Realization of the global survey method in real-time

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Abstract: The global survey method was developed at ShICRA of SB RAS more than 40 years ago. It is a powerful and useful instrument for studying of the interplanetary medium. The essence of method is that the world neutron monitor network is used as the unified omnidirectional device. It allows to receive information on a spatial distribution of cosmic rays (CR) with a high accuracy for each hour of measurements. The notion of accepting vectors is a basis for this method. The influence of atmosphere and geomagnetic field on the measured cosmic ray intensity at each point of observation is taken into consideration. At present, realization of global survey method in real-time became possible with a creation and development of database of neutron monitor measurements (NMDB). This report is a continuation of work by authors on development of methods for the space weather forecast by means of CR measurements. The first results of determination of CR daily anisotropy parameters by means of the global survey method in real-time and their connections with solar wind large-scale disturbances are given.

Keywords: cosmic ray, geomagnetic storm, solar wind disturbances, neutron monitor database, global survey method.

1 Introduction

At present the study of cosmic ray (CR) anisotropy is carried out by many research groups in real-time [1, 2, 3, 4], and the results of its determination are available in the Internet (see, for example, `http://cr20.izmiran.rssi.ru/MonitoringCRAnisotropy/Index.php`, `http://www.bartol.udel.edu/gp/neutronm/spaceweather/welcome.html`, `http://www.mustang.uni-greifswald.de/spaceweather.htm`). A number of methods are used for determining the CR anisotropy on the base of data of the neutron monitors and muon telescopes. Along with them, more than 40 years ago at ShiCRA of SB RAS the global survey method was developed. In this method the world neutron monitor network as a omnidirectional device is used [5]. The method allows to study rapid changes of CR anisotropy caused by dynamic processes in the interplanetary medium and allows to determine with a higher accuracy 9 parameters of the CR distribution function per each current hour of measurements. At present time it becomes possible to use in real-time the measurement data of about 30 neutron monitors from the well-known neutron monitor database (NMDB) (`http://www.nmdb.eu`). In this case the realization of global survey method considerably expands the possibilities of monitoring and forecast of space weather by means of measurements of CR intensity on the Earth.

2 Method

The essence of global survey method is as follows. Each neutron monitor of the world CR station network in the current time registers the particles arriving in it from a specific direction. As the device is installed on the Earth which rotates around its axis then its orientation to some directional CR flux is determined once a day. The Larmor radius of particles registered by neutron monitors is much greater than the size of the Earth, therefore, one can consider the whole ground network of the CR station as a single the omnidirectional device. In this case it will be capable to allow us to construct a global pattern of CR modulation in the volume defined by the Larmor radius of particles.

The distribution of CR intensity in sphere $I(\theta,\phi)$ is convenient to represent [7] by an expansion into a series according to a system of spherical functions which are solutions of the Laplace equation:

$$I(\theta,\phi) = \sum_{n=0}^{\infty}\sum_{m=0}^{n}(A_n^m \cdot cos(m\phi) + B_n^m \cdot sin(m\phi)) \times \times P_n^m(sin\phi),$$

where θ and ϕ are latitudinal and longitudinal angles in some coordinate system, $P_n^m(sin\phi)$ are joined functions of Legendre. One can represent this distribution in the form of multidimensional vector $\vec{A} = \vec{A}\{A_n^m;B_n^m\}$ with the infinite number of components ($0 \le m \le n < \infty$). Then for each point detector one can determine such receiving vector $\vec{R} = \vec{R}\{X_n^m;Y_n^m\}$ that the CR intensity I registered by the detector will be equal to the scalar product $I = \vec{A} \cdot \vec{R}$.

