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Investigation of short-term disturbances of the solar wind using a tensor anisotropy method

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In this work the dynamics of tensor anisotropy of cosmic rays during the passage of large-scale disturbances of the solar wind for the 22-24 solar cycles is studied. The information on the anisotropy was obtained using a global survey method based on the data of the worldwide neutron monitor network. For the analysis of the obtained results the data on the interplanetary magnetic field state and solar wind parameters were used.

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1. Introduction

The continuous observation of cosmic rays with neutron monitors has been carried out for more than half of a century. The world-wide neutron monitor network whose data is presented at the website of neutron monitor database NMDB[1] registers cosmic ray primary particles with the threshold energies up to 14.1 GeV.

Spreading in the heliosphere the galactic cosmic rays are exposed to various modulating effects of the solar wind. In the earlier works for explanation of 1 and 2 angular moments of cosmic ray distribution in the interplanetary medium, the mechanisms of convective-diffusive and drift motion of particles, shielding of cosmic rays by a sectorial magnetic field [1, 2] and shear flow of the solar wind [3, 4] were mainly proposed.

Deviations of cosmic rays from the isotropic distribution in the directions of their motion are very small - less than one percent. However, their all-round study is quite justified because they give the information on dynamic properties of the solar wind. A small value of anisotropy requires the application of special methods for data processing and their complex analysis for its study. Such methods were developed in ShICRA at 1960-s: crossed telescopes, receiving vectors and global survey and. This methods are described in [5, 1].

In the work [6, 7] using the methods of receiving vectors and crossed telescopes [1] during a period since 1971 to 2011 based on the data of underground complex of muon telescopes of st. Yakutsk [2] and multidirectional muon telescopes of st. Nagoya [3] the parameters of semidiurnal R_2^2 variation of cosmic ray intensity were calculated. The obtained results show a steady annual course of R_2^2 during all the period. Besides the semidiurnal variation, the second spherical of cosmic ray intensity also creates antisymmetric diurnal variations R_2^1. In the work [8] by the data of Nagoya muon telescopes the behaviour of this component was obtained. It turns out that the R_2^1 also has a seasonal change. In order to explain this seasonal changes of R_2^1 and R_2^2 the mechanisms of cosmic ray screening and solar wind shear flow were suggested.

In this work in addition to the earlier obtained results, the behavior of the tensor anisotropy components (R_2^1 and R_2^2) during a short-term disturbances of solar wind was investigated. To study this short-term events special methods of data processing the global survey method is used. This method allows to determine hour to hour changes of the tensor anisotropy parameters. As experimental data we used the data of NMDB. We also used the data of interplanetary magnetic field intensity, solar wind speed, Dst-index which are provided by NASA database [4] and computed coronal field synoptic charts of the Wilcox Solar Observatory [5].

2. Investigation method

The cosmic ray distribution can be expanded into series of spherical functions which are solu-

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[1] http://www.nmdb.eu

[2] www.ysn.ru/ipm

[3] www.stelab-nagoya-u.ac.jp/ste-www1/div3/muon

[4] http://omniweb.gsfc.nasa.gov/form/dx1.html

[5] http://wso.stanford.edu

tions of Laplace's equation:

$$J(\theta,\varphi)=\sum_{n=0}^{\infty}\sum_{m=0}^{n}(a_n^m cosm\varphi+b_n^m sinm\varphi)P_n^m(sin\theta), \tag{2.1}$$

where θ, φ are latitudinal and longitudinal angles in some coordinate system, P_n^m is associated Legendre polynomials. The distribution of intensity (2.1) can be presented as multidimensional vector $\vec{A}=\{a_n^m,b_n^m\}$ with infinity number of components ($0\le m\le n<\infty$). Then we can determine an receiving vector $\vec{Z}$ (which is also infinite dimensional) so that the intensity J registered by the detector is equal to the scalar multiplication

$$J=\vec{A}\cdot\vec{Z} \tag{2.2}$$

From (2.1) and (2.2) it follows that:
$\vec{R}=\{x_n^m,y_n^m\}, where(0\le m\le n<\infty)$,
$x_n^m=cosm\varphi P_n^m(sin\theta)$,
$y_n^m=sinm\varphi P_n^m(sin\theta)$.

