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FEATURES OF LONG PERIOD VARIATIONS OF GALACTIC COSMIC RAY INTENSITY IN RELATIONS WITH THE TURBULENCE OF THE INTERPLANETARY MAGNETIC FIELD in 1968-2014

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Data of super neutron monitors, Bx, By, Bz components of the interplanetary magnetic field (IMF) a have been used to study a relation of the long-period variations of the galactic cosmic ray (GCR) intensity with IMF turbulence for the period of 1968-2014. We find that the changes of the rigidity spectrum exponent γ of the GCR intensity variations and the exponents ν_y, ν_z, ν_x of the power spectral density (PSD) of the By, Bz, Bx components show a radical alternation of the large–scale structure of the IMF turbulence in period 1968-2014. We also study the properties of the probability distribution function (PDF) of the Bx, By, Bz components and their differences δBi=Bi(t+τ)-Bi(t) (i=x, y, z) of the IMF, over the varying time scales τ=1,2,3,4,5 days.
We find that for the time scales $\tau \geq 4$ days the skewness and kurtosis of the IMF turbulence almost equal zero. So, at first approximation, one can state that the PDFs are almost Gaussian and anisotropy and inhomogeneous of the IMF turbulence can be ignored in large vicinity of space ($\geq 10^{13}$ cm). However, for smaller vicinity of space ($<10^{13}$ cm) the turbulence of the solar wind plasma can be an anisotropic. As a result, for large part of space one can state that IMF turbulence could be fully described by the parameters of $PSD = P \cdot f^{-\nu}$ (P-power and ν–exponent) and employ to calculation of transport coefficients of GCR in heliosphere.

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We suppose that the changes of the turbulence in the range of frequencies (10^{-6}-10^{-5})Hz (responsible for the scattering of the GCR particles of the energy 5-50 GeV) and the module of the IMF versus solar activity can be considered as the general reasons of the long period variations of the GCR intensity.

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1. Introduction

The crucial contribution to the scattering of GCR particles in the heliosphere is setting up by the components B_y and B_z of the IMF turbulence perpendicular to the radial direction; although roles each of them are not equal at all. The power P of the PSD of the B_y component is greater than for the B_z component (about ~1. 5 times), but the temporal changes of the exponents ν_y and ν_Z are in good correlation [1].
In ours papers [1] and [2] was found inversely correlations between γ and ν_y and between γ and ν_z in period 1977–1989; however for 3 other periods 1968–1976, 1990–2002 and 2003-2012 relations between γ and ν_y and between γ and ν_z are not considered. It should be noted that the annual average values of ν_y and ν_z of the PSD of the B_y and B_z components of the IMF were calculated (from here called as the first method) for the same constant values of the solar wind velocity U_{sw} and strength B of the IMF for the whole period 1968–2014. There was considered the resonant frequency interval $\Delta f= f_2–f_1=3^x10^{-6}$Hz ($f_1=1x10^{-6}$Hz, $f_2=4^x10^{-6}$Hz), responsible for the scattering of GCR particles to which neutron monitors respond, remain constant upon solar activity. On the other, the solar wind velocity U_{sw} and strength B of the IMF vary from year to year in whole considered period 1968–2014 and the resonant frequencies using for calculation of the interval Δf are changed, correspondingly. In connection with this, it is of interest how behave correlations between γ and ν_y and between γ and ν_z when ν_y and ν_z are calculated for the frequency intervals $\Delta f= f_2–f_1$ obtained based on the alternated magnitudes of the solar wind velocity U_{sw} and strength B of the IMF from year to year (from here called as the second method) for whole considered period 1968–2014. A high inversely correlation is observed in 1977–1989 (II period) between temporal changes of γ and $\nu_{y,}$ and γ and ν_z. A level of correlation does not depend whether the ν_y and ν_z are calculated by the first or by the second methods. The values of ν_y and ν_z for different frequency range of the IMF turbulence corresponding to various resonant frequency versus level of solar activity don't distinct in scope of the calculation accuracy for the whole period of solar cycle 21. A remarkable distinction between temporal changes of γ and ν_y, and γ and ν_z are observed for periods 1968–1976 (I period), 1990–2002 (III period) and 2003-2012 (IV period) A clear inverse correlation takes place between temporal changes of γ and ν_y, and γ and ν_z for shifted frequency range versus solar activity corresponding to the alternation of resonant frequency.

