Low energy electron radiation environment for extreme events

Natalia Ganushkina (1, 2) and **Stepan Dubyagin** (1)

Special thanks to Jean-Charles Matéo-Vélez (3)

(1) Finnish Meteorological Institute, Helsinki, Finland
(2) University of Michigan, Ann Arbor MI, USA
(3) ONERA, Toulouse, France

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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 (*Whipple*, 1981; *Garrett*, 1981; *Purvis et al*., 1984; *Frezet et al*., 1988; *Koons et al*., 1999; *Hoeber et al*., 1998; *Davis et al*., 2008).

- The distribution of low energy electrons, the seed population (10 to few hundreds of keV), is critically important for radiation belt dynamics (*Horne et al*., 2005; *Chen et al*., 2007)

- 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. (*Kennel and Petschek*, 1966; *Kennel and Thorne*, 1967; *Tsurutani and Smith*, 1974 *; Li et al*., 2008, 2012; *Meredith et al*., 2001).

  The electron flux at the keV energies is largely determined by convective (*Korth et al*., 1999; *Friedel et al*., 2001; *Thomsen et al*., 2002; *Elkington et al*., 2004; *Miyoshi et al*., 2006; *Kurita et al*., 2011) and **substorm-associated** (*Vakulin et al*., 1988; *Grafodatskiy et al*., 1987; *Degtyarev et al*., 1990; *Fok et al*., 2001; *Khazanov et al*., 2004; *Kozelova et al*., 2006; *Ganushkina et al*., 2013) electric fields and varies significantly with geomagnetic activity driven by the solar wind

Importance of keV electrons in the inner magnetosphere

- **Louis Lanzerotti – one of the fathers of the space physics and space weather:**

Space weather is more than storms

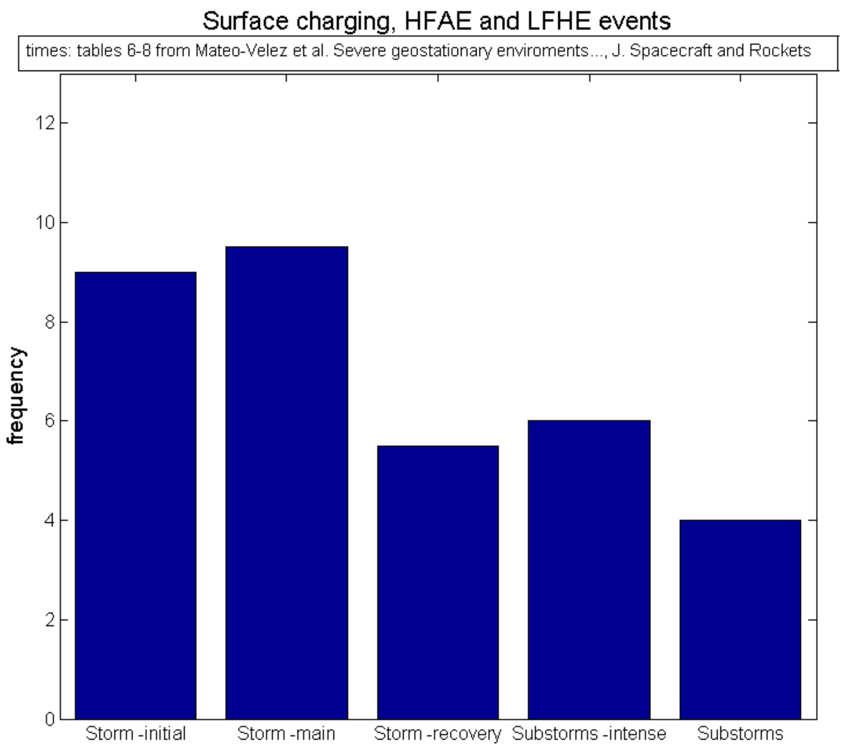
It is **NOT necessary to have even a moderate storm for significant surface charging** event to happen

- The electron flux at the keV energies varies significantly with geomagnetic activity **variations on time scales of minutes!**

No averaging over an hour/day/orbit!

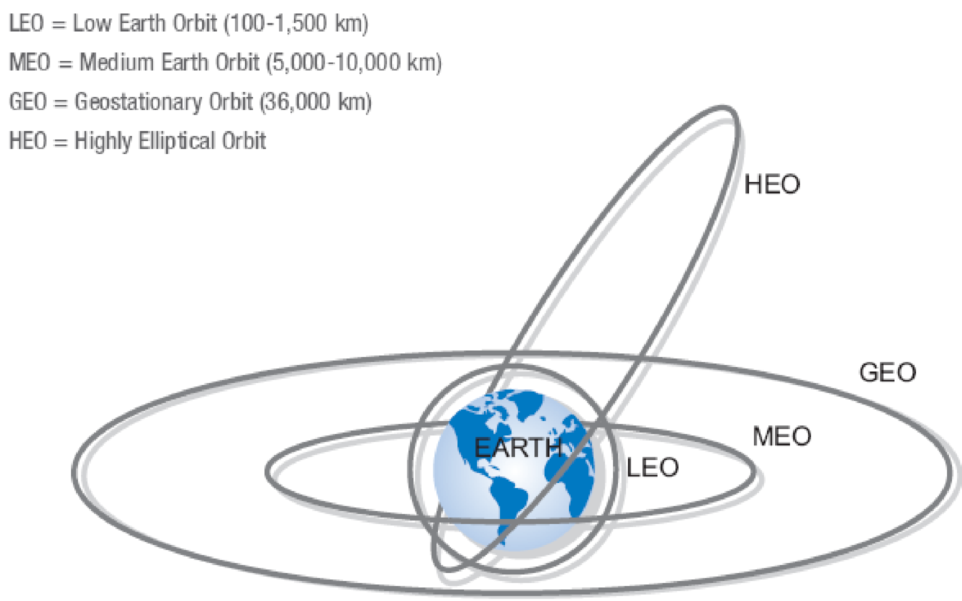
Open question: what if there is not just intense storm but an extreme event?

