29th International Cosmic Ray Conference Pune (2005) **00**, 101-104

Cosmogenic Radionuclide Evidence on the Solar Activity Behaviour Affecting the Climate of the Earth

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At present the natural detectors of GCRs – cosmogenic radionuclides with different half-lives (especially Mn-54 and Na-22) in the chondrites fallen to Earth in 1959-2000 – provide the data on the GCR intensity (R>0.5 GV) at ~2-4 AU over ≥4 solar cycles. The correlative analysis of these data with the different indexes of solar activity (the sunspot numbers and the intensity of the green coronal line), as well as with the inclination of the heliospheric current sheet and with the IMF strength, testifies to a deep disturbance of the IMFs during and after the 20-th solar cycle , which could be conditioned by a peculiar transformation of the SMF structures, namely, by the last change of the secular cycle that happened just in the 20-th solar cycle. An ascent of a still longer solar cycle (~ 600 y?) takes place, which might be connected with the observed global rise in temperature on the Earth. The correlative analysis of the solar activity and temperature variations in the earth's atmosphere leads to the conclusion that the solar activity may be considered as one of the main factors exerting the influence upon the climate of the Earth.

1. Introduction

The processes on the Sun, e.g., the solar activity, have an impact on the processes in the heliosphere due to formation and disturbance of the interplanetary magnetic fields (IMF). The most striking example is the solar modulation of galactic cosmic rays (GCR), i.e., the GCR intensity changes at the different heliocentric distances and at the different heliographic latitudes, in accordance with the variations of the solar activity. Thus, it is clear that the GCR intensity may be considered as a subtle tool for the study of electromagnetic structure of the heliosphere and its changes conditioned by the solar activity. However, for such investigations the long series of uniform data (over a number of 11-year solar cycles) on the GCR intensity in the interplanetary space are required. At present only the natural detectors of GCRs – cosmogenic radionuclides with different half lives $T_{1/2}$ in the chondrites fallen to Earth in 1959-2000 – provide such data on the GCR intensity at ~2-4 AU over ≥4 solar cycles [1]. The most valuable detectors are ^{54}Mn ($T_{1/2}$=300 days), ^{22}Na ($T_{1/2}$=2.6 years) and ^{26}Al ($T_{1/2}$=7.4·10^5 years), which provide information on the average GCR intensity along the chondrite orbits for ~450 days, ~4 years and ~1 million years, respectively, before the fall of the chondrites to the Earth. Such an averaging smoothes essentially the temporal, as well as, the spatial variations of GCRs along the meteorite orbits, which derives the most important regularities [2].

2. Correlative analysis of the solar activity and GCR variations in the heliosphere

Virtually, the structure and dynamics of the IMFs are determined by the structure and dynamics of the magnetic fields on the Sun (SMFs). The well-known 11-year solar cycle is only a half of the 22-year magnetic solar cycle, when after two successive reversals the polarities of the north and south hemispheres of the Sun return to their initial states. However, there are, apparently, solar cycles of longer duration: 80-year, or secular cycles; 600-year cycles; etc. [3]. It is clear that their presence must be expressed as some violations of the ordinarily observed picture of the solar activity influence on the processes in the heliosphere. In this connection, the rigorous correlation analysis of distribution and variation of GCRs in the heliosphere, depending on different parameters of the solar activity, is of paramount importance. We have carried out such an analysis of the correlations of GCR gradients (meteorite data [1], GCR rigidity R>0.5 GV) with the different indexes of solar activity (the sun spot numbers [4] and the intensity of the green coronal line (GCL, λ=5303 Å) [5]), as well as with the inclination of the heliospheric current sheet [6] and with the IMF strength [7]. In Fig.1 the results of the correlation analysis of the GCR gradients and the GCL intensity at the polar angles $\theta=60^{o}$ and $\theta=120^{o}$ are presented.

