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The relation of global magnetic solar field indices and solar wind characteristics with long-term variations of galactic cosmic rays

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In this work we improve the semi-empirical model of galactic cosmic rays (CR) modulation in the heliosphere proposed previously, which describes the behavior of the CR variations in the solar cycles by using parameters of the solar magnetic field calculated on the solar wind (SW) source surface (the tilt of the heliospheric current sheet, average strength of the magnetic field and its polarity). The above characteristics of the solar field describe relatively well the long-term CR variations and partly the short-term variations. The model improving is motivated by a necessity to account properly variations with the short-time scale and performed with consequent attraction of data on variations of the SW parameters and indexes of solar activity (SA). For this purpose we introduce to the model calculations additionally: heliospheric parameters - the SW velocity and magnetic field strength combination and a number of solar flares. We analyze an impact of these parameters on CR variations. The model verification is performed accounting an influence of corrections on saturation in magnetic field measurements. In this work CR modulation during the decay phase of the 23rd SA cycle is discussed. The adequate model of the CR modulation should provide a retrospective description and should predict changes of CR density, one of the main components of the interplanetary medium.

1. Introduction

The study of heliospheric conditions and solar-terrestrial coupling with a view to space-weather forecast is based on understanding and prediction of time variations of CR fluxes as an important element of space environment. The long-term variations of galactic CR have been compared with the behavior of different SA indices and heliospheric parameters many times. The magnetic field parameters of the Sun, calculated for the SW source surface [1], take a special place in this series: they determine the structure and properties of the heliomagnetosphere. To model the long-term CR modulation the amplitudes of the magnetic field spherical harmonics on the source surface successfully used in the work [2]. The tilt of the heliospheric current sheet α is determined precisely on the source surface. The strong connection of this parameter with the CR behavior has been justified theoretically and confirmed multiple times by experimental data for the last quarter of a century. Now it is becoming more and more obvious that particular characteristics of CR modulation cannot be explained without using the global magnetic solar field indices on the SW source surface: the tilt α, the intensity of average field B_{ss} and the magnitude and sign of the polar magnetic field h_{pol}. Variations of α control long-term variations (cycles of 11-years and their main features) and variations of B_{ss} control short-term variations. Accordingly the tilt α plays the main role during periods of low and moderate solar activity, but B_{ss} - near maximums of solar cycles. In this paper the model improving is motivated by a necessity to account properly variations with the short-time scale. The purpose of this work is to account changes SA characteristics and parameters of the interplanetary medium in the model calculations of CR modulation; to continue the model description till the current 23rd cycle.

2. Data and method

To analyze the connection of long-term CR variations with variations in the characteristics of solar magnetism and interplanetary space, we used the amplitude of the density variations of particles with a rigidity of 10 GV. The rigidity spectrum of CR variations for each month was obtained from the data of neutron monitors of the entire global network of CR stations, stratospheric sounding data and space monitoring of CR variations for 1976–2004. The characteristics of the solar magnetic field calculated on the SW source surface (the tilt of the heliospheric current sheet α, average strength of the magnetic field B_{ss} and polar magnetic field h_{pol}). The choice of the parameters is explained in detail in [3-5]. The method for determining the solar magnetic field parameters was developed by [1] and was updated by [6].

In this paper we determine more precisely an impact of magnitude and sign of the polar field h_{pol} from magnetic field observations (WSO observatory [7]) to CR modulation. Earlier in the model [5] the simplified variant was adopted, where the polarity is ±1 for positive and negative directions of the polar field and 0 during periods of reversals of the sign. In this model of CR modulation have been used observable magnitude and sign of the polar magnetic field. Magnetic field data were corrected according to [8] for saturation of the magnetograph signal in dependence on the cycle phase and latitude of the point of observation**.** Model description of CR variations allowed the preferable version of correction to be chosen from those offered by heliophysicists under processing of the observed solar magnetic fields.

The modulation model we are dealing with in this work is a modification of the model described in the above references [3-5]. Calculations were performed using the multi-parameter regression analysis, which allowed us to estimate the contribution of each parameter of the model to the expected CR modulation taking into account their own maximum delay times. Using characteristics of the solar magnetic field it is possible to describe the long-term changes of CR density, but for adequate description of the short-term variations during the whole time interval of 1977-2004 years the modulation model incorporates additional solar-geophysical information. Data of temporal changes of heliospheric parameters were included: a number of solar flares with X-ray importance ≥ *M1* (n_X) and combined parameters vB, vB^2, v^2B (a product of SW velocity v and its square on the IMF module B and its square). Beside the above characteristics the solar magnetic field B_r calculated for the Earth projection to the SW source surface [10] was used. The empiric relation was established in [10] between B_r and SW velocity, IMF components. The temporal dependence of *CR*, B_r, B_{ss}, n_X, h_{pol} and α for the whole considered period (Fig.1) one should note that during maximums and minimums of SA changes of B_r and n_X parameters are similar; lower values of B_r in comparison with B_{ss} are associated with impact of high latitude solar field to changes of average strength B_{ss}**,** determined for the whole surface of the SW source, but this behavior of the fields has conserved only till the maximum of the 23-rd cycle.

