SH 3.2.25

On Connection of Cosmic Ray Long Term Variations with Solar-Heliospheric Parameters

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Abstract

Density variations of galactic cosmic rays (GCR) are compared with variations of interplanetary magnetic field strength and solar wind velocity as well as with changes of heliospheric current sheet inclination and polarity of the general solar magnetic field for the last 28 years. The proposed multi-parameter model reliably presents GCR observations during different cycles of the solar activity.

1 Introduction:

This study of connection between long-term CR variations and variations of solar wind (SW) characteristics and the solar magnetic field continues a set of our previous works (Belov et al., 1995,1997,1999 and references therein), where CR long-term variations have been calculated and their model description has been proposed. Arbitrary for studies of this kind different characteristics of the solar activity (SA) are used: a number of solar spots, the intensities of coronal lines, the radio-emission, the magnetic field of the Sun as a star, the spherical heliomagnetic harmonics, the inclination of the heliospheric current sheet etc. The CR variations observed near the Earth are an integral result of numerous solar and heliospheric phenomena, so it would be difficult believe that any parameter alone can determine a behavior of CR. Therefore, a reliable model of CR modulation should incorporate at least several solar-heliospheric parameters. For this purpose it would be better to select only phenomena that effect directly on CR. So, in this work we consider the heliospheric current sheet tilt η, the module H of interplanetary magnetic field, the solar wind velocity V, the polarity p (qÀ>0, qÀ<0) of the general solar magnetic field.

Numerous theoretical and experimental works discuss a strong influence of the HCS tilt and the polarity on the long-term CR variations (e.g. Jokipii & Thomas, 1981; Smith & Thomas, 1986). An existence of relation between SW magnetic field and long-term CR variations seems to be apparent. However, only when long data series of SW measurements had been accumulated, a strong correlation between the CR modulation and the IMF module was definitely established (Cane et al., 1999; Belov et al., 1999). A role of the sola-r wind velocity V for CR modulation was mentioned previously (Chirkov, 1985). It seems necessary to account its influence, because the SW velocity determines two components of the CR modulation mechanism: the convection and adiabatic energy changes. Recently some evidences have appeared that changes of the solar wind velocity near the Earth may have not only local, but also the global character (Sheeley et al., 1991; Richardson et al., 1998).

2 Data and Method:

Data used in this work are normalized to the monthly+ base and selected accounting their statistical reliability. The analysis of connections between CR and heliospheric parameters was performed for variations ä(t) of CR with 10 GV rigidity (details see in Belov et al., 1997,1999). Values of H were obtained from hourly satellite data for 1964-97 years (OMNI data). Belov et al. (1999) studied connections of the interplanetary magnetic field with magnetic field of the Sun as a star from one hand and with the CR modulation from another. The average magnetic field H_s of the Sun as a star (a lower curve, Fig. 1) was obtained from data of solar observations in the Crimea Astrophysical Observatory during the period of 3.68-10.76 (Kotov & Severny, 1983) and in Stanford Solar Observatory during the period of 5.75-1.98

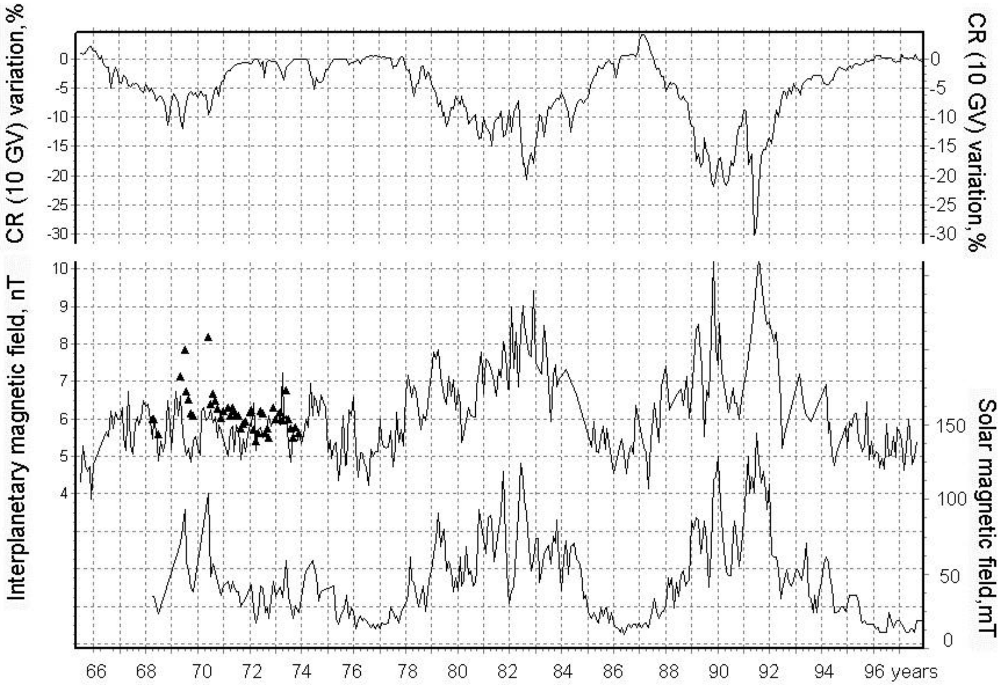

Figure 1: The behavior of the solar magnetic field as a star, interplanetary magnetic field module and cosmic ray variations during 1965-1997 years

