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ON THE DEVELOPMENT OF THE CURRENT SOLAR CYCLE 23 ON THE SUN, IN THE INNER HELIOSPHERE, AND IN THE GALACTIC COSMIC RAY INTENSITY

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Abstract

The development of the current solar cycle is considered in the solar and inner heliospheric characteristics and in the galactic cosmic ray intensity near the Earth. Our attention is focused on 1) the features of the solar cycle maximum phase in the galactic cosmic ray intensity in the inner heliosphere and the solar and heliospheric factors responsible for these features and 2) what intensity time profiles can be expected in the next few years (the end of solar cycle 23 and minimum phase of the next cycle) corresponding to the (A < 0) phase of the 22-year (or magnetic) solar cycle.

1. Introduction

The investigation of the 11- and 22-year solar and heliospheric variations may be of interest not only for those studying the Sun, heliosphere, cosmic rays, but for the magnetosphere researchers as well, as it presents the slowly changing environment of the magnetosphere. The current (23-rd) solar cycle at the century boundary is somewhat unusual when compared with the previous cycles in the second half of the 20-th century. Besides, during the last five solar cycles the spacecraft have been exploring the heliosphere at progressively greater heliocentric distances and now they send the data from the heliocentric distances r = 75-93 AU. In our previous works [1-6] we studied the development of the current solar cycle, especially its maximum phase, in the GCR intensity, both near the Earth and in the outer heliosphere. In this paper we consider the overall features of this cycle on the Sun and at the Earth's orbit, especially its maximum phase and the end of the cycle, the minimum phase of the next, 24-th, solar cycle.

2. The development of the maximum phase of solar cycle 23 on the Sun and near the Earth

Fig. 1 shows for 1995-2004 the time history of some solar activity data and heliospheric and cosmic ray characteristics near the Earth: the strength of the interplanetary magnetic field (IMF) B_{IMF} (the solid line; taken from http://nssdcftp.gsfc.nasa.gov/spacecraft_data/omni/omni_27_av.dat) and the sunspot area S (the dotted line; from http://science.nasa.gov/ssl/PAD/SOLAR/greenwch.html) in the panel *a*; the line-of-sight component of the polar photospheric magnetic field as seen from the Earth, $B_{ls}^{N,S}$, and the latitude boundary of the IMF sector-structure zone, $\lambda_t^{N,S}$, (the panels *b* and *c*, respectively) for the north (the dotted lines) and south (the dashed lines) solar hemispheres, (both from http://sun.stanford.edu/~wso/wso.html); and the GCR intensity (the relative count rates $\tilde{N}_{GCR}$ of the Huancayo and Climax neutron monitors (ftp://ulysses.sr.unh.edu /NeutronMonitor/DailyAverages.1951-.txt) and of the omnidirectional Geiger counter in the Pfotzer maximum in the stratosphere at Moscow and Murmansk, listing from top to bottom in panel d). All the initial monthly, Carrington rotation or 27-day averaged data were smoothed with a 0.5-year period. The cosmic ray data were additionally normalized to 100 % for February, 1997. For the current solar cycle the maximum phase in the GCR intensity, that is the period $\Delta t_{Max}^{23} = t_{g2}^{23} - t_{g1}^{23}$ between two main gaps (t_{g1}^{23} and t_{g2}^{23}), lasted for three years, from 2000.7 to 2003.7, and it is shown by the shaded band in Fig. 1.

One can see from Figure 1 that the special features of the current solar cycle are both the very long maximum phase in the GCR intensity and the strange behavior of the high-latitude photospheric magnetic field and of the IMF sector zone. The polar magnetic fields in both hemispheres changed sign approximately simultaneously around 2000.0, but soon stopped increasing in strength and were rather small (less than a half of their maximum value) during next 3 years. This weak polar magnetic field is also reflected in rather large (≈ ±40°) and constant for three years latitude boundaries of the IMF sector-structure zone. So the long maximum phase in the GCR intensity variation in solar cycle 23 can be related, beside the behavior of the IMF strength (which reflects the toroidal or sunspot branch of solar activity, see [7]), to the prolonged period of the weak high-latitude poloidal solar magnetic field.

