Mem. S.A.It. Vol. 76, 969

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Once again about global warming and solar activity

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Abstract. Solar activity, together with human activity, is considered a possible factor for the global warming observed in the last century. However, in the last decades solar activity has remained more or less constant while surface air temperature has continued to increase, which is interpreted as an evidence that in this period human activity is the main factor for global warming. We show that the index commonly used for quantifying long-term changes in solar activity, the sunspot number, accounts for only one part of solar activity and using this index leads to the underestimation of the role of solar activity in the global warming in the recent decades. A more suitable index is the geomagnetic activity which reflects all solar activity, and it is highly correlated to global temperature variations in the whole period for which we have data.

Key words. Solar activity, Global warming

1. Sunspot number and global temperature

The most popular index of solar activity is the International sunspot number (*R*). A reconstruction of the yearly averaged of *R* based on sunspot group (Hoyt & Schatten 1998) is available since 1610. No other solar activity index reaches into the past as far and as continuously, so it is natural to use *R* to study the long-term phenomena like climate change. In Figure 1 the global temperature anomalies (deviations from the values in the base period 1961-90) from the Climatic Research Unit (Jones and Moberg 2003) are compared to *R*. While in the beginning of the period global temperature closely follows the variations in *R*, in the last decades *R* decreases while the temperature continues increasing. This has provided arguments in favor of the anthropogenic impact on the global warming (e.g. Solanki and Fligge 1998).

2. Mechanisms for solar influences on climate

Three main groups of mechanisms have been proposed to explain how changing solar activity can influence the climate:

1) variations in the total solar irradiance leading to variations in the direct energy input into the Earth's atmosphere (Cubasch and Voss 2000);

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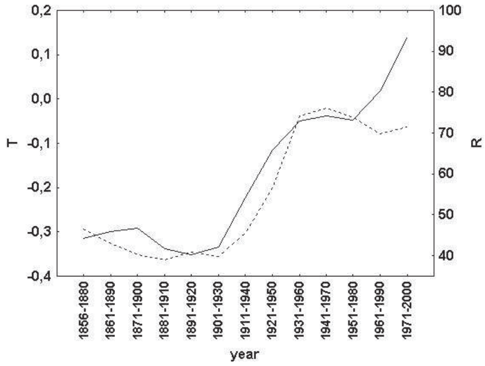

Fig. 1. Global temperature anomalies *T* (solid line) and International sunspot number *R* (broken line) for the period 1856-2000; climatic normals.

2) variations in solar UV irradiance causing variations in stratospheric chemistry and dynamics (Hood 2003);

3) variations in solar wind modulating cosmic ray flux which affects the stratospheric ozone and small constituents (Veretenenko and Pudovkin 1999) and/or the cloud coverage (Svensmark and Friis-Christensen 1997), and thus the transparency of the atmosphere.

How well does the sunspot number reflect the variations in solar irradiance and solar wind? Sunspots themselves are not geoeffective. Geoeffective are the solar active regions in which sunspots are embedded. These are regions of strong magnetic field with closed field lines geometry (magnetic flux tubes). The brightness of the flux tubes (and hence the solar irradiance) depend on the magnetic field strength which also determines the number of sunspots, so there is a linear relationship between sunspot number and irradiance (Fligge and Solanki 2000). When flux tubes become unstable, they erupt and give rise to solar flares and/or coronal mass ejections (CMEs). The most intense geomