Recent revisions of the IMPTAM model

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The Model: IMPTAM

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
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.

Modelling

Main question: which variations in the observed electron fluxes are caused by
(1) Variations of SW and IMF parameters (used in time-dependent boundary conditions, magnetic and electric fields;
(2) Electron losses;
(3) Variations of electromagnetic fields associated with substorms.

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)

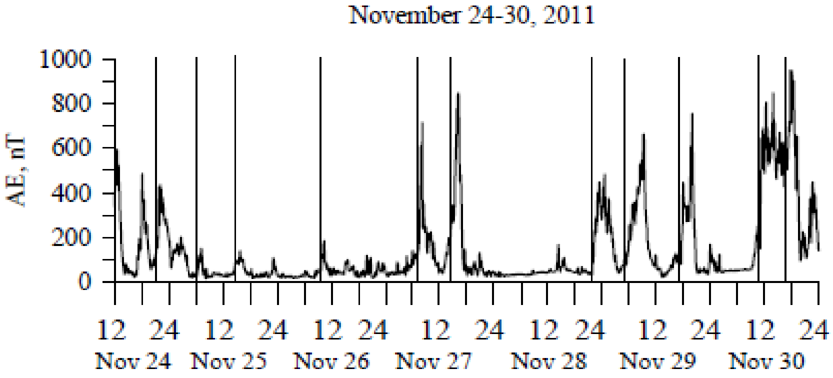
Losses: Kp, magnetic field
Strong diffusion (L=10-6): $\tau_{sd} = \left(\frac{\gamma m_0}{p} \right) \left[\frac{2\Psi B_h}{1-\eta} \right]$

Weak diffusion (L=2-6): $\tau_{wd} = 4.8 \cdot 10^4 B_w^{-2} L^{-1} E^2, \quad B_w^2 = 2 \cdot 10^{2.5+0.18Kp}$

Electromagnetic pulses at substorm onsets:

$$\mathrm{E}_\phi = -\mathrm{E}_0 \left(1 + c_1 \cos(\phi - \phi_0)\right)^p \exp\left(-\xi^2\right),$$

(*Li et al.*, 1998; *Sarris et al.*, 2002)
Timing and amplitude from AE index



Distribution function at the model's boundary

Previous studies:
we set the model **boundary at 10 R_E** and use the **kappa electron distribution** function. Parameters of the kappa distribution function: **number density *n* and temperature *T*** in the plasma sheet given by the empirical model derived from Geotail data by *Tsyganenko and Mukai* [2003].

In IMPTAM simulation, the **electron *n* is assumed to be the same as that for ions** in the model but **Te/Ti = 0.2** is taken into account (*Kaufmann et al.* [2005], *Wang et al.* [2012]).

Applying this model for boundary conditions has a number of **limitations**:

(1) Model was derived from Geotail data for ions.

(2) ratio Te/Ti can vary during disturbed conditions.

(3) at distances closer than 10 Re, the correlation between Ti and Te might not exist at all and no certain ratio can be determined (*A. Runov*, 2015, private communication).

(4) simple $\sin^2$ MLT dependence.

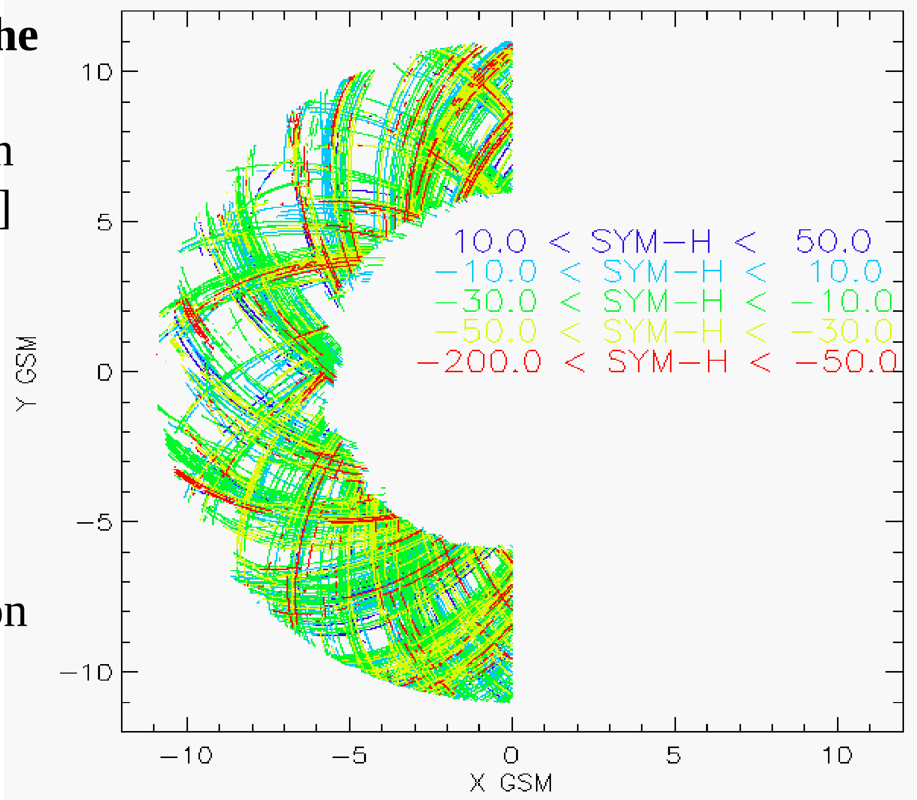
Revision of boundary conditions in the plasma sheet using THEMIS data

THEMIS data for ions and electrons used:
ESA (a few eV up to 25 (30) keV) and **SST** (25 keV- few MeVs).

Data for **storm periods**: All the periods with SYM-H<-50nT and one day before and one day after these periods for 2007-2013. The quiet periods before the storms are also in our database.