To use the global survey method it is necessary to take into account the geometry of neutron monitors, and also the influence of the atmosphere and magnetic field of the Earth on the registered CR intensity. It is taken into account by means of the concept of receiving vectors $\vec{R}$ [7]. The neutron monitors having different locations and different receiving vectors, register the CR intensity which it is possible to present at each time moment as follows [7]:

$$I = \sum_{n=0}^{\infty}\sum_{m=0}^{n}(A_n^m \cdot X_n^m + B_n^m \cdot Y_n^m), \quad (1)$$

where A_n^m and B_n^m are the components of distribution function vector of CR intensity $\vec{A}$, the X_n^m and Y_n^m are components of the receiving vectors $\vec{R}$.

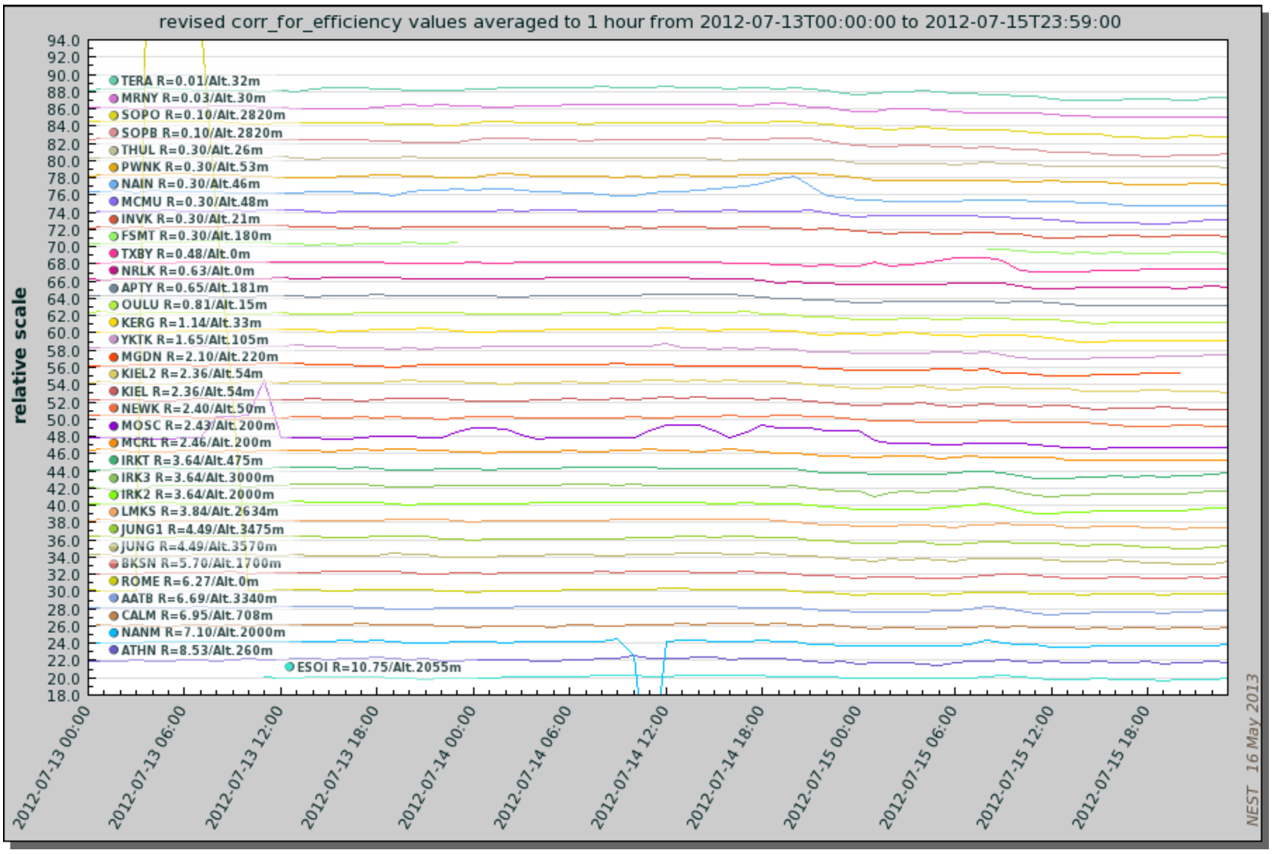

Fig. 1: The CR measurements for July 13-15, 2012 from the neutron monitor database – NMDB (`http://www.nmdb.eu`).

