Low energy electrons at MEO during observed surface charging events

N. Ganushkina (1, 2), **I. Sillanpää** (1), Jean-Charles Matéo-Vélez (3), S. Dubyagin (1), Angélica Sicard-Piet (3), S. Claudepierre (4), B. Larsen (5)

(1) Finnish Meteorological Institute, Helsinki, Finland;
(2) University of Michigan, Ann Arbor MI, USA;
(3) ONERA The French Aerospace Lab, Toulouse, France
(4) Aerospace Corp., CA, USA
(5) LANL, NM, USA

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keV electrons at MEO

The fluxes of < 200 keV electrons in the inner Earth's magnetosphere constitute **the seed population, which is critically important for radiation belt dynamics**.

The keV electron flux varies significantly with geomagnetic activity and even during quiet time periods on the scale of minutes or even shorter. The electrons stay near the satellite surface but they are responsible for **surface charging effects** which is a serious risk for satellites.

Most satellites are located in GEO and LEO. At the same time, MEO is the orbit for GNSS, US GPS, European two test satellites GIOVE-A and –B of the radio-navigation system Galileo, and Russian GLONASS systems are all at MEO.

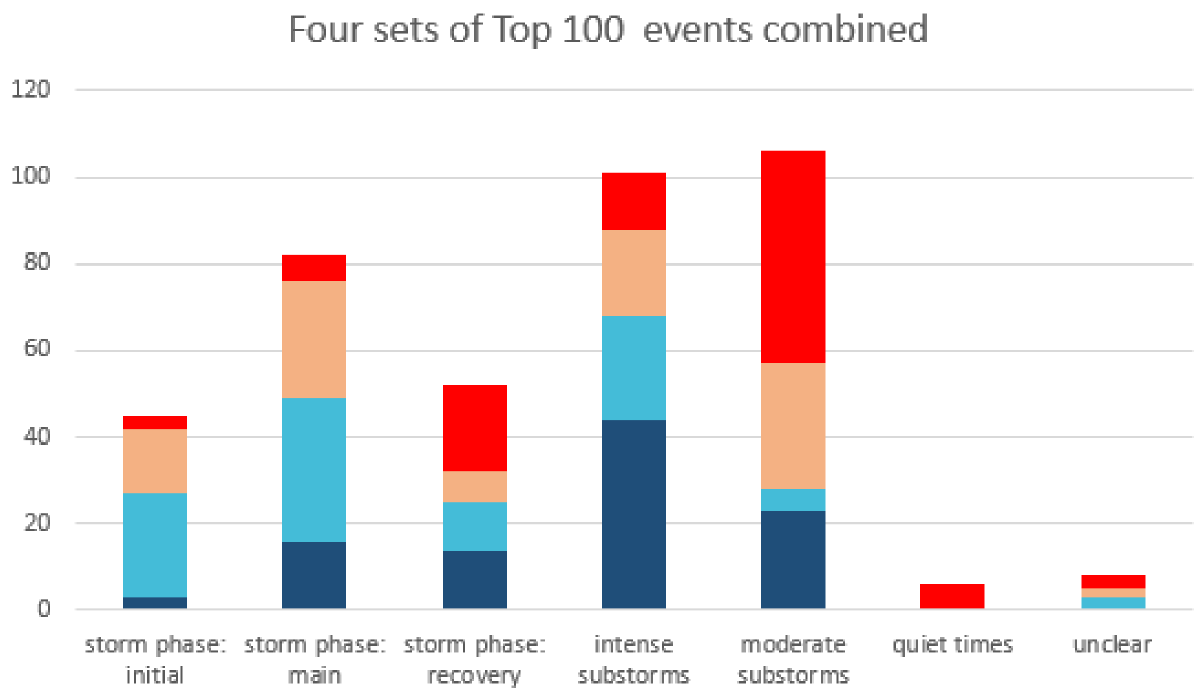
Designing satellites for MEO requires data on the space radiation environment. The GPS satellites have been collecting data on MEO for several years but they are not generally available. There are data from scientific satellites such as CRRES, SCATHA, and CLUSTER but useful data were only collected for a short period of time. The GIOVE –A and –B satellites do not carry instruments for measuring low energy electrons.

There no models specifically focused on modeling of keV electrons at MEO. AE8 [*Vette*, 1991] and AE9 [*Ginet et al*., 2013] models were constructed from relatively sparse datasets and provide the average conditions for solar min and solar max.

Surface charging vs geomagnetic conditions

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

Types of surface charging events:
(1) Top 100 of 15 min worst cases, HFAE (High flux all energies);
(2) Top 100 of 15 min worst cases, HFAE > 10 keV;
(3) Top 100 of 15 min worst cases, LFHE (low flux at high energies (>200 keV));
(4) Top 100 longest series of potentials < -5000V

