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# Semiannual fluctuation depending on the polarity of the solar main magnetic dipole field

T. Baranyi and A. Ludmány
Heliophysical Observatory of the Hungarian Academy of Sciences, Debrecen

G. Terdik
Center for Informatics and Computing, Kossuth University, Debrecen, Hungary

**Abstract.** We examined the recently found semiannual fluctuation in the Sun-weather relations on a broader European region. The fluctuation means stronger solar effects on the weather in the spring and autumn periods than in summer or winter. The existence of this effect has been confirmed but only during the parallel orientations of the terrestrial and solar main magnetic dipole fields; this latter varies by a 22-year period. The phenomenon probably contributes to the interconnection mechanisms between the solar and terrestrial magnetic fields and apparently, through a completely unknown mechanism, to certain tropospheric processes. Although the fluctuation is perceivable, it should be noted that the statistical evidence of the results is still far from striking, and the physical explanation is still missing.

## 1. Introduction

The problem of the Sun-weather relations is rather ambiguous at present because of the complexity of the processes and the weakness and variability of any regularities. Only a few reported findings have survived the subsequent checks, the extension of the database, and so on [*Pittock*, 1978, 1983]. Considering the complexity of the processes, the subject can be simplified by either temporal or spatial approach. The former one was used in a recent paper [*Baranyi and Ludmány*, 1992, henceforth referred to as paper 1.] by analyzing the dynamics of the *aa* index-temperature-precipitation relations at a single station (Budapest, Hungary). The present report describes a spatial extension on a broader European region to check the most interesting temporal pattern found, the semiannual fluctuation. This fluctuation means that the periods of the equinoxes are more effective in transferring solar effects to the terrestrial atmosphere than the summer and winter periods.

The *aa* index of geomagnetic activity was used as an indicator of the solar impact [*Mayaud*, 1972; *Legrand and Simon*, 1989; *Simon and Legrand*, 1989; *Terdik*, 1995]. This seems to be one of the most useful tools for long-range solar-terrestrial studies because it constitutes a continuous and homogeneous material since 1868, and thus it is the longest data set of this kind. The semiannual wave of the geomagnetic activity is a fluctuation of the mean geomagnetic activity level, having two maxima around the equinoxes and two minima around solstices. The phenomenon has been known for a long time and it is fairly well analyzed [*Russell and McPherron*, 1973; *Crooker and Siscoe*, 1986].

On the other hand, the semiannual fluctuation of the Sun-weather relations, described in paper 1, shows up in the plot of correlation of the geomagnetic-meteorological parameters in the following way: If correlation coefficients are computed between the monthly mean values of the geomagnetic activity index and a meteorological parameter for the values of only January, only February, and so on, then the annual run of these correlations has two extremes around the equinoxes and nearly zero values in summer and winter, the extremes are positive for temperature and negative for precipitation (in Budapest). This result can be interpreted in such a way that the atmospheric circulation processes are more effectively influenced around the equinoxes than far from them in connection with the varying Sun-Earth attitude.



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## 2. Processing of the data

In order to check the above effect, data sets of 22 European stations were used in the present study. Unfortunately, it was almost impossible to gather complete and up-to-date data sets for all stations, so the lengths of period from the different stations are different. The final years are as follows (the first year is 1873 unless indicated): Basel (1970), Berlin (1970), Budapest (1986), Central England (1980), Copenhagen (1970), Utrecht/De Bilt (1984), Debrecen (1986), Edinburgh (1959), Frankfurt am Main (1987), Geneva (1969), Genoa (1986), Greenwich (1962), Helsinki (1987), Hohenpeissenberg (1970), Kiev (1881-1987), Lisbon (1921-1987), Paris (1970), Prague (1987), Trondheim (1969), Uppsala (1987), Vienna (1961), and Zürich (1985). Moreover, precipitation data are not available in most cases, so we restricted the study to the temperature.