If the number of CR stations are enough, the components A_n^m and B_n^m for first two spherical harmonics of the CR distribution function can be found from the linear equation system (1). In this case the absolute geographical coordinate system is used. In this system the receiving vectors $\vec{R}$ do not depend on time, and the vector of CR anisotropy $\vec{A}$ changes within 24 hours. As a result of solution of the system (1) the values of 9 parameters of the first two angular moments of CR distribution function are determined. They are an isotropic component of CR intensity A_0^0; the coefficients A_1^0 and A_2^0 determined by the contribution of the 1st and 2nd spherical harmonics into the isotropic part of CR intensity; the A_1^1 and B_1^1 are the radial and azimuthal components of the 1st spherical harmonic of CR distribution function; A_2^2 and B_2^2 are the radial and azimuthal components of the 2nd harmonic; the A_2^1 and B_2^1 coefficients reflect the contribution of the 2nd harmonic of the CR intensity distribution function into the 1st spherical harmonic. Then, based on the already obtained results, by data of high-latitude stations 3 components of north-southern CR anisotropy (C_0, C_1^0 and C_2^0) are determined, where C_0 is the isotropic component of north-southern CR anisotropy, C_1^0 and C_2^0 are its daily and semidiurnal components, respectively.

3 Results and discussion

Earlier in [10] for the first time we realized a method of global survey in real-time in which the data of measurements of CR intensity are used from the well-known neutron monitor database (NMDB) (`http://www.nmdb.eu`). In November, 2011 the number of stations presenting the data of neutron monitor measurements in a digital form increased up to 30 when the American segment of stations joined to the NMDB. These CR stations are uniformly distributed over the whole globe sufficiently and their cones of receiving cover almost the entire celestial sphere. It allows us to determine the parameters of daily CR anisotropy in real-time with a tolerable accuracy.

Figure 1 presents the results of primary 1-hourly measurements of CR intensity with the neutron monitors obtained in the network on July 13-15, 2012. As is seen from figure 1, during that period of time the data of measurements of 35 CR stations were available but their quality left much to be desired. In the data of registration of CR intensity at different stations trends and failures of different types are often observed. They are largely caused by the conditions of carrying out of the experiment. Such situation is usual for stations when operating in real-time. So, before the use of such data it is necessary to carry out a special procedure for their correction. In this case it is necessary to understand and take up all risks of work with the data in real-time.

It is known that in correspondence with a convective-diffusive theory of CR modulation, the amplitude of daily CR anisotropy, on the average, under the non-disturbed conditions in the solar wind (SW), is equal to $\approx 0.5\%$ and the anisotropy vector $\vec{A}$ has the direction at 06 pm of local time [6, 9]. It is in satisfactory agreement with numerous experimental results on the study of daily CR anisotropy. From studies of various authors it is also known that in the presence of large-scale SW disturbances, both the value and direction of CR anisotropy considerably vary. The retrospective analysis of results of global survey carried out by us for the 1981-1999 period has shown that in more than 70% of cases of registration of large-scale SW disturbances there is a rotational displacement of the daily anisotropy vector in a direction from the Sun. In this case, a steady (within more than 4 hour) value of radial component of CR anisotropy in the direction from the Sun with the amplitude more than 0.4% for time from 1 till 2 days before arrival of disturbances at the Earth are observed.

We realized a method of global survey in real-time in May, 2012. From June till December, 2012 we forecasted 6 of 9 registered moderate geomagnetic storms in which values of D_{st}-index were less than -50 nT. Now the method of forecast of geomagnetic disturbances on the basis of global survey is at a finishing stage. Basically it is caused by problems with the elimination of failures of different types which are often observed in the primary data entering the NMDB in real-time.

