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Global and Local Indices of Cosmic Ray Activity

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Abstract

Till now the quantitative estimations of cosmic ray (CR) disturbance have not been used, as, for example, it is for the geomagnetic activity. In present work we try to give the special indices characterized the level of cosmic ray activity and some peculiarities of the space weather. The global indices are calculated for every hour and every day within the period of 1990-1996 on the base of cosmic ray density and anisotropy, obtained from the world neutron monitor network. As examples of these indices behavior several events during this period are considered. Apart from the global indices we can obtain the local indices from a single station data. The advantages of the high mountain neutron monitor data (Alma-Ata station, 3340 m) in the calculating of the local indices of cosmic ray activity are discussed.

1 Introduction:

Various indices, as a simplified quantitative characteristic of complicated versatile phenomena, are extensively used in solar-terrestrial physics. The indices of the solar activity (Wolf numbers, for example) and geomagnetic disturbances (Kp, Ap, Dst, AA and others) allow to select and compare the different phenomena, to distinguish quiet and disturbed periods (Bartels, 1957; Mayaud, 1972). The first attempt to introduce the similar indices for CR variation was in fiftieth (Malurkar, 1955). It was daily index, based on the dispersion of one detector twohourly data. Much later another CR index, based on the shortperiod fluctuations (Kozlov & Tugolukov, 1992) was appeared. Belov et al. (1998) proposed to use the changes of 10 GV particle density and anisotropy as measure of CR disturbance.

Cosmic rays, being a component of the interplanetary medium, naturally respond to its changing, and not less sensitively, than the Earth magnetosphere. The analogues of magnetic storms in cosmic rays are Forbush-effects (FEs), associated with the solar ejecta and with propagating solar wind disturbances. In fact, these are the storms in cosmic rays, when a density and anisotropy of CR are changing significantly and sometimes catastrophically (for examples, Belov et al. 1997). Even more strong disturbances may occur with the solar CR incoming at Earth, when CR flux may grow more than in order, and anisotropy increases practically to 100% (Shea and Smart, 1993). Surely, such events are rare enough, but variations of CR are evident forever, and the level of their disturbance changes permanently, reflecting the conditions of the interplanetary medium. However, no accepted quantitative characteristic of such a disturbance exists till now. The aim of the present work is to discuss the methods for calculation of CR activity indices (CRA-indices) as global so local and to study a behavior of these indices.

2 Global Indices:

Data from the world wide neutron monitor (NM) network have been used as the basis to obtain of CRA indices. This multichannel detector has a long (>40 years) homogenous set of data, containing an information about variations as density, so anisotropy of cosmic rays. These variations reflect all great disturbances in the interplanetary space and most important solar cosmic ray enhancements. Hourly data of density and first harmonic of CR anisotropy (for CR 10 GV rigidity) through 1990-1996, found by the global survey method (Belov at al., 1997), have been used to calculate the indices.

Intuition suggests, what a distinct is between quiet and disturbed state of the cosmic rays. In the quiet conditions density and anisotropy of CR are almost constant and amplitude and direction of the anisotropy are close to the normal for a given period. On the contrary, the big changes of density and anisotropy and significant deflections from normal anisotropy are inherent for disturbed period.

Let we know the density variation A_o and three component of the anisotropy vector A_x, A_y, A_z for two consecutive hours t-1 and t. We can present a disturbance of CR as following (Belov et al.,1998):

$$\mathbf{CRA} = \sqrt{2\left(\frac{\Delta_0}{s_0}\right)^2 + \left(\frac{\Delta_1}{s_1}\right)^2 + \left(\frac{\Delta_{xy}}{s_{xy}}\right)^2} - \mathbf{1}, \qquad (1)$$

where $\Delta_0^2 = \left(A_0(t) - A_0(t-1)\right)^2$, $\Delta_1^2 = \left(A_x(t) - A_x(t-1)\right)^2 + \left(A_y(t) - A_y(t-1)\right)^2 + \left(A_z(t) - A_z(t-1)\right)^2$,

$\Delta_{xy}^2 = \left(A_x(t) - A_{x0}\right)^2 + \left(A_y(t) - A_{y0}\right)^2$ and s_0, s_1, s_{xy} – are the normalizing coefficients.