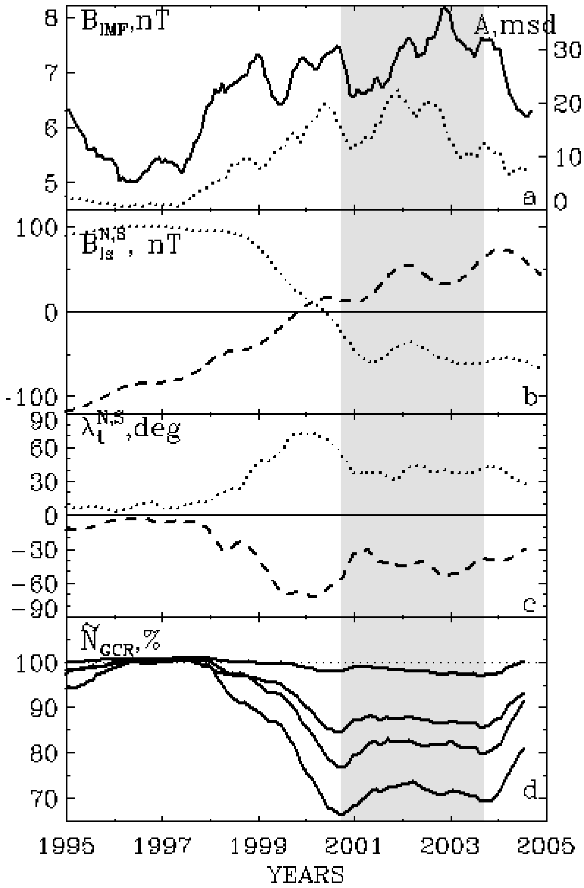

Figure 1. The solar cycle 23 in different solar data and heliospheric and cosmic ray characteristics near the Earth.

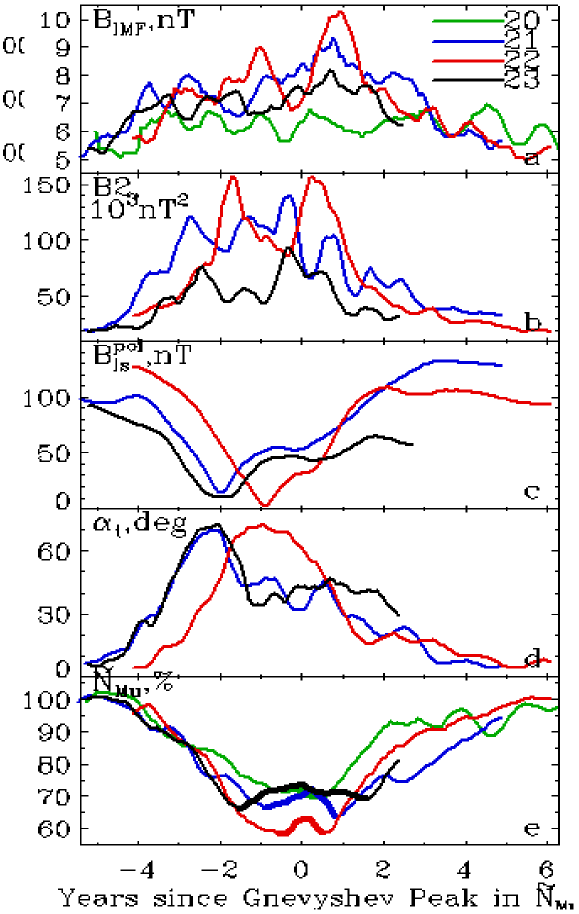

Figure 2. The comparison of the variations in some solar data and the heliospheric and cosmic ray characteristics near the Earth for solar cycles 20-23 as function of the time elapsed since the middle of the solar cycle maximum phase (the Gnevyshev peak) in the GCR intensity.

In order to facilitate a search of the factors responsible for the length and modulation depth of the solar cycle maximum phase in the GCR intensity we superposed in Fig. 2 for the solar cycles 20-23 the time histories of the solar, heliospheric and cosmic ray characteristics, already discussed for the current solar cycle, as functions of the time $t'' = t - t^i_{GP}$ elapsed since the middle of the solar cycle maximum phase in the GCR intensity (or since the Gnevyshev peak, $t^i_{GP} = (t^i_{g1} + t^i_{g2})/2$, in the GCR intensity corresponding to the Gnevyshev gap in its modulation). Note that we chose the stratospheric relative count rate at Murmansk, $\tilde{N}_{Mu}$, as a GCR intensity index (the maximum phases shown by the thicker parts of the lines in panel e) and instead of the polar magnetic field and latitude boundary of the IMF sector-structure zone in each hemisphere we show the average characteristics: $B^{pol}_{ls} = \sqrt{(B^{N\,2}_{ls} + B^{S\,2}_{ls})/2}$ (the panel *c*) and $\alpha_t = (\lambda^N_t - \lambda^S_t)/2$ (the panel *d*, the pseudotilt of the IMF current sheet) for solar cycles 21-23, when we have the systematic data on the solar magnetic fields. Besides, in panel *b* we show (also for the cycles 21-23) one more solar factor, *B2*, the energy density of the solar magnetic field averaged over the photosphere (see [8] and references therein), clearly demonstrating the Gnevyshev Gap effect.