Surface charging 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, 2016.*

Need to have a model for low energy electrons in the near-Earth space



- No continuous measurements of radiation environment.

- No continuous simultaneous measurements of spacecraft potential

- Need to know what level of low energy electron flux (level of risk of surface charging) is and will be at times and locations where we do not have any measurements.
  KNOW NOW AND PREDICT

With the development of the **Inner Magnetosphere Particle Transport and Acceleration model (IMPTAM),** the computational view on the low energy electron fluxes in the near-Earth space is now feasible

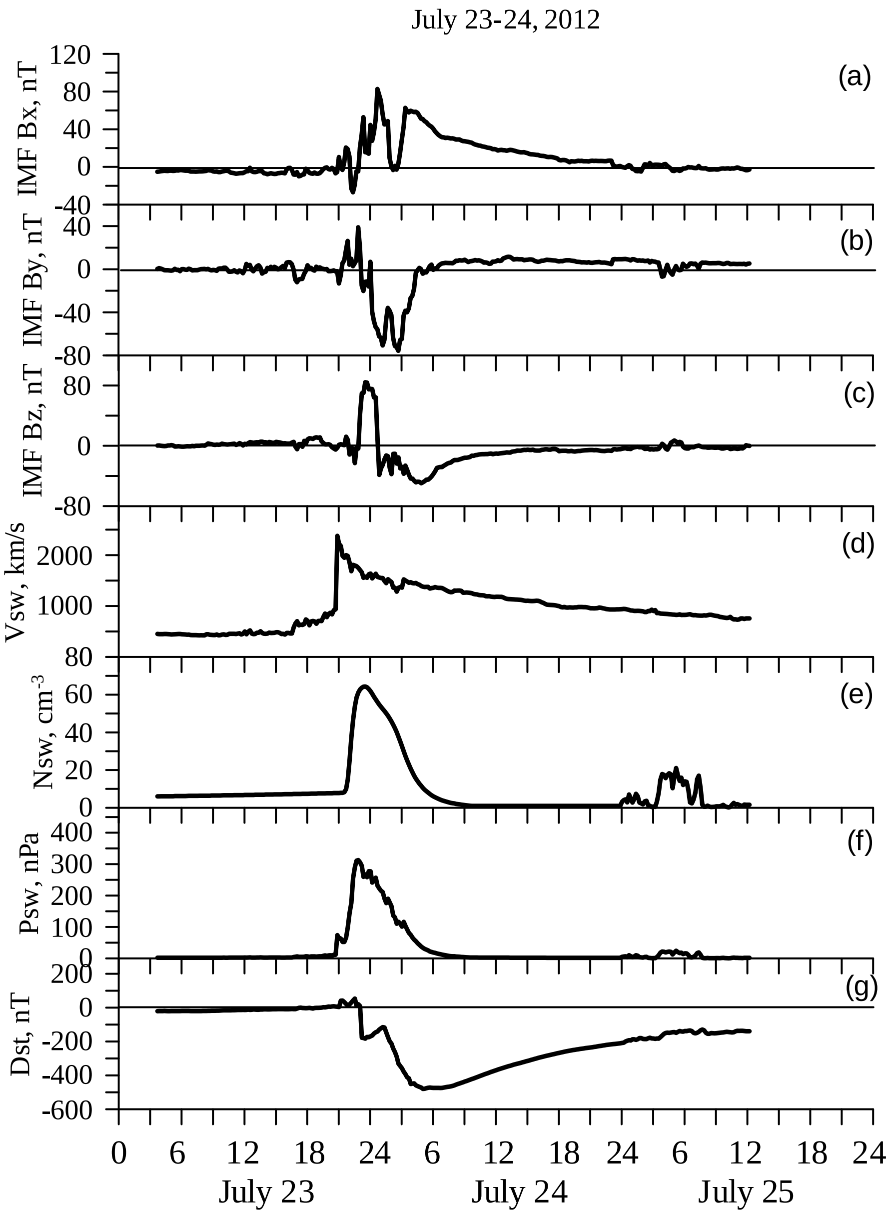
Inner Magnetosphere Particle Transport and Acceleration Model

The inner magnetosphere particle transport and acceleration model:
- follows distributions of ions and electrons with arbitrary pitch angles
- from the plasma sheet to the inner L-shell regions
- with energies reaching up to hundreds of keVs
- in time-dependent magnetic and electric fields.
- distribution of particles is traced in the guiding center, or drift, approximation

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;
(2) magnetic and electric fields everywhere dependent on time;
(3) drift velocities;
(3) all sources and losses of particles.

