EFFICIENCY FACTORS IN THE SOLAR-TROPOSPHERIC RELATIONS

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Abstract Two basic paradigms of solar-tropospheric relations are reviewed and compared in the paper. They are based on different energy transfer mechanisms: the irradiance and the solar corpuscular radiation. It used to be widely accepted for a long time that the solar impact affects the troposphere through irradiance variations. It turned out, however, that under certain circumstances the impact of the particle flux variations may be more efficient than that of the irradiance. The efforts of the Debrecen Observatory are devoted to study both paradigms in a parallel and comparative way, both approaches need long-term datasets. On one hand the irradiance studies are supported by our sunspot catalogues, the Debrecen Photoheliographic Data which is a catalogue of sunspot positions and areas (like the Greenwich Photoheliograph Results), and a new, ambitious project in preparative state, the Historical Solar Image Database, which will contain full disc white light images of the Sun for every day since the beginnig of the regular observations. On the other hand the paradigm of corpuscular impacts is also investigated by using long-term datasets of the surface temperatures and the aa-index. These latter studies revealed several previously unknown regularities in the terrestrial responses to the incoming solar effects, they are mainly of vectorial nature which is a clear signature of corpuscular influence. The atmospheric response depends on 1) the polarity of the main solar magnetic dipole field (22-yr modulation), 2) the mutual attitudes of the Sun-Earth axes (semiannual fluctuation), 3) the solar origin of the plasma flow (polar or equatorial), and 4) the terrestrial hemisphere (Eastern or Western). It is not appropriate to treat any of these paradigms in an exclusive way, we provide their brief comparison in order to overview their relevance.

1. Introduction – corpuscular or irradiance effects?

The overwhelming majority of previous solar-tropospheric investigations was based on the apparently self-evident assumption, which presupposed the decisive role of the irradiance variations in these relations. In the beginning the sunspot number was the most obvious choice to describe the solar effects and the first successes seemed to be convincing. A fluctuating behaviour similar to the 11-year cycle has been found in several terrestrial parameters ranging from meteorological and biological phenomena to agricultural production. These studies have not revealed the underlying nature of the relations, they just provided hints at an existing mechanism. The literature dealing with terrestrial 11-year fluctuation phenomena proliferated but in most cases the only result was that some solar impacts must be effective. This approach became much more realistic when spacecraft measurements revealed that the irradiance variations (the fluctuations of the solar constant) were related to the coverage of solar surface by sunspots, this result opened a new era in these investigations (see Withbroe and Kalkofen, 1994). Recently the total area of the sunspots and faculae on the visible solar hemisphere are taken into account as measures of the solar irradiance deficit and excess respectively. So these parameters are suitable as proxy data for the irradiance variations for the earlier decades. As the terrestrial atmospheric processes are extremely sensitive to the solar energy input it is quite plausible that irradiance variations of as low as a few thousandths may affect their regime.

However, there were also pitfalls in the earlier studies. Broad reviews of the literature (Pittock, 1978; Herman and Goldberg, 1978) pointed out that several methodological mistakes and, in some cases, even deliberate manipulations resulted in misleading conclusions. These reviews analyze the problems in detail, here we would like only to focus on a rather embarrassing feature. Several regularities have been found which occasionally can disappear or reverse their sense without any apparent reasons, mostly around the 1930's (examples in Herman and Goldberg, 1978 p.134.). In such a situtation we could either reject the effect as a probable mistake or we can also scrutinize our starting assumption. If we assume that the processes are governed by a scalar parameter (irradiance) then the correlations cannot change their sign. If, however, we accept that the input agent can be of vectorial nature then its orientational behaviour may affect the sign reversals of the correlations. The only candidate for this role may be the corpuscular radiation which transports solar magnetic fields being subject of the Hale's law. Therefore our strategy was to point out any proporties of correlations attributable to the solar magnetic fields and their polarity reversals.

The role of corpuscular effects in the lower atmosphere is not as obvious as in the magnetospheric and upper atmospheric processes. A serious objection could be that the flux of energy transported by corpuscular radiation at the Earth ($10^{-1}\ erg/cm^2 \sec$) can be neglected in comparison with the electromagnetic flux ($1.36x10^6\ erg/cm^2 \sec$). This is true, their difference is of seven order, but the point is that the genuine variation of the irradiance may be a few thousandths of the quiet value whereas the range of variability of the corpuscular energy flux may be larger than its quiet value. Thus, although the quiet stationary regime is obviously governed by the irradiance, the activity effects could be sheared by both channels. On the other hand, the irradiance acts globally, whereas the atmospheric input of the corpuscular events may be concentrated in a localized area by influencing atmospheric circulations which enhances the efficiency of the impact.

In order to check the viability of these assumptions, long-term datasets were considered because the length of the magnetic cycle is about 22 years. Unfortunately no direct datasets are available on a long-term basis, so we are restricted to proxy data. As was mentioned before, the Wolf-number is an acceptable parameter to estimate the role of the irradiance, it is recorded for centuries. As a measure of the corpuscular radiation the geomagnetic aa-index can be used (Mayaud, 1972) because it follows very precisely the solar wind velocity at the Earth, it has been recorded since 1886. Retrospective classification of the geomagnetic events for the entire period are taken from Legrand and Simon (1989). As for the terrestrial response, the most evident parameters are the meteorological measurements, here the temperature data of the GHCN database (Vose et al., 1992) have been used. Finally, the dates of the polarity reversals of the solar main magnetic dipole field were taken from Makarov and Sivaraman (1986) who obtained these data from the poleward migration of the prominences.

2. Test of the two paradigms

The first attempts (Baranyi and Ludmány 1992) were devoted to the comparison of the two (irradiance vs. corpuscular) approaches. The first hint was provided by the semiannual character of the correlations between the temperature data *(T)* of Budapest, Hungary and the *aa*-parameters, *C(T,aa)*, which have been separately calculated for only the January values, February values, etc. over a 119-year period starting in 1868. The annual distribution of the *C(T,aa)* correlations in the middle panel of Figure 1. exhibits a semiannual character which might be interpreted in such a way that the efficiency of solar effects is higher around the equinoxes than around solstices. The upper panel of Fig.1. shows the 119-year monthly means of the aa-index, which exhibits the well known semiannual fluctuation of the geomagnetic disturbances, this is a consequence of the Russell-McPherron effect, the McIntosh effect and the heliographic latitude excursion of Earth position (Crooker and Siscoe, 1986). The seasonal variation of the geomagnetic effectiveness of eruptive solar events caused by the Russel-

McPherron polarity effect is also observed (Cliver and Crooker, 1993). This similarity suggests that an underlying corpuscular mechanism can also be suspected in the solar-tropospheric relations. As the lower panel shows, the *C(T,Rz)* correlations between the temperature and Wolf numbers does not exhibit any semiannual character, as is also expected that the irradiance impacts are independent of the terrestrial attitude.