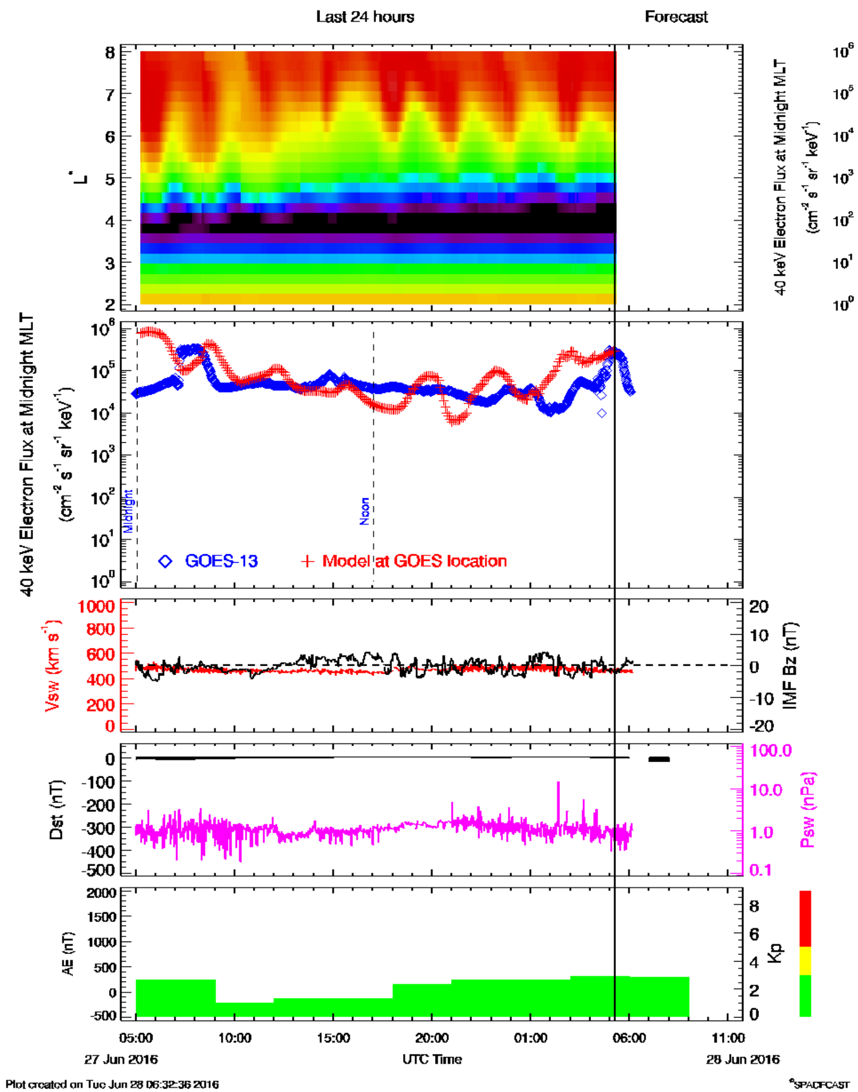


Inner Magnetosphere Particle Transport and Acceleration Model

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

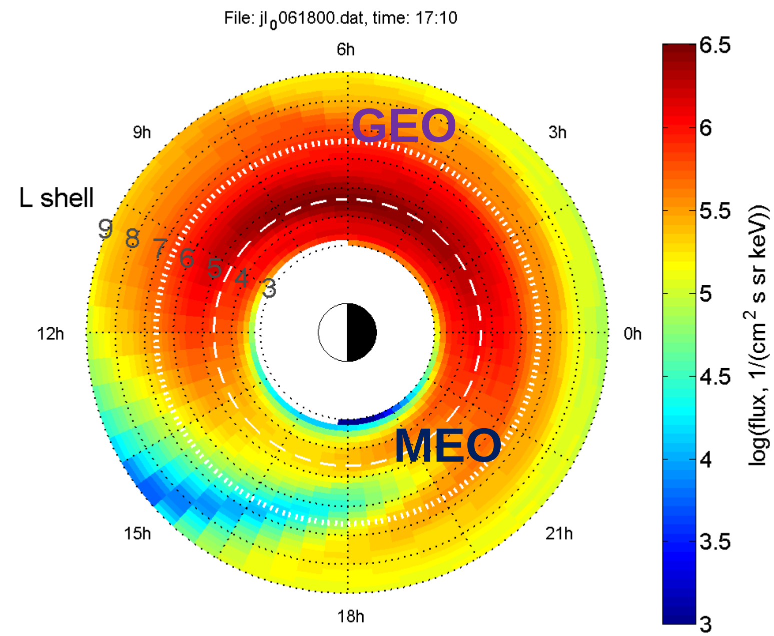
In order to follow the evolution of the particle **distribution function** f and particle **fluxes** in the inner magnetosphere dependent on the **position, time, energy, and pitch angl**e , it is necessary to specify:
(1) particle distribution at initial time at the model boundary;
(2) magnetic and electric fields everywhere dependent on time;
(3) drift velocities;
(3) all sources and losses of particles.
Magnetic field model: 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

IMPTAM compared to GOES MAGED 40 keV e- fluxes



IMPTAM: traces **electrons (< 200 keV)** with arbitrary pitch angles (**drift approximation)** from the plasma sheet to the inner L-shells in time-dependent magnetic and electric fields

Taken into account: **radial diffusion and** electron losses as convection outflow and pitch angle diffusion by the **electron lifetimes**



http://fp7-spacecast.eu
imptam.fmi.fi

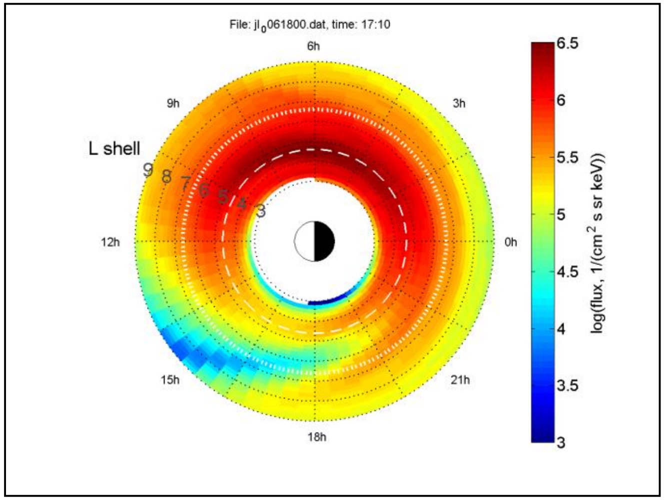
Ganushkina et al., JGR, 2013, 2014; Space Weather, 2015.

