Definition of cosmic ray density and anisotropy beyond the magnetosphere in real time mode

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***Abstract*. Experimentally, directly from the data of each neutron monitor we obtain variations of the secondary cosmic ray component which is generated in the Earth atmosphere. Our task is to get the cosmic ray variations in the space, beyond the Earth's atmosphere and magnetosphere using data from the world wide NM network. This task is solved by means of the Global Survey Method (GSM) which is a complicated version of the spherical analysis method. In the frame of FP7 NMDB project this task has been solved in a real time mode. The program GSM012T was developed as modified version of the main GSM program adjusted to real time calculations. The results are published in digit and graphical forms.**

***Keywords*: Neutron Monitor, Cosmic Ray Variations**

I. INTRODUCTION

Cosmic rays are an integral part of our vital environment and they provide the valuable information on processes on the Sun and in interplanetary space. The anisotropy of cosmic rays (CR) in the energy range of 1-100 GeV is capable to give a lot of information on conditions in interplanetary space [1-2 and references there]. Structural features and processes in a solar wind within the wide spatial (10^9 -10^{15} cm) and time (10^3 - 10^8 s) scales, are reflected in the CR anisotropy observable at the Earth and data on the anisotropy from ground level CR observations derived might be considered as reliable tool for interplanetary space diagnostics [3-9]. The goal is on deriving of hourly parameters of CR density variations and first spherical harmonic of anisotropy outside the magnetosphere from NM network data. The operative version of GSM (Global Survey Method) program was elaborated and the parameters of CR density and anisotropy were calculated over the period 1957-2007: ftp://cr0.izmiran.rssi.ru/NMDB_doc/GSM/. The task being solved in the frame of NMDB project is to adjust this algorithm to real-time mode. This has been tested in IZMIRAN already by the data from local database, and internet project is created where the calculation of CR parameters outside the magnetosphere are carried out in real time mode http://cr0.izmiran.ru/CosmicRayAnisotropy. The main problem is insufficient number of well operating stations with real time data presentation (it takes as minimum 15 stations homogeneously distributed by the globe). In this work we considered the results obtained by the real time data and by usual way - after the data checking and correction.

II. DISCRIMINATION OF GALACTIC COSMIC RAY PARAMETERS

The worldwide neutron monitor (NM) network is a unique tool for obtaining with high accuracy a density variations, energy spectrum and anisotropy of Cosmic Rays in the Earth orbit, outside its atmosphere and magnetosphere. In common, the method of a detection of CR anisotropy from ground based CR observations (Global Survey Method - GSM) is a various modification of spherical analysis [10-13]. One of GSM versions, used in IZMIRAN for the CR parameters calculation over the history of observation is described in [14] The system of equations describing observable variation of counting rate at each station is being solved by the RLS method to derive the following parameters of the CR: A_0 - isotropic part of CR variations (density) with its spectral characteristics; A_x, A_y, A_z - three components of CR anisotropy, and discrepancy between the model of CR variation and real CR observations at every station. A plenty of used stations should provide both a good accuracy of obtained characteristics, and fully continuous data set on CR anisotropies at any considered period. For the NMDB project these parameters are calculated every hour in real time, and the list of all implemented stations is given in Table 1.Here are short and full name of station, standard atmospheric pressure, geomagnetic cut-off rigidity and type of detector. Sign * near the station number means that the data of this station were taken from NMDB. We should emphasize that not all and not a constant number of stations operate at every moment (due to breaks down, closing of stations, run the new ones and so on) and in various periods there is different number of stations fully suited for calculations. The main requirement to every station is its stable and reliable operating which can provide high quality data.