Magnetic field model: TS05 (Dst, Psw, IMF By and Bz, and Wi, i = 1, 6)
Electric field model: Boyle (Vsw, IMF B, By, Bz)
Boundary conditions: n and T by Dubyagin et al. (2016) (Vsw, IMF Bz, Nsw)
Losses given as electron lifetimes: newly developed BAS lower and upper band chorus diffusion model (**Kp, magnetospheric magnetic field)**

Large CME-driven storm, July 23-24, 2012
(event that missed the Earth)



Extremely fast coronal mass ejection on 23 July 2012 (initial speed of 2500 km/s) in opposite direction from the Earth.

(a-c) STEREO-A: magnetic field of 100 nT

(d) PLASTIC detector, average propagation speed of 2100 km/s

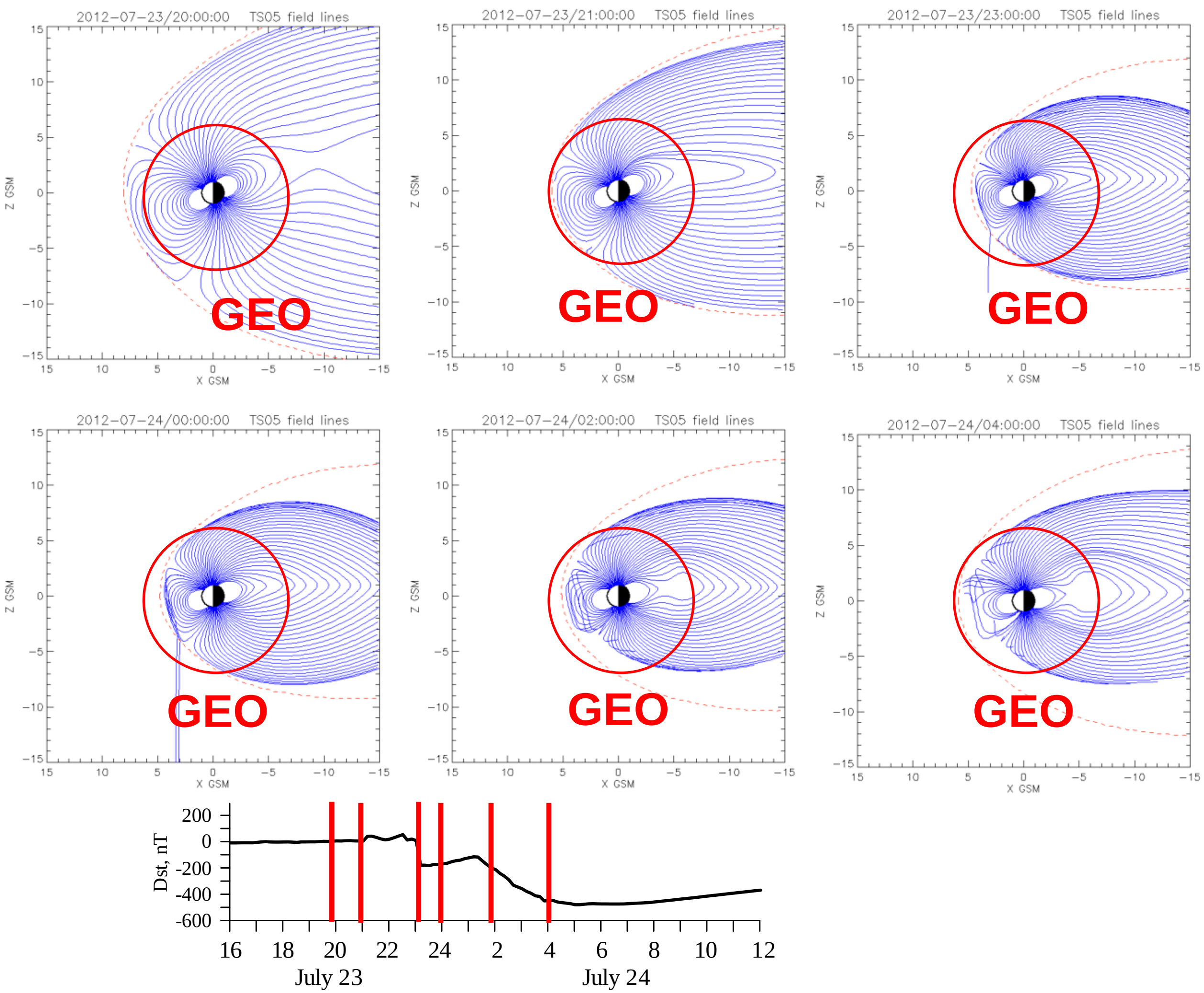
Wang-Sheerley-Arge, ENLIL and cone modelling reconstruction:
(*Pizzo et al.*, 2011).
(e) solar wind density estimates at STEREO-A, up to 60 cm^{-3})

(f) dynamic pressure of about 300 nPa

(g) *Temerin and Li* (2006) predictive model of Dst as low as -480 nT.

