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Some Particle Effects in the Solar-Terrestrial Relations

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Abstract. The distinction of the roles of photons and particles is of crucial importance in understanding the real processes in the Sun-weather relations, so these channels have to be separated. The specific impact of the solar corpuscular radiation on the terrestrial atmosphere can be pointed out in different ways: on the one hand, the similarity of an effect to a well known particle effect may give a hint, and on the other hand, if any solar-terrestrial phenomena or regularities exhibited dependence on the polarity conditions of solar magnetic fields, then it might be regarded as a signature of some particle effect. By using the *aa*-index of geomagnetic activity as well as the surface temperature data of 129 European stations, the following results have been obtained: 1.) The efficiency of the solar impact exhibits semiannual fluctuation; 2.) Disturbances coming from the Sun's polar and equatorial regions release opposite meteorological responses; 3.) Both previous regularities depend on the polarity of the Sun's main magnetic dipole field. The whole complex of phenomena depends on the geographical position; in the present material it is mainly confined to European middle latitudes - this may hint at some indirect mechanism, probably through affecting atmospheric circulation.

1. Introduction: Photons or Particles?

The roles of the electromagnetic and corpuscular fluxes are not yet clear in the Sun-weather relations. Some new aspects were presented in our previous studies (Baranyi & Ludmány 1992 hereafter Paper I; 1994 Paper II; Baranyi et al. 1995, Paper III, Baranyi & Ludmány 1995a, Paper IV and 1995b Paper V). The electromagnetic flux is homogeneous and isotropic, but the corpuscular flux is highly anisotropic and both temporally and spatially highly inhomogeneous. By taking these features into account, the separation of corpuscular and electromagnetic effects becomes possible. The electromagnetic flux is estimated to be stronger than the corpuscular one by orders of magnitude, but the inhomogeneity of the latter seems to be an important factor in influencing atmospheric processes.

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2. Data Sets: *aa*-index, Temperature

The solar corpuscular impact was derived through the monthly means of the geomagnetic *aa*-index introduced and analyzed by Mayaud (1972); see also Legrand & Simon (1989); Simon & Legrand (1989), and Terdik (1993). It is a reliable parameter of the corpuscular impact on the terrestrial magnetosphere. Its main importance lies in its unique recorded length: it has been continuously recorded since 1868.

The atmospheric response was studied by using monthly means of surface temperatures taken from a comprehensive meteorological database, the Global Historical Climatology Network (GHCN) (Vose et al. 1992). European temperature data sets were selected from this database for those stations for which the time-span of the records was not shorter than 80 years in the period 1868-1987. Their list is as follows: 1 Belfast, 2 Valentia, 3 Akueyri, 4 Grimsey, 5 Reykjavik, 6 Stykkisholmur, 7 Teigarhorn, 8 Vestmanneyjar, 9 Thorshavn, 10 Lyon, 11 Marseille, 12 Barcelona, 13 Madrid, 14 Palma de Mallorca, 15 Valladolid, 16 Coimbra, 17 Lisbon, 18 Genova, 19 Milano, 20 Napoli, 21 Roma, 22 Luqa, 23 Athinai, 24 Istambul, 25 Nicosia, 26 Astrahan, 27 Erevan, 28 Lencoran, 29 Mahackala, 30 Soci, 31 Tbilisi, 32 Bodo, 33 Karasjok, 34 Trondheim, 35 Vardo, 36 Haparanda, 37 Helsinki, 38 Arhangelsk, 39 Kem-Port, 40 Leningrad, 41 Onega, 42 Tallin, 43 Bergen, 44 Oslo, 45 Stockholm, 46 Uppsala, 47 Bogo, 48 Copenhagen, 49 Tarm, 50 Vestervig, 51 Berlin, 52 Hannover, 53 Potsdam, 54 Koszalin, 55 Warszawa, 56 Kaliningrad, 57 Liepaja, 58 Minsk, 59 Riga, 60 Smolensk, 61 Vasilevici, 62 Velikie Luki, 63 Vilnjus, 64 Aberdeen, 65 Bidston, 66 Cambridge, 67 Edinburgh, 68 Dumfries, 69 Durham, 70 Glasgow, 71 Greenwich, 72 Lossiemouth, 73 Oxford, 74 Plymouth, 75 Ross-on-Wye, 76 Rothamstead, 77 Scarborough, 78 Sheffield, 79 Stonyhurst, 80 York, 81 De Bilt, 82 Uccle, 83 Luxembourg, 84 Basel, 85 Geneve, 86 Saentis, 87 Zurich, 88 Nantes, 89 Paris, 90 Friedrichshafen, 91 Hohenpeissenberg, 92 Erfurt, 93 Frankfurt/M, 94 Muenchen, 95 Stuttgart, 96 Kremsmuenster, 97 Wien, 98 Praha, 99 Wroclaw, 100 Budaors, 101 Zagreb, 102 Debrecen, 103 Cluj-Napoca, 104 Sibiu, 105 Sulina, 106 Timisoara, 107 Cernovcy, 108 Kiev, 109 Lvov, 110 Uman, 111 Genicesk, 112 Harkov, 113 Jalta, 114 Kamennaja Step, 115 Krasnodar, 116 Kursk, 117 Nikolaev, 118 Odessa, 119 Poltava, 120 Rostov-na-Donu, 121 Tambov, 122 Elatma, 123 Gorkij, 124 Kazan, 125 Kirov, 126 Oktjabrskij Gorodok, 127 Saratov, 128 Totma, 129 Vologda.

