COMPARATIVE STUDY OF THE ATMOSPHERIC EFFECTS DRIVEN BY IRRADIANCE VS. CORPUSCULAR RADIATION

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ABSTRACT

The overwhelming majority of the literature dealing with the solar-climatic effects treats the problem in terms of irradiance variations. The present contribution yields an overview of the rival paradigm: the role of the variations of plasma streams, and also demonstrates the necessity of distinction between the two possible energy channels. They can be confused in certain cases which may mislead the interpretation of the possible underlying mechanisms. The efficiency factors of the two solar energy channels are discussed, it is demonstrated that the corpuscular channel cannot be neglected, but in some respects it can be at least as important as the irradiance impacts. A reasonably convincing set of evidences has been published in our earlier papers a new kind of semiannual fluctuation as well as three polarity rules exhibited by atmospheric phenomena with respect to solar magnetic field polarities. The possible role of these polarities is discussed in terms of the interplanetary magnetic field components. This is partly controlled by the solar main magnetic dipole field, on the other hand it is also governed by the magnetic field topology of the CME's front region preserving the helicity of the originating active region.

INTRODUCTION

Lots of publications are devoted to the problem of the Sun-climate relations. Although this was the favourite topic of the early solar-terrestrial investigations, the progress was relatively small for a long time in this field. The possible reasons were also thoroughly investigated in several studies which revealed several components of the problem. The most remarkable feature of the early studies was a pure empirical approach, the authors simply looked for the signatures of the 11-year cycle in the time serii of any surface phenomena, or they studied their correlations with the Wolf numbers. It was a common property of most solar-climatic studies (admitted or not) that the irradiance variations were assumed to be responsible for the atmospheric impact. The use of the Wolf-numbers was an obvious choice in most cases because it is the longest homogeneous solar dataset. Two indirect meanings can be attributed to it. On one hand it simply represents the level of the solar activity which is an obvious simplification because a scalar quantity cannot give account about all relevant properties of the evolution of the magnetic features. On the other hand, as recent results show, the solar irradiance follows quite reliably the 11-year solar cycle (Fröhlich and Lean, 1998), so long-term investigations based on the Wolf-number concern the irradiance impacts. It was a popular index and very useful in providing evidences for the connections between solar phenomena and the lower atmosphere, although several methodological problems made some earlier studies contradictory (Pittock, 1978; Herman and Goldberg, 1978) and several findings cannot be explained with irradiance effects (Tinsley, 1996).

The starting assumption of our project was of paradigmatic nature. If one chooses some physical quantities to study, the basis of the choice is generally some preliminary conjecture about the unknown mechanism, a personal prejudice, if you like. The possibility of the role of corpuscular streams apparently used to be neglected without any satisfactory explanation. Thus it appeared appropriate to examine the impact and role of plasma effects to get closer to the underlying mechanisms. The monthly mean of Wolf-number may have a high correlation with some parameters of the plasma stream, so a plasma effect on the lower atmosphere might be detected by using it, but the interpretation would be mislead because the Wolf-number suggests irradiance effect. Thus it is highly necessary to distinguish between these two paradigms.

TWO CHANNELS OF SOLAR ENERGY

If plasma effects in the lower atmosphere were mentioned at all, they were commented as highly improbable because of the small amount of energy carried by plasma streams. It may be illuminating to compare the characters of the radiative and plasma effects. The following properties can be decisive in the efficiency of a solar impact.

Full amount of transported energy. In this respect the irradiance, no doubt, predominates overwhelmingly. The energy fluxes carried by the two medias at the mean Sun-Earth distance are:

electromagnetic: 1.36x $10^6 erg \cdot cm^{-2} \cdot s^{-1}$

corpuscular: $\sim 10^{-1} erg \cdot cm^{-2} \cdot s^{-1}$

which is a difference of seven orders of magnitudes, apparently a quite convincing electromagnetic predominance. However, this only means that the stationary energy budget of the atmosphere installed by

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the quiet Sun is basically determined by the electromagnetic flux.

Relative variance. This is a much more relevant indicator in the present context, the consequence of activity phenomena. If the stationary regime is set then the terrestrial response will depend on the deviation of the solar fluxes from the quiet values. The variation of the full elextromagnetic flux - the solar constant - is about a few thousandths of the stationary value whereas that of the flux carried by corpuscular streams may be hundreds of percents. The density increase of the corpuscular flux may be one order of magnitude and the velocity may have a fivefold growth. The electromagnetic variability is the highest in the short wavelength range, but this does not affect too much the full energy output and it affects mainly the upper atmospheric ionization. This means that if we consider the events of solar activity, the corpuscular channel cannot be neglected.

