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MONITORING OF MAGNETOSPHERIC PARAMETERS BASED ON COSMIC RAY EFFECTS IN AUGUST 2018

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Abstract. Using data (uncorrected for the temperature effect) from the global network of neutron monitors (GNNM), along with data from the Yakutsk muon telescope complex and the muon hodoscope URAGAN (Moscow), we have applied a modified spectrographic global survey (SGS) method to the 2018 August event in order to split cosmic ray variations into components of primary, magnetospheric, and atmospheric origin. We obtained time variations in the 4 GV-rigidity primary particle isotropic flux and pitch-angle anisotropy, as well as in the interplanetary magnetic field (IMF) orientation. We also showed variations in the geomagnetic cutoff rigidity (GCR) in Irkutsk.

Using the obtained data on the changes in the planetary system of GCR within a simple model of a bounded magnetosphere, we have calculated some parameters of magnetospheric current systems, namely, the ring current radius, the magnetopause current radius, and the *Dst* index.

Keywords: cosmic rays, magnetosphere, ring current, geomagnetic storms.

INTRODUCTION

Large-scale solar disturbances, such as coronal mass ejections (CMEs), have a significant impact on near-Earth space. In particular, when a CME or a shock wave reaches Earth, the magnetosphere is compressed under the pressure of the solar wind, and the ring current is amplified due to the injection of charged particles. Both of these phenomena have an effect on the geomagnetic cutoff rigidity of cosmic rays (CRs) and thereby lead to marked magnetospheric variations.

August 2018 was characterized by low solar activity. An exception was the CME that occurred on August 20 at 21:43 UTC as a result of a filament eruption (N40W05). The solar wind (SW) speed did not exceed 400 km/s. The modulus and B_z component of the interplanetary magnetic field (IMF) were 3.3 and −1.9 nT respectively. At the same time, no significant changes in the soft X-ray flux were recorded by GOES spacecraft. Nevertheless, on August 25–26, 2018, this relatively slow CME caused an unusually strong magnetic storm [Abunina et al., 2020]. During the geomagnetic storm, the *Dst* index decreased to −175 nT, the SW speed was 444 km/s, the IMF modulus and B_z component were as large as 18.2 and −14.7 nT respectively [https://omniweb.gsfc.nasa.gov/ow.html].

The magnetic storm was followed by a Forbush decrease. At some stations (mainly in the Northern Hemisphere), after the Forbush decrease there was a sharp increase in the CR intensity. An abnormal increase in the CR intensity was observed at many stations located at different latitudes, including at the stations Oulu (R_c=0.8 GV), Moscow (R_c=2.43 GV), Thailand (R_c=16.8 GV); in this conditions, the CR behavior differed: for example, the neutron monitor in Moscow on August 26 recorded two intensity peaks — at 07:00–08:00 and 14:00 UTC. Stations in the Southern Hemisphere (for example, McMurdo, Mirny, South Pole), did not observe such a CR intensity behavior [Abunin et al., 2020].

The aim of this work is to estimate parameters of Earth's magnetosphere during the August 25–26, 2018 geomagnetic storm from effects in cosmic rays. Similar studies have already been carried out for other events and are described, for example, in [Kravtsova et al., 2020]. A significant difference of this work is the involvement of muon detector data.

DATA AND METHOD

The CR event at the end of August 2018 has been analyzed using the spectrographic global survey (SGS) method [Dvornikov et al., 1986; Kovalev et al., 2022]. This method is based on data from the global network of CR stations and is successfully employed to analyze events in the interplanetary medium and geomagnetosphere [Dvornikov et al., 2013]. Along with phases of the first and second harmonics of pitch-angle anisotropy, the method can determine the rigidity spectrum of the CR isotropic component and anisotropy, obtain information about IMF orientation from the phase of the second harmonic, as well as find variations in the mass average temperature over the stations observing unstable components of secondary CRs (when using data uncorrected for the temperature effect) and the planetary GCR system at each moment of observation during geomagnetic disturbances.

To study the period of August 2018 by the SGS method, we have used data from

- the global network of neutron monitors (36 stations);
- the muon hodoscope URAGAN without temperature corrections (particle fluxes recorded by three supermodules (15 channels) at zenith angles 0–17°, 17–26°, 26–34°, 34–44°, 44–90°, integrated with respect to an azimuth angle);
- the muon telescope complex in Yakutsk without temperature corrections (data, smoothed by a running mean, from 10 telescope channels at levels of 0 and 7 m of water equivalent [http://www.ysn.ru/ipm /]).

The average counting rate for August 1, 2018 was taken as the reference level for calculating the relative intensity. Time resolution of the data is 1 hr.

A number of parameters of magnetospheric current systems are calculated from changes in the planetary GCR system. To estimate these parameters, we have employed the simplest axisymmetric model of a bounded magnetosphere [Kichigin, Sdobnov, 2017]. As a result, we have obtained some parameters of current systems in Earth's magnetosphere, namely, radii of the ring current r_{DR} and the magnetopause current r_{DCF}, as well as the *Dst* index. These parameters are determined by minimizing the functionality:

$$\left(\sum_i \left[\Delta R_{obs}\left(R_i\right) - \Delta R_{calc}\left(R_i, r_{DR}, r_{DCF}, Dst\right) \right]^2 \right) = \min,$$

where $\Delta R_{obs}\left(R_i\right)$ is a change in GCR for a station with GCR R_i obtained by the SGS method; $\Delta R_{calc}\left(R_i, r_{DR}, r_{DCF}, Dst\right)$ is a change in GCR for a station with GCR R_i calculated by the model of a bounded magnetosphere with r_{DR}, r_{DCF}, and *Dst*.

RESULTS AND DISCUSSION

Figure 1 shows the IMF modulus |*B*| and the solar wind speed *V*; the IMF vector latitude Ψ_0 and longitude λ_0 observed on SC (solid line) [https://omniweb.gsfc.nasa.gov/ow.html] and calculated (dashed line) from ground-based measurements at the global network of CR stations; variations in the isotropic flux $\Delta J/J$ and the particle flux intensity $\Delta I/I$ at the station Oulu; the amplitude A_1 of the first harmonic of pitch-angle anisotropy for particles with a rigidity of 4 GV; geomagnetic cutoff rigidity variations ΔR_c for Irkutsk compared to *Dst* variations.

It is possible to note a satisfactory agreement between the data on the IMF vector obtained by SC and the SGS method. Furthermore, there is a decrease in the intensity of the isotropic particle flux with a rigidity of 4 GV at the magnetosphere boundary on August 25–27 to ≈–15 %, as well as an increase in amplitude A_1 on August 25–27 to 30 %, indicating that Earth went into and out of a magnetic trap type structure. There is no significant increase in the amplitude of the second harmonic of pitch-angle anisotropy. The maximum variation ΔR_c during the geomagnetic disturbance in Irkutsk was ≈−1.0 GV, and the time variation in ΔR_c correlates well with that in the *Dst* index (≈0.8 correlation coefficient).

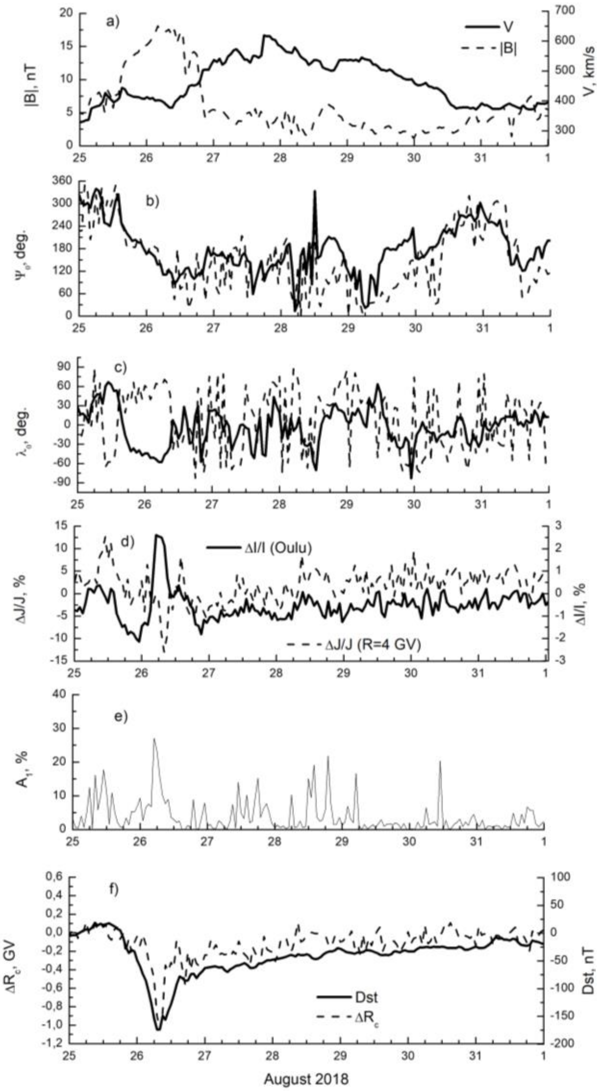

Figure 1. Variations in the IMF modulus |*B*| and the SW speed *V* (*a*), as well as in the ecliptic longitude ψ_0 (*b*) and latitude λ_0 (*c*) of IMF orientation; relative variations in the isotropic component $\Delta J/J$ and the particle flux intensity $\Delta I/I$ at the station Oulu (*d*), as well as in the first pitch-angle anisotropy harmonic A_1 for particles with a rigidity of 4 GV (*e*); variations in GCR in Irkutsk ΔR_c and *Dst* (*f*) on August 25–31, 2018

Figure 2 shows the dependences of ΔR_c on R_c obtained by the SGS method (solid line) and the method of calculating the ring current during different magnetic storm phases. On the right of each panel are the radii (in Earth radii R_E) of the ring current (r_{DR}) and the magnetopause current (r_{DCF}); *Dst* calculated (Dst_{calc}) and observed (Dst_{obs}). The observed and calculated *Dst* values, the ring current (Dst_{DR}) and magnetopause current (Dst_{DCF}) contributions to *Dst*, as well as the current intensity (I_{DR}, I_{DCF}) in the current system are presented in Table. The magnetospheric subsolar point is shown to shift to (7÷8) R_E during the maximum modulation phase; during the storm, the ring current radius varies from ~4.7 R_E to ~4.9 R_E, and the ring current intensity varies from 11.9×106 to 25.6×106 A.