3. Polar Reversals of the Sun's Main Dipole Field

Two subdivisions of years were selected in which the solar main dipole field had opposite directions as in Trisková (1989). The years of unambiguous field directions were taken from the paper of Makarov & Sivaraman (1986) (see Table 1). Only those years were selected in which the polarity was unambiguous throughout the whole year. We called a year "parallel" in which the solar and terrestrial magnetic fields are parallel throughout the year.

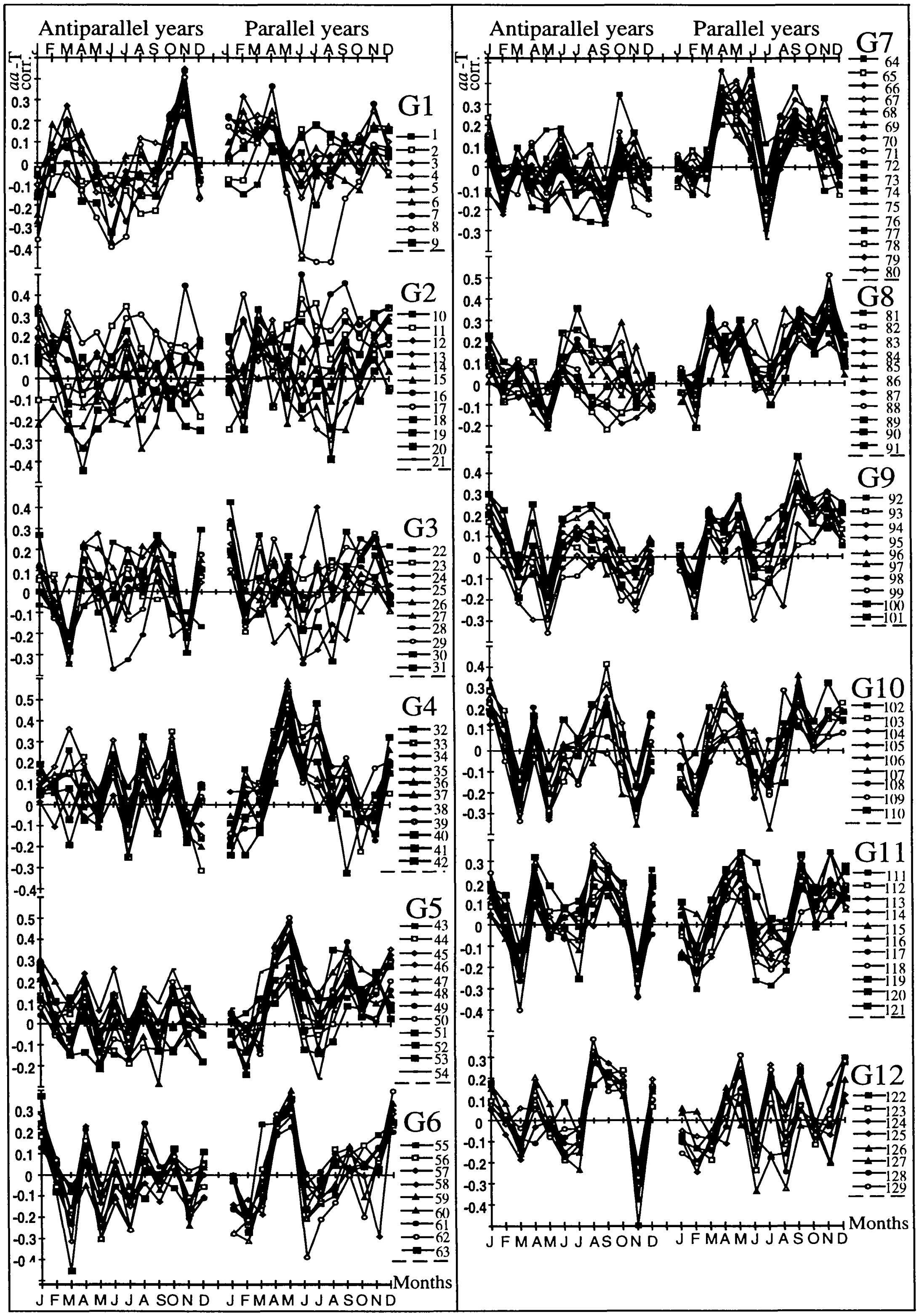

Figure 1. Annual variations of *aa*-index - temperature correlations at 129 European stations.

Table 1. Magnetic field orientations. Anti-parallel and parallel periods of the solar and terrestrial magnetic main dipole fields according to Makarov & Sivaraman (1986).

Years of anti-parallel fields	Years of parallel fields
-	1873-1882
1886-1894	1895-1904
1909-1917	1919-1926
1930-1939	1941-1948
1951-1957	1960-1968
1972-1980	1982-1987

4. Semiannual Fluctuation

Correlation coefficients of the *aa*-index and temperature were computed for all calendar months involved, as if they were independent data sets, and the annual distribution of these correlations was plotted. Fig. 1. shows the annual distributions of correlations for the years of anti-parallel and parallel solar and terrestrial dipole fields respectively. The plots are arranged into 12 geographic groups.

The semiannual fluctuation means enhancements of correlations around the equinoxes. This is not discernible at the stations of groups 1-3. Group 4 has a unique northern character: high summer maxima in the "parallel" years. The semiannual fluctuation is convincingly present in groups 5-12. The semiannual character is clear in the parallel years and it is replaced