Charging at MEO

Very few data available

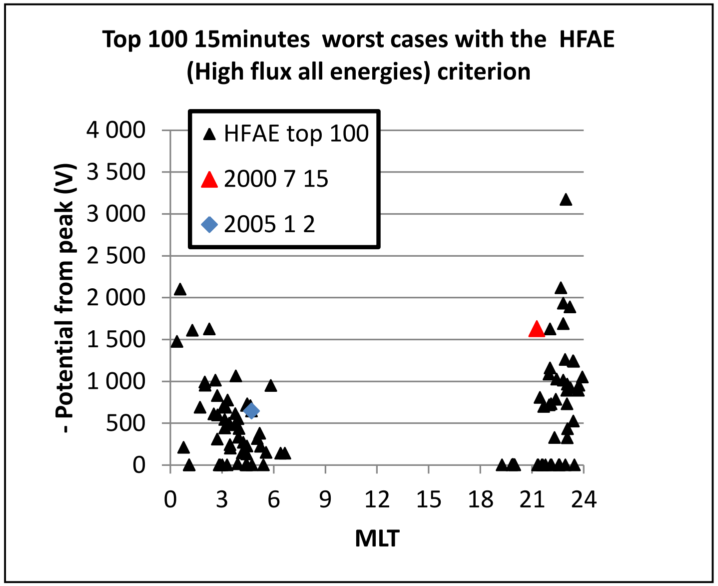
Method to obtain MEO worst case flux

1. Select dates of charging events at LANL (list provided by ONERA
2. Use the IMPTAM (FMI) to transport electrons from GEO (LANL) to MEO L = 4.6
3. Select time and position of worst case electron fluxes at MEO

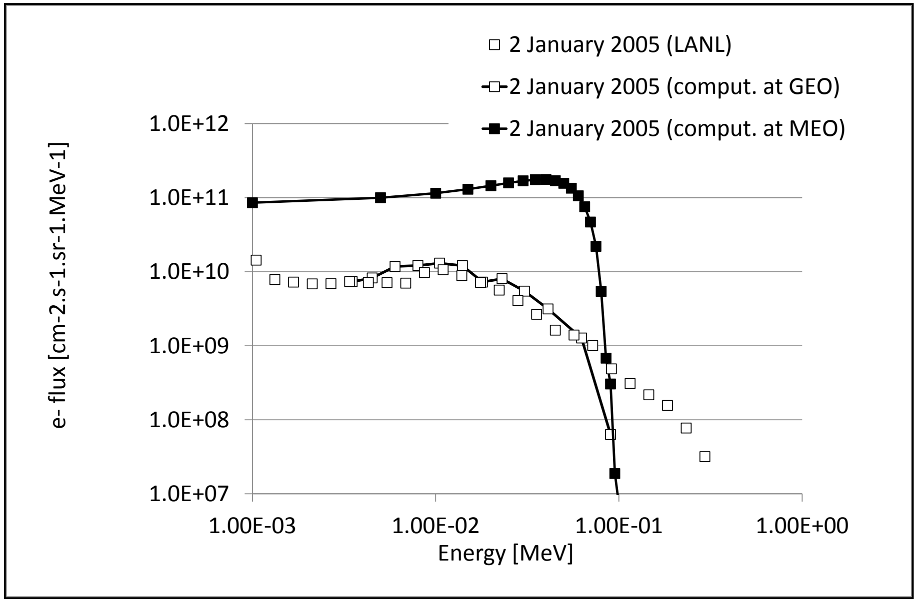


2.IMPTAM

Mateo-Velez et al 2016, 14th SCTC



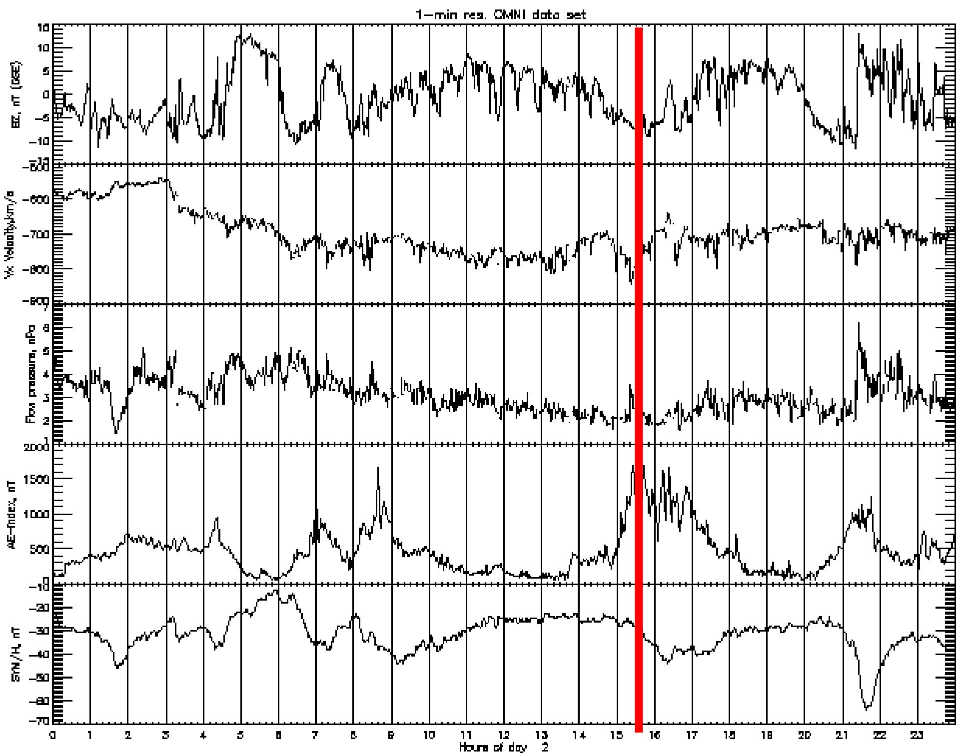
1. GEO LANL (courtesy of CNES)



3. Specification at MEO

Top 100 of 15 minutes worst cases with the criteria HFAE (High flux all energies) on 02 January 2005 (LANL observations)

Top 100 of 15 minutes worst cases with the criteria HFAE (High flux all energies) on **02 January 2005** at 154612 UT (LANL observations)
Not a storm, but **intense substorm** with AE of 1700 nT



