Definition of parameters of daily anisotropy of cosmic rays according to the world network of neutron monitors

V G Grigoryev, S A Starodubtsev, V D Potapova
Yu G Shafer Institute of Cosmophysical Research and Aeronomy of SB RAS, Yakutsk, Russia
E-mail: grig@ikfia.ysn.ru

Abstract. In our previous works we have created the method of determination of parameters of cosmic ray daily anisotropy in the interplanetary environment based on the data provided by only single station - cosmic ray spectrograph named after A.I. Kuzmin. This method allows to predict the ingress of the Earth into large-scale solar wind disturbances with a probability of more than 70% and in advance time of about from several hours up to 2 days. Now it became possible to use the data of the neutron monitor networks, which can be seen in the neutron monitor database (NMDB) in real time. In this case the well-known method of global survey is applied for determination of cosmic ray anisotropy. Usage of the data of the cosmic ray station network allows to determine parameters of daily cosmic ray anisotropy with a greater accuracy.

1. Introduction
As is shown earlier in [1, 2], we developed and realized the method of behaviour diagnostics of galactic cosmic ray (CR) anisotropy in real-time by data of only a single station i.e. a CR spectrograph named after A.I. Kuzmin. A basis of method is application of a harmonic analysis for the determination of parameters of the CR diurnal anisotropy vector A for each hour of observations and their analysis. In calculations the data of the 24-NM-64 neutron monitor and muon telescope installed at the level of ground surface are used. In this case the receiving characteristics of devices [2] and phase change of observable anisotropy vector arising owing to the rotation of the Earth are considered. From results given in [1, 2] it follows that the occurrence of radial component of the galactic CR diurnal anisotropy with the amplitude of more than 0.2% in a direction from the Sun with a probability of approximately 70%, is connected with the approach of the area of large-scale solar wind disturbance to the Earth. The criterion of predictor quality of the disturbance arrival is the simultaneity of occurrence of the significant radial anisotropy component in the data of both devices during the time of more than 3 hours.

For the example, in Fig. 1 the behaviour of solar wind speed U and results of determination of radial ($A_X$) and azimuth ($A_Y$) components of the diurnal anisotropy before the arrival of interplanetary shocks (IPS) during the large-scale interplanetary disturbance on October, 24, 2011 are shown. Here the anisotropy parametres have been obtained by data of only a single station i.e. the CR spectrograph named after A.I. Kuzmin. As is seen from Fig. 1b, the occurrence of radial anisotropy component in the direction from the Sun with the amplitude of more than 0.2% is observed long before the disturbance onset. The azimuth component of CR anisotropy $A_Y$ also changes its direction to opposite already before the IPS arrival but for less time (Fig. 1). Such a behaviour of CR anisotropy components does not keep within frameworks of a diurnal variation mechanism [3, 4]. It can serve as an additional indicator of approaching large-scale solar wind disturbance.
Figure 1. Dependence of value of solar wind speed $U$ (a), radial $A_X$ (b) and azimuth $A_Y$ (c) components of diurnal CR anisotropy on the time for the event on October 24, 2011. The occurrence onset of predictor and IPS arrival are shown by vertical dotted lines. The CR anisotropy is presented in the $GSE$–coordinate system.

The development of this method in real time is based on the results of the study of CR anisotropy by the use of the global survey method proposed by Yu. G. Shafer Institute of Cosmophysical Research and Aeronomy of SB RAS (ShICRA SB RAS) more than 40 years ago [5]. In this method the whole world CR station network is used as one multidirectional device and instead of the generally accepted anisotropy vector $A$ the notion of the CR current $W$ is introduced. In this case the vectors $A$ and $W$ are bound up with each other by a relationship $W = -cA/(\gamma + 2)$, where $c$ is the speed of light, $\gamma$ is the index of the undisturbed spectrum of galactic CRs. Note that a bit of later other variants of the spherical analysis of the data from the CR station network [6, 7] have appeared.

From the results obtained by us earlier it follows that for the interplanetary medium disturbances considered for the 1966 to 1999 period the significant changes of value and phase of the CR current vector $W$ before the IPS arrival are observed. Thus, the most cases are characterized by the occurrence of stable (from several hours up to 2 days) radial component $W_r > 0.2\%$ directed to the Sun.
The aim of this work is embodying of the global survey method in real time and the comparison of results of it and harmonic analysis by data of various stations. The joint use of these two methods allows to determine parameters of CR diurnal anisotropy vector $A$ to greater accuracy. It considerably increases possibilities of the monitoring of interplanetary medium condition carried out by us by means of CR and will allow to advance essentially in working out of methods for the space weather forecast.

2. Experimental data and results
At present it became possible to use 1-hourly data of neutron monitor network which enter the well-known NMDB database, and to realize the global survey method in real time. For calculation of parameters of the first 2 angular moments of CR distribution function [5] by the method of global survey we use the data of 27 neutron monitor stations. And for the harmonic analysis one can choose any necessary number of the stations distributed in longitude.

As an example, in Fig. 2 the behaviour of value of radial anisotropy component ($A_X$) calculated by means of the harmonic analysis (Fig. 2a) and global survey (Fig. 2b) for the April 21-23, 2012 period is shown. As the indicator of geomagnetic field condition in Fig. 2c the $D_{st}$-index for the same period of time is given.

As is seen from Fig. 2 the temporal change of radial anisotropy component ($A_X$) calculated by the global survey method (Fig. 2a) and harmonic analysis of CR stations chosen separately (Fig. 2b) are in a good agreement among themselves. The analysis of results obtained by means of these methods, allows to conclude about the approach of large-scale disturbance of the solar wind to the Earth. Really, at the end of April 23, 2012 the geomagnetic storm has been registered. It has been caused by its interaction with the Earths magnetosphere.

3. Conclusion
1. By the neutron monitor network data entering the well-known NMDB, the method of global survey in real time has been realized.
2. On the basis of the same data the possibility to carry out a harmonic analysis in real time has been realized. In this case the receiving characteristics of stations and the effect of the Earths rotation are taken into account.
3. The simultaneous joint use of results of CR anisotropy calculation by the methods of global survey and harmonic analysis considerably increases the possibilities of monitoring carried out at present using the diagnostics of ingress of the Earth into large-scale disturbances of the interplanetary medium.

Acknowledgments We wish to thank the World Data Center for Geomagnetism (Kyoto), the CELIAS/MTOF experiment aboard the Solar Heliospheric Observatory (SOHO) spacecraft and the NMDB database (http://www.nmdb.eu), founded under the European Union’s FP7 programme (contract no. 213007), for providing data in real time. This work was supported by the Russian Foundation for Basic Research (projects Nos. 10-02-00877-a, and 12-07-00227-a), Program No. 10 of the Presidium of the Russian Academy of Sciences, and grant No. NSh-1741.2012.2 from the President of Russia for support of leading scientific schools.

4. References
[1] Grigoryev V G et al. 2008 Adv. Space Res. 41 943
[2] Grigoryev V G and Starodubtsev S A 2011 Proc. 32-nd Int. Cosmic Ray Conf. vol 11 p 101
[3] Krymsky G F 1964 Geomag. Aeron. 4 977
[4] Krymskij G F 1969 Modulation of cosmic rays in interplanetary space (Moskva: Nauka) p 152
[5] Altuchov A M et al. 1969 Proc. 11-th Int. Cosmic Ray Conf. vol 4 p 457
[6] Nagashima K and Ueno H 1971 Rep. Ionosph. Space Res. Jpn. 25 212
[7] Belov A V et al. 1973 Proc. 13-th Int. Cosmic Ray Conf. vol 2 p 1247
Figure 2. Changes of the value of radial CR anisotropy component by data of the harmonic analysis (a), global survey (b) before the onset of geomagnetic field disturbance (c) in April 2012. Critical levels of the value \( A_X \) for the forecast are shown by dahed lines. The occurrence onset of predictor are shown by vertical dotted line. The CR anisotropy is presented in the \( GSE \)—coordinate system.