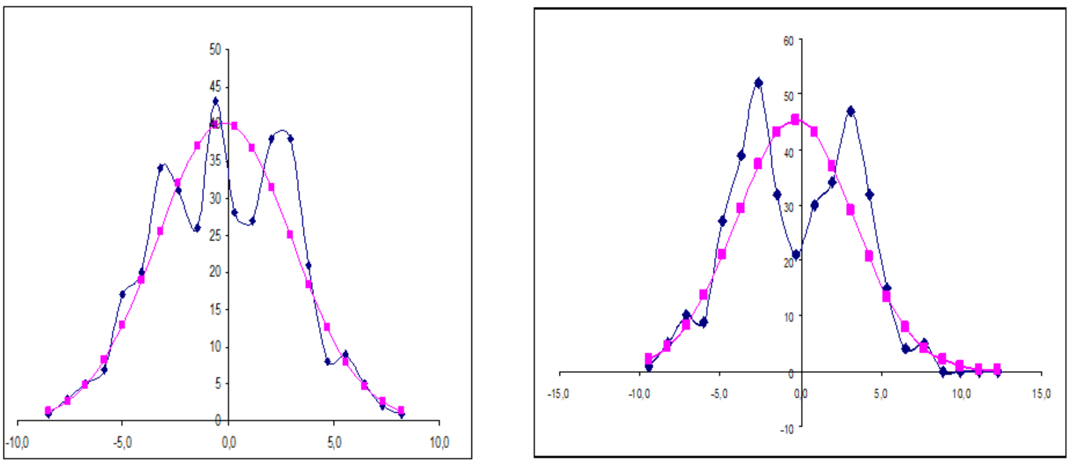
1. Experimental data, methods and discussion

In this paper we try to interpret the relationship between the three exponents $\nu_{y,}$ $\nu_{z,}$ ν_x of the PSD of the By, Bz, Bx components of the IMF turbulence and the exponent γ of the rigidity R spectrum of the 11-year variations of the GCR intensity for the whole period of 1968 – 2014 that were obtained in the works [2]. To shed light on these peculiarities, we analyze four periods 1968-1976, 1977-1990, 1991-2002 and 2003-2014 separately for each exponent $\nu_{y,}$ $\nu_{z,}$ ν_x and the exponent γ of the rigidity R spectrum of the 11-year variations of the GCR intensity.
We assume that a clear anti-correlation between *γ* and each exponent ν_y , ν_z, ν_x for the period of 1977–1990 (could be observed due to the homogeneous and isotropic IMF turbulence (Gaussian distribution) in the whole vicinity of the interplanetary space (including regions of in situ measurements), where the formation of the rigidity spectrum of the long period variations of the GCR intensity takes place. We assume that in this period in situ measurements of the IMF do not correspond to the average state of the IMF turbulence in the whole vicinity of the interplanetary space where the formation of the rigidity spectrum of the GCR intensity variations takes place. The reasons of the violation of the relationship between exponents γ and ν, can be an anisotropy character of the IMF turbulence/or, an existence of the intermittence of the IMF turbulence in the part of the space where in situ measurements of the IMF have carried out.

For the purpose we also study the properties of the PDF of the differences of the Bx, By, Bz components of the IMF, δBi=Bi(t+τ)-Bi(t) (i=x, y, z) over the varying time scales τ=1,2,3,4,5 days. A point is that a PDF gives a possibility to judge in what degrees the IMF turbulence has or has not the Gaussian distribution, e.g. PDF cannot have Gaussian distribution for small scales τ, whilst for large scales τ there could be observed a Gaussian distribution [2].