(Hoeksema & Sherrer, 1986; Hoeksema, 1999). The correlation between values of the H è H_s fields was high during the period of 8.73-9.97, when the IMF data were mainly provided by IMP-8. This allows recovering some gaps in data sets of H and H_s. The correlation between H and H_s is worse for the period of 3.68-7.73, when even the 11-year periodicity is not observed in the IMF data. The correlation is practically absent for 1969-1970 years. During these years the set IMF data is consisted from short data sets obtained aboard the Heos, AIMP-2 and IMP-5 spacecrafts, so we may suppose that data of different space-crafts have not been normalized correctly. If we will use the obtained correlation between H_s and H values, then we can calculate expected variations of H during 1969-1970 years (see Fig. 1, where triangles show the H values calculated using H_s data). Cyclic variations of the IMF module are clear seen in this figure.

3 Results and Discussion:

The regression analysis done for H and ä(t) for 1981-1991 years (qÀ<0) and 1991-1997 years (qÀ>0) reveal a high correlation between them (Fig. 2, average values are presented). The regression coefficient was considerably higher (about 1.5 times) for the negative polarity, then for the positive polarity (Belov et al., 1997). Then, we consider the model accounting the IMF module H and the HCS tilt η, in which:

$$\delta(t) = a + b_{\eta}\frac{\sum_{\tau=0}^{\tau_{u\eta}} w_{\eta}(\tau)\eta(t-\tau)}{\sum_{\tau=0}^{\tau_{u\eta}} w_{\eta}(\tau)} + b_{H}\frac{\sum_{\tau=0}^{\tau_{uH}} w_{H}(\tau)H(t-\tau)}{\sum_{\tau=0}^{\tau_{u\eta}} w_{H}(\tau)} \qquad (1),$$

where w(t) is a weight function, ô is a time lag.

Parameters of the model (1) were calculated by the mean square method for different periods. For all instances the two-index model provide results significantly better in comparison with any one-index model. For example, Fig. 3 shows the mostly quiet period of last decade (1994.05-1997.07). There is a reasonable agreement between the measured and simulated variations (rms error of the model is 0.27%), when both factors provide significant and almost equal contribution to the total variation. It is interesting, that the lag

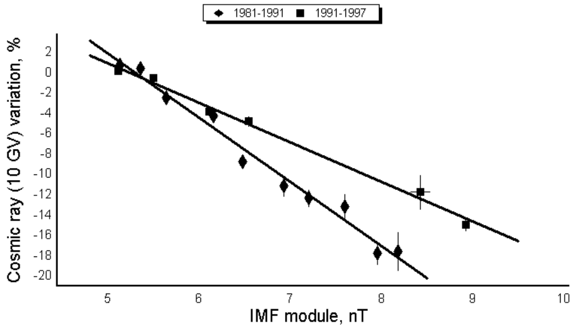

Figure 2: The relation cosmic ray variations with IMF module on two periods (1981-1991 and 1991-1997) with different polarity of the global magnetic solar field

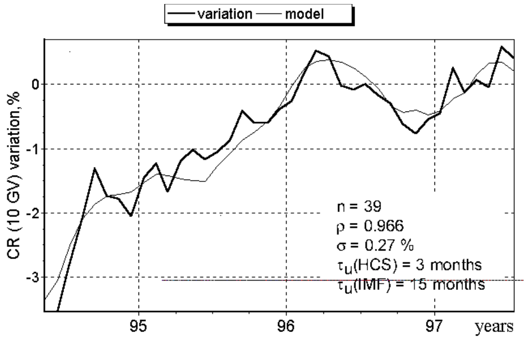

Figure 3: The agreement between the observed and simulated CR variation with HCS tilt and IMF module as modulating parameters for quiet period (1994-1997 years).

between CR and η was small (ô$_{u\eta}$=3±1 months) during this time and much less than the lag between CR and H. In general, for the majority of other periods the opposite relation ô$_{u\eta}$>ô$_{uH}$ was observed. Possibly, a small value of ô$_{u\eta}$ is a distinctive feature of the (qA<0) solar activity minimum, when cosmic rays response almost without delay on changes of the HCS tilt. The two-index model provided good results for periods of low and moderate solar activity and during all periods with similar polarity. The correlation is worse during periods of the high solar activity, but even in these cases an application of the two-index model makes results better. A correlation analysis done for different periods reveals some regular features in behavior of the model parameters. Mostly important, that the regression coefficient b_η for the negative polarity is substantially bigger than for positive.