The vectors $\vec{A}$ and $\vec{R}$ can be represented in the complex form as:
$\vec{A}=\{r_n^m\} \qquad r_n^m=a_n^m+ib_n^m$
$\vec{R}=\{Z_n^m\} \qquad Z_n^m=x_n^m+iy_n^m=e^{im\varphi}P_n^m(sin\theta)$

and in the case of vectors with complex components

$$J=\frac{1}{2}(\vec{A}\cdot\vec{R}^*+\vec{A}^*\cdot\vec{R}) \tag{2.3}$$

Thus, at the Earth, because of its rotation, the diurnal variation would be registered. This variation is determined by the Fourier series

$$J(t)=\sum_{n=0}^{\infty}(A_m cosm\omega t+B_m sinm\omega t), \tag{2.4}$$

where $A_m=\sum\limits_{n=m}^{\infty}(a_n^m x_n^m+b_n^m y_n^m)$, $B_m=\sum\limits_{n=m}^{\infty}(-a_n^m y_n^m+b_n^m x_n^m)$, ω is the angular velocity of Earth's rotation.

A calculation of receiving vectors $\vec{Z}$ is made taking into account the directional sensitivity of the detector, particle drift angles, coupling coefficients and power spectrum of anisotropy.

The devices with different receiving vectors register corresponding intensity J which is determined as follows:

$$J=\sum_{n=0}^{\infty}\sum_{m=0}^{n}(a_n^m x_n^m+b_n^m y_n^m), \tag{2.5}$$

If the number of devices is enough then the components a_n^m, b_n^m of the vector of cosmic ray distribution intensity (for the first two spherical harmonics) at each time moment can be found from the presented system of equations (2.5).

Since the power sensitivity of the detectors are different, it is necessary to introduce the quantities $k_n^{(j)}$ defined by

$$k_n^{(j)}=\frac{\int\limits_{\varepsilon_{min}}^{\infty}W^j(\varepsilon)f_n(\varepsilon)d\varepsilon}{\int\limits_{\varepsilon_{min}}^{\infty}W^0(\varepsilon)f_n(\varepsilon)d\varepsilon}, \tag{2.6}$$

where $f_n(\varepsilon)$ is the power spectrum of the spherical harmonic of the order n, $W^j(\varepsilon)$ $(j = 1,2,...)$ are the differential energy sensitivities if the detector in consideration, and W^0 is some arbitrary differential sensitivity. Equation (2.5) assumes the form

$$I^j = \sum_{n=0}^{\infty} \sum_{m=0}^{n} (a_n^{m,0} x_n^{m,j} + b_n^{m,0} y_n^{m,j}) k_n^j \tag{2.7}$$

where $a_n^{m,0}$ and $b_n^{m,0}$ are unknown coefficients independent of j. The system obtained can be solved by means of the least squares method provided that the series converges quickly and higher order terms may be neglected.

In order to get free from noise due to the instability of the detectors the next original data filtering method was used. The observed intensity J is divided into high frequency $J_{h.f.}$ and low frequency $J_{l.f.}$ parts and thus the device variations will be in the first part, the anisotropy in the second part and the isotropic variations in both parts. The low frequency part is revealed by the moving average method over 37 hours. So, the high frequency is equal to $J_{h.f.} = J - J_{l.f.}$. Having analyzed the high frequency part by means of equation (2.7), we obtain the components of anisotropy vector $\vec{A}$.