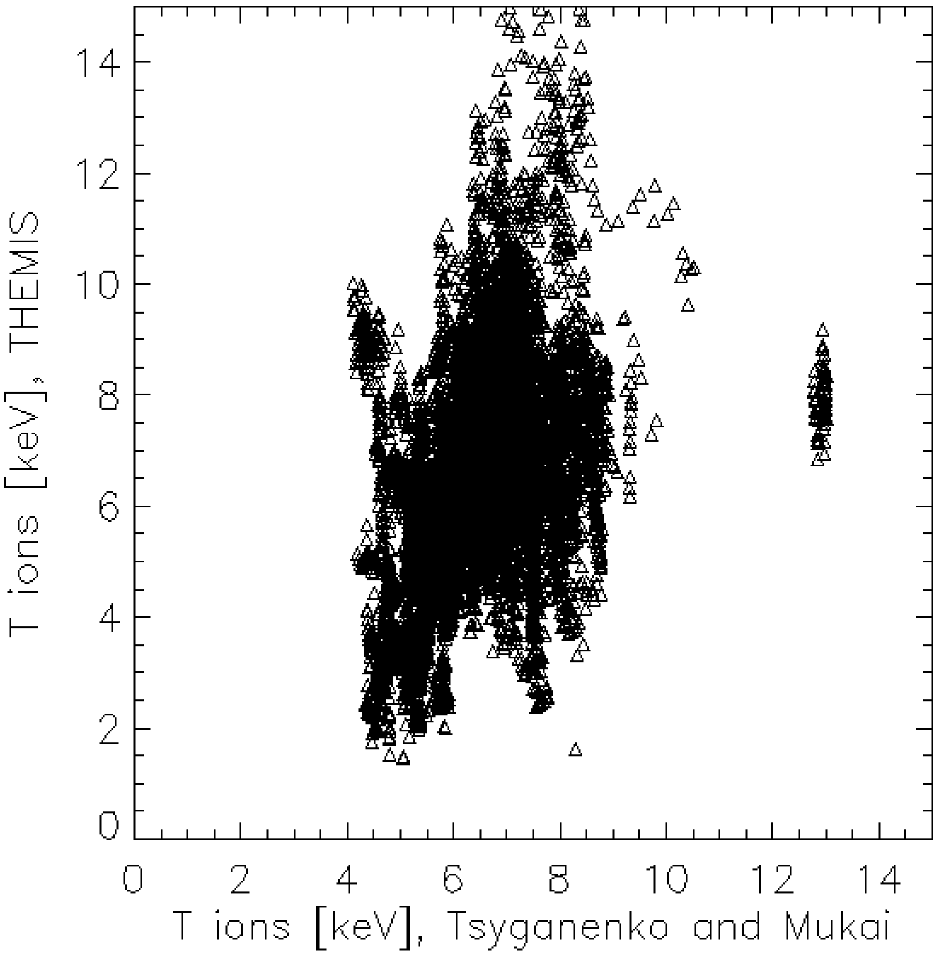
To control the **spacecraft position relative to the neutral sheet** (R =6-11 R_E):
(1) Select all periods when the probes are within 1.5Re from the *Tsyganenko and Fairfield* [2004] model neutral sheet;
(2) Select only measurements when $|B_N|>|B_T|$, where B_N and B_T are the normal and tangential to the model neutral sheet.

Then we computed the **plasma moments** using last calibration procedures. After synchronization of the solar wind data with THEMIS plasma moments we got ~66,000 datapoints.



Comparison of ion temperatures from THEMIS data and *Tsyganenko and Mukai* [2003] model

Subset of the data with R=10-10.5 R_E used.

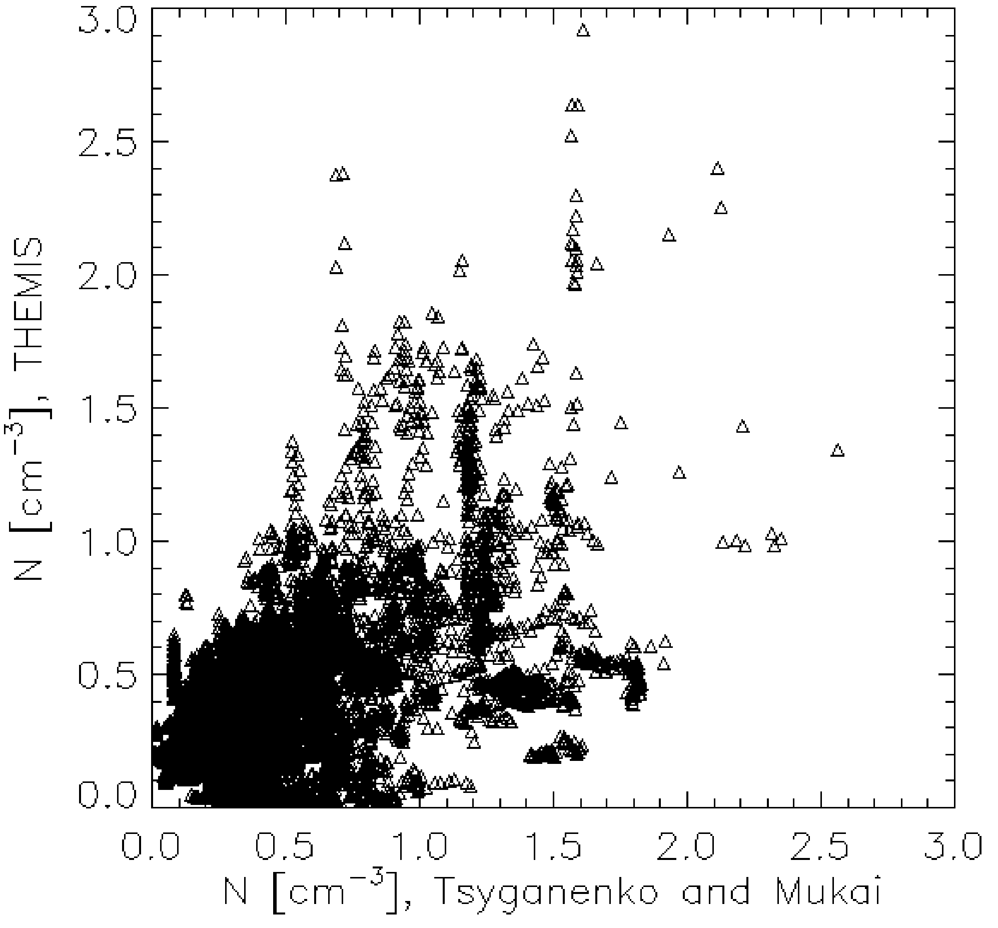


Correlation is very low (CC = 0.22) in comparison with high correlation obtained for such comparison in TM03 paper (CC=0.7).

Due to limited range of radial distances in our comparison while the whole range of the Geotail (R=10-50 R_E) was used in TM03 model.

However, the points mostly fit the TM03 dependence confirming high quality of the THEMIS plasma data.

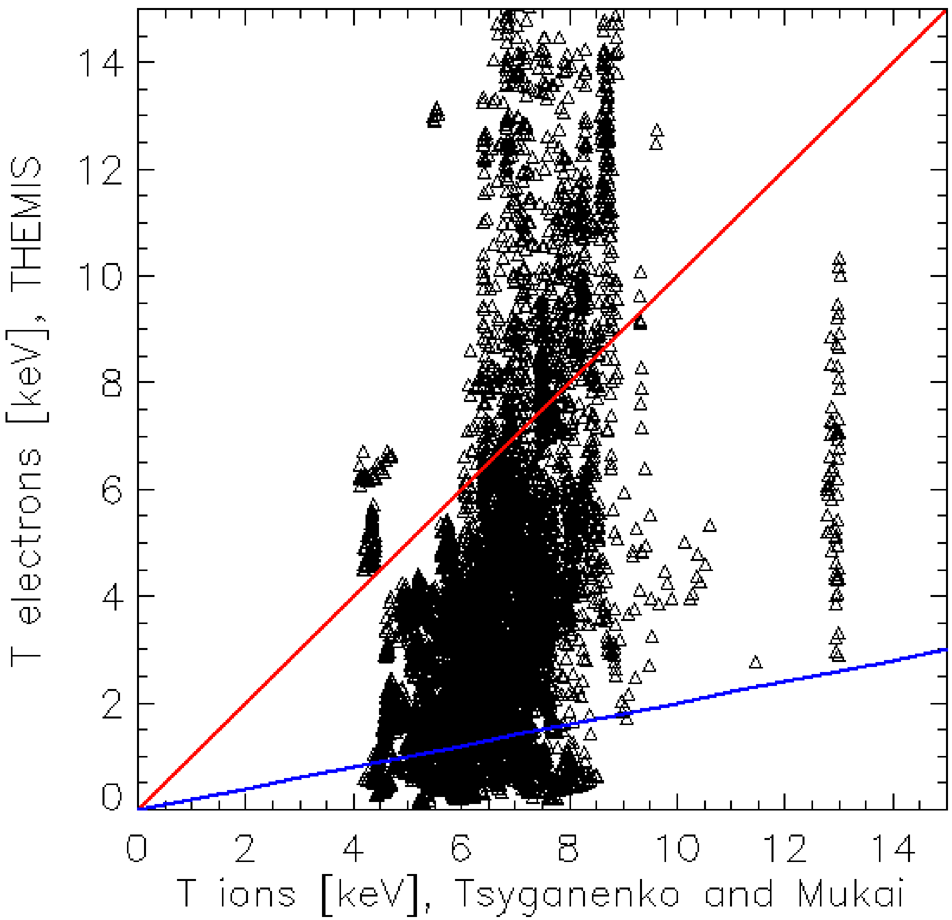
Comparison of number densities of electrons from THEMIS data and of ions from *Tsyganenko and Mukai* [2003] model



The correlation is 0.49
(close to 0.56 by TM03) in spite of limited range of the radial distances.

