Space Weather of the Heliosphere: Processes and Forecasts
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Monitor and Prediction of Near-Earth Radiation Environment in the Frame of Space Monitoring Data Center at Moscow State University

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Abstract. Radiation environment of near-Earth space is one of the most important factors of space weather. Space Monitoring Data Center of Moscow State University provides operational monitor and forecast of radiation conditions both at Geostationary Orbits (GEO) and at Low Earths Orbits (LEO) of the near-Earth space using data of recent space missions (Vernov, CORONAS series) and current (Lomonosov, Meteor-M, Electro-L) ones. Internet portal of Space Monitoring Data Center of Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University (SINP MSU - [swx.sinp.msu.ru]) provides possibilities to monitor and analyze the space radiation conditions in the real time mode together with the geomagnetic and solar activity including hard X-ray and gamma-emission of solar flares.

Keywords. Sun: Flares, Space weather: radiation, Space weather: magnetic storm, Space weather: forecast

1. Introduction

Radiation environment is one of the main factors of near-Earth space that should be taken into account in the analysis of space weather. With the development of space technology, we are becoming much more dependent on the processes that occur in near-Earth space, and the ability to quickly predict these processes becomes very important. With increasing number of space missions, there is an issue of operational receipt, storage and real time access to the data of space measurements. Sources of this data as well as modern computing and communication permit to provide new opportunities for space conditions operational analysis and forecasting based on space weather applications developed during the last years.

Solar UV and soft X-ray fluxes, produced by solar flares, can cause short-wave communication disruption in high-latitude areas, as well as lead to malfunctions in navigation systems. According to the estimates of experts (see e.g.: Cole, 2003), more than half of failures in the operation of on board spacecraft equipment are due to the adverse impact of space weather factors. Charged particles cause degradation of semiconductor materials, malfunctions in microchips in systems of spacecrafts, electrilization of a spacecraft.

Energetic charged particles can lead to damage and failure of electronics and harm people on board spacecraft. If solar protons come to Earth during the main phase of a magnetic storm, when the boundary of their penetration into the magnetosphere shifts to lower latitudes, not only astronauts, but also pilots and passengers of airliners during transpolar flights are exposed to space radiation. So we have to create a complex set of coupled operational models from Sun to Earth that permit to predict the radiation risk for satellites in different orbits, and also the magnetic storms. The solution of this problem is to collect all relevant space-related data sets acquired by multiple satellites of various purposes and capabilities as well as by ground stations, and to develop the operational services that use space weather models and collected data to produce forecasts.

To correctly evaluate the radiation conditions, it is necessary to take into account the influence of geomagnetic activity on the acceleration, propagation and scattering of charged particles in the magnetosphere. Also, it is necessary to take into account the characteristics of solar activity: the state of the solar corona, the neutral radiation of solar flares - UV, X- and gamma-rays.

There are many centers around the world which provide such kind of service: e.g. Space Weather Prediction Center (SWPC/NOAA), integrated Space Weather Analysis System (iSWA), Space Situation Awareness (SSA) etc. The main monitoring space missions as well as models of space factors provide real-time data for analysis of space weather. Each center provides analysis based only on its own set of implemented operational models. The monitoring data necessarily contain the measurements at GEO and LEO, spacecrafts in solar wind, solar observatories to show the whole picture of space weather.

Space Weather Analysis Centre of SINP MSU (SWX) [swx.sinp.msu.ru] provides information about the current state of near-Earth's space in the real time. For data analysis, the models of the space environment, working in off-line as well as in on-line mode, have been implemented. Interactive services allow one to retrieve and analyze data in a given time moment. Space Monitoring Data Center (SMDC) of SINP MSU [smdc.sinp.msu.ru] also uses the data from these spacecrafts, and, in addition, it uses data from Russian satellites, Electro-L, Meteor-M and Lomonosov. All centers provide access to satellite data, space weather models, and forecasts online through their websites. Data are available through either an FTP server or an HTTP server. In this paper we will give a short overview of SWX, its data sources and operational services.

2. Interactive Data Analysis

The analysis of data measurement is the most important stage of the near-Earth space investigation. The study of various processes in the Sun, in the solar wind and in the Earth's magnetosphere requires different data for different time periods. Data sets often overlap, sometimes it is difficult to determine what data are required for the current scientific research. The service presented at this page allows the researcher to select the necessary data for his analysis, to preview it in graphical representation for subsequent calls to the database of online space monitoring.

Operational monitor and forecast of the Earth's radiation environment is very topical both for solving fundamental scientific problems of solar-terrestrial physics, and for providing safety of space missions and polar aviation. Therefore, data of experiments on board LEO (low-altitudes polar) spacecraft are very important. Now, a lot of data of experiments are available, including measurements of LEO spacecraft like Meteor-M No. 1 and POES NOAA series. The latest Russian satellites - RELEC, Meteor-M No. 2, Lomonosov were also launched to LEO orbit. However, data transmitted from LEO spacecraft have peculiarities connected with the features of LEO orbit: a spacecraft

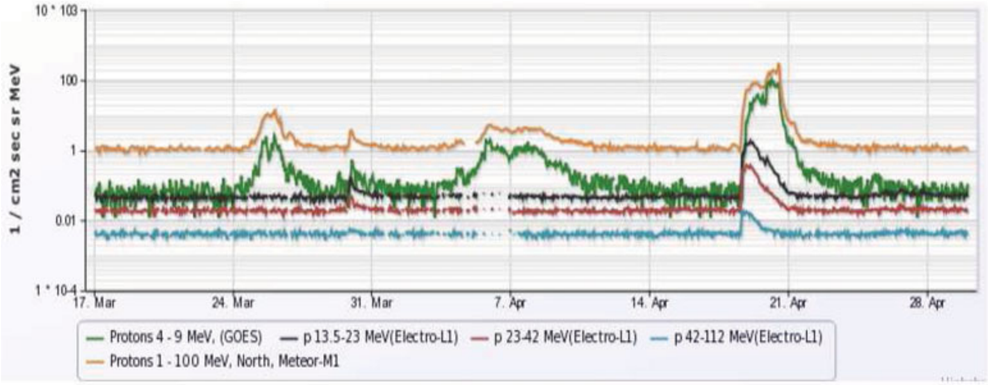

Figure 1. Time dependencies of SEP proton flux measured in experiments on board the Meteor-M No. 1, GOES and Electro-L1 satellites from March, 24 to April, 24 2014

consistently passes different areas of near-Earth space - polar caps, area of outer Earth's Radiation Belts (ERB), middle latitudes, inner ERB. No public systems intended for analysis of radiation conditions at low altitudes, which could allow quick comparison of data obtained in L1 point with those from LEO and GEO, were created until now.

The automatic system of separation of LEO-satellite data developed in SINP MSU permits to carry out comparative analysis of variations of SEP flux in polar caps and particles of the outer ERB at low altitudes with ones measured at GEO, and between different LEO experiments data also. The result of such comparison of SEP flux measured at LEO in polar caps (after automatic separation) with ones measured at GEO during one month of 2014 is shown in Figure 1.

The storage of information managed by Oracle's high-performance database provides the ability to perform intelligent processing and fast analysis of incoming information. There are the following threshold values for the key space environment factors corresponding to the values used in NOAA's Space Weather Center, the excess of which indicates the development of potentially dangerous processes and phenomena in the near-Earth space: 1) The solar energetic proton flux with energies $>$ 10 MeV exceeds 10 particles / (cm^2-s-sr); 2) The flux of electrons of outer Earth's belt with energies $>$ 2 MeV exceeds 10^3 particles / (cm^2-s-sr); 3) Flare soft X-ray (GOES data) index exceeds the level of M5.0; 4) Geomagnetic activity is characterized by the values of Dst $<$-50 nT and / or Kp$>$5. The warning system carries out continuous comparison of measurement data with specific threshold values and generates bulletins with reports on changes in the radiation and geomagnetic situation. The current state of the space radiation environment is presented in the bulletin [swx.sinp.msu.ru/bulletin.html].

3. Space weather forecast problem

The main sources of disturbances of the Earth's magnetosphere are the coronal mass ejections, reaching the Earth's orbit, and high-speed streams of solar wind (SW). A necessary (and perhaps a sufficient) condition for the emergence of magnetic storms is the presence of the south (negative) z-component of the interplanetary magnetic field (IMF Bz), which enables the transfer of energy from the SW into the Earth's magnetosphere. So, for short-term prediction it is especially important to have operative information about the values of SW and IMF parameters. The authors of this paper have their experience of the Dst index prediction using scientific models based on artificial neural

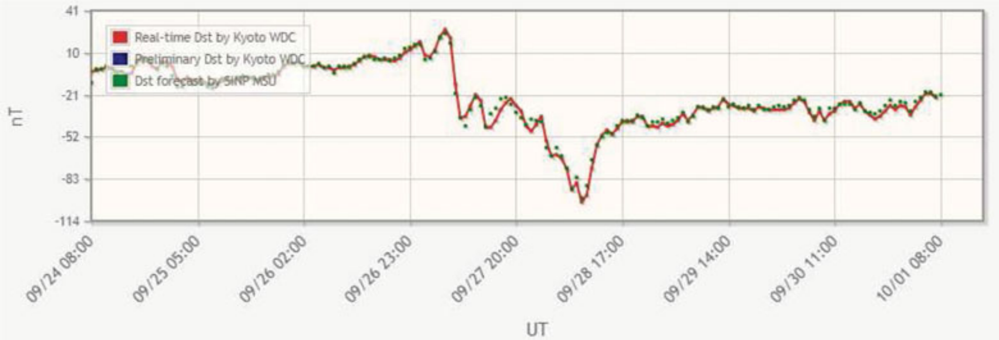

Figure 2. The short-term forecasting of Dst-variations obtained in real time during September 2017

networks (ANN) technology, as well as experience of using adaptive (including ANN) methods for prediction of electrons flux in the outer radiation belt of the Earth (Efitorov *et al.* 2016). It was shown that the best quality of the Dst-index forecast is achieved when constructing a neural network model that uses both the history of the Dst index and the parameters of the solar wind (its velocity and density) and IMF (modulus and Bz component) as input data. In Figure 2, results of the short-term forecasting of Dst variation during September 2017 in real time using ANN are presented - forecast shown in green points, experimental data - as the red curve.

The empirical model based on CORONAS-F and the “University-Tatiana” data obtained during magnetic storms in 2001 - 2006, was created. It allows one to estimate the position of the extreme value (minimum invariant latitude) of the boundary of SEP protons penetration into the Earth’s magnetosphere in the evening and night-time sector (Myagkova *et al.* 2009). On this basis and using the ANN forecast of Dst and Kp index, the operation model for the realization of short-term (1 hour ahead) forecast of the extreme position of the SEP penetration boundary was created.

4. Summary

The new methodological concept was developed of automatic processing of the experimental data of spacecraft at LEO (circular polar orbit at the low altitude), which is based on separation of the experimental data in accordance with the physical areas passed by the satellite as it moves along its orbit, and thereby with the origin of energetic charged particles, which are detected at these parts of orbits. To provide short-term forecasting of the Earth’s magnetosphere state - the geomagnetic indexes and the flux of relativistic electrons in the outer ERB - we used artificial neural networks. The directions of research to increase the horizon and to improve the quality of the prediction are considered.

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