by random distribution in the anti-parallel years. However, an interesting tendency can be observed: the semiannual character starts rising in groups 9-11 in the anti-parallel years as well, and the situation seems to be reversed in group 12, in the innermost area studied on the continent. The geographic distribution of this phenomenon is depicted in Fig. 3.

5. Sensitivity to the Polarity Conditions of Solar Sources

The geomagnetic disturbances can be categorized on the basis of their temporal runs and this behavior allows a given geomagnetic event to be associated with a given solar feature. The classification scheme is published elsewhere (Legrand & Simon 1989, 1991; Simon & Legrand 1989). The main point is that the Shock activity and the Fluctuating activity are associated with solar sources around the solar equator, whereas the overwhelming majority of Recurrent activity is associated with polar coronal holes. By using the above classification scheme, the meteorological impacts of the different particle streams, or implicitly, the different solar events and features can be separated. The categorization of disturbance types means that all disturbed days are assigned with the type and measure of one of the mentioned activities giving a type-dependent response. Correlation coefficients were computed between the annual mean temperature (T) and the annual sums of shock (s), fluctuating (f), and recurrent (r), activities, i.e. three correlation coefficients ($K_{s,T}, K_{f,T}$ and $K_{r,T}$) for each station, both for anti-parallel and parallel years; they are plotted in Fig. 2. for anti-parallel and parallel orientations and for all stations. The enumeration and grouping of the stations is the same as in the case of the semiannual fluctuation.

