FORECAST METHOD OF CATASTROPHIC GEOPHYSICAL PHENOMENA

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ABSTRACT

A forecast method for catastrophic geophysical phenomena based on an early diagnosis of interplanetary shocks is proposed. An early diagnosis is achieved by the detection of the prefront shock (turbulent magnetic sheet). The turbulent magnetic sheet becomes visible in "light" of cosmic rays due to their intense scattering. The intense scattering of the background galactic cosmic ray (GCR) is registered at ground-based cosmic ray stations as scintillations. A spectral presentation of scintillations allows us to introduce a diagnostic index. Values exceeding the critical value of the diagnostic index indicate the approach of a shock.

INTRODUCTION

Spectral representation of GCR intensity scintillations allows us to introduce a scintillation index to quantitatively determine the measure of change of the fluctuation frequency spectra (Kozlov et al., 1973; Kozlov, 1978; and Berezhko et al., 1987). It is important because it can be used to reveal the regularity in scintillation dynamics observed before shocks. The obtained regularity consists of quasi-periodic (period 3±1 days) variations of the scintillation index directly before a catastrophic process in the heliospheric plasma. The variations of the scintillation index have been termed "**activity waves**" (Kozlov and Tugolukov, 1989; 1992). It is has been shown that the activity waves in the scintillation index are also caused by quasi-periodic variations of plasma density and interplanetary magnetic field (IMF) intensity, with a period of 3-4 days. The temporal change of IMF southward, $\mathbf{B}_z$ -component, has two minima with almost the same interval of 4 days. Whereas, the main minimum is registered at the shocks and the preceding minimum falls at IMF sector boundaries. The behaviour of solar wind parameters at these times are in agreement with their behaviour at the heliospheric current sheet (**HCS**) sector boundary. Consequently, it is most probable that the activity waves in the scintillation index reflect oscillations of the HCS. Moreover, it should be noted that there is a coincidence of phase of the solar wind parameter oscillations before the shocks, with maximum values of parameters at the shocks themselves. The above serves as a basis to propose that in the process of non-linear steepening of activity waves, shock generation is possible.

The possibility of shock generation in the process of a non-linear "goffer" of the HCS oscillation structure allows us to understand the reason that the geoefficiency of the catastrophic process reflects multiple and, mostly quasi-periodic influence of the HCS on the Earth due to a goffer of the HCS during the active period. This method was developed on the basis of work using a neutron monitor in the Polar Geophysical Observatory at Tixie Bay (ground-based cosmic-ray station experimental complex of Institute of Cosmophysical Research and Aeronomy). The prognosis of the "**on line**" experiment carried out in Tixie Bay in March-July, 1991, showed a high forecast efficiency for radiation disturbances, geomagnetic storms, radio communication black-out, and planetary seismic activity. The operative prognosis was given 2 days before magnetic storms and 3±1 days before planetary seismic activity.

RETROSPECTIVE ANALYSIS RESULTS

In light of the logical development of the catastrophic process in the heliospheric plasma caused by the destruction of the Suns activity complex, it is interesting to consider the influence of such a process on geomagnetic storms and global seismic activity using the epoch superposition method. Fig. 1 shows a comparison of galactic cosmic ray intensity variation and scintillation index with geomagnetic and seismic activity for 30 events of Forbush-effects (a sharp decrease in galactic cosmic ray intensity during the registration of a shock). The increase of the scintillation-index two days before the Forbush decrease and the magnetic storms (day"**-2**"), is clearly revealed. The application of criterion χ^2 to the scintillation index leads to the level of significance P=99 percent. Excess of the level of daily sum $\Sigma \mathbf{K}_i=40$ in the day "$\mathbf{t}_0$" is shown by a section-lining. Excess of the given level means, as a rule, the registration of a universal magnetic storm.

For the analysis of seismic waves we have introduced the index of seismic activity $\overline{\mathrm{S}}_i$, involving the 24-hourly sum of significant seismic wave magnitudes from collected volumes of data from seismic station networks of Russia and other countries from the Institute of Physics of the Earth of the Russian Academy of Sciences. Since the calendar of 30 Forbush-effect events is known, then as with the mean intensity $\overline{\mathbf{N}}_i$ and the average scintillation-index $\overline{\mu}_i$, we can obtain the daily average index of seismic activity $\overline{\mathrm{S}}_i$.

