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Operative center of the geophysical prognosis in Izmiran

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Abstract. IZMIRAN was founded about 65 years ago with one of the goals of carrying out geomagnetic prognoses. More or less, this activity has been developed during its entire history, but about 6 years ago this aim became sufficiently feasible due to the organization of the Forecasting Center of helio-geo-physical conditions. This Center appeared in response to new technologies, numerous new data available and new social demand. The Center uses the extended experimental basis of IZMIRAN and all available Internet sources. Its main tasks consist of continuous monitoring of the processes at the Sun and in the near-Earth environment, development of different kinds of prognoses and delivering them to users. The main product is a short-term (1–6 days) prognosis of geomagnetic activity (mainly daily A_p-index and maximum K_p-index), a long-term (from weeks to years) prognosis and detailed forecasting on the special fixed dates. Among its consumers it is worth mentioning the Russian Space Agency, the Russian Ministry of Civil Defense, Emergencies and Disaster Relief, railway departments, a number of medical institutions, and mass media. In this work we discuss some activities of the Center, along with presenting several examples of the real influence of geomagnetic disturbances on different sides of human activity. Our six years of experience show a growing interest in prognoses of this type and this tendency seems to be retained.

Keywords. Magnetospheric physics (Solar wind-magnetosphere interactions, Storms and substorms) – Solar physics, astrophysics, and astronomy (Flares and mass ejections)

1 Introduction

Sun is the source of the life at the Earth, and at the same time it exposes this life to hard tests. Prodigious energy about 10^{23} kW partly reaches the Earth either as a radiation within the widest frequency range or as fluxes of charged particles. The whole complex of the solar phenomena and their manifestation at and near the Earth, the so-called "Space Weather", essentially effects different sides of the human vital activity (Feynman and Gabriel, 2000; Baker, 2004; Brekke, 2004; Watermann and references there, 2004).

It has already been mentioned in many references that strong space weather variations can influence various technical systems of the spacecraft and ground level devices. In particular, it may result in:

- Anomalies and catastrophic failures in the operating of ground level, avionic and space technique (Allen and Wilkinson, 1993; Belov et al., 2004; Iucci et al., 2005);
- Breaks in the long distance communication and in the navigation systems working both on the short waves and on significantly higher frequencies (Lanzerotti, 2001);
- Increase of the radiation hazard for the cosmonauts and passengers of civil aviation;
- Changes in the satellite static charge;
- Heating of the upper atmosphere and consequent strong changes in the atmospheric density profile that cause the loss of orientation of the spacecraft and involuntary departure from the orbit;
- Inducing strong telluric currents resulting in the failure of the long electric lines and the breakdown of gas and oil pipelines due to increasing corrosion and anomalies in the system of anodic defense (Campbell, 1980; Boteler, 2000; 2003; Pirjola et al., 2000; Watermann, 2004);
- False functioning of the automatic and light-line systems on the railways (Oraevsky et al., 2003a).

Space weather also exerts influence directly on people's health:

- It deteriorates the total feeling of healthy people and enhances pathology of the chronic clients, in conjuntion

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with vascular desease (Dmitrieva et al., 2000; Gurfinkel et al., 2003);

- Increase in a number of psychology disorders, as well as changes in the reaction speed and probability of inadequate solutions, suggestive of an effect of the weak magnetic field on biological systems (see Aksyonov et al., 2001; Bingi and Savin, 2003).

Until now, the space weather influence on the climate variability and its potentially catastrophic manifestation has not been sufficiently studied yet. It is difficult to estimate this influence quantitatively. In any case it seems more reasonable to try to somehow prevent the effects of space weather than to struggle with its consequences.

It turns out that in Russia the easy-access sources of space weather information have been absent for a long time. Due to scientific passivity, the mass media were filled with pseudoscientific information and geomagnetic prognoses, at best of astrological origin that led to the faked psychological - "space weather" effect on the population. Thus, the true and timely information on heliophysical conditions became of keen necessity for the society.

Considering the above-mentioned requirements, an operative Center of Forecasting of geophysical conditions was created at IZMIRAN. This allowed for the special possibilities and advantages of IZMIRAN as a scientific institute with more than 60 years of experience to be realized and utilized. A problem of solar-terrestrial relations is being studied at IZMIRAN comprehensively and from all possible aspects, due to the specialized theoretical scientific content and essential experimental base. The staff of the Center consists of the experts from various fields: solar physics, interplanetary physics, magnetosphere, ionosphere and cosmic ray physics. Such a group is able to comprehend most of the space weather data, to estimate operatively the situation at hand and to substantiate a tendency of the space weather evolution (Belov et al., 2004; Panasuyk et al., 2004).

The Center poses the following problem to be solved:

- Monitoring of the processes occurring at the Sun, in the interplanetary and near-Earth space by means of all available data sources and measurements;

- Continuous analysis of the helio-geophysical situation with account of the current information, pre-history and potential tendency for further evolution;

- Producing the different warning geomagnetic prognoses (nowcasting, short-time, mean time and long-term prognosis) and documents. Delivering them to users;

- Communication and collaboration with partners;

- Improving the forecasting methods with modern scientific approach.

2 Data and methods

There are two key statements in the basis of the geomagnetic prognosis:

1. Geomagnetic storms are created at the Sun;
2. Two main sources of the geomagnetic storms are coronal holes and coronal mass ejections (CME).

The prognoses of the IZMIRAN Center are mainly based upon the same sets of observations and operative data, which are used in all other space weather centers, in particular:

- Pictures and movies of the Sun within the optical, ultraviolet and X-ray ranges inform us about a position and evolution of the coronal holes, about evolution of the active regions and appearance of the new one, about filament activity, and eruptive and post eruptive phenomena;

- Changes in the photosphere magnetic fields provide the information on the development of the active complexes at the Sun and allow for the magnetic field distribution to be calculated on the solar wind source surface and in the interplanetary space;

- Solar radio burst measurements provide information about active processes at the Sun (coronal mass ejections-CME, shocks, acceleration of the charged particles);

- Data on the X-ray, gamma-ray, solar cosmic ray measurements (satellite and ground level observations) give the first evidences of the powerful energy release at the Sun;

- Pictures and movies from the satellite coronographs give the most direct information on the solar ejections. Unfortunately, ejecta, coming directly towards the Earth, are seen in these pictures much worse than ejecta passing by the Earth.

- Data of helio-seismology allow for an indirect estimation of the stage and speed of the evolution of the active regions at the invisible portion of the solar disk;

- Variations of the interplanetary plasma velocity, density and temperature reflect dynamic features of the near-Earth solar wind, which directly influences the magnetosphere;

- Variations of the interplanetary magnetic field (IMF) intensity B and its three components, A_p, B_y, B_z, are used for the shortest time prognosis. The space apparatus located between the Sun and Earth near the libration's point, record disturbances originating from the Sun 20–60 min prior to when they start to impact the Earth's magnetosphere. On this basis it is possible to provide a rather reliable short time prognosis, or a well substantiated alert, just before the geomagnetic storm commencement;

- Cosmic ray variations of the solar, interplanetary and galactic origin measured on-board satellites and by the ground level neutron monitor network are used to define the onset of proton events, and Forbush effects usually associated with the geomagnetic storm. At present, data from about 25 ground level cosmic ray stations are accessible in a real-time regime;
- Variations of the geomagnetic field are available in real time from the measurements at more than 30 ground level stations distributed over the Earth. One of them is the IZMIRAN magnetic observatory;
- Variations of the geomagnetic field by the spacecraft measurements and associated changes in the electron fluxes inside the magnetosphere.
- Ionospheric data

Despite that the prognoses in our Center are guided by the same data as those in the other centers, substantial peculiarities exist in the IZMIRAN approach and methods, due to the long experience in the study of the solar-terrestrial relations.

3 Our production and users

The activity of the IZMIRAN Forecasting Center is intended to elaborate on the following kinds of prognoses:

- Short-term (1–6 days) forecasting of geomagnetic activity;
- Daily mean A_p-index for the next 1–6 days;
- Long-term prognosis (4–45 days and more);
- Probability of the maximum K_p-index for the next 1–6 days;
- Prognosis for the fixed days by special request;
- Detailed information and analytical overview of the solar and geomagnetic activity for the past month and preliminary prognosis for the next one.

Short-term prognoses are formed several times per day; every day throughout a week they are given out and delivered by various types of contact with the interested organizations. Reliable contacts are formed with the Russian Space Agency (the Exploitation Center of the objects of ground space infrastructure, the Mission Control Center - MCC, Baykanur and Plesetsk Kosmodroms) and with the Russian Ministry of Civil Defense, Emergencies and Disaster Relief.

In order to sustain this collaboration, our Center launched the program of forming detailed databases on various extreme situations of natural and technogenic origin. Now our Center provides information for the Russian spacecraft launches and further exploitation of the space objects by operative prognoses. Due to this information on large geomagnetic storms, often it turned out to be possible to retain space objects in orbit, for example, as in the case of the "OCEAN-O" satellite. The Center also operatively collaborated with the staff of the MCC during the final stage of the orbital complex "MIR" landing.

Apart from this, our prognoses are delivered to the Russian Academy of Sciences, the Institute of Medical-Biological problems, was well as to a number of various medical centers and hospitals (Oraevsky et al., 2002; 2003b). Every day, the information on space weather is forwarded to different mass media (radio, TV, newspapers). For the first time in the world, an automatic system with a round-the-clock prognosis of the geophysical conditions is run in the from of a telephone answering machine. In addition to the standard prognosis, the current data on the geomagnetic disturbance and meteorological parameters are reported to these telephone callers, too.

There are several prognosis centers operating around the world, but unfortunately the accuracy of these prognoses is not so high yet. We analyzed data from different centers: SEC – Space Environment Center (NOAA, USA) (http://sec.noaa.gov/today.html), IPS – Australian Space Weather Agency (http://www.ips.gov.au/), SIDC–Solar Influence Data Analysis Center- RWC Belgium (http://sidc.oma.be/index.php3), and IZMIRAN Forecasting Center of Geophysical Conditions, Russia (http://forecast.izmiran.rssi.ru) – abbreviations these centers are seen in Figs. 1a and b.

One can see from Fig. 1 that the probability of an A_p-index prognosis declines with the time of forecasting: it is the best for a one-day prediction and becomes very low for a three day prognosis. On the whole the correlation is not high even for the first day, nevertheless, the prognosis' quality has apparently increased during the last two years (plots for 2003–2004).

4 Some applications

4.1 Overcoming of the extreme situation in the orbit

One of the space weather hazards for the low orbital satellites is the strong variation in the upper atmosphere density profile during the magnetic storm, leading to the abrupt braking of the spacecraft and to the loss of orientation.

In particular, this problem arise from the first days after the launch of the spacecraft "OCEAN-O", which was developed for the purposes of remote scanning of the Earth and world ocean in optical, infrared and microwave spectral ranges. The standard way of remote control of the on-board apparatus became unreliable during the extreme atmospheric variations throughout the magnetic storms. To improve the situation the solar battery configuration was reformed. This was severely, checked during the large magnetic storm on 15–16 July 2000, the greatest one in the last 10 years. The operative group of the Mission Control Center received in time the IZMIRAN Center warning and after the storm onset began to cope with its consequences. During the time of each connection (which lasted not longer than 12 min),

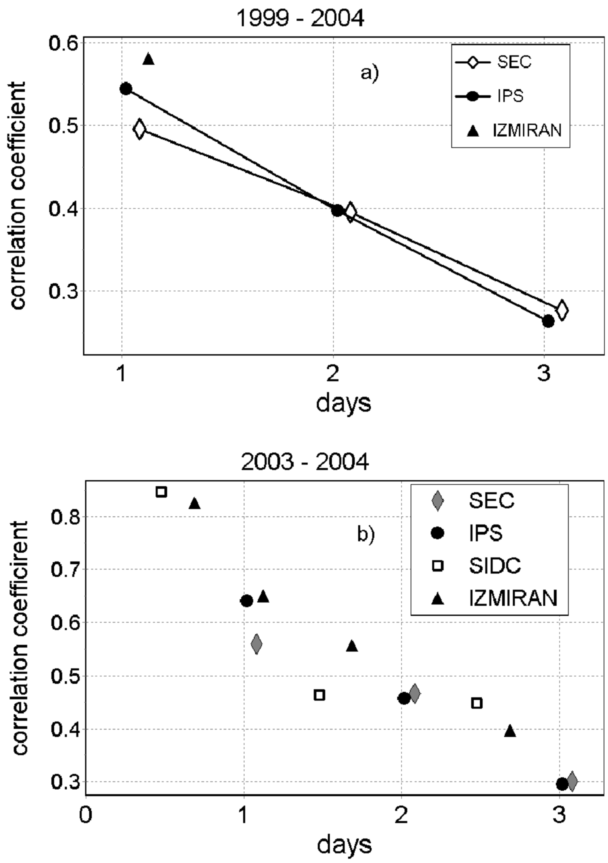

Fig. 1. Correlation coefficients between observed daily A_p-indices and these forecasted by different Centers for 1, 2 and 3 days in advance: upper picture **(a)** presents results averaged within the 1999-2004 period; lower figure **(b)** the results averaged over the 2003–2004 period.

the necessary angle and program of the battery panel turning were defined, a sequence of the corresponding commands was elaborated and transferred on-board; their correct transmission and response to the on-board system was checked. In particular, in the hours of maximal geomagnetic activity the solar battery panel was turned in parallel to the spacecraft' movement. With all necessity this work required the prognosis of geomagnetic disturbances to be carried out in a round-the-clock regime, and, as a result, allowed the "OCEAN-O" to be saved during this severe magnetic storm. This method was also used to retain this spacecraft' orbit during the next strong magnetic storms, which occurred very often throughout 2000–2001. Unfortunately, the Japanese satellite ASCA, during the same magnetic storm in July 2000, lost its orientation. Its on-board control system automatically attempted to turn on the safety mode, but it was not possible to return back to normal functioning from this mode; the spacecraft solar battery lost the Sun and stopped producing the current. On the 2 March 2001 the uncontrolled ASCA satellite entered dense atmospheric layers and sank in the Pacific Ocean.

4.2 Mission on the space complex "MIR" leading off the orbit

The need continue monitoring of the geomagnetic situation was considered when a decision was required on the complex "MIR" landing in 2001. The IZMIRAN Forecasting Center provided daily mean A_p-indices and values of solar radio flux $F_{10.7}$, as well, since both of these parameters were required for the atmosphere model and trajectory calculations. In addition, the special method of long-term prognosis (up to 45 days) of the A_p and $F_{10.7}$ indices was elaborated on, to provide long-term forecasting for the orbital complex landing. An optimal operation assumed the fall of the orbital complex down to 180 km, followed by a set of braking impulses after that. There was a danger that the orbit complex would fall lower than this level and freely leave the orbit when the magnetic storm arose. For example, in the quiet and unsettled geomagnetic conditions the daily decrease in the orbit was about 500 m, whereas during the magnetic storm on 19–20 March, the fall was as much as 8.1 km. Every day during 3 months the ballistics experts from the Mission Control Center calculated the parameters of the orbit on the basis of the IZMIRAN prognosis, which were compared with the trajectory measurements. During the winter months, the conditions were very quiet, whereas a new burst of solar activity had been expected by the end of March, thus, the operation needed to be finished without a delay. On the closing step the Space Agency and IZMIRAN were working in a round-the-clock regime. The operation was finished on 23 March and all ensuing events on the Sun and in the magnetosphere could be considered as an evidence of the timeliness of the "MIR" sinking. As one can see from Fig. 2 the severe magnetic storm was recorded on 31 March – one of the greatest storms over the last solar cycle. The next month - April - was also extremely disturbed. It would be impossible to keep the complex "MIR" in the orbit and conduct a controlled fall under such conditions.

4.3 Failures of the railway automatics during the geomagnetic storm

The significant currents in the ionosphere during the geomagnetic storms may induce the so-called telluric currents in the long conductors, for example, in the electro-transmission lines, gas and oil pipelines, and railways, leading to anomalies in the operating of the mentioned systems (Boteler, 2003).

During 2000–2001 and then in 2003–2004, IZMIRAN was receiving a lot of reports from the Nyandoma part (63–64° N) of the Northern railway regarding the cases of failure of the railway ,devices (signalization, centralization and block system) for a number of railway stations (see Fig. 3): Shozhma, Lelma, Shalakusha, Lepsha, Ivaksha, Plesetskaya, Sheleksa, Puksa, Emtsa, Letneozersky, Shestiozersky. Some similar reports from the Gorky railway were also received during the last few years.

Table 1. Periods of railway failures and characteristics of the geomagnetic conditions at that time.

Date	Max K_p-index	Daily A_p-index	Min D_{st}
6–7 April 2000	9−	82.74	−321
15–16 July 2000	9	164.5	−300
18 September 2000	8+	56.7	−172
31 March 2001	9	192	−358
2 April 2001	7	63	−51
11 April 2001	8+	85	−256
6 November 2001	9	142	−257
24 November 2001	8+	104	−225
29–31 November 2003	9	236	−402
8–10 November 2004	9	186	−383

They reported about false signals at the duty tables regarding blockage on the tracks along the main railway (Oraevsky et al., 2003a). It caused a delay in the train moving. The time and anomaly characteristics where compared to protocols. It is characteristic that the checking of the apparatus after these anomaly signals indicated whether they were functioning properly or not. Comparison of the received reports with the data on the geomagnetic field variations revealed a well pronounced correlation between the anomalies in the railway automatics and big disturbances in the geomagnetic field during the greatest magnetic storms in these years. Table 1 shows the dates of the anomalies on the Northern railway, the 3-h K_p-index maximum, daily A_p-index, and the minimum hourly D_{st} index. It is clearly seen that almost all malfunctions fall during the time of severe geomagnetic storms (maximum K_p is 8+ and more) and only in one case was there a strong storm (K_p-index is 7). A more detailed analysis indicates a coincidence between the time of the anomalies and the most active geomagnetic periods with an accuracy up to hours. It is noteworthy to emphasize that these periods were selected by the information on the railway anomalies, and not by the geophysical situation. We did not receive any information on a similar problem in the quiescent periods. Although it may be assumed that analogous malfunctions (probably less in number) could occur during the weaker geomagnetic disturbances and not only at the Northern railway, the railway experts tried to explain them by simple technical anomalies or by the operator's mistakes. However, the reason for these phenomena may really be the currents induced in the extended system of the railway automatics. They seem to have occurred often enough at all high latitudinal railways. The reports on similar anomalies have also been received from Sweden in 1982 and Norway in January 2000, and another Russian high latitude (Gorky) railway.

To reduce the risk of possible extreme events at the high latitudinal railways the information for railway stations should be provided by a well-timed prognosis of

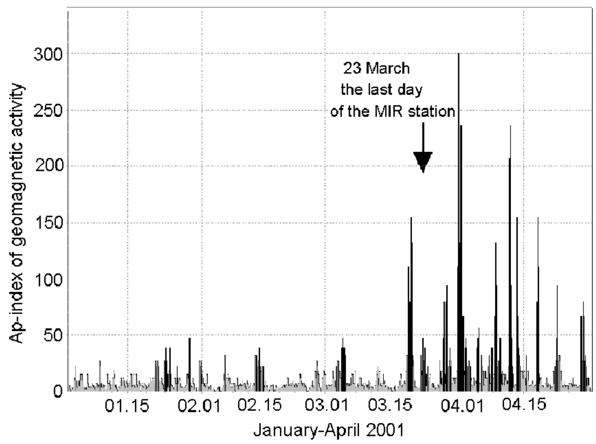

Fig. 2. Geomagnetic situation between January-April 2001 during the mission on the "MIR" landing.

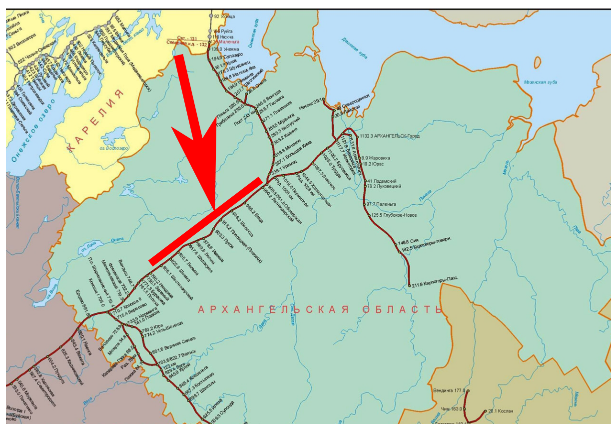

Fig. 3. Nyandoma part of the Northern railway reported on failures in the automatic control systems. In the upper portion one can see a part of Northern Ice Ocean.

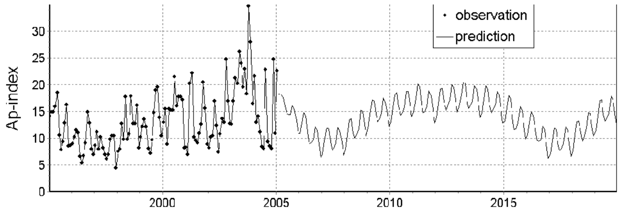

Fig. 4. Monthly mean A_p-indices throughout the last 10 years and their forecasting.

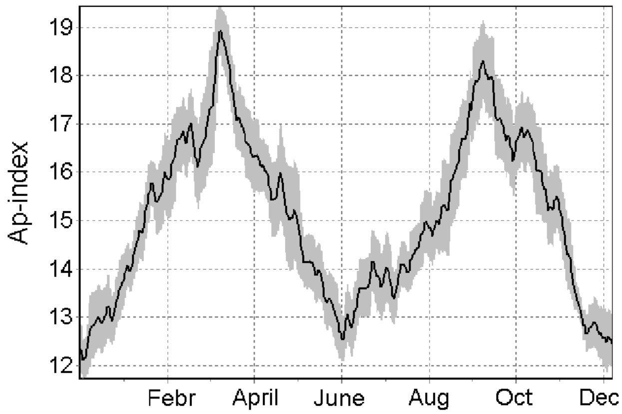

Fig. 5. Seasonal behavior of the A_p-index averaged over the last 137 years. A_p indices have been averaged since 1932, and before this time the aa-indexes were normalized.

geomagnetic activity and by the information about the current geomagnetic situation.

5 Basis for the long-term prognosis

A long-term prognosis for A_p-indices is presented in Fig. 4. It was calculated on the basis of some scientific results on the study of long-term solar-terrestrial dependences. To obtain this long-term curve the behavior of the solar activity index (or, more accurately, the sunspot number) in the 24th cycle was supposed to be the same as the averaged index behavior, averaged over the last 7 cycles. It was also taken into account that the base indices of geomagnetic activity vary regularly within the solar cycle, therefore the averaged behavior of the A_p-index over the 17–23 cycles was defined for the different phases of the solar cycle separately. This averaged behavior of the A_p-index, in combination with its seasonal tendency (see Fig. 5), obtained from the multi- year data, directly forms the basis for the long-term prognosis thus offered. In Figs. 6a and b, a fraction of the days with the magnetic storms (K_p>=5) for different months during the year is presented, together with its autocorrelation function. These data have also been used for the long-term prognosis.

Of course, we can calculate only a smoothed variation of geomagnetic activity, and the real behavior will be less regular. The new, unexpected bursts of solar activity will

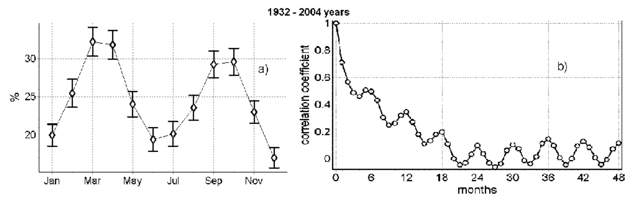

Fig. 6. Monthly distribution of a fraction of days with the magnetic storms (K_p>5) **(a)** and its autocorrelation function **(b)** derived from the data over the 1932–2004 period.

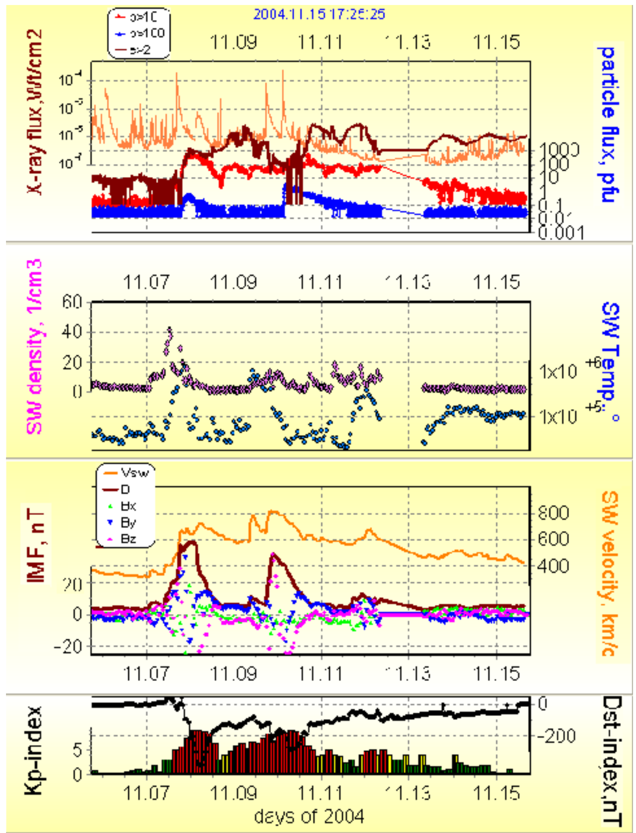

Fig. 7. Behavior of the different space weather parameters measured by the satellite systems and ground level detectors during the solar activity burst in January 2005 (from real-time data).

inevitably occur and cause numerous storms, exceeding the predicted numbers in some cases.

6 Possibilities of further improvement

The numerous works are carried out in IZMIRAN, which may be directed towards refining the geomagnetic prognosis. In particular, the efforts are concentrated on the following models:

– Model of the magnetic field at the solar wind source surface for the current moment;

– Model of the relation between characteristics of the magnetic field on the source surface and of the solar wind near the Earth. This plasma, incoming to the Earth, crosses the surface of the solar wind source several days prior. Thus, the solar wind behavior near the Earth, and the consequent variations of geomagnetic activity appear to be predicted if plasma properties on the source surface are known. The essential prerequisites (Wang and Sheley, 1992) exist for the prognosis of different components of the IMF and solar wind velocity. It requires regular observations and measurements of the magnetic field at the photosphere and a reliable method allowing the field at the source surface to be calculated on the basis of photosphere observations;

– Model of the geomagnetic cloud structure from observations of the solar filaments and solar magnetic field;

– Model of the solar wind fast stream from the coronal hole;

– Model of the coronal holes – interrelation of active regions.

Some new improvements, used as a tool to analyze the current conditions and for the short-term forecasting, are discussed now, such as a stacked plot of data in real time to show the key parameters (Fig. 7), combining solar X-rays (GOES), solar wind and interplanetary magnetic field (ACE), solar protons (GOES), high-energy electrons (GOES), K_p and D_{st} geomagnetic indices.

7 Conclusions

The IZMIRAN Forecasting Center, basing on a long-term studies of solar-terrestrial relation and modern elaborations and on the real-time sets of various measurements, determines prognoses of geomagnetic conditions, which are claimed and used in many organizations at different levels. Six year of experience show that there is a necessity to develop and to deepen the scientific understanding of the processes in the Sun-Earth space. The second necessary issue for prognosis is to provide continuous monitoring of different parameters which are intrinsic to the processes at the Sun, in the space and the Earth's vicinity.

Although there is no reason to expect an extremely high solar activity in the new cycle, it may be even more dangerous because humanity, on average, becomes more "meteo-dependent":

– Communication and navigation are more and more supported by the satellite technologies;

– Megapolis electric systems become more complicated and ramified;

– Exploitation of the high latitude railways become more intensive;

– Dependence on the automatic and microelectronic systems within the wide area of human life becomes stronger.

So, the storms in the next solar cycle may turn out to be more dangerous for humanity than in the previous cycles, and we should be ready for this new challenge.

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References

Allen, J. H. and Wilkinson, D. C.: Solar-terrestrial activity affecting systems in space and on Earth, in: Proceedings of the Workshop Solar-Terrestrial Predictions-IV (Ottawa, Canada, 18–22 May 1992), edited by: Hruska, J., Shea, M. A., Smart, D. F., and Heckman, G., 1, 75–107, NOAA Environmental Research Laboratories, Boulder, CO, 1993.

Aksyonov, S. I., Bulychev, A. A., Grununa, T. Y., Goryachev, S. N., and Turovetsky, V. B.: Effects of FLF-FMF treatment on wheat at different stages of germination and possible mechanisms of their origin, Electro- and Magnetobiology, 20, 231–253, 2001.

Baker, D. N.: Specifying and Forecasting Space Weather Threats to Human Technology Effects on Space Weather on Technology Infrastructure, edited by: Daglis, I., NATO Science Series, 176, 1–26, 2004.

Belov, A. V., Dorman, L. I., Iucci, N., Kryakunova, O. N., and Ptitsyna, N. G.: The relation of high- and low-orbital satellite anomalies to different geophysical parameters, Effects of Space Weather on Technology Infrastructure, edited by: Daglis, I. A., NATO Science Series, II Math., Phys., Chem., 176, 147–164, 2004.

Belov, A. V., Gaidash, S. P., Ivanov, K. G., and Kanonidi, Kh. D.: Unusual High Geomagnetic Activity in 2003, International Symposium on Solar Extreme Events of 2003, Cosmic Res., 42, 6, 1–10, 2004.

Bingi, V. N. and Savin, A. V.: Physical problem of the weak magnetic field affect on biological systems, Uspekhi Fizicheskikh Nauk (in Russian), 173, 265–300, 2003.

Boteler, D.: Geomagnetic effects on the pipe-to-soil potentials of a continental pipeline, Adv. Space Res., 26(1), 15, 2000.

Boteler, D.: Geomagnetic hazards to conducting networks, Natural Hazards, Kluwer, 537, 2003.

Brekke, P.: Space Weather Effects, First European Space Weather Week (ESWW), ESA-Estec, Noordwijk, 2004.

Campbell, A: Observation of electric currents in the Alaska oil pipeline resulting from auroral electrojet current sources, Geophys. J. R. Astr. Soc., 61, 437, 1980.

Dmitrieva, I., Khabarova, O., Obridko, V., Ragoulskaya, M., and Reznikov, A.: Experimental confirmation of bioeffective influence of magnetic storms. Astronomical and Astrophysical Transactions, 19, 67–77, 2000.

Feynman, J. and Gabriel, S. B.: On space weather consequences and predictions, J. Geophys. Res., 105(A5), 10 543–10 564, 2000.

Gurfinkel, Y. I., Kanonidi, K. D., Mitrofanova, E. V., Mitrofanova, T. A., and Oraevsky, V. N.: Geomagnetic activity and heart-vascular system of man, Atlas vremennyx variatsy, pripodnyx antropogennyx and social processes, 3, (in Russian), 496–505, 2003.

Iucci, N., Levitin, A. E., Belov, A. V., Eroshenko, E. A., Ptitsyna, N. G., Villoresi, G., Chizhenkov, G. V., Dorman, L. I., Gromova, L. I., Parisi, M., Tyasto, M. I., and Yanke, V. G.: Space weather conditions and spacecraft anomalies in different orbits. Space Weather, 3, s01001, doi:10.1029/2003sw000056, 2005.

Lanzerotti, L: Space weather effects on communications, Space Storms and Space Weather Hazards, NATO Science Series II-38, Kluwer, 313, 2001.

Oraevsky, V. N., Kanonidi, K. D., Belov, A. V., and Gaidash, S. P.: Operative Center IZMIRAN on Forecasting of Heliophysical conditions, Problem of the forecasting of extreme situations and their sources. Trudy Nauchno-practicheskoj Conferentsii on 26–27 June 2001. M.: Center "Antistikhiya" (in Russian), 222–229, 2002.

Oraevsky, V. N., Kanonidi, K. D., Belov, A. V., Gaidash, S. P., and Lobkov, V. L.: Failures in the operation of the railway automatic during the geomagnetic storms. Trudy Nauchno-practicheskoj Conferentsii on 26 October 2002. M.: Center "Antistikhiya" (in Russian), 23–24, 2003a.

Oraevsky, V. N., Kanonidi, Kh. D., Belov, A. V., and Gaidash, S. P.: Various geomagnetic prognosis. Problem of the extreme situation forecasting. Trudy Nauchno-practicheskoj Conferentsii on 26 October 2002. M.: Center "Antistikhiya" (in Russian), 17–18, 2003b.

Panasyuk M. I., Kuznetsov, S. N., Belov, A. V., Gaidash, S. P., Kanonidi K. D., and Lazutin, L. L., et al.: Magnetic Storms in October 2003, Collaboration "Solar Extreme Events in 2003 (SEE-2003)", Cosmic Res., 42, 5,489–534, 2004.

Pirjola, R., Boteler, D., Viljanen, A., and Amm, O.: Prediction of geomagnetically induced currents in power transmission systems, Adv. Space Res., 26(1), 5, 2000.

Wang, Y. M. and Sheeley, N. R.: On potential field models of the solar corona, Astrophys. J. V., 392, 310–319. 1992.

Watermann, J.: Space Weather Effects Observed on the Ground-Geomagnetic Effects, First European Space Weather Week (ESWW), ESA-Estec, Noordwijk, 2004.