The semiannual effect cannot be detected in general in the above described form. However, it becomes perceivable by selecting two types of periods from the entire period following the results of *Makarov and Sivaraman* [1986]: one part comprises those years in which the solar main dipole field is antiparallel to that of the Earth, the other part contains the years of parallel situation, and the ambiguous years are omitted (Table 1.). These polarities can be considered to be the same as those of the interplanetary magnetic field [*Rosenberg and Coleman* 1969].

The result is depicted in Figure 1. The left and right graphs show the curves of correlation in the years of the antiparallel and

**Table 1.** Magnetic Field Orientations

| Antiparallel Fields | Parallel Fields |
|---|---|
| | 1873-1882 |
| 1886-1894 | 1895-1904 |
| 1909-1917 | 1919-1926 |
| 1930-1939 | 1941-1948 |
| 1951-1957 | 1960-1968 |
| 1972-1980 | 1982-1987 |

Antiparallel and parallel periods of the solar and terrestrial magnetic main dipole fields according to *Makarov and Sivaraman* [1986].

parallel fields, respectively. The difference is perceivable: The semiannual character is present in parallel years with definitely positive correlations, and it is absent in antiparallel years. The effect seems not to be detectable at Genoa, Lisbon, and Trondheim in the given form (Figure 2).

In preparing the data sets for analysis the mean and the seasonal means by seasonality of 12 months were subtracted from each temperature series, as has been done by *Brillinger* [1975] in some similar cases. The influence of this transformation is very attractive. When the high peak was removed from the periodogram, the time series became stationary and Gaussian. The same transformation was used for the time series of the

