Project No 637302

Horizon 2020, Call: H2020-PROTEC-2014

PROGRESS: Prediction of Geospace Radiation Environment and Solar Wind Parameters

WP5, Low energy electrons model improvements to develop forecasting products

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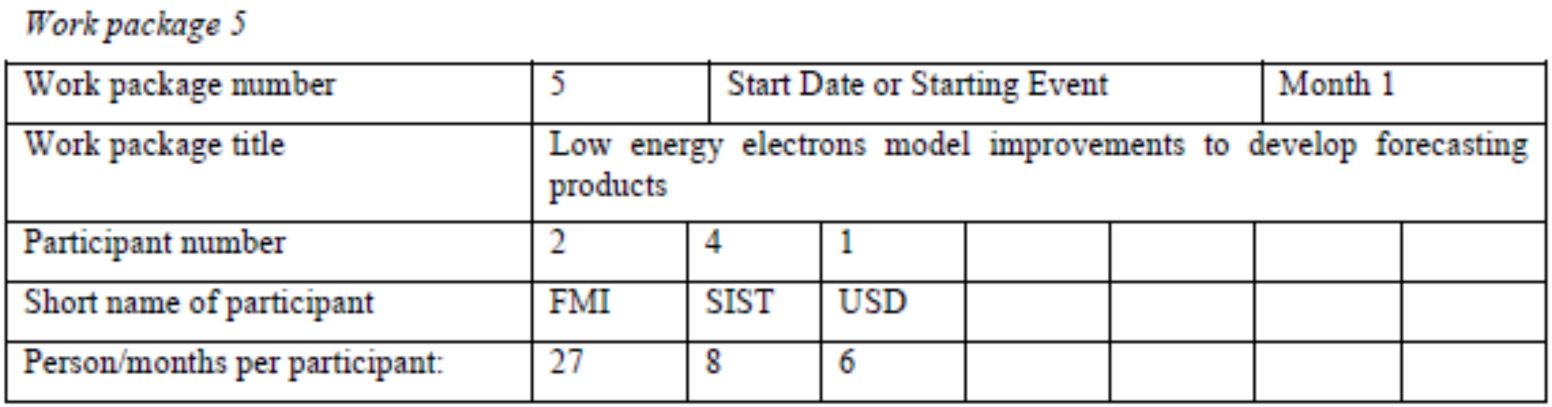
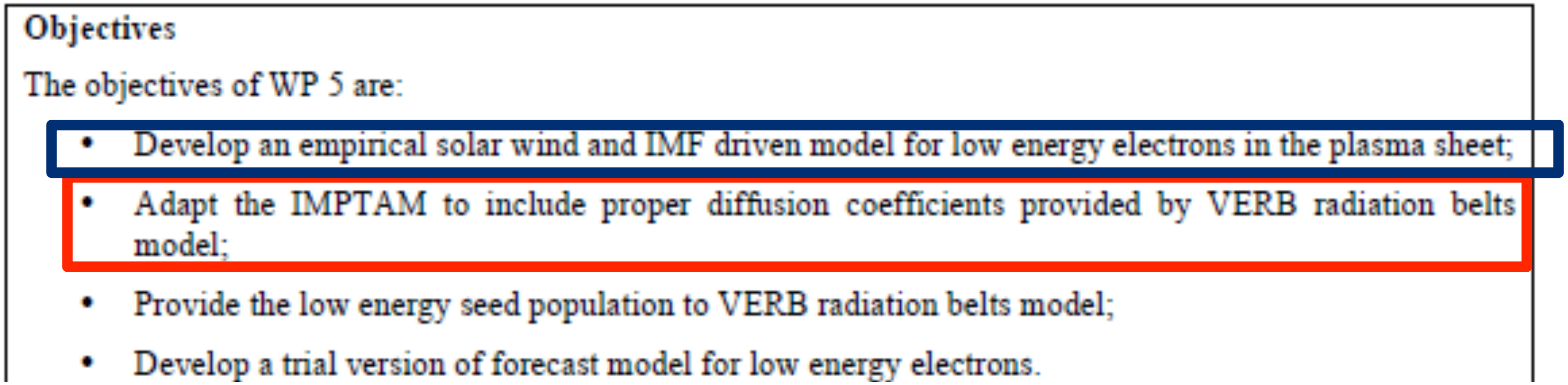
PROGRESS Annual Report and Steering Committee Meeting, 9-11 January 2017, Potsdam, Germany

WP5 (led by FMI, 27 months)



Work package 5

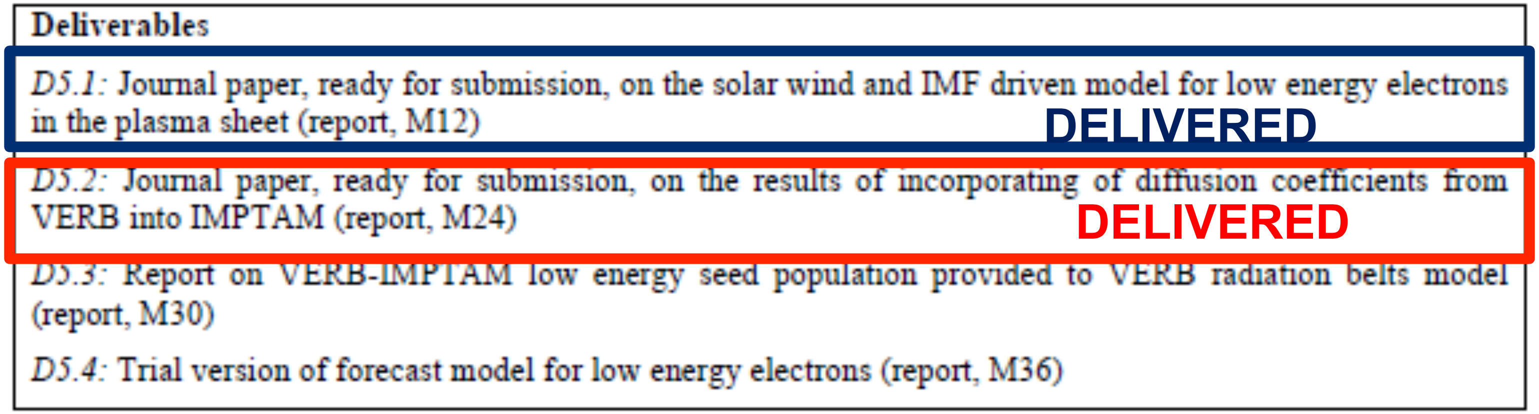
Work package number	5	Start Date or Starting Event		Month 1			
Work package title	Low energy electrons model improvements to develop forecasting products						
Participant number	2	4	1				
Short name of participant	FMI	SIST	USD				
Person/months per participant:	27	8	6				



Objectives

The objectives of WP 5 are:

- Develop an empirical solar wind and IMF driven model for low energy electrons in the plasma sheet;
- Adapt the IMPTAM to include proper diffusion coefficients provided by VERB radiation belts model;
- Provide the low energy seed population to VERB radiation belts model;
- Develop a trial version of forecast model for low energy electrons.



Deliverables

D5.1: Journal paper, ready for submission, on the solar wind and IMF driven model for low energy electrons in the plasma sheet (report, M12)

DELIVERED

D5.2: Journal paper, ready for submission, on the results of incorporating of diffusion coefficients from VERB into IMPTAM (report, M24)

DELIVERED

D5.3: Report on VERB-IMPTAM low energy seed population provided to VERB radiation belts model (report, M30)

D5.4: Trial version of forecast model for low energy electrons (report, M36)

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.

Run online in real time: imptam.fmi.fi

Electron losses in the inner magnetosphere

- Electron losses occur on the time scales of minutes or hours which is much shorter than those times for ions.

- In the inner magnetosphere, the dominating loss process is pitch-angle scattering due to wave-particle interactions.

- **Chorus** waves contribute significantly to the scattering processes of keV electrons **outside the plasmapause**. Electron pitch angle scattering occurs due to interactions with the plasmaspheric **hiss waves** **Inside the plasmasphere**.

- It is difficult to quantify globally the electron losses due to interaction with waves, since the rate of pitch-angle diffusion depends on the wave amplitude, wave frequency, and wave normal distributions, as well as the plasma density and background magnetic field.

Electron losses in IMPTAM

The electron losses due to wave-particle interaction are introduced in IMPTAM as an electron lifetime $\boldsymbol{\tau}_{\mathbf{eL}}$:

For every time IMPTAM solves:

1)Transport, using Liouville’ s theorem

2)Radial diffusion and losses

$$\frac{\partial f}{\partial t} = L^2 \frac{\partial}{\partial L}\left(L^{-2} D_{LL} \frac{\partial f}{\partial L}\right) - \frac{f}{\boxed{\tau_{eL}}}$$

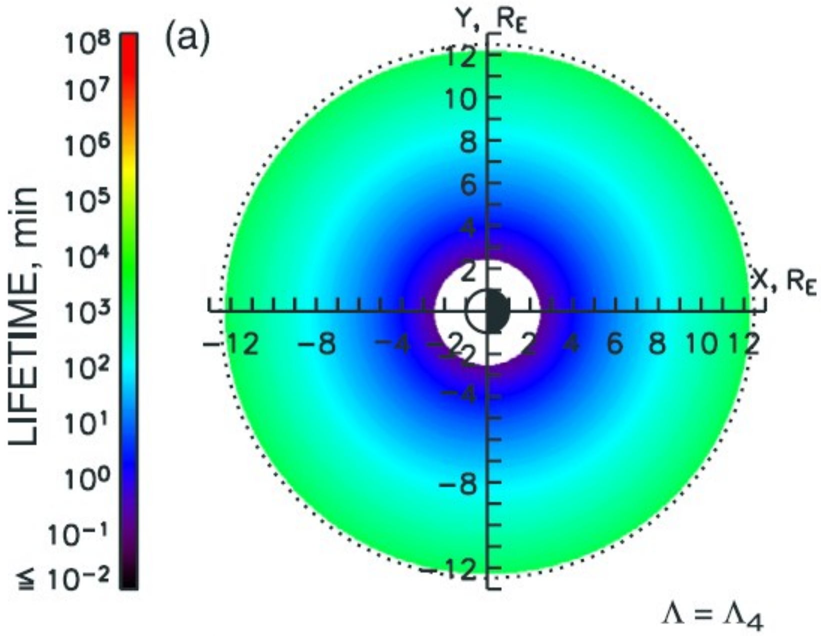
depends on location, activity

Previous IMPTAM version used electron lifetimes following *Chen et al.*, [2005] ; **Oversimplified, no activity dependence**

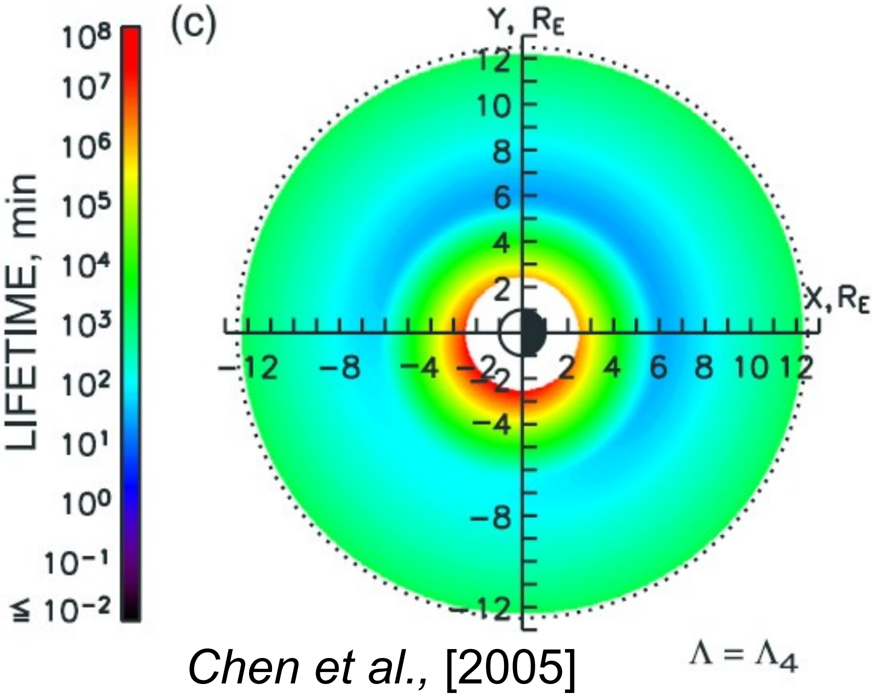
In this workpackage, we test a few empirical models of electron losses due to wave-particle interaction. The IMPTAM output is compared with in situ observations.

Electron losses, Empirical models

Chen et al., [2005] used strong-pitch angle diffusion approximation as well as "less than everywhere strong" diffusion with MLT dependence. The latter model was normalized to reproduce the experimental values of electron lifetimes *Roberts* [1969], *Van Allen* [1969]. No activity dependence is included.



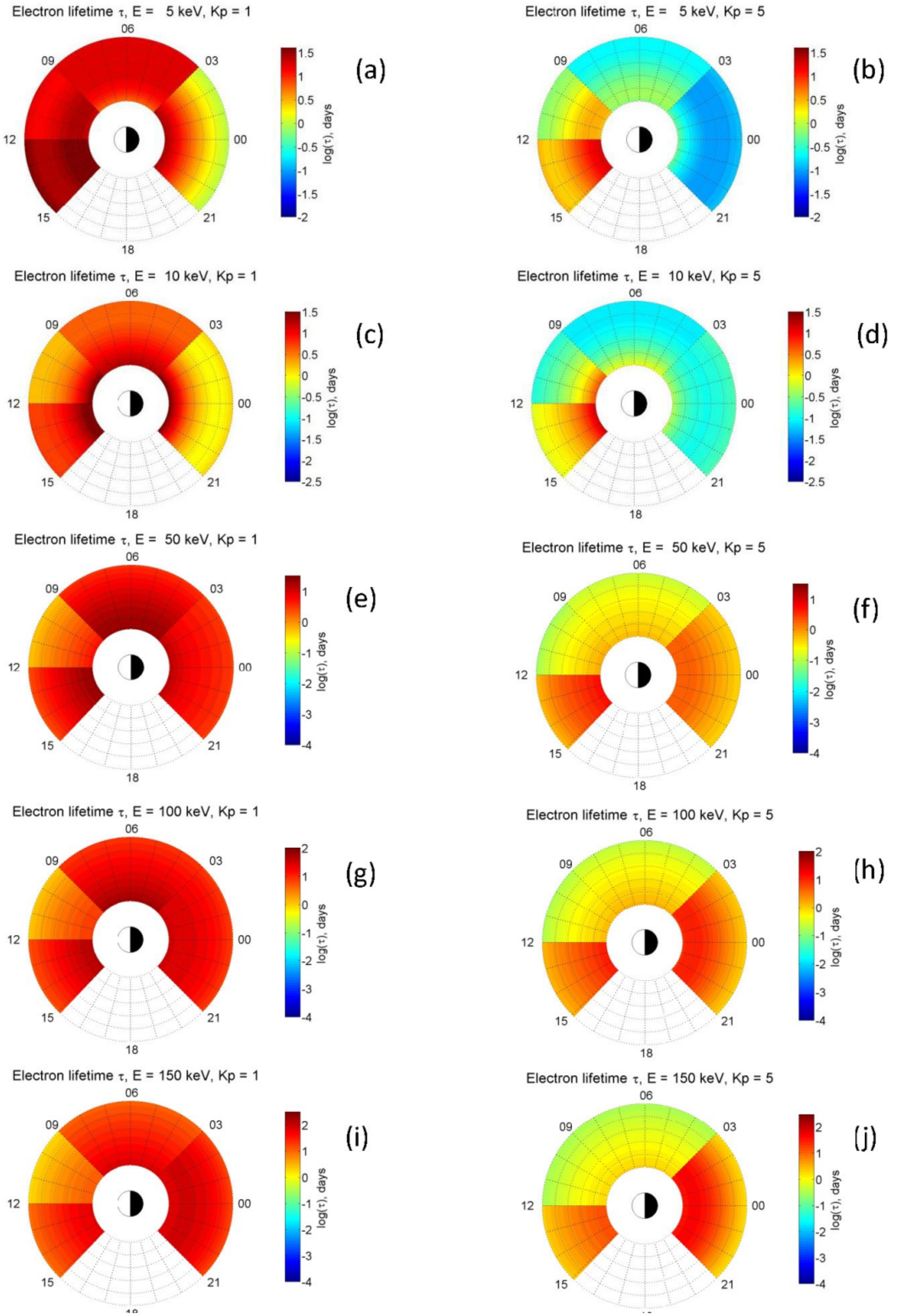
Chen et al., [2005]



Chen et al., [2005]

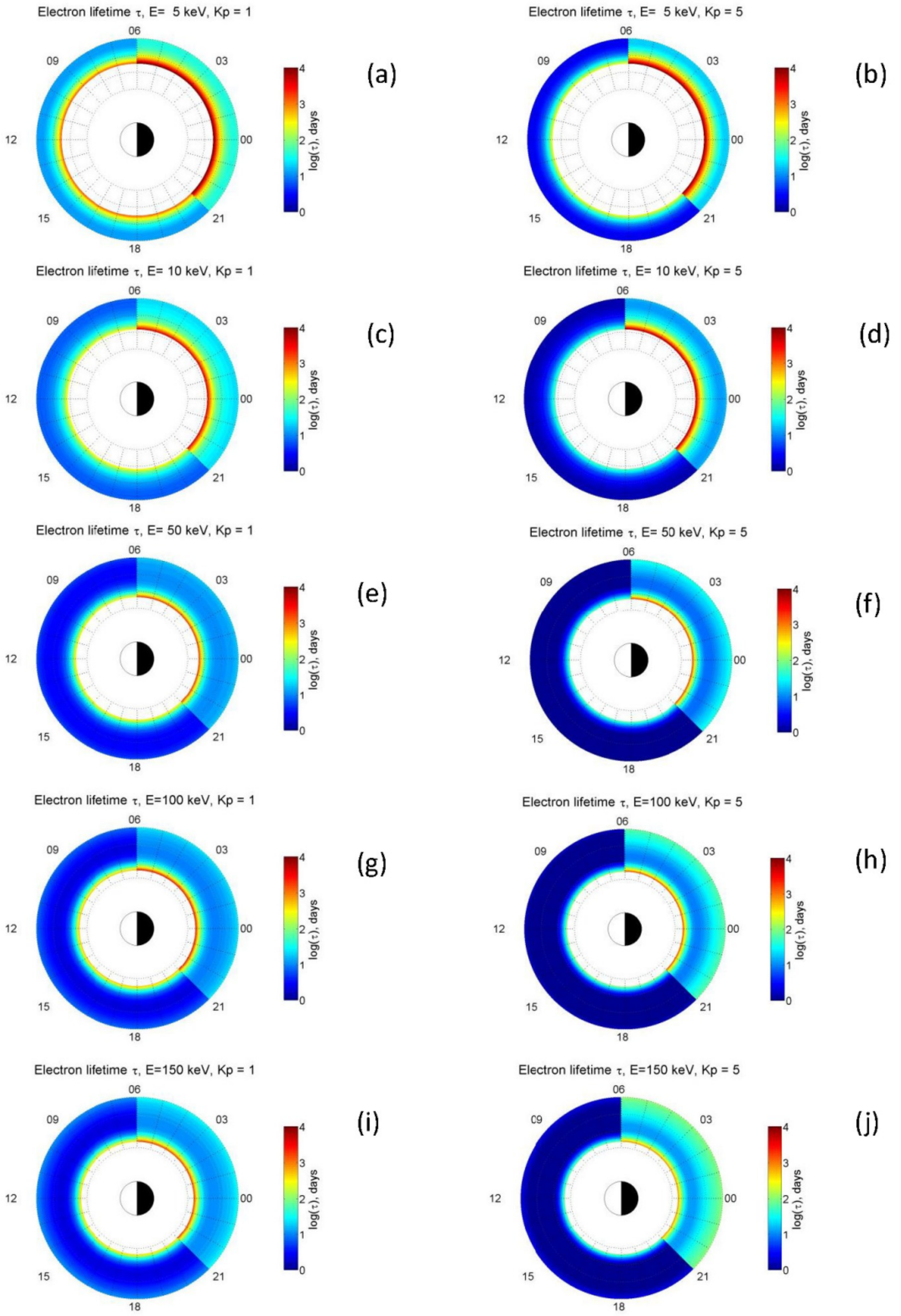
Electron losses, Empirical models

Shprits and Orlova [2014], electron lifetimes due to **<u>chorus waves</u>**. R=3-8 Re. Activity depedence is parameterized by Kp index.



