COSMOGENIC RADIONUCLIDES IN METEORITES, GALACTIC COSMIC RAY MODULATION, SOLAR ACTIVITY AND CLIMATE OF THE EARTH.

V. A. Alexeev, and G. K. Ustinova, Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Moscow 119991 Russia; e-mail: aval@icp.ac.ru

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, deriving the most important regularities [2].

Correlation 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 θ=60^{o} and θ=120^{o} are presented. The curve for the GCR

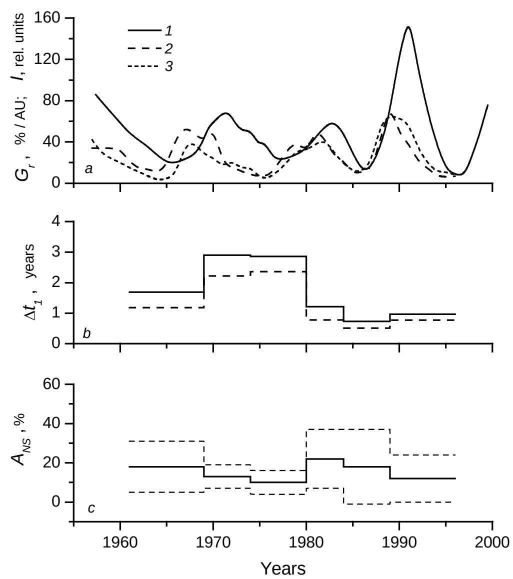

Fig.1- (a) GCR gradient variations, according to the meteorite data (1) and variations of GCL intensity at θ=60^{o} (2) and 120^{o} (3); (b) time delays Δt_1 (θ=60^{o}, solid line) and Δt_2 (θ=120^{o}, dashed line) of the GCR gradient change from the GCL intensity change at the maximum correlation coefficients; (c) N-S asymmetry of the delays at θ=60^{o}and θ=120^{o}: A_{NS}=[Δt_1-Δt_2]/ [Δt_1+Δt_2]·100% (solid line); dotted line is ±1σ

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) and rising above ~20% in 1977-1986 (the negative phase of the magnetic cycle). Such an effect is 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.

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±50 y) solar cycle. Indeed, in Fig2*a* the secular cycles of 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 Fig2*b*) with such a growth of the solar activity. Indeed, the analysis of the regression lines in Fig.2*a*,*b* displays that the solar activity gradient is 0.22%/year, whereas the temperature gradient of the Earth low atmosphere is 0.0054%/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. Therefore, the solar activity may be considered as one of the main factors exerting the influence upon the climate of the Earth.

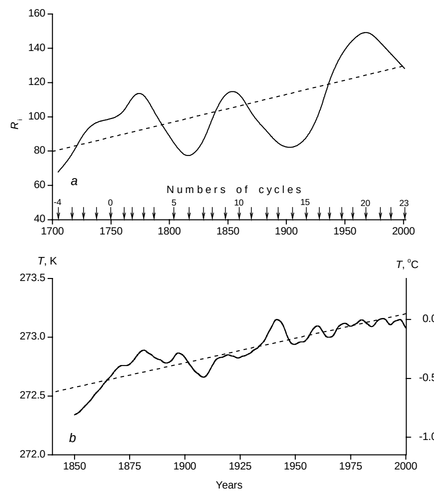

Fig.2 (a) Secular cycles of the solar activity in 1700-2001 (solid curve); R_i are maximum values of the Wölf annual average numbers smoothed by the Gleisberg method [9]; (b) temperature variations in the Earth low atmosphere over the last 150 years (solid curve); dotted regression lines are y=-203+0.17x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

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