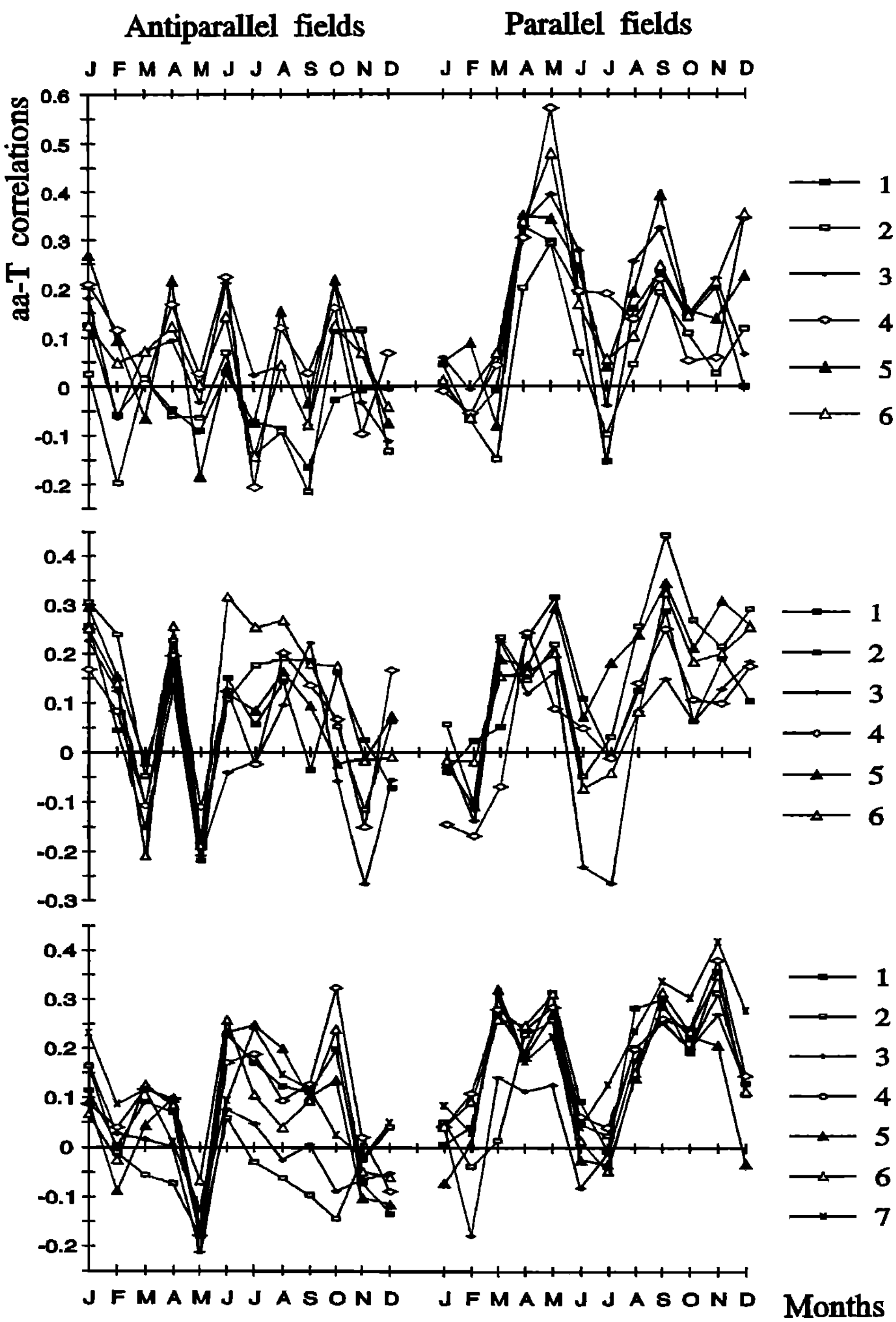


**Figure 1.** Annual run of the temperature-*aa* index correlations in the years of antiparallel and parallel orientations of solar and terrestrial magnetic dipole fields at 19 European stations. (Top) 1, Central England; 2, Edinburgh; 3, Greenwich; 4, Helsinki; 5, Copenhagen; 6, Uppsala. (Middle) 1, Berlin; 2, Budapest; 3, Debrecen; 4, Kiev; 5, Prague; 6, Vienna. (Bottom) 1, Basel; 2, Utrecht/De Bilt; 3, Frankfurt am Main; 4, Geneva; 5, Hohenpeissenberg (Germany); 6, Paris; 7, Zurich.

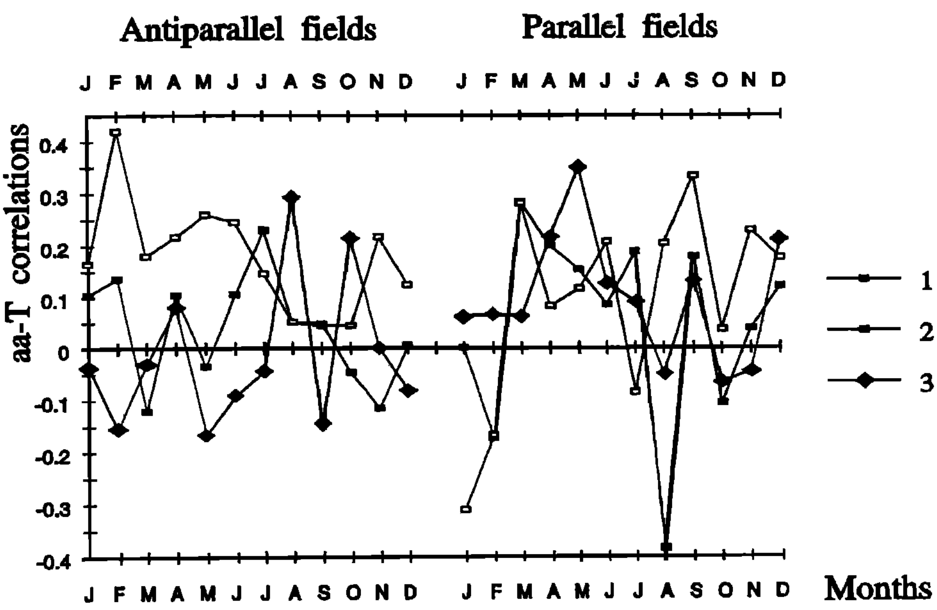


**Figure 2.** Exceptions; the same as in Figure 1 for three European stations having no semiannual behavior: 1, Genoa; 2, Lisbon; 3, Trondheim.

geomagnetic *aa* index by the seasonality of 6 months and 11 years. The remaining statistical problem was only to remove the internal dependence of the data sets (the February value is not fully independent from that of January and so on). This has been done in the following way. First, an autoregressive model was fitted to each series, and then it was prewhitened by the estimated linear filter. The above procedure is well based, as the linear filter does not change the coherence [*Newton*, 1988]; moreover, the prewhitening makes it possible to get constant variance of the estimates of the correlations.

The annual correlation curves of the prewhitened data sets are shown in Figure 3. These belong to the same 19 European stations as those in Figure 1. The presence and absence of the semiannual character is even clearer in the parallel and antiparallel periods than in Figure 1. The curves of the antiparallel case seem to scatter around zero, and those of the parallel case have two definitely positive enhancements around the equinoxes.

The significances can be studied only on the correlations of the prewhitened data sets (Figure 3). We summarize the

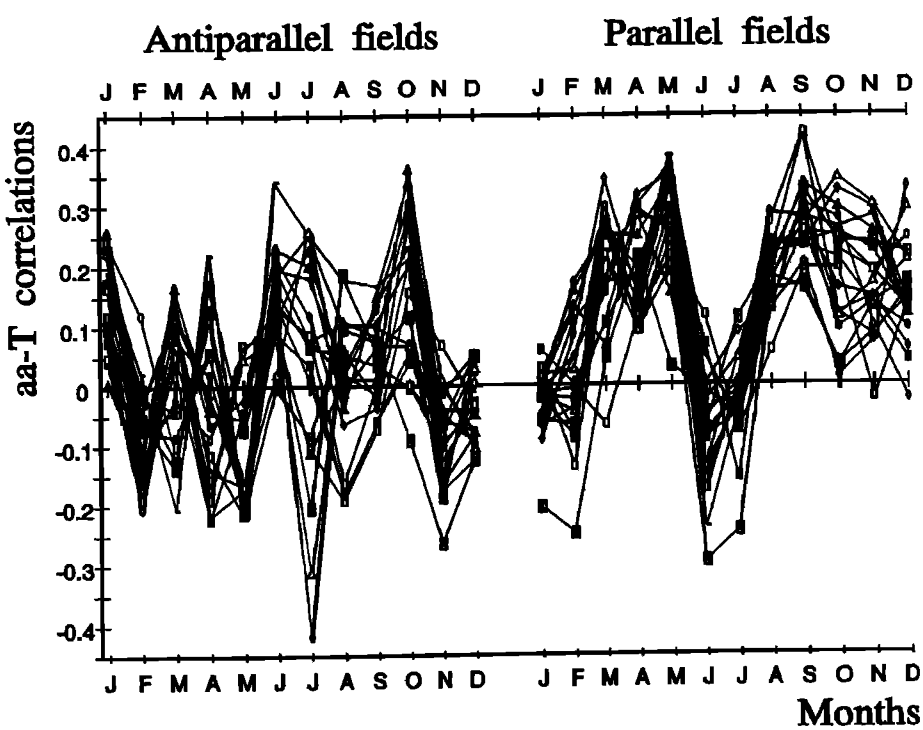


**Figure 3.** Correlations by months in antiparallel and parallel years at the 19 stations depicted in Figure 1 after prewhitening the data sets.

significances only for the equinoctial maxima in the parallel periods because our main assertion is that the correlation is significant under these conditions; otherwise it is not significant. Table 2 lists the data samples (numbers of parallel years at the given stations), spring and autumn correlation maxima, and the relevant significance values. Most of them are higher than 90% (in spring, >95%), whereas there are everywhere summer and winter months in which the solstice correlations fulfill the zero hypothesis (an interesting exception is occasionally Debrecen, where the June-July correlations have deep negative values and the autumn maximum is very low, so it appears that the whole curve is shifted downward but its semiannual character remains).

## 3. Discussion

These results appear to confirm the existence of the semiannual fluctuation, albeit with an important restriction. The effect is detectable at Budapest for the total 119 years studied probably by chance, but the apparent dependence on the interplanetary magnetic field (IMF) polarity yields further possible evidence of the solar impact on the weather through the corpuscular channel. Furthermore, these results answer the criticisms received of previous results (paper 1) concerning the reality of this fluctuation by saying that it could be either an artifact or merely an intrinsic meteorological effect without any solar influence. However, such factors should act uniformly in both IMF directions, and at the present moment it seems to be improbable that any (unknown) intrinsic atmospheric process of 22-year period would exist in phase with that of the Sun without any solar connections.

What can be the a priori reason for the equinoctial enhancements? We originally expected a single winter maximum (paper 1) on the basis of energetic considerations, but we get two maxima around the equinoxes. However, this unexpected result could also be fitted to existing data, because this behavior is quite similar to the semiannual variation of the geomagnetic activity also having two equinoctial maxima. On the other hand, the phenomenon cannot be caused merely by the semiannual behavior of the *aa* index as a mathematical artifact, but both are probably the consequences of the same circumstance: They are sensitive to the Sun-Earth attitude. Considering that the energy transfer is realized through solar and terrestrial magnetic field reconnections, which are most effective even around the equinoxes (details are summarized by *Crooker and Siscoe*, [1986]), it should also be polarity dependent in accordance with the present results.

The reported effect does not reveal too much about the real processes involved, mainly within the atmosphere. The main result is the existence of the regularity, which is no mathematical artifact. It is probably no purely atmospheric phenomenon either, because such phenomena would not distinguish between the solar polarity conditions. It is probably not connected with luminosity variations, because all phenomena of semiannual run are related to solar corpuscular effects (see the review of *Crooker and Siscoe* [1986] for the examples and details), and it is improbable that the irradiance effects would be sensitive to the magnetic polarities.

The above mentioned reconnection process could transfer solar energy to the outer polar atmosphere. If this is the case, then the effect may be related to that involved in the phenomenon published by *Wilcox et al.* [1976]. If so, they probably affect the circulation pattern (e.g., the Icelandic Low in Europe), which in turn affects the local weathers. This may be the cause of the exceptions in Figure 2, because they are in the peripheries of the affected region. No details can be given, however, about the possible propagation of this effect within the atmosphere, because the result is detected only on the surface, and there is no hope to reconstruct the middle or outer atmospheric processes on this centennial interval.

The statistical evidence of the results is still far from striking, and any physical explanation is still missing. The direction of the IMF may be problematic for the interpretation, as one would expect a stronger effect in the case of antiparallel dipole fields because this is the favorable orientation for the magnetic field line reconnection. A concurrent possibility might be the modulation of the galactic cosmic rays. They are also affected by polarity conditions, but this interpretation would certainly raise even more questions. In any case, although the details remain unclear, it can be established that the solar corpuscular effects on weather appear to be sensitive to the large-scale polarity conditions of the IMF.

**Table 2.** Equinoctial Maxima of *aa-T* Correlations for Prewhitened Data Sets in Parallel Years with Significance Levels (α)

| Station | Sample | Spring | α, % | Fall | α, % |
|---|---|---|---|---|---|
| Basel | 45 | 0.381 | 99 | 0.278 | 92 |
| De Bilt | 50 | 0.294 | 96 | 0.236 | 90 |
| Frankfurt am Main | 51 | 0.198 | 80 | 0.255 | 92 |
| Geneva | 50 | 0.337 | 98 | 0.323 | 98 |
| Hohenpeissenberg | 45 | 0.361 | 98 | 0.299 | 95 |
| Paris | 45 | 0.337 | 97 | 0.333 | 97 |
| Zurich | 49 | 0.286 | 95 | 0.343 | 98 |
| Berlin | 45 | 0.346 | 98 | 0.289 | 94 |
| Budapest | 50 | 0.297 | 96 | 0.421 | 99.7 |
| Debrecen | 50 | 0.263 | 93 | 0.169 | <80 |
| Kiev | 42 | 0.215 | 80 | 0.160 | <80 |
| Prague | 51 | 0.335 | 98 | 0.323 | 98 |
| Vienna | 38 | 0.293 | 93 | 0.311 | 96 |
| Central England | 45 | 0.293 | 94 | 0.230 | 87 |
| Edinburgh | 36 | 0.215 | <80 | 0.193 | <80 |
| Greenwich | 39 | 0.351 | 97 | 0.274 | 92 |
| Helsinki | 51 | 0.366 | 98 | 0.202 | 84 |
| Copenhagen | 45 | 0.283 | 94 | 0.416 | 99.5 |
| Uppsala | 51 | 0.283 | 95 | 0.256 | 92 |

See Figure 3. *T* is temperature.

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## References

Baranyi, T., and A. Ludmány, Semiannual fluctuations and efficiency factors in Sun-weather relations, *J. Geophys. Res.*, *97*, 14,923, 1992.

Brillinger, D. R., *Time Series Analysis: Data Analysis and Theory*, Holt, Rinehart, and Winston, Orlando, Fla., 1975.

Crooker, N. U., and G. L. Siscoe, The effect of the solar wind on the terrestrial environment, in *Physics of the Sun*, vol. III, edited by P. A. Sturrock, chap. 21, p. 193, D. Reidel, Norwell, Mass., 1986.

Legrand, J. P., and P. A. Simon, Solar cycle and geomagnetic activity: A review for geophysicists, I, The contributions to geomagnetic activity of shock waves and of the solar wind, *Ann. Geophys.*, *7*, 565, 1989.

Makarov, V. I., and K. R. Sivaraman, On the polarity reversals of the polar magnetic field of the sun during 1870-1982, *Bull. Astron. Soc. India*, *14*, 163, 1986.

Mayaud, P. N., The *aa* indices: A 100-year series characterizing the magnetic activity, *J. Geophys. Res.*, *77*, 6870, 1972.

Newton, H. J., *Timeslab: A Time Series Analysis Laboratory*, Wadsworth & Brooks, Pacific Grove, Calif., 1988.

Pittock, A. B., A critical look at long-term Sun-weather relationships, *Rev. Geophys.*, *16*, 400, 1978.

Pittock, A. B., Solar variability, weather and climate: An update, *Q. J. R. Meteorol. Soc.*, *109*, 23, 1983.

Rosenberg, R. L., and P. J. Coleman Jr., Heliographic latitude dependence of the dominant polarity of the interplanetary magnetic field, *J. Geophys. Res.*, *74*, 5611, 1969.

Russell, C. T., and R. L. McPherron, Semiannual variation of geomagnetic activity, *J. Geophys. Res.*, *78*, 92, 1973.

Simon, P. A., and J. P. Legrand, Solar cycle and geomagnetic activity: A review for geophysicists, II, The solar sources of geomagnetic activity and their links with sunspot cycle activity, *Ann. Geophys.*, *7*, 579, 1989.

Terdik, G., Linear and nonlinear modeling of the geomagnetic aa indices, in *Proceedings of the 1993 Padova Conference "Applications of Time Series Analysis in Astronomy and Meteorology"*, edited by T. S. Subba Rao, Chapman and Hall, New York, in press, 1995.

Wilcox, J. M., L. Svalgaard, and P. H. Scherrer, On the reality of a Sun-weather effect, *J. Atmos. Sci.*, 33, 1113, 1976.

T. Baranyi and A. Ludmány, Heliophysical Observatory of the Hungarian Academy of Sciences, P.O. Box 30, H-4010 Debrecen, Hungary. (e-mail: baranyi@tigris.klte.hu; ludmany@tigris.klte.hu)

G. Terdik, Center for Informatics and Computing, Kossuth University, P.O. Box 58, H-4010 Debrecen, Hungary. (e-mail: terdik@tigris.klte.hu)

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