In the table 1 is presented properties of the PDF of the differences of the By, Bx, Bz components of the IMF, δBy=By(t+τ)-By(t) over the varying time scales τ=0,1,2,3,4,5.. days. **1**-Gaussian distribution (if $\chi^2 < \chi^2_{crit}$), **0 -** non Gaussian distribution (if $\chi^2 > \chi^2_{crit}$). In the table 2 are presented the analyses of the PDF of the IMF strength By component for four periods: 1968-1976, 1977-1990, 1991-2002 and 2003-2014. Table 3 is the same as table 2 but for Bx and Table 4 is the same as table 2 but for Bz components respectivly. We can see that years with a Gaussian distribution is more in the period II for By component but for periods I , III and IV we have most years without a Gaussian distribution. For the Bx and Bz components all four periods have most years without a Gaussian distribution (see tables 2, 3 and 4). A distribution of differences δ*By*(*t*)) , δ*Bx*(*t*)) gradually approaches to the Gaussian distribution upon increasing of τ. At large scales of *τ* the PDF are almost Gaussian i.e. the skewness and kurtosis of the PDF of the IMF turbulence almost equal zero and so, anisotropy and inhomogeneous in first approximation could be ignored. There are observed Gaussian distribution for differences δ*By*(*t*)), δ*Bx*(*t*)) (when τ≥4). But for δ*Bz*(*t*)), we don't observe gradual approach to the Gaussian distribution upon increasing of τ (when τ≥4) For example in the figure 1 is presented PDF of the IMF strength By component in 1984 and 1991.

Gaussian distribution -1984 Non Gaussian distribution -1991



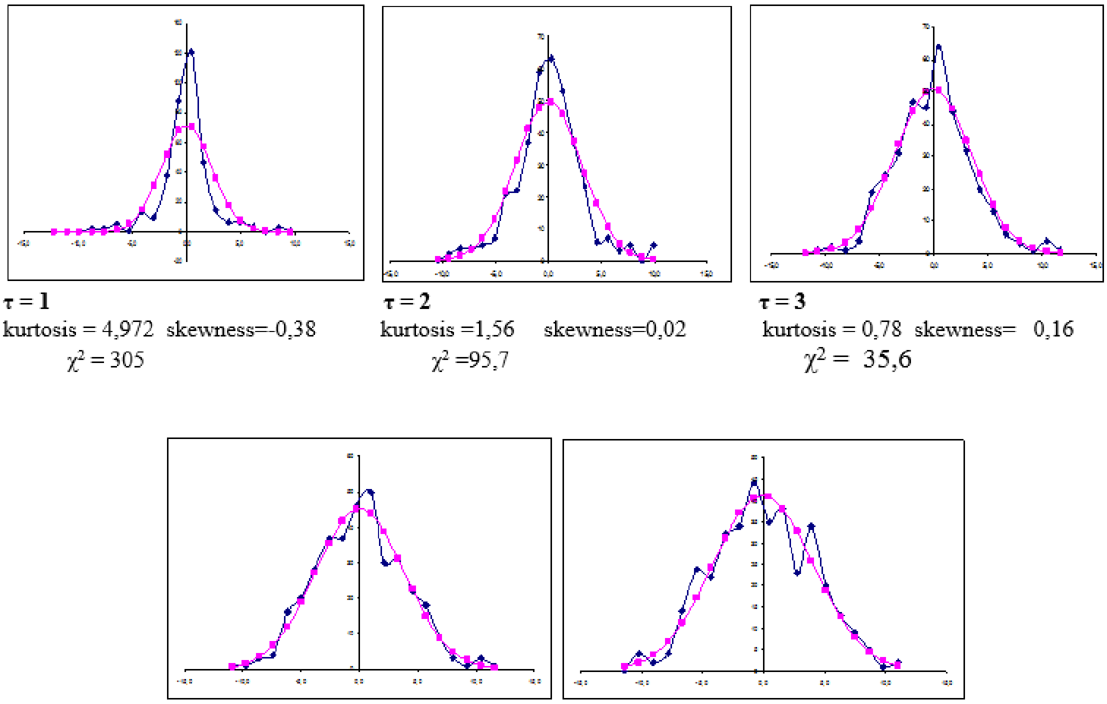
Kurtosis = -0,45 skewness=-0,05 Kurtosis = -0,52 skewness=0,03

$\chi^2 = 24{,}5$ $\chi^2 = 55{,}9$

Figure 1 The PDF of the IMF strength By component in1984 and 1991

In the figure 2 is presented the evolution of the PDF of the IMF strength differences δB_y component in:1984 $\delta B_y=B_y(t+\tau)-B_y(t)$; for τ=1,2,3,4,5.