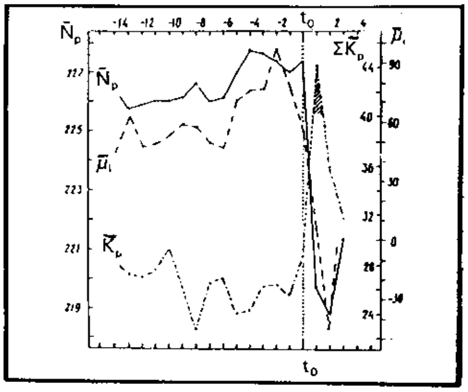


Fig. 1 The daily average values of galactic cosmic ray intensity $\overline{N}_i$ (solid curve) for 30 events from Tixie Bay; $\overline{\mu}_i$, the average scintillation index (dashed line); and $\overline{K}_i$, the index of geomagnetic disturbances (dot-and-dash line). The cosmic ray intensity scale ($\overline{N}_i$) is at left, and the index scales ΣK_i and $\overline{\mu}_i$ are at right. Registration days of the Forbush-effect caused by shocks ("t_0"- day), are marked by a dotted line.

In Fig. 2 there is a comparison of the intensity, the scintillation index and seismic activity index fourteen days and more before the shocks registration in day "t_0". The intensity scale $\overline{N}_i$ (solid curve) is shown in the left part of figure and the $\overline{\mu}_i$ index scale is on the right. The scintillation μ_i index is shown by a dashed curve, the seismic activity $\overline{S}_i$ index is shown by a dot-and-dash curve. The day of shock registration is marked by a dotted line. Two maxima of the seismic activity index registered at "**-12**" day and "**+3**" day and are marked by a section lining. Note, the interval between maximum splash of seismic activity equals to 13-15 days. The seismic activity index for 2-4 days after shock waves has a level higher than average, as shown by section-lining.

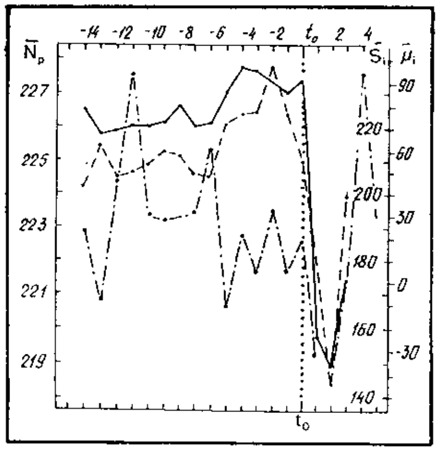


Fig. 2 The temporal change of daily average values of seismic activity $\overline{S}_i$ index, relatively the GCR intensity $\overline{N}_i$ (solid line) and the scintillation index $\overline{\mu}_i$ (dotted line).

