Asymptotic longitudinal distribution of cosmic ray variations in real time as the method of interplanetary space diagnostic

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***Abstract*. Continuous ground level observations of cosmic rays give a chance to reveal the precursors of large interplanetary disturbances and geomagnetic storms. The picture of CR variations distributed by the asymptotic longitudes shows the characteristics features evidencing about an approach of interplanetary disturbance. These distributions can be pictured and studied using the ring station method which is realized in real time mode in the frame of e-Infrastructures project NMD in the Seventh Framework Programme. The Internet project is created for monitoring of such events**

***Keywords*: precursor, neutron monitors network**

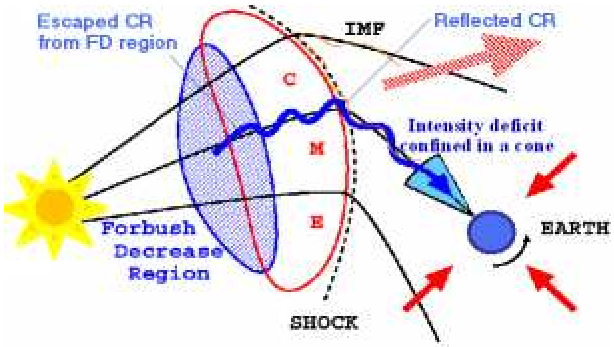

Fig. 1: Loss-cone effect.

I. Introduction

The galactic cosmic rays (GCR) interact with transients moving in the space toward the Earth. Due to their high speed they are the only agent might provide the information about coming disturbed region well advance its arrival to Earth. Existence of so-called precursors in the CR registered by ground detectors, was supposed almost from the very beginning of continuous CR registration by a network of stations [1]. Later it has been found out in the data of neutron monitors before the beginning of strong magnetic storms and large Forbush effects [2,3], and since that time a detailed researches of these effects started [4-11]. Precursor effect consists of combination of two kinds of galactic CR variations: pre-decrease and pre-increase, on a miscellaneous distributed by various CR stations at the same time before the shock arrival. Precursory decreases apparently result from a loss-cone effect, in which a neutron monitor station is magnetically connected to the cosmic ray-depleted region downstream the shock [2,9 and references there]. In (Fig.1) this effect is visually shown.

Pre-increase is usually caused by particles reflecting from the approaching shock. The many of predictors have a peculiar longitude (or, pitch-angle) dependence of CR intensity with the abrupt transfer from minimum to maximum which cannot be fitted by the sum of only the first two harmonics of CR distribution. These sharp transfers occur most probably within the 140°-180° and 270°-310° regions, near the usual direction of the magnetic field line (sunwards and anti-sunward) [7]. It is nature to suppose that effect of the shock on the major part of cosmic rays will be appreciable at a distance of one larmour radii ρ from the front. For the protons of 10 GV rigidity on the quiet background of the mean IMF intensity before the SSC (of 5.1±0.1 nT) the larmor radii ≅0.043 AU, and the shock with 500 km/s velocity passes this distance for 3.6 hours . These anomalies are most often observed in the last hours before shock arrival, typically within 4 hours. However, they sometimes span a longer period, and persist downstream of the shock. The NMN is a good tool for detecting such anomalies in the pitch-angle or longitudinal distribution. At present, when data of many stations are accessible in real time, it would be desirable to search such anomalies in real time mode and use this information in the short time forecasting of geomagnetic activity.

II. Data and Method.

For searching and study of precursory effects one hourly data from NM network are usually used. Precursory effect is very anisotropic, thus the sky coverage in the asymptotic directions of the stations, should be as full as possible, otherwise we can miss any precursor. In Fig. 2 the longitudinal distributions of the observed CR variations in the event on September 1992 are presented by the full number of neutron monitor network and for the limited numbers as well. It is seen that we lose very strong precursor if number of stations is limited within very narrow longitude range.