TABLE I: List of NMs used for real time calculations

N	name	H0	Rc	Type	Station
1*	aatb	675	6.69	18NM64	Alma-AtaB
2*	apty	1000	0.65	18NM64	Apatity
3*	athn	1000	8.72	6NM64	Athens
4*	bksn	820	6.91	6NM64	Baksan
5	caps	1016	0.45	12NM64	Cape_Shmidt
6*	ervn	800	7.60	18NM64	Yerevan
7*	erv3	700	7.60	18NM64	Yerevan3
8*	esoi	800	10.0	6NM64	ESOI_Israel
9	fsmt	1000	0.30	18NM64	Fort_Smith
10	invk	1011	0.18	18NM64	Inuvik
11*	irk2	800	3.66	12NM64	Irkutsk2
12	irkt	965	3.66	18NM64	Irkutsk
13*	jun1	643	4.48	12IGY	Jungfraujoch
14*	jung	643	4.48	3NM64	Jungfraujoch
15*	kerg	1000	1.19	18NM64	Kerguelen
16*	kiel	1007	2.29	18NM64	Kiel
17*	lmks	733	4.00	8NM64	Lomnicky_St.
18	mcmd	992	0.01	18NM64	McMurdo
19*	mgdn	982	2.10	18NM64	Magadan
20*	mosc	1000	2.46	24NM64	Moscow
21*	mrny	1013	0.04	12NM64	Mirny
22*	nvbk	1000	2.91	24NM64	Novosibirsk
23	nwrk	1013	1.97	9NM64	Newark
24*	oulu	1000	0.81	9NM64	Oulu
25*	pwnk	1000	0.50	18NM64	Peawanuck
26*	rome	1009	6.32	17NM64	Rome
27*	tera	1000	0.01	9NM64	Terre_Adelie
28	thul	1005	0.10	9NM64	Thule
29*	txby	1000	0.53	18NM64	Tixie_Bay
30*	yktk	1000	1.70	18NM64	Yakutsk

III. EXAMPLES OF THE GSM RESULTS USE

The parameters of galactic cosmic rays obtained by GSM are employed for studying either long term or short time processes in the heliosphere. Below several examples of such application are present. It is already known during the more than 50 years [15] that averaged characteristics of the GCR anisotropy vector vary with 11- and 22-year periodicity. By the beginning of 70-s after researches by [16,17] it became clearly, that anisotropy variations in the solar magnetic cycle are defined by the hall component variations and caused by the transverse gradient of the CR density. The results below (Fig.1) submit monthly averages of the CR anisotropy derived by the hourly data from the worldwide neutron monitor network [18].

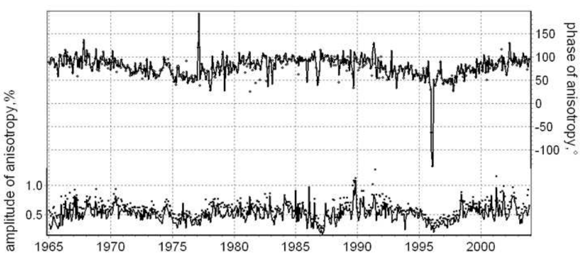

Fig. 1: Monthly values of the amplitude and phase of the CR solar diurnal anisotropy for the quiet (solid lines) and disturbed (points) periods derived by the hourly data throughout the 1965-2003.

There is the 22-year recurrence of the phase and 11-year recurrence of amplitude are notable. On this background the numerous fluctuations and anomalies are seen, certainly not of statistic origin since the statistic errors are very small here. Especially big deflections in the phase behavior revealed in 1976 and 1996- in the minima of the solar cycles. It is pertinent to note that analogous behavior was observed also in 1954. Characteristic and rather inhomogeneous phase distribution and amplitude-phase interrelation are the main properties of the anisotropy which exists for all long enough intervals gradually changing within the solar cycles. Cosmic rays observable on the Earth response to approach of the interplanetary shock prior its arrival, and this subject is especially actively developed in last 15 years [19 and references there]. The effect of arriving shock (precursor) is a complicated combination of the preincrease and predecrease in the CR variations and presupposes unusual pitch-angle distribution of the CR intensity which cannot be exactly described by the sum of the first spherical harmonics. Nevertheless, this effect may be revealed in variations of the zero (CR density) and first (CR anisotropy) cosmic ray spherical harmonics. Changes of the CR anisotropy may be seen not only directly before the shock but earlier as well, that is shown in Fig.2, where the hourly variations of CR density and Axy component of anisotropy averaged by the superposed epoch method on the hundreds of Forbush effects are depicted relatively the SSC moment [19].

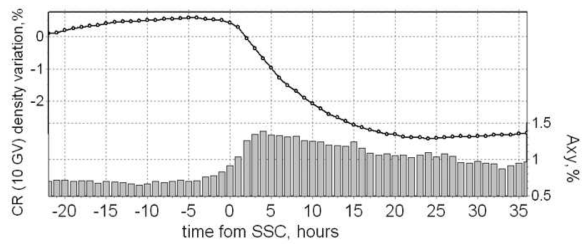

Fig. 2: Averaged by 332 FEs variations of CR density and amplitude of the first harmonic of anisotropy for the periods before and after the SSC.