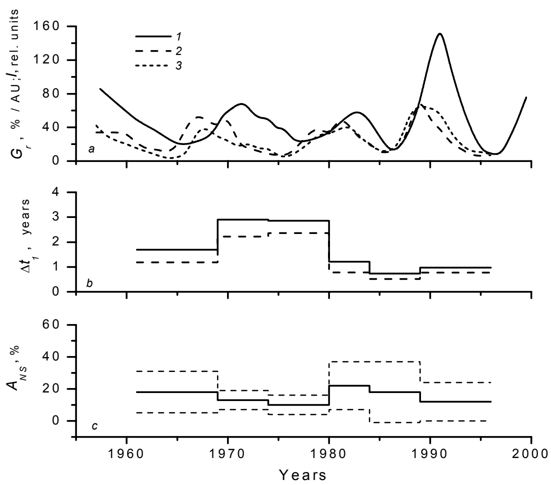

Figure 1. (*a*) GCR gradient variations, according to the meteorite data (1) and variations of GCL intensity at $\theta=60^{o}$ (2) and 120^{o} (3); (*b*) time delays Δt_1 ($\theta=60^{o}$, solid line) and Δt_2 ($\theta=120^{o}$, dashed line) of the GCR gradient change from the GCL intensity change at the maximum correlation coefficients; (*c*) *N-S* asymmetry of the delays at $\theta=60^{o}$and $\theta=120^{o}$: $A_{NS}=[\Delta t_1-\Delta t_2]/\ [\Delta t_1+\Delta t_2]\cdot 100\%$ (solid line); dotted line is $\pm 1\sigma$

The curve for the GCR gradients is doubly smoothed over experimental points for each 5 points by the polynomial of the first degree [8]. One can see that the GCR gradient variations are successively behind the GCL intensity changes. The average delay amounts to ~1 year, and it is about 3 times higher in 1970-1980 (especially in *N*-latitudes) at the correlation coefficients as high as 0.9. The average *N-S* asymmetry totals 17±10%, decreasing below ~10% in 1971-1982 (the positive phase of the magnetic cycle, A>0) and rising above ~20% in 1977-1986 (the negative phase of the magnetic cycle, A<0). The positive and negative phases of the magnetic cycle are distinguished by the direction of the charge particle drift. If A<0, the vectors of magnetic momentum of the sun and angular velocity of its rotation are oppositely directed, so that the positively charged particles drift along the heliospheric current sheet towards the sun and from equator to poles of the heliosphere, increasing radial gradients and decreasing latitude gradients of GCRs. If A>0, the directions of both the vectors coincide, and the reverse drift goes on from poles towards equator and along the heliospheric current sheet from the sun, which decreases radial gradients and increases latitude gradients of GCRs in the heliosphere. Evidently, in the last case, the GCR intensity in the inner heliosphere is enhanced without the solar activity correlation. The GCR variations under the solar activity constraint are sharply broken just under the reversal of the general solar magnetic field. Therefore, it is easy to understand that the effect of *N-S* asymmetry is mainly conditioned by the different moments and durations of the solar polar magnetic field inversions in *N* and *S* hemispheres.

The strong growth of time delay of the GCR gradient variations is observed in the correlation analysis with all the other parameters: solar spot numbers, inclination of the heliospheric neutral current sheet and the IMF strength. Everywhere the 20th solar cycle (1965-1976) and the first part of the 21st solar cycle stand out sharply against the regularities in the other time intervals. That testifies to a deep disturbance of the IMFs during those periods, which could be conditioned by a peculiar transformation of the SMF structures, as compared with the commonly observed events.

3. Discussion

The cause of such strong violations, apparently, lies in replacing the solar cycle of much longer duration than 11-year cycle. First of all, it may be a secular (80±50y) solar cycle. Indeed, in Figure 2*a* the secular cycles of