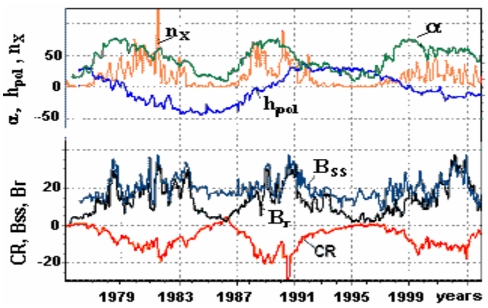

Figure 1. Temporal changes of CR intensity (% to the year of 1976), average values of solar magnetic field strength B_{ss} and field strength near the Earth B_r (μTl), flare index n_X, current sheet tilt α *(*grad) and polar field h_{pol} (μTl)

3. Results and Discussion

The analysis of data for 1976–2004 has revealed a good correlation between the multi-parameter model and 10GV galactic CR behavior during long period, spanning several cycles of solar activity. For all listed parameters the model description of CR variations was provided for the whole period of 1976-2004 years and separately for periods of the same direction of the polar field (here the time reversals of the polar field sign is included*):* $h_{pol}<0$ *(*03.1980-04.1990 and 07.1999-12.2004) and $h_{pol}>0$ (11.1976-02.1980 and 05.1990-06.1999). A feature of this work is that temporal boundaries of polarities and value of h_{pol} are determined by data of polar field observations by using the WSO magnetograph and calculated by the method [6]. The drift direction of CR particles is govern by the solar magnetic field polarity [9] and this looks important, because it leads to relatively large effect of the CR modulation (±5% depending on direction of the global solar field). The model description of the CR modulation, which accounts polar fields determined in such a way, is more reliable (the correlation coefficient ρ increases from 0.83 to 0.89 for this parameter changes only in the multi parametric model), than in a case of the simplified consideration previously considered *(*$h_{pol}=0, \pm 1$*)*.

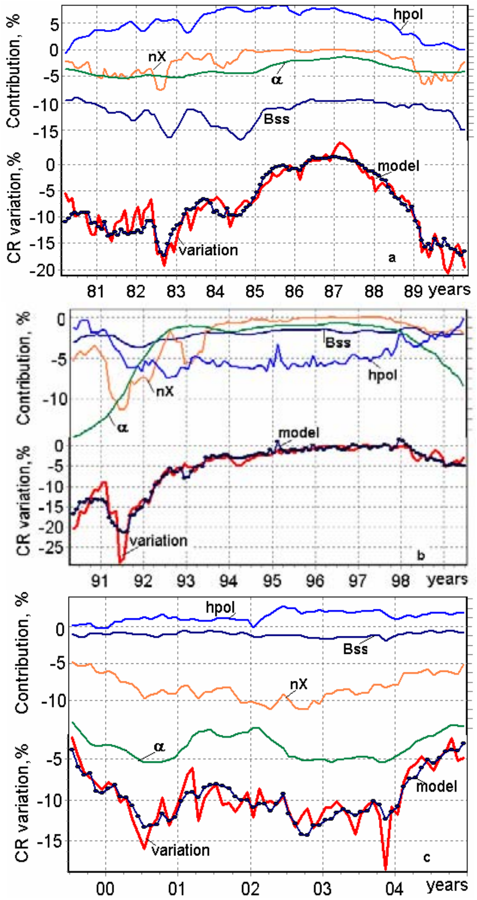

Figure 2. Monthly CR variations observed and simulated by the multi-parameter model for a) 1980-1990 h_{pol}***<0***, for b) 1990–1999 h_{pol}***>0*** and for c) 1999-2004 years h_{pol}***<0***. A contribution of n_X, B_{SS},, α, h_{pol} to simulated variations - upper part fig. a, b,c.

