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 Telecon, 5 December 2017

WP5 (led by FMI)

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) **Due on January 31, 2018**

D5.4: Trial version of forecast model for low energy electrons (report, M36) **Due on December 31, 2017**

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

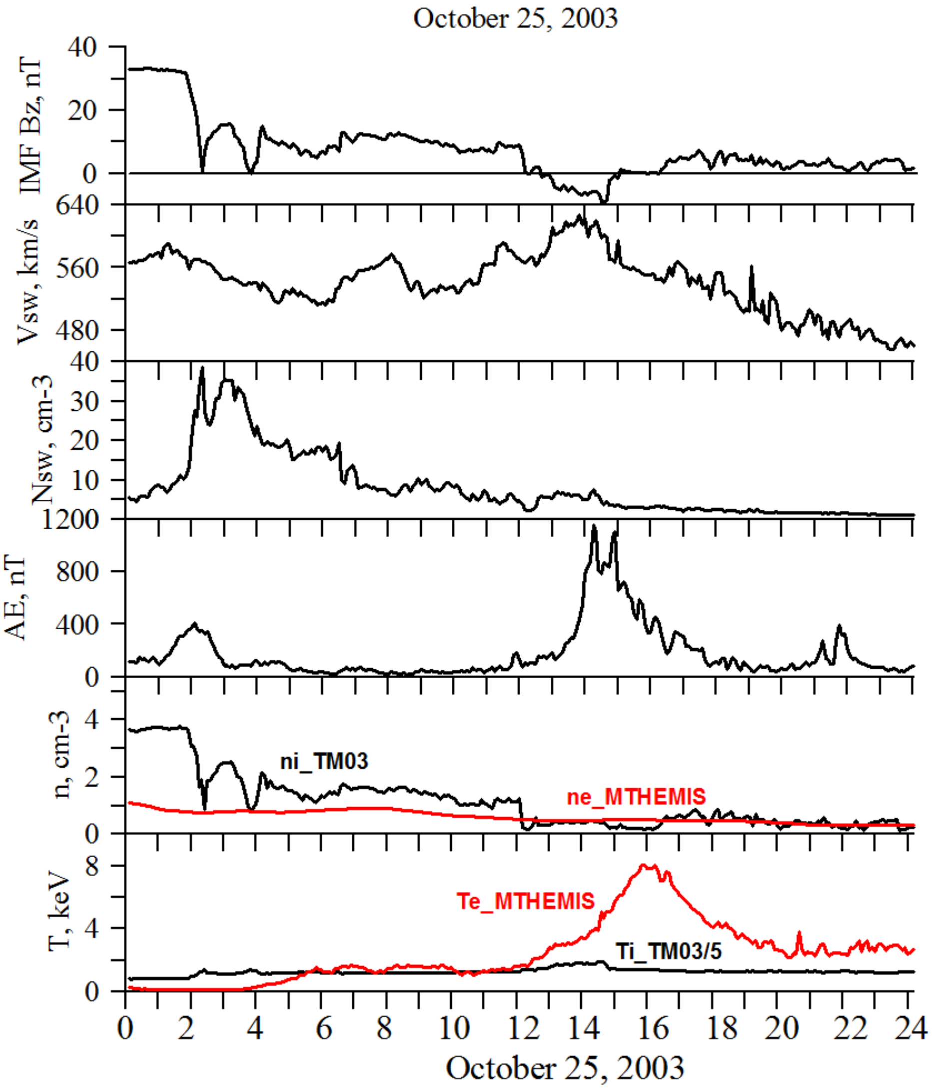
- for the obtained distribution function, we apply **radial diffusion** by solving the radial diffusion equation

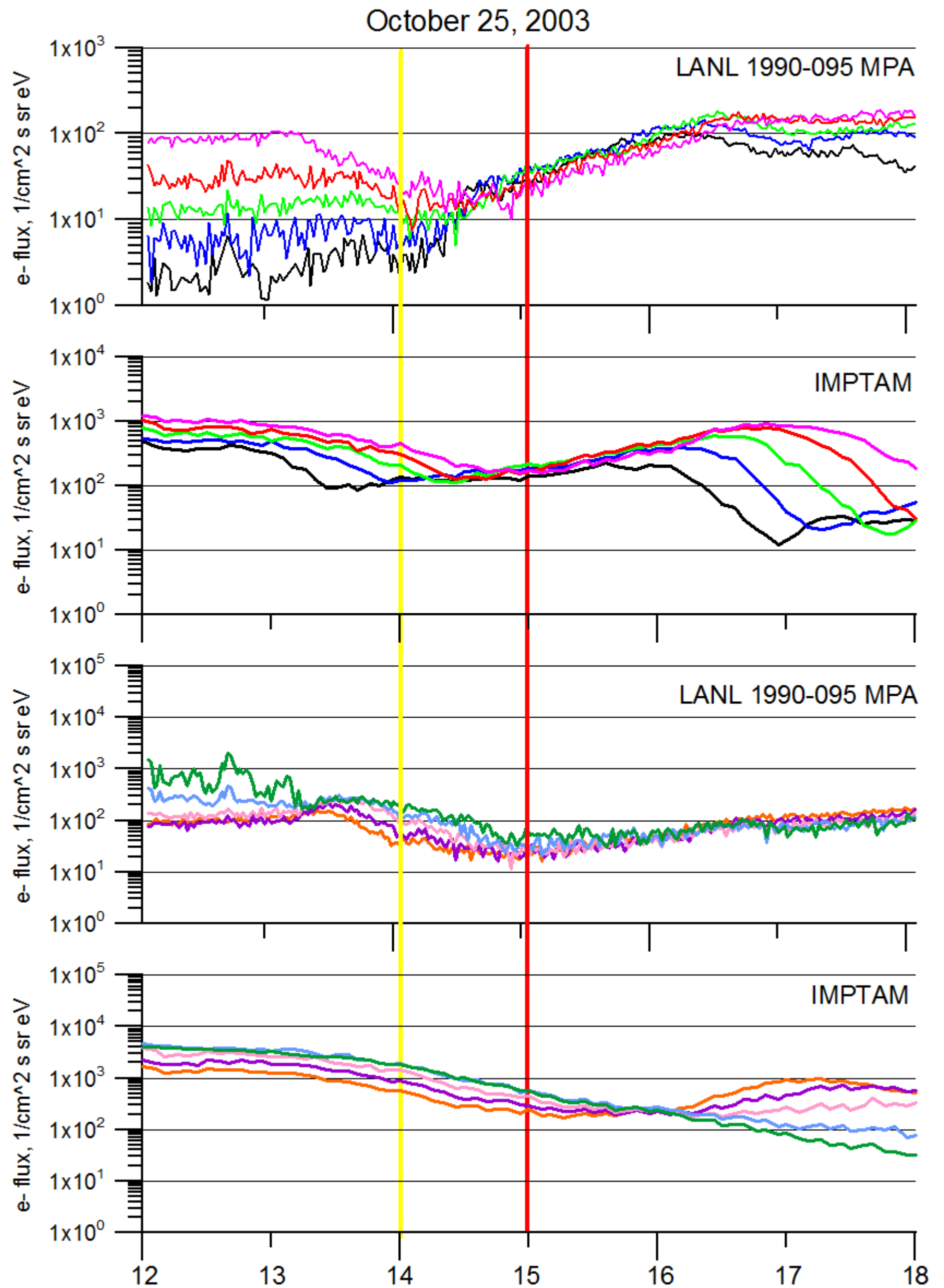
- electron losses: convection outflow and pitch angle diffusion by the **electron lifetimes**

- advantage of IMPTAM: can utilize any magnetic or electric field model, including self-consistent magnetic field and substorm-associated electromagnetic fields.