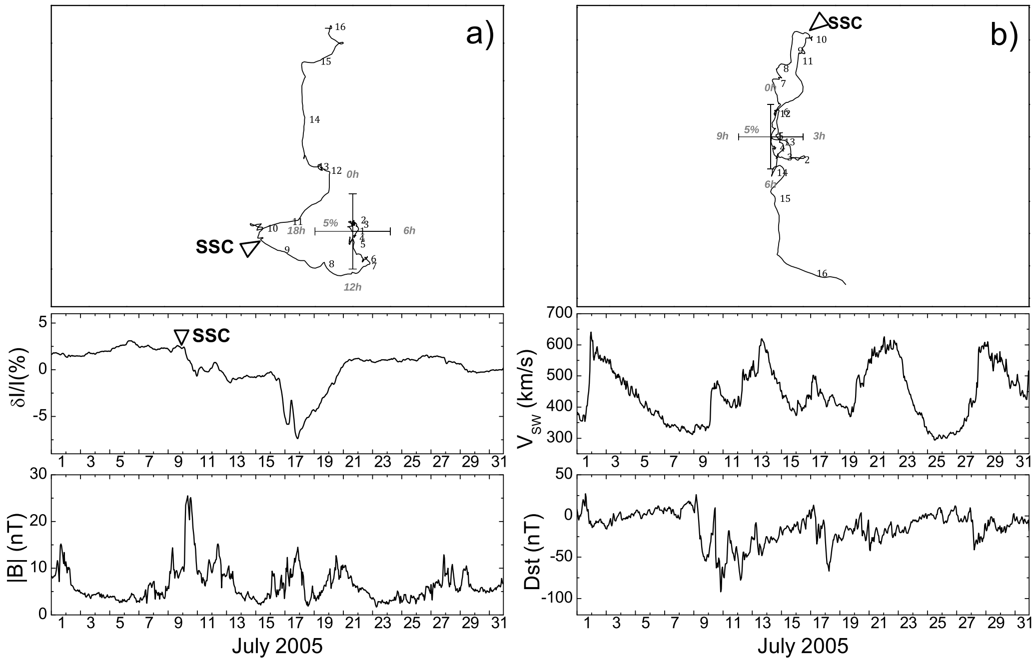

Figure 1: The vector diagram of the components of tensor anisotropy R_2^1 (a), R_2^2 (b) in July 2005. On a hour dial the numbers indicates the day of month. $\delta I/I$ is the isotropic part of cosmic ray intensity, V_{SW} is the solar wind speed, $|B|$ is the magnitude of interplanetary magnetic field intensity, the Dst is the index of geomagnetic activity.

3. Obtained results

We have obtained the behavior of diurnal (R_1^1), antisymmmetric diurnal (R_2^1) and semidiurnal (R_2^2) variations of cosmic ray intensity by the method of global survey using the hourly data

