ON THE GEOEFFECTIVITY OF SOLAR ACTIVITY BEFORE THE SPACE ERA

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As a background reference for space weather issues, the space climate deals with variations of the solar, heliospheric, and geomagnetic activities at inter-annual, decadal, and centennial timescales. Geoeffectivity refers to geomagnetic activity, geomagnetic storms included, resulted from variations of solar outputs (solar eruptive phenomena, solar wind and magnetic fields). We present (1) an approach based on the correlation between the geomagnetic indices and parameters characterizing the solar wind, to reconstruct the evolution of the interplanetary merging electric field in the last 150 years, and (2) an approach on the variation of the geoeffectivity of solar activity in the last 400 years, based on the analysis of the *gufm1* (Jackson *et al.*, 2000) model for the main (core) geomagnetic field.

Key words: solar activity, solar wind, main (core) geomagnetic field models.

1. INTRODUCTION

The so-called space era in space weather studies began in the decade '50–'60 of the previous century, when space missions have been launched, destined to *in situ* measurements of parameters characterizing the solar wind and the interplanetary (heliospheric) magnetic field. The cause–effect relatioship between the solar activity and the geomagnetic one has been known for a long time; as a matter of fact, the study of some geomagnetic phenomena, such as the magnetic storms and substorms, bays, pulsations, together with solar observations and studies, made the progress in solar physics and the development of the solar-terrestrial science possible. The space era has brought a large volume of *in situ* data on the corpuscular and radiative outputs of the Sun, as well as on the heliospheric magnetic field in which the magnetosphere is embedded, on one hand, and on processes that develop in the Sun and at its surface, on the other. Data from geomagnetic observatories are used to calculate various geomagnetic indices that stand as proxies to describe the evolution of current systems that develop in magnetosphere and ionosphere as a result of interaction of the solar wind with the geomagnetic (magnetosphere) field. Such indices are Dst, for variations caused in the geomagnetic equatorial zone by the magnetospheric ring current, or AE (with derived AU, AO, AL indices), for the geomagnetic field variations caused by the ionospheric auroral electrojets. To characterize the interplanetary electric field, of importance for estimating the energy transferred from the solar wind to magnetosphere, the PC index is used. To describe the geomagnetic activity at midlatitudes the *aa* and Ap indices are used (Fig. 1). While for the *aa* index the timeseries begins at 1868, the other indices have much shorter series (Ap – 1932; Dst, AE – 1957; PC – 1980). Previous research (Demetrescu and Dobrică, 2008; Demetrescu *et al.*, 2010) showed that various geomagnetic indices correlate with each other, meaning that the current systems they describe vary in phase, indicating a common source, namely the solar dynamo. Svalgaard and Cliver (2005, 2007), Rouillard *et al.* (2007), Demetrescu *et al.* (2010) showed that geomagnetic indices IDV, IHV, and *aa* can be used, due to their correlation to the heliospheric magnetic field B, and respectively to the product BV^2, where V is the solar wind speed, as proxy for the temporal evolution of the two quantities (V and B) for the time period prior to space era.

In the present paper we show results that attempt to characterize the **space climate** (variations of the solar, heliospheric, and geomagnetic activities at inter-annual, decadal, and centennial timescales). We present (1) an approach based on the correlation between the geomagnetic indices and parameters characterizing the solar wind, to reconstruct the evolution of the interplanetary merging electric field in the last 150 years, and (2) an approach on the variation of the geoeffectivity of solar activity in the last 400 years, based on the analysis of the *gufm1* (Jackson *et al.*, 2000) model for the main (core) geomagnetic field.