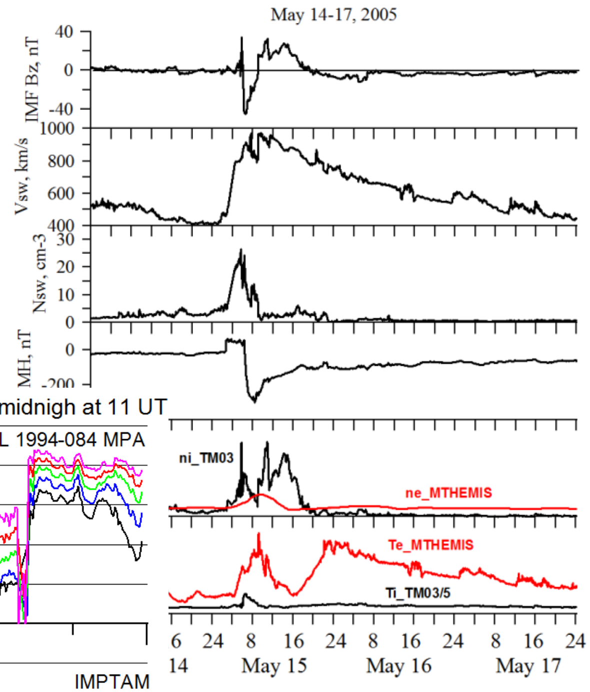
Run online in real time: imptam.fmi.fi

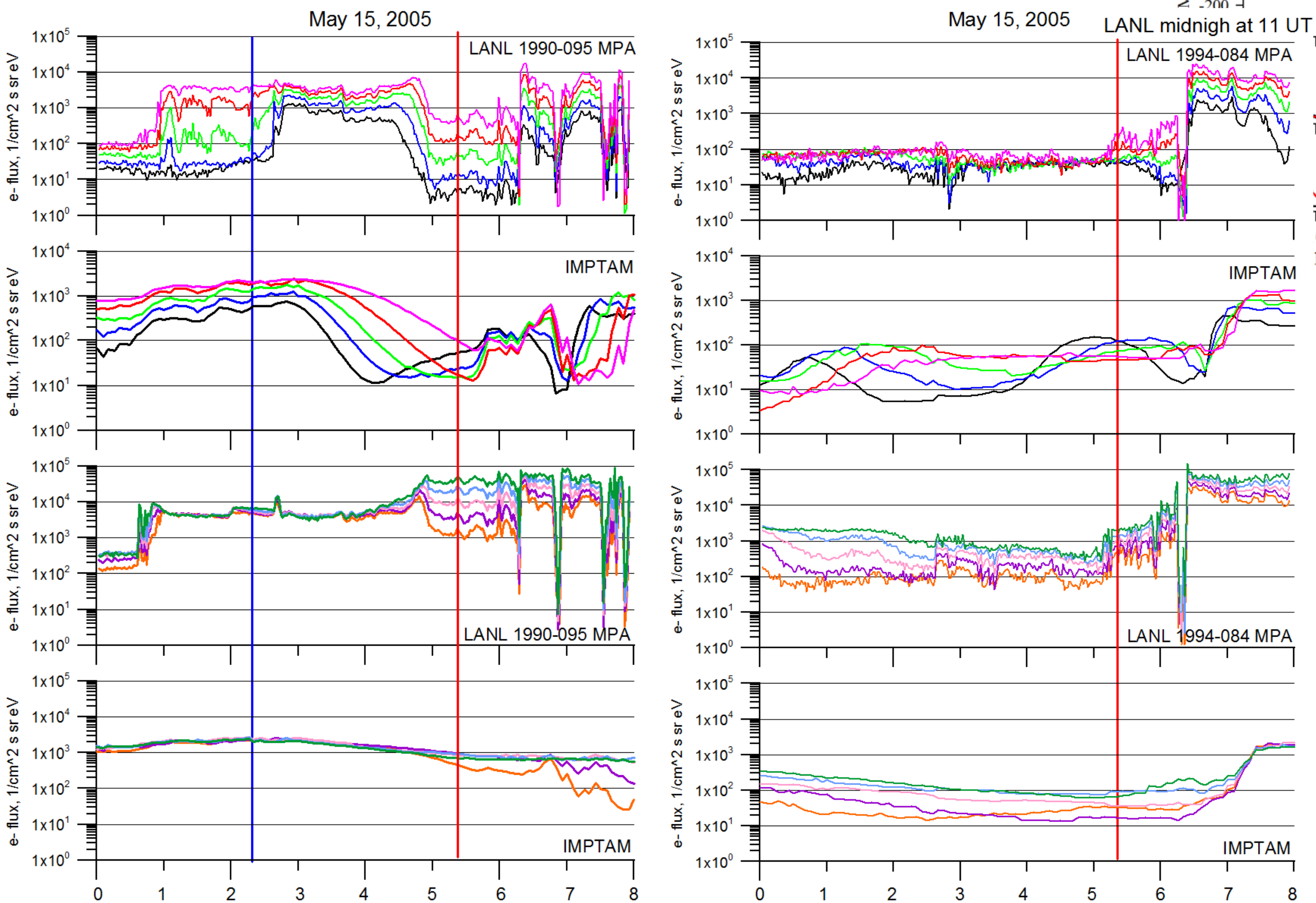
IMPTAM validation example (1)