As an example, in figures 2 the results of determination of CR daily anisotropy $\vec{A}$ by means of the global survey method in real-time for the July 13 -15, 2012 period are shown. Here, for the purpose of standard representation, a transition from the initial coordinate system into the GSE-coordinate system was made and the complete three-dimensional vector of daily (of the first spherical harmonic) CR anisotropy $\vec{A}$ was presented by the following 3 components: $A_x = A_1^1$, $A_Y = B_1^1$ and $A_Z = C_1^0$.

We leave a subject of behaviour of the azimuth and north- southern components of CR anisotropy beyond frameworks of this paper and pay attention only to the radial component.

From figure 2 it is seen that the decrease of CR intensity began on July 14, 2012 and the occurrence of steady radial component of CR anisotropy A_X with a considerable amplitude in the direction from the Sun was observed on July 13, 2012, i.e. more than 1.5 days before the onset of CR decrease. In correspondence with the results obtained by us earlier [10, 8], one can consider such modifications of the CR daily anisotropy phase as a predictor of arrival of geo-effective large-scale SW disturbance at the Earth and beginning from July 13, 2012, within 2 days one can expect a geomagnetic storm.

Figure 3 presents measurements of SW parameters (the IMF module (a) and SW speed (b)) which were registered aboard the ACE spacecraft and also the variations of the geomagnetic field disturbance (D_{st}-index (c)) for the same period of time. As is seen from figure 3, really, in correspondence with the our forecast, at the beginning of July 14, 2012 on the Earth the moderate magnetic storm was registered. Its reason was the arrival of the SW disturbance at the Earth's orbit.

Thus, this example presented for the event registered on July, 2012 illustrates the possible use of the global survey method for the forecast of space weather.

4 Conclusion

The early use of data of the whole world network in real-time was impossible. Therefore, this method was applied for retrospective studies of the structure and properties of the interplanetary medium. One should expect that realization of this method in real-time, on the basis of measurements presented in the NMDB, will considerably improve prospects of the further studies. In particular, as is seen in this paper, results of global survey can serve as the effective and useful instrument for the forecast of space weather and research of interplanetary medium properties.

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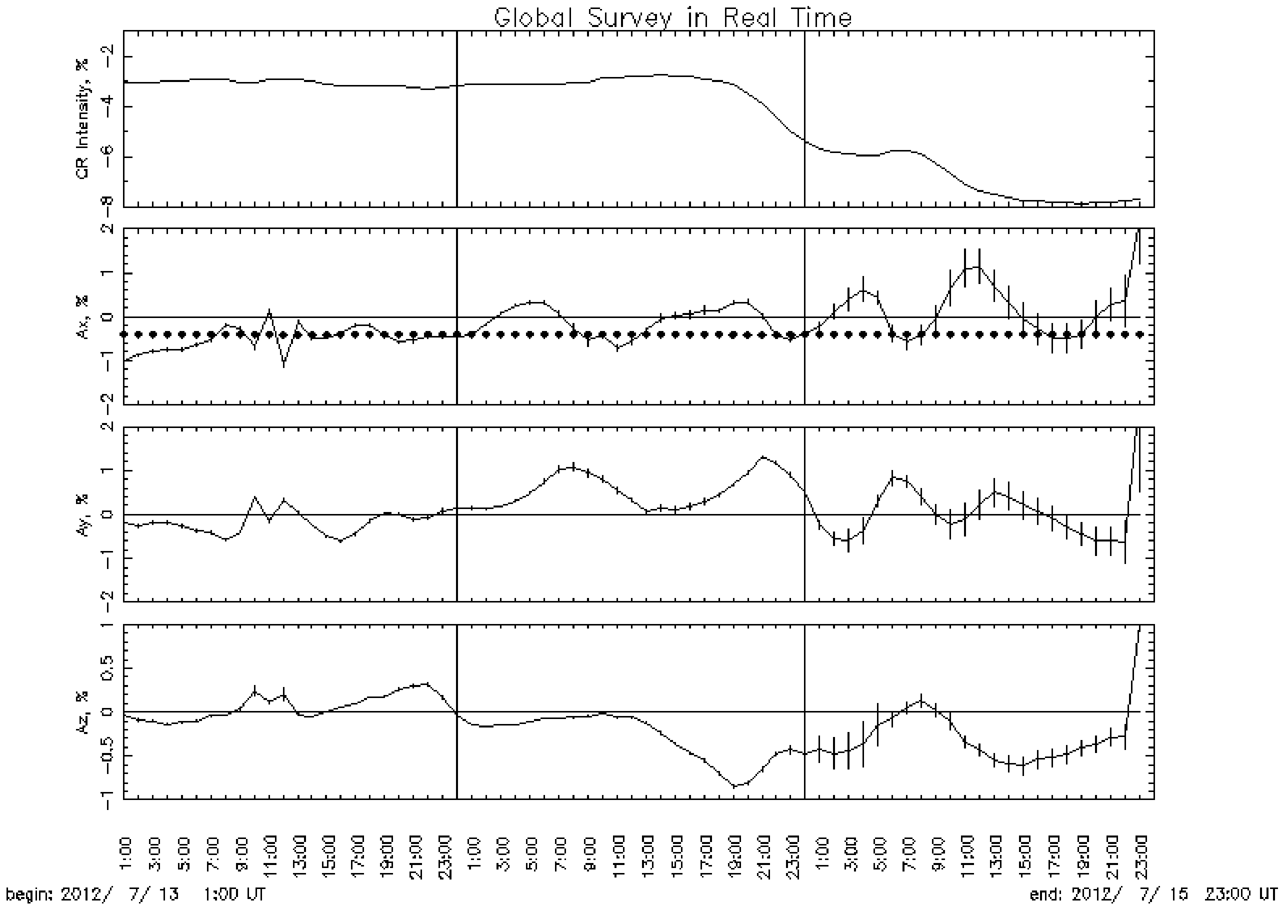