Temporal run. The efficiency of corpuscular phenomena is even more remarkable if we consider as to how well defined are the events temporally. The difference is also significant. The main ingredients of the solar constant variability are the faculae and spots. It takes several days for both of them to alter the solar constant by a few thousandths of the stationary value even in the most rapidly developing active regions or by turning in the visible hemisphere. At the same time it takes less than one hour for the plasma velocity and density to reach the mentioned increase. Thus the difference of temporal factors is about two orders of magnitude.

Spatial concentration. A further aspect is the distribution of the atmospheric energy input. The electromagnetic radiation is evenly distributed on the global surface whereas the corpuscular streams are confined to the terrestrial magnetic fields and they reach the lower layers in specific restricted areas in the auroral oval, so their distribution is highly inhomogeneous.

The above properties mean that, although the absolute value of the energy carried by the plasma streams is much lower than that of the irradiance, the plasma effects are much more concentrated in space and time and they deviate much more from the stationary value. This means that, at least on a short time scale, the plasma effects may be expected more efficient than those of irradiance. In other terms, on a longer timescale the total solar irradiance is responsible for the overall energy budget of the atmosphere, but on a shorter timescale the solar activity phenomena act mainly by means of the plasma streams. In this latter case the result is obviously no global temperature variation but some modification of the global atmospheric circulation. If a big amount of energy is input into a restricted volume within a short time then the expected result may be an alteration of the circulation patterns.

This expectation is corroborated by the finding which was only referred to for a while as a signature of plasma effects in the lower atmosphere. A specific variation of the vorticity area index (VAI) has been detected at those times when the Earth crossed interplanetary sector boundaries (Wilcox et al., 1973, Tinsley et al. 1994). This result showed that events of the interplanetary plasma may in fact have impact onto the lower atmosphere by means of reconnection processes.

CONDITIONS OF ATMOSPHERIC RESPONSES

Our strategy was to base the studies on as long datasets as possible. This meant that practically all physical quantities should have been described by some proxy data which were being recorded for a reasonably long time. Solar wind velocity data were represented by the geomagnetic aa-index (Mayaud, 1972); the atmospheric response was represented by surface temperature data (Vose et al., 1992); polarities of the solar main dipole field were determined by Makarov and Sivaraman (1986) on the basis of prominence positions; and finally, distinction was made between the solar sources of specific geomagnetic events on the basis of the time-profile analysis by Legrand and Simon (1989). These datasets allowed the analysis starting from the year 1868. The investigations revealed a very complex behaviour indicating a definite sensitivity of the atmosphere to the magnetic field topologies of solar plasmas. A brief overview of the findings is as follows.

1. A semiannual fluctuation was the first signature detected (Baranyi and Ludmány, 1992). We wanted to check the conjecture of Bucha (1976) about a winter predominance of corpuscular effects on the basis of Hungarian data and an equinoctial preference was found: the aa-index - temperature correlations are higher at equinoxes than around solstices.

2. The polarity-dependence of the semiannual fluctuation was the second signature (Baranyi et al. 1995, Baranyi and Ludmány, 1995a). On an extended material (a number of European meteorology stations) the semiannual fluctuation was only detected in those years when the solar dipole field was parallel with that of the Earth (figure 1.).

3. The dependence on solar sources is perhaps the most intriguing and complex feature. It was found (Baranyi and Ludmány, 1995b) that the sense of the atmospheric response given to the specific geomagnetic event depended on the solar location of the source ejecting the given plasma stream. In particular, plasma effects originating from the polar regions as well as from the activity belts, release opposite atmospheric changes. This feature also depends on the magnetic cycle. If the years of opposite solar main dipole field polarities are separated, then the senses of the atmospheric responses are exchanged. When the main dipole is parallel with that of the Earth then the correlation of temperature data is positive with events from the activity belts and it is negative with those coming from the polar coronal holes, and these senses are exchanged in antiparallel years (figure 2.).