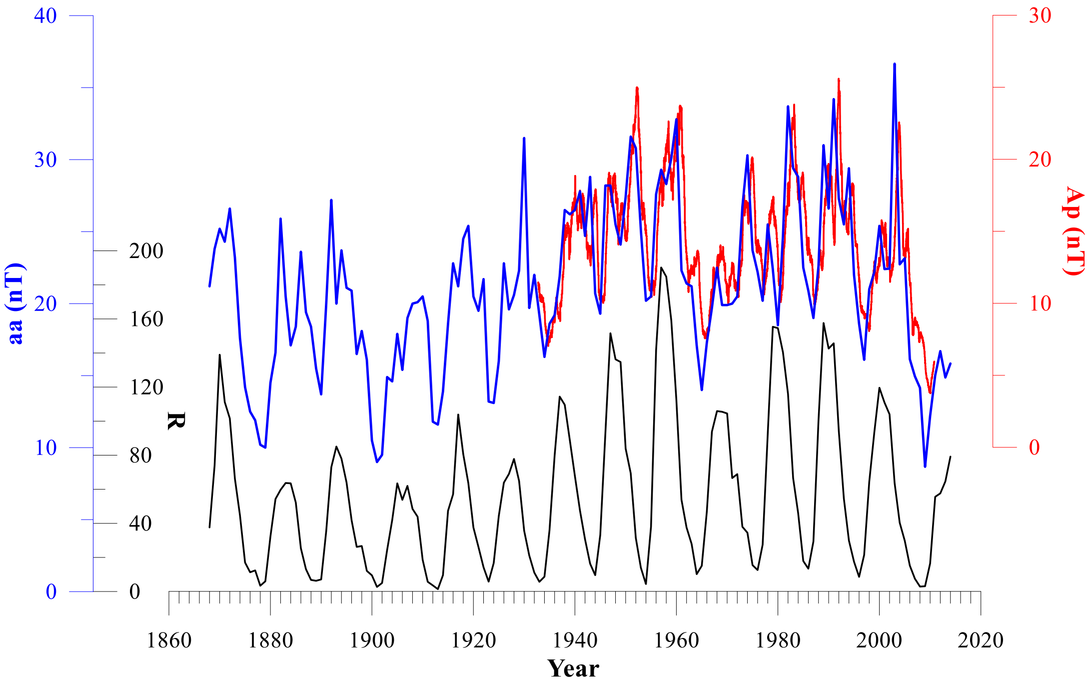

Fig. 1 – Evolution of geomagnetic activity (*aa* and Ap indices) as compared to solar activity (sunspot timeseries) for the last 150 years.

2. EVOLUTION OF THE INTERPLANETARY ELECTRIC FIELD IN THE LAST 150 YEARS

In this section we present results of analyzing the effects the variations in the merging interplanetary electric field Em (called geoeffective electric field) have on the magnetospheric and ionospheric current systems. Such effects could lead to dangerous disturbances of the geomagnetic and geoelectric fields (geomagnetic/geoelectric hazards). Em forms as a result of the solar wind charged particles motion in the presence of the interplanetary (heliospheric) magnetic field. In the analysis, the PC geomagnetic index was used as a measure of the merging electric field, in relation to other geomagnetic indices that describe the general disturbed state of magnetosphere and ionosphere (*aa* and Ap). The PC index has been recently defined (1980); it is built based on permanent recording of the geomagnetic field at the North polar cap station Thule of the Space Science Institute, Denmark, in such a way that following the statistical processing of the geomagnetic records and of solar wind and heliospheric magnetic field data, PC reflects the interplanetary geoeffective electric field Em, PC~Em = $V_{SW}*B_T*(\sin(q/2))^2$, where q = acos (B_z/B_T). In terms of annual averages, the correlation between Em and PC amounts to 94% (Fig. 2).

We now look at the correlation of instrumentally determined PC with geomagnetic indices *aa* and AE. These correlations are shown in Fig. 3, in terms of annual averages, and amount to 92 and, respectively, to 90%. The corresponding linear relations are indicated on each plot.

Based on them, the PC index and consequently the merging electric field can be reconstructed back to 1868, based on the *aa* index, and back to 1958, based on the AE index.

The result is shown in Fig. 4, confirming that at inter-annual time scale the evolution of the magnetospheric and ionospheric current systems is similar.