Fig. 2: Results of calculation of the isotropic CR intensity and components of CR anisotropy vector $\vec{A}$ in the GSE-coordinate system in real-time for July 13-15, 2012. By a dotted line a critical level of value of the radial component of CR daily anisotropy A_X for the development of forecast of arrival of the large-scale SW disturbance at the Earth is shown.

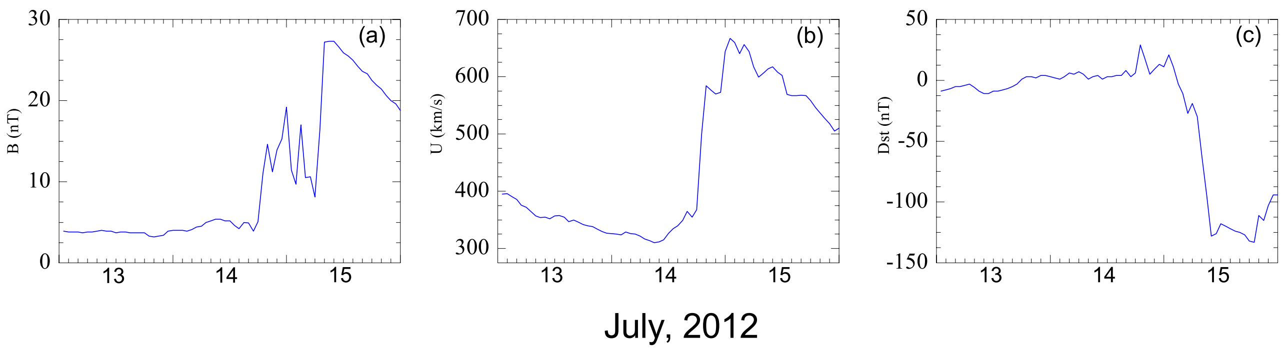

Fig. 3: Measurements of the module of interplanetary magnetic field B (a), SW speed U (b) and geomagnetic activity D_{st}-index for the same time period (`http://nssdc.gsfc.nasa.gov/omniweb/ow.html`).