Here, we consider a range of frequencies ($f \approx 4 \times 10^{-6}$–$10^{-5}$ Hz) of the IMF turbulence for which the time scale *τ*>1 day, so the assumption about the almost Gaussian distribution of the IMF turbulence should be accepted. However, for time scales *τ*<1 day the IMF turbulence is anisotropic and inhomogeneous [3, 4] and it must be taken into account for the calculation of diffusion coefficient *χ* of the GCR particles, especially of the energy <1 GeV as it is shown in paper [5, 6].



τ = 1
kurtosis = 4,972 skewness=-0,38
$\chi^2 = 305$

τ = 2
kurtosis =1,56 skewness=0,02
$\chi^2 = 95{,}7$

τ = 3
kurtosis = 0,78 skewness= 0,16
$\chi^2 = 35{,}6$

τ = 4
kurtosis = 0,10 skewness=0,07
$\chi^2 = 13{,}1$

τ = 5
kurtosis = -0,26 skewness=0,004
$\chi^2 = 17{,}3$

Figure 2
The evolution of the PDF of the IMF strength differences $\delta B_y = B_y(t+\tau) - B_y(t)$ for τ=1, 2, 3, 4, 5 of the By component in 1984

Owing to our postulation about the Gaussian distribution of the IMF turbulence we assume, that the exponent ν_y obtained by local in situ measurement satisfactorily describes the average state of the IMF turbulence in the whole space where a formation of the rigidity spectrum of the long period variations of the GCR intensity takes place. In doing so, the contribution of the intermittent (sporadic irregular changes)/or anisotropy of the IMF turbulence, which should be destroyed the Gaussian distribution, could be ignored. Diffusion coefficient χ depends on the GCR particle's rigidity R, as $\chi \propto R^{\alpha}$ [7], where $\alpha = 2 - \nu$ (ν is the exponent of PSD of the IMF turbulence ($PSD = Pf^{-\nu}$, where P is power and f is the frequency); on the other $\gamma \propto \nu$, and there is expected a remarkable anti correlation between the exponents γ and ν_y, as it is really observed by the experimental data in the period of 1976–1990. Thus, we suppose that the relationship between exponents γ and ν, is almost a universal from point of view of the long period GCR intensity variations, i.e. we can successfully use the exponent γ as an important index (proxy), to study different classes of the GCR intensity variations, caused by the changes of IMF turbulence.

Contrary, the exponent γ calculating based on the GCR experimental data has a clear physical sense; it shows a rigidity dependence of the amplitudes of the considering type of variations of the GCR intensity and can be directly included in the transport equation through diffusion coefficient, e.g., as $\chi \propto R^{\alpha}$ ($\gamma \propto \alpha$) in the modelling of different classes of the GCR intensity variations.

Table 1. The property of the PDF of the differences of the By, Bx, Bz components of the IMF, δBy=By(t+τ)-By(t) over the varying time scales τ=0,1,2,3,4,5.. days **1**-Gaussian distribution (if $\chi^2 < \chi^2_{crit}$), **0 -** non Gaussian distribution (if $\chi^2 > \chi^2_{crit}$)