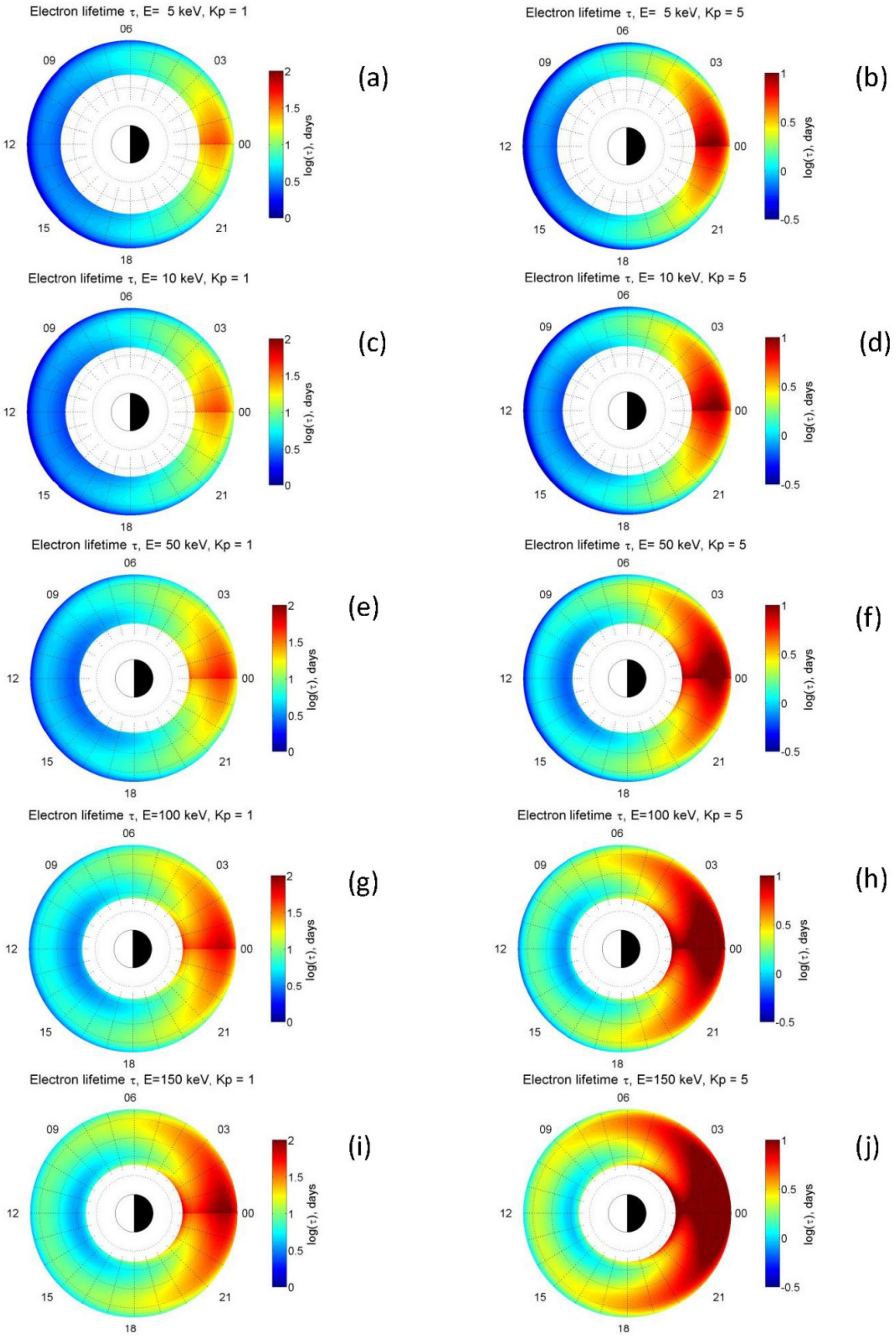
Electron losses, Empirical models

Orlova et al., [2014], electron lifetimes due to plasmaspheric **hiss waves**.
CRRES data were used.
R=3-6 Re.
Activity dependence is parameterized by Kp index.

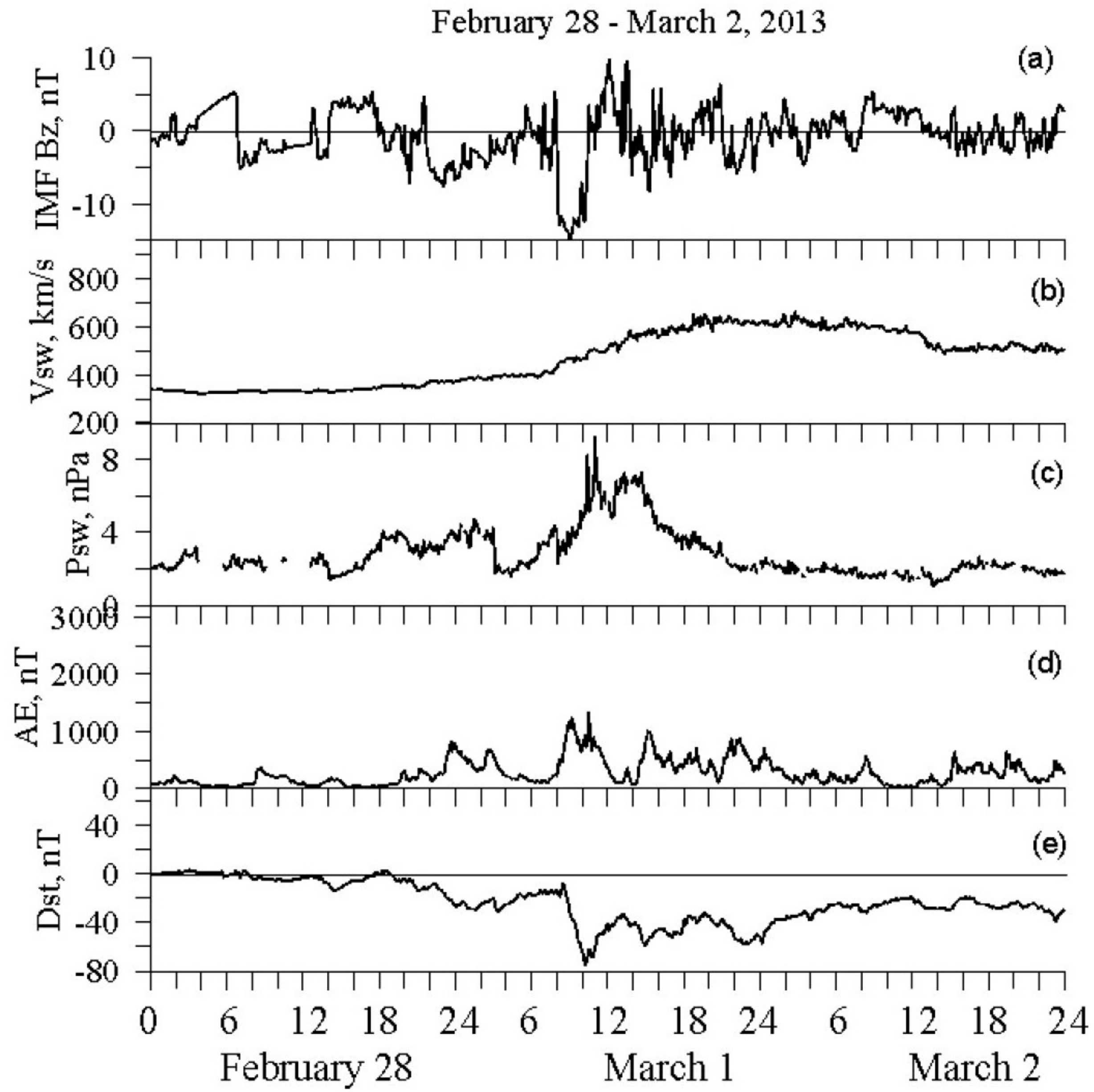


Electron losses, Empirical models

Orlova et al., [2016] electron lifetimes due to plasmaspheric **hiss waves**. Empirical model *Spasojevich et al.*, [2015] of hiss intensity obtained from Van Allen probe data were used. R=1.5-5.5 Re.
Activity dependence is parameterized by Kp index.