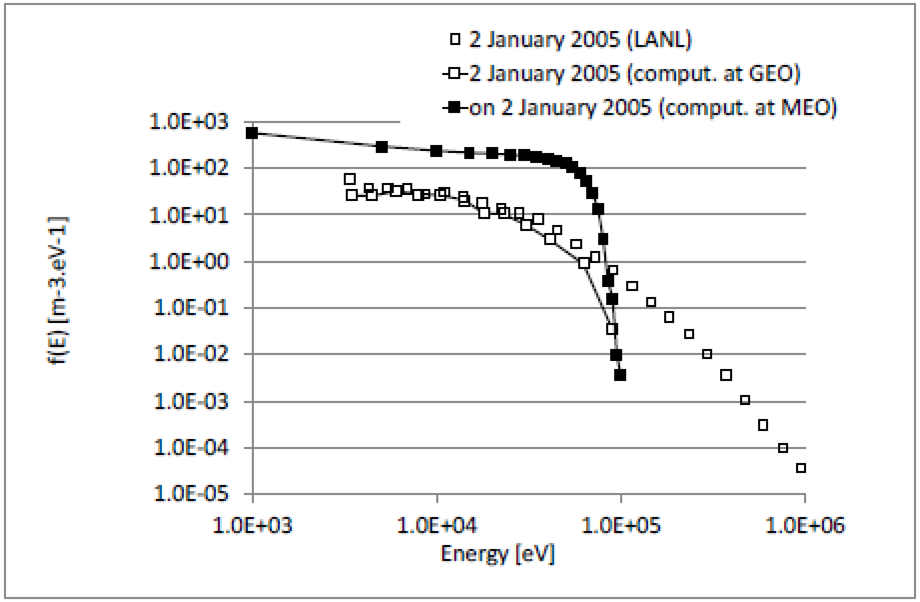
Movie to be shown

Selected GEO environments #1

LANL_1994_084 2005/01/02 15h46min12s MLT 04 47

3. IMPTAM computations

Surface event detected at LANL



GEO

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

MEO L = 4.6

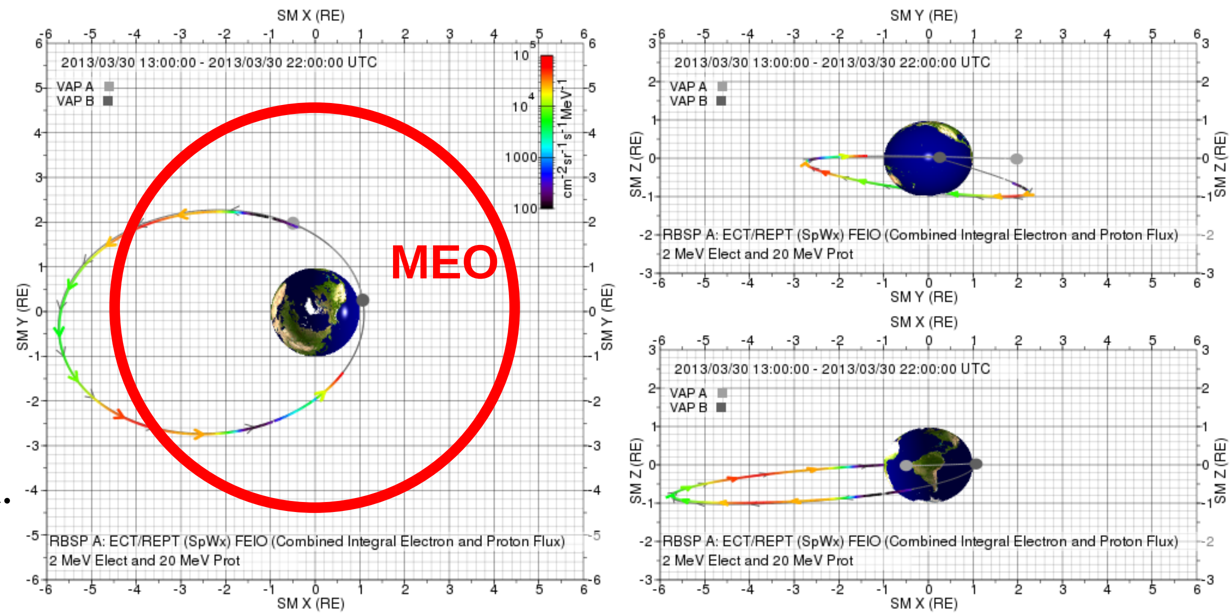
Flux *5-10 at low energy
Flux > 10-50 times the flux at GEO

IMPTAM e- flux at MEO as input to SPIS, the Spacecraft Plasma Interaction System
Software toolkit for spacecraft-plasma interactions and spacecraft charging modelling.
http://dev.spis.org/projects/spine/home/spis

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

Van Allen Probes data analysis at MEO: HOPE and MagEIS instruments

Van Allen Probes:
launched in August 2012;
2 spacecraft in elliptical orbits around Earth; one lapping the other every ~2.5 months;
near-equatorial,
at 1**.1 R_E to 5.8 R_E**,
(10°) inclination, 9-hour period.

