Behavior of zonal components of cosmic ray distribution and Dst-index of geomagnetic field during periods of geoeffective disturbances of solar wind

S A Starodubtsev, V G Grigoryev and P Yu Gololobov

Yu. G. Shafer Institute of Cosmophysical Research and Aeronomy of the Siberian Branch of the RAS (ShICRA), 31 Lenin ave., Yakutsk, Russia, 677980

Abstract. On a basis of processing of data of measurements of the world-wide neutron monitor network database NMDB by a global survey method in real-time, the behavior of the first two angular moments of cosmic ray distribution function are investigated during the periods of geomagnetic storms that were observed in 2017. It is shown that abrupt increases of positive amplitudes of zonal components, which can be considered as predictors of geomagnetic field disturbances with a probability around 75%, precede geomagnetic storms with Dst < -50 nT. The predictor’s lead time is from a few hours to 1.5 days. A monitoring of geomagnetic disturbances is carried out in real-time mode and results of the forecasting is presented in the Internet through the link: [http://www.ysn.ru/~starodub/SpaceWeather/global_survey_real_time.html](http://www.ysn.ru/~starodub/SpaceWeather/global_survey_real_time.html).

1. Introduction

As was shown in the works [1, 2, 3], investigation of the distribution of cosmic rays (CR) in real time on the basis of the data of world-wide network of neutron monitors and muon detectors could become one of the most effective instrument for short-term forecasting (from a few hours to days) of a beginning of major geomagnetic storms. Depending on the level of geomagnetic perturbation, the probability of forecasting can reach 75% and higher. The basic parameters, that react on arrival of geoeffective disturbances of the interplanetary medium to the Earth, are behaviors of amplitudes of zonal (north-south) components of isotropic intensity $C_0^0$ and first two angular moments of CR distribution function $C_{10}$ and $C_{20}$ [4, 5, 6, 7]. For this components, we have determined the critical levels of their positive values $C_{00}^+$, $C_{10}^+$ and $C_{20}^+$ which were observed before the beginnings of magnetic storms. Moreover, their total factor $C^+ = C_{00}^+ + C_{10}^+ + C_{20}^+$ are also taken into account. The results of the CR monitoring are available in the Internet through the link: [http://www.ysn.ru/~starodub/SpaceWeather/global_survey_real_time.html](http://www.ysn.ru/~starodub/SpaceWeather/global_survey_real_time.html).

Below, on the basis of real-time realization of the global survey method using the NMDB database, we have carried an analysis of the predictor appearances and their relationship to geomagnetic disturbances that were observed in 2017 (WDC for Geomagnetism, Kyoto, [http://wdc.kugi.kyoto-u.ac.jp/index.html](http://wdc.kugi.kyoto-u.ac.jp/index.html)).
2. Experimental data and method

For processing the measurements of the data of neutron monitors with the global survey method in real time [8], we use 1-hour data that are presented in database NMDB (http://www01.nmdb.eu). Characteristics of CR intensity observed by each device are defined by receiving characteristics of the registering device, which are unified under the concept of receiving vectors [9] and reflects its geometry, geographical position and the type of registered particles. Calculations of the receiving vectors of real devices are held with knowing of: coupling coefficients between the secondary $W(E)$ and primary particles, directional diagrams of the detector $N(\theta, \phi)d\omega$, which reflects geometrical features of the device and also zenith-azimuthal sensitivity of particles, energy spectrum $f_n(E)$ of investigated CR variations and asymptotic angles of arrival of particles $\Psi(E, \theta, \phi)$, $\Phi(E, \theta, \phi)$.

The devices that has different receiving vectors $\vec{R}_m$ register CR intensity $\vec{I}$ that are defined by the following equation:

$$ I = \sum_{n=0}^{\infty} \sum_{m=0}^{n} (a_n^m x_n^m + b_n^m y_n^m), $$

where $x_n^m$, $y_n^m$ are components of receiving vector, $a_n^m$, $b_n^m$ are the components of a multidimensional vector of CR distribution $\vec{A}$. Then, for the selected devices we create the system of linear equations [9] which, in matrix form, has the next representation:

$$ \vec{I} = M \cdot \vec{A}, $$

where $\vec{I}$ is a vector column of observational data and $M$ is a matrix of receiving vectors (coupling coefficients). The obtained system is solved by the last square method under the assumption that the decomposition of the CR distribution into the series of spherical functions is converges fast. So, usually, except an isotropic part, only first two harmonics of the distribution, which are well observed in the experiment, are taken into account. According to this, the first 9 components of the vector $\vec{R}$, including mentioned $C_{00}$, $C_{10}$ and $C_{20}$, are need to be defined.

3. Results

As the analysis of the monitoring during 2017 has shown, the values of positive amplitudes of the components $C_{00}^+, C_{10}^+$, $C_{20}^+ > 0.8\%$ or the sum of their positive values $C^+ > 0.9\%$ can be considered as a predictor of the beginning of geomagnetic disturbance. If there is an excess of this critical values which indicates on oncoming of a magnetic disturbance, an appropriate warning is generated.

At the beginning of the geomagnetic disturbance, it starts the abrupt decrease of negative values of zonal harmonics $C_{00}^-, C_{10}^-, C_{20}^-$. If their summary value $< -0.9\%$, then the message about the storm passing is generated. During the chosen period the predictors with different durations were observed 20 times. 2 of them were false and 3 had appeared after the beginning of disturbance. The other 15 predictors had appeared before the storm with the lead-times 5-16 hours and were associated with a passage of a large-scale disturbances of solar wind which cause the storms with Dst $< -30$ nT.

As examples, in figures 1 and 2 the time dependencies of Dst-index and zonal components $C_{00}$, $C_{10}$, $C_{20}$, $C^+$ and $C^-$ during two major geomagnetic storms in May and September 2017, when Dst-index has reached their minimal values -125 and -124 nT, respectively, are shown. The critical values for each component are shown by dotted lines. The up and down arrows shows the time moments when the components exceed the positive and negative critical values, respectively.

As seen from the figures 1 and 2 the geomagnetic storms in 28th May and 8th September 2017 had the predictors in the values $C_{20}$ and $C^+$ and were accompanied by decrease of value $C^- < -0.9\%$ 6 hour after appearance of the predictor of disturbance.
Figure 1. Behavior of the zonal harmonics $C_{00}$, $C_{10}$, $C_{20}$, the sum of their positive $C^+$ and negative $C^-$ values and Dst-index during the periods of geomagnetic disturbances in May 2017. Solid triangles at the bottom indicate on a sudden commencement of storm SSC.

Figure 2. Behavior of the zonal harmonics $C_{00}$, $C_{10}$, $C_{20}$, the sum of their positive $C^+$ an negative $C^-$ values and Dst-index during the periods of geomagnetic disturbances in September 2017. Solid triangles at the bottom indicate on a sudden commencement of storm SSC.

4. Conclusion
The analysis of the results of monitoring of geomagnetic disturbances during 2017 carried out in ShICRA SB RAS have shown that the reliability of short-term forecasting of entering of the Earth into the geoeffective disturbances of solar wind is around 75%.

5. Acknowledgements
The work was carried out using the data of Unique scientific installation of the Russian national ground level network of cosmic ray stations and with the support of grant RFBR No. 18 − 42 − 140002 − r_a.
References
[1] Kuwabara T, Bieber J W, Clem J and et al 2006 Space Weather 4 S08001
[2] Rockenbach M, Lago A D, Gonzalez W D and et al 2011 Geophys. Res. Lett. 38 L16108
[3] Belov A V, Eroshenko E A, Yanke V G and et al 2018 Geomag. Aeron. 58 356–372
[4] Grigoryev V G and Starodubtsev S A 2015 Bull. of the RAS: Physics 79 649–653
[5] Grigoryev V G, Starodubtsev S A and Gololobov P Y 2015 Proceedings of Science PoS(ICRC2015) 076
[6] Grigoryev V G, Starodubtsev S A and Gololobov P Y 2017 Bull. of the RAS: Physics 81 200–202
[7] Gololobov P Y, Grigoryev V G and Starodubtsev S A 2017 Proceedings of Science PoS(ICRC2017) 022
[8] Altukhov A M, Krymsky G F and Kuzmin A I 1970 Proc. 11-th ICRC 4 457–460
[9] Krymsky G F, Kuzmin A I, Krivoshapkin P A and et al 1981 Cosmic ray and solar wind (Novosibirsk: Nauka) p 224