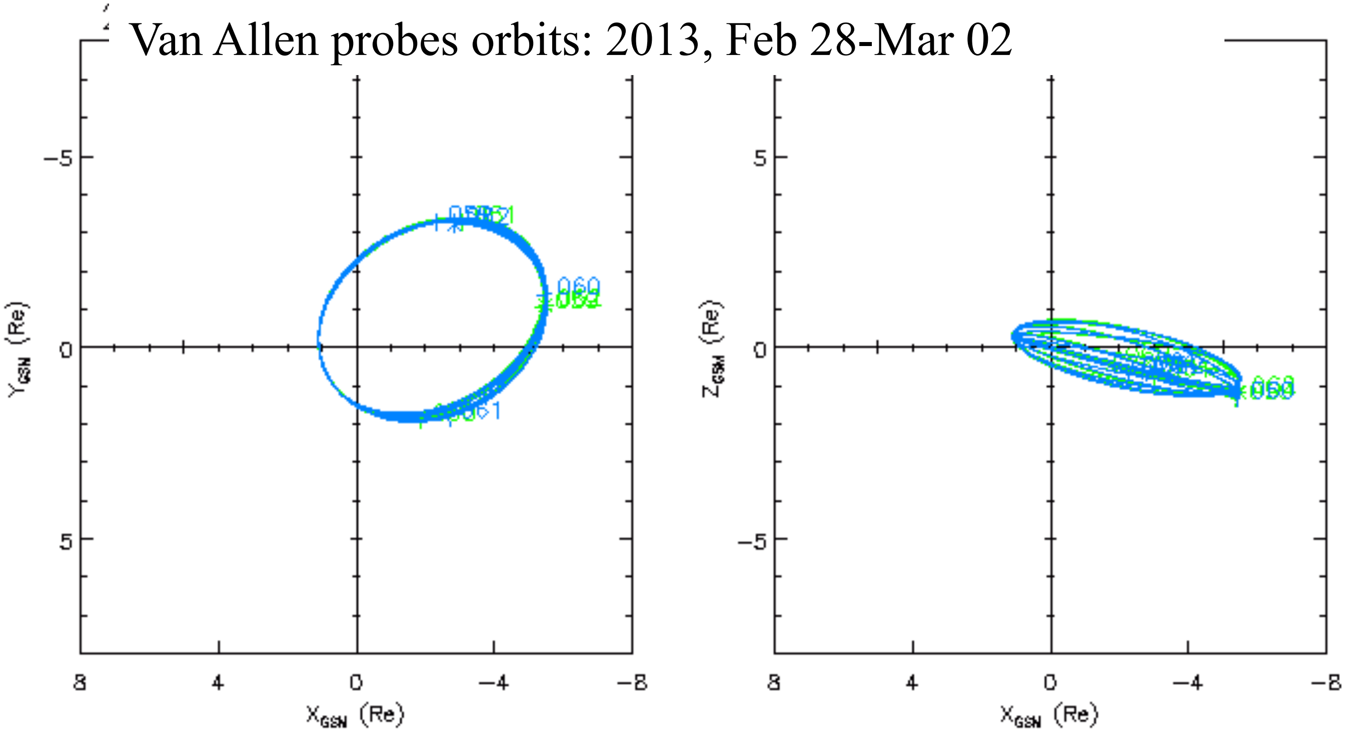
Event overview



Comparison with observations of electron fluxes

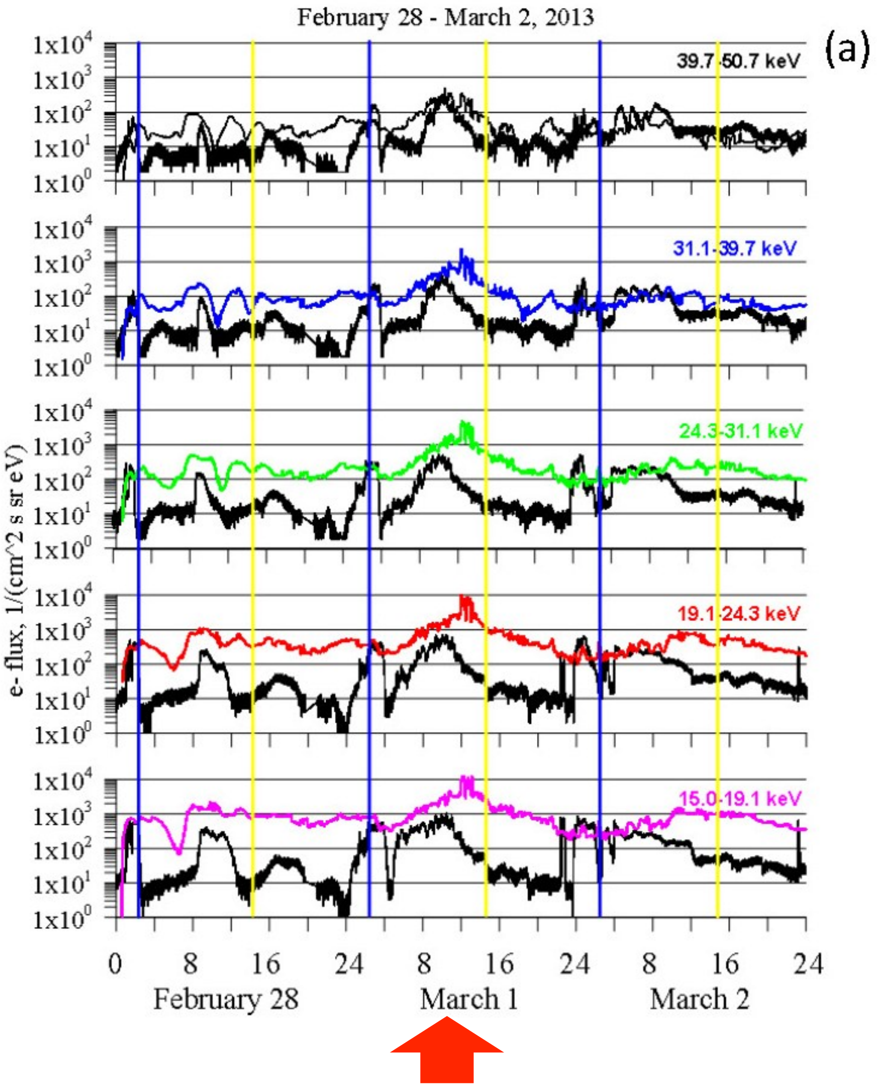
☐ AMC-12 (geosynchronous orbit)
ESA 5- 50keV, 10 energy channels

☐ Van Allen probes (aka RBSP), two probes on slightly elliptic orbits apogee 5.8Re, perigee 1.1 Re
HOPE instrument 30eV - 45keV
MagEIS instrument 30keV - 4MeV