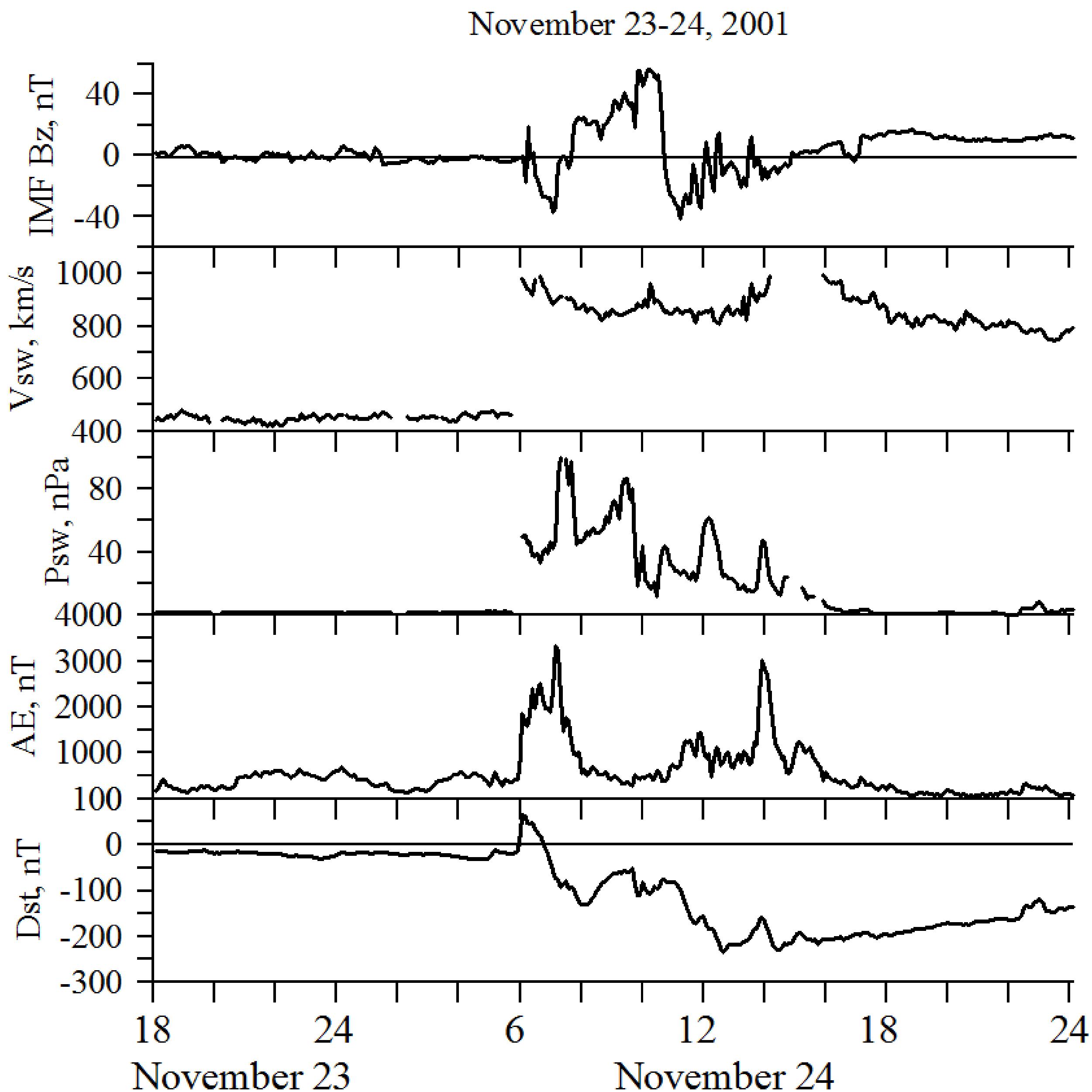




IMPTAM
validation example (2)