The TM03 equation for number density for ions can be used for electrons for IMPTAM simulation.

Comparison of temperatures of electrons from THEMIS data and of ions from *Tsyganenko and Mukai* [2003] model



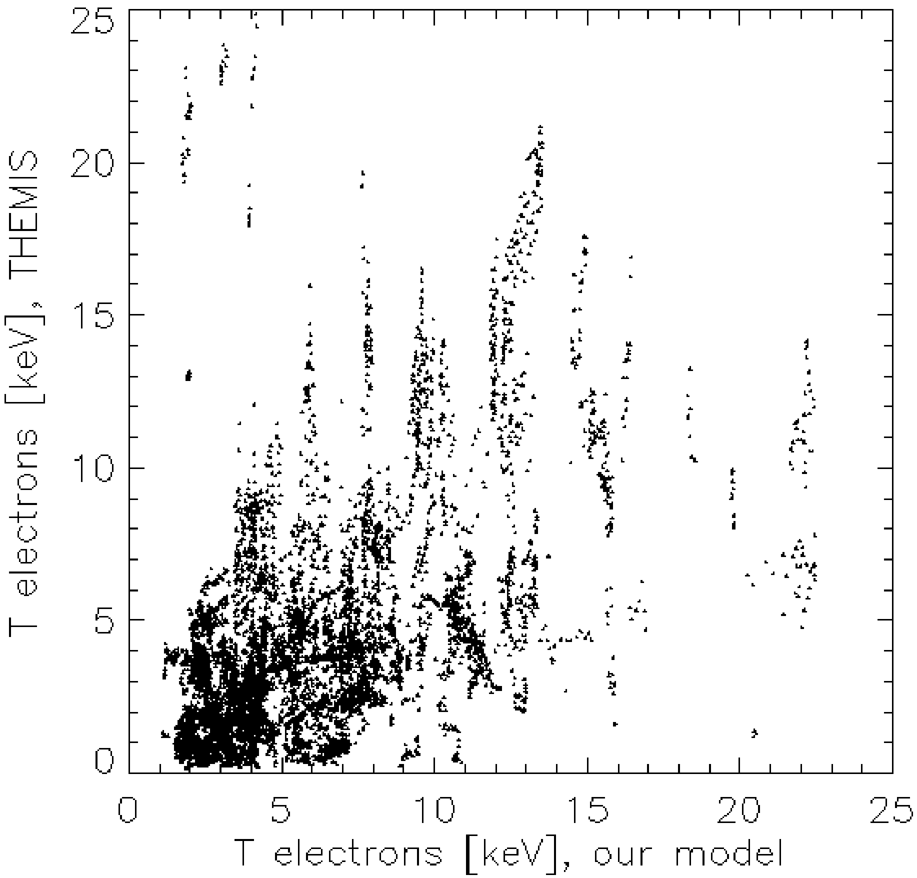
Red line: Te=Ti
Blue line: Te=Ti/5

If the relation Te=Ti/5 would have been valid in this region, the points would be distributed along blue line.

TM03 ion temperature shows **almost no correlation** with measured electron temperature.

Similar to *Runov* [2015] (private communication): there is **no correlation between Ti and Te at geocentric distances closer than R=12Re.**

Empirical model for electron temperature at 6-11 R_e



It was found that only **solar wind velocity** shows prominent correlation with electron temperature for at 6-11 R_E.

Model depending on R, Ψ, and V_{sw}, where R is the radial distance, Ψ is the azimuthal angle from midnight in radians,

$$\Psi = arctg\left(-\frac{Y_{GSM}}{X_{GSM}}\right)$$

and V_{sw} is the solar wind velocity.

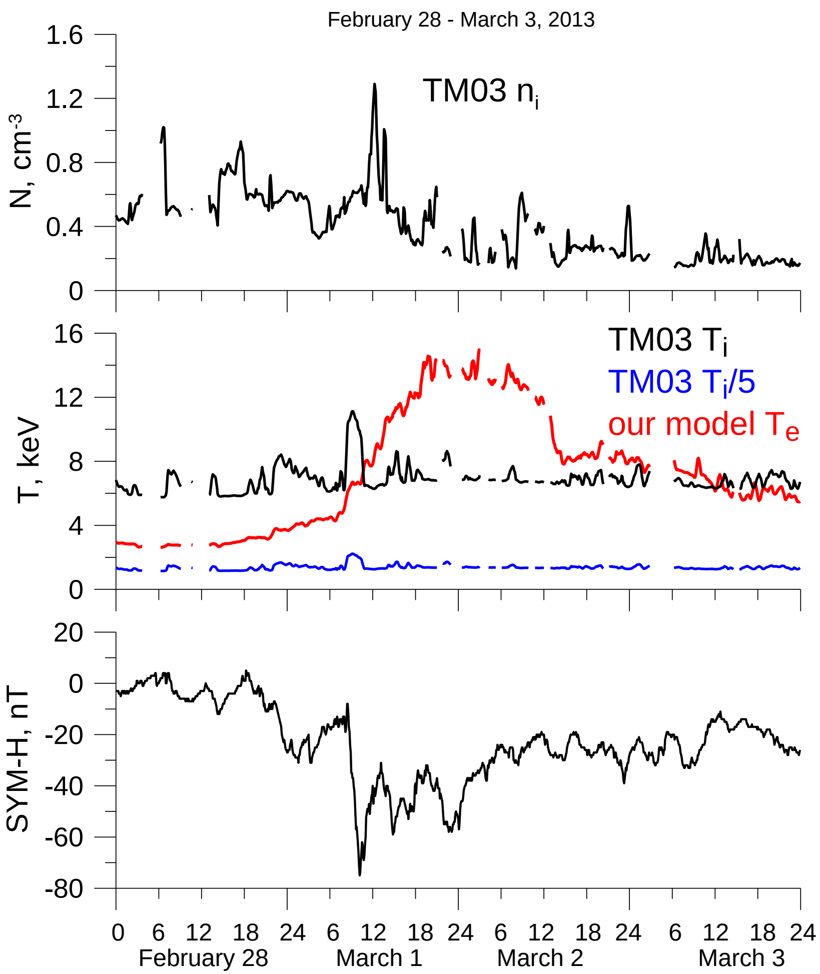
R and V_{sw} are normalized by 10 R_E and 500km/s.

