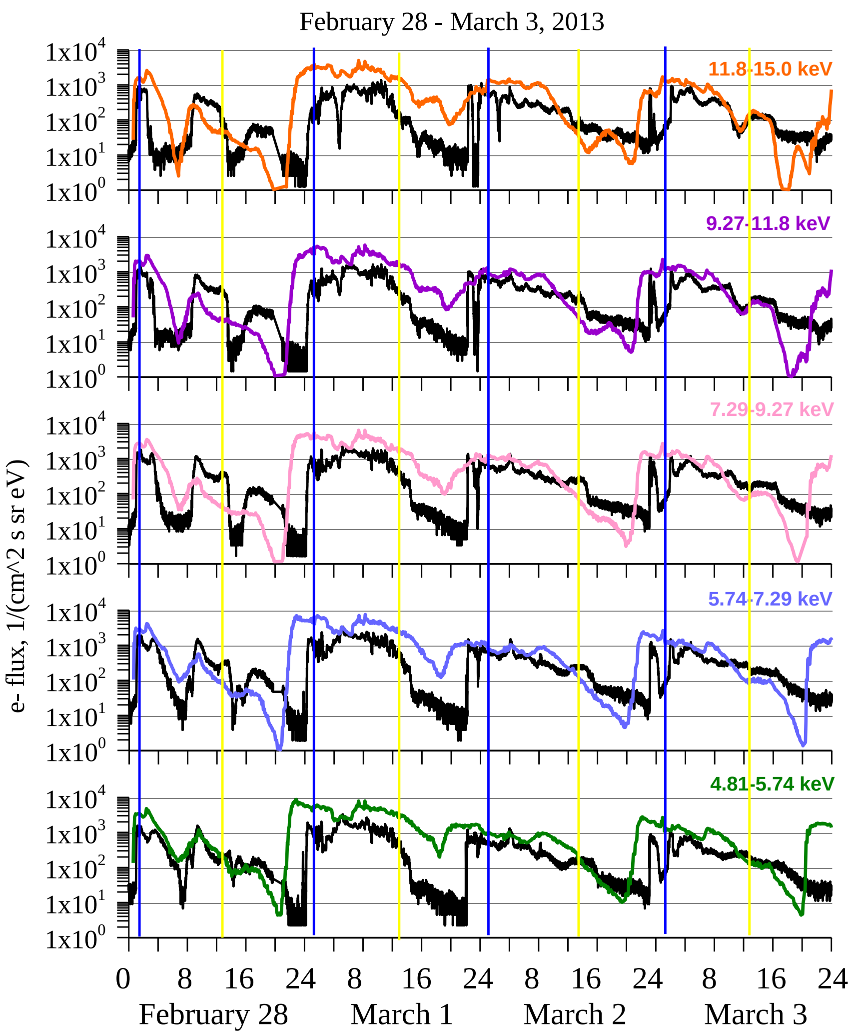
(2) magnetic and electric fields everywhere dependent on time;
The **magnetic field model is Tsyganenko T96 model** [*Tsyganenko*, 1995] with Dst index, solar wind pressure P_{SW}, and IMF B_Y and B_Z as input parameters. The **electric field** is determined using the solar wind speed V_{SW}, the IMF strength B_{IMF} and its components B_Y and B_Z (via IMF clock angle θ_{IMF}) being the ***Boyle et al*. [1997] ionospheric potential**.

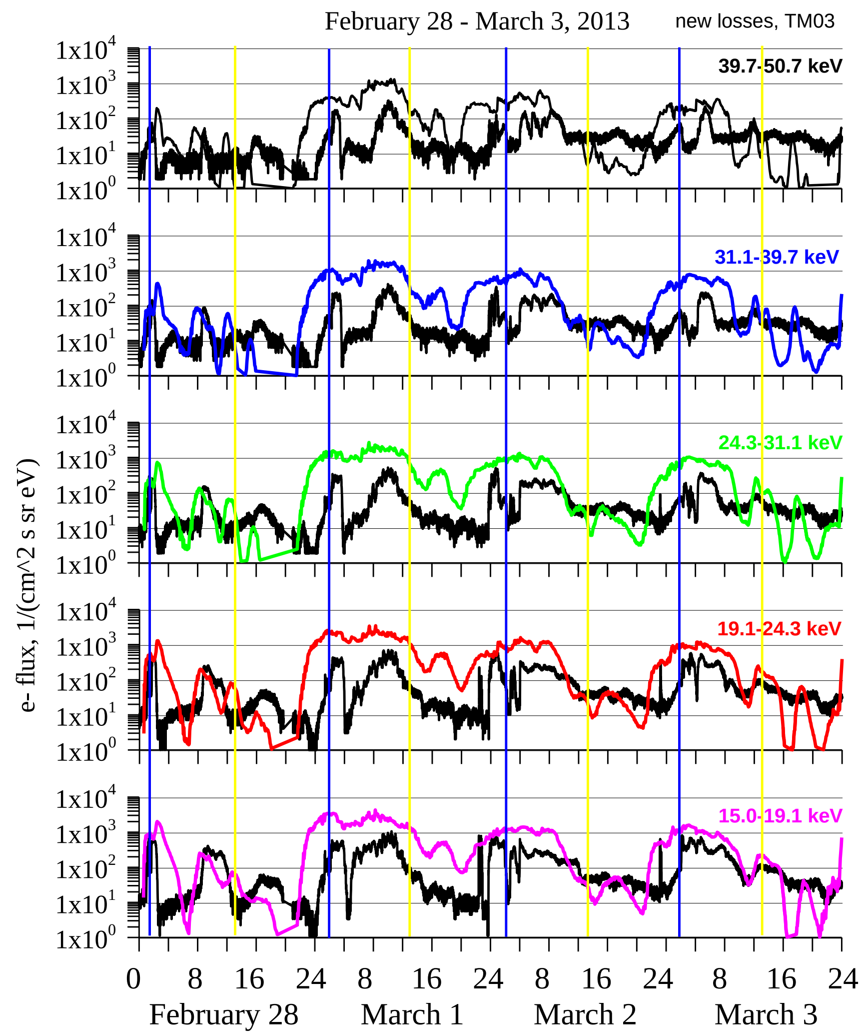
(3) drift velocities;

(4) all sources and **losses of particles**.
Most recent and advanced parameterization of the **electron lifetimes** due to interactions with chorus and hiss waves obtained by *Orlova and Shprits* [2014] and *Orlova et al*. [2014].

Electron fluxes observed by AMC 12 CEASE II ESA instrument for 15-50 keV energies and modeled

With **THEMIS** model and ***Orlova and Shprits* [2014] and *Orlova et al.* [2014]** electron lifetimes