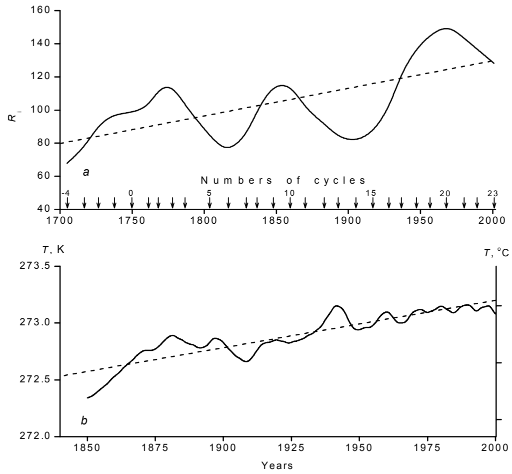

Figure 2. (*a*) Secular cycles of the solar activity in 1700-2001 (solid curve); R_i are maximum values of the Wölf annual average numbers smoothed by the Gleisberg method [9]; (*b*) temperature variations in the Earth low atmosphere over the last 150 years (solid curve); dotted regression lines are y= -203+0.17x (*a*) and y=265+0.0042x (*b*).

the solar activity in 1700-2001 are presented. The secular curve is obtained due to smoothing the maximum average annual numbers of the solar spots [9]. One may see that the last change of the secular cycle happens just in the 20th solar cycle. The secular curve has a character of free harmonic oscillations, conditioned by cyclic variations of the depth of the convective zone of the Sun and reflected in the strong SMF transformations. The increasing character of the secular regression line is interesting. It may imply that an ascent of a still longer solar cycle (~600 y?) takes place. It is tempting to connect the observed global rise in temperature on the Earth [10] (see Figure 2*b*) with such a growth of the solar activity. Indeed, the analysis of the regression lines in Figure 2*a,b* displays that the solar activity gradient is 0.22%/year, whereas the temperature gradient of the Earth low atmosphere is 0.0015%/year. The low temperature gradient is natural, for instance, due to many inertial processes on the Earth, firstly, due to the inertial processes in the world ocean, which fortunately decelerate and alleviate the effects of the temperature growth for the long temporal scale. Nevertheless, one can see rather a clear conditionality of the terrestrial temperature by the solar activity in Figure 3*a,b*, where the distributions of the annual mean values of the earth atmosphere

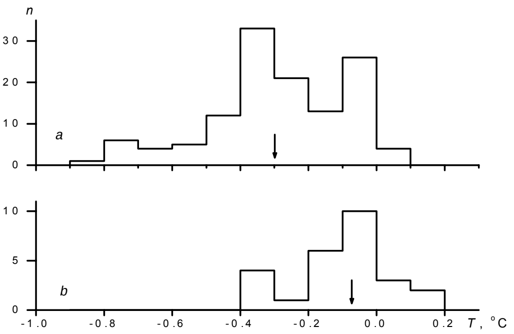

Figure 3. Distributions of the annual mean values of the earth atmosphere temperature in 1850-2000 for the years with the average solar spot numbers $N < 100$ (*a*) and $N > 100$ (*b*). The arrows mark the median values of the temperatures: $T_{\mathrm{med}} = -0.30 \pm 0.02$ °C (*a*) and $T_{\mathrm{med}} = -0.075_{-0.045}^{+0.065}$ °C (*b*); errors ($\pm 2\sigma$) are estimated with the nonparametric approach to the data processing [11]

temperatures in 1850-2000 are shown for the years with the average solar spot numbers $N < 100$ (*a*) and $N > 100$ (*b*). The arrows mark the median values of the temperatures: $t_{med} = -0.30 \pm 0.02$ °C (*a*) and $t_{med} = -0.075_{-0.045}^{+0.065}$ °C, i.e., in the periods of higher solar activity ($N \geq 100$) the mean annual values of temperature of the low atmosphere of the earth are higher, on the average. It is interesting to note that this effect remains at small temperature delays from the solar spots (about several years), and it smoothes away at the big ones (about several tens years), which just demonstrates the inertial mechanism of the nature processes: a relatively prompt response of the low atmosphere temperature to the level of the solar activity, and the slow smoothing of the temperature fluctuations over a long time scale (100 y ?), mainly, due to the huge inertial potential of the world ocean. Therefore, the solar activity may be considered as one of the main factors exerting the influence upon the climate of the Earth.

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