Magnetospheric magnetic field configuration during July 23-24, 2012

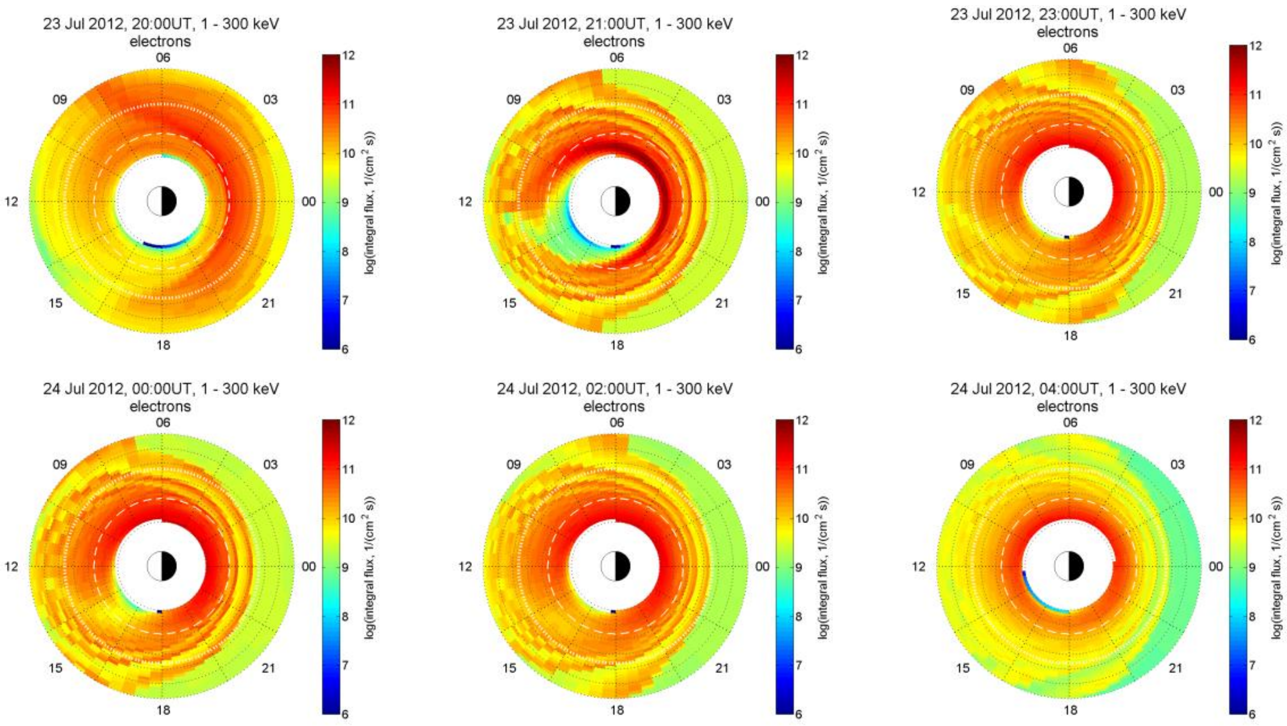
Dst = -500 nT (usually up to -200 nT), Psw=300 nPa (usually 50 nPa),
Vsw = 3000 km/s (usually 400-600 km/s)

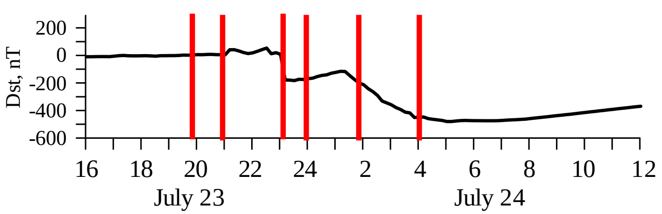


Magnetosphere becomes so compressed on the dayside and so stretched on the nightside that electrons are lost since they happen to be on larger L-shells.

KeV electrons in the inner magnetosphere during July 23-24, 2012

Dst = -500 nT (usually up to -200 nT), Psw=300 nPa (usually 50 nPa), Vsw = 3000 km/s (usually 400-600 km/s)





keV electron fluxes are not significantly high during extreme event.

At GEO and MEO the fluxes may be even lower than during non-extreme event.

Magnetosphere becomes so stretched that electrons are lost since they happen to be on larger L-shells.

Possible effect on magnetosphere during July 23-24, 2012

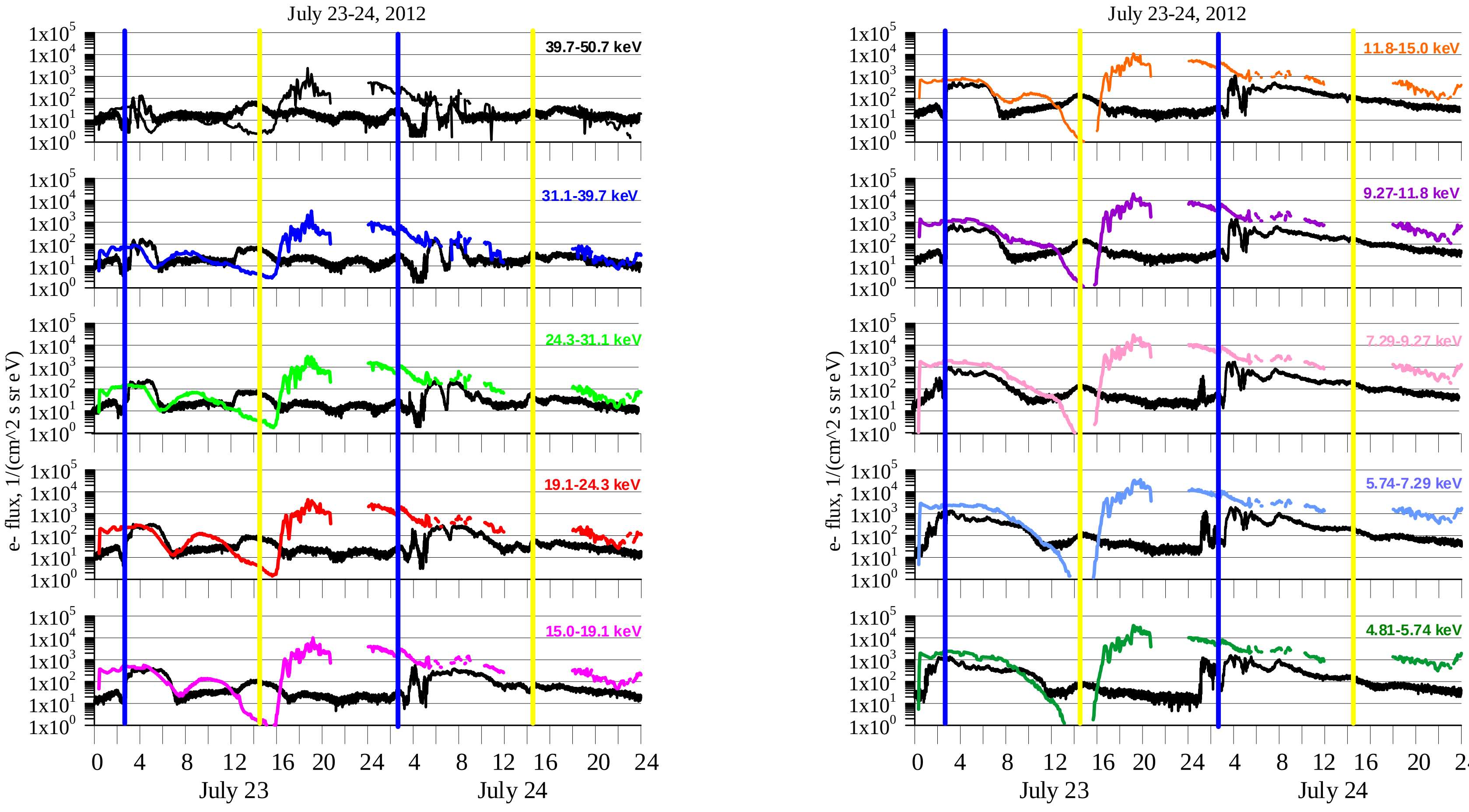
Comparison to AMC12 data at GEO for possible effect on the magnetosphere.

July 23d (00-12 UT): modeled fluxes are comparable with the observed ones.

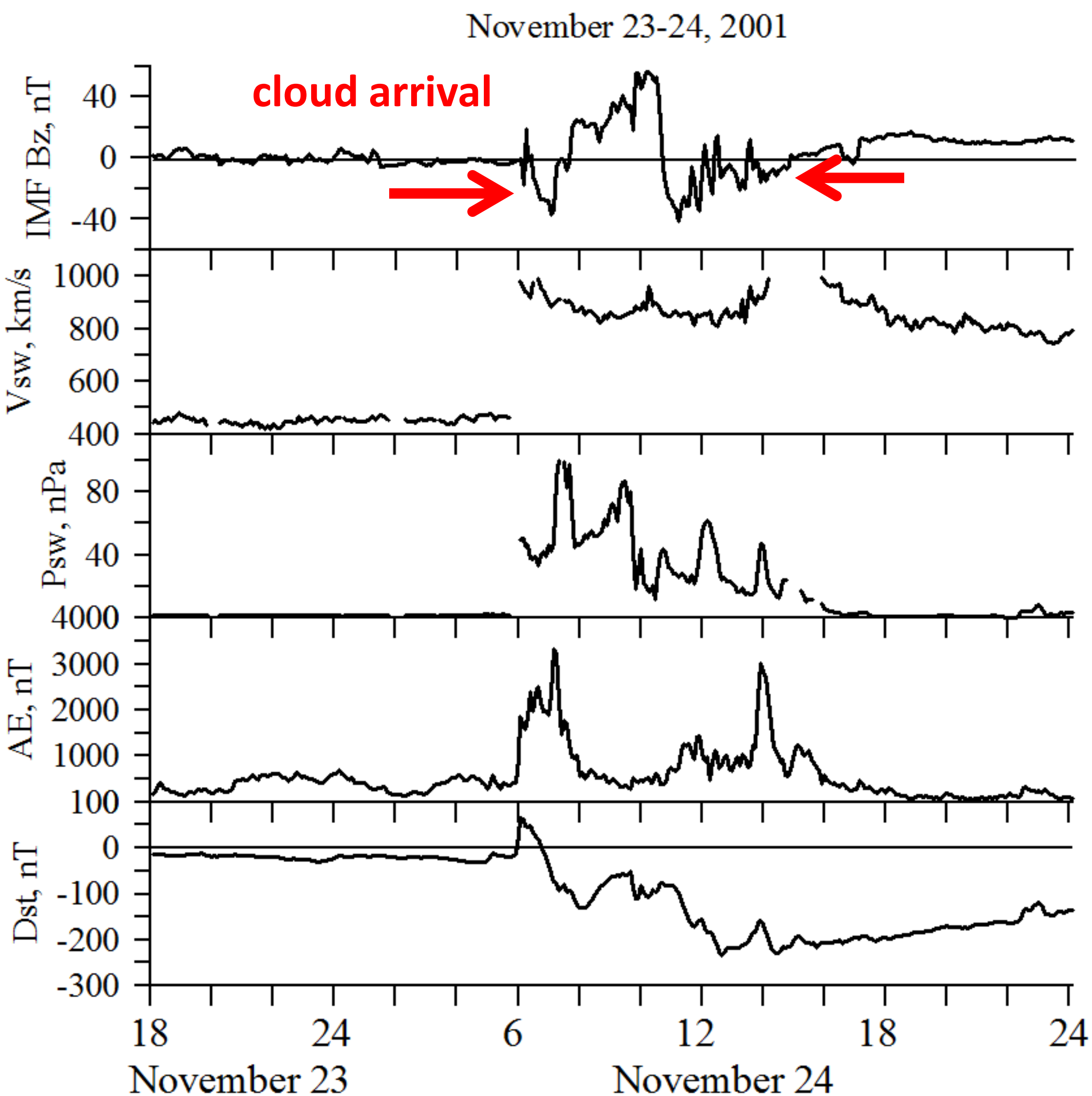
At noon: very much compressed magnetosphere, modeled fluxes drop to zero values (GEO outside the magnetopause)

Dusk-midnight on July 24th: modeled fluxes are 2 orders of magnitude higher than the observed.

Intervals with zero modeled fluxes correspond to highly stretched (compressed) magnetosphere.



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.**

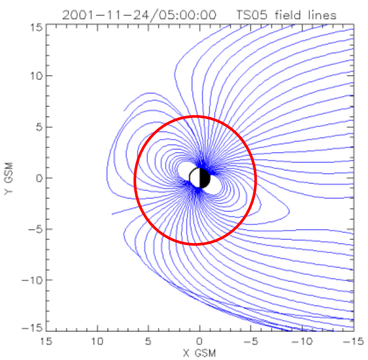
By 1600 UT, IMF Bz turns positive and remains for more than a day.

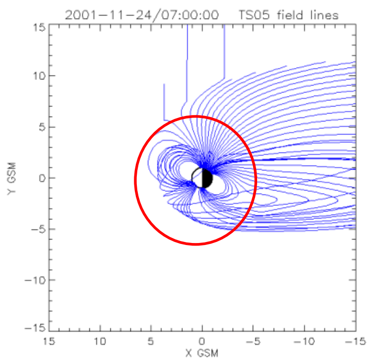
The IMF and SW data show the arrival of **a CME-induced magnetic cloud** over the Earth. The cloud arrived at around 1600 UT following a compressed upstream sheath-like region between 0600 and 1600 UT. **Several strong pressure pulses** between 0600 and 1600 UT.

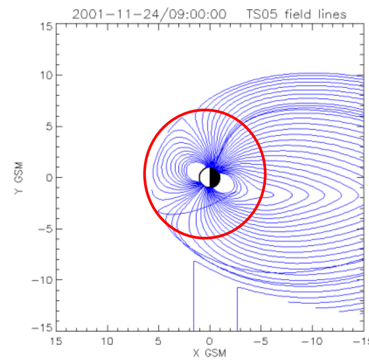
The Sym-H index was **−234 nT** at 1237 UT.

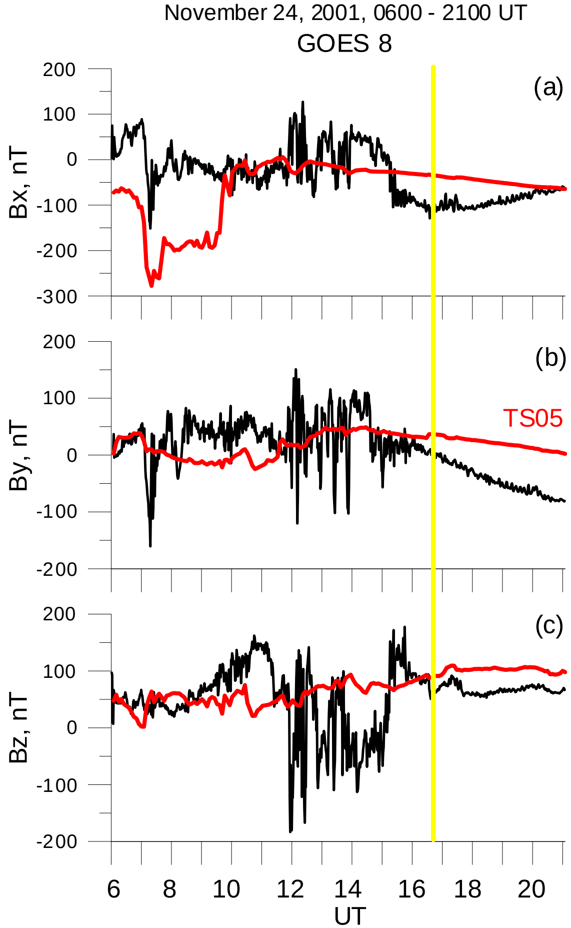
Magnetospheric magnetic field configuration during November 23-24, 2001

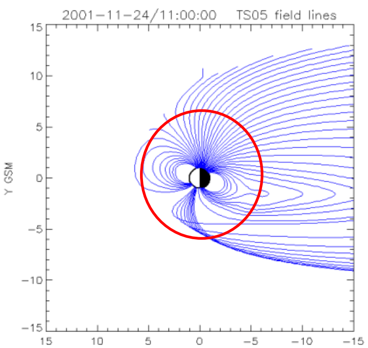
TS05 is not able to reproduce the observed magnetic field at GEO.
GEO is outside magnetopause and field lines are highly stretched on the nightside.