One can see from Fig.2 that the depth of the GCR intensity modulation corresponds (at least qualitatively) to the maximum level of both B_{IMF} and *B2*. As to the correspondence between the behavior of the poloidal solar magnetic field characteristics and the characteristics of the maximum phase in the GCR intensity, three solar cycles 21-23 are divided into two groups: 1) the solar cycle 22 for which there is a small time advance (less than 1 year) of the Gnevyshev gap in *B2* factor with respect to the Gnevyshev peak in the GCR intensity and 2) the solar cycles 21 and 23 characterized by the greater time advance (≈ 2 years) of the Gnevyshev gap in *B2* and by the subsequent period of the weak poloidal solar magnetic field (and the large IMF sector-structure zone). Probably, this division reflects one more aspect of the 22-year wave in the GCR intensity modulation around solar activity maximum beside in the magnitude of the enerhy hysteresis (see [5]).

3. The expected behavior of the GCR intensity in the minimum phase of solar cycle 24

In Fig. 3 we show the same the time history of the GCR intensity as in Fig. 2, *e*, however for solar cycles 19-23 and prolonged till the next solar cycle maximum. It is easily seen that in this format the time profiles of the GCR intensity for solar cycles 19-22 are divided into two well-known groups: 1) the pointed profiles inherent in the minimum phase of the even cycles characterized by the $A < 0$ IMF polarity (curves for solar cycles 19, 21) and 2) the mesa-type profiles inherent in the odd cycle minimum phase characterized by the $A > 0$ IMF polarity (curves for solar cycles 20, 22).

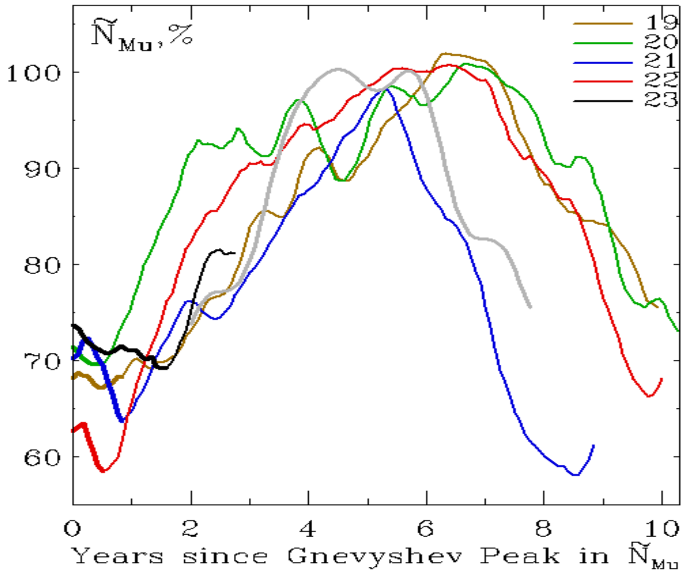

Figure 3. The comparison of the variations in the GCR intesity for solar cycles 20-23 as functions of the time elapsed since the middle of the solar cycle maximum phase in the GCR intensity.

As since 2000 the heliosphere is again in the $A < 0$ state, it is most likely that in the next few years we shall observe the pointed time profile of the GCR intensity. The detailes of the profile depend on the geometry of the global heliospheric current sheet and on the position of the Earth in the highly inhomogeneous space distribution of the GCR intensity innate to this state. We are working on the quantitative description of the GCR intensity in 2005-2009.

So the 22-year or magnetic cycle in the GCR intensity near the Earth manifests itself rather significantly both around solar maximum (the magnitude of the enerhy hysteresis; the correspondence between behavior of the poloidal solar magnetic field characteristics and that of the characteristics of the maximum phase in the GCR intensity) and around solar minimum (the form of the time profile; the correspondence between solar activity parameters, the sunspot area vs the tilt of the global heliospheric current sheet, and GCR intensity). It forces us to suggest that the magnetic solar cycle near the Earth should be noticeable not for the test particles (the galatic comic rays) but for the solar wind plasma as well.

4. Conclusions

1) The depth in the galactic cosmic ray intensity modulation during the solar cycle maximum phase qualitatively corresponds to the maximum levels of the strength of the interplanetary magnetic field and of the average magnetic field energy density on the photosphere. For the length and position of this phase the behavior of the high-latitude solar magnetic fields and of the latitude range of the interplanetary magnetic field sector-structure zone is also important. By the length of the maximum phase in the intensity and its position with respect to time of the solar magnetic field reversal the current solar cycle reminds the solar cycle 21 and differs from the cycle 22, probably reflecting one more aspect of the 22-year wave in the galactic cosmic ray intensity modulation.

2) In the next few years the pointed time profile of the galactic cosmic ray intensity will be observed. To predict the detailes of the profile the geometry of the global heliospheric current sheet should be predicted and the position of the Earth in the highly inhomogeneous space distribution of the galactic cosmic ray intensity should be taken into account.

3) The 22-year effects in the galactic cosmic ray intensity near the Earth are rather significant almost all the time. As the cosmic rays are just test particles, the magnetic cycle should also manifest itself in the solar wind plasma as well, that could be important for the magnetospheric phenomena.

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