Behavior and distribution of the CRA components was investigated during the selected quiet period. For our data it was 1995 year, when rms deviations for Δ_0, Δ_1, Δ_{xy} were 0.07%, 0.14% and 0.21% respectively. These values have been used as normalizing coefficients s_0, s_1, s_{xy}. As the components of the normal anisotropy A_{x0} è A_{y0} we used running averaged A_x and A_y for one solar rotation, directly preceded to the current hour. For more convenient using CRA values were rounded off to an integer and replaced on 0 when right side in (1) was <0. On the basis of hourly means CRA it is easy to obtain indices averaged by more long intervals, for example, for the last 3 or 24 hours: CRA_3, CRA_{24}. Respectively, daily index CRA_d is an averaged CRA for one day.

Indices CRA, CRA_3, CRA_{24} and CRA_d were calculated through the period of 1990-1996. These 61368 hours contain as the extremely disturbed periods (in 1991), so the quiet ones (especially in 1995-1996). So, our data set includes practically all possible levels of solar and cosmic ray activity. Mean CRA-index over this whole period was 3.46±0.01, median and mode were 3. Zero values occurred only in 1.3% of all hours. The most frequently CRA-index was into 1-5 interval. Although the range of values extends to 210, CRA exceeded 30 only once from 1000. CRA>8 appeared once per day, >15- once a week, and >27 - once per month. The distribution of CRA indices in different periods could strongly differ from the average. Thus, in the quiet 1996 CRA indices exceeded 7 only once per 12 days and never was >10. The most disturbed hours were recorded during the increasing of solar cosmic rays (GLE) 24.05.90 and 15.06.91. We have to note here, that used global survey method is not dedicated for GLE analysis, so, found for GLE hours characteristics density and anisotropy are not associated with 10 GV particles, sooner with 3 GV. However, they reflect adequately enough the level of CR disturbance, and we can expand on these hours the common method of CRA-indices calculation. Periods with significant contribution of solar cosmic rays are very seldom.

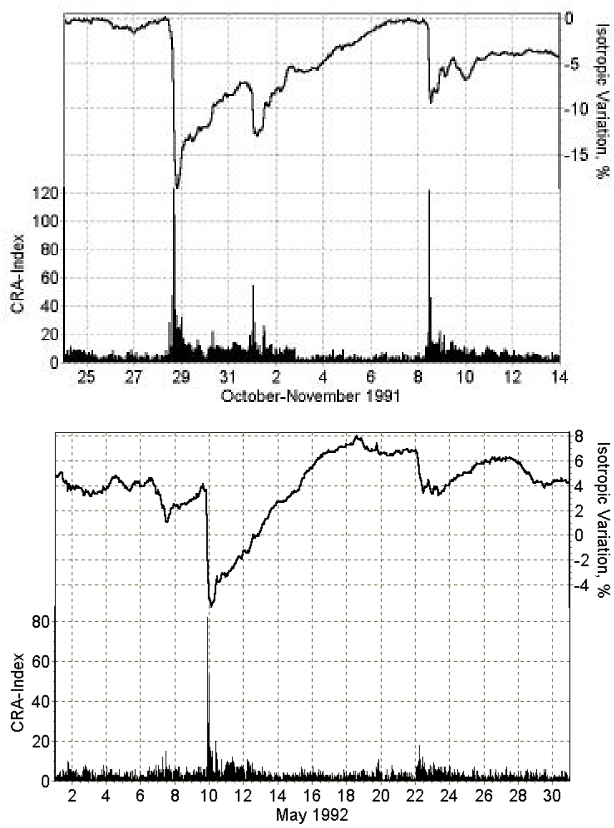

Figure 1. Variations of CR density and CR activity index in disturbed periods of 1991 and 1992.