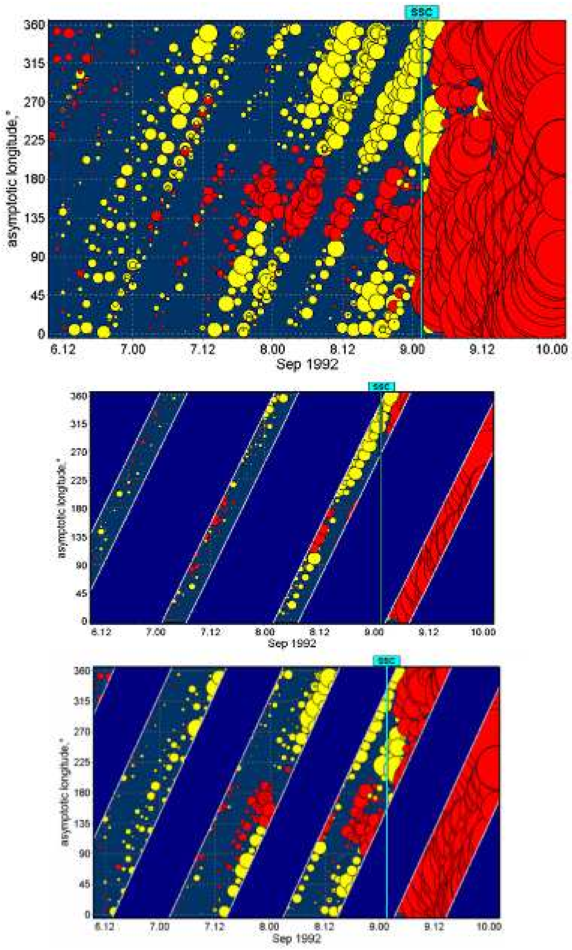

Fig. 2: Upper: Distribution of CR variations by the asymptotic longitudes of different stations (black circles-decrease, grey- increase of CR variations) before the shock arrival (vertical line) in September 1992. This picture is plotted by 45 world wide network stations and shows clearly pronounced pre-decrease at the stations viewing along IMF force line (around 135°);
Middle: The same event but plotted only by European stations;
Down: The same event but plotted only by European + Russian NMS.

In the Bartol Research Institute the system of real time monitoring of the precursors is created using pitch angle distributions http://neutronm.bartol.udel.edu//spaceweather/. They use a limited number of stations (only 9) but distributed homogeneously by longitudes (Space Ship Earth). The system is working well but it depends on the reliability of operating of all the stations (break at one station create a gap in the scanning of ≈50° of celestial sphere) and on a persistence of interplanetary magnetic field (IMF) data which are used for pitch angle calculations. IZMIRAN offers another approach based on the ring station method. Hourly NM data of the stations with cutoff rigidity R_c <4 GV and latitudes >70° are used

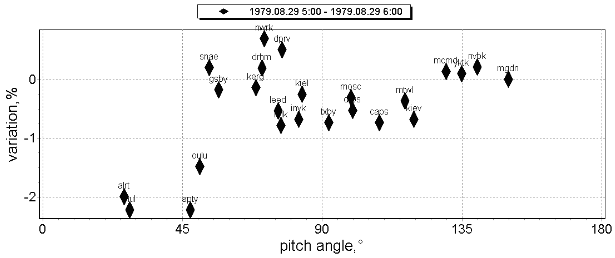

Fig. 3: Pitch angle distribution of the CR variations from different stations at 5-6 UT on 29.08.79.

for the SR method. Shift of the effective position of station relatively the geographic longitude because of the Earth magnetic field was taken into account by using the coupling coefficients for the flat rigidity spectrum up to 100 GV of the first harmonic. This method is a good addition to the global survey method and provides some advantages. For instance, it allows obtaining a different than harmonic longitudinal distribution of CR intensity, and it is less depended on an uncertainty of the model of isotropic and anisotropic variations. And it doesnt depend on the IMF measurements. As a result the longitude-time distributions of the CR intensity were found for different FDs and before their onsets in many various cases. Creation of NMDB “Real time neutron monitor database with short time resolution“ allows the use hourly data from many stations (about 24 at present) in real time for constructing and plotting asymptotic longitudinal distribution of the CR variations at any time. This application is realized and is located by the address [12] so far.

III. Examples of Predictors in the Asymptotic Longitudinal CR Distribution.

Some examples may be considered on the retrospective events when the shock precursors were manifested in the NM data. In Fig. 3 a peculiar behavior of CR variations just before the shock arrival is plotted for the case of August 29, 1979. There are characteristic features in CR distribution (sharp changes from low to high CR variations)seen. There was not big but well formed FD with sudden onset in the recovering phase after series of other FEs. The solar wind disturbance was relatively modest (Vm=549, Bm=16.6). Interplanetary disturbances didnt effect strongly a density of the CR during 24-26.08, but they increased the amplitude of CR anisotropy. The CR density was increasing gradually from 26 to 28.08 on about 3%, and phase of the solar diurnal variation was turning from ≈130° to ≈60°. In the end of 27.08 the anisotropy reduced up to the normal level, and the next day is confident for the base period. A weak magnetic storm occurred on 24-26.08. After this a geomagnetic activity was mainly unsettled. Just before the shock arrival on 29.08 Kp index was 3. Nearly 18 UT on the 28.08 the CR density stopped to recover