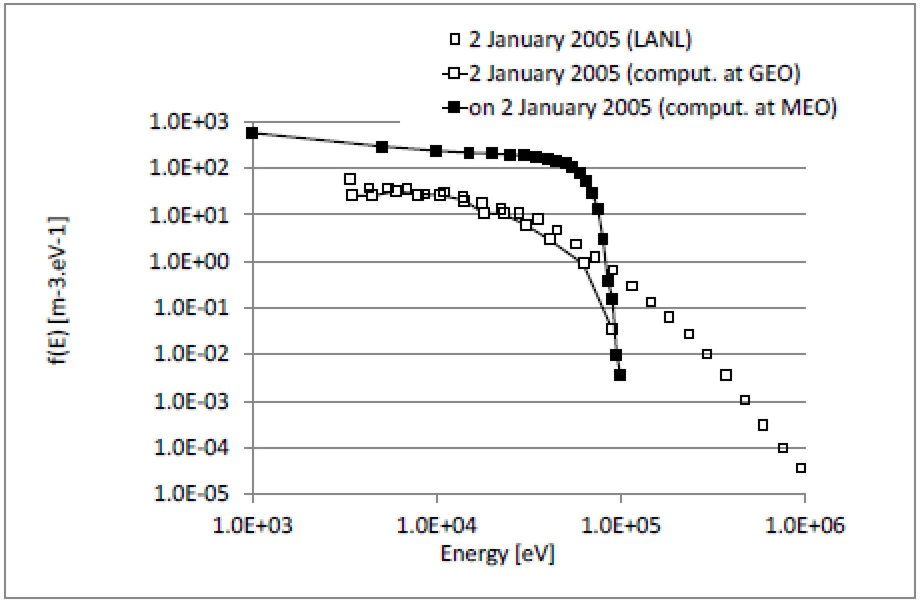




Selected GEO environments #1

LANL_1994_084 2005/01/02 15h46min12s MLT 04 47

3. IMPTAM computations



GEO

Very good agreement with LANL< 50keV
Flux > 10 * LANL @ 100 keV

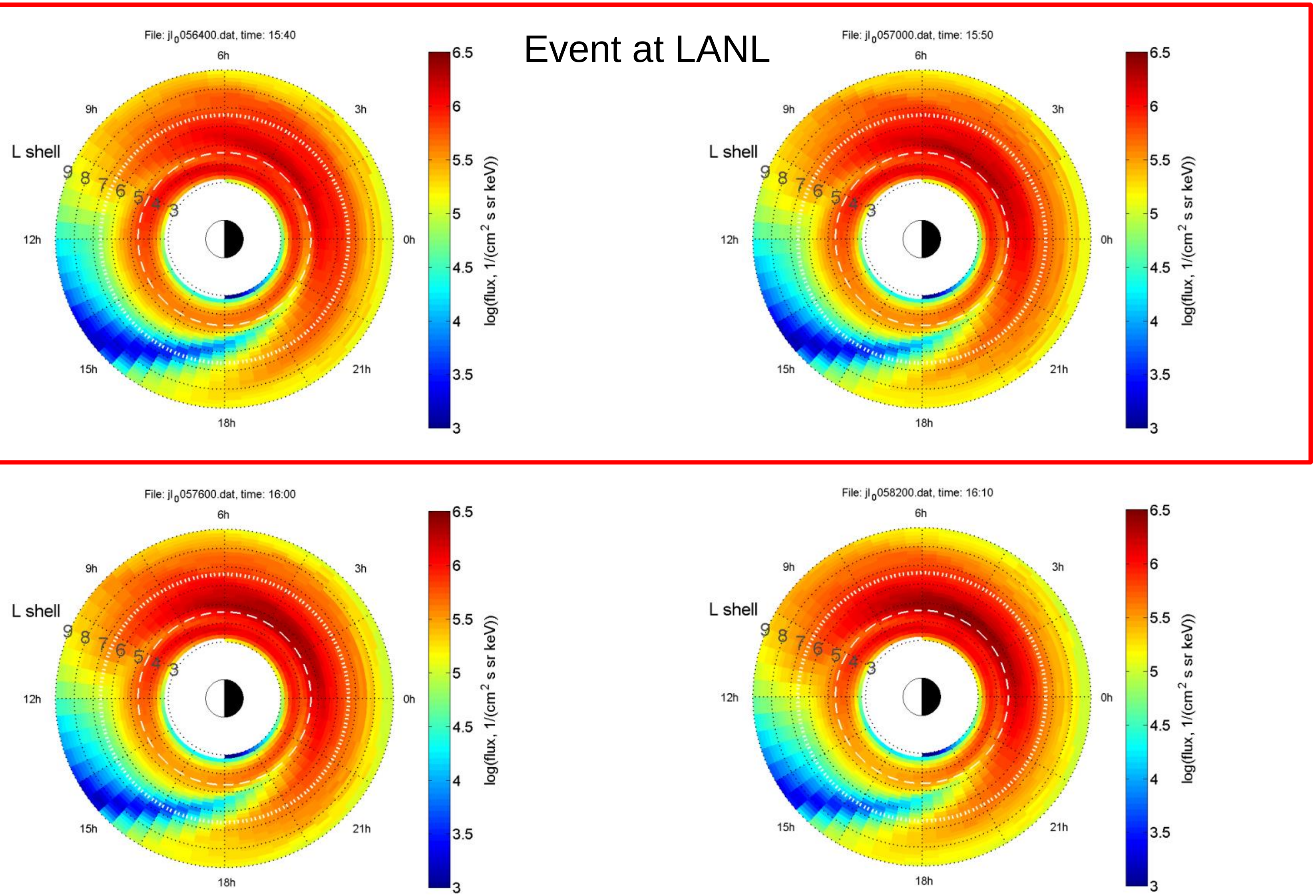
MEO L = 4.6

Flux *5-10 at low energy
Flux > 10-50 times the flux at GEO

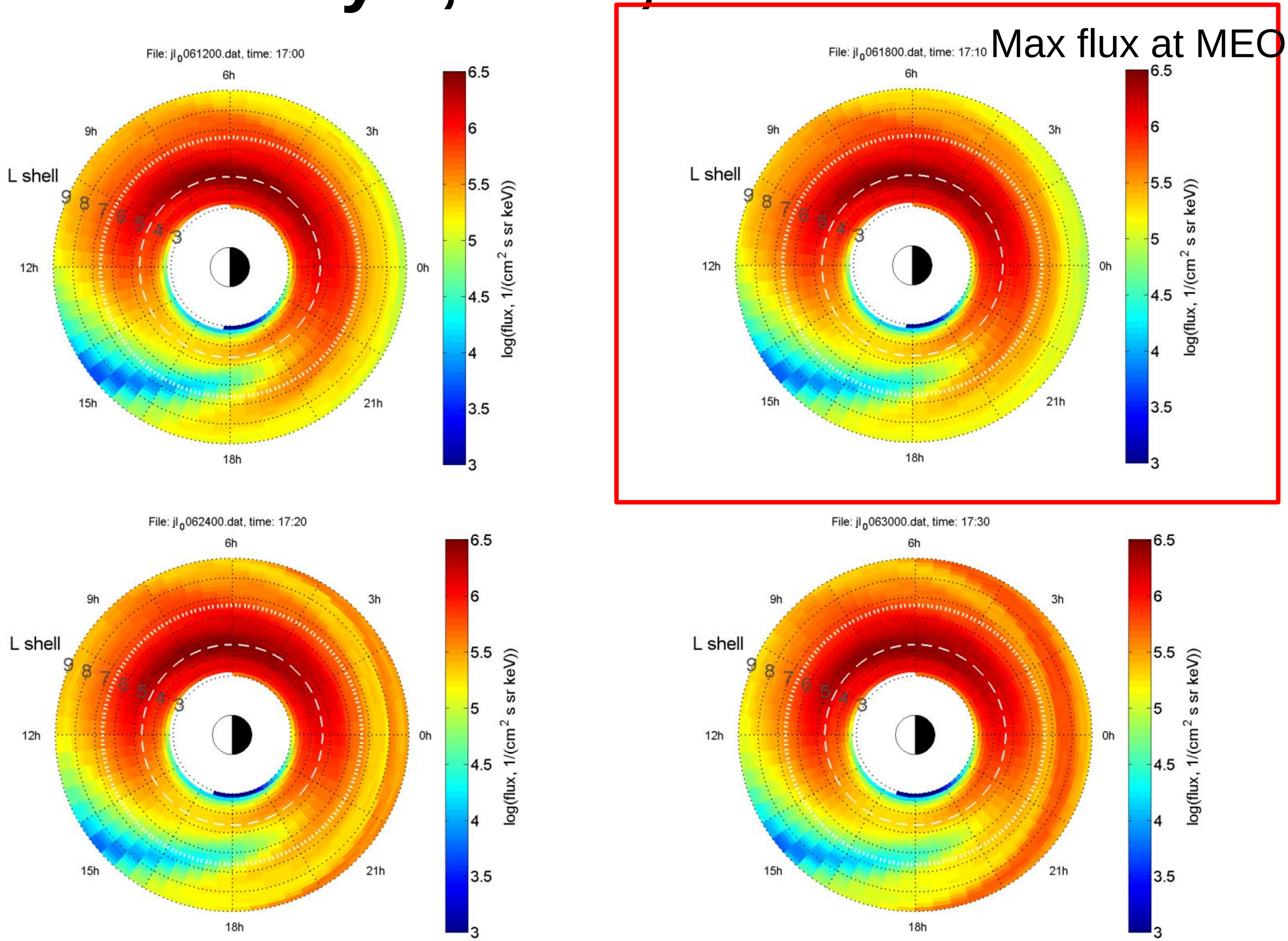
ONERA THE FRENCH AEROSPACE LAB

From presentation at **SCTC 2016, April 4-8, Noordwijk, The Netherlands: “**From GEO/LEO environment data to the numerical estimation of spacecraft surface charging at MEO” by J.C. Mateo-Velez et al.

January 2, 2005, 1540 -1610 UT



January 2, 2005, 1700 -1730 UT



Summary

1. IMPTAM is very suitable for modeling of fluxes of low energy electrons (< 200 keV) responsible for surface charging

2. It is NOT necessary to have even a moderate storm for significant surface charging event to happen. Substorms are important but low energy electrons (at geostationary) are not organized by AE index, for example.

3. It is a challenge to model low energy electrons with their important variations on 10 min scales. Advance made: A revision of the source model at 10 Re in the plasma sheet was done using the particle data from THEMIS ESA and SST instruments for years 2007-2013. Most advanced representation of loss processes for low energy electrons due to wave-particle interactions with chorus and hiss were incorporated using electron lifetimes following *Orlova and Shprits* [2014] and *Orlova et al*. [2014].

4. Modeling of documented surface charging events detected at LANL with further propagation to MEO: good agreement at GEO, reasonable values at MEO?

5. Still open issue: proper incorporation of substorm effects