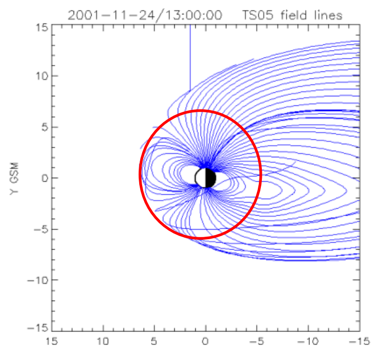










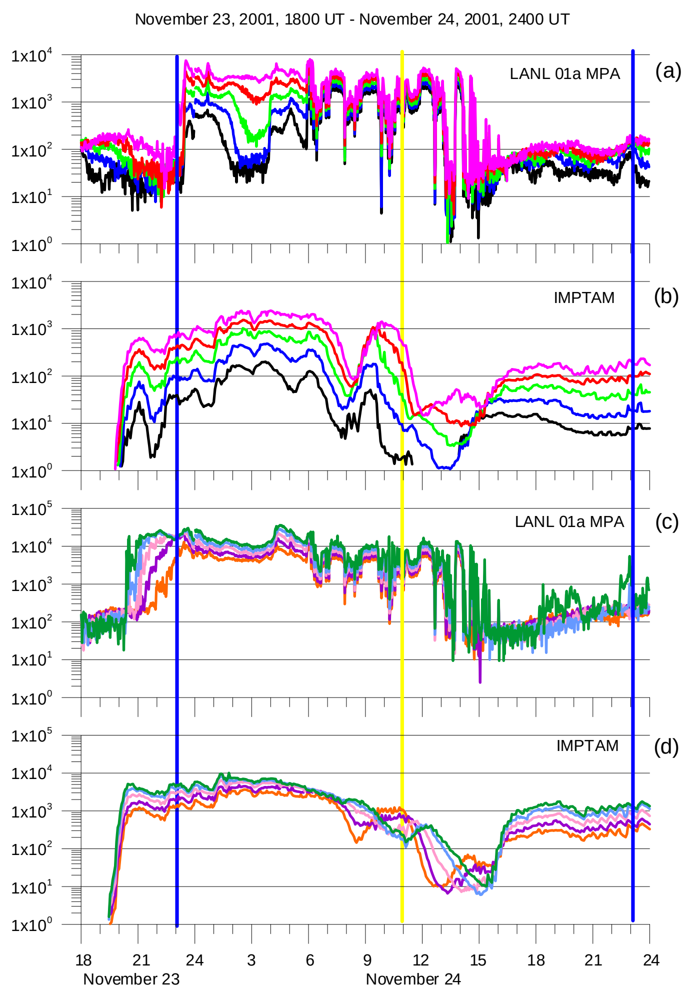


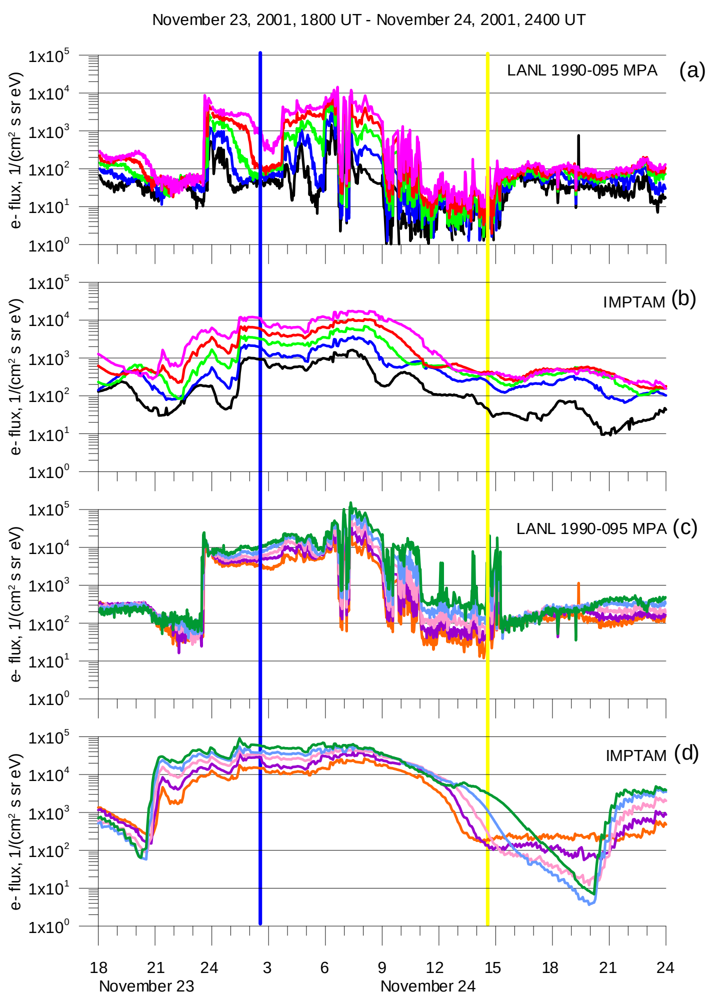
Modeled electron fluxes are expected to be different from the observed and to have less dramatic variations.

TS05 is the best available model for large events,

Comparisons with LANL MPA data at GEO during November 23-24, 2001

Magnetopause inside GEO (06-13 UT) due to large Psw and high IMF Bz<0.
Nightside GEO in the lobe, nightside magnetic field very highly stretched.
IMPTAM is able to get the correct magnitudes, misses sharp variations



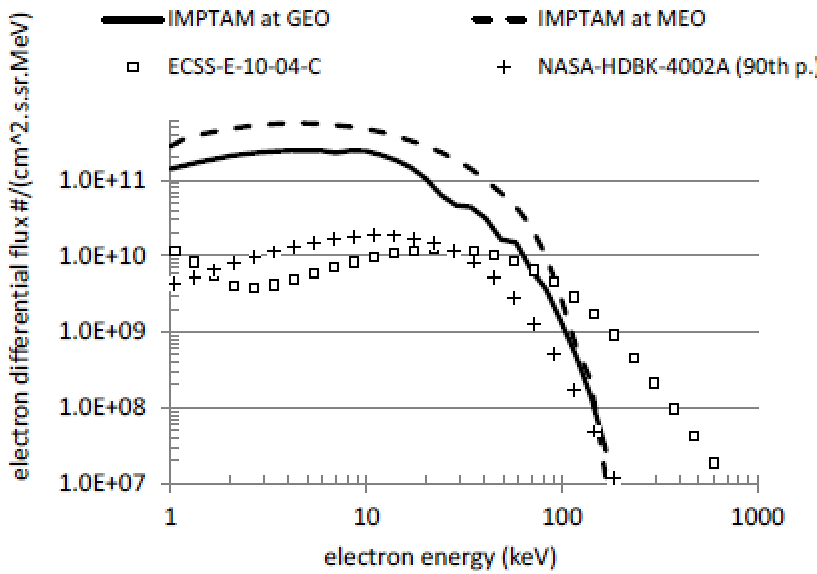


Summary

1. keV electron fluxes are not expected to be significantly high during extreme events

2. When the solar wind dynamic pressure and velocity are high, the magnetopause comes closer than geostationary orbit. TS05 is not always able to capture the observed location of the magnetopause. When it does capture the magnetopause location, the electrons are lost in a rather wide region in MLT, both on dawn and dusk, not only at noon.

3. On the nightside, the magnetosphere is very
at L-shells of 10 or even 15. Electrons are also
the fluxes may be even lower than during non-
It is possible to determine the maximum electr



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Extreme event keV electron environment:
The maximal value reached at MEO on July 23
2012, at 2040 UT, 6.4 MLT was
$6*10^{11}$ 1/(cm2 s sr MeV), 6 times higher than
that for the similar type of the event.

The flux is also well above the ECSS and NASA worst-cases.
At the same time, during the storm peak, at GEO and MEO the fluxes may be even lower than during non-extreme event.

IMPTAM is online, near-real time,

provides output at any location and
at any orbit in the magnetosphere

http://fp7-spacecast.eu
imptam.fmi.fi
http://csem.engin.umich.edu/tools/imptam