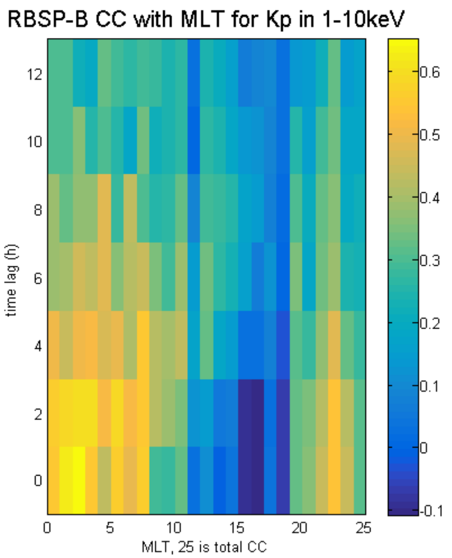


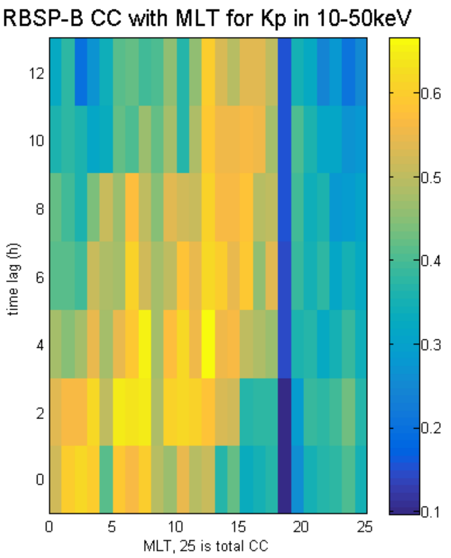
The **HOPE (Helium Oxygen Proton Electron)** instrument:
part of the Thermal plasma (ECT) suite;
measures the pitch angle distribution of electrons over the energy range from **30 eV up to ~50 keV**.

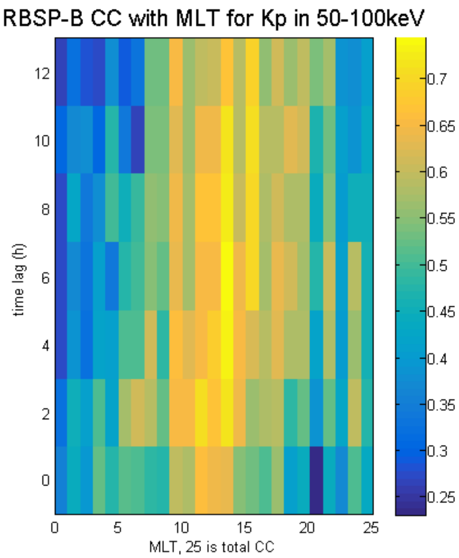
The **Magnetic Electron Ion Spectrometer (MagEIS)** instrument:
uses magnetic focusing and pulse height analysis;
provide the cleanest possible energetic electron measurements over the critical energy range of ~**30 keV to 4 MeV**.

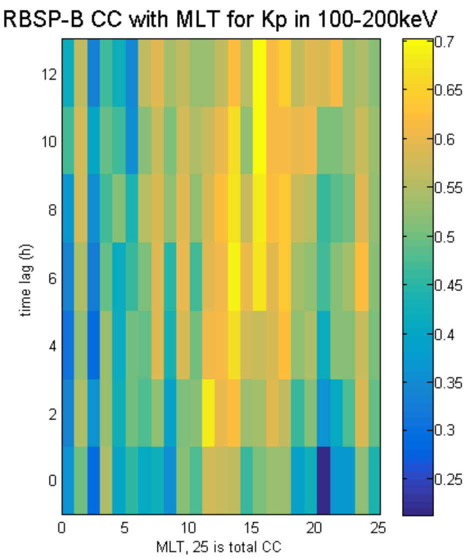
Van Allen Probes data analysis at MEO:
SW, IMF and geomagnetic index time lags

Correlation coefficients used to determine optimal (average) time lags for parameters:









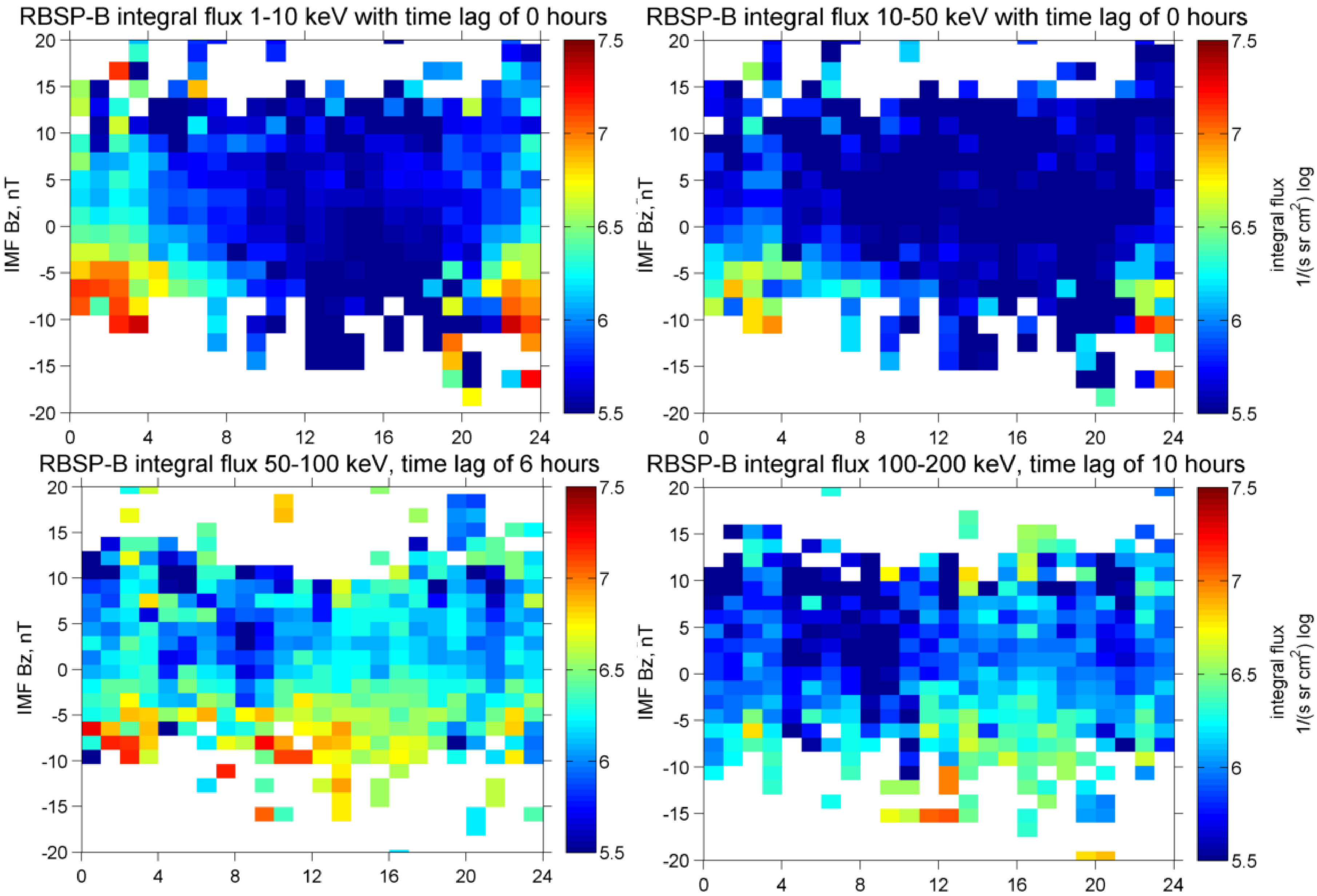
Van Allen Probes data analysis at MEO: SW, IMF and geomagnetic index time lags

Correlation coefficients used to determine optimal (average) time lags for parameters:

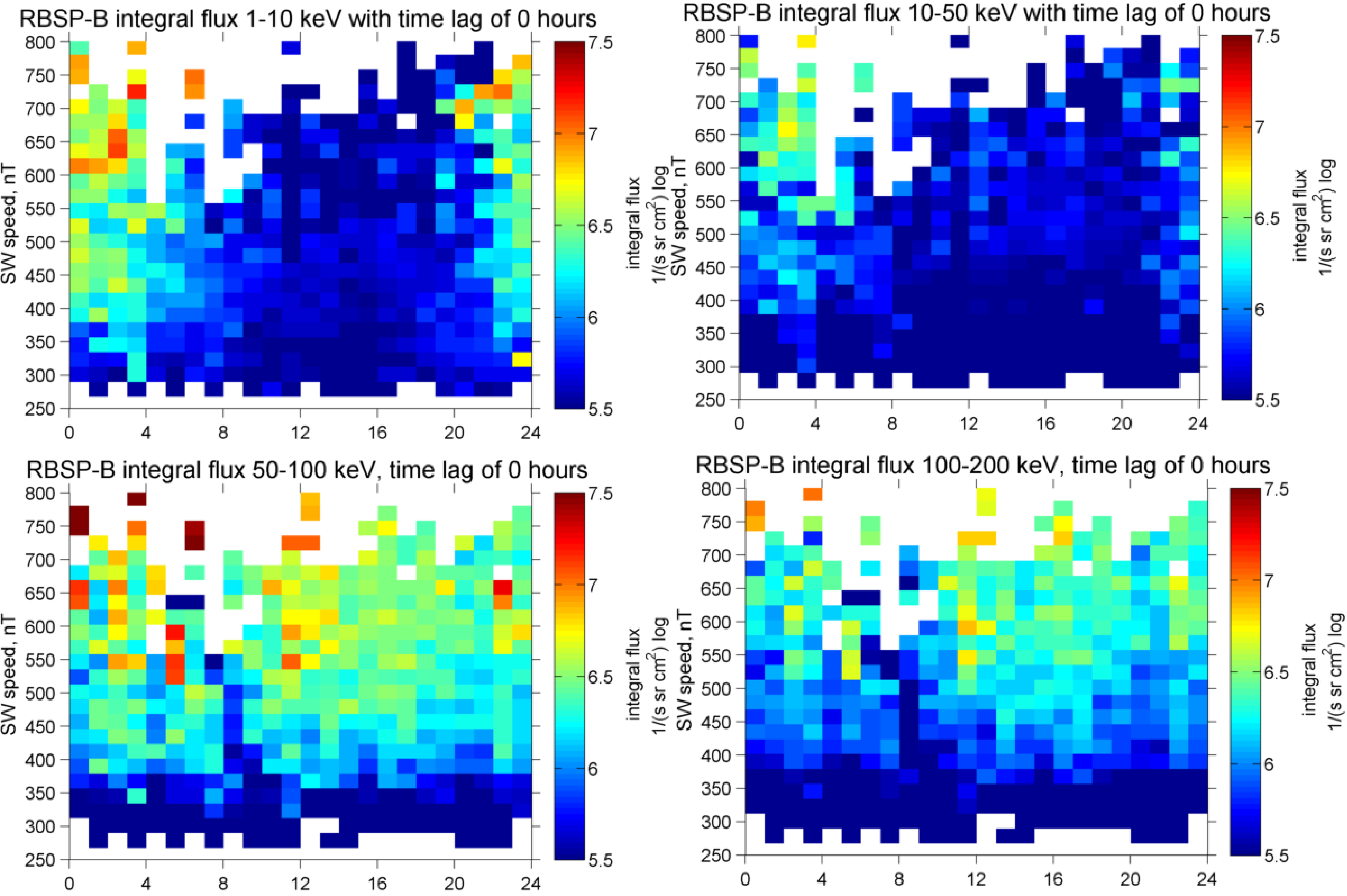
n_{SW} had a poor CC overall

Time lags (h) based on CCs	1-10 keV	10-50 keV	50-100 keV	100-200 keV
IMF |B|	0	0	2-4	10
IMF B_Z<0	2	2	6	6-10
V_{SW}	0	0	0	0
p_{SW}	0	6-8	6	10
AE	0	0	0	10
Kp	0	2	8	10
SYM-H	0	0	0	2

