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Correction of Data from the Neutron Monitor Worldwide Network

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Abstract—The method for correcting data from individual neutron monitors at the worldwide network of cosmic ray stations, characterized by the instrument drift and sporadic variations, has been proposed. The correction is performed using the method of spectrographic global survey. The proposed method makes it possible to correct data from the global network of stations immediately during processing and can be used in studies of cosmic-ray intensity long-term variations and in the real-time operation mode.

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1. INTRODUCTION

Ground-based monitoring of time variations in the cosmic ray (CR) intensity, using neutron monitors at the global network of stations, has been performed from the middle of the past century. Unique data, which make it possible to study both long-term variations in the CR intensity and numerous sporadic phenomena, have been obtained during this period. Recently, the possibilities of using ground-based observation data from the worldwide network of stations have substantially increased with the appearance of the Internet, which makes it possible to effectively collect and process data from CR stations, distributed throughout the globe, along with data of local detectors. At present, about 20 neutron monitors function in the real-time operation mode. We can hope that subsequently, with increasing number of stations operating in this mode, it will become possible to effectively monitor variations in the rigidity spectrum and anisotropy of relativistic CRs and changes in the planetary system of the geomagnetic cutoff rigidity during each hour of observations. Thus, it will be possible to use ground-based CR observations not only in scientific studies but also to solve practical problems of the space weather monitoring and prediction, as a result of which the quality of these observations should meet specific requirements.

The worldwide network of CR stations is equipped with standard neutron monitors. However, these devices are not calibrated and are located at different levels in the Earth's atmosphere, in different rooms with floors of different thickness, under different climatic conditions, etc. Therefore, relative variations in CR intensities rather than the absolute values of these intensities registered at stations are as a rule used. Variations in the CR intensity calculated relative to a certain selected (basis) level are usually analyzed. However, all causes of a limited data usage are not eliminated in this case because of the instrument variations (drifts) due to a change in the detector properties and unstable operation of the electronic channel elements. Moreover, several destabilizing factors cause false variations in the CR intensity. The usage of a constant barometric coefficient when correcting data for the barometric effect (although this effect depends on variations in the primary CR spectrum [Dorman, 1972; Dvornikov and Sdobnov, 1999]), the presence of snow on roofs of station buildings, etc. can be considered as such factors.

The data quality problems at CR stations were discussed in [Belov et al., 1988, 1993, 2007]. Specifically, Belov et al. [2007] estimated the long-term stability of operation of monitors at the worldwide network of CR stations, using two independent methods: the model method (based on the version of the global survey method adapted to the study of long-term variations) and the method of relations. These researchers presented the advantages and disadvantages of these methods and discussed the difficulties in data correction related to instrument drifts.

The proposed work considers the method for correcting data of ground-based CR observation at the worldwide network of stations, using the method of spectrographic global survey (SGS) [Dvornikov et al., 1983; Dvornikov and Sdobnov, 1997]. The method makes it possible to correct data immediately during their processing and can be used to study long-term variations in the CR intensity and during the operation in the real-time mode.