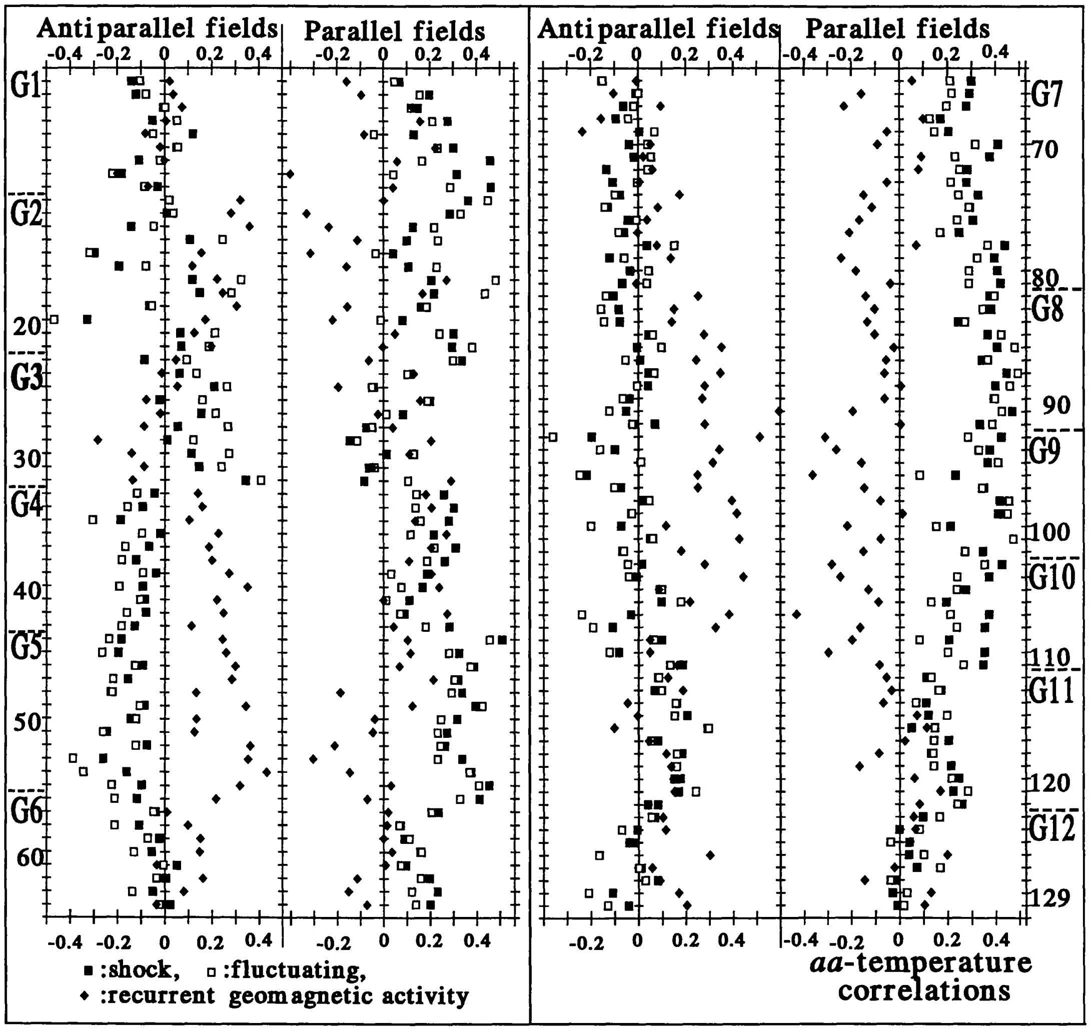

Figure 2. Dependence of the temperature - *aa*-index correlation on the orientation of the solar vs. terrestrial magnetic dipole fields as well as on the type (shock, recurrent or fluctuating) of the corpuscular impact for 129 European stations.