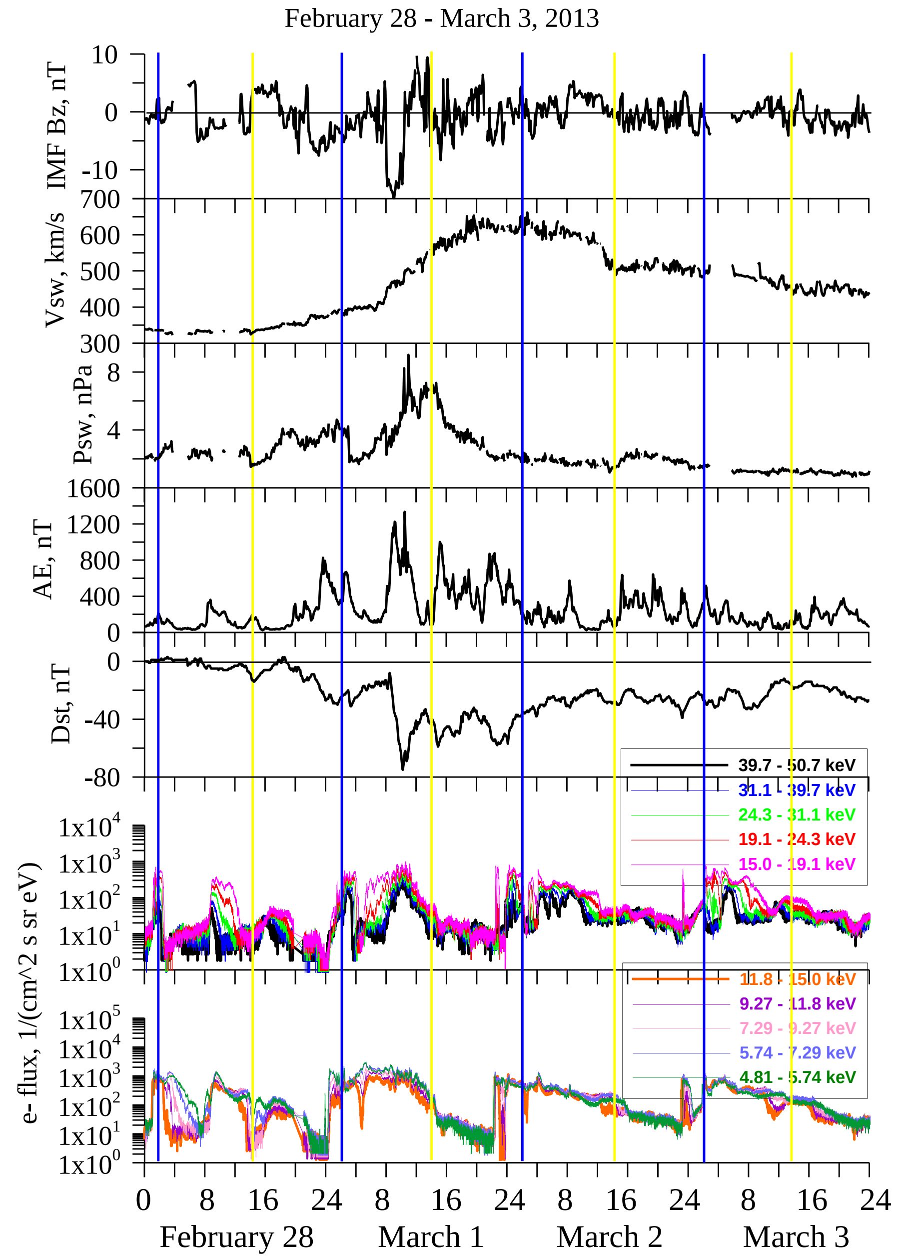
The **correlation coefficient** for the whole range of distances R= 6-11 R_E is **0.54.**

$$T_e = \begin{bmatrix} 2.84 - 2.90R - 0.0045\Psi + 0.00501\Psi^2 - 0.00386\Psi^2 R + \\ \left(2.34R - 0.00183\Psi^2\right)Vsw \end{bmatrix}^{2.5}$$

AMC 12 CEASE II ESA data

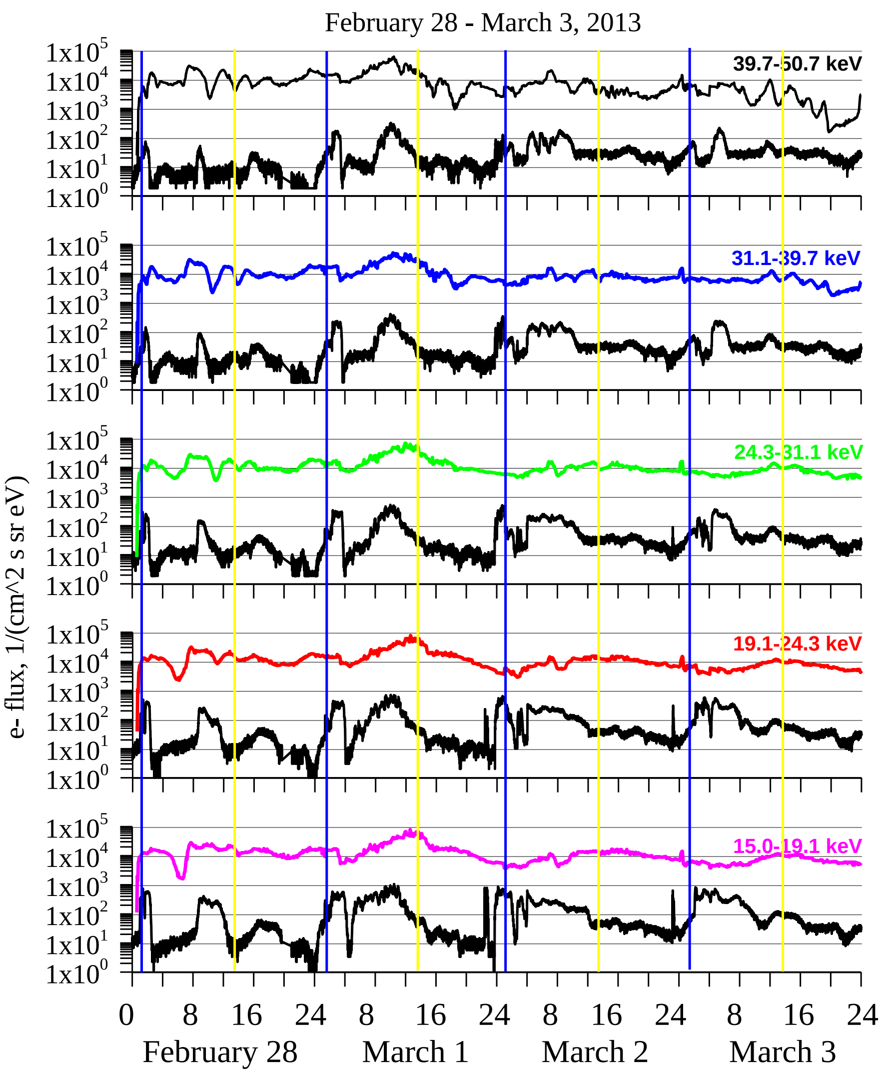
AMC 12 geostationary satellite, CEASE-II instrument contains an Electrostatic Analyzer (ESA) for measuring low energy electron fluxes in 10 channels, 5 - 50 keV.