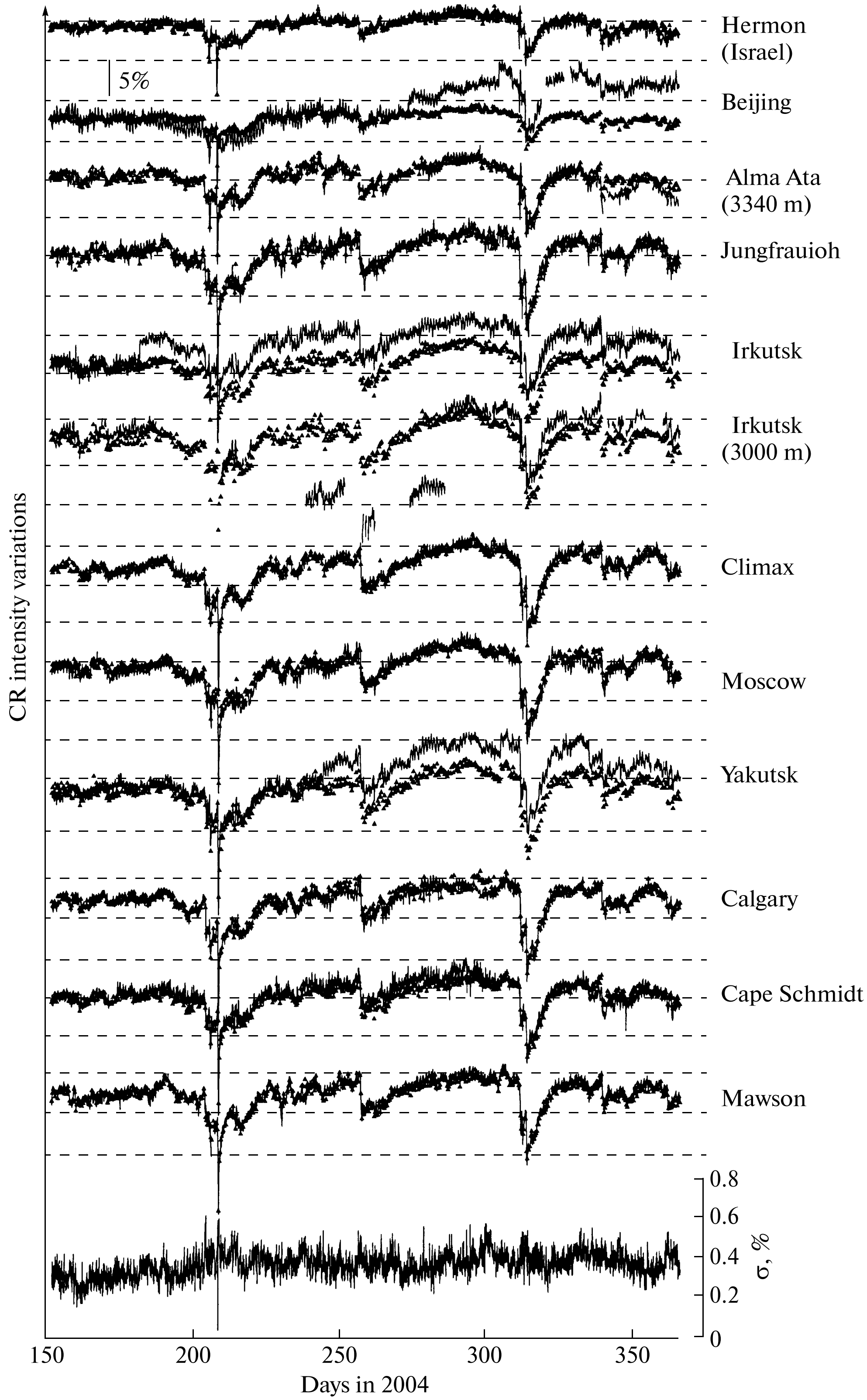

Fig. 1. Time profiles of variations in the intensity of the CR neutron component for individual stations of the global network (solid line), calculated relative to the daily average value (basis level) on June 10, 2004, and the data corrected using the described method (triangles). The lower plot shows the rms deviations (σ) during the calculations with corrected data.