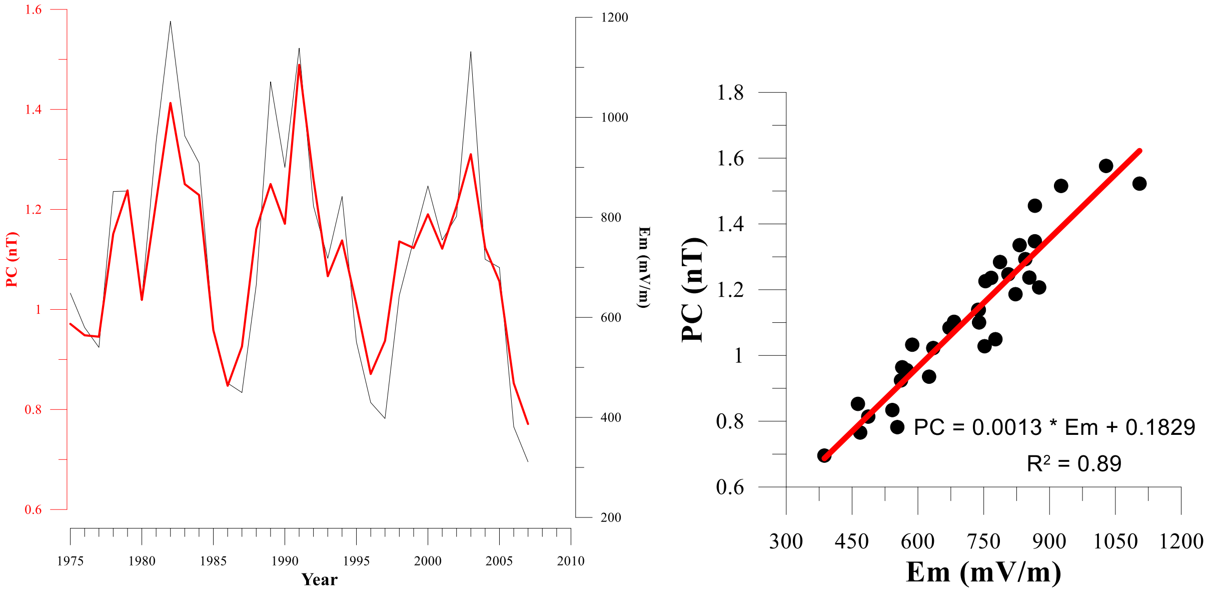

Fig. 2 – Evolution of PC index and geoeffective electric field, Em (left) and the scatter plot between them (right) (http://PCindex.org/).

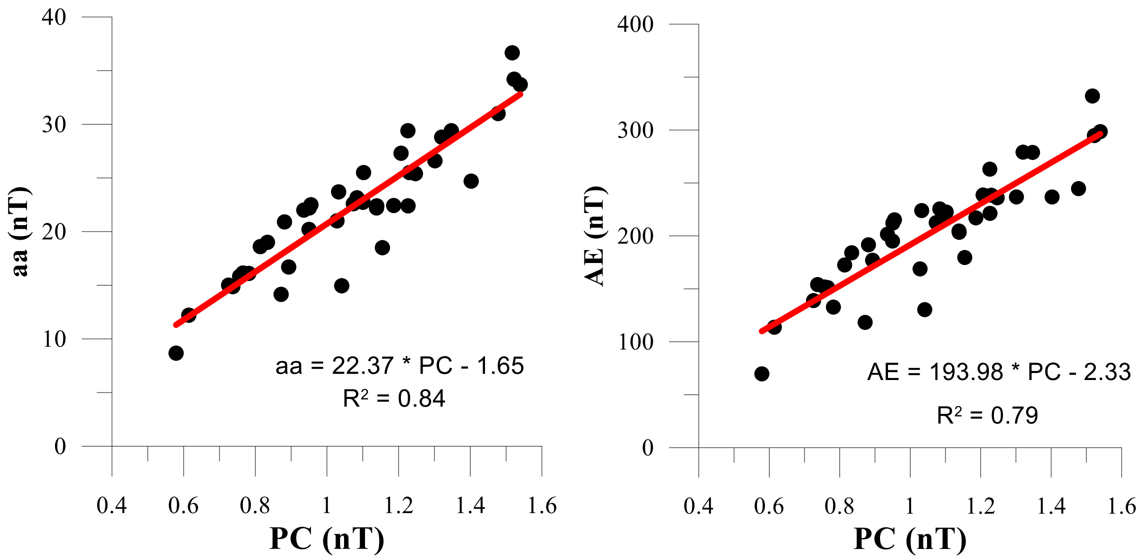

Fig. 3 – Correlation plots between PC index and geomagnetic indices *aa* (left) and AE (right).