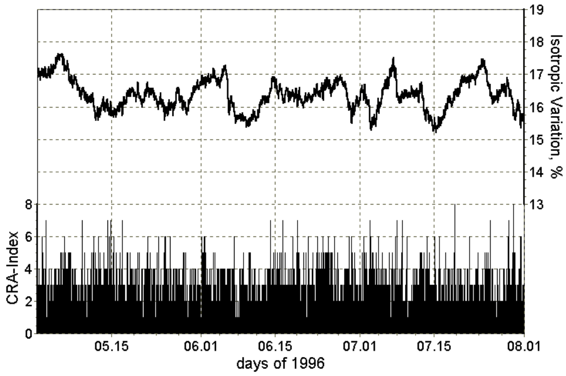

Figure 2: Variations of CR density and CR activity index in quiet period of 1996.

Practically all changes of CRA-indices are conditioned by the galactic cosmic ray variations and disturbances of the interplanetary space.

The behavior of CRA-indices in two disturbed periods is presented in Fig. 1. The biggest increasing of the activity we see during the great FEs 28.10.1991, 8.11.1991 and 9.05.1992. In the first two events CRA-index reached the 127 value. It is the greatest modulation effects over the whole 7 years. FE of 28.10 is among the biggest FEs for the history of observations, and FE on 08.11 despite of the lower amplitude of decrease, was followed by the extremely large magnetic storm, when Dst-variation fall down to -345. On these periods CRA-indices very often exceeded 10, and small indices (0-4) appeared rarely. For a comparison the quiet period (practically any time of 1995-1996) was considered. The variations of CR density and CRA-index in May-July 1996 are presented in Fig.2. Of course, CR variations don't disappear completely near the solar activity minimum, but large effects are absent at this time. Indeed, no one FE during considered 3 months exceeded 1.5%, and total change of CR density was less 2.5%. CRA-index reached 8 only twice for this time. From other side, there were several long intervals, when CRA indices was <=4. It seems, the increasing CRA to 6-10 is typical enough for the small FEs.

The behavior of daily CRA_d indices over the whole 7 years is presented in Fig.3. The range scale for CRA_d is, naturally, less than for CRA indices, it varied from 1 to 38, but mainly was 2-4. CRA_d reached the maximal value on 24.03.91, and this day was most disturbed over the whole studied period. From this picture a relation of CR disturbance with solar activity is seen well: near maximum on 1991 annual CRA-index was 4.9, whereas close to minimum it decreased to 2.6 (1995) and 2.7 (1996).

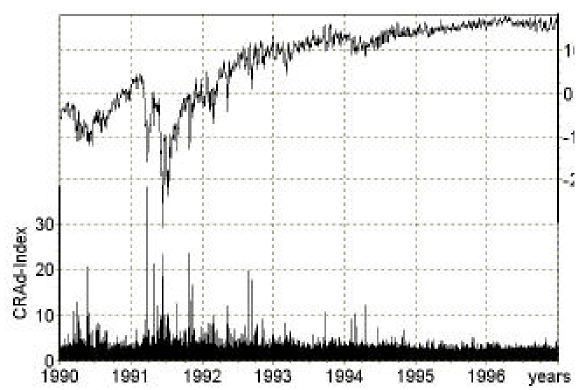

Figure 3: CR density variations and CRAd-index through 1990-1996.

3 Local Indices:

In comparison with the whole NM network the measurements from a single detector have some evident and essential drawbacks. The limited asymptotic cone of each detector for coming CR cause the main deficiency of indices, obtained from such a data. Detector responds to CR disturbance only into his own cone and will not «notice» a disturbance in other directions. So, sensitivity of a single detector to CR disturbance will depend on direction of anisotropy and on the time of day, and will vary with time. Such data doesn't allow to distinguish density and anisotropy variations. These variations and station moving because of the Earth rotation may superimpose on one another by such a way, that counting rate from detector will remain unchanged even under strong disturbance. However, data from a single NM has a decisive advantage: these data allow to estimate of CR disturbance in the real time.