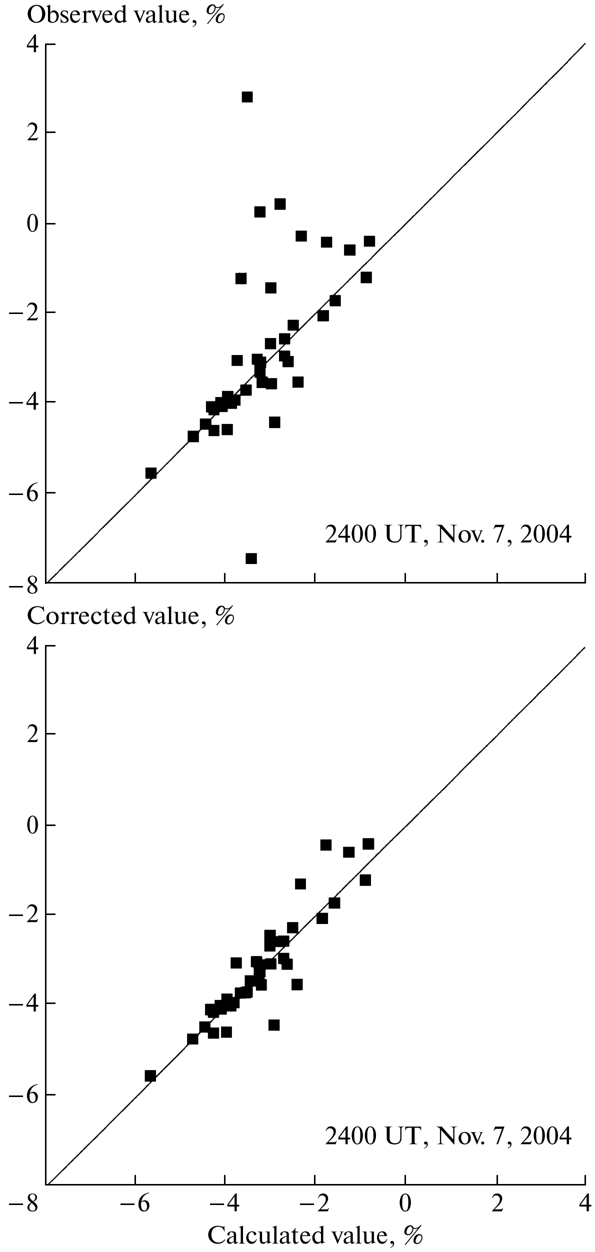

Fig. 2. Correspondence of the observed and corrected variations in the CR intensity to the values calculated for 2400 UT on November 7, 2004.

2. METHOD AND DATA

The effectiveness of the model approach to data correction largely depends on the adequacy of the model used to develop this approach. When we developed the SGS method, we used different assumptions of the form of the CR distribution function in the interplanetary space in order to select the best fit expression for the observed global distributions of the secondary CR intensity even during extreme events. A comparative analysis of information about electromagnetic conditions in the interplanetary and near-Earths space, obtained from the CR effects (within the scope of this model), with factually observed conditions is one more criterion of model adequacy.

As a result of the performed studies, we based the SGS method on the assumption that CR intensity variations outside the magnetosphere are described as follows:

$$\frac{\delta J}{J}(R, \Psi, \lambda) = \sum_{k=1}^{3} a_{0k}R^{-k} + \sum_{n=1}^{2}\sum_{k=1}^{2}[(c_{nk}R^{-k})P_n(\mu)] + \sum_{k=1}^{2}(d_{1k}R^{-k})P_1(v), \quad (1)$$

where $P_n(\mu)$ and $P_n(v)$ and the Legendre polynomials.

$$\mu = \cos\Theta = \sin\lambda\sin\lambda_0 + \cos\lambda\cos\lambda_0\cos(\psi - \psi_0), \quad (2)$$

where Θ is the angle between the vectors of particle velocity (**V**) and IMF (**B**, pitch angle), angles ψ_0 and λ_0 characterize the IMF vector orientation in the geocentric ecliptic coordinate system, and angles ψ and λ characterize the particle direction of motion outside the magnetosphere.

$$v = \cos\Phi = \sin\lambda\sin\xi_0 + \cos\lambda\cos\xi_0\cos(\psi - \Phi_0), \quad (3)$$

where Φ is the angle between **V** and $\mathbf{B}\times\nabla n_\perp$; $\nabla n_\perp$ is the component of the CR density gradient perpendicular to the IMF vector, angles ξ_0 and Φ_0 characterize the orientation of the $\nabla n_\perp$ vector from the orthogonality condition for the **V** and $\mathbf{B}\times\nabla n_\perp$ vectors, and angle ξ_0 is defined by the expression

$$\xi_0 = \arctan[-(\cos\psi_0\cos\Phi_0 + \sin\psi_0\sin\Phi_0)\cos\lambda_0]. \quad (4)$$

The rigidity spectra of the isotropic component and anisotropy were approximated by the series in terms of inverse particle rigidity degrees. Under these assumptions, the global distribution of the secondary CR intensity variations is described by the following sets of nonlinear algebraic equations:

$$\frac{\delta I_c^i}{I_c^i}(h_l) = -\Delta R_c W^i(R_c, h_l)\left(1 + \frac{\delta J}{J}(R_c)\right) + \int_{R_c}^{\infty}\left\{\sum_{k=1}^{3} a_{0k}R^{-k} + \sum_{n=1}^{2}\sum_{k=1}^{2}[(c_{nk}R^{-k})P_n(\mu)] + \sum_{k=1}^{2}(d_{1k}R^{-k})P_1(v)\right\}dR. \quad (5)$$