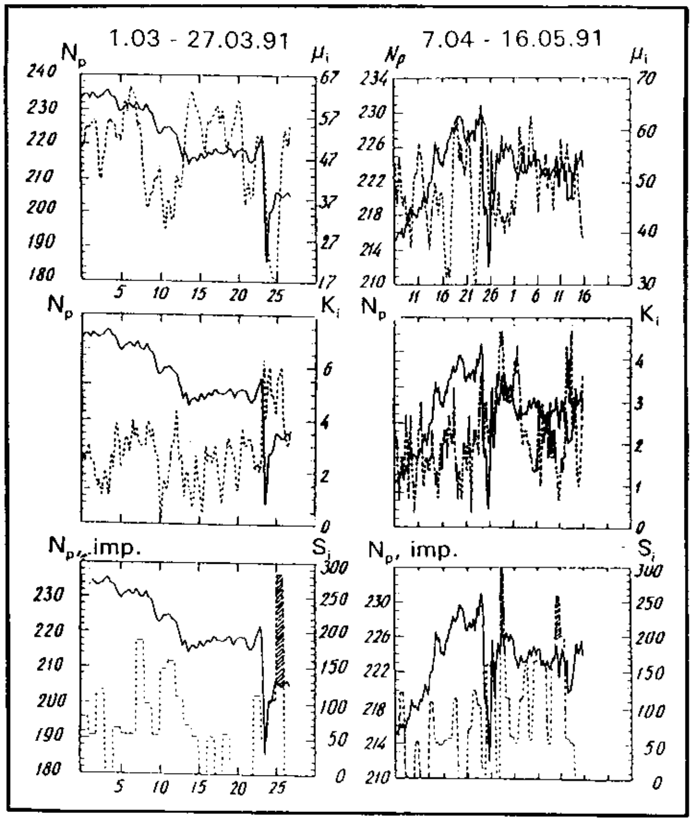
PROGNOSIS EXPERIMENT "ON LINE" REGIME

The experiment reported here was carried out in March-July 1991 in Tixie Bay to predict catastrophic phenomena in the heliospheric plasma. It was a period of solar activity maximum. Experimental results are important from the point of view that it tests the efficiency of the forecast method under conditions of a complex geophysical situation. One of the most powerful events in the whole period of observations was in June 1991. Dates of the events analyzed, in chronological order are as follows: March 1-27, 1991, April 7 - May 16, 1991, May 16 - June 20, 1991 and June 22 - July 17, 1991. For convenience of analysis, comparison of the investigated characteristics were carried out in the following scheme (Fig. 3). The calculated μ_i indices of cosmic ray scintillation, geomagnetic disturbance K_i , and seismic activity S_i (all three indices shown by dashed lines), were compared with GCR intensity N_i (solid lines). The values of the K_i index were obtained from St. Paratunka, Kamchatka. The seismic activity index S_i (daily sum of important magnitudes) was obtained by data from the Tixie seismic station.

In Fig. 3 (on the left), the result of such an analysis for March 1-27, 1991 are shown. The intensity scale, N_i , is on the left and the μ_i scale is on the right. It should be noted that all studied characteristics are smoothed by three points using the moving-average method. The Forbush-effect on March 24 was registered against a background of a smooth Forbush decrease. Activity waves in the scintillation index precede both Forbush effects. In this case, the increase of μ_i index up to $\mu_i > 60$ is observed. On the contrary, just during the Forbush-effect a considerable decrease of μ_i index takes place. It indicates a more regular character of the magnetic field beyond the shock front, i.e., at a passage stage of the magnetic cloud. Even during a smooth Forbush decrease, the geomagnetic activity increases from $K_i = 2\text{-}3$ to $K_i = 4$. The most powerful Forbush decrease on March 24 was followed by a world storm ($K_i = 6\text{-}7$ at the rather low-latitude of St.Paratunka). Results of the comparison of GCR intensity N_i with the index of planetary seismic activity S_i are of great interest.

It is notable that the double structure is also seen in the seismic activity index S_i (its increase on March 8-12 and 23-26). In the smooth Forbush-decrease on March 5-15, it is more difficult to make a temporal identification, than during the pronounced Forbush-effect on March 24, in which it is more definable. A considerable S_i index value (300 arbitrary units) was reached on March 26, three days after the "t_0"- day, March 24.

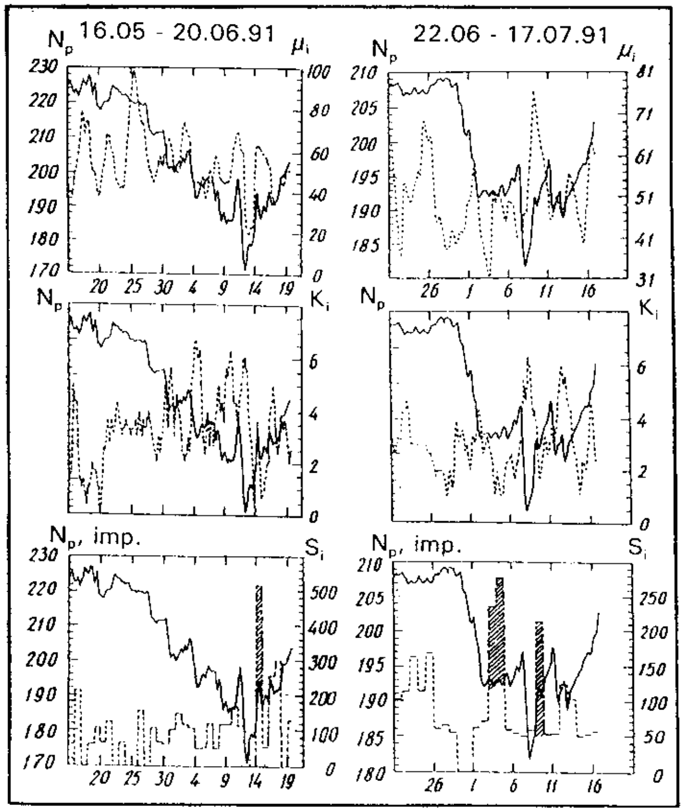
Fig. 3. The temporal profiles of scintillation index μ_i, geomagnetic disturbance $\mathbf{K}_i$, seismic activity $\mathbf{S}_i$, in arbitrary units and cosmic ray intensity $\mathbf{N}_i$, in impulses by operative diagnostics data for periods during March 1-27, 1991 and April 7 - May 16, 1991.