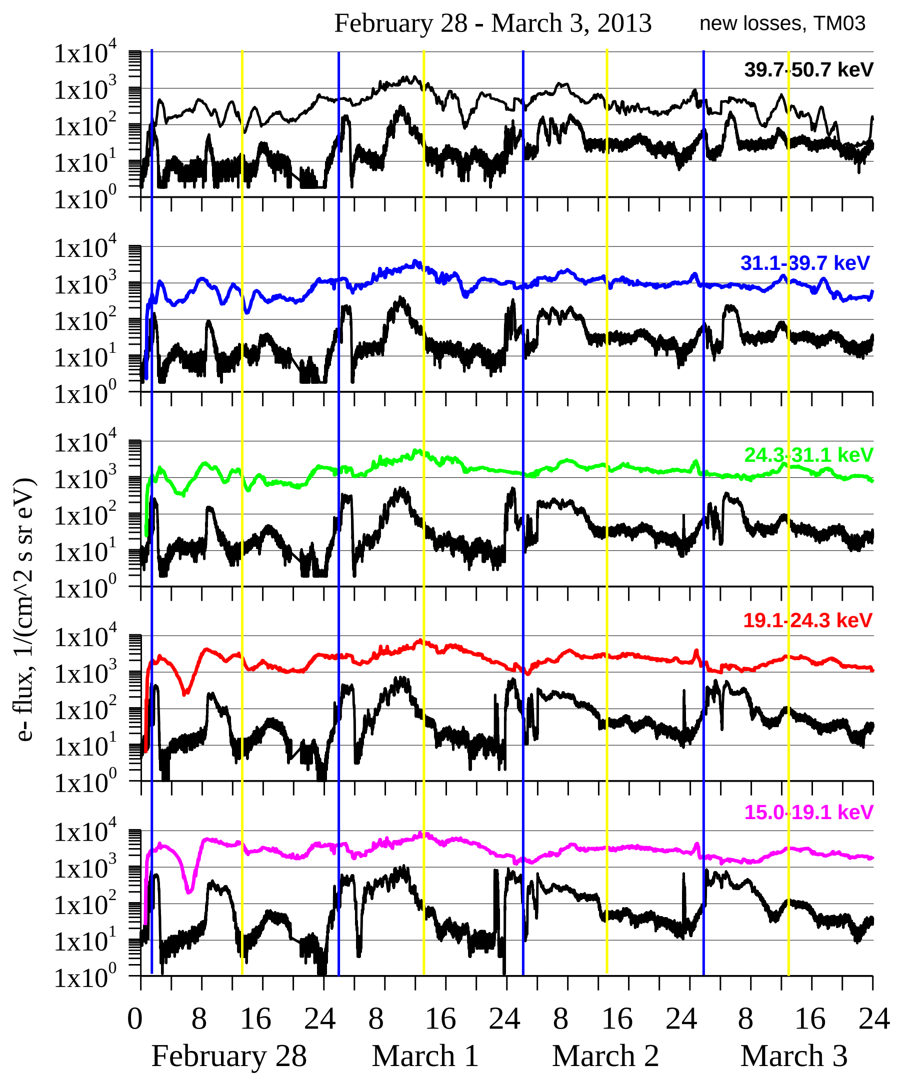


Electron fluxes observed by AMC 12 CEASE II ESA instrument for 15-50 keV energies and modeled. No losses are considered.