Here, $\frac{\delta I_c^i}{I_c^i}(h_l)$ are the variations in the integral flux of type i secondary particles (relative to a certain background level I_c^i), observed at a geographic point c at a level h_l in the Earth's atmosphere; R_c is the effective geomagnetic cutoff rigidity; and $W_c^i(R, h_l)$ is the function of relation between the primary and secondary CR variations. The asymptotic angles of particle arrival to a given point, $\psi_c(R)$ and $\lambda_c(R)$, should be used in Eqs. (2)–(4) instead of variables ψ and λ. The ΔR_c dependence on the threshold rigidity is approximated by the expression $\Delta R_c(R_c) = (b_1 R_c + b_2 R_c^2)e^{-\sqrt{R_c}}$. The problem is reduced to finding unknown parameters a_{01}, a_{02}, a_{03}, b_1, b_2, c_{11}, c_{12}, c_{21}, c_{22}, d_{11}, d_{12}, ψ_0, λ_0, ξ_0, and Φ_0, at which expression (5) in the best way describes the global variations in the secondary CR intensity at any analyzed instant.

The weight equal to unity is given to each equation at the first stage of solving set (5). The rms deviation (σ) in the entire data sample for a current hour is calculated upon solving set (5) of equations. The discrepancies are subsequently analyzed for each station at the considered instant, the zero weight is given to some station if the discrepancy magnitude for this station exceeds 2σ (i.e., the data of this station are rejected), and the set of equations is solved again. This procedure is repeated until data of only "high-quality" CR stations remain. The hourly values of discrepancies for each station are stored in a certain selected time interval (e.g., daily). The daily average values of discrepancies for each station are used as corrections at the next daily interval, and so on. These corrections are close to zero for stations with high-quality data, and the calculated corrections are applied to data of drifting stations. Short-term outliers in data of CR stations are automatically eliminated and ignored when daily average discrepancies are calculated.

In an analysis we used the data of ground-based observations at the worldwide network of CR stations (38 stations) from the Database of the Worldwide Network of Neutron Monitors (//ftp://cr0.izmiran/rssi/ru/COSRAY!/FTP_NM/C/) for June–December, 2004.

3. RESULTS OF ANALYSIS

Figure 1 presents the time profiles of variations in the intensity of the CR neutron component for individual stations at the worldwide network (solid line), calculated relative to the daily average value (basis level) of June 10, 2004 and corrected according to the describe method (triangles). Figure 1 indicates that the instrument drifts are maximal at Beijing and Yakutsk stations. The intensity increased once as a result of a change in the scaling factor at Irkutsk station and sporadically suddenly changed at Irkutsk station (3000 m), which was accompanied by interruptions in power supply that resulted in data gaps. However, even in this case, the proposed method makes it possible to correct data and to fill gaps with calculated intensity values. The lower plot in Fig. 1 presents the hourly values of the rms deviations of the CR intensity variations, observed at the worldwide network of stations, from the data calculated after correction with the help of the proposed method.

The lower panel in Fig. 2 demonstrates how the hourly values of variations agree with the values, calculated for 2400 UT on November 7, 2004, at a maximal modulation during the Forbush effect in the case when the data were corrected. The upper panel demonstrates the same but without data correction. This plate indicates that particle intensity was registered irregularly during five months at six of 38 stations, which would considerably affect the accuracy in determining the rigidity spectrum parameters and primary CR anisotropy, as well as the changes in the planetary system of geomagnetic cutoff rigidity, without data correction.

4. CONCLUSIONS

The proposed method makes it possible to formalize correction of data from individual stations of the worldwide network, characterized by an instrument drift and sporadic instrument variations. This method can be used to correct such data immediately during their processing. The application of the proposed method, together with the realization of the system of automatic data acquisition through the Internet, will make it possible to control data quality at the entire network of stations as a unified multi-channel detector in the real-time operation mode and to monitor and predict electromagnetic and radiation conditions in the interplanetary and near-Earth space based on the effects in CRs.

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