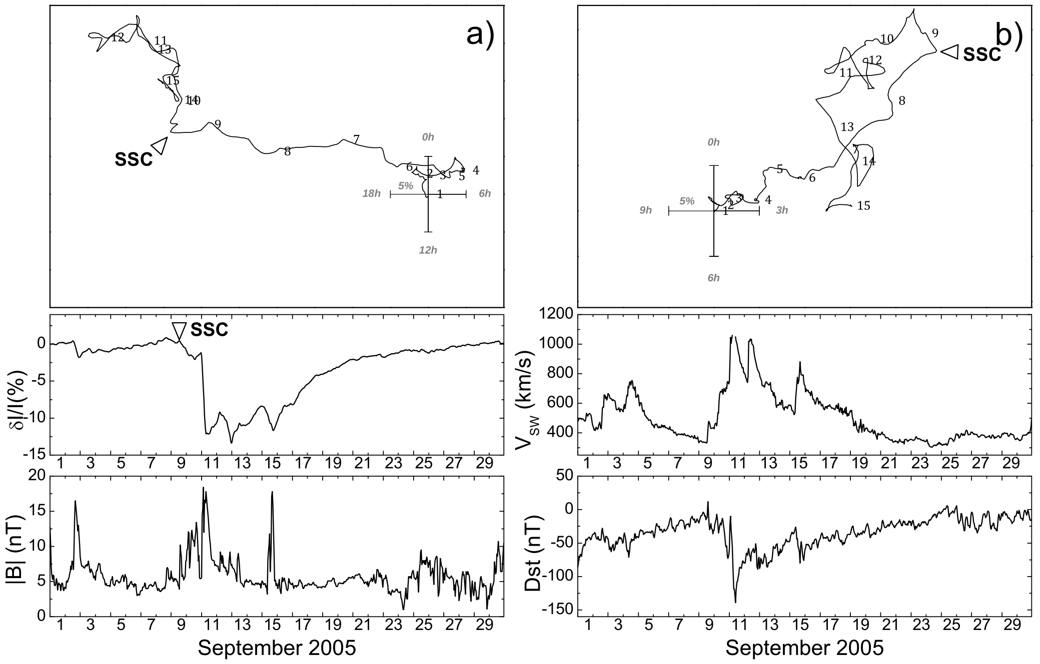

Figure 2: The vector diagram of the components of tensor anisotropy R_2^1 (a), R_2^2 (b) in September 2005. On a hour dial the numbers indicates the day of month. $\delta I/I$ is the isotropic part of cosmic ray intensity, V_{SW} is the solar wind speed, $|B|$ is the magnitude of interplanetary magnetic field intensity, the Dst is the index of geomagnetic activity.

of the neutron monitor worldwide network ($\sim$ 30 stations) for 1990-2012. Also the data about the interplanetary magnetic field state, solar wind speed, Dst-index and computed coronal field synoptic charts of the Wilcox Solar Observatory and some solar proton events affecting the earth environment [6]. The analysis of the obtained data shows the unusual amplitude-phase oscillations of antisymmetric diurnal R_2^1 and semidiurnal R_2^2 variations (table 1). The next 2 events of unusual behavior of the tensor anisotropy components during Forbush decreases at July 2005 (fig.1) and September 2005 (fig.2) are shown as examples. The SSC beginnings are shown by arrows.

In September 2005 the decrease of the cosmic ray intensity has an amplitude of 14%. The reason of this effect is the solar flare that happened in 07.09.2005 on the eastern limb (S06E98) of the Sun at the south of helioequator. This decrease is caused by the increase of interplanetary magnetic field in 09.09.2005 and accompanied by the solar wind speed increase up to 1200 km/s and the geomagnetic disturbance is caused. Before the beginning of forbush decrease the component R_2^1 was directed to $\sim$ 18h and R_2^2 to $\sim$ 2h of local time. Hence, with the arrival of shock wave both vectors R_2^1 and R_2^2 changed their to $\sim$ 23h and $\sim$ 8h respectively.

In July 2005 the forbush decreases at 10th days of month with amplitude $\sim$ 3 % is observed. As in the previous event, this decreases were accompanied by the jumps of solar wind speed up to 500 km/s, the interplanetary magnetic field intensity and Dst-index

The possible reasons of this abrupt direction changes of R_2^1 and R_2^2 to the reverse are the

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[6] http://umbra.nascom.nasa.gov/SEP/seps.html

Table 1: The selected months when the components R_2^1 and R_2^2 have the unusual behavior

No	Date	No	Date
1	November 1990	20	June 2005
2	December 1991	21	July 2005
3	May 1992	22	August 2005
4	September 1992	23	September 2005
5	October 1993	24	July 2007
6	November 1993	25	September 2007
7	January 1994	26	February 2010
8	April 1995	27	March 2010
9	April 1996	28	September 2010
10	March 2000	29	November 2010
11	October 2000	30	December 2010
12	January 2001	31	February 2011
13	August 2001	32	March 2011
14	September 2002	33	September 2011
15	October 2002	34	March 2012
16	March 2003	35	April 2012
17	June 2003	36	July 2012
18	July 2003	37	September 2012
19	August 2003	38	November 2012

formation of a magnetic mirror at the jumps of interplanetary magnetic field intensity. Inside of the regular magnetic field the trapped particles changes are occur. The similar events during forbush decrease or solar wind speed abrupt increases are presented in the table.

4. Conclusion

The behavior of the components R_1^1, R_2^1 and R_2^2 during the various short-term solar wind disturbances obtained using the method of global survey by the hourly data of neutron monitor worldwide network. The unusual change of amplitude phase oscillations of anisymmetric diurnal and semidiurnal variations of cosmic ray intensity, specifically the abrupt change of the direction of vectors R_2^1 and R_2^2. The possible reason of this phenomenon is the formation of the magnetic mirror at the jumps of interplanetary magnetic field intensity.

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