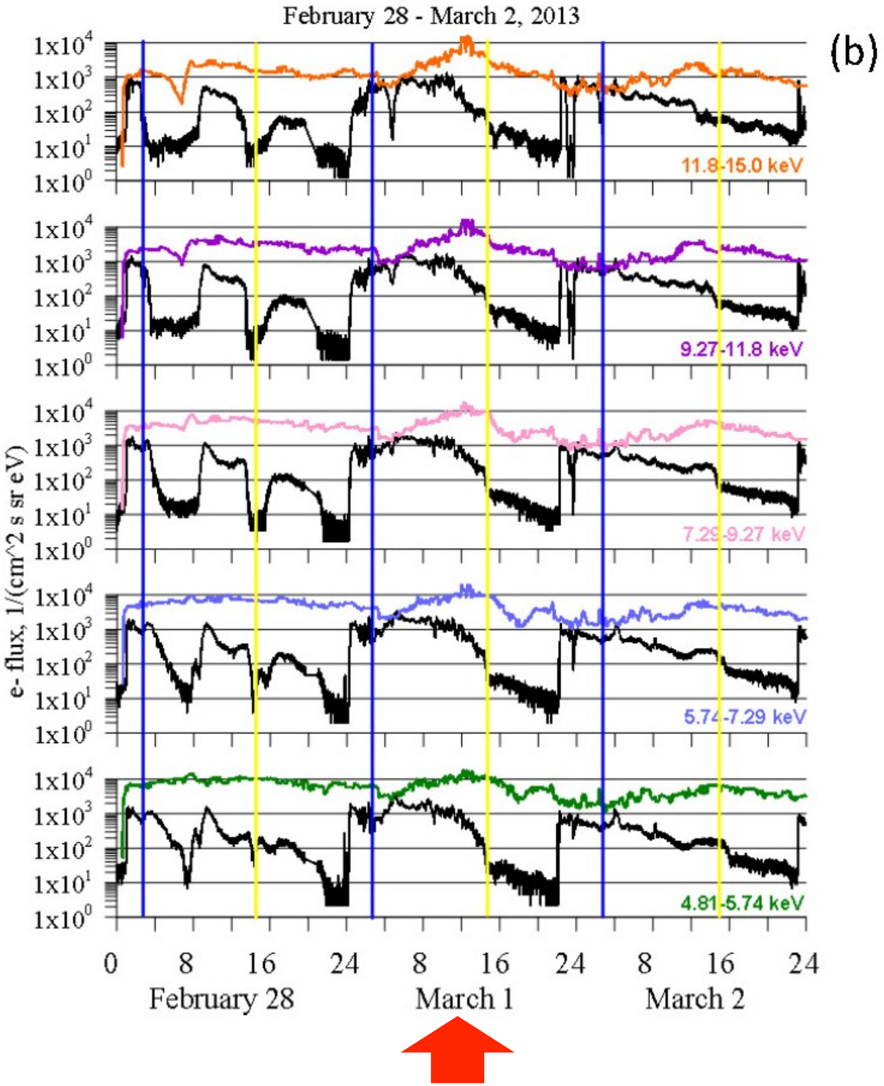


Van Allen probes orbits: 2013, Feb 28-Mar 02

No electron losses included; geosynchronous orbit

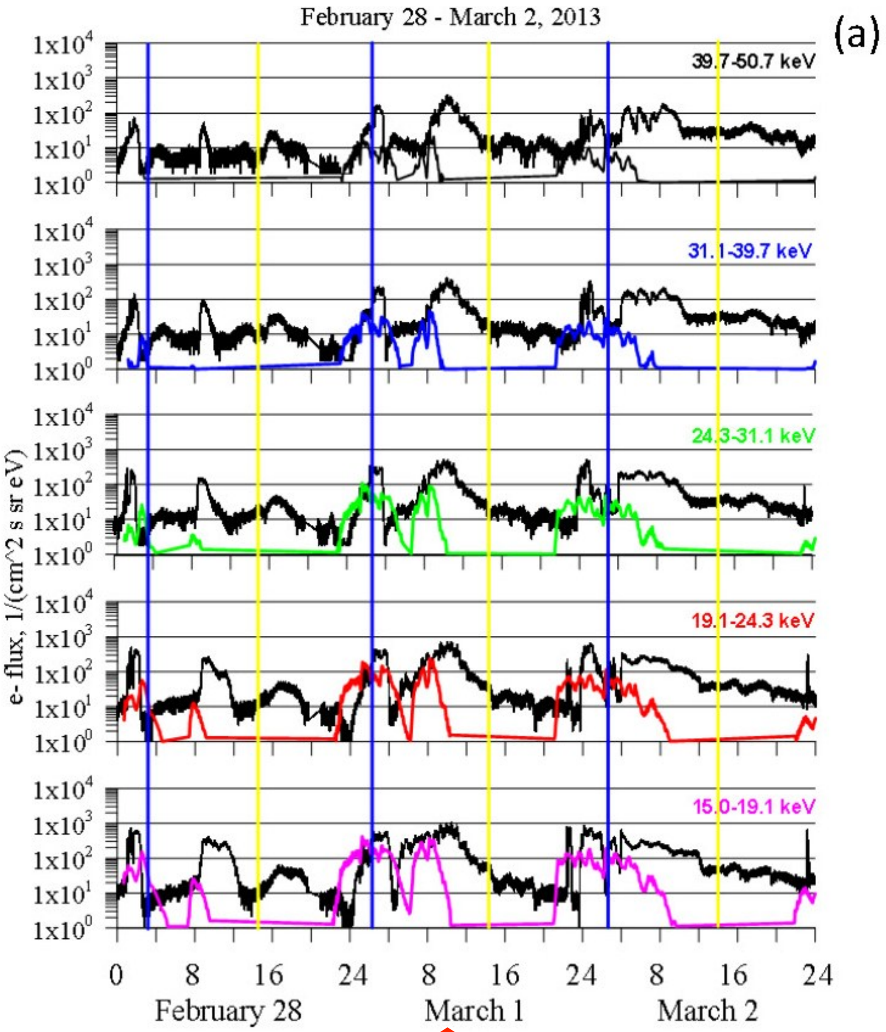


Storm peak

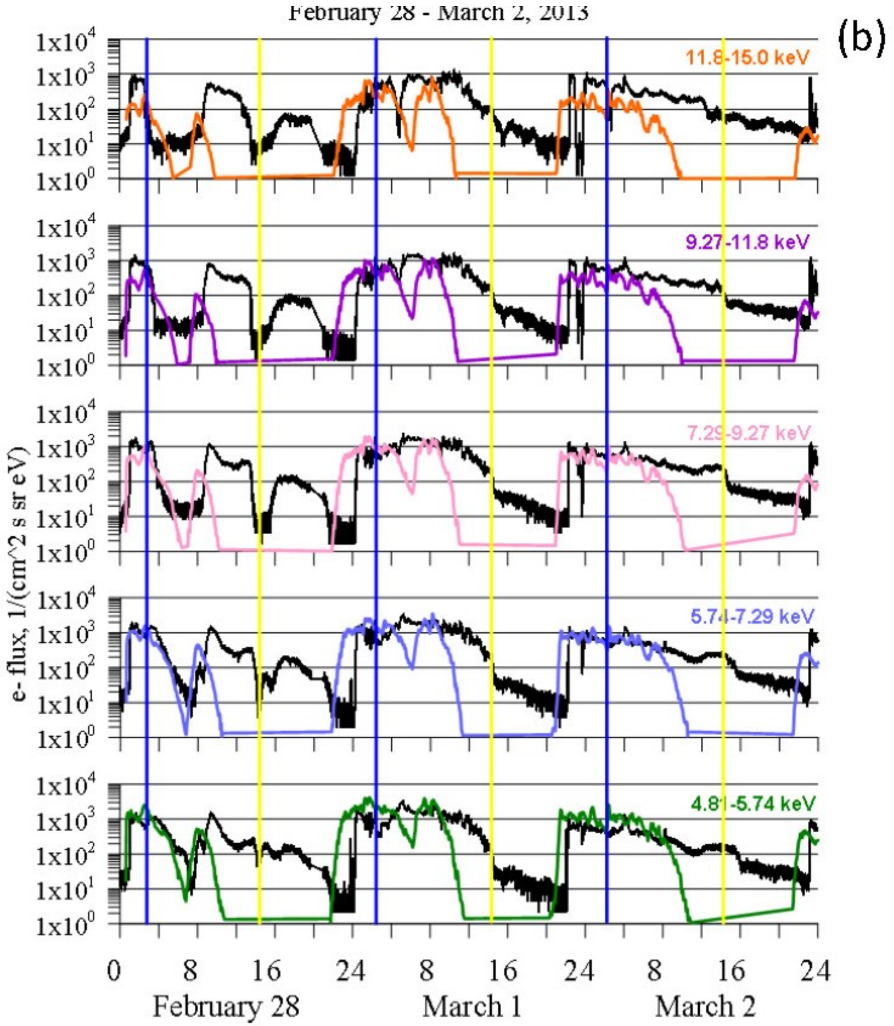


Storm peak