To apply the approach, already used for CRA calculation, to the single detector data, we have to study daily run of the counting rate. During quiet days we have in the NM data sinuslike daily variation. The characteristics of the normal for the current period anisotropy and location of the station define it. Thus, on Moscow station counting rate mainly increases on the first half of day and decreases on the second one. The density changing and the anomalous anisotropy behavior lead to distortion of daily run, and the greater is of

CR disturbance, the more is distortion. Let in hour t the variation of the counting rate relatively to daily mean is δ(t), and its hourly change is d(t)= δ(t)- δ(t-1). Comparing this value with the same for the quiet period $d_0(t)$, we can find hourly indices of CR disturbance for the single station as:

$$\mathbf{CRAmosc} = \mathbf{b}\frac{|\mathbf{d(t)} - \mathbf{d_0(t)}|}{\mathbf{s}} - \mathbf{a} \qquad (2)$$

Four-letter station name, added to the index denotation (here is for Moscow station) is taken from the standard list using in GLE Database (Shea et al., 1987). Parameter s is a statistical error of the hourly mean counting rate. For Moscow station this value was obtained as 0.17% from distribution of 1-minute data in the quiet periods. Constant a is inserted to reduce the influence of small random variations and b - to match local and global indices. Smoothed indices CRAmosc3, CRAmosc6, CRAmosc24 may be obtained by averaging hourly indices for 3, 6, 24 hours. This approach was realized for Moscow station and the behavior of the local indices can be seen via INTERNET (http://helios.izmiran.rssi.ru/cosray/main.htm) in real time.

The problem of the random variations on using indices from a single station becomes more pressing than for global CRA-indices. The use of CR detector with high counting rate as high-mountain Alma-Ata neutron monitor is preferable here.

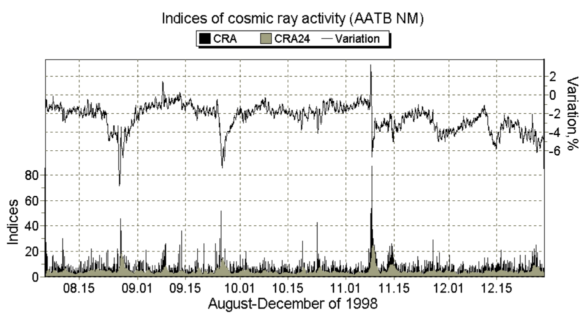

Figure 4: The Alma-Ata (3340 m) NM counting rate variation and CRAaatb-indices for Aug-Dec 1998

CRA indices for Alma-Ata station were calculated (with s=0.09%, b=3, a=1) through 1995-1998 years. Most disturbed part of this period is shown in fig. 4. This time falls on the phase of the solar activity growth, and CR disturbance here is rather higher than in preceding two-three years. The increasing of CRAaatb index is especially evident on August, September and November 1998, when the biggest in the current solar cycle Forbush-effects were observed. However the behavior of CRAaatb-indices reveals not only the greatest CR disturbances but the smaller CR variations as well.

4 Conclusion:

The variations of CR density and anisotropy, calculated by the global survey method, give the reliable base for the retrospective analysis of CR disturbances and calculation of the global CRA-indices. Data from a single NM (especially from high mountain) allow to follow of CR disturbance in real time. The involving on INTERNET data from other stations in real time, is bound to improve the CRA-indices quality.

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References

Malurkar, S.L. 1955, Acta phys. Acad. scient. hung., **5**, 2, 241.
Bartels, J. 1957, Ann. Intern. Geophys. Year **4**, part I, 215
Belov, A.V., Eroshenko, E.A., Yanke, V.G., 1997, Proc. 25th ICRC, **1**, 437
Belov, A.V., Eroshenko, E.A., Yanke, V.G., 1998, ESA Space Weather Workshop, ESTEC, (in press)
Kozlov ,V.I., & Tugolukov, N.N. 1992, Geomagn. and Aeronom., **32**, 157.
Mayaud, P.N. 1972, Journal of Geophysical Research , **77**, 34, 6870
Shea, M.A., & Smart D.F. 1993, Nucl. Phys. B, **39A**, 16
Shea, M.A., et al., 1987, Proc. 20th ICRC, **3**, 171