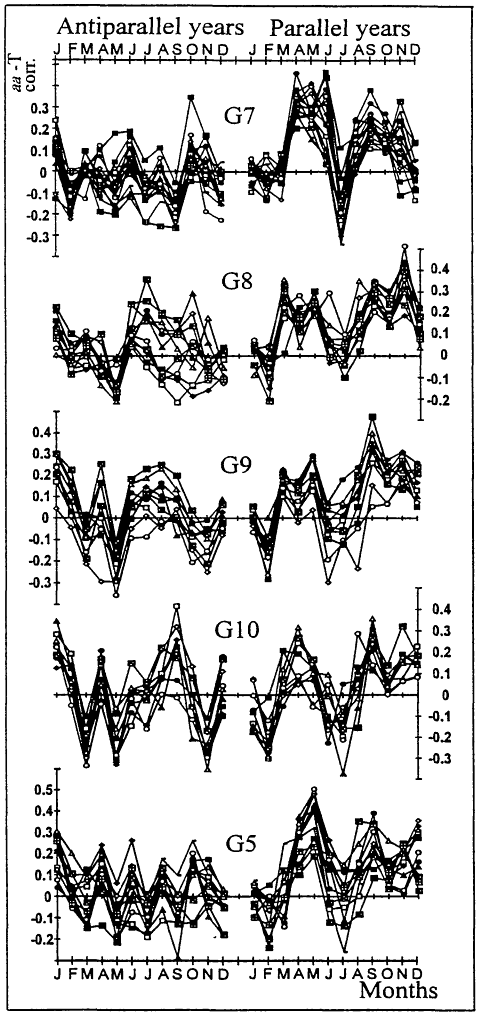

Figure 1: The polarity-dependent semiannual fluctuation. Annual variation of the efficiency of plasma effects at 58 European stations (taken from Baranyi and Ludmány, 1995a, names of the stations see therein), where the effect was recognizable. Regions of the groups of stations: G7: Great Britain, G8: France, G9: Germany-Austria, G10: Middle Europe, G5: Southern Scandinavia.

4. The sense of the terrestrial response is also site-dependent (Baranyi et al, 1998), opposite responses were found on the hemispheres separated by the magnetic meridian (the plane of rotational and magnetic axes).

It should be stressed that the above regularities are found on the datasets of 712 northern meteorological stations. It is not surprising that they are not valid everywhere. Stations exhibiting these rules constitute specific patterns, they are confined to powerful circulation features like the Icelandic Low. This is one of the most characteristic property of this set of rules

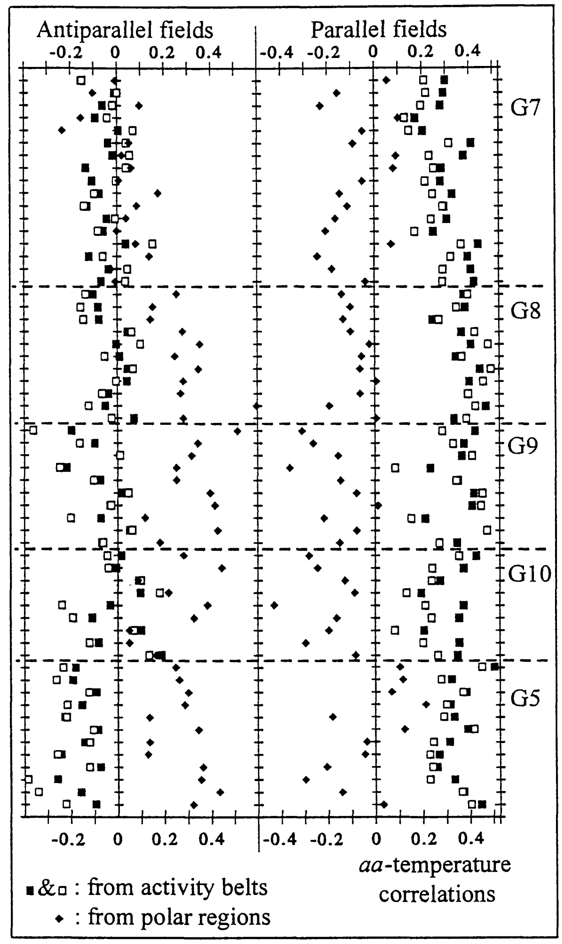

Figure 2: The polarity and source-dependent atmospheric response at the same 58 stations as in figure 1 (more details in Baranyi and Ludmány, 1995b)

also corroborating the corpuscular background because the corpuscular streams do not act globally and homogeneously, as mentioned in the previous section, but they reach the lower layers in relatively narrow regions and they can only contribute to or modify the existing circulation processes.

Studies based on the irradiance assumption were unable to interpret the disappearance of a correlation if it was checked on a different time-interval or geographic site, and an occasional sign reversal of a correlation was even more confusing. However, such phenomena are natural consequences of the highly complicated vectorial behaviour of the plasma effects, as the above properties demonstrate. This also means that a satisfactory description of the solar-tropospheric relations cannot be given by using only the scalar parameter of the irradiance.

VARIATIONS IN THE IMF

It is remarkable that the listed regularities reflect a systematic behaviour. To treat them in a consistent scenario, it is worth considering the possible role of the components of the interplanetary magnetic field as the solar plasma can interact with the terrestrial environment by magnetic field reconnections.