A day before SSC the density of CR gradually increases a little. This is a recovery after preceded Forbush decreases. But in the last 12 hours this increase slow down firstly and then was exchanged by some decrease which is well seen at least 5 hours prior the SSC. The Axy value is close to the mean (≈0.7%). In the last 5-7 hours a gradual increase of Axy is observed which became faster to the SSC moment and continues after the SSC. Note, that CR anisotropy reaches its maximum in 3-4 hours after the SSC for this kind of FEs (caused by sporadic phenomena).

It is natural to suppose that effect of the shock on the major part of cosmic rays will be appreciable at a distance of one larmor radii from the front. In the used set of 332 events started on the quiet background the mean IMF intensity before the SSC was 5.1±0.1 nT. For

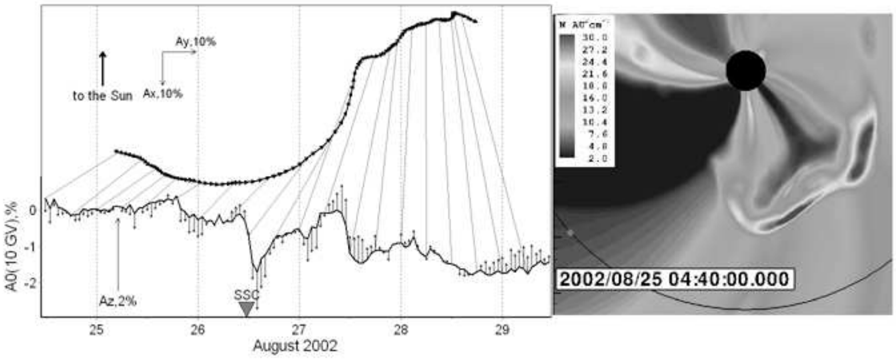

Fig. 3: Behaviour of CR density and anisotropy and model calculation of the interplanetary plasma [21] in the August 2002 event.

the protons of 10 GV rigidity the larmor radii ≈0.043 au in such field and the shock of 500 km/s velocity will cover this distance for 3.6 hours. The precursor effect is obviously decreased while averaging, and it is clear that for separate events and FE groups the effect should be more pronounced. One more example confirmed the CR parameters as a source of the information on the structure of interplanetary disturbances is present in Fig.3. During the events caused by far eastern or western sources near Earth measurements did not show a high perturbation in the Earth vicinity [20]. The high magnitude of FEs from such remote sources on this quiet background assumes great power of a disturbance and tells about modulating area wider than the size of disturbance. How it may occur in the case of western source may be in particular illustrated by Fig.3 where the picture of disturbance propagating [21] and behavior of CR anisotropy are present together.

FE started on August 26, 2002 after arrival of a weak shock on the background of moderate interplanetary and geomagnetic activity (B_m ≈15 nT, Kp=5_-, minimum Dst=-47 nT). The FE magnitude was not big-only≈2%, but CR anisotropy was rather large for such small effect - 3.3%. It was caused by a CME originated from the western limb (W88) and associated with X3.1/1F solar flare. The Space Weather Modeling Framework was employed by Lugaz et al. [21] for calculation of plasma density distribution. In this event the flank of the CME propagated into a region of newly open magnetic field connected to the Earth, that is confirmed also by a direction of CR anisotropy in the left side of Fig.3. As a result this CME originated from the western limb caused a noticeable FE with large CR anisotropy.

IV. What is going in real time?

The development of a real-time database (NMDB project) is an important step to enable the providing of important key parameters of the CR via web-based calculations: density and anisotropy of 10 GV cosmic rays, pitch-angle distribution, galactic CR spectra and radiation doses. The operative work with data should make use of the NM network as a single multidirectional instrument to provide an operative patrol and analysis of near-Earth space environment. We selected hourly data in March of 2009 for checking data quality and comparing the results obtained by GSM automatically in real time mode with those derived by usual way, after preliminary data correction.