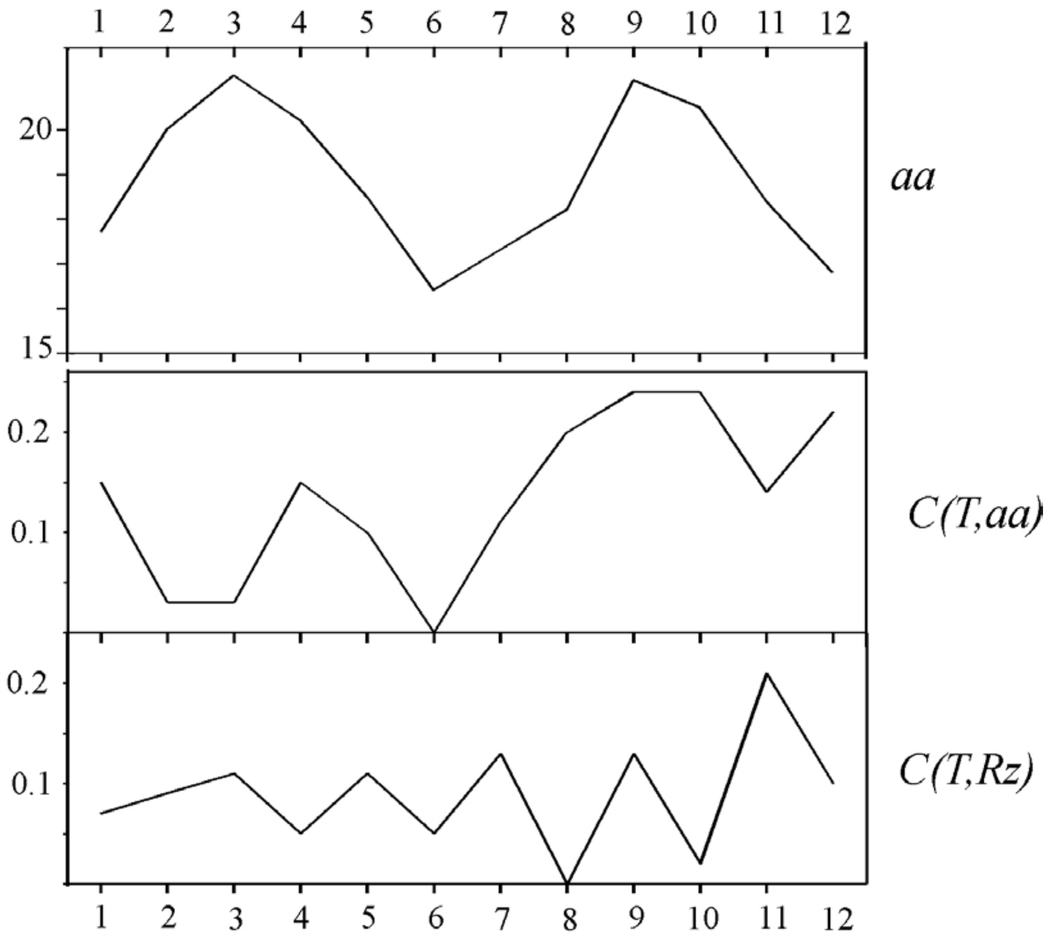

Figure 1. Top panel: annual distribution of the 119-year monthly means of the aa-index; middle panel: annual distribution of the monthly temperature-aa index correlations (*C(T,aa)*); bottom panel: annual distribution of the monthly temperature-Wolf number correlations (*C(T,Rz)*).

Another example may also be interesting from the starting attempts. Correlations have been computed from the annual means of the data for 15 year periods and they have been plotted in such a way that the correlation value indicated at a given year refers to the next 15 years, the correlation values were computed also by using the precipitation data *(r)* see Figure 2. This is a sliding correlation which may be a signature of the variable conditions for the impact efficiency. If we recall the finding about the correlation reversals and disappearances about the thirties (Herman and Goldberg, 1978, p.134.), the remarkable fluctuations of the curves in Fig.2. and the apparently consistent behaviour of the correlations of different parameter pairs may indicate a further condition for the impact efficiency. As Třisková (1988) has pointed out, an interesting change has taken place in these decades, the majority of the sunspot activity has been transferred from the southern hemisphere to the northern one. This has no importance from the point of view of the irradiance, but it may be relevant for corpuscular mechanisms.

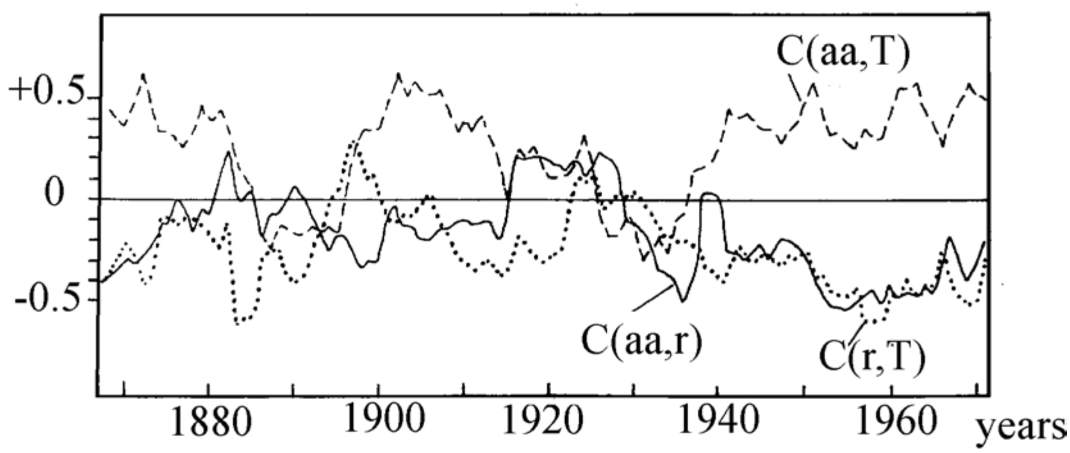

Figure 2. Long-term behaviour of sliding correlations of the aa index, temperature (T) and precipitation (r), see text.