With *Tsyganenko and Mukai* (2003) boundary conditions

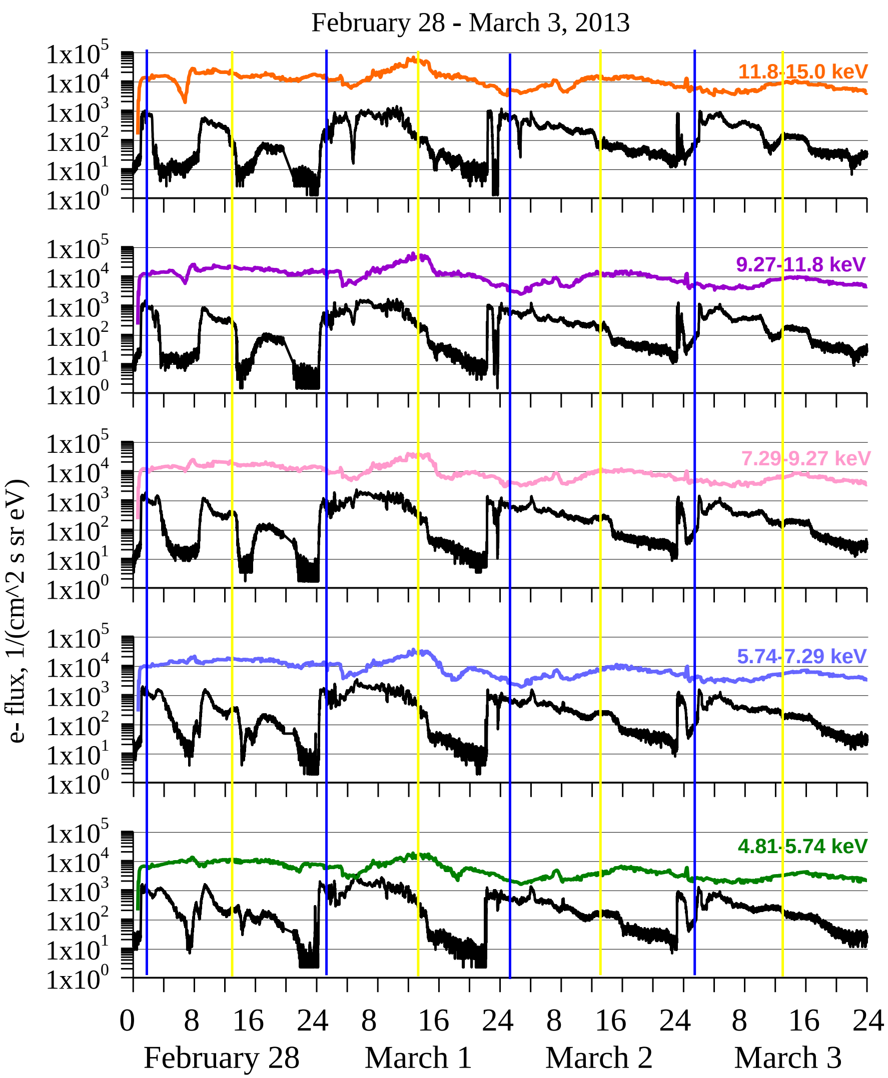


with newly developed model for boundary conditions based on THEMIS data

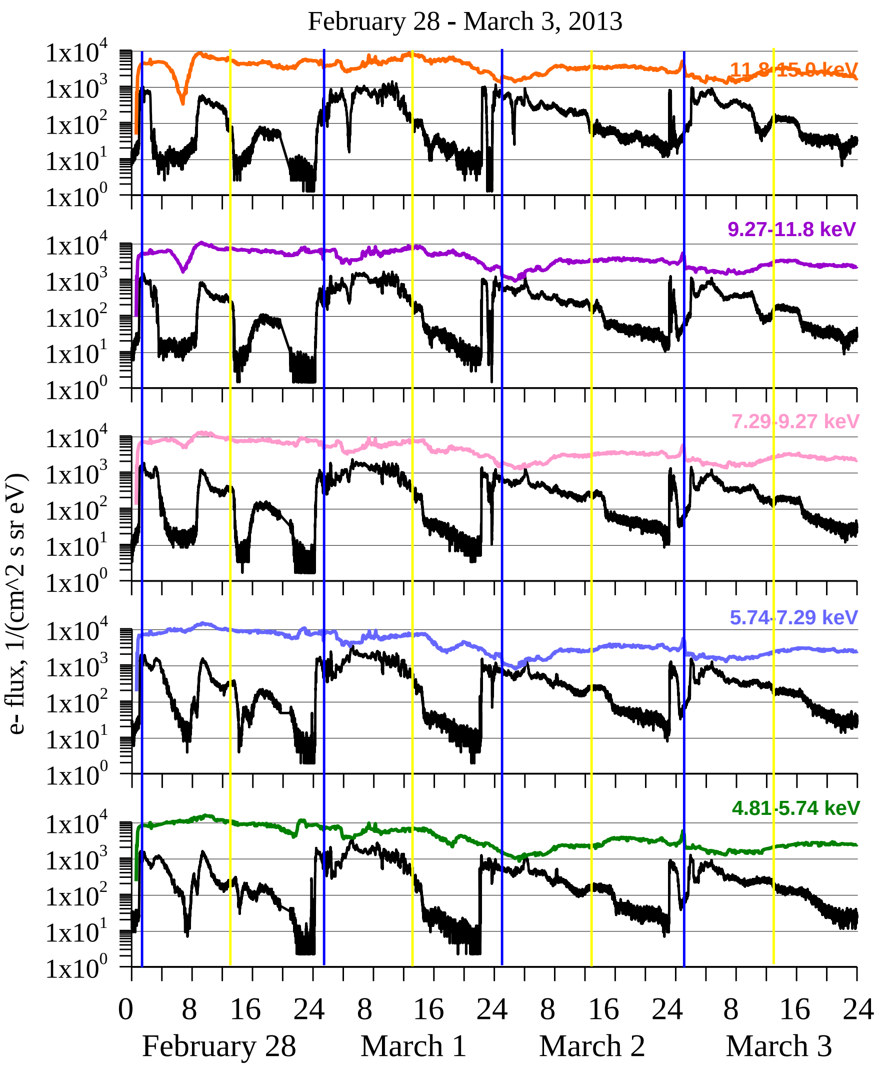


Electron fluxes observed by AMC 12 CEASE II ESA instrument for 5-15 keV energies and modeled. No losses are considered.

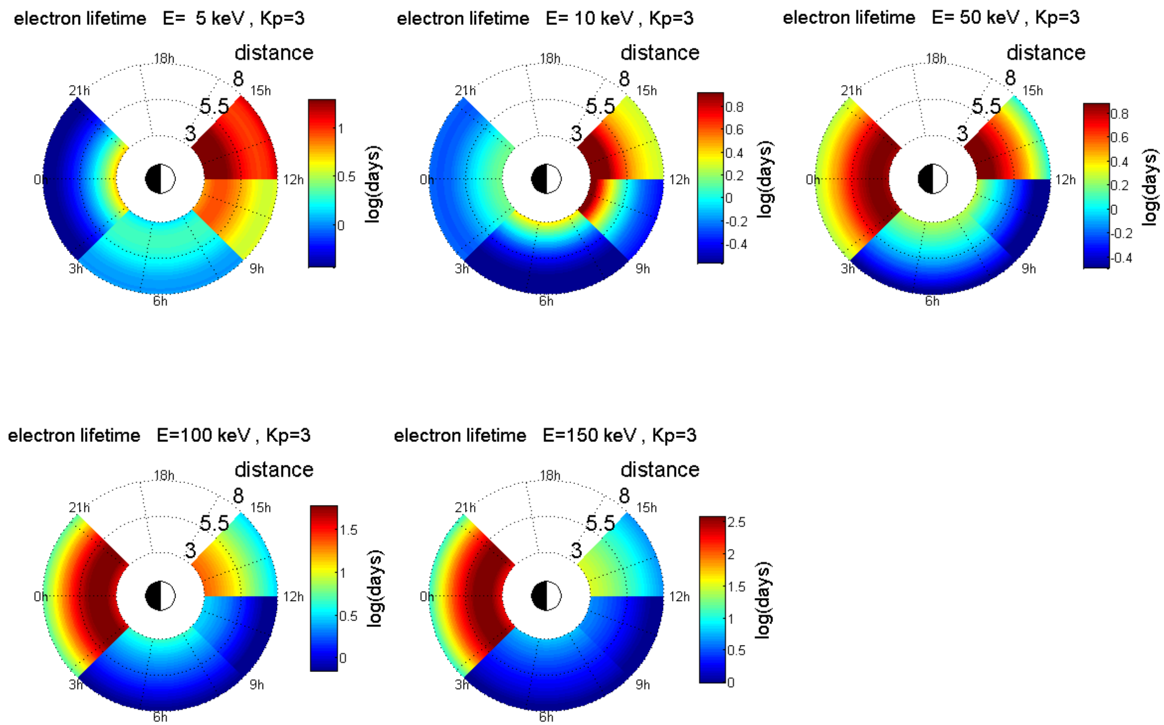
With *Tsyganenko and Mukai* (2003) boundary conditions