In this paper, we employ the simplest axisymmetric model of a bounded magnetosphere to estimate magnetospheric effects. The ring and magnetopause current radii

Contribution of the DR and DCF current systems to the development of the magnetic storm in August 2018.

Phase	Dst_{obs}, nT	Dst_{calc}, nT	Dst_{DR}, nT	Dst_{DCF}, nT	I_{DR}, $\times10^6$ A	I_{DCF}, $\times10^6$ A
Initial phase (August 25, 20:00)	−25	−48	−148	100	11.9	3.19
Max. modulation phase (August 26, 08:00)	−174	−196	−477	281	25.6	10.6
Recovery phase (August 26, 21:00)	−81	−80	−203	123	14.0	4.35

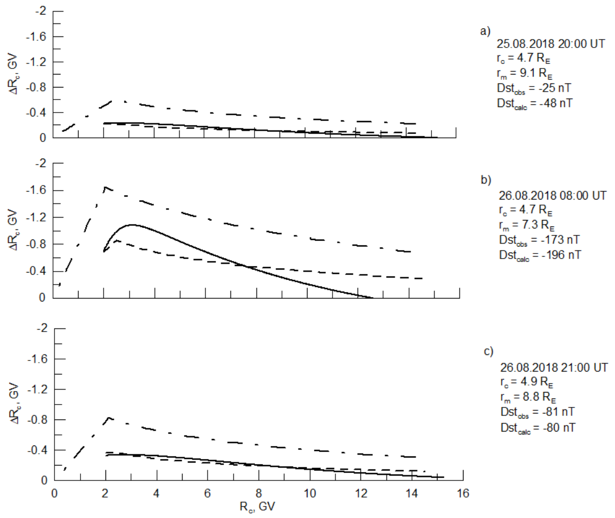

Figure 2. GCR variations as function of GCR in the initial phase (*a*), at the time of maximum modulation (*b*), and in the recovery phase (*c*) during the magnetic storm in August 2018: the results obtained by the SGS method from ground-based observations of CRs (solid line); the results of calculations by the axisymmetric model of a bounded magnetosphere (dashed line); the contribution of the ring current, calculated by the axisymmetric model of the magnetosphere, to GCR variations (dashed dot line). On the right are date, radii of ring current (r_{DR}) and magnetopause current (r_{DCF}); the *Dst* index observed (Dst_{obs}) and calculated (Dst_{calc})

we deal with reflect, in fact, the total contributions of several current systems, so it is more correct to say about the effective radii of current systems that contribute to *Dst* as do the ring current and the magnetopause current. Yet, contributions of a number of current systems are not taken into account. There is, however, good agreement between calculated and observed *Dst* values, which suggests that the main contribution to the intensity of magnetic storms is made by the ring current and magnetopause currents.

CONCLUSIONS

With the SGS method and ground-based CR observations made at the global network of stations, as well as by the Yakutsk complex of muon telescopes, and the muon hodoscope URAGAN, we have calculated variations in the planetary system of GCR during the geomagnetic storm at the end of August 2018. We used data on charged components without temperature corrections. From the results we obtained and with the axisymmetric model of a bounded magnetosphere, we have calculated parameters of the ring current and magnetopause currents, the contribution of the ring current to GCR variations, as well as have estimated the contributions of the ring current and currents at the magnetopause to the geomagnetic activity index *Dst* in different phases of the event:

- During the initial phase, the ring current radius reached (hereafter estimated values) 4.7 R_E; its intensity, 11.9×10^6 A. The distance to the subsolar point was 9.1 R_E, the magnetopause current was 3.19×10^6 A. The contribution of the ring current to *Dst* was −148 nT; that of the magnetopause currents, 100 nT.
- During the maximum modulation phase, the ring current increased to 25.6×10^6 A, the magnetopause current increased to 10.6×10^6 A, the subsolar point shifted to 7 R_E. The contribution of the ring current to *Dst* was −477 nT; that of the magnetopause currents, 281 nT.
- During the recovery phase, the ring current radius was as large as 4.9 R_E; the distance to the subsolar point, 8.8 R_E. The ring and magnetopause current intensities decreased to 14.0×10^6 and 4.35×10^6 A respectively. The contribution of the ring current to *Dst* was −203 nT; that of the magnetopause currents, 123 nT.

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