3. Solar magnetic polarities

The above hints may be interesting but they are insufficient to draw decisive conclusions, so the next step was the verification of the semiannual fluctuation on a broader area. All attempts failed with the given method, but if the total period was subdivided into periods in which the polarity of the global solar magnetic dipole field was unambiguous (Makarov and Sivaraman, 1986), then the semiannual character reappeared (Baranyi et al. 1995, Baranyi and Ludmány 1995a, 1996). Fig.3 shows the annual curves for groups of 136 European stations separately for those years when the solar main magnetic dipole field is either parallel or antiparallel to the terrestrial field, this is alternating due to the 22-year magnetic cycle. Following an appropriate time-series analysis (Baranyi et al 1995, Terdik, 1996) this procedure can be carried out on the relevant subsets. The difference is remarkable in most cases, the curves exhibit semiannaual character in parallel years but this character is missing in antiparallel years. This is already a definitely vectorial feature which indicates the involvement of plasma processes.

It is true, however, that the presented stations belong to the western part of Europe, the effect is not detected in the inner parts of the continent. This may indicate that the mechanism controls the atmospheric processes in inhomogeneous ways, probably through specific circulation features.

The next polarity rule is related to the solar origin of the geoactive particle events (Baranyi, Ludmány 1995b). As is well known, the solar activity cycle consists of the alternating regimes of poloidal and toroidal fields, phenomena of the dipole field are confined to the areas close to the poles, whereas the toroidal field is closer to the equator and it is the source of the active regions. Careful analysis of the temporal runs of all geomagnetic disturbances beginning with 1868 (Legrand and Simon, 1989; Simon and Legrand, 1989) resulted in a dataset in which all events are classified according to their sources into the following categories. The geomagnetic *shock activity (s)* is an impact of short, energetic solar phenomena, such as flares or CMEs, the *fluctuating activity (f)* is related to the corotating wind streams not far from the neutral sheet, and the *recurrent activity (r)* is the signature of the high velocity wind streams. The sources of the first two types are the solar activity belts whereas the third type is due to the polar coronal holes in the overwhelming majority of the cases. So this analysis allows to distinguish between the equatorial vs. polar sources of the geomagnetic events, as a proxy information.