with newly developed model for boundary conditions based on THEMIS data

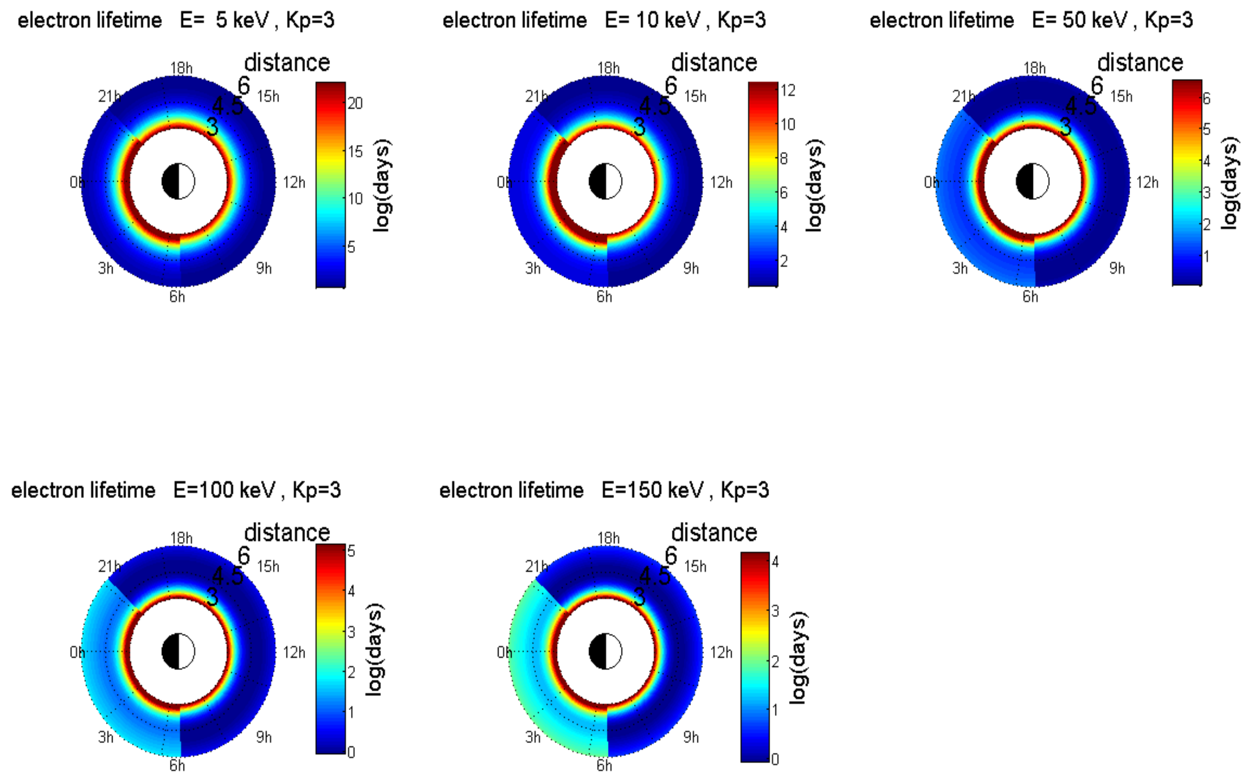


Losses for low energy electrons due to wave-particle interactions



Parameterization of the electron lifetimes due to interactions with chorus waves
[*Orlova and Shprits*, 2014]:
polynomial expressions with 33 coefficients dependent on energy, radial distance, MLT sector and Kp.
The model can be used for R=3-8 R_E, Kp= 0-6, and electron energies from 1 keV to 2 MeV. MLT sectors include the night (-3≤MLT≤3), dawn (3≤MLT≤9), prenoon (9≤MLT≤12), and postnoon (12≤MLT≤15) segments.

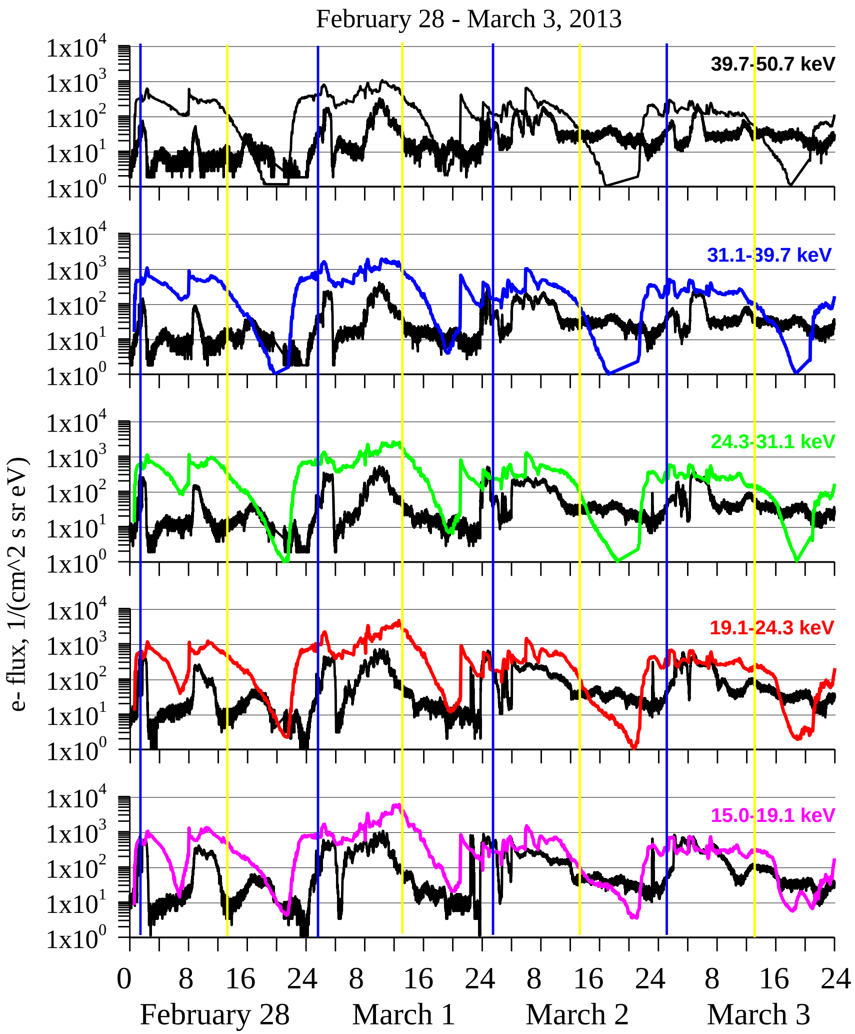
Losses for low energy electrons due to wave-particle interactions



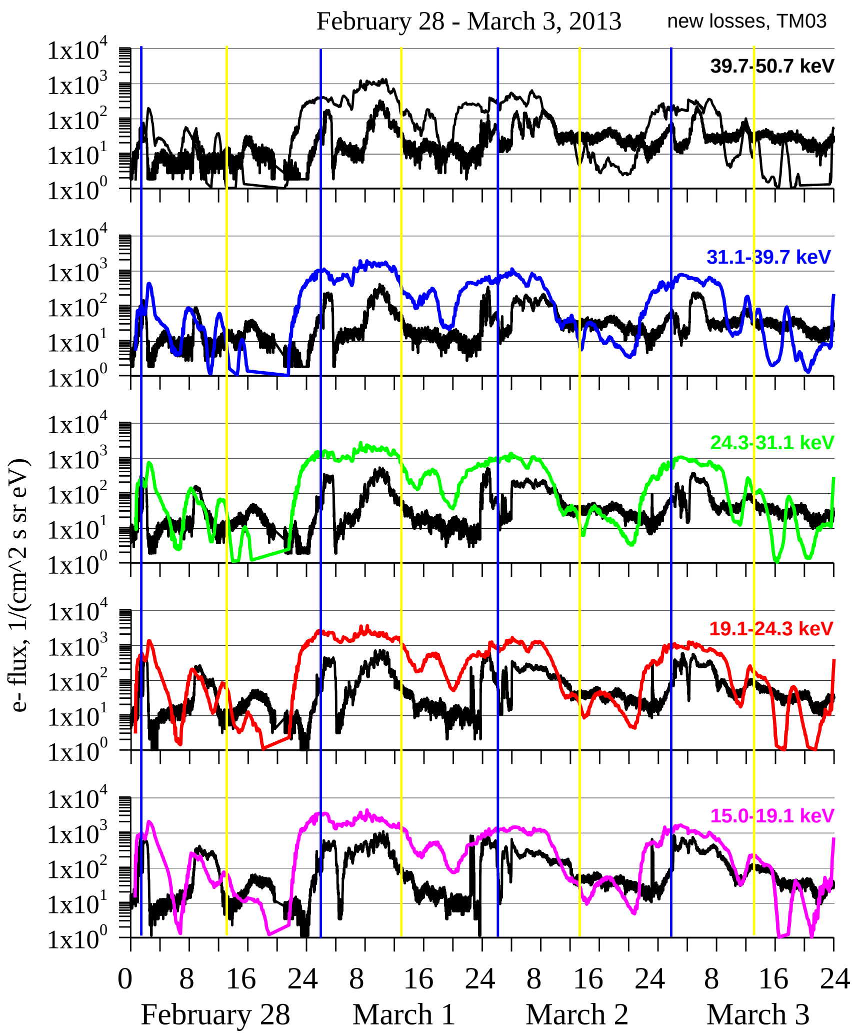
Parameterization of the electron lifetimes due to interactions with hiss waves
[*Orlova et al.*, 2014]:
two sectors, nightside at 21-06 MLT and dayside at 06-21 MLT,
with corresponding coefficients. The obtained parameterization is valid for distances from 3 to 6 Re, *Kp*-indices up to 6, and energies from 1 keV to 10 MeV.

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

with **TM03** model and ***Chen et al.* [2005]** electron lifetimes for strong and ***Shprits et al.* [2007]** for weak diffusion

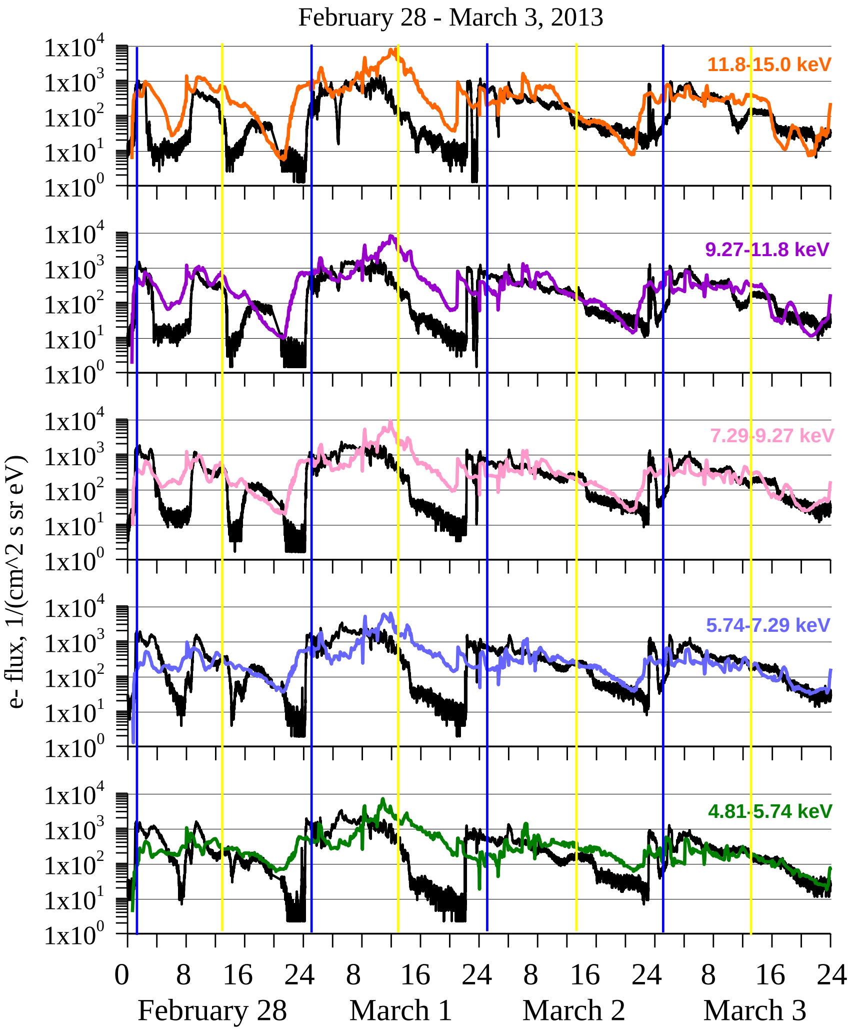


With **THEMIS** model and ***Orlova and Shprits* [2014] and *Orlova et al.* [2014]** electron lifetimes

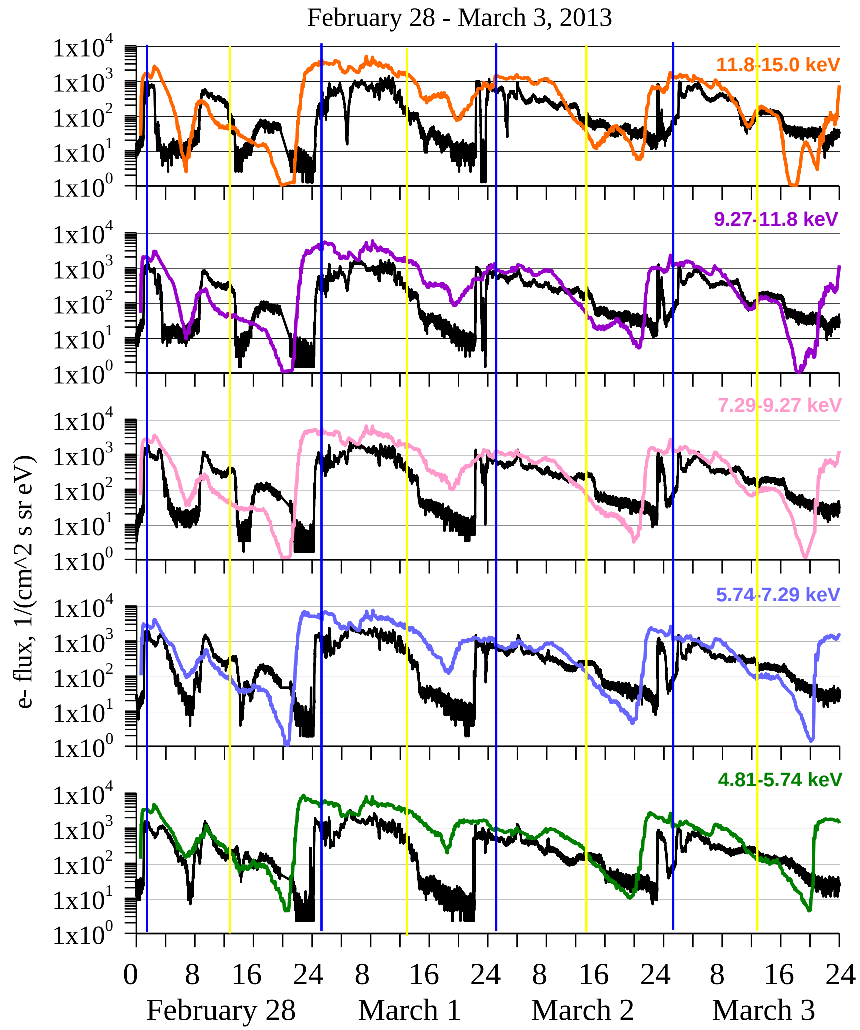


Electron fluxes observed by AMC 12 CEASE II ESA instrument for 5-15 keV energies and modeled

with **TM03** model and ***Chen et al.* [2005]** electron lifetimes for strong and ***Shprits et al.* [2007]** for weak diffusion



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



Summary

1. A revision of the source model at 10 Re in the plasma sheet was done. The particle data from THEMIS ESA and SST instruments were analyzed for years 2007-2013 and a new empirical model for electron temperature and number density in the plasma sheet was developed. We plan to conduct more validation studies comparing the model output with data from other satellites which were not used for the development of the model such as Cluster, Polar, Geotail.

2. 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]. When these losses and new boundary conditions incorporated into IMPTAM, the modeled fluxes follow reasonable well the observed ones. The comparison was done for AMC 12 CEASE II electron data for 5-50 keV. At the same time, there are time intervals, especially during storm main phase, when there are deviations of modeled fluxes from the observed. We plan to continue working under correct loss processes for low energy electrons by incorporating pitch angle diffusion coefficients from radiation belts models.