Judging by the character of the geomagnetic field variation envelope, the next event also had a double structure with an interval of 13-15 days (Fig. 2). A large disturbance occurred on April 25-30 and another one on May 10-13. The intensification of the scintillation index variation reached values of $\mu_i > 60$ on April 18-25 and May 11, and preceded both disturbances. A double structure with practically the same interval is observed in the index of seismic activity S_i on April 29 and May 11. Note, that in a case of a sharp Forbush-decrease on April 25-26, there was a seismic activity maximum on April 29, four days after the GCR intensity minimum.

One of the most powerful events for the whole period of observations was an event on May 28 - June 15. A series of GCR intensity decreases (Forbush decreases) began on May 28 and further on May 31, and June 4-5, 8-9, and 12-13 (Fig. 4). This period is characterized by powerful and long-term disturbances of the geomagnetic field preceded by a considerable variation of the spectral scintillation index on May 26. The intensity decreases on May 28 and 31, and on June 4 and 8 turned out to be local. The global intensity minimum of N_i was reached on June 13 ("t_0" - day). The most powerful seismic activity increase ($S_i = 500$ arbitrary units) was registered on June 15, on the third day after the "t_0" - day.

Fig. 4 The temporal profiles of scintillation index μ_i, geomagnetic disturbance $\mathbf{K}_i$, seismic activity $\mathbf{S}_i$ (in arbitrary units), and cosmic ray intensity $\mathbf{N}_i$, in impulses by operative diagnostics data for periods during May 16 - June 20, 1991 and May 22 - July 17, 1991.



In Fig. 4 on the right, the operative diagnostic results from July are shown. The Forbush-decrease began on June 30. During the same period, an insignificant enhancement of the geomagnetic activity was observed. On July 9 and 13, a magnetic storm ($K_i > 6$) from data of St.Paratunka was registered. The increase of the scintillation index variation amplitude up to $\mu_i > 60$ has been observed on June 22-26, before the complex Forbush-decrease. The maximum seismic activity enhancement on July 4-5 was 2-3 days after July 3. The next maximum of seismic activity was detected on July 10, on the second day after the sharp intensity minimum N_i on July 9.

DISCUSSION AND SUMMARY

First of all, it should be noted that seismic activity increases an average of three days after a global GCR intensity minimum (Figs. 2-4). During the predictive experiment, it is practically impossible to differentiate the global minimum from the local minimum of the Forbush-decrease using only GCR intensity registration data. It is essential to calculate the **global** minimum using a scintillation μ_i index which has a **simultaneous** minimum with the intensity minimum N_i. These conditions define the seismic activity modulation effect of interplanetary shocks allowing the prediction of global seismic activity in a complex geophysical situation.

Thus, we suggest the adoption of this forecast method for predicting radiation and electromagnetic disturbances, and **global** seismic activity in the Earth with an operative advance forecast of $t=3\pm1$ days, based on extreme solar wind parameter values. The merit of this method is in its simplicity, reliability and economical efficiency. Existing forecast satellite systems for the detection of geomagnetic storms are expensive and complicated. Up to now, there are no analogous methods of prediction in other countries.

The forecast would be more effective if **two** high-latitude cosmic ray stations were used (neutron monitor in Tixie Bay or Yakutsk and any American or Canadian station) and united by a computer net. The creation of a forecast expert system (ES) "**Foreshock**" on the basis of such a complex is planned. This ES system will represent the core of the Regional Prognosis Center.

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