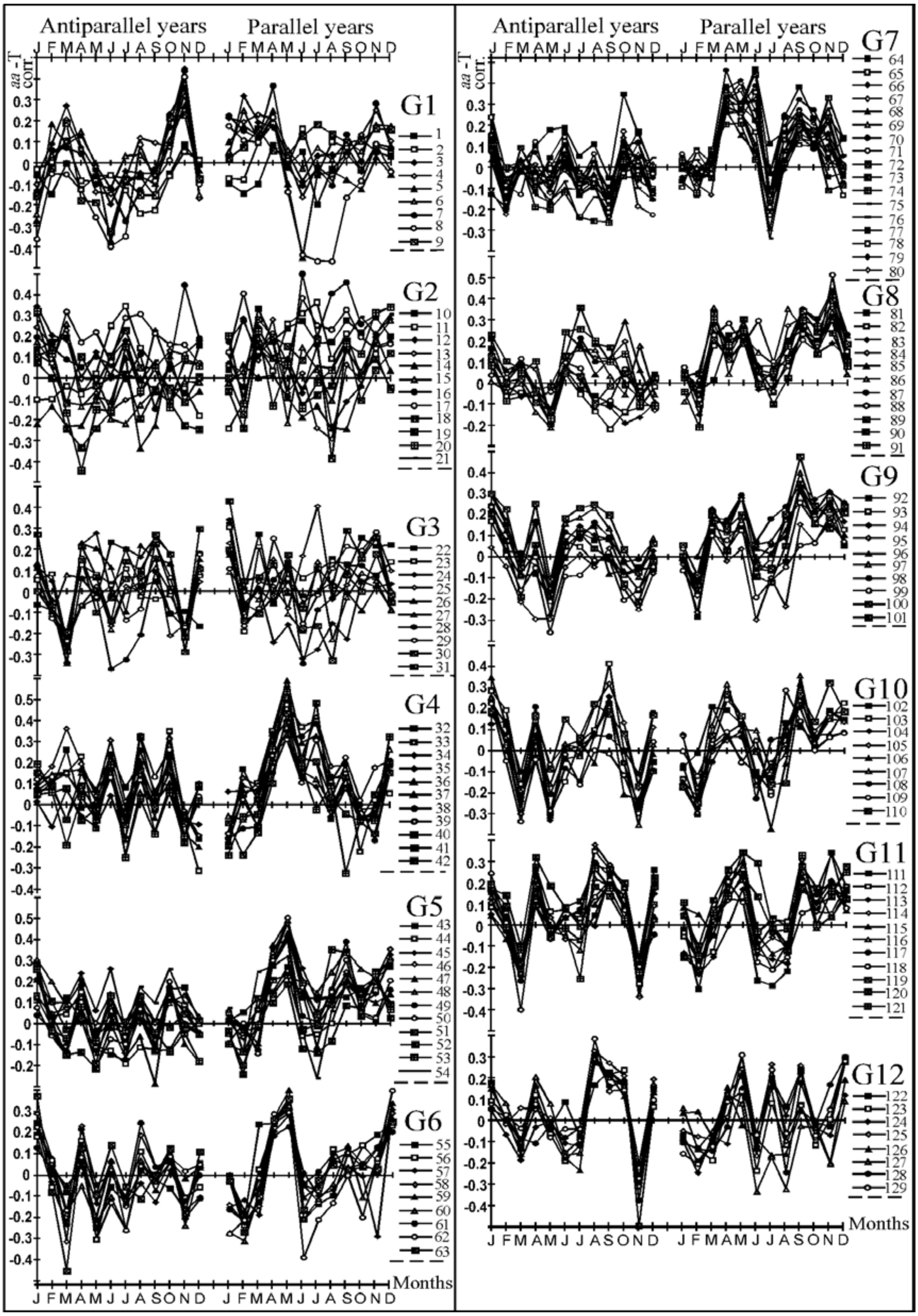

Figure 3. Annual variations of the aa-index – temperature correlations at 129 European stations. The stations are indicated by numbers, their list see at Fig.4.

If then we compute the *C(s,T), C(f,T)* and *C(r,T)* correlations in such a way that the *T* values are annual mean temperatures at a given station, the *s,f* and *r* values are annual sums of the relevant parameters, furthermore the years of parallel and antiparallel polarities are separated in the above way, then an interesting behaviour can be recognized (Fig.4.).

