COSMOGENIC RADIONUCLIDES IN THE SUCCESSIVELY FALLEN CHONDRITES IN 1959-2009 AND THE PECULIARITIES OF THE VARIOUS SOLAR CYCLES. V. A.Alexeev and G. K. Ustinova, Vernadsky Institute of Geochemistry and Analytical Chemistry, RAS, Moscow V-334, 119991 Russia; E-mail: AVAL37@chgnet.ru

Meteorite Data: The investigation of cosmogenic radionuclides with different $T_{1/2}$ in the chondrites with various dates of fall, which have various extension and inclination of orbits, provides us with the long sequences of homogeneous data on variation of the GCR intensity and integral gradients (E >100 MeV) in the 3D heliosphere [1]. The long sequences of homogeneous data on the GCR intensity in the stratosphere [2] are used for evaluation of the gradients. Nowadays, such a sequence of certain homogeneous data on the GCR intensity and gradients in the inner heliosphere covers ~5 solar cycles (see Fig. 1) [3]. This smoothes, to a considerable extent, both the temporal and spatial GCR variations revealing the most important general regularities (curve 1), namely: the dependence of the GCR gradients in the inner heliosphere (at 2–4 AU from the Sun) on the phase of the solar cycles and the constancy of the mechanism of the solar modulation of GCRs, at least over the last ~1 Ma.

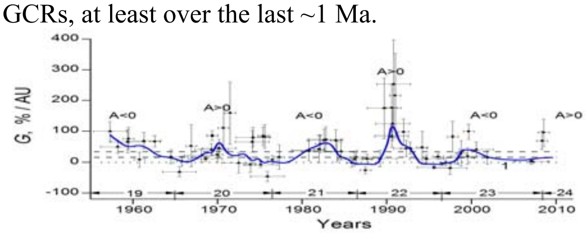

Fig. 1. *Variations of the GCR integral gradients G in 1954–2009 along the orbits of fallen chondrites (see their list in [3]). The curve 1 fits the data by a first-order polynomial with taking into account the weight of each point.*

Correlative Analysis: The existence of scaling in the power of the interplanetary magnetic field fluctuations [4] leads to necessity of separation of the stochastic effects and the effects caused by the solar activity (SA) in modulation of GCRs. In this connection, rigorous analyses of correlations between the distribution and variations of GCRs and various indexes of SA, as well as the strength of interplanetary magnetic fields (IMF) and the tilt of the heliospheric current sheet (HCS) in the three-dimensional heliosphere, turn out to be of paramount importance. Fig. 2 shows the positive correlation of GCR radial gradients at 2 - 4 AU with the SA [5], as well as with the strength of IMF [6] and the HCS tilt angle up [7]. However, the correlation differs for various solar cycles, as well as for growth and decay phases of solar cycles. Indeed, along with general positive correlations of the gradients with the level of SA, there are time lags, Δt, of the gradient variations from R_j variations. It is seen in Fig. 3 that Δt values vary in the range of ~ 1.27-2.38 years up to the maximum of the 22nd solar cycle, and then they drop rapidly down, even to negative values (perhaps, due to the SA decrease for the following years).

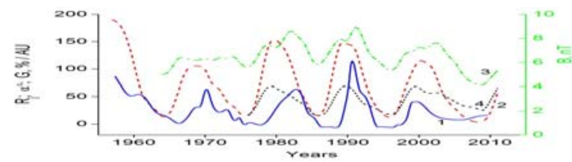

Fig. 2. *Variations of GCR gradients (curve 1 from Fig. 1) in comparison with variations of SA (Wolf numbers R_j), strength B of IMF and tilt angle α of HCS (curves 2-4)*

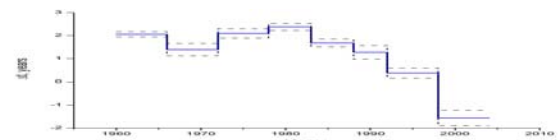

Fig. 3. *Change of time lags of variations of the GCR gradients from the variations of SA for the considered time scale.*

Effects of the total solar magnetic field (TSMF) inversions on depth of the GCR modulation: Violation of correlations of the GCR gradients with SA might be conditioned by the disturbance of the SA itself by stochastic processes, e.g., by the processes of inversion of TSMF during the maximum phases of the solar cycles [8]. The TSMF inversion periods differ in their character and duration in N- and S-hemisphere of the Sun for various solar and magnetic cycles [9]. Indeed, in the 20 solar cycle the inversion began developing in March 1968 at heliolatitudes of 40°–50° in the S-hemisphere, and reached the pole in September 1969. In the N-hemisphere, the inversion started in the 40°–50° zone only in August 1970, but it reached the pole within one year. This means that since September 1969 both the poles were negative for about two years. Thus, owing to TSMF inversion, the heliosphere proved to be open not only near the poles but also partly in the near-equatorial zone at ±40°. This additional possibility for the penetration of charged particles into the heliosphere was probably responsible for the general higher level of GCR intensity in solar cycle 20 as compared with cycle 19.