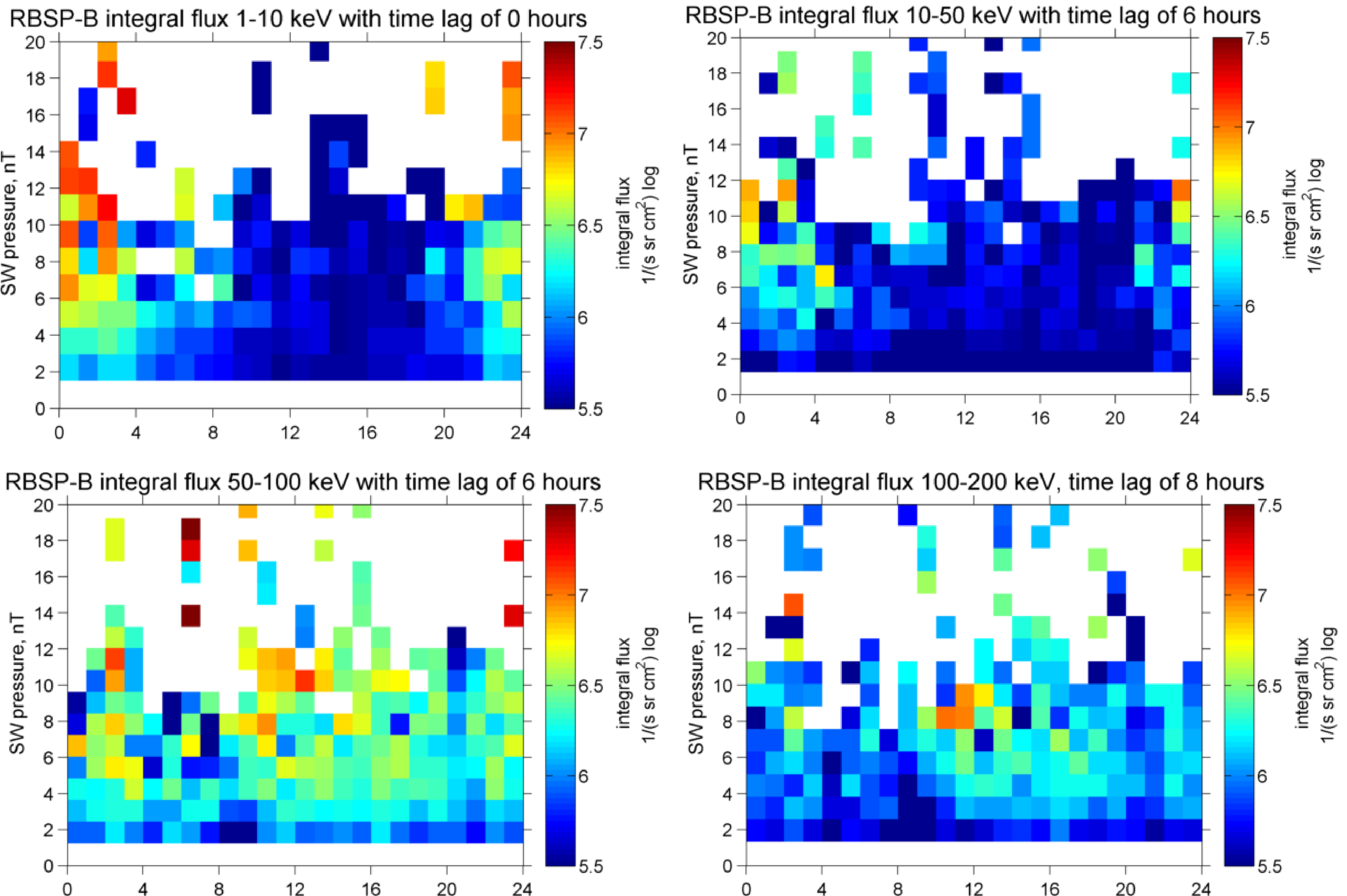
keV electron fluxes at MEO: IMF Bz



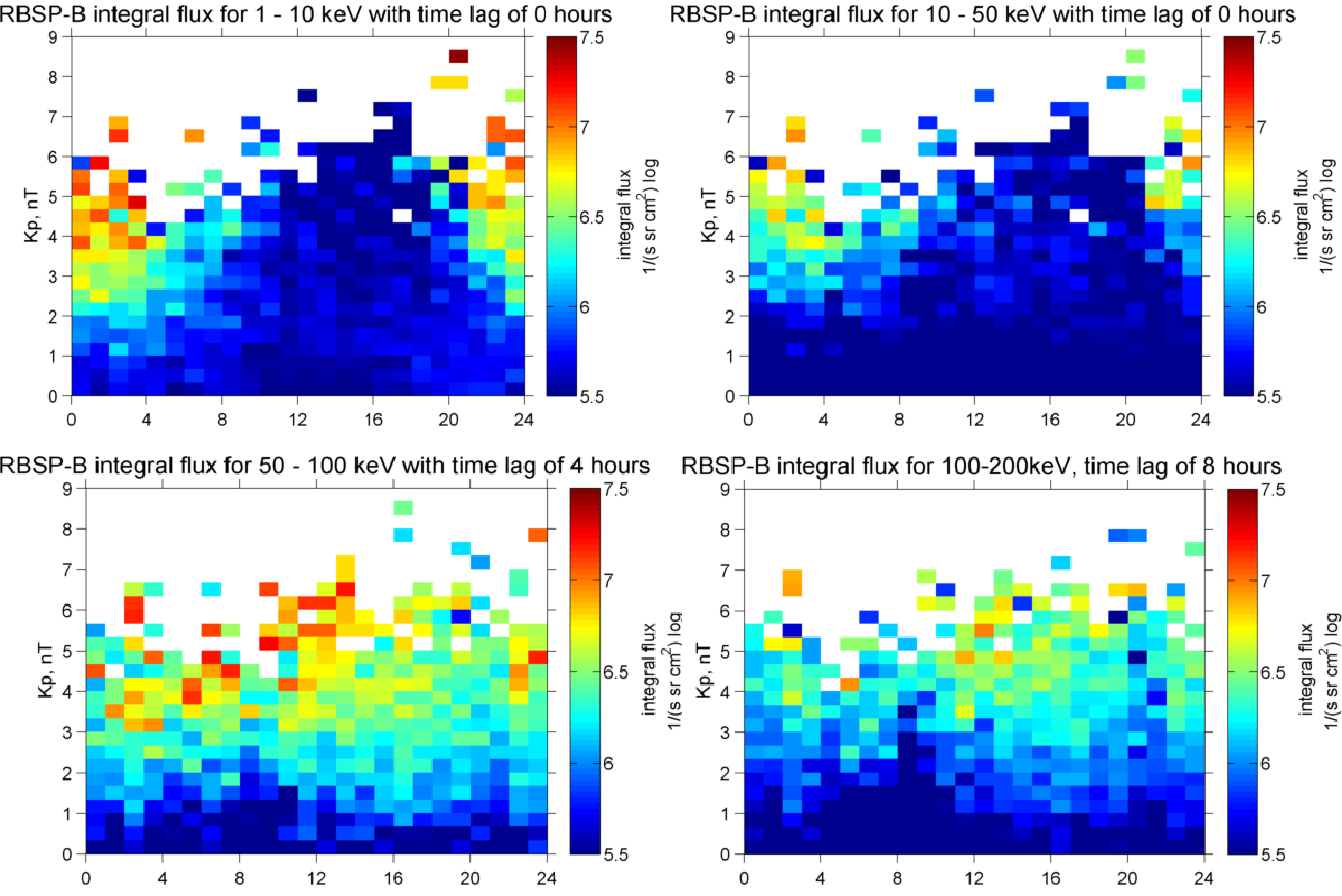
keV electron fluxes at MEO: Vsw



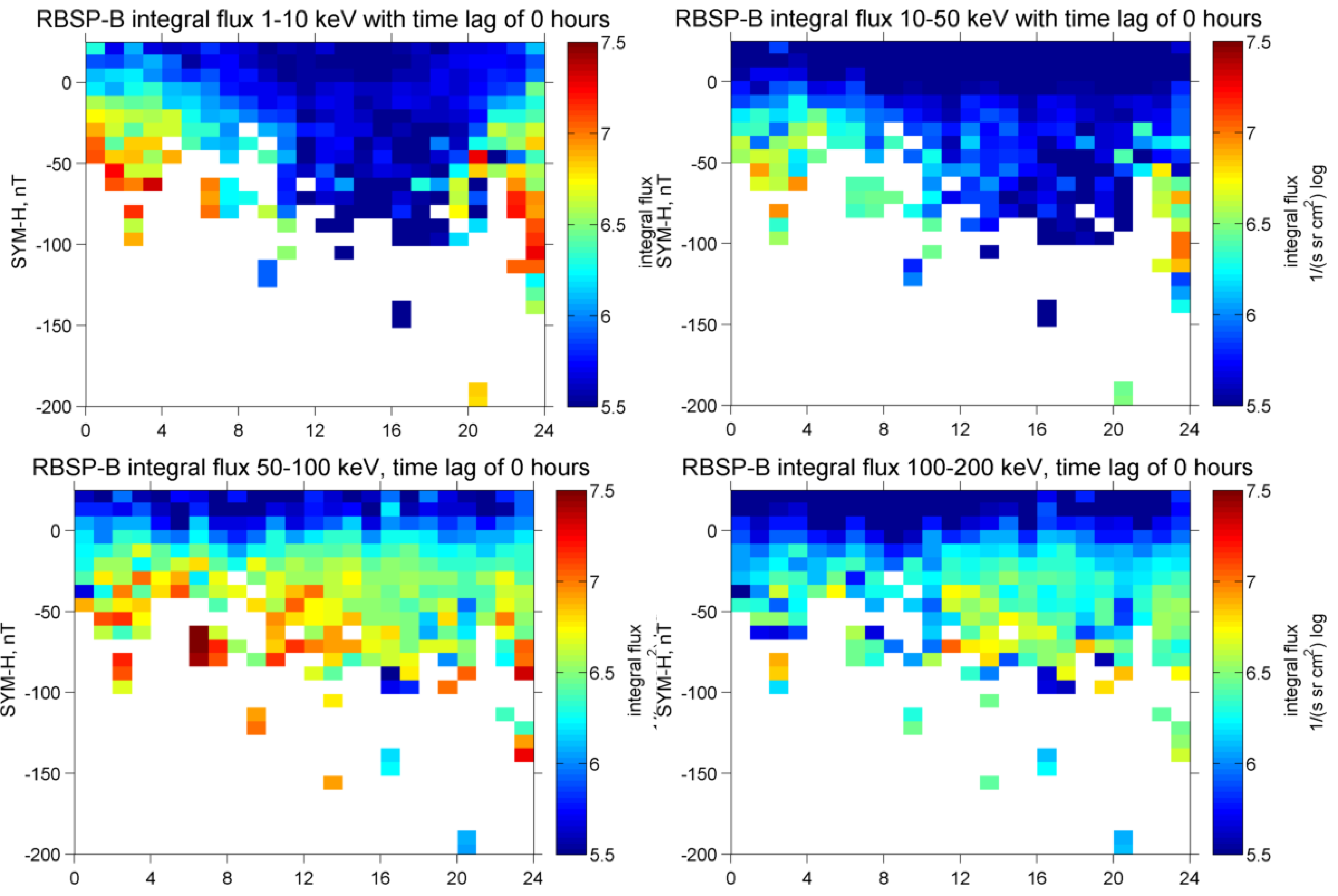
keV electron fluxes at MEO: Psw



keV electron fluxes at MEO: Kp



keV electron fluxes at MEO: SYM-H



Summary

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

2. It is NOT necessary to have even a moderate storm for significant surface charging event to happen. Substorms are important.

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

4. Van Allen Probes electron fluxes at MEO: IMF and SW parameters and indices dependencies