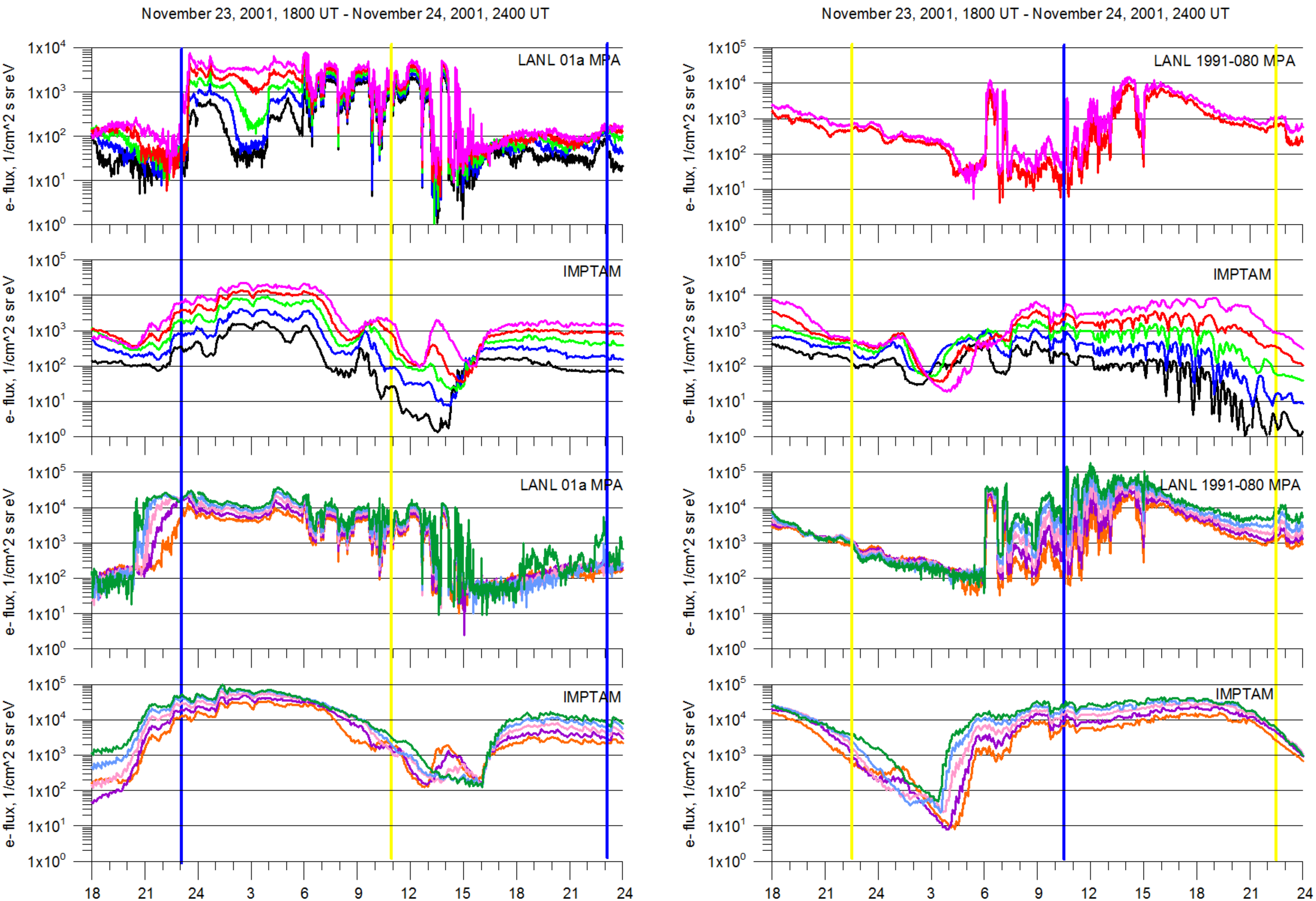




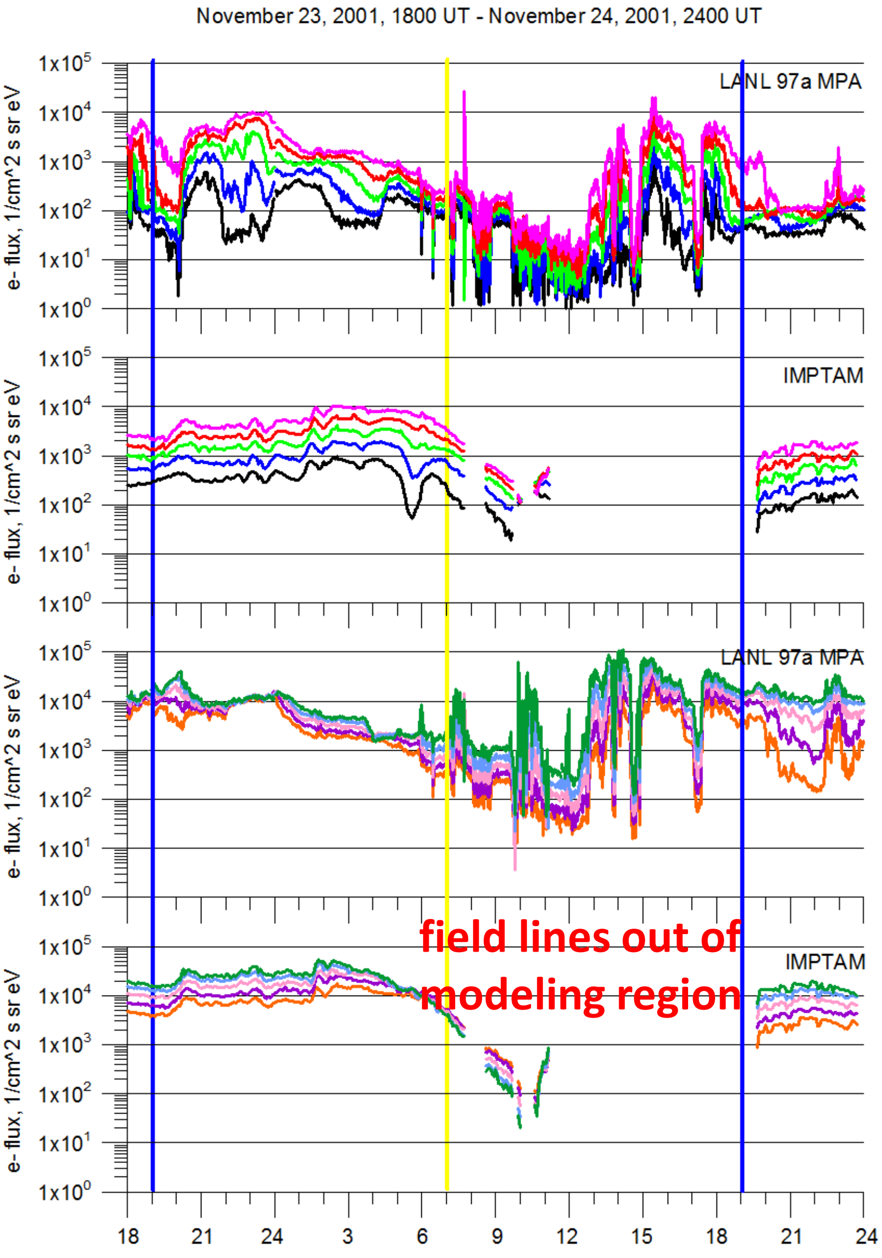


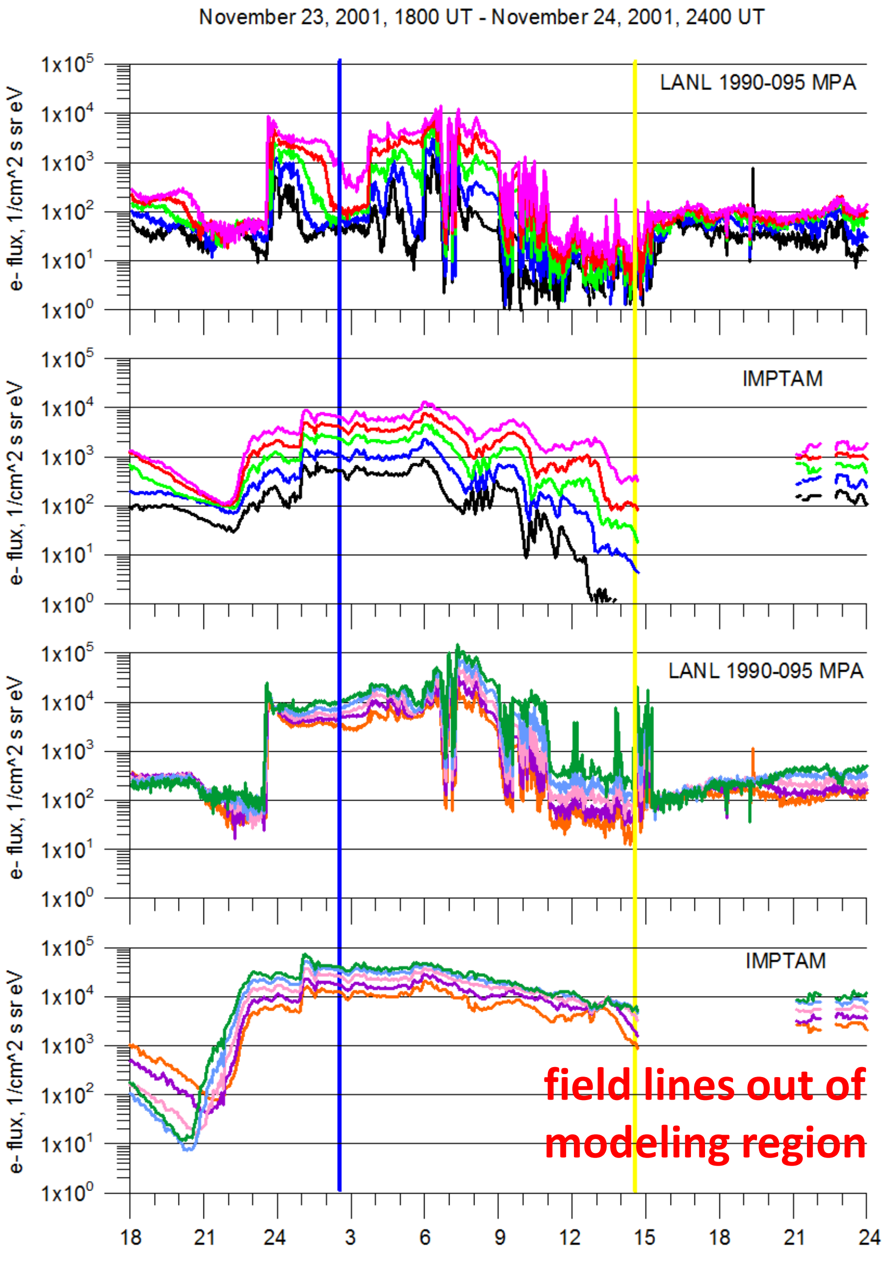
November 23-24, 2001
IMF Bz, nT
40
0
-40
Vsw, km/s
1000
800
600
400
Psw, nPa
80
40
4000
AE, nT
3000
2000
1000
100
Dst, nT
0
-100
-200
-300
18
24
6
12
18
24
November 23
November 24

IMPTAM validation example (3)



IMPTAM validation example (4)





Task 5.3, WP5 (1)

Task 5.3: Providing the low energy seed population to VERB radiation belts model
IMPTAM output for VERB: maps in (L, MLT, pitch angle, energy) of low energy electrons

Provided to GFZ as seed keV population for VERB for further accelerations to MeV energies, format explained.

```
<header
        step="480"   INSIDE STEP
        timeRun="57600"   TIME IN SECONDS
        time="1054224000"> UNIX TIME
        <data type="grid">
                <grid
                        info="Rs, Re" RADIUS, ACTUALLY, L*, UNITLESS
                        node="{1 30 3 9}"> 1-LINEAR GRID, 30-NUMBER OF INTERVALS IN R, 3-MIN IN R, 9-MAX IN R
                        <grid
                                info="Longitude, deg" LONGITUDE, NOT MLT, STARTS AT NOON, LONGITUDE=0 AT NOON
                                node="{3 60}"/> FROM 0 TO 2PI, 60-NUMBER OF INTERVALS IN LONGITUDE
                </grid>
                <data
                        type="grid">
                        <grid
                                info="B/Beq, #" THIS IS USED FOR COMPUTING SECOND INVARIANT AND PITCH ANGLE, 1 CORRESPONDS TO 90 DEG PITCH ANGLE
                                node="[1 1.04 1.09648 1.31826 1.58489 1.90546 2.29087 2.75423 3.31131 3.98107 4.7863 5.7544 6.91831 8.31764 10 12.0226 14.4544 17.378 20.893
25.1189 30.1995 36.3078 43.6516 52.4807 63.0957 75.8578]">
                                <grid
                                        info="MagMoment, keV/nT" MAGNETIC MOMENT, NOT ENERGY
                                        node="{2 45 0.002 6}"/> 2-LOGARITHMIC, 45-NUMBER OF INTERVALS IN MAGNETIC MOMENT, 0.002-MIN, 6-MAX
                        </grid>
                        <data
                                type="unit"
                                info="phaseden, f"/> TO COMPUTE FLUX WE NEED TO MULTIPLY F BY ENERGY, SO WE WILL HAVE FLUX IN UNITS 1/CM2 S SR KEV
                </data>
        </data>
</header>
```

The output is a 4D array [R, lon, B/Beq, magmoment] where magmoment is innest index.

Task 5.3, WP5 (2)

