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INVESTIGATION OF THE RELATIONSHIP OF ELECTRON FLUX ENHANCEMENTS WITH INTERPLANETARY AND GEOPHYSICAL CHARACTERISTICS

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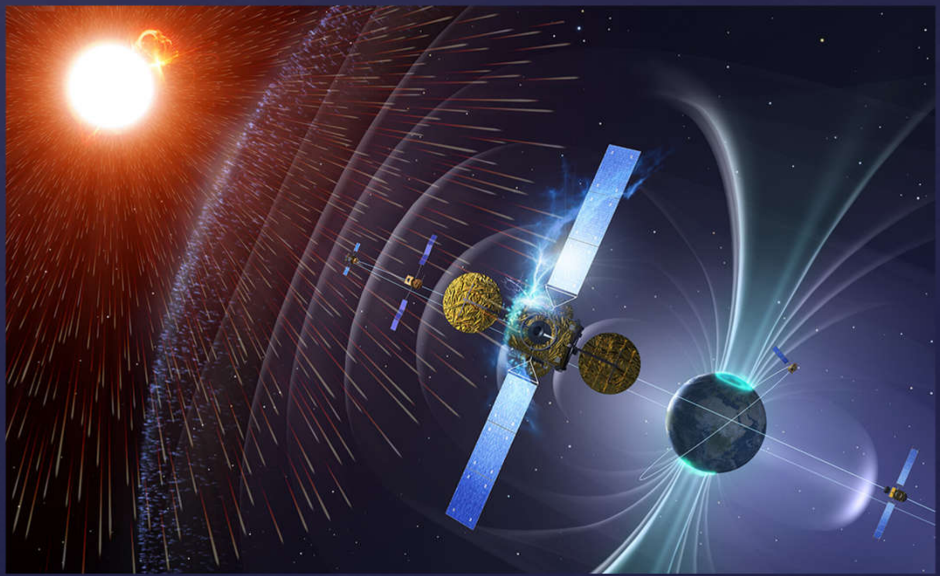
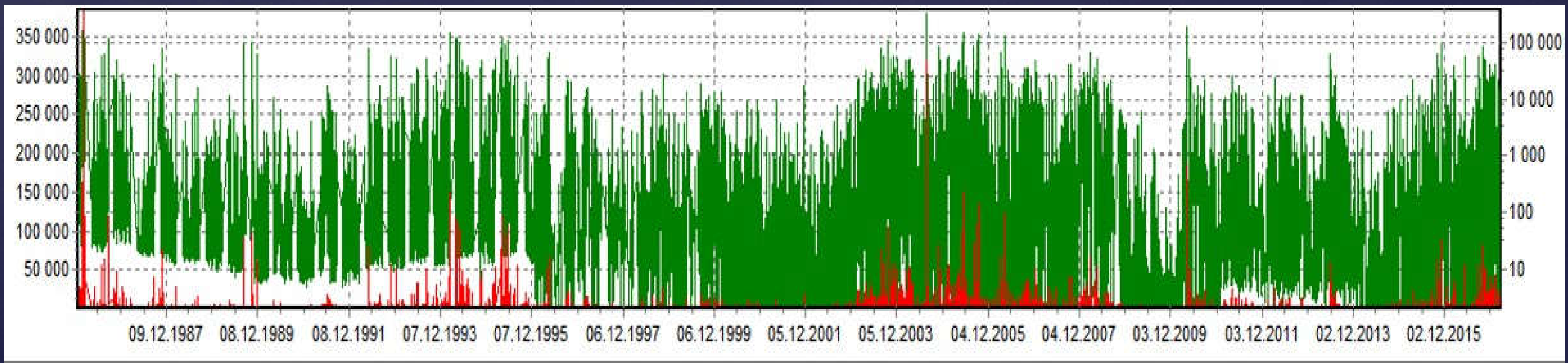


THE DANGER OF INCREASING OF HIGH-ENERGY MAGNETOSPHERIC ELECTRONS WITH E>2 MEV

Why is this task so important for Space Weather research?

Large enhancements in the fluxes of relativistic electrons lead to spacecraft malfunctions and have in a number of cases resulted in the failure of satellites. The anomalies were most frequently associated with false commands caused by internal electrostatic discharges.

HIGH ENERGY ELECTRON FLUX (>2 MEV) IN 1986-2016



In 1986–2016, daily fluence *F* of high-energy (>2 MeV) electrons measured by the GOES satellites varied within wide limits, from 1.4×10^4 to 9.3×10^9 electrons $(cm^2\ sr\ day)^{-1}$.

DATA USED

As main characteristics of magnetospheric electron fluxes in geostationary orbits the following were chosen: the particle flux directly measured on the GOES satellites (the number of particles$\cdot$cm$^{-2}\cdot$sr$^{-1}\cdot$s^{-1}) and the diurnal fluence (total flux per day) of relativistic magnetospheric electrons with energies above 2 MeV.

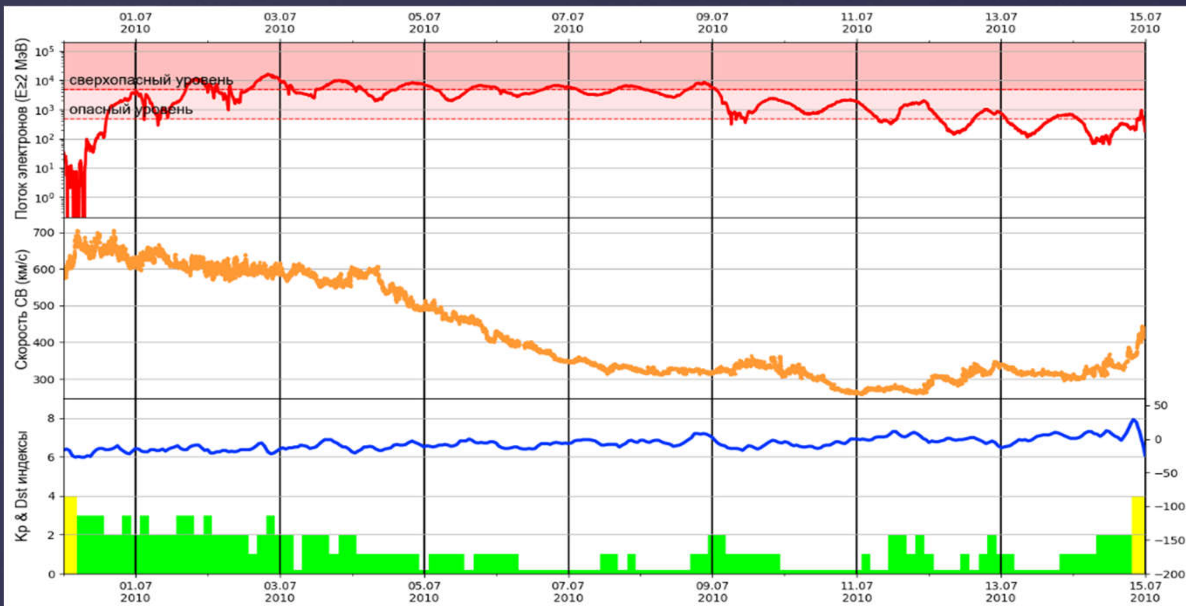
Information about high-energy electrons, characteristics of solar and interplanetary activity is collected in the Solar and Geomagnetic Activity (SGA) database, created and maintained at IZMIRAN.

This database contains information on:

- Diurnal electron fluences obtained onboard the GOES satellites over a 35-year period (1987-2021) — ftp://ftp.swpc.noaa.gov/pub/lists/particle/
- SW parameters are taken from the OMNI database — ftp://spdf.gsfc.nasa.gov/pub/data/omni/high_res_omni
- Geomagnetic activity – Kp- and Ap -indices — ftp://ftp.gfz-potsdam.de/pub/home/obs/kp-ap/wdc
- Dst-index — http://wdc.kugi.kyoto-u.ac.jp

The SGA database is updated daily

EXAMPLES OF ELECTRON ENHANCEMENT EVENTS

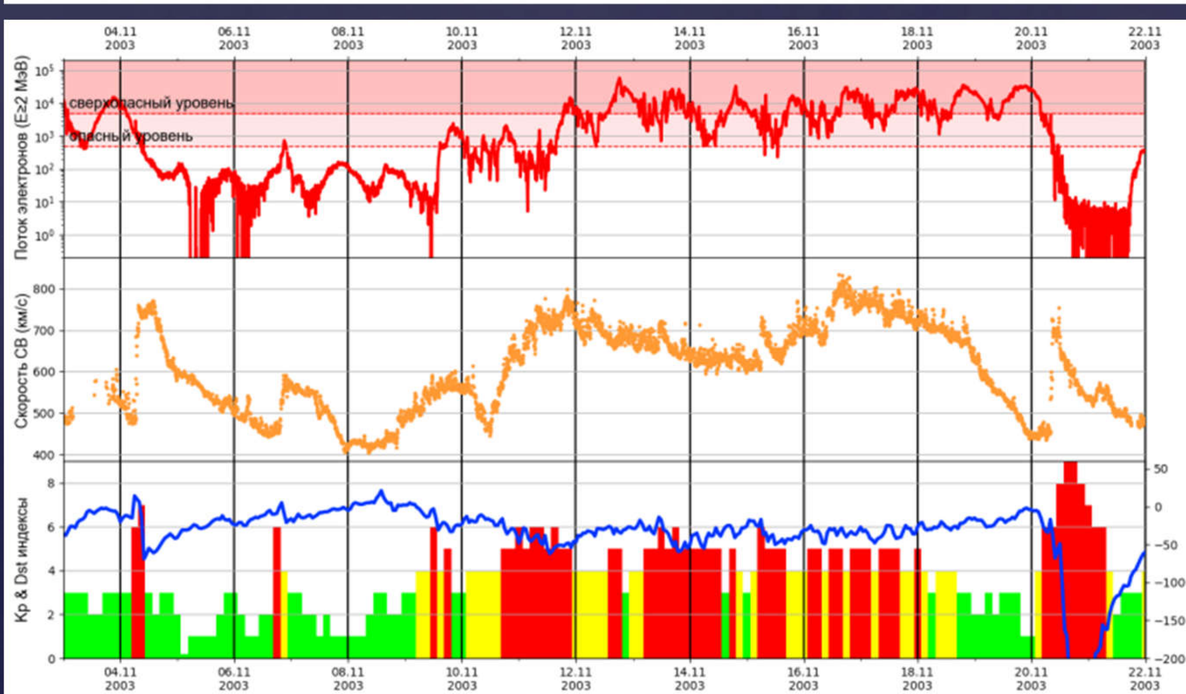


Dangerous enhancement in the flux of electrons on June 30 - July 14, 2010

Consideration of the available electron enhancement events shows that some of the electron enhancements were not accompanied by magnetic storms and can be observed in:

- disturbed
- weakly disturbed
- calm geomagnetic conditions

← For example



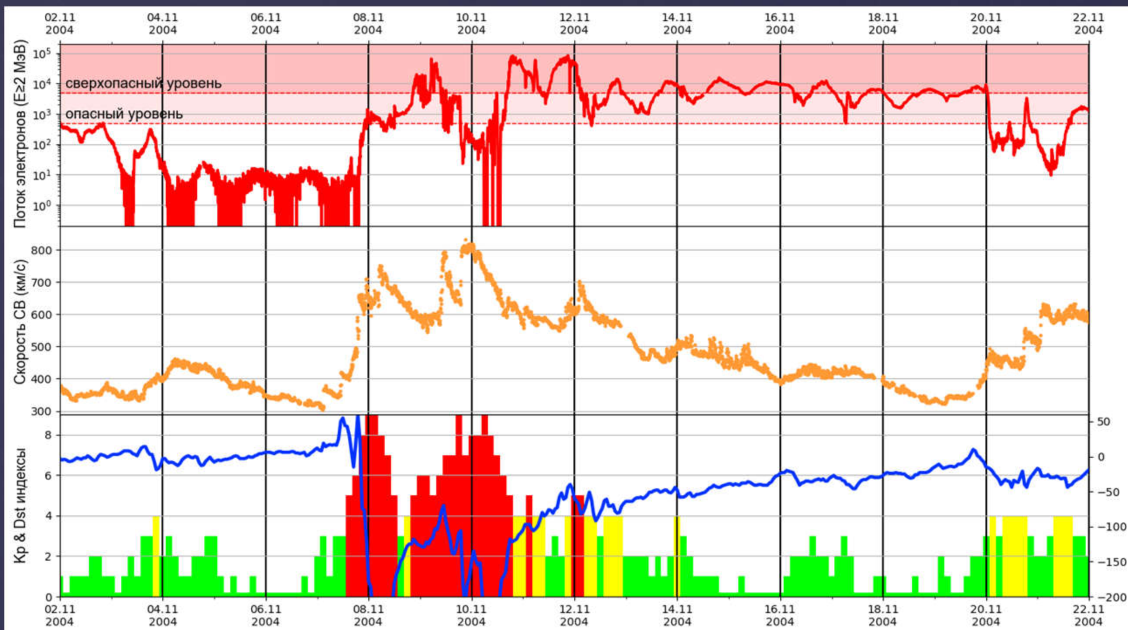
Dangerous enhancement in the flux of electrons on November 19 - 28, 2003

The most powerful solar flare, X28.0, occurred on November 4, 2003.

Prolonged moderate magnetic storm was recorded, lasting almost 9 days.
The speed of the solar wind reached 800 km/s.

The event lasted 8 days

EXAMPLES OF ELECTRON ENHANCEMENT EVENTS

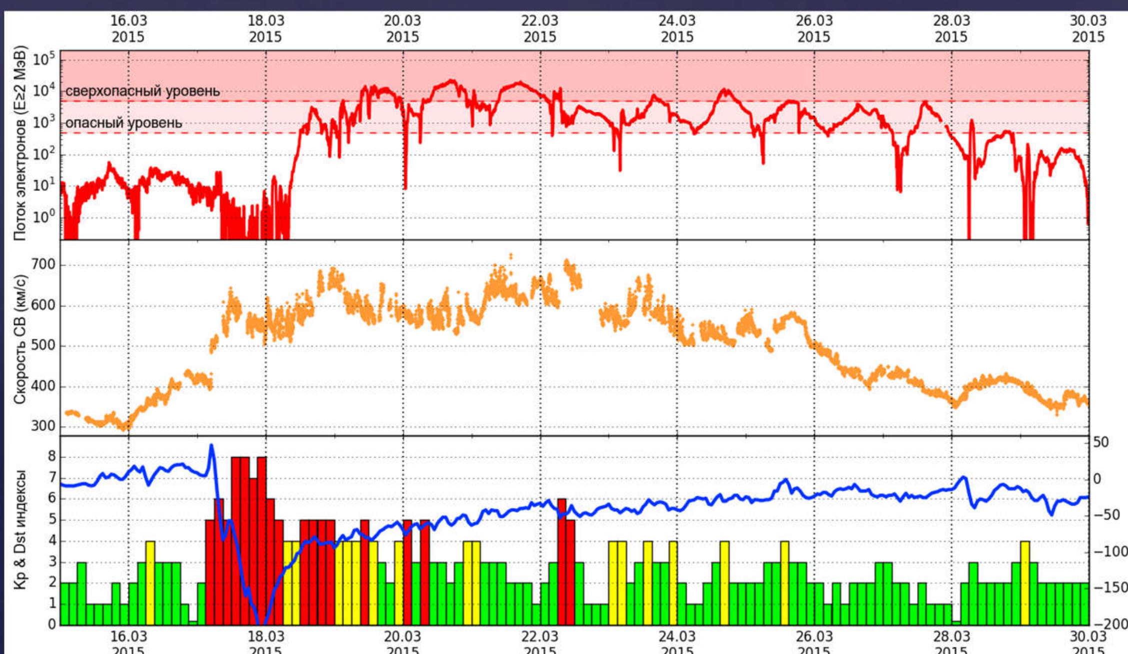


Dangerous enhancement in the flux of electrons on November 8 - 19, 2004

Figure shows data during two extremely large storms that occurred on November 7-8 and 9-10, 2004. The storms were caused by CME from powerful X2.5 and X2 class solar flares.

The speed of the SW obtained

- 750 km/s during the first storm
- 820 km/s during the second.

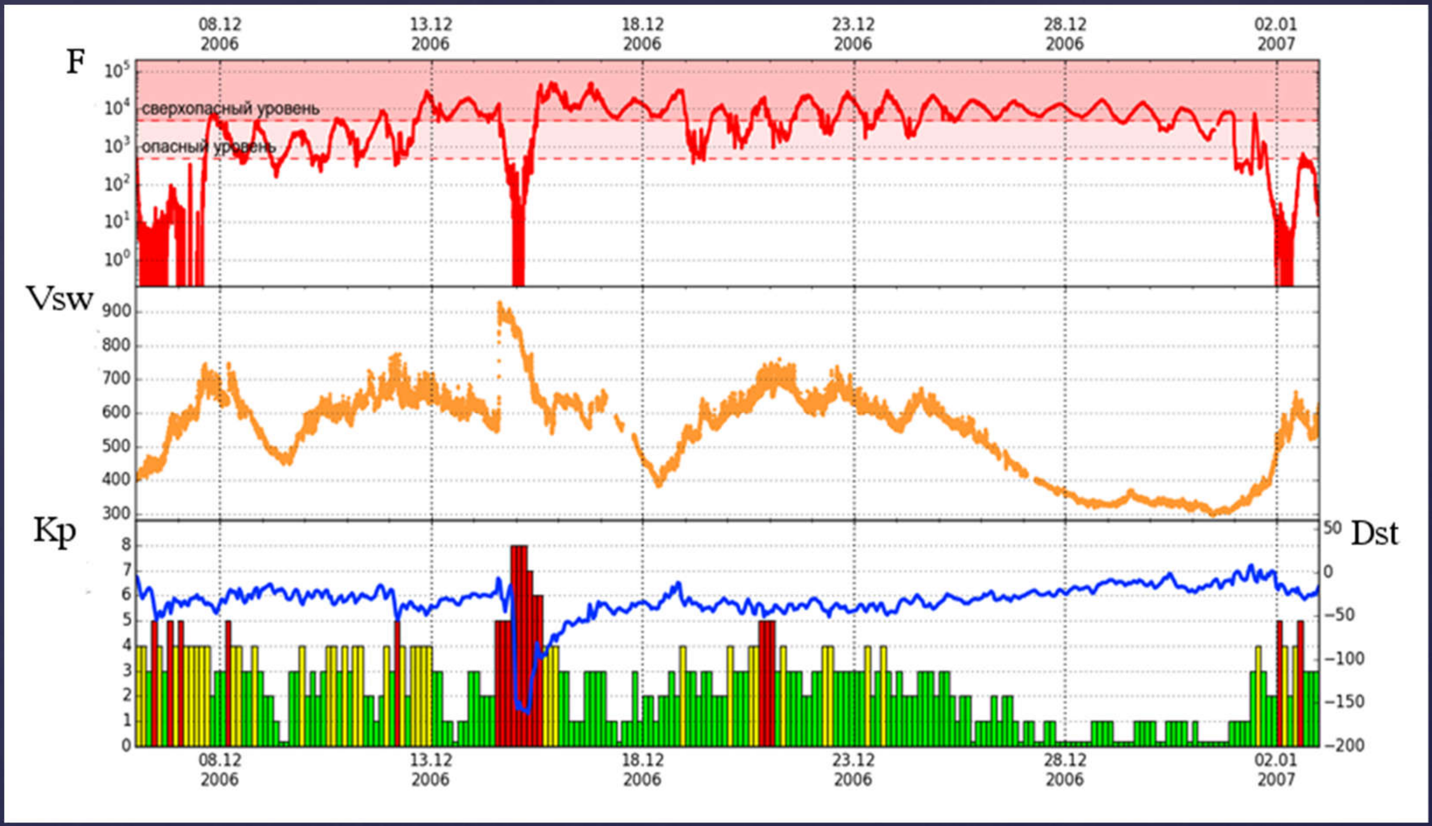


Dangerous enhancement in the flux of electrons on March 18 - 27, 2015

The storm occurred as a result of the combined effect of the solar wind flux from the northern coronal hole CH659 and CME (partial halo).

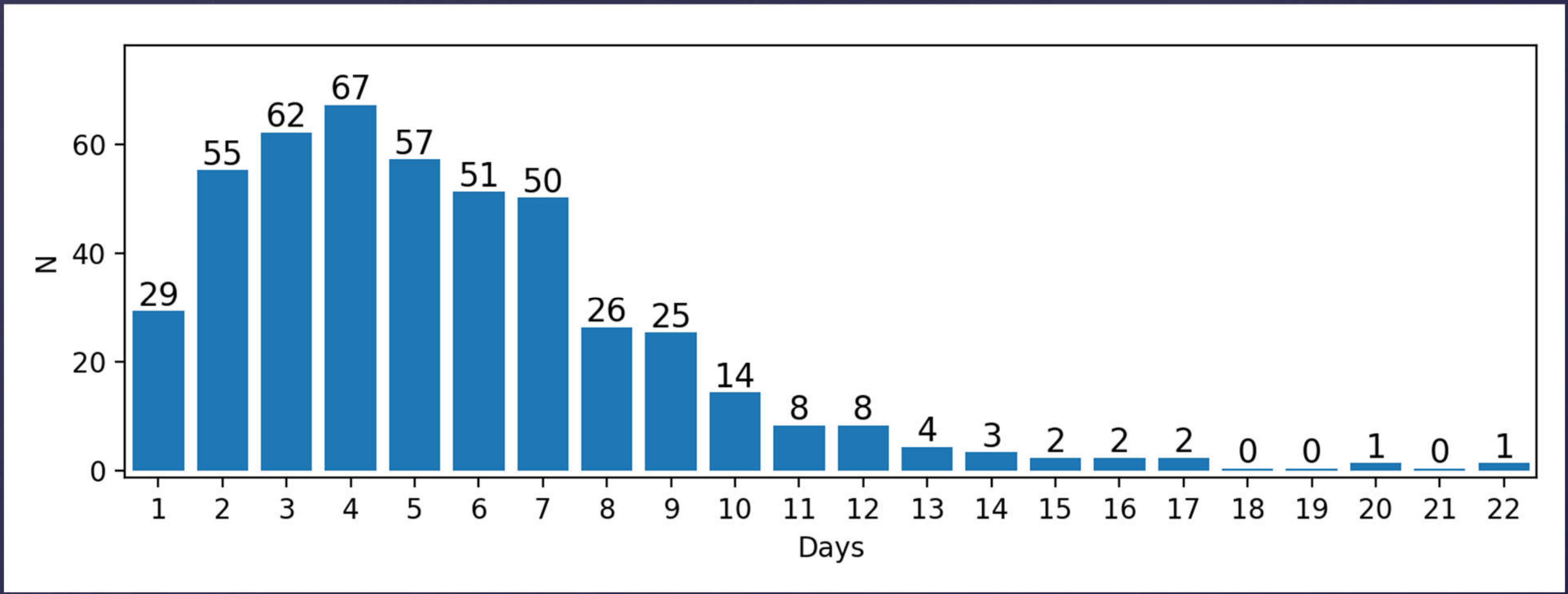
The dangerous level was observed for almost 3 days, the return to the normal level began after 6 days.
The solar wind speed increased to 700 km/s.

Let us consider the durations of electron enhancements of high-energy magnetospheric electrons with energy >2 MeV in the geostationary orbit. The duration of electron enhancements is usually 1 - 3 days. The longest enhancement in the history of electron flux measurements, which lasted 22 days, was observed from 10 to 31 December 2006



The flux of high-energy electrons (upper panel), SW velocity (middle panel) and geomagnetic indices Kp and Dst (lower panel) on December 10 - 31, 2006

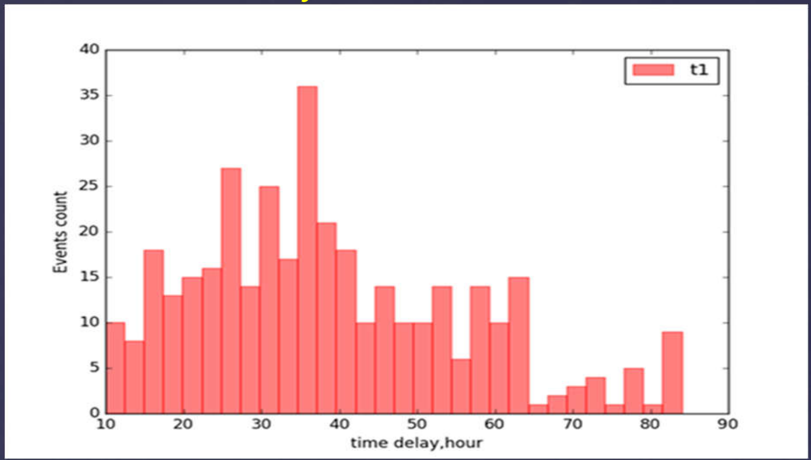
In more detail, we considered the durations of electron enhancements in 1994-2021. Figure shows the distribution of electron enhancements with different durations. The numbers above the histogram columns show the number of events N with the corresponding duration.



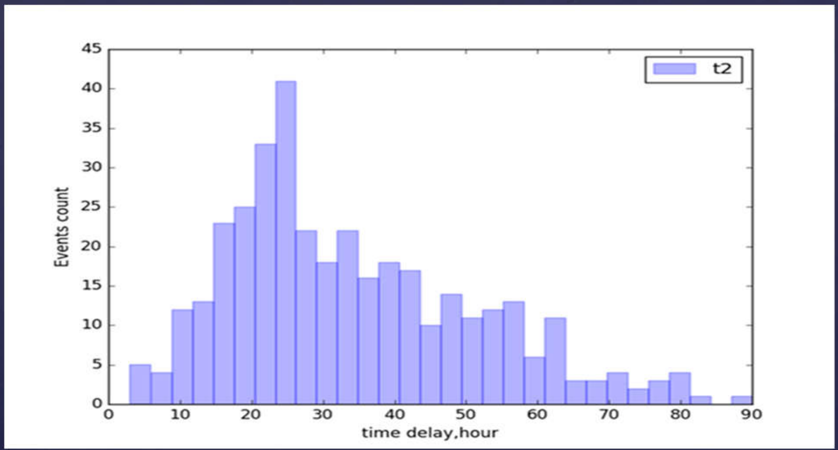
The number of electron enhancements *N* in 1994-2021 depending on the duration of events

DETERMINATION OF THE DELAY TIMES FOR THE ONSET OF ELECTRON ENHANCEMENTS RELATIVE TO GEOMAGNETIC DISTURBANCES AND ENHANCEMENTS IN THE SOLAR WIND SPEED IN 1987-2020

Daily fluence

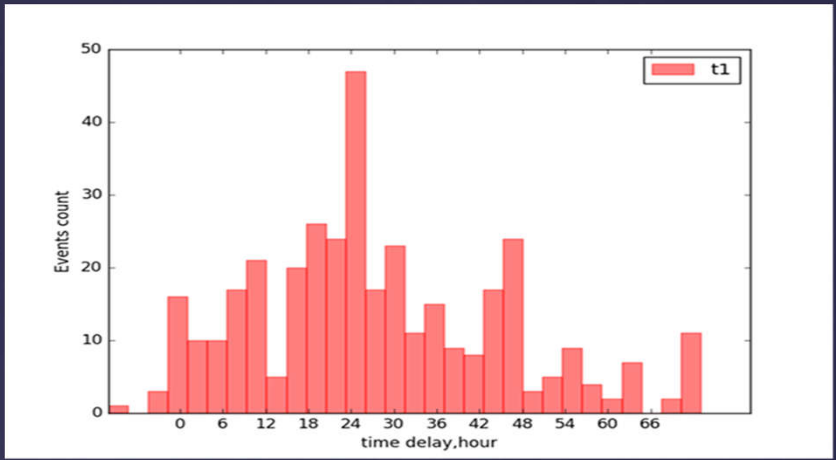


Δ t_1 delay time of the electron increase from the beginning of the geomagnetic disturbance
Δt_1 mean = 35 - 40 hours (~1.5 days)

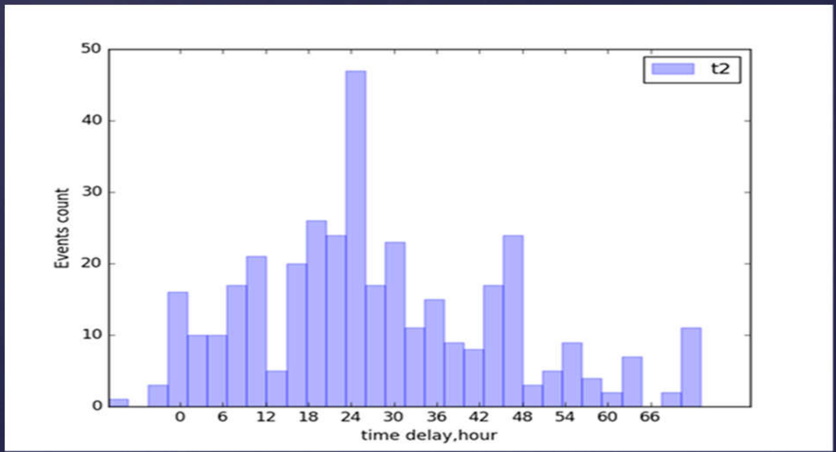


Δ t_2 is the delay time of the electron increase from the beginning of the solar wind increase. for
Δ t_2 mean = 20-26 hours (~1 day).

Onset electron flux enhancement

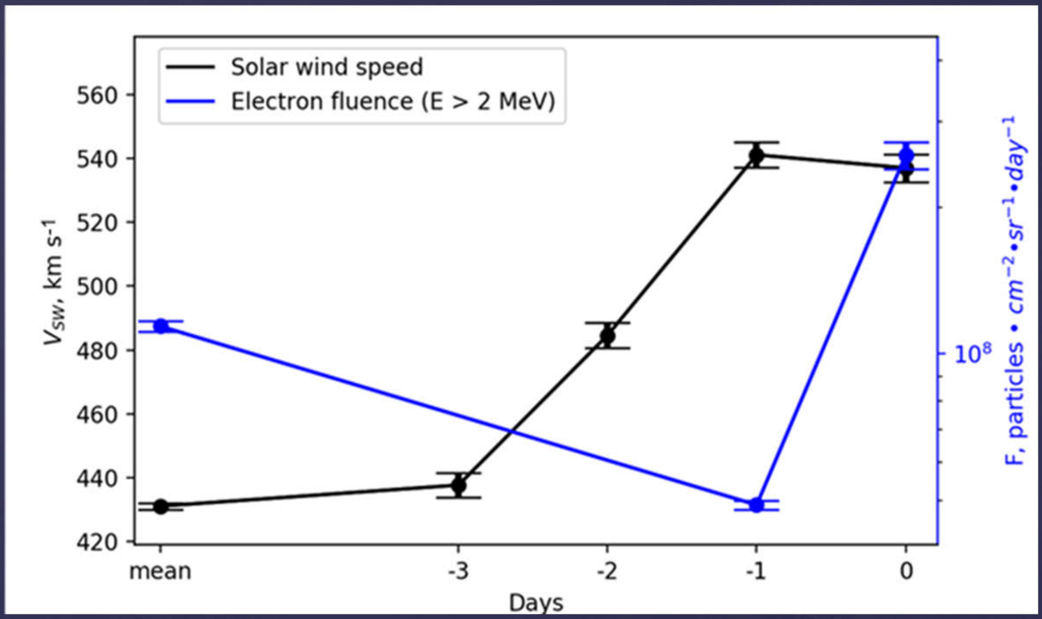


Δ t_1` delay time of the electron increase from the beginning of the geomagnetic disturbance
Δt_1` mean = 24 - 26 hours (~1 day)

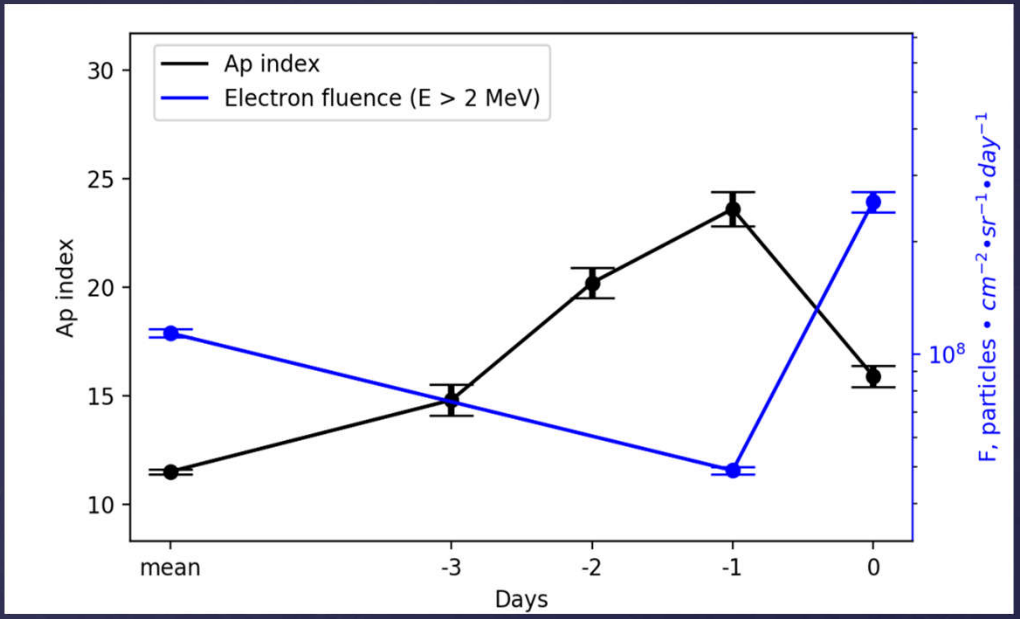


Δ t_2` is the delay time of the electron increase from the beginning of the solar wind increase.
Δ t_2` mean = 24-26 hours (~1 day).

THE TYPICAL BEHAVIOR OF THE SOLAR WIND VELOCITY AND THE AP-INDEX OF GEOMAGNETIC ACTIVITY BEFORE THE ELECTRON FLUX ENHANCEMENT AND DURING ITS ONSET (1987-2021)



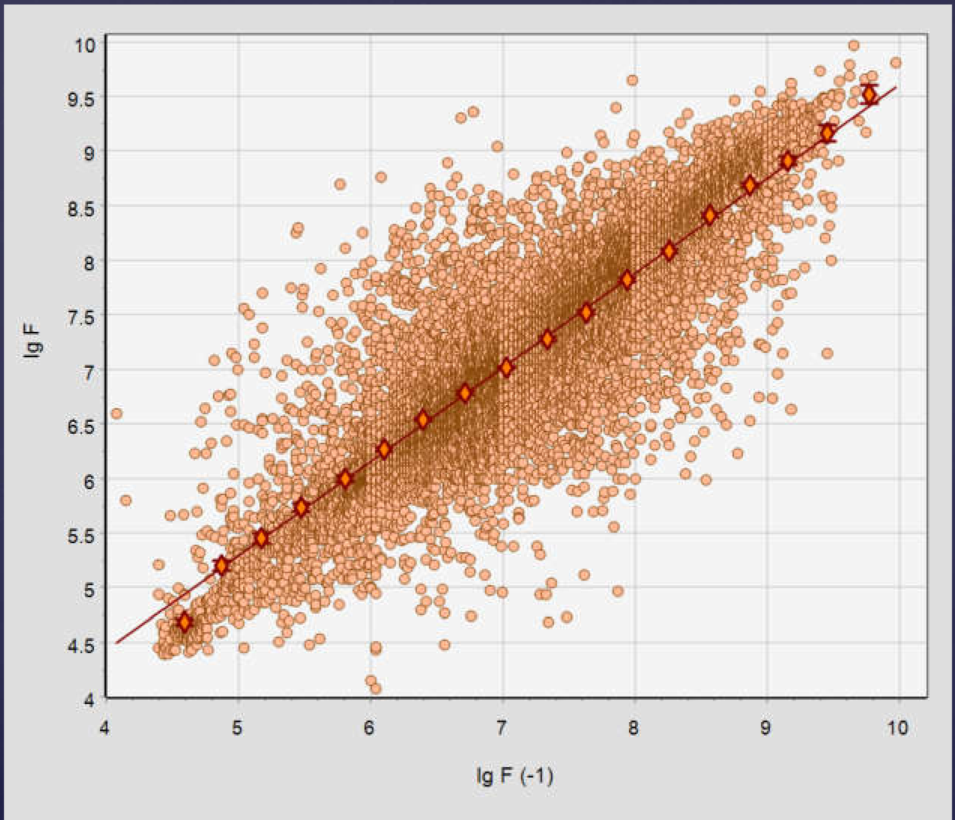
Behavior of the averaged SW velocity and diurnal fluence of magnetospheric electrons before the beginning of electron flux enhancements



Behavior of the averaged Ap-index of geomagnetic activity and diurnal fluence of magnetospheric electrons before the beginning of electron flux enhancements

RELATIONSHIP BETWEEN CHANGES IN THE ELECTRON FLUENCE AND INTERPLANETARY AND GEOMAGNETIC CHARACTERISTICS

Relationship between the current value of the electron fluence and the values for the previous days



Relationship between the current day fluence F(0) and the previous day fluence F(-1) in the case of a power representation.

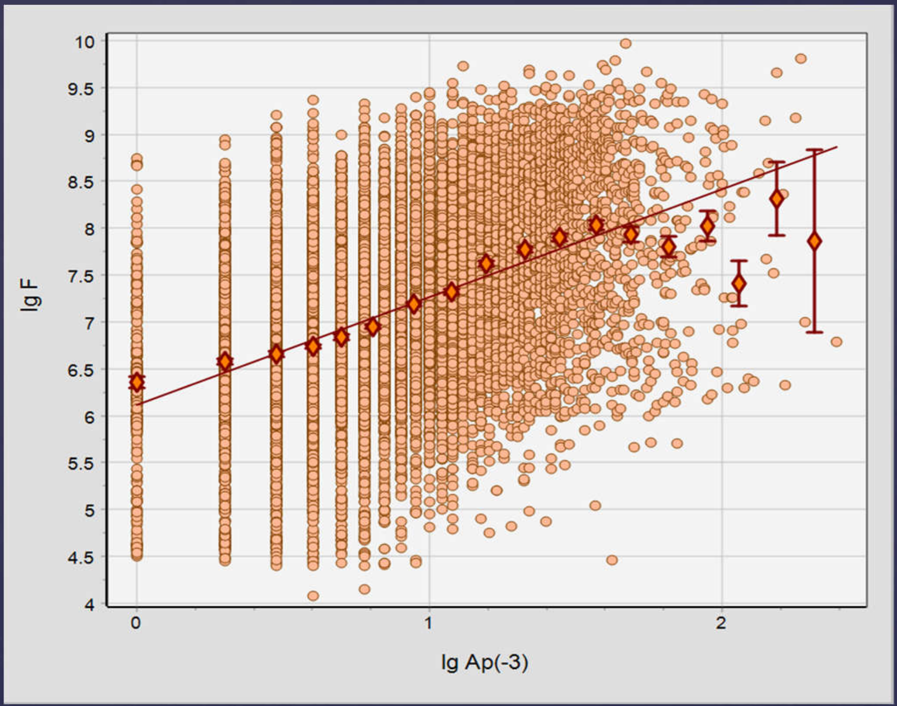
It follows from Figure that the relationship between the fluences F(0) and F(-1) for neighboring days is quite close (correlation coefficient K_F = 0.792±0.005).

If we compare the fluence F(0) with F(-2), then the relationship becomes weaker (correlation coefficient K_F = 0.55±0.01), but remains quite clear.

The highest correlation coefficient can be seen in the case of a power law representation (Figure 1~~b~~).
In this case, the correlation coefficient K_F = 0.863±0.005.
The error bar represents the standard statistical error (σ).

Relationship with Geomagnetic Activity Indices

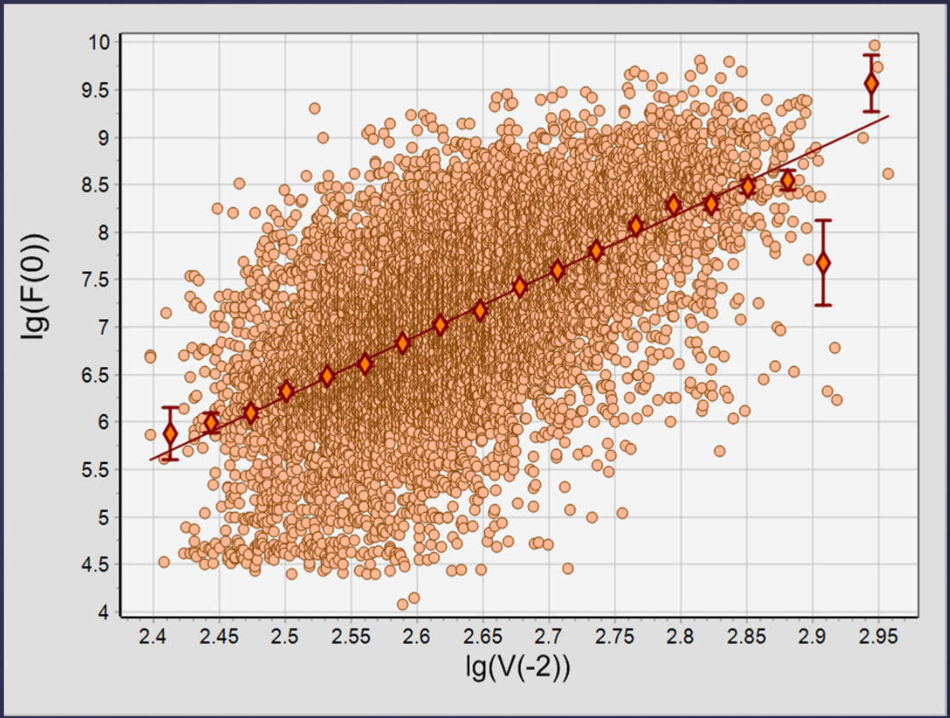
The maximum correlation coefficient is observed with the Ap-index measured 2 – 3 days earlier.



Relationship between the electron fluence and the geomagnetic activity Ap-index measured 3 days earlier

Relationship with solar wind speed

Calculated the linear regression coefficients for the relationship between the electron fluence and the solar wind speed with a shift from 0 to 3 days. The corresponding correlation coefficients are shown in Table



Correlation between the electron fluence and the solar wind speed with a shift of 2 days in the case of a power representation.

Correlation coefficients between the electron fluence and various parameters

Parameter	0 day	-1 day	-2 day	-3 day	- 4 day
Electron fluence	-	0.792±0.005	0.55±0.01	-	-
Ap-index	0.03±0.01	0.17±0.01	0.30±0.01	0.32±0.01	0.29±0.01
Solar wind speed	0.24±0.01	0.37±0.01	0.43±0.01	0.38±0.01	-

PREDICTIVE MODEL

To create an effective predictive model for the fluence of high-energy magnetospheric electrons, we decided to combine the indices associated with the prehistory of the fluence with indices that include the solar wind speed and the level of geomagnetic activity.

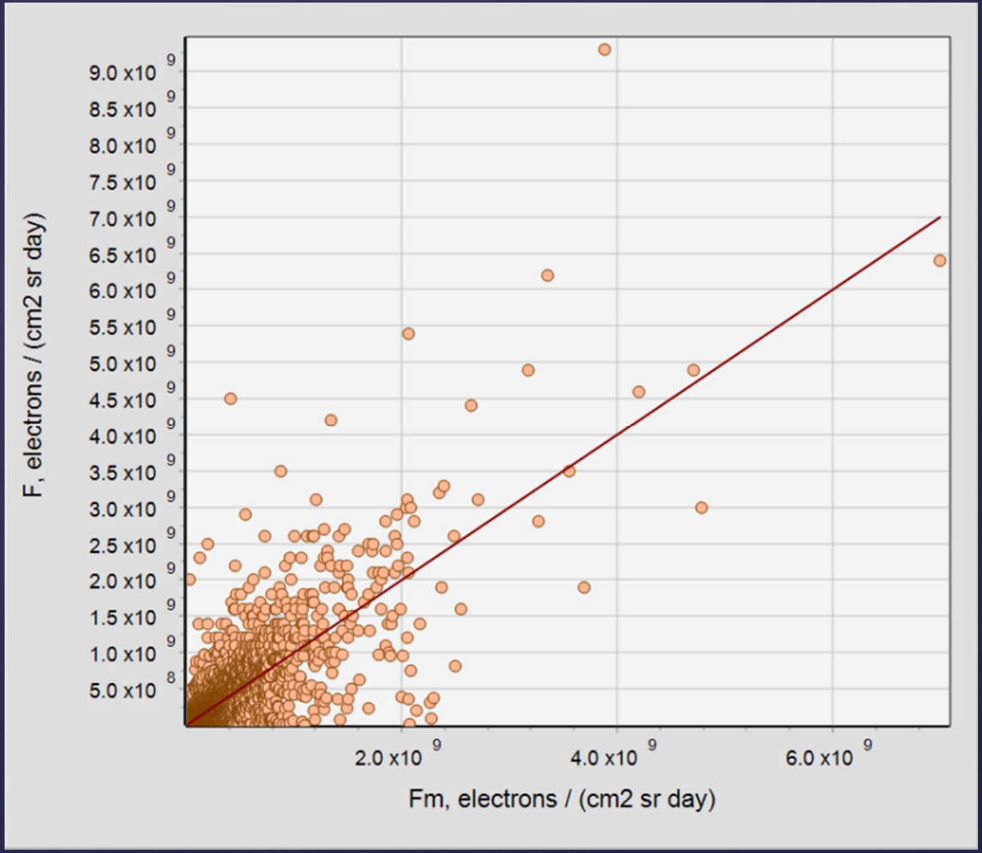
A multiparameter model of the high-energy magnetospheric electron fluence can be presented as follows:

$$F_M = a + b \cdot F + c \cdot V + d \cdot Ap$$

Such a model with three different indices gave the best results (correlation coefficient K_N=0.82) when using

1. previous day electron fluence – F(-1),
2. previous day solar wind velocity – V(-1),
3. geomagnetic activity Ap-index measured 2 days earlier – Ap(-2).

Note that the values of the correlation coefficient given in Table for Ap(-3) are somewhat larger than for Ap(-2), but Ap(-2) showed better results in the simulation.



Together with the statistical errors of the regression coefficients for the selected parameters, we have:

$$F_M=(-1.29\pm0.11)\cdot10^8 + (0.882\pm0.010)\cdot F(-1) + (1.62\pm0.21)\cdot10^6\cdot V(-1) + (3.65\pm0.38)\cdot10^5\cdot Ap(-2)$$

CONCLUSIONS

- The features of sharp increases in the flux of high-energy magnetospheric electrons and the state of the interplanetary and near-Earth medium are studied.
- The delay times for the onset of electron enhancements relative to geomagnetic disturbances and enhancements in the solar wind velocity for each event in 1987-2020 are calculated and analyzed.
- A three-parameter model has been obtained for predicting the fluence of high-energy magnetospheric electrons. The model is based on the prehistory of the fluence behavior, data on the geomagnetic activity Ap-index, and measurements of the solar wind speed.

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Institute of Ionosphere

Thank you for your attention !

Tamgaly-Tas Petroglyphs «Man-Sun» in Kazakhstan