χ^2_{crit}	**40,8**	τ=1	τ=2	τ=3	τ=4	τ=5	**40,8**	τ=1	τ=2	τ=3	τ=4	τ=5	**40,8**	τ=1	τ=2	τ=3	τ=4	τ=5
1968	dBy_68	0	1	1	1	1	dBx_68	0	1	1	1	1	dBz_68	0	0	0	0	0
1969	dBy_69	0	0	1	1	1	dBx_69	0	1	1	1	1	dBz_69	0	0	0	0	0
1970	dBy_70	0	0	0	0	1	dBx_70	0	0	0	1	1	dBz_70	0	0	0	0	0
1971	dBy_71	0	1	1	1	1	dBx_71	0	1	1	1	1	dBz_71	0	0	0	0	0
1972	dBy_72	0	0	1	1	1	dBx_72	0	1	1	1	1	dBz_72	0	0	0	0	0
1973	dBy_73	0	0	1	1	1	dBx_73	0	0	1	1	1	dBz_73	0	0	0	0	0
1974	dBy_74	0	0	0	0	0	dBx_74	0	0	0	1	1	dBz_74	0	0	0	0	0
1975	dBy_75	0	0	1	1	1	dBx_75	0	0	0	1	1	dBz_75	0	0	0	0	0
1976	dBy_76	0	0	0	1	1	dBx_76	0	1	1	1	1	dBz_76	0	0	0	0	0
1977	dBy_77	0	0	0	1	1	dBx_77	0	0	1	1	1	dBz_77	0	0	0	1	0
1978	dBy_78	0	0	1	0	1	dBx_78	0	0	1	1	1	dBz_78	0	0	0	0	0
1979	dBy_79	0	1	1	1	1	dBx_79	0	1	1	1	1	dBz_79	0	0	1	0	0
1980	dBy_80	0	1	1	1	1	dBx_80	0	1	1	1	1	dBz_80	0	0	1	0	1
1981	dBy_81	0	1	1	1	1	dBx_81	1	0	1	1	1	dBz_81	0	0	1	0	0
1982	dBy_82	0	0	0	0	1	dBx_82	0	1	1	1	1	dBz_82	0	0	0	0	0
1983	dBy_83	0	0	1	1	1	dBx_83	0	0	0	1	1	dBz_83	0	0	1	1	1
1984	dBy_84	0	0	1	1	1	dBx_84	0	0	0	1	1	dBz_84	0	0	0	0	1
1985	dBy_85	0	0	1	1	1	dBx_85	0	0	0	0	1	dBz_85	0	0	1	1	1
1986	dBy_86	0	0	0	0	1	dBx_86	0	0	0	0	0	dBz_86	0	0	0	0	0
1987	dBy_87	0	0	1	1	1	dBx_87	0	0	0	0	1	dBz_87	0	0	0	0	1
1988	dBy_88	0	0	0	1	1	dBx_88	0	0	1	1	1	dBz_88	0	0	1	1	1
1989	dBy_89	0	0	1	1	1	dBx_89	0	0	0	0	0	dBz_89	0	0	0	0	0
1990	dBy_90	0	0	1	1	1	dBx_90	0	0	0	1	1	dBz_90	0	0	0	0	1
1991	dBy_91	0	0	1	1	1	dBx_91	0	0	1	1	1	dBz_91	0	0	0	1	0
1992	dBy_92	0	0	1	1	1	dBx_92	0	0	0	1	1	dBz_92	0	0	0	0	0
1993	dBy_93	0	0	0	1	1	dBx_93	0	0	1	1	1	dBz_93	0	0	0	0	0
1994	dBy_94	0	0	0	0	1	dBx_94	0	0	0	0	0	dBz_94	0	0	0	0	0
1995	dBy_95	0	1	1	0	1	dBx_95	0	0	1	1	1	dBz_95	0	0	0	0	1
1996	dBy_96	0	0	0	1	1	dBx_96	0	1	1	1	1	dBz_96	0	0	0	1	0
1997	dBy_97	0	0	0	1	1	dBx_97	0	0	0	1	1	dBz_97	0	0	0	0	0
1998	dBy_98	0	1	1	1	1	dBx_98	1	1	1	1	1	dBz_98	0	0	0	0	0
1999	dBy_99	0	0	1	1	1	dBx_99	0	0	1	1	1	dBz_99	0	1	1	0	1
2000	dBy_00	0	0	0	0	1	dBx_00	0	0	1	1	1	dBz_00	0	0	0	0	0
2001	dBy_01	0	0	0	0	0	dBx_01	0	0	0	0	0	dBz_01	0	0	0	0	0
2002	dBy_02	0	0	0	0	0	dBx_02	0	0	0	0	1	dBz_02	0	0	0	0	0
2003	dBy_03	0	0	0	0	1	dBx_03	0	0	0	0	0	dBz_03	0	0	0	0	0
2004	dBy_04	0	0	0	1	1	dBx_04	0	0	1	1	1	dBz_04	0	0	0	0	0
2005	dBy_05	0	0	0	1	1	dBx_05	0	0	0	0	0	dBz_05	0	0	0	0	0
2006	dBy_06	0	0	1	1	1	dBx_06	1	1	1	1	1	dBz_06	0	0	0	0	0
2007	dBy_07	0	0	1	1	1	dBx_07	1	0	1	1	1	dBz_07	0	0	0	0	0
2008	dBy_08	0	0	0	0	1	dBx_08	0	1	1	1	1	dBz_08	0	0	0	0	1
2009	dBy_09	0	0	1	1	1	dBx_09	1	1	1	0	1	dBz_09	0	0	0	0	0
2010	dBy_10	0	0	1	0	1	dBx_10	0	1	1	1	1	dBz_10	0	0	0	0	0
2011	dBy_11	1	1	1	1	1	dBx_11	0	0	1	1	1	dBz_11	0	0	0	0	0
2012	dBy_12	0	1	1	1	1	dBx_12	0	0	0	1	1	dBz_12	0	0	0	0	0
2013	dBy_13	0	1	1	1	1	dBx_13	1	1	1	1	1	dBz_13	0	0	0	0	0
2014	dBy_14	0	0	1	1	1	dBx_14	0	0	0	0	1	dBz_14	0	0	0	0	0