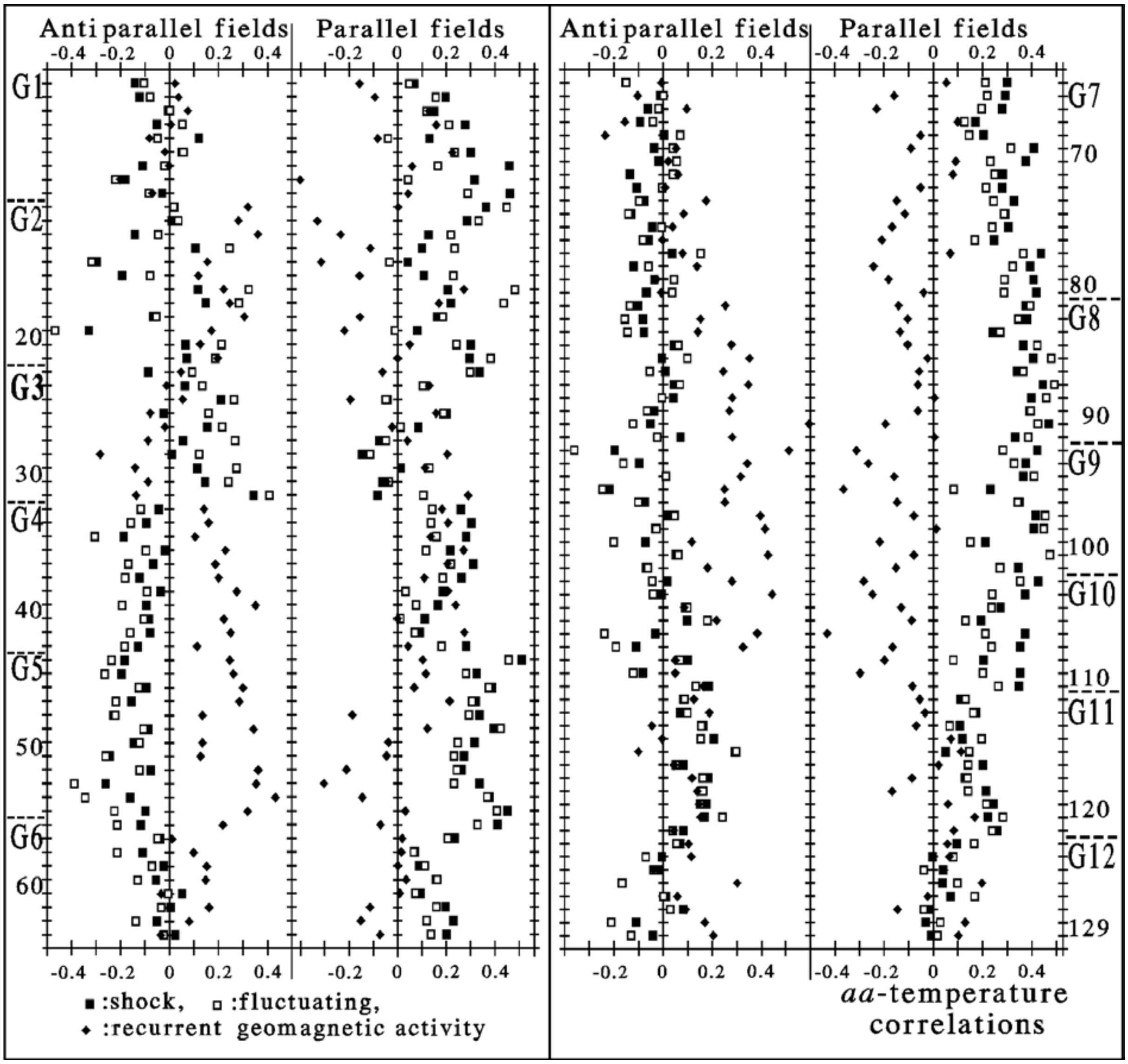

Figure 4. Dependence of the temperature - aa-index correlation on the orientation of the solar vs. terrestrial magnetic dipole fields as well as on the type (shock, recurrent or fluctuating) of the corpuscular impact for 129 European stations.

Names of the stations: 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.

In the years of parallel fields the correlations of shock and fluctuating activities (originating in the activity belts) with temperature are positive and that with recurrent activity (from the polar regions) is negative or nearly zero, whereas in antiparallel years these senses are reversed. The phenomenon is mainly confined to those areas where also the polarity-dependent semiannual fluctuation was found. This is a further refinement of the polarity conditions and a further evidence for the plasma processes. This alternating behaviour of the different types of activities affects the semiannual fluctuations too. If we consider those years when there was no recurrent activity we can investigate the pure effect of the activity belt. In this case we have found that the activity belt causes negative semiannual fluctuation in the antiparallel years which is in agreement with the negative correlation in Fig.4. for this interval (Baranyi and Ludmány, 1997).

4. Terrestrial conditions

Beyond the solar topology the mechanism also appears to be ifluenced by terrestrial circumstances. The effect presented in Fig.4. has ben tested on the entire Northern hemisphere (Baranyi et al. 1998), but the 712 stations under study would yield an enormous plot. In order to make it easier to survey, some criteria have been defined and the result is depicted in Fig.5. Actually, Fig.4. shows the European type of the phenomenon: in antiparallel years the terrestrial responses released by solar polar effects are more dominant than those released by solar equatorial ones (this is designated by empty circles in Figure 5.) and in parallel years the equatorial effects predominate (empty crosses), in other words, the European type of response means predominating polar effects in antiparallel years and predominating equatorial effects in parallel years. However, there are locations on the northern hemisphere where the opposite pairing prevails, i.e. equatorial predominance in antiparallel years (filled circles) and polar predominance in parallel years (filled crosses), for more precise terms see Baranyi et al, 1998. One can recognize a reasonably simple pattern on the northern hemisphere in Fig.5. The open marks (European type) are to be found mostly on the Eastern half of the region and the filled marks representing the opposite response are mainly Western features, there are a few exceptions. It may be interesting that the border separating the two areas lies close to the meridian crossing the Earth's magnetic pole.

5.Conclusions

To overview the present state of these studies we can summarize the reported evidences for the role of solar corpuscular events in the tropospheric processes.

1 The semiannual fluctuation indicates that the terrestrial impact depends on the mutual attitude of the solar and terrestrial magnetic axes, the mechanism may be related mainly to the Russell-McPherron effect.

2 The dependence of the semiannual fluctuation on the polarity of the solar main magnetic dipole field (in other words: the solar effect takes place only in case of favourable polarity conditions) probably indicates a reconnection mechanism.