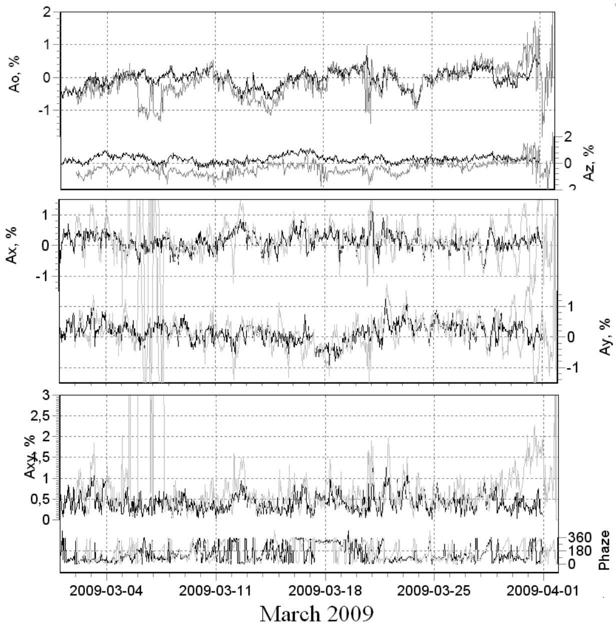

Fig. 4: Results of the GSM calculations: A_0 , A_x, A_y, A_z, amplitude and phase of the equatorial component of CR anisotropy (A_{xy} and Phase). Black curves correspond to the calculations by the checked and corrected data. Gray lines indicate the real time calculations.

In Fig.4 the results are presented for both ways of calculation. One can see that there is very unstable behavior of the parameters obtained automatically by real time raw data (grey curves) as compared with retrospective calculations. We see large sharp deflections in A_0 at the beginning of March and during several periods in the middle and the end. Behavior of A_x, A_y and A_{xy} correspondingly, tells about large drawbacks in real time data within the separate time intervals. Systematic daily waves in the first harmonic of anisotropy in some periods testifies to drift of the data of the local origin at a number of stations. To verify our suppositions we have checked and compared data taken in real time with those prepared for retrospetive processing or with real time data from stable operating stations. In Fig.5 some examples of data quality at armenian stations are presented.

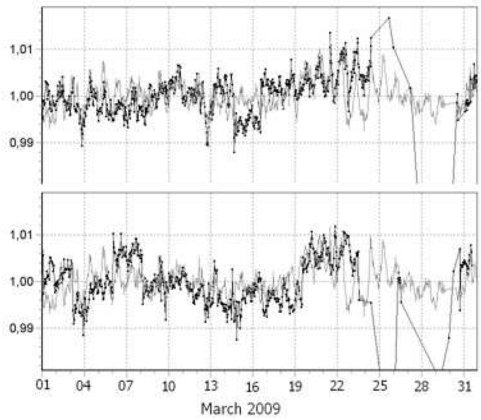

Fig. 5: Real time data from Yerevan stations (black curves): Aragats -upper panel and Noramberd- lower one, together with data from Almaty NM (grey)

There are seen in Fig 5 long breaks in Yerevan data and large deflections from Almaty data at different time.

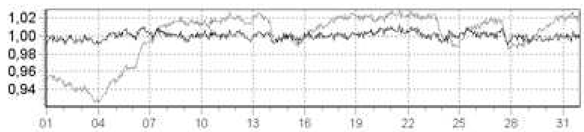

Fig. 6: Data from ESOI station together with reference NM (Almaty, or Rome, or Athens)

The snow variations up to 6% observable at ESOI, undoubtedly lead to the false effect in the GSM results, mainly in the behavior of CR density. This false contribution may be expected from some mountain and ground level stations where the wet snow is often phenomena. On the basis of considered snow effect at different stations the method of automated accounting this effect and data correction is developed by IZMIRAN group [22]. The next step should be adjusting this software to real time mode. Besides, the effects of second order were testified in data behavior: influence of the wind (effect of dynamic pressure) on the air pressure measurements, especially at the mountain and coastal stations; the barometric coefficient needs to be checked and recalculated at some stations; and pressure sensors at some stations have to be exchanged.

V. Conclusion

Parameters of the galactic CR (density and vector anisotropy) derived from the data of the world wide neutron monitor network by GSM are able to provide the information about dynamic of the interplanetary space. It is desirable to get these parameters in real time mode, and such a possibility gives the real time database created in the frame of FP7 European project NMDB213007. The software implemented in usual retrospective calculations was adjusted to real time mode and the internet project was created for this application. The first results obtained by real time measurements and compared with those calculated by usual way (after data checking) indicated a number of drawbacks in the initial data from some stations feeding the NMDB. It is clear that total number of stations (24 from the NMDB and 6 added at the western longitudes) would be sufficient to provide GCR characteristics in real time if all data are of good quality. Now it becomes to be the main goal to ensure a stable operation of the NMs and provide high quality of the data.

Acknowledgements

This work is partly supported by Russian FBR grants 07-02-00915, European Community's Seventh Framework Programme (FP/2007-2013) under grant agreement no 213007, Program No 6 BR of the Presidium RAS "Neutrino Physics". Authors thank all NM data providers: http://cr0.izmiran.ru/ThankYou/main.htm.

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