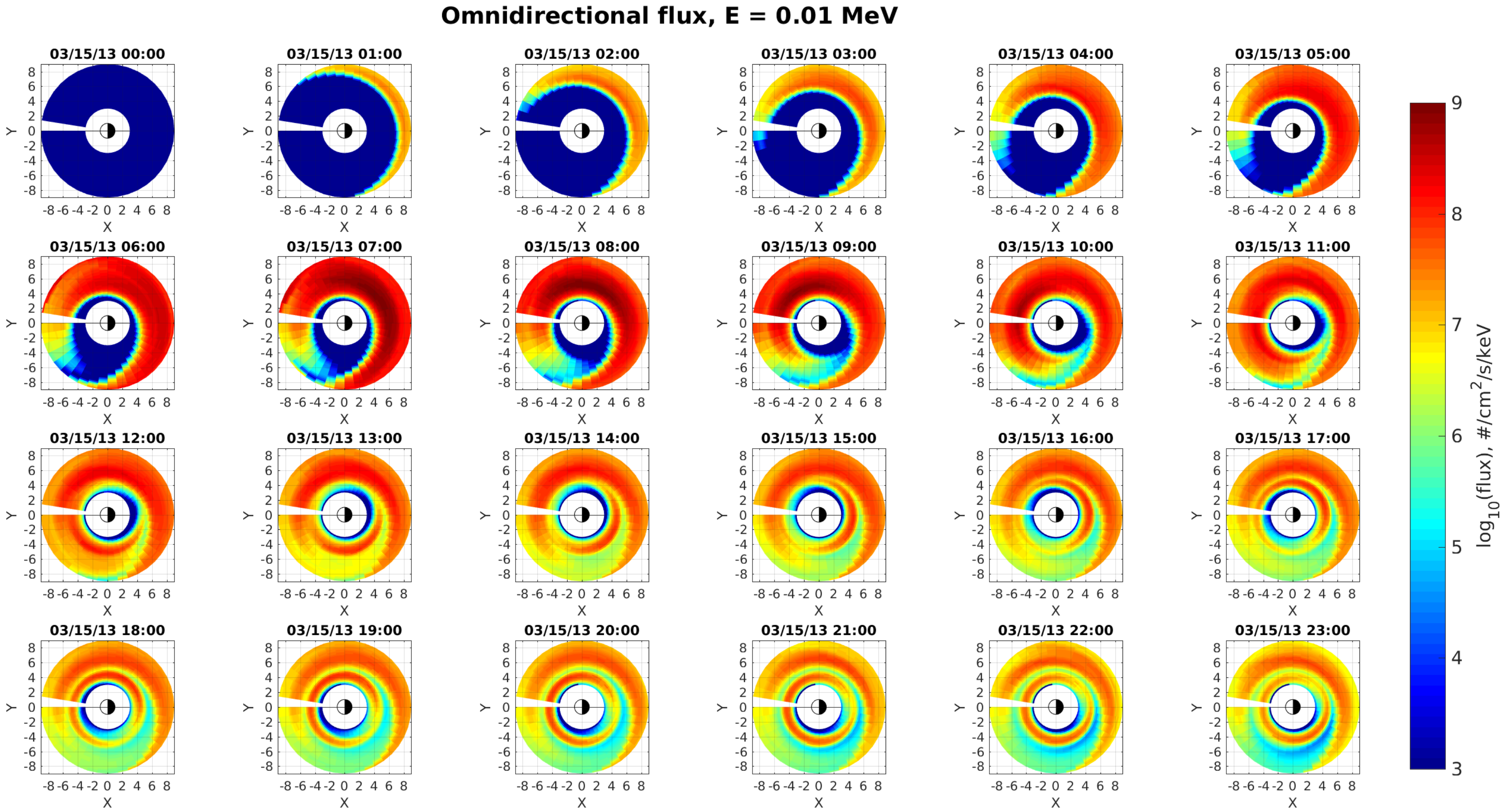
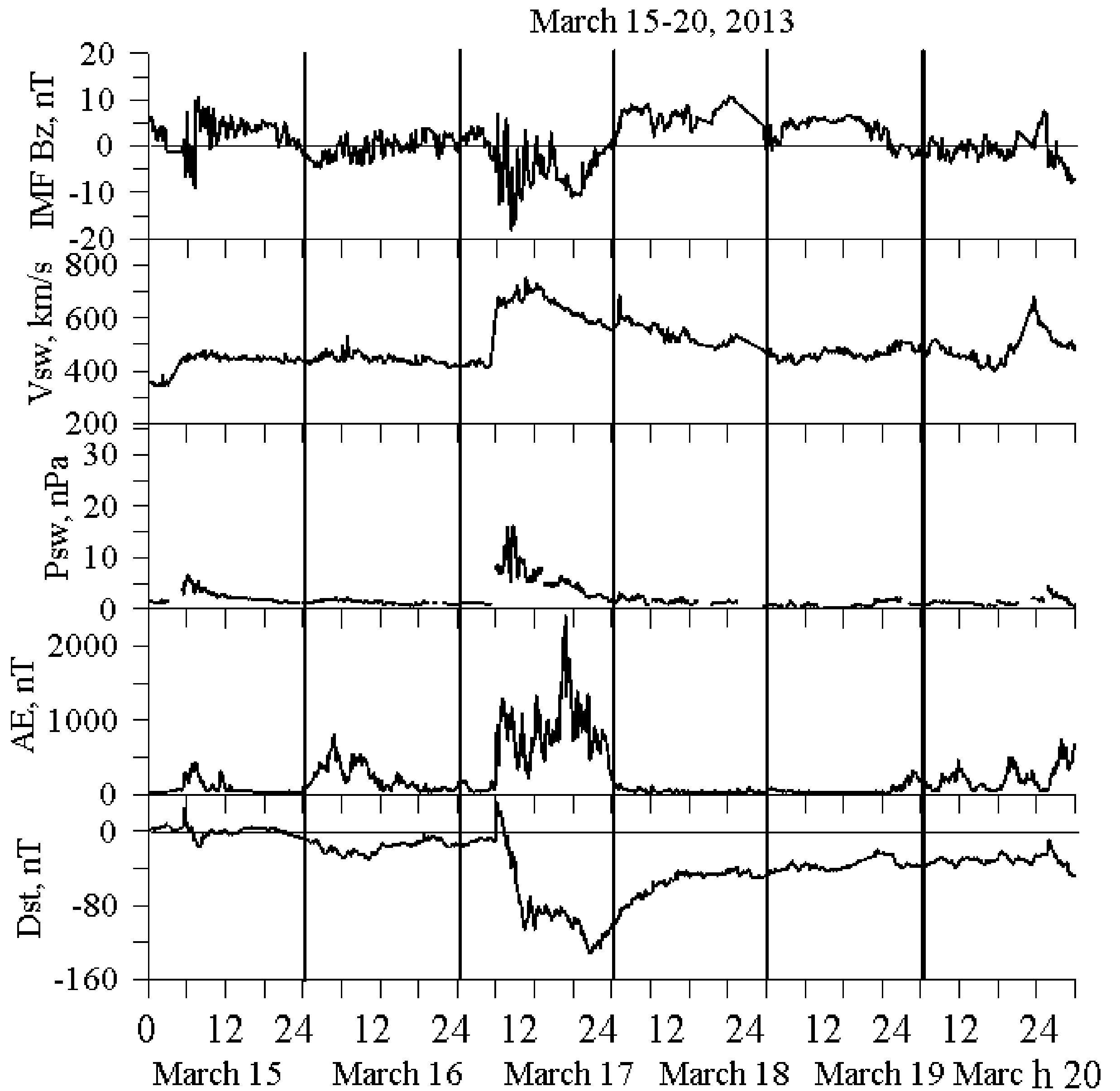
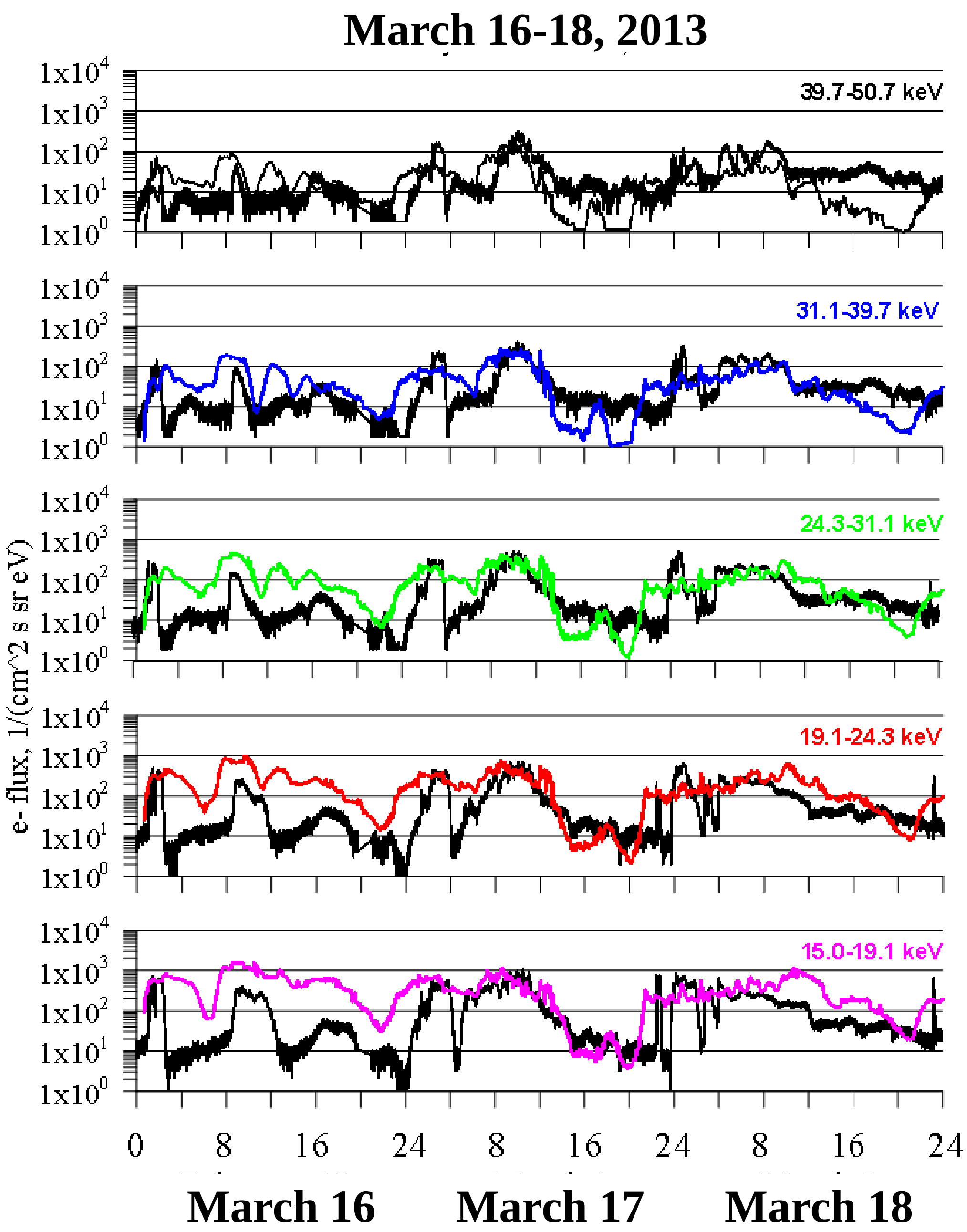


Illustration of omnidirectional fluxes for 10keV as a function of radial distance and MLT, Sent by N. Aseev (GFZ).