The mentioned regularity is not a general feature; it is only remarkable for groups 5,7-10. In the years of parallel fields, the correlations of shock and fluctuating activities with temperature are positive and the correlation of temperature with recurrent activity is negative (or nearly zero), whereas in anti-parallel years these correlations are reversed. To make the survey of the 129 stations easier, certain criteria were introduced. We say that the K coefficients show the above-mentioned symmetry in parallel and anti-parallel years (this is the type-dependent response) if,

(i) $K_{s,T}$ and $K_{f,T} < K_{r,T}$ in anti-parallel cases and $K_{r.T} > 0.2$;

(ii) $K_{r,T} < K_{s,T}$ and $K_{f,T}$ in parallel cases and $(K_{s,T} + K_{f,T})/2 > 0.2$

The distribution of the type-dependent response is worth comparing with the distribution of the polarity-dependent semiannual fluctuation (see Fig. 3). In regions numbers 1-3 6,7,11 and 12, these phenomena are either absent or just partly present. There is, however, an easily discernible area comprising the groups 5 and 8-10 in which both phenomena are recognizable.

The regularity determined by (i) and (ii) was also studied (Paper V) by considering periods with no recurrent activity, i.e. $r = 0$ (Legrand & Simon 1991) with similar results.

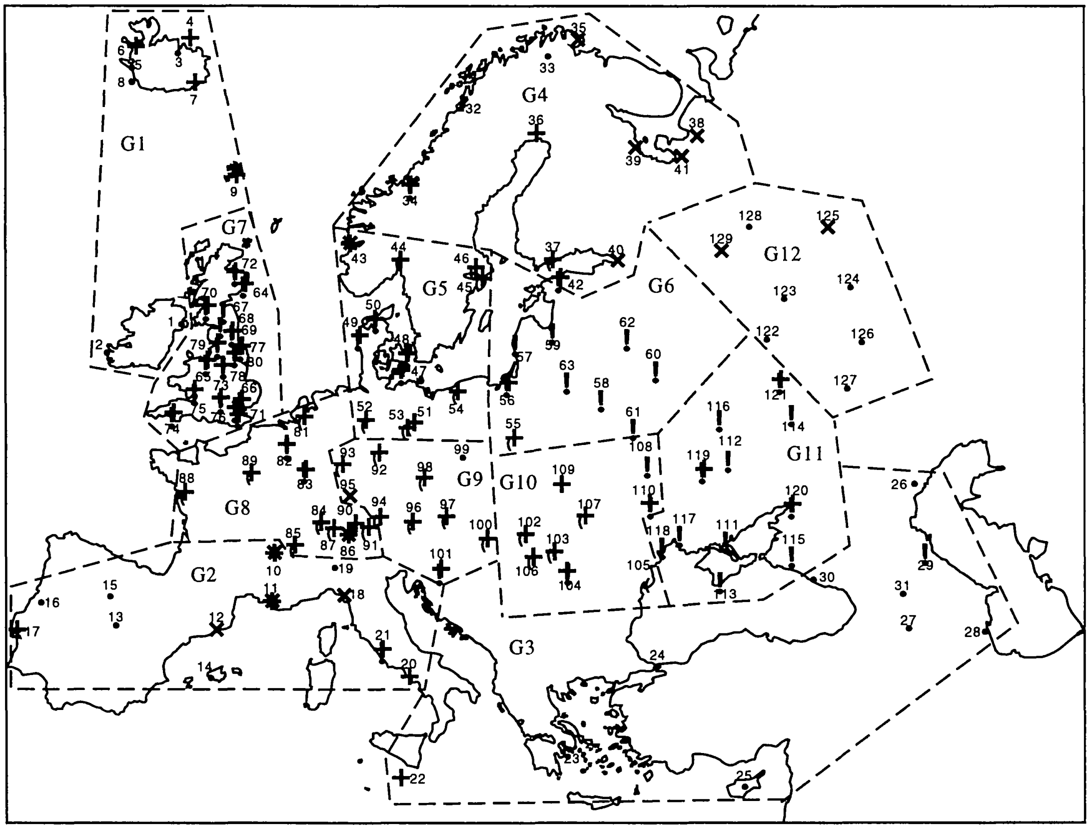

Figure 3. Distribution of the reported effects in Europe arranged into 12 groups. ○: the semiannual fluctuation is detected; ×: (i) criterion of the type-dependent response is fulfilled; +: (ii) criterion is fulfilled; •: none of them detected. Combination of marks means combined effect.

6. Summary, Role of Solar Corpuscular Streams

Let us summarize the basic results:

(1) *Semiannual fluctuation.* The periods close to the equinoxes are more favorable for the manifestations of the solar impacts than those of the solstice.

(2) *Dependence on the polarity of the solar main dipole.* The semiannual effect works only in the years of parallel solar and terrestrial fields. This is a

decisive argument for the solar origin of the phenomenon.

(3) *Signatures of solar surface polarity conditions in the atmospheric response.* The most complex behavior is presented in Fig. 2. The polarity-dependence is detectable both on a global scale (main dipole field) and on an active region scale (distinction of polar and equatorial sources).

(4) *Geographical distribution; influencing via atmospheric circulations.* The whole complex of phenomena depends on the geographic position in the European region; the solar influence on the weather is rather indirect, working probably via modification of the atmospheric circulation which then determines the local weather.