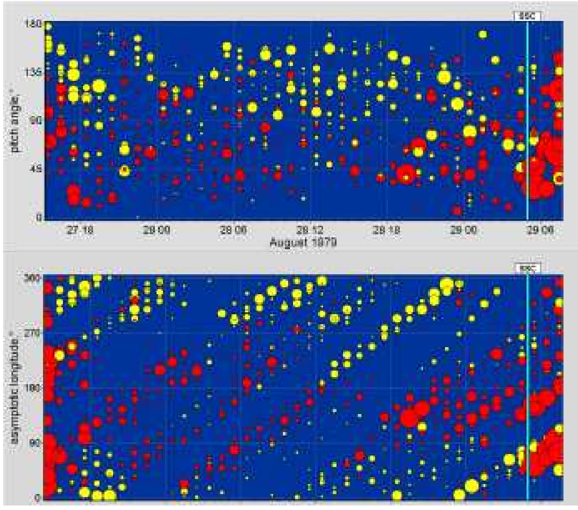

Fig. 4: Pitch angle (upper panel) and asymptotic longitude (lower panel) distribution of CR variations before the FE in August 1979.

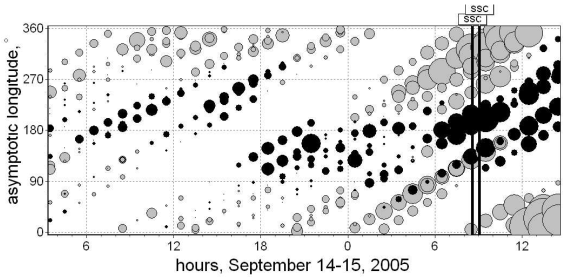

Fig. 5: Forbush effect on September 15, 2005: distribution of the CR variations by asymptotic longitudes after reduction of the isotropic part. Black circles signify a decrease of intensity and gray circles an increase relatively to the base value before the FE. The size of the circle is proportional to the amplitude of CR variation. Vertical lines indicate the timing of the shocks (8:35UT and 9:04UT).

and a small decrease even seemed to be evident. At the same time the signs of precursor appeared in the CR anisotropy (Fig.4). In this case a loss cone effect is better indicated not in the pitch-angle (Fig. 4, upper), but in the longitudinal-time distribution of the CR variations (Fig.4, lower) because of the IMF fluctuations. Before the shock an intensity of the IMF was about normal, but IMF direction was very unstable. These IMF fluctuations make pitch angles, found at every hour, unfeasible. A decrease within the narrow longitudinal sector along the average direction of the IMF one can see during 11 hours before the shock. The clearest effect in the pitch-angle distribution is observed at 5 UT on 29.08, in the last minute of which the shock arrived (vertical line in Fig.4). This peculiar distribution is evidently of the same origin (loss cone). And it is a precursor of a large FE, which most probably was much greater to the west of Sun-Earth line than that observed near Earth. This is an evidence of the strong magnetic fields in the solar wind disturbance which the Earth entered that time, and caused by this a possibility of the strong magnetic storm evolving. In this moment Kp index was 5-, but in 10 hours it really reached the level 8 (severe magnetic storm).

One more example is related to a disturbance arriving on September 15, 2005 after X1.5 flare occurred on September 13. The associated shock did not produce strong changes in the interplanetary space parameters or in the geomagnetic activity, but led to a significant Forbush decrease (4.2%). It is interesting to note that the shock arrived later than the onset in CR density decrease. Thus, this case appears to be a good example of a precursor to Forbush decrease [11]. The change of CR anisotropy direction starts from about 03:00UT on September 15 - long before the shock arrival (at 09:04UT). After the minimum of FD, with the beginning of a recovery phase, the anisotropy vector takes usual westward direction that is provided by a recovering flux from the eastern side. This direction remains for several days until the end of recovery of the CR intensity. In Fig 5, the longitudinal distribution of CR variations in asymptotic longitudes obtained by the ring station method [7] is plotted for September 14 -15. It is worth mentioning that around 03:00UT on September 15 the narrow region of longitudes (in a sector 90°-180°) with low CR intensity stands out against the background of increases in CR variations. This peculiarity became especially well pronounced from 06:00 UT (3 hours prior to the SSC). As was described in [3-5], the pitch-angle distribution of the CR variations, before the disturbance arrival assumes a specific form when abrupt changes (from negative to positive or vice versa) of the CR variations occur at very close longitudes, near the magnetic force line of the IMF.