It is obtained that the modulating parameters, which describe the whole analyzed period, are a number of solar flares n_X and characteristics of the solar magnetic field (α, B_{ss} and h_{pol}*)*. Introducing of the additional heliospheric parameter n_X (for transfer to the 4-parameter case) the correlation coefficientis increased from 0.88 (the standard r.m.s. deviation σ=2.77%) to 0.92 (σ=2.23%). The regression analyses shows a more close connection of the observed and simulated variations CR for the polarity of solar global field $h_{pol}>0$. So, for the period of $h_{pol}>0$ (1990-1999) it is obtained ρ=0.96 (σ=1.76%) for the same parameter combination effectively acting on CR (Fig.2b), but for $h_{pol}<0$ (1980-1990) the best model description has ρ=0.94, σ=1.96% The model results are a little improving, if the 4D case would be considered instead of to the 3D case introducing the strength solar magnetic field near the Earth B_r. However this description is worse in comparison with results obtained by using a number of solar flares n_X. Note, the similar conclusion was made and for using of the solar magnetic field characteristics together with any variant of the combined parameter of SW velocity and IMF value introduced additionally for improving of the CR modulation model.

So, for description of the CR modulation observed in the near Earth space it is important to consider changes of the solar magnetic field on the surface of SW source together with variations of the SA index – a number of solar flares n_X. Changes of B_{ss} effect preferably on CR modulation in 1980-1990 years, but changes of h_{pol} do so for 1990-1999. A number of solar flares and current sheet tilt are responsible for description of short-term variations in both cases.

The period of 1999-2004 is the most complex for the considered model, ρ=0.87, σ=1.60% (Fig.2c). The discrepancy between the model and observations increases beginning from the middle of 2000, before that time we have ρ=0.93, σ=2.22% during the period of 1976-2000. Modeling of part of the 23rd cycle shows that in this case the tilt α and the flare index n_X are more effective for the modulation, but changes of h_{pol} and B_{ss} have a much less impact to the observed CR variations. It is possible explaining the worse model description by a) results of the solar field observations at WSO from Nov. 2000 till July 2002, when problems with a sensitivity have appeared and the data have been recalibrated as well as possible, but still some oddities possibly remain in the data between these dates and during following registration; b) the specific of the current cycle possibly requires other modulating parameters.

Note that variations of B_{ss} и B_r fields practically coincide during the decay phase of 23rd solar cycle in 2001-2004, but n_X variations are relatively large; the second maximum of solar spot number was observed in 2001 and the current sheet tilt was large (from 50º to 60º) during 5,5 years, till the middle of 2004. A possible reason of the observed coincidence B_{ss} and B_r fields is caused by such structural heliospheric features and, that the decay phase of the 23rd solar cycle is the most disturbed (remember events of autumns 2003 and 2004) during the whole period solar-terrestrial studies. This period is outstanding by large input of solar matter and energy into the heliosphere, moreover, not only the equatorial region was active, but the magnetic flux from polar regions was enlarge, that might be associated with increase of the dipole component in the solar field structure [11] and all together are related to the integral heliosphere index as CR intensity.

3. Conclusions

For improving of the model description of CR variations observed in 1976-2004 and reflecting by this model of complex and ambiguous connection of solar magnetic fields and SW, the solar-heliospheric parameters (a current sheet tilt, an average strength of solar magnetic field at the SW source surface, a polar field and flare index) were united. The united model provides a better description of long-term and short-term variations of CR during several cycles of SA, possibly, by accounting the polar field sign and module and additionally introducing to the model the flare index. It is shown that the combination of modulating parameters is suitable for description of CR variations as during the whole period well as periods with different direction of the solar global magnetic field. The problematic features of CR behavior and its modeling during the current 23rd solar cycle are discussed.

4. Acknowledgements

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References

[1] J.T.Hoeksema and P.H. Sherrer. Solar magnetic field:1976-1985, WDCA, Boulder, (1986).
[2] V.P.Mikhajlutsa. Geomagn. and aeron. 30, 893 (1990).
[3] A.V. Belov et.al. J. Atmos. Sol.-Terr. Phys. 63. (18), 1923 (2001).
[4] A.V. Belov et.al. Izv. Akad. Nauk. Ser. Fiz. 67, 508 (2003).
[5] A.V. Belov et.al. Geomagn. and aeron. 42, 693 (2002).
[6] V.N. Obridko and B. D. Shelting. Solar Phys. 184, 187(1999).
[7] J.T. Hoeksema., 2004. http://quake.stanford.edu/~wso (courtesy of J. T. Hoeksema).
[8] R.K. Ulrich 7th Cambridge Workshop on “Cool Stars.” ASP Conference series. 26, 265(1992).
[9] J.R. Jokipii et.al. Astrophys.J. 213, 861 (1977).
[10] A.V. Belov et.al . To appear in Geomagn.and aeron. 45 (2005).
[11] V.I. Makarov et.al. Astronom. J., 78, 859 (2001).