These results underline the importance of the distinction between spatially or temporally different features. It should be noted that the semiannual fluctuation of the solar-meteorological correlations cannot be the result of the semiannual fluctuation of the geomagnetic activity because of features (2) and (3), but they presumably have a common reason: sensitivity to the Sun-Earth attitude.

The corpuscular impacts on weather appeared questionable for a long time due to energetic considerations, but certain groups have investigated Sun-weather connections through corpuscular channels (Wilcox et al. 1976; Rostoker & Sharma 1980, Tinsley et al. 1994); they studied the IMF-environment of the Earth. The phenomena reported here relate data measured on the solar surface with those measured on the terrestrial surface, thus linking the most distant domains of the Sun-weather events chain.

The periods under study are generally treated as unified and it is embarrassing when a clear regularity disappears or reverses its sign (Herman & Goldberg 1978), although this may be caused simply by a parameter sign reversal not accounted for. Two consecutive cycles cannot be treated in the same way in the case of corpuscular effects. The detected result is similar to that reported by Wilcox et al. (1976), which has recently been re-confirmed (Tinsley et al. 1994). Our map also seems to support the fact that the phenomenon presented here works in a wide band under the influence of the same European circulation pattern, the Icelandic low, but is lacking beyond its reach. This circulation may also be affected by solar corpuscular energies.

A possible scenario: The energy transfer to the magnetosphere depends on the efficiency of reconnection of solar and terrestrial magnetic field lines. This reconnection depends, on the one hand, on the position angle of the terrestrial magnetic axes (semiannual effect, feature 1.) and, on the other hand, on the polarity conditions of the IMF-environment. The latter are primarily determined by the polarity of the solar main dipole field (feature 2.), but are also influenced by the polarity conditions of the incoming corpuscular effects. These effects can originate either from equatorial regions (shock and fluctuating disturbances) or from polar regions (overwhelming majority of recurrent disturbances); the predominant polarities of their effects are apparently different (feature 3.). The inhomogeneities caused in the polar heating are different for disturbances of opposite polarities; thus the atmospheric circulation as well as the local weather are modified differently (feature 4.). Nothing can be said, however, about the propagation of the effect within the atmosphere; furthermore, the reconnection process is just a possible suggestion; polarity-dependent cosmic ray effects may also play a role (Tinsley 1994).

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