Selected event for modeling



AMC 12 – IMPTAM comparison



Task 5.3, WP5 (3)

VERB code utilizes the seed population and make its own verification. Coupled VERB and IMPTAM are validated against observations in the heart of the outer radiation belts. VERB-IMPTAM will form alternative to NARMAX-VERB combination of codes.

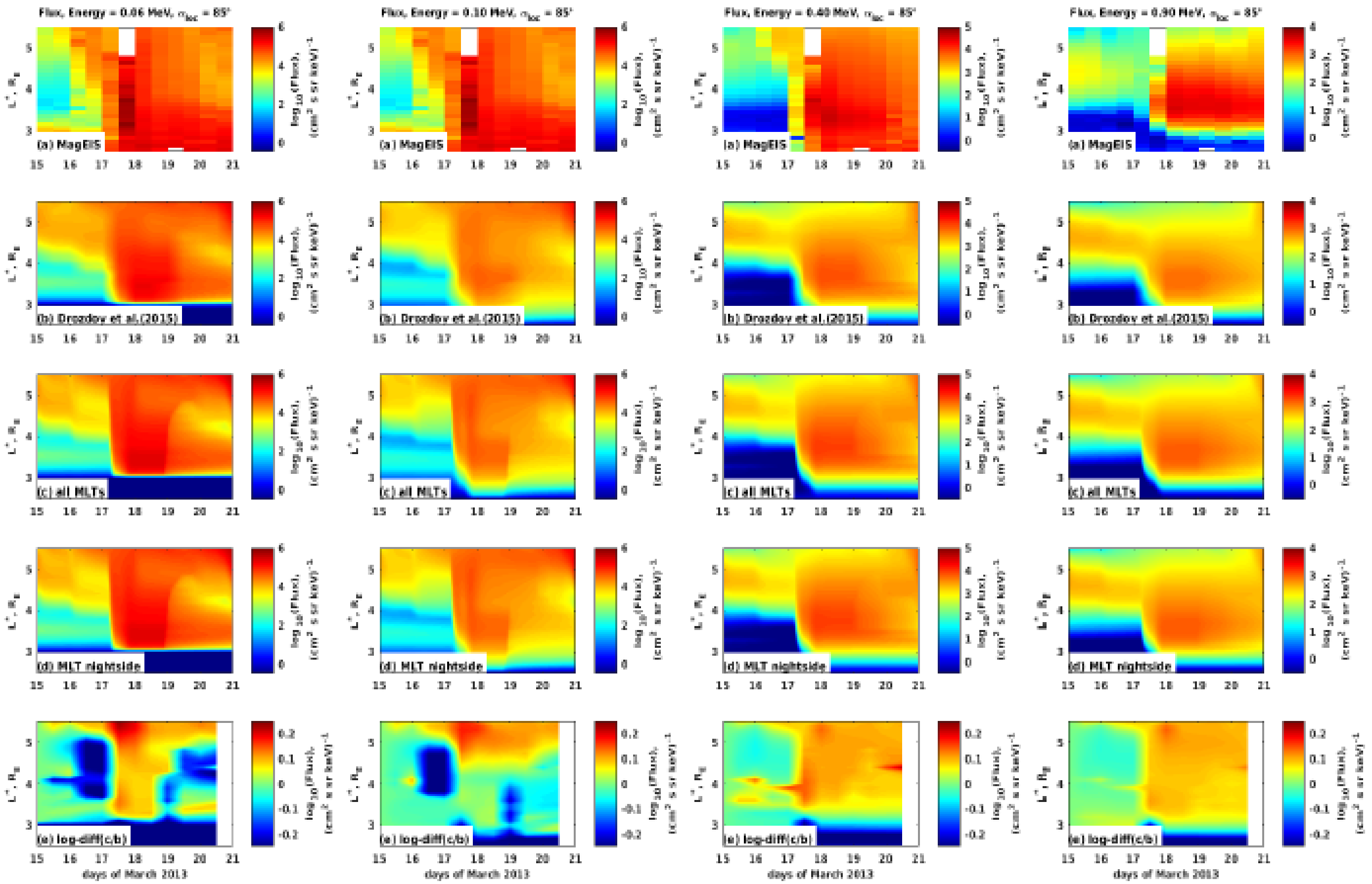


Figure 1: Electron fluxes as function of L^* and time. Each column displays the results of our simulation for local pitch angle $\alpha_{loc} = 85°$ at fixed energies 0.06 MeV, 0.10 MeV, 0.40 MeV and 0.90 MeV. The panels in each column show: a) MagEIS data, b) base simulation from Drozdov et al. (2015), c) VERB-simulation using IMPTAM-fluxes averaged over all MLTs, d) VERB-simulation using IMPTAM-fluxes averaged over the night side, e) logarithmic difference calculated between panels b) and c) for the corresponding energy.

Task 5.4, WP5 (1)

Task 5.4: Developing a trial version of forecast model for low energy electrons

IMPTAM is driven by the real time solar wind and IMF parameters, such as,
Nsw, PSW, VSW, IMF BY, BZ, and B_IMF

AWSoM + SWIFT Predictions
https://warwick.ac.uk/fac/sci/physics/research/cfsa/people/bennett/swift-data

Task at present:
Getting the predictions correctly in real time

satellite	"Earth"
end_date	"2017-12-07T12:08"
arrays	
Temperature_ion	{...}
Energy_electron	{...}
Time	{...}
Y_Position	{...}
Z_Position	{...}
Temperature_electron	{...}
Energy_ion	{...}
Unix time	{...}
Pressure	{...}
Pressure_ion	{...}
Rho	{...}
Bx	{...}
By	{...}
Bz	{...}
Vx	{...}
X_Position	{...}
Pressure_electron	{...}
Cs	{...}
Vy	{...}
Vz	{...}
co-ordinates	"Cartesian"
swift_version	"0.1.4"
start_date	"2017-11-23T12:04"
output_version	2
magnetogram_date	"2017-12-03T12:03"
co-ordinate system	"GSM"
swift_run_date	"Sat Nov 25 05:01:17 2017"
swift_commit_id	"v0.1.4-616-gdb0248c-dirty"