Longitudinal and pitch-angle distributions of the CR variations have been calculated by the ring station method for many individual events in a set of works [3-11]. This approach allows the picturing a longitudinal distribution of CR intensity at any moment in time. At present, when data of many stations are accessible in real time, and especially after the European real time data base on neutron monitors is created, the monitoring of longitude distribution of CR variations in real time became feasible. It can provide the search for such anomalies in real time mode and using this information in the short time forecasting of geomagnetic activity. It would be valuable also to analyze the predictors not only before the effects after sporadic phenomena, but to consider events caused by coronal holes and get the information about 'hole' disturbance propagating. The prototype of such a program working in real time is created in IZMIRAN on the basis of real time NM database. This program operates on the IZMIRAN web site [12] and allows obtain asymptotic longitude distributions either for current data and for retrospective data

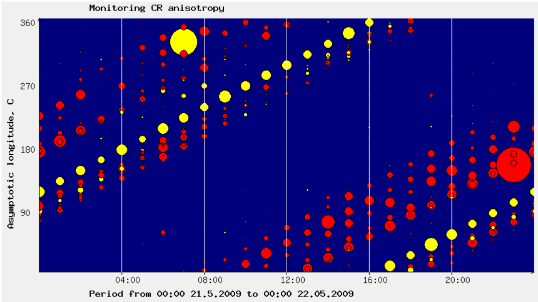

Fig. 6: The asymptotic distribution of CR variations obtained for 22.05.09 by the data from NMDB. Large empty belts by the longitudes are the result of insufficient number of stations providing observations at that time.

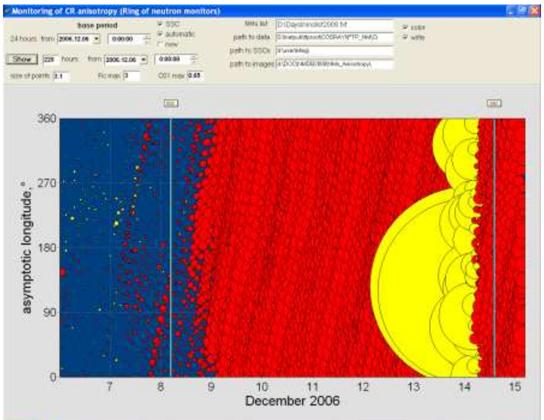

Fig. 7: Distribution of the CR variations by the asymptotic longitudes for December 2006.

as well. Below is the picture characterized a longitudinal distribution for any last hour. Grey circles mean an increase and black ones-a decrease of CR variations. Wide empty belts are the result of insufficient number of stations working within corresponding longitudinal ranges. We hope, this problem will be solved with the time, when more number of stations is included into the database. Realtime data have not been subjected to rigorous quality control; it may contain "glitches" that can produce false alarms or fail to detect true space weather disturbances The example of construction of longitudinal distribution by the retrospective data is shown in Fig.7. A much greater effect of GLE as compared with all others is clearly seen at two southern stations . Before the first SSC a clear pre-decrease (as a precursor) is seen at the stations within the asymptotic longitude range ≈45° - ≈135° along the IMF direction.

During last years no one large FE or strong magnetic storm occurred, so we could not observe any precursor in real time, but we are ready to register them when they appear.

IV. Conclusions

Using mentioned above events as the examples (actually we considered much more events) it can be argued that majority of FDs have the predictors revealed itself by different way in the CR behaviour some hours before the FD onset.The "station ring" method gives a good possibility to detect and study these predictors by NMs data. The many of predictors have a peculiar nonharmonical longitude dependence of CR intensity with the abrupt transfer from minimum to maximum. These sharp transfers occur most probably within the 140°-180° and 270°-310° regions, near the usual direction of the magnetic field line. These results with the space data give a good possibility to investigate the structure of transients and character of their moving. Another kind of studies which has never been carried out yet is the structure and propagating transient from the coronal holes. Now, with a creation of real time nmdb database there is a chance to make precursor monitoring in real time. The software and internet project providing these calculations in real time are created in IZMIRAN. The next step is elaboration of software for graphical plot of longitudinal and pitch angle distribution of hourly CR variations in real time.

Acknowledgements

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