Strong pitch-angle diffusion *Chen et al.,* [2005]**;**
geosynchronous orbit

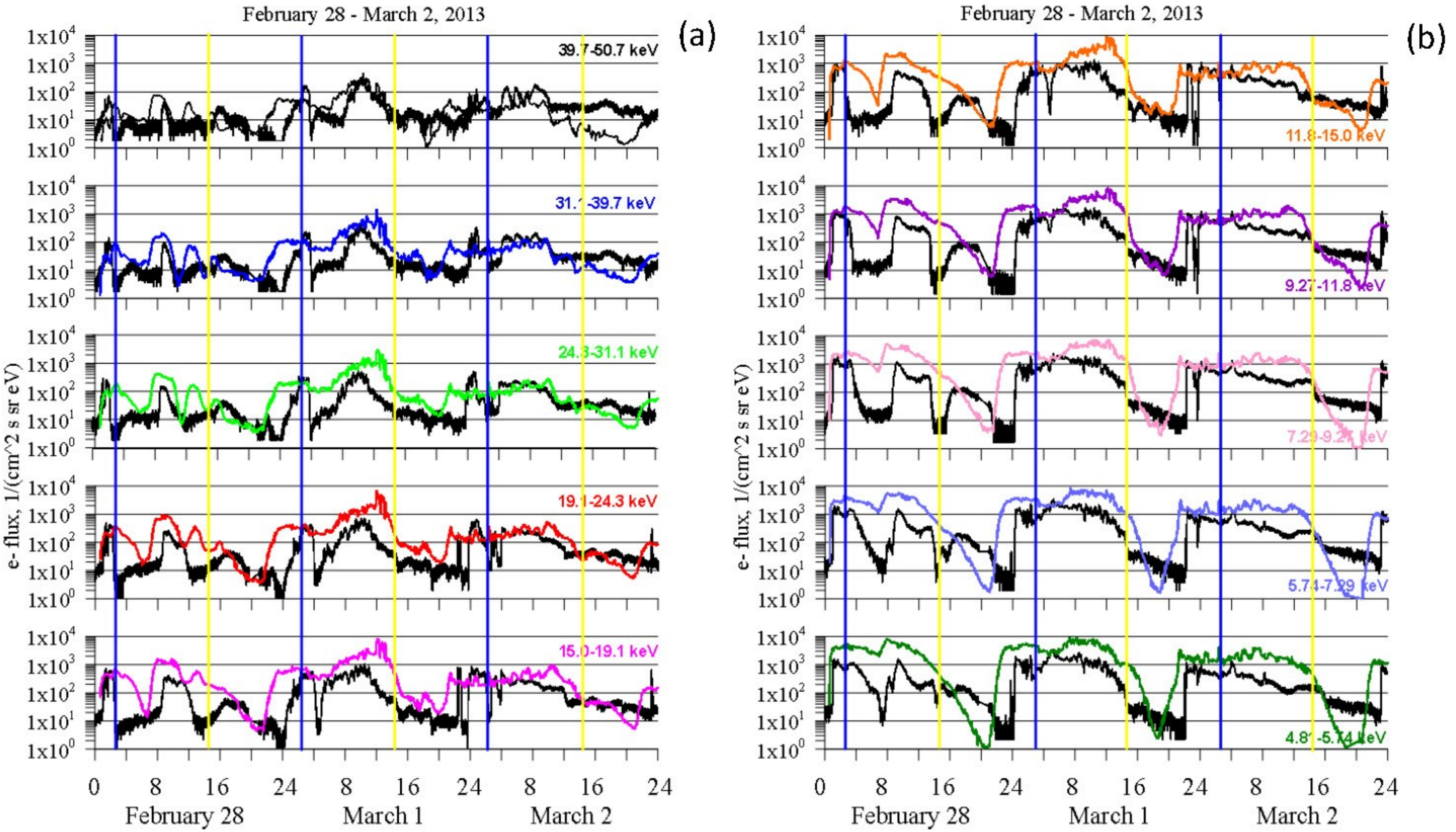


Storm peak



Storm peak

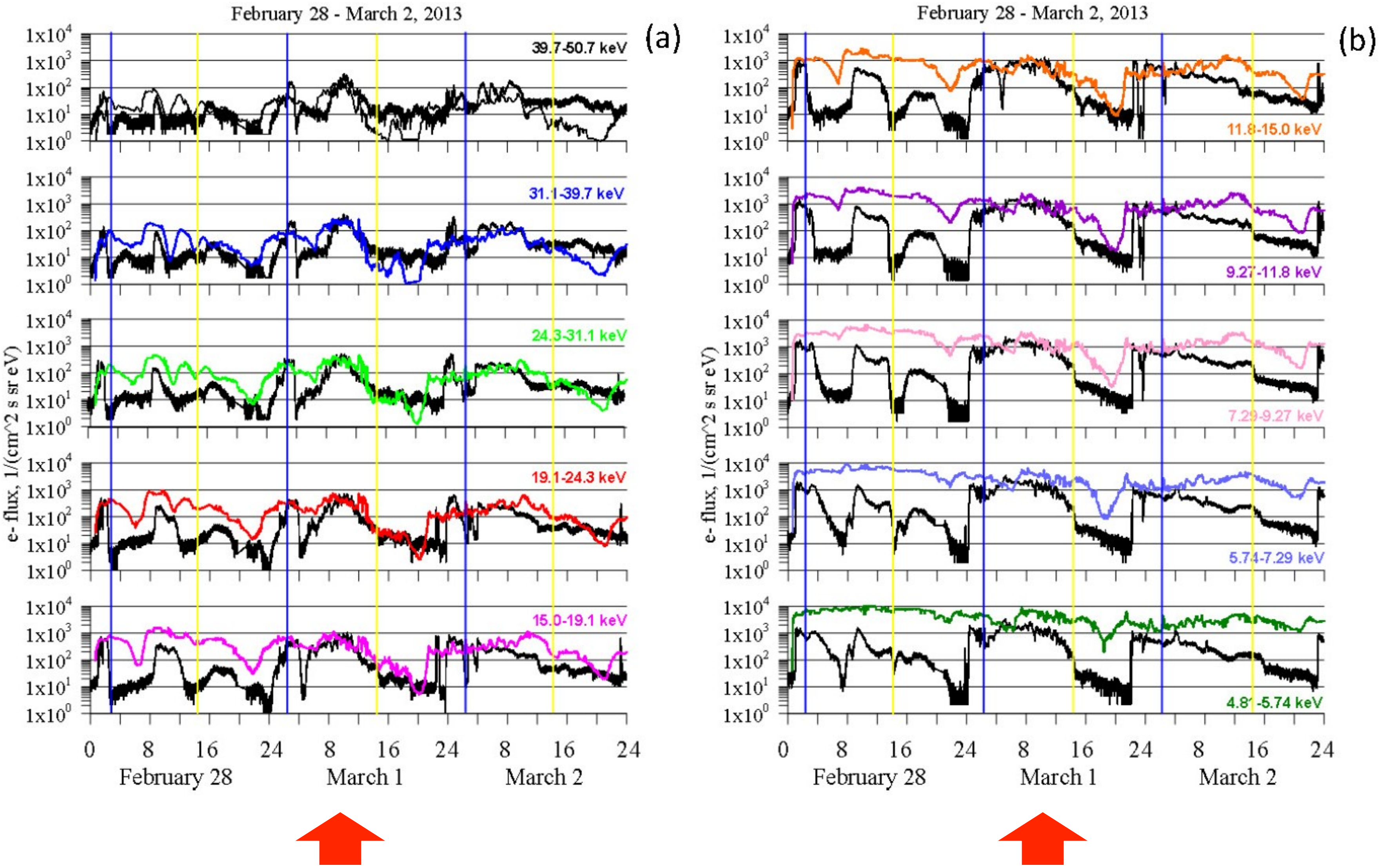
Strong and weak pitch-angle diffusion *Chen et al.*, [2005]; **geosynchronous orbit**