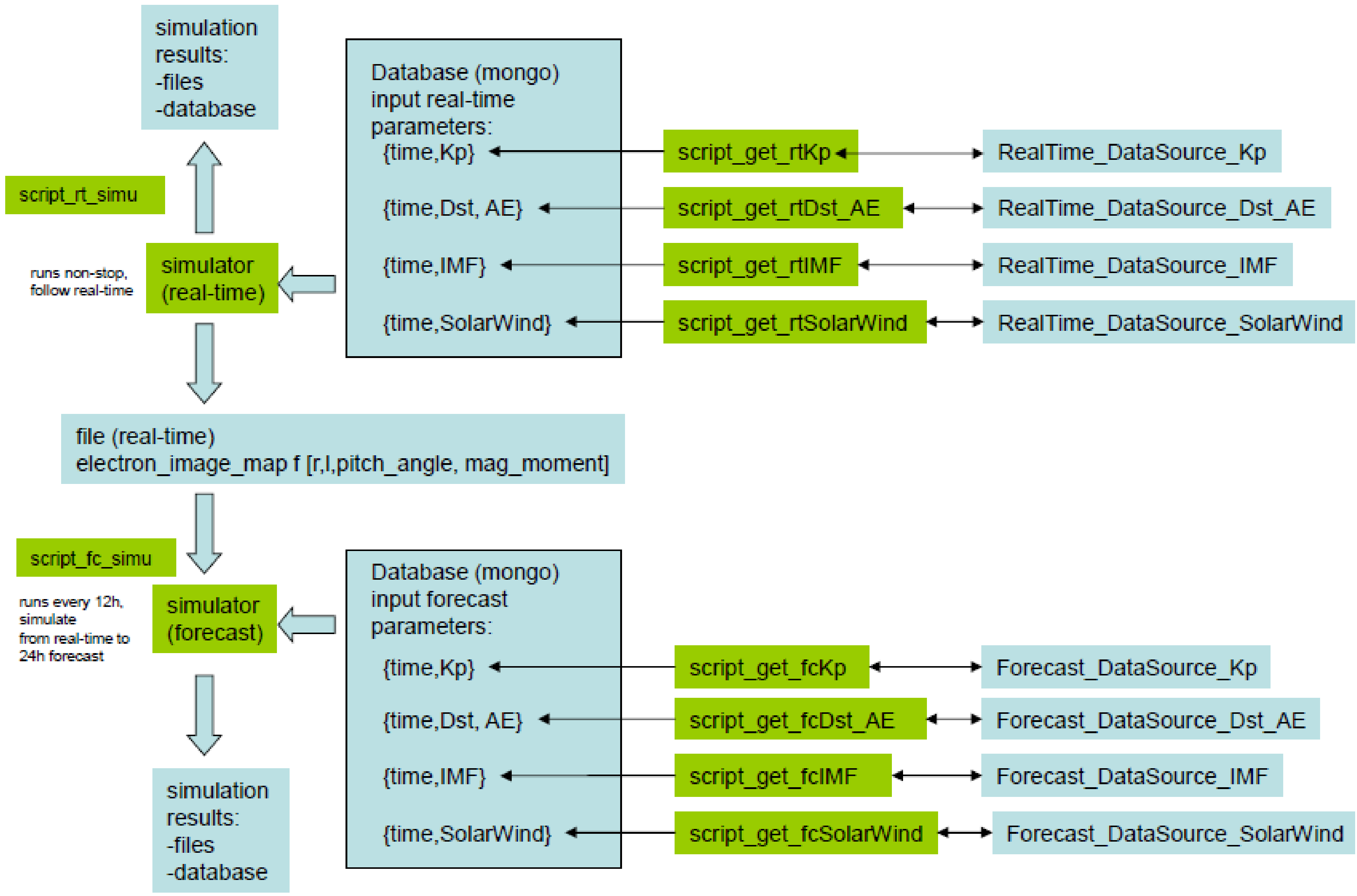
Task 5.4, WP5 (2)

Task 5.4: Developing a trial version of forecast model for low energy electrons

IMPTAM is driven by the real time by geomagnetic indices, such as,
(1) hourly values of the Dst index (magnetic field model in the magnetosphere);
(2) 3-hour Kp index (empirical parameterizations for electron lifetimes for electron losses);
(5) 1 minute AE index (to determine timings to launch electromagnetic pulses to reproduce substorm changes for additional electron acceleration).

Task right now:
Getting the predictions correctly in real time from IRF Lund

IMPTAM as a forecasting tool architecture



“This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 637302*”*

Personnel for the project in FMI

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

2. **Dr. Stepan Dubyagin** is the project's participant.

Dissemination, since January 2017 (1)

Papers

1. **Natalia Ganushkina**, Allison Jaynes, **Michael Liemohn**, Space Weather Effects Produced by the Ring Current Particles, Space Science Reviews, Volume 212, Issue 3–4, pp 1315–1344, DOI 10.1007/s11214-017-0412-2, 2017.

2. John D. Haiducek, Daniel T. Welling, **Natalia Y. Ganushkina**, Steven K. Morley, and Dogacan Su Öztürk, SWMF Global Magnetosphere Simulations of January 2005: Geomagnetic Indices and Cross-Polar Cap Potential, Space Weather, accepted, 2017.

3. **I. Sillanpää, N. Yu. Ganushkina, S. Dubyagin**, and J. V. Rodriguez, Electron fluxes at geostationary orbit from GOES MAGED data, Space Weather, accepted, 2017.

Dissemination, since January 2017 (2)

<u>Papers, submitted, under review</u>:

1. **S. Dubyagin, N. Yu. Ganushkina**, Formation of 30 keV proton isotropic boundaries during geomagnetic storms, submitted to JGR, July 2017.

2. **Natalia Ganushkina, Michael Liemohn, S. Dubyagin**, Current Systems in the Earth's Magnetosphere, submitted to Reviews of Geophysics, October 5, 2017.

3. Marina Kubyshkina, Vladimir Semenov, Nikolai Erkaev, Evgeny Gordeev, **Stepan Dubyagin**, **Natalia Ganushkina**, and Maria Shukhtina, Relations between vz and Bx components in solar wind and their effect on substorm onset, submitted to Geophysical Research Letters, October 2017.

4. E. E. Grigorenko, **S. Dubyagin**, A. Yu. Malykhin, Yu. V. Khotyaintsev, E. A. Kronberg, B. Lavraud, and **N. Yu. Ganushkina**, Strong magnetic gradients observed at electron kinetic scales during dipolarization growth and flux pile up in the near-Earth magnetotail, submitted to Geophysical Research Letters, November 2017.

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Dissemination, since January 2017 (3)

Orals, invited

1. **N. Ganushkina, S. Dubyagin, M. Liemohn**, Storm-time near-Earth magnetotail dynamics examined using 30 keV proton isotropic boundaries, The Magnetosphere: New Tools, New Thinking, New Results", November 12-17, 2017, Puerto Varas, Chile

Orals, contributed:

1. **N. Ganushkina**, Isotropic Boundaries Observed at LEO as a Proxi for SWMF Magnetic Field, 2nd SWMF User Meeting, February 27 - March 1, 2017, University of Michigan, Ann Arbor, USA
2. **N. Ganushkina, S. Dubyagin**, Low energy electron radiation environment for extreme events, ESWW, November 27 – December 1, 2017, Ostende, Belgium.
3. N. Ganushkina, S. Dubyagin, Jean-Charles Matéo-Vélez, Specification of electron radiation environment at GEO and MEO for surface charging estimates, AGU Fall meeting, 11-15 December 2017, New Orleans, LA, USA.
4. Natalia Y Ganushkina, Stepan Dubyagin, and Michael Liemohn, Probing storm-time near-Earth magnetotail dynamics using 30 keV proton isotropic boundaries as tracers of precipitating and trapped populations, AGU Fall meeting, 11-15 December 2017, New Orleans, LA, USA.