Table 2. The PDF of the IMF strength By component for 4 periods: I(1968-1976); II(1977-1990); III(1991-2002) and IV(2003-2014) where **1**-Gaussian distribution (if $\chi^2 < \chi^2_{crit}$), **0 -** non Gaussian distribution (if $\chi^2 > \chi^2_{crit}$).

I period			II period			III period			IV period		
	40,8		1977	By_77	1	1991	By_91	0	2003	By_03	0
1968	By_68	0	1978	By_78	1	1992	By_92	1	2004	By_04	0
1969	By_69	0	1979	By_79	0	1993	By_93	0	2005	By_05	0
1970	By_70	0	1980	By_80	0	1994	By_94	0	2006	By_06	0
1971	By_71	1	1981	By_81	0	1995	By_95	1	2007	By_07	0
1972	By_72	0	1982	By_82	0	1996	By_96	0	2008	By_08	0
1973	By_73	0	1983	By_83	0	1997	By_97	0	2009	By_09	1
1974	By_74	0	1984	By_84	1	1998	By_98	0	2010	By_10	0
1975	By_75	0	1985	By_85	0	1999	By_99	0	2011	By_11	1
1976	By_76	0	1986	By_86	1	2000	By_00	1	2012	By_12	0
			1987	By_87	0	2001	By_01	1	2013	By_13	1
			1988	By_88	1	2002	By_02	0	2014	By_14	0
			1989	By_89	1						
			1990	By_90	1						

Table 3. The PDF of the IMF strength Bx component for 4 periods: I(1968-1976); II(1977-1990); III(1991-2002) and IV(2003-2014) where **1**-Gaussian distribution (if $\chi^2 < \chi^2_{crit}$), **0 -** non Gaussian distribution (if $\chi^2 > \chi^2_{crit}$).

I period			II period			III period			IV period		
	40,8		1977	Bx_77	0	1991	Bx_91	0	2003	Bx_03	0
			1978	Bx_78	1	1992	Bx_92	0	2004	Bx_04	0
1968	Bx_68	0	1979	Bx_79	1	1993	Bx_93	0	2005	Bx_05	1
1969	Bx_69	0	1980	Bx_80	0	1994	Bx_94	0	2006	Bx_06	0
1970	Bx_70	0	1981	Bx_81	0	1995	Bx_95	0	2007	Bx_07	1
1971	Bx_71	0	1982	Bx_82	0	1996	Bx_96	0	2008	Bx_08	0
1972	Bx_72	0	1983	Bx_83	0	1997	Bx_97	0	2009	Bx_09	1
1973	Bx_73	0	1984	Bx_84	0	1998	Bx_98	0	2010	Bx_10	0
1974	Bx_74	0	1985	Bx_85	0	1999	Bx_99	0	2011	Bx_11	0
1975	Bx_75	0	1986	Bx_86	1	2000	Bx_00	0	2012	Bx_12	0
1976	Bx_76	0	1987	Bx_87	0	2001	Bx_01	1	2013	Bx_13	1
			1988	Bx_88	0	2002	Bx_02	0	2014	Bx_14	0
			1989	Bx_89	1						
			1990	Bx_90	0						

Table 4. The PDF of the IMF strength Bz component for 4 periods.