Meanwhile, the character of TSMF inversion during the maximum of the 22 solar cycle essentially differed from that in the 20 cycle. The fact is that the inversions terminated earlier in the S-hemisphere, at the maxima of solar cycles 18, 19, and 20, and in the N-hemisphere they terminated at the maxima of solar cycles 21 and 22 [10]. This is related to the fact that during seven 11-year cycles, up to cycle 20, the activity in the N-hemisphere was higher than in the S-hemisphere; however, since 1981 the S-hemisphere became more active than the N-hemisphere. At the maximum of the 21 solar cycle the TSMF inversion from + to – terminated earlier in N-hemisphere (02.–11.1979) vs. (09.1979–05.1980) in S-hemisphere, and its duration was less than a year, so that such a short-term TSMF deviation from dipole was not especially displayed. However, at the maximum of cycle 22 the inversion from – to + in N-hemisphere covered the range of (01.1989–03.1990), which was considerably shorter than the inversion period of (08.1989–05.1991) from + to – in S-hemisphere. Hence, some period should exist when both the poles were positive. It means that the heliosphere was closed for positively charged particles, except for two neutral cones with high inclination. That resulted in the deepest minimum of the GCR intensity in stratosphere in 1990-1991 [2] and the highest GCR gradients for the 22nd solar cycle (see Fig. 1).

At last, the 23 solar cycle is considered to be unusual because of very low amplitude of SA and prolonged minimum before the development of the 24 solar cycle [11]. The TSMF inversion from + to – in N-hemisphere took place during about one year (11.1999–10.2000), whereas in S-hemisphere the inversion from – to + lasted for about 2 times longer (06.1999–06.2001), so that the period when both the poles turned out to be negative (as well as in the 20 cycle), was prolonged enough. With decline of the IMF, observed since 2000 [6], the heliosphere turned out to be still more open for GCR penetration, which is confirmed by decrease of their gradients (see Fig. 1). The weakness of the magnetic fields as well as the unusual duration of the SA decline before the 24 solar cycle testify to the transformation of the magnetic field generation in the convective zone of the Sun [11], which becomes more evident with the development of the 24 solar cycle.

Secular cycles and the solar dynamo: In contrast to the 11-year cycles connected with the frequency of SA phenomena, the secular cycles reflect mainly variations in their intensity, and thus they allow us to judge about the state in the convective zone of the Sun [10]. It is clearly seen in Fig. 4 that just with the 20 solar cycle the decrease of the current secular cycle has begun, and nowadays we are at – or approach to – its minimum, which may evidence the decrease of depth of the convective zone of the Sun. The turbulent convection of the solar plasma and its differential rotation underlie free-running operation of the solar dynamo [12]. When some conditions of generation of convection are disturbed, the states of instability can arise, and the prolonged minima of SA, being similar to the Maunder minimum, are coming. Nowadays, there is, apparently, just such a trend of events. It will depend, to a large extent, on the character of the inversion in the 24 cycle, which is expected in ~2014 [11]. Cycle 24, being similar to cycle 22, must pass through the stage when both the poles will be positive. However, at low SA the magnetic fields near the poles can be only neutralized, but the inversion will not take place. The disappearance or extreme weakness and instability of the magnetic fields near the poles will open free penetration of GCRs into the heliosphere. The exit from such a state of instability can depend on its duration. In the protracted case, a prolonged minimum of SA can come as well as a cold period on the Earth. According to many authors (see, e.g., [13]), SA is the possible cause of the observed global warming on the Earth. However, the superposition of the cycles of various duration and their disturbance demonstrate the complexity of this mechanism. As seen from Fig. 4, the replacement of every successive secular cycle occurs at the higher level of the solar activity. This means that the more prolonged cycle (perhaps, 600-year cycle) is on the rise, and just it may be one of the reasons of the observed global warming on the Earth.The future will show whether this tendency to warming will endure a competition with cooling through stochastic turning-off (or attenuation) of the SA cycles or not.

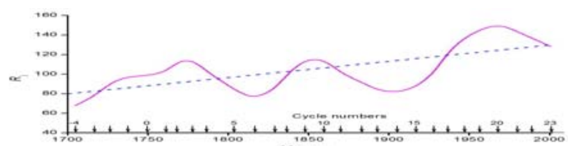

Fig.4. *Secular cycles of SA in 1700–2001 (solid curve is a variation of maximum annual R_j smoothed by the Gleisberg method; the arrows show the maxima of the cycles; the dotted line is a regression line $y = -203 + 0.166x$).*

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