The first feature, the semiannual fluctuation may seem to be a consequence of the well known semiannual behaviour of the geomagnetic activity, but it is not. The latter is the enhancement of the geomagnetic disturbances around the equinoxes and the above reported fluctuation is the enhancement of the tropospheric response, i.e. the correlation. Nevertheless, they may have a common reason, the Russell-McPherron effect (Russell and McPherron, 1973), in which the Bz komponent plays a central role, as the By component of the inward as well as outward directed interplanetary magnetic field projects a negative Bz component in the magnetospheric system in March and September respectively. The main difficulty with the interpretation was that the above reported semiannual fluctuation takes place in those years when the dipole fields of the solar and terrestrial main magnetic fields are parallel and they are absent when the solar dipole field turns over, although one would expect the opposite effect by assuming reconnection interactions. The explanation can only be given by considering the rest of the listed regularities.

It is suitable to distinguish between the poloidal and toroidal components of the solar activity which are simultaneously present with varying weights and polarities (Legrand and Simon, 1991). The above results suggest that the roles of these two contributors are different in controlling the IMF components. The poloidal component of the IMF is provided by the solar wind from the quiet Sun and its variations (the recurrent variability) are given by the fast streams from the polar coronal holes, whereas the toroidal component is represented by the ejected plasma clouds. Variations of both components release different geomagnetic disturbances, this made possible to Legrand and Simon (1989) to distinguish between them, but the main ingredient, the Bz component should be negative by any geomagnetic events. An important difference between poloidal and toroidal events is in the way of producing negative Bz component.

The Bz components of the quiet solar wind and the fast recurrent streams in the Geocentric Solar Equatorial System (GSE) flucuate around zero at the distance of the Earth, the Bz component of these streams in the Geocentric Solar Magnetospheric System (GSM) is mainly realized through the projection effects of the By component which is highly significant because of the spiral structure. On the other hand the plasma clouds from active regions (causing the so called fluctuating geomagnetic activity) have intrinsic Bz component in the GSE. There is a growing number of evidences that significant plasma ejections originate mostly from distorted flux ropes, the helically kinked fields are the most probable sources of CMEs (Rust and Kumar, 1996; Canfield et al., 1999). In turn, the CMEs can transport the frozen-in helical topology of the source region (Bieber and Rust, 1995; Bothmer and Schwenn, 1999) thus the forefront of the inflating CME usually has significant Bz-values, which may also be increased by the inflation of the cloud for simple geometrical reasons (Felix Pereira and Girish, 1998). It should be added that by recent observations the magnetic field of the CME may be more complex than a single kinked flux rope (Kahler et al., 1999) but a dominant Bz component is generally present.

The 2-3 regularities (figure 2) can only be interpreted by some key factors which act reversely in the poloidal and toroidal events. This assumption has also been checked on the semiannual fluctuation in such a way that a further restriction was made on the datasets (Baranyi and Ludmány, 1997). Only those years were taken into account in both (parallel and antiparallel) orientations when no recurrent disturbances were observed, i.e. no effects from the polar coronal holes reached the terrestrial atmosphere and all disturbances could have been attributed to events from the activity belts. The sense of the semiannual fluctuation also alternated in the consecutive cycles, (like the 3-4 regularity) and the correlation with the streams from the activity belt showed negative extrema in antiparallel years.

The above considerations show that the differences between the IMF properties of the poloidal and toroidal events are quite well analysed (see also Gonzalez et al., 1996; Gonzalez et al., 1999) and it is apparently not surprising that they result in different atmospheric responses. The most unexpected feature of the 2 figure is that these two processes exchange their roles by the reversal of the solar dipole polarity. To reveal the key factor(s) of this exchange several properties of the incident streams have been examined in the parallel and antiparallel years but the obtained differences cannot be regarded to be decisive without further examinations excepting one factor, the By component. Though these results should be regarded to be preliminary as yet, it may be appropriate to mention here that the most conspicuous difference is exhibited by the occurrence probabilities of the oppositely directed By components. More details of this comparisons will be published elsewhere.

It is worth mentioning that the By component is a key factor in the modulation of global electric circuit and atmospheric circulation (Tinsley, 2000). Furthermore, the asymmetric behaviour of By may also be responsible for the above mentioned 4.feature, the E-W asymmetry of the atmospheric response.

CONCLUSIONS

Recent results support the common opinion that the irradiance is a key factor in long-term solar-climatic processes (Soon et al., 2000). However the present results and several here cited reports demonstrate that in short-term processes the importance of the plasma effects is not negligible, in some respects it may be decisive, for instance in affecting the atmospheric circulation patterns. The reported regularities and considerations may help in revealing the relevant factors and conditions from the solar surface until the atmosphere. Besides the mentioned global electric circuit, recent publications report some possible impacts, as the modification of the local pressure (Tóth and Szegedi, 2000) as well as the dominant pressure system and distribution of temperature and pressure deviations (Bohníček et al., 1999).

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