We use the revealed features to simulate the long-term CR variation by the multi-parameter model, adding data of the solar field polarity and the solar wind velocity. We determine a polarity of the general solar magnetic field as a function p(ô), which is ±1 for positive and negative polarity and is 0 during the reversal time. Supposed, the polarity can not effect directly on CR, changing a level of their intensity, but can do it indirectly, intensifying or attenuating an efficiency of HCS tilt changes. It can be written

$$\delta(t) = a + b_\eta \sum_{\tau=0}^{\tau_{u\eta}} \eta(t-\tau)(1+b_{\eta p}p(t-\tau)) + b_p \sum_{\tau=0}^{\tau_{up}} p(t-\tau) + b_v \sum_{\tau=0}^{\tau_{uv}} v(t-\tau) + b_H \frac{\sum_{\tau=0}^{\tau_{uH}} w_H(\tau)H(t-\tau)}{\sum_{\tau=0}^{\tau_{u\eta}} w_H(\tau)} \tag{2}$$

where $w_H(0)$ = ñ$_0$, w_H(ô) = ô^{á} (ô >0)

We have applied this model to describe CR variations with 10 GV rigidity during a rather long period (1972.09-1998.12), when reliable information on the IMF module, the SW velocity and the HCS tilt is available. Fig. 4 (bottom) presents CR variations, observed and calculated by (2). The following parameters were used for calculations: a=6.44, b_H=-0.014, b_η=-0.221, b_p=-1.43, b_v =-0.30, $b_{\eta p}$=-0.40, á=0, c$_0$=1; ô$_{uH}$=2, ô$_{u\eta}$=9, ô$_{up}$=1, ô$_{uv}$=31 months. In general, the model fits rather well experimental data. The obtained correlation coefficient is ñ=0.953, and the correlation is considerably better than for the one-parameter model with any single solar index. Besides, Figure 4 (top) shows contributions of different terms of the expression (2) into the total level of CR variation. These terms are determined by the IMF module, the solar wind velocity V, and the HCS tilt (accounting its polarity) and the solar magnetic field polarity. Changes of these parameters appear to be reflected in the CR behavior by different way. The largest and mostly long-term variations are mainly associated with changes of the HCS tilt, the magnetic field polarity and the solar wind velocity V, but variations with shorter period are conditioned by behavior of the IMF module.

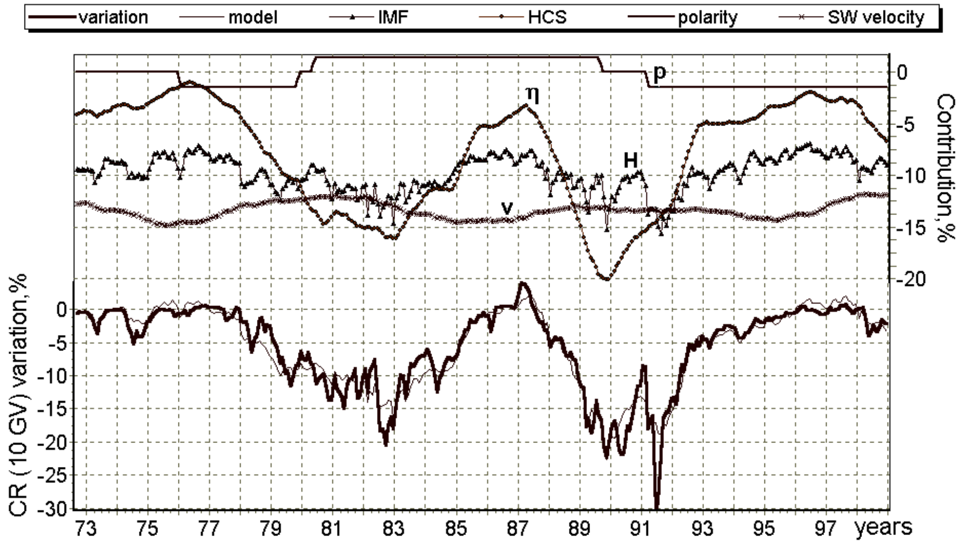

Figure **4:** The observed and simulated in multi-parameter model CR variations for 1972-1998 years (lower part). Contributions in simulated variations from changes IMF module H, HCS tilt η, solar wind velocity V and heliomagnetosphere polarity p (upper part).

4 Conclusion:

The presented model does not pretend on completeness at all. More exact description of variation and account of lag changes can improve it, even without involving new parameters. These upgrades can reduce discrepancy for periods of low and moderate solar activity, which are small even now. However, significant discrepancies will persist close to all reversal periods (1982-1983 and especially 1990-1991 years). The heliosphere is reconstructed permanently, but its changes are mostly intensive and specific (Thomas and Goldstein, 1983) during these periods and a special approach is required. In any case, the characteristics (the IMF module, the HCS tilt, the solar wind velocity, and the polarity) considered in this work is a part of necessary set for construction of any empirical model of the CR modulation.

This work is supported by the Russian Federal Program "Astronomy" and Russian Foundation for Fundamental Research, grants 99-02-18003 and 98–02-17315.

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