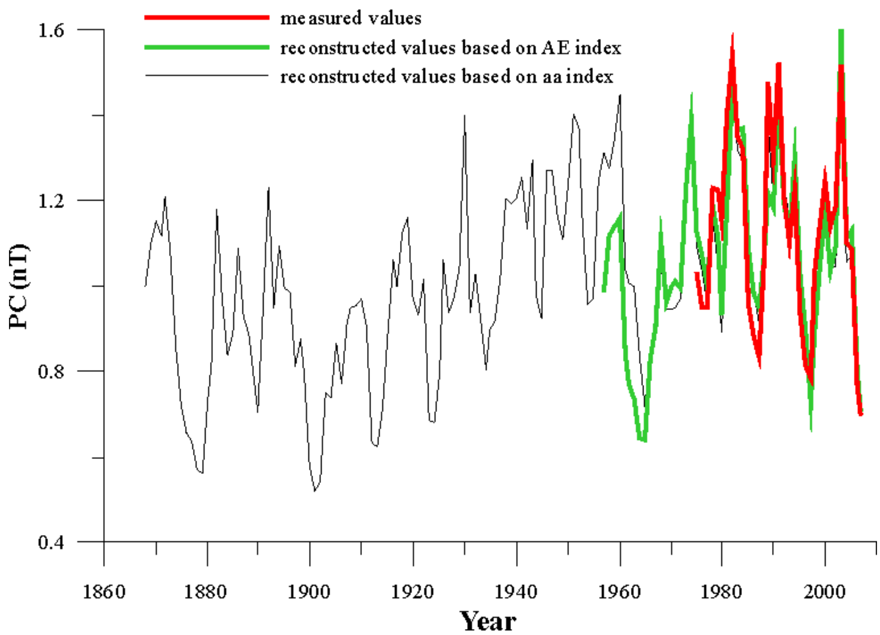

Fig. 4 – Reconstruction of the PC index, based on AE and *aa* indices.

3. ON THE GEOEFFECTIVITY OF SOLAR ACTIVITY IN THE LAST 400 YEARS

The research we shortly present in this section is based on two observations regarding some models for the main (core) geomagnetic field, namely: (1) the annual mean values of geomagnetic elements provided by geomagnetic observatories, that are the input in modeling, are contaminated by the incomplete averaging out of geomagnetic storm effects, leading to a solar-cycle-related variation in data; (2) the contribution of external sources (mainly the magnetospheric ring current) to annual mean values is also found in the coefficients of the spherical harmonic model that represents the surface field distribution, if variations of external origin are not eliminated from the input data of the model.

We used the *gufm1* (Jackson *et al.*, 2000) model, by which the evolution of the geomagnetic field for the time interval 1590–1990 is obtained. The model allows the construction of the timeseries for any given point on the Earth's surface. From such timeseries the constituent at the decadal timescale, considered by us as generated by external sources, mainly by the magnetospheric ring current, is extracted by filtering (Hodrick and Prescott, 1997). In Fig. 5 we show such a timeseries, for the location of the Niemegk geomagnetic observatory, choice that allows also a comparison with measured values. An examination of the cyclic component of the analysed timeseries reveals two regimes, namely one at the 11-year timescale back to ~1860, and one at the ~22-year timescale, back to 1590. The latter shows an attenuation going back in the past, which is to be expected as the model strongly attenuates older information. However, when compared to sunspot number timeseries, the signal in the geomagnetic one shows the presence of the geomagnetic activity during the well known solar activity minima (Maunder, 1645–1715, and Dalton, 1790–1830), that demonstrates the existence of solar cycles even in times of strongly decreased solar activity (Fig. 6). The sunspot number timeseries available at http://www.sidc.be/silso/datafiles, is completed for the time interval 1590–1700 with reconstructed values, available at http://www.gao.spb.ru/database/esai, by Nagovitsyn *et al.* (2004).

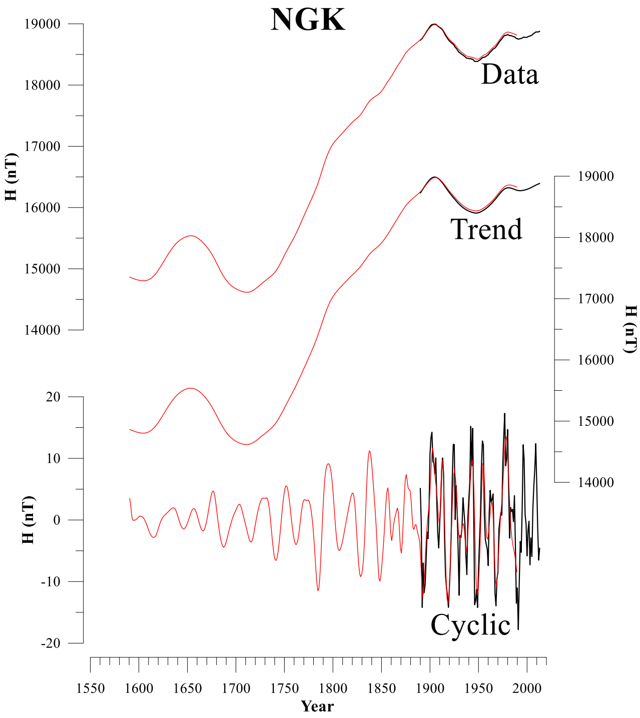

Fig. 5 – Data, trend and variation at decadal timescale, related to the solar cycle modulated geomagnetic activity, for the location of the Niemegk geomagnetic observatory. Black – measured values; red – calculated values (*gufm1*).

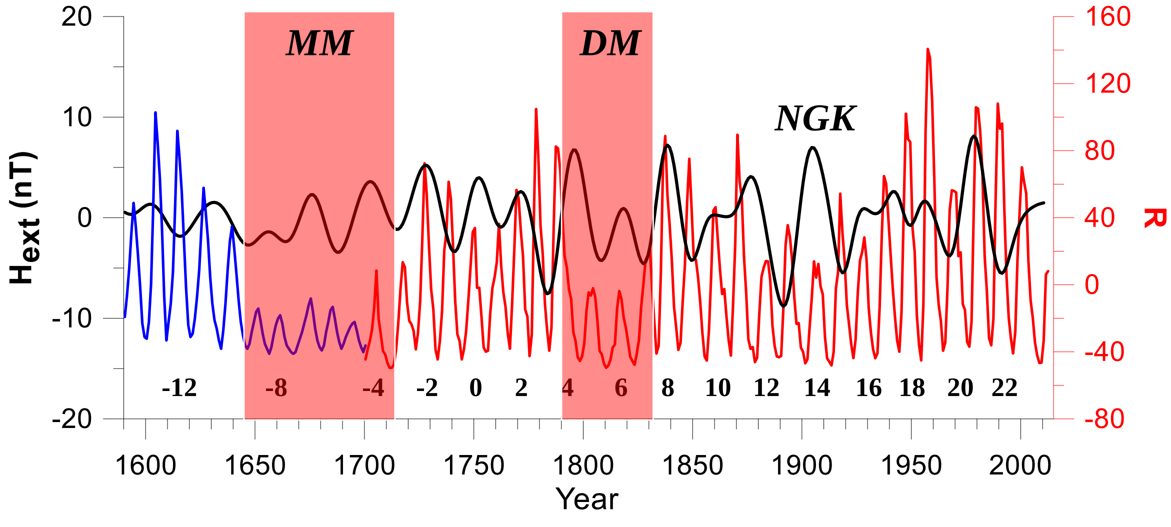

Fig. 6 – Comparison of the external signal at NGK (black) with the observed (red) and reconstructed (blue) sunspot number. MM – the Maunder Minimum, DM – the Dalton Minimum of the solar activity.

The preliminary result of this study opens new perspectives on research regarding the space climate and space weather, that will be continued and developed in future papers.

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