I period			II period			III period			IV period		
1968	Bz_68	0	1977	Bz_77	1	1991	Bz_91	1	2003	Bz_03	0
1969	Bz_69	0	1978	Bz_78	0	1992	Bz_92	0	2004	Bz_04	0
1970	Bz_70	0	1979	Bz_79	0	1993	Bz_93	0	2005	Bz_05	0
1971	Bz_71	0	1980	Bz_80	0	1994	Bz_94	0	2006	Bz_06	0
1972	Bz_72	0	1981	Bz_81	0	1995	Bz_95	0	2007	Bz_07	0
1973	Bz_73	0	1982	Bz_82	0	1996	Bz_96	0	2008	Bz_08	0
1974	Bz_74	0	1983	Bz_83	0	1997	Bz_97	0	2009	Bz_09	0
1975	Bz_75	0	1984	Bz_84	0	1998	Bz_98	0	2010	Bz_10	0
1976	Bz_76	0	1985	Bz_85	0	1999	Bz_99	0	2011	Bz_11	0
			1986	Bz_86	0	2000	Bz_00	0	2012	Bz_12	0
			1987	Bz_87	0	2001	Bz_01	0	2013	Bz_13	0
			1988	Bz_88	0	2002	Bz_02	0	2014	Bz_14	0
			1989	Bz_89	0						
			1990	Bz_90	0						

Conclusions

1. The essential rearrangement of the structure in the range (10^{-6}–10^{-5} Hz) of the IMF turbulence throughout the 11-year cycle of solar activity takes place. This region of the IMF turbulence is responsible for the scattering of the GCR particles with the energy to which neutron monitors respond.
2. The rigidity spectrum exponent γ of the long period variations of the GCR intensity can be successfully used for the estimation of the state of the IMF turbulence in the range of (10^{-6}–10^{-5} Hz). Therefore, data of GCR intensity variations are unique.
3. The exponent ν_y ν_z ν_x obtained by local in situ measurement describes completely the average state of the IMF turbulence, when it has a Gaussian distribution. Any case, the rigidity spectrum exponent γ of the long period variations of the GCR intensity can be considered as a broadly acceptable proxy to study problems of the solar-terrestrial physics.

References

[1] Alania, M.V. Iskra K. and Siluszyk M., *On relation of the long period galactic cosmic rays intensity variations with the interplanetary magnetic field turbulence, Adv. Space Res.* 45, 10, 1203–1210, 2010

[2] Siluszyk M., Iskra K., Alania, M.V. *Rigidity dependence of the long period variations of galactic cosmic ray intensity: a relation with the interplanetary magnetic field turbulence for 1968–2002, Solar Physics*, 289, 11, 4297-4308, 2014

[3] Sorriso-Valvo et al., *Intermittency in the solar wind turbulence through probability distribution functions of fluctuations*, Geophys. Res. Lett. 26, 13, 1801–1804, 1999

[4] Matthaeus, W. H. et al., *Transport of cross helicity and radial evolution of Alfvenicity in the solar wind*, GRL, vol. 31, 12803, 2004

[5] Zank, G.P., W.H. Matihaeus, and C.W. *Smith Evolution of turbulent magnetic fluctuation power with heliospheric distance*, J. Geophys. Res., 101, 17, 093-17, 107, 1996

[6] Shalchi, A.; Li, G.; Zank, G. P., *Analytic forms of the perpendicular cosmic ray diffusion coefficient for an arbitrary turbulence spectrum and applications on transport of Galactic protons and acceleration at interplanetary shocks*, Astrophysics and Space Science, 325, 1, 99-111, 2010

[7] Jokipii, J.R., *Propagation of cosmic rays in the solar wind*, Rev. of Geophysics and Space Physics, 9, 27-87, 1971