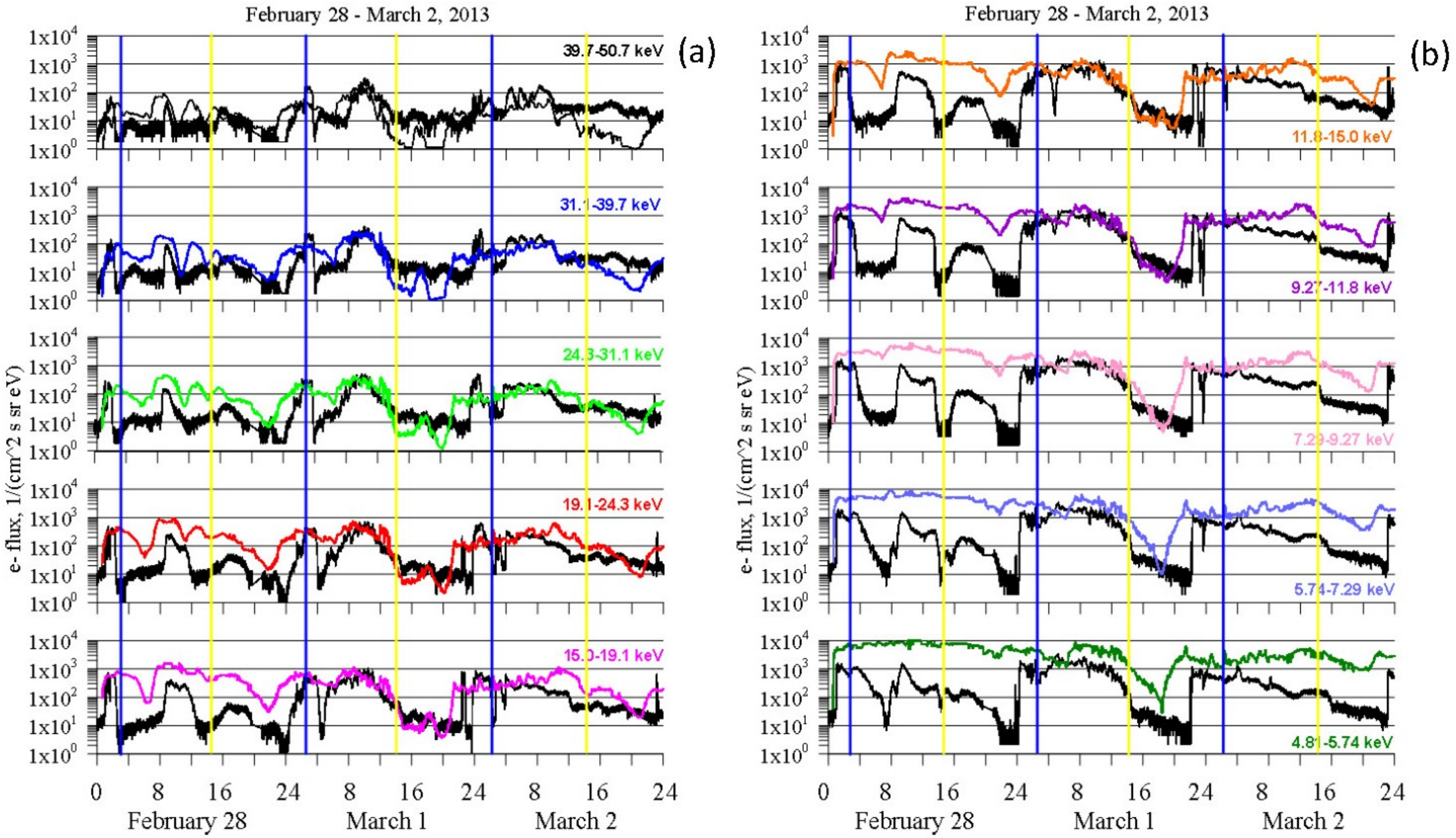
Storm peak

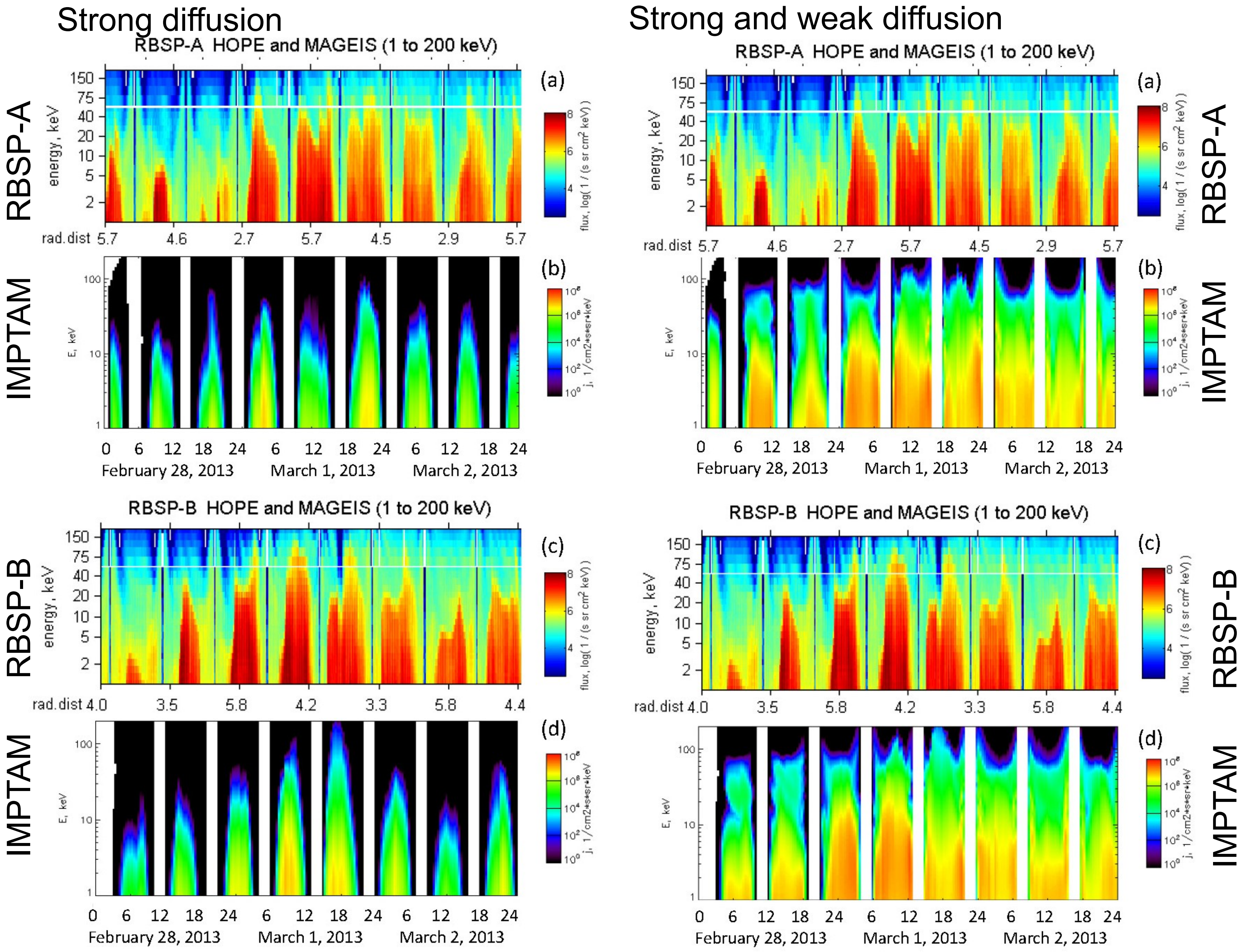
Storm peak

Chorus waves: *Orlova and Shprits* [2014]
Hiss waves: *Orlova et al.*, [2014]
geosynchronous orbit



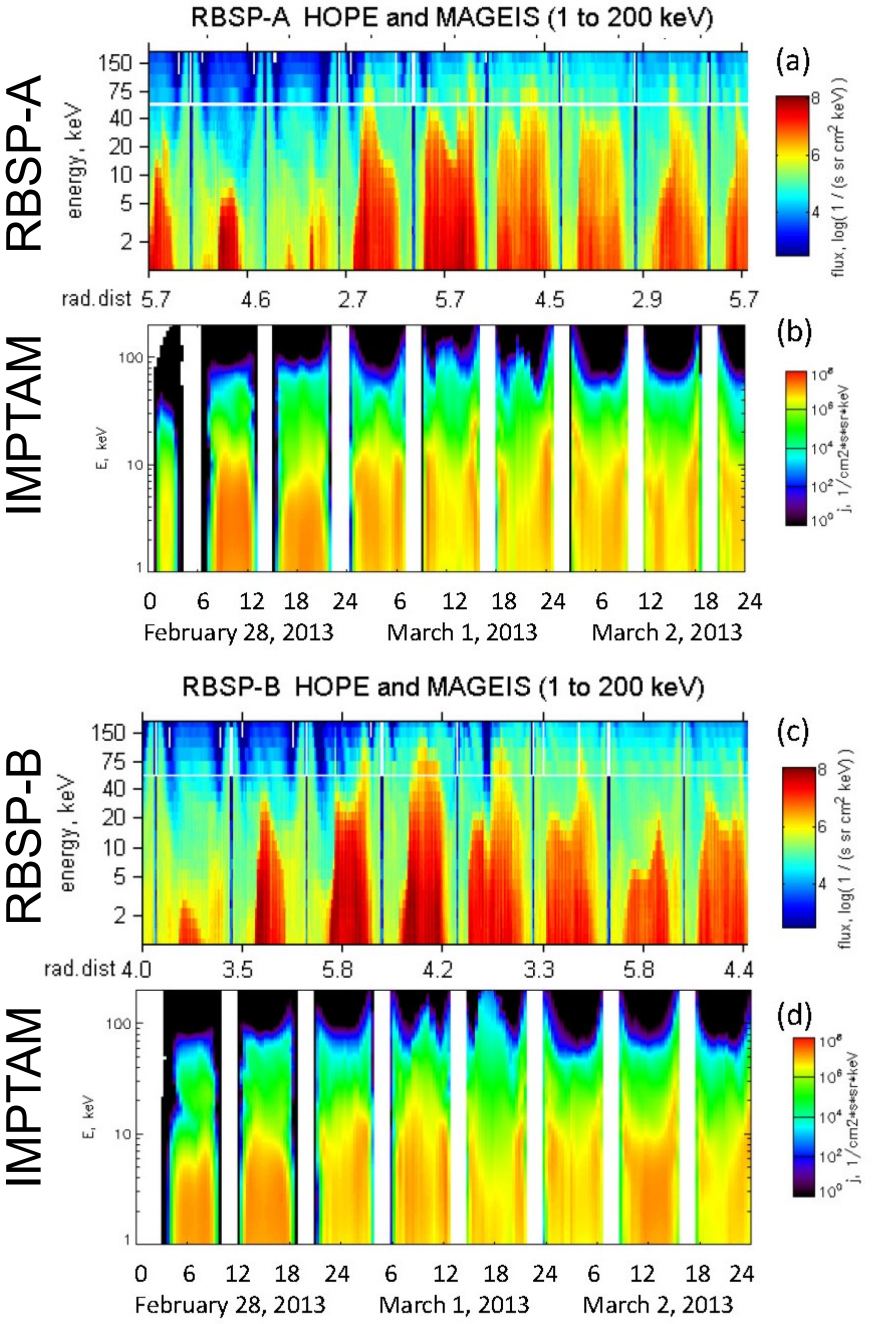
Chorus waves: *Orlova and Shprits* [2014]
Hiss waves: *Orlova et al.*, [2016]
geosynchronous orbit



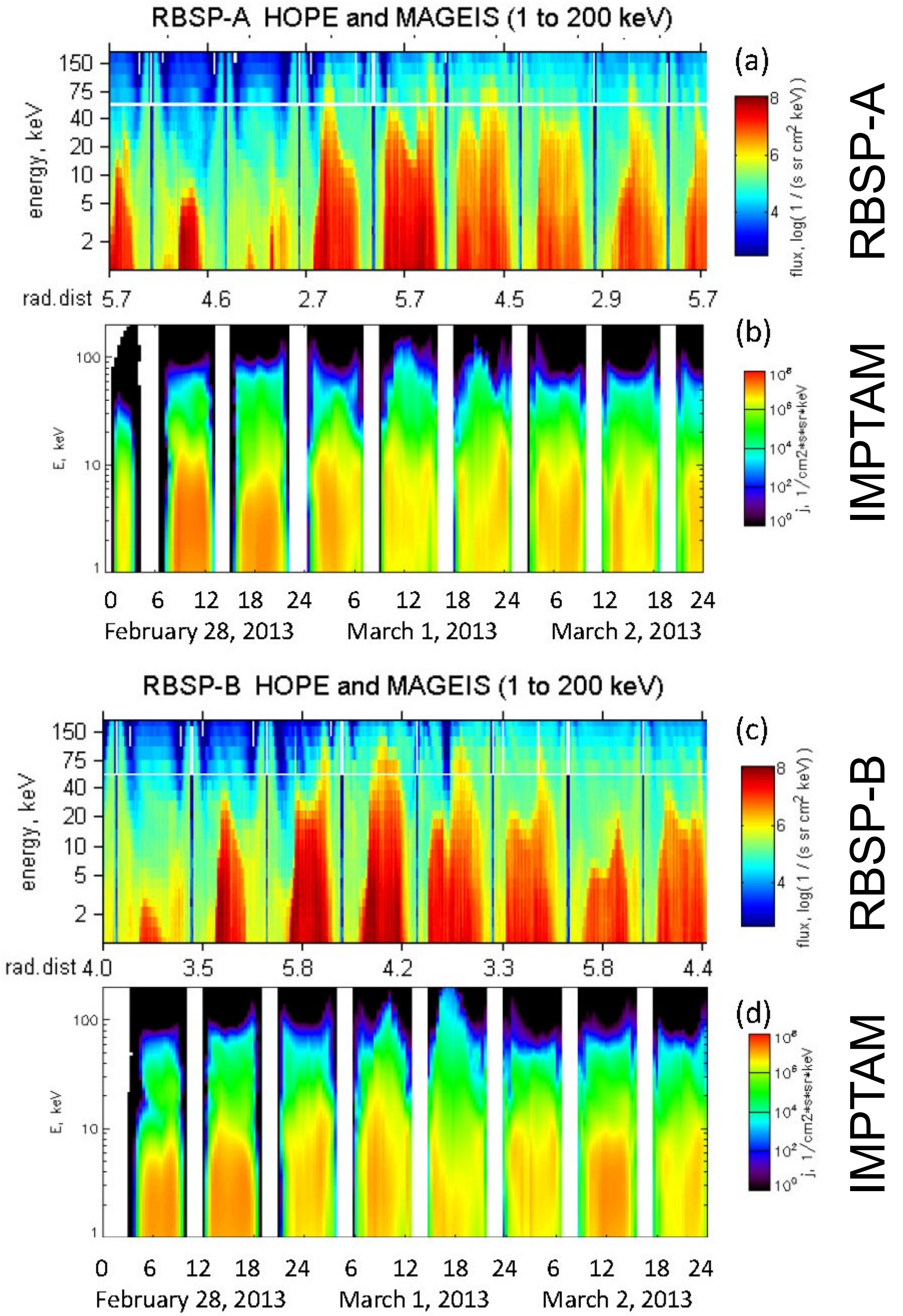

Strong diffusion

Strong and weak diffusion

Orlova and Shprits [2014], *Orlova et al.,* [2014]



Orlova and Shprits [2014], *Orlova et al.,* [2016]



RESULTS

- The losses are taken into account by incorporating the electron lifetimes into IMPTAM following several models.
- The data-model comparison are made for observations at geostationary orbit by AMC12 satellite and inside geostationary orbit by Van Allen Probes for one example storm event on February 28 - March 2, 2013
- Taking into account the electron losses by electron lifetimes for strong and weak diffusion (following *Chen et al.,* [2005]), led to somewhat reasonable agreement between the observed and modeled fluxes with the modeled fluxes being one order of magnitude higher than the observed ones during storm peak. The fluxes with electron energies from 15 to 50 keV show better agreement.
- When the electron losses due to interactions with chorus waves *Orlova and Shprits*, [2014] and with hiss waves *Orlova et al.,* [2014, 2016] were introduced, the observed geostationary electron fluxes were well reproduced during the storm maximum. The fluxes of electrons with energies from 15 to 50 keV were closer to the observed ones than those with lower energies.