3. Beyond the main field polarity the sense of the impact depends on the location of the source of the specific solar event, which is either the polar region or the activity belt. This is apparently a refinement of the 2. polarity condition.

4. The above mentioned 3. feature (dependence on the solar main polarity and solar types) also depends on the terrestrial location, its sense is opposite on the Western and Eastern hemispheres separated by the magnetic meridian.

Figure 5. Distribution of the investigated regularities on the northern hemisphere. In parallel periods the equatorial or polar predominances are marked with empty or filled crosses respectively; in antiparallel periods the polar or equatorial predominances are marked with empty or filled circles respectively. Combination of marks means combined effect. If none of the searched effects can be detected, the station is marked with a dot.

It should be added in all the above cases that "wherever the effect can be detected at all". In fact, there are regions where no effects can be pointed out, but the above features can be found on large unintermittent areas which seem to be related to certain global circulation patterns.

The 1-4. features are signatures of corpuscular events, the irradiance effects cannot depend on the mentioned conditions. This does not exclude mechanisms which are released by irradiance variations, both of them should be taken into account. The corpuscular paradigm needs a more sophisticated approach than that based on the irradiance. It is inappropriate to ask as to what is the consequence of a solar event. It should also be examined as to “when” (antiparallel or parallel dipole cycles cycles, solstice or equinox), “where” (close to the Icelandic Low or far from it, Eastern or Western hemisphere) and “which kind of event” (CME or recurrent stream). Confusion of these conditions may have led to mistakes in several cases of the early solar-terrestrial studies, as mentioned in the introduction.

Detailed interpretation would be premature at the present state of the work, but it can be remarked that these findings can be results of two known mechnanisms, which perhaps do not exclude each other. In both of them the effect of an alternating By component of the interplanetary magnetic field plays a decisive role. Tinsley (Tinsley et al., 1994; Tinsley, 1996) states that the main process of the effect of solar particles on atmospheric circulation is the change in Jz air-Earth current density due to solar wind modulation. Energetic particles, chemical and nucleation reactions as well as radiative flux changes modulate the atmospheric dynamics by modulating Jz. The By component contributes to the effect of Bz, forming the potential distributions across the polar cap. The potential variations imply variations in Ez and Jz there. Another scenario was published by Rostoker et al. (1980). They found an antiphase relationship between pressure variations associated with +/- and -/+ IMF sector boundary crossings. In their theory the main process is the ion drag and the By plays a decisive role through the Svalgaard-Mansurov effect. For By positive, there is an average northward electric field of about 50 mV/m existing across a strip of latitudinal extent of about 500 km and longitudinal extent of about 12 hours of local time centered at noon. When By is negative, the electric field is southward and the direction of the associated ion flows also reverses.

6. Importance of the historical databases

Finally, an interesting methodological property is worth mentioning. No direct data have been used in the course of the above studies. Wolf-numbers were used instead of irradiance (even the more plausible sunspot areas are proxy data); aa-indices instead of solar wind velocity; latitudes of prominences instead of solar (moreover: interplanetary) polarity changes; shapes of disturbances instead of solar events; lots of local temperatures instead of global circulation patterns. In such a way all necessary pieces of information were available in the form of proxy data since as early as 1868, when solar magnetic fields, solar wind and other interplanetary phenomena were not even conjectured.

This circumstance rends the historical observations very important and valuable. These investigations need long-term data which cover several polarity changes. The supply is not too abundant, lists of ancient aurora observations (Schröder, 1992) can contribute to the analysis besides the above mentioned data, furthermore, the sunspot group number defined and analysed by Hoyt and Schatten (1998) can replace the Wolf number in future studies. Recently most of the efforts in the Debrecen Observatory are devoted to produce a photoheliographic catalogue containing precise sunspot position and area data. This is the Debrecen Photoheliographic Data (formerly Debrecen Photoheliographic Results) which is a catalogue of sunspot positions and areas, a continuation of the classic Greenwich Photoheliograph Results. The other relevant major project of Debrecen is the Historical Solar Image Database, this material will comprise all historical solar full-disc observations, at least one image for each day, when observations have been made wherever in the world. This database will allow to obtain further informations of geoeffective relevance, such as the complexity of sunspot groups (as a measure of flaring probability, through McIntosh classification) and further aspects of the above mentioned North-South asymmetry which is also proven to be important for the solar-terrestrial relations.

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