***This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No* 637302**

CONCLUSION

The discrepancy between the modeled and the observed fluxes is likely due to the way how the electron lifetimes were parameterized for low energies. Although, the detailed dynamics of observed fluxes was not fully reproduced, the representation for electron lifetimes for keV electrons obtained from *Orlova and Shprits*, [2014] and *Orlova et al.,* [2016] is the best available model at present. The keV electron fluxes vary significantly on the time scales of tens of minutes. The electron lifetimes parameterized by 3-hour Kp index do not reflect the full picture of shorter time variations. Further IMPTAM validation will lead to better understanding of the necessity to develop the model for electron lifetimes with more detailed dependence on energy and other than Kp geomagnetic indices or/and solar wind parameters. The steps towards this will be taken during the work under **Task 5.3.** The maps in (L, MLT, pitch angle, energy) of low energy electrons will be constructed as output from the improved IMPTAM. Both quiet and disturbed events will be selected according to data availability and modelled and the model output will be compared to the observed electron fluxes to further model verification.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No **637302**

Relation to other workpackages

The results of the IMPTAM will be validated against satellite observations and will be also compared with the NARMAX predictions (Task 6.3 in WP6).

Task 5.4 will result in developing of a trial version of forecast model for low energy electrons which will be part of Task 7.2 in WP7 for implementation of VERB-IMPTAM model in fusion of forecasting tools.

Dissemination (1)

Papers

1. Dubyagin, S., N. Y. Ganushkina, I. Sillanpää, and A. Runov (2016), Solar wind-driven variations of electron plasma sheet densities and temperatures beyond geostationary orbit during storm times, J. Geophys. Res. Space Physics, 121, doi:10.1002/2016JA022947.
2. Grigorenko, E. E., E. A. Kronberg, P. W. Daly, N. Y. Ganushkina, B. Lavraud, J.-A. Sauvaud, and L. M. Zelenyi (2016), Origin of low proton-to-electron temperature ratio in the Earth’s plasma sheet, J. Geophys. Res. Space Physics, 121, doi: 10.1002/2016JA022874.
3. Liemohn, M. W., N. Y. Ganushkina, R. Ilie, and D. T. Welling (2016), Challenges associated with near-Earth nightside current, J. Geophys. Res. Space Physics, 121, 6763–6768, doi:10.1002/2016JA022948.
4. Walker, S. N., A. G. Demekhov, S. A. Boardsen, N. Y. Ganushkina, D. G. Sibeck, and M. A. Balikhin (2016), Cluster observations of non–time continuous magnetosonic waves, J. Geophys. Res. Space Physics, 121, doi:10.1002/2016JA023287.
5. Boynton, R. J., M. A. Balikhin, D. G. Sibeck, S. N Walker, S. A Billings, and N. Ganushkina (2016), Electron flux models for different energies at geostationary orbit, Space Weather, 14, doi:10.1002/2016SW001506.

Dissemination (2)

Orals, invited

1. Natalia Ganushkina, Low energy electrons in the inner Earth's magnetosphere, Dynamical Processes in Space Plasmas, April 3-10, 2016, Ein Bokek, Israel.
2. Natalia Ganushkina, Ilkka Sillanpää, Stepan Dugyagin, D. Pitchford, J. Rodriguez, A. Runov, Low energy electrons in the inner Earth's magnetosphere, European Geosciences Union General Assembly 2016, Vienna, Austria, 17–22 April 2016.
3. Ilkka Sillanpää, N. Ganushkina, S. Dubyagin, IMPTAM Runs at CCMC, 8th CCMC Workshop, Annapolis, MD, USA, April 11-15, 2016.
4. Natalia Ganushkina, Space weather effects in the ring current, The Scientific Foundation of Space Weather, International Space Science Institute Workshop, Bern, Switzerland, 27 June – 1 July 2016.
5. N. Ganushkina and S. Dubyagin, Forecasting the keV-electrons in the inner Earth's magnetosphere responsible for surface charging, International Symposium on Recent Observations and Simulations of the Sun–Earth System III, Golden Sands, Bulgaria, September 12–16, 2016
6. Natalia Ganushkina, Stepan Dubyagin, Ilkka Sillanpää, Modeling of the low-energy near-Earth electron environment using IMPTAM, Global Modelling of the Space Weather Chain, 24 – 28 October 2016, Aalto University, Espoo, Finland.
7. Natalia Ganushkina, Stepan Dubyagin, Ilkka Sillanpää, From studying electron motion in the electromagnetic fields in the inner magnetosphere to the operational nowcast model for low energy (< 200 keV) electron fluxes responsible for surface charging, Thirteenth European Space Weather Week, November 14-18, 2016, Oostende, Belgium.
8. N. Ganushkina and SPACESTORM and PROGRESS teams, Understanding the radiation environment in the Earth's inner magnetosphere, Fourth Joint Cluster-THEMIS Workshop, incorporating ARTEMIS, 7-12 November 2016, Palm Springs, CA, USA.

Orals, contributed:

Dissemination (3)

<u>**Orals, contributed**</u>:

1. Natalia Ganushkina, Wave-particle interactions for low energy electrons in the inner Earth's Magnetosphere, ISSI International Team "Analysis of Cluster Inner Magnetosphere Campaign data, in application the dynamics of waves and wave-particle interaction within the outer radiation belt", January 19-23, 2015, Bern, Switzerland.
2. Natalia Ganushkina, Modeling of the ring current with IMPTAM, First meeting of ISSI Team “Ring current modeling: Uncommon Assumptions and Common Misconceptions” (leaders R. Ilie and N. Ganushkina), March 7-11, 2016, Bern, Switzerland.
3. Natalia Ganushkina, Stepan Dubyagin, Ilkka Sillanpää, Losses of keV electrons as electron lifetimes in IMPTAM, Second meeting of ISSI International Team "Analysis of Cluster Inner Magnetosphere Campaign data, in application the dynamics of waves and wave-particle interaction within the outer radiation belt", May 9-13, 2016, International Space Science Institute, Bern, Switzerland.
4. S. Dubyagin, N. Ganushkina, A. Runov, Solar Wind Control of the Plasma Sheet Thermal Electrons at r=6-11 Re: Empirical Model, International Symposium on Recent Observations and Simulations of the Sun–Earth System III, Golden Sands, Bulgaria, September 12–16, 2016.
5. Ilkka Sillanpää, Natalia Ganushkina, Stepan Dubyagin, Juan Rodriguez, IMPTAM verification and validation on GOES MAGED data for long-term variations of electron fluxes at geostationary orbit, Thirteenth European Space Weather Week, November 14-18, 2016, Oostende, Belgium.
6. Natalia Ganushkina, Ilkka Sillanpää, Jean-Charles Matéo-Vélez, Stepan Dubyagin, Angélica Sicard-Piet, Low energy electrons at MEO during observed surface charging events, Thirteenth European Space Weather Week, November 14-18, 2016, Oostende, Belgium.

Dissemination (4)

Posters:

1. Michael Liemohn, Natalia Ganushkina, Darren De Zeeuw, Daniel Welling, Gabor Toth, Raluca Ilie, Tamas Gombosi, Bart van der Holst, Maria Kuznetsova, Marlo Maddox, and Lutz Rastaetter, Quantitative Assessment of the CCMC's Experimental Real-time SWMF-Geospace Results, European Geosciences Union General Assembly 2016, Vienna, Austria, 17–22 April 2016.
2. Ilkka Sillanpää, Natalia Ganushkina, Stepan Dubyagin, Jean-Charles Matéo-Vélez, Case studies with van Allen Belt Probes and IMPTAM modeling, Global Modelling of the Space Weather Chain, 24 – 28 October 2016, Aalto University, Espoo, Finland.
3. Stepan Dubyagin, Natalia Ganushkina, Andrei Runov, Solar wind driven empirical model of electron plasma sheet densities and temperatures beyond geostationary orbit during storm times, Thirteenth European Space Weather Week, November 14-18, 2016, Oostende, Belgium.
4. Natalia Ganushkina, Stepan Dubyagin, Andrei Runov, Solar Wind Driven Variations of Electron Plasma Sheet Parameters Beyond Geostationary Orbit During Storm Times, Session: SM51B Magnetotail Dynamic Processes: Recent Progress in Observations and Simulations, AGU Fall meeting, 12-16 December 2016, San Francisco, CA, USA.

Personnel for the project in FMI

1. Leader: **Dr. Natalia Ganushkina**

2. Dr. Stepan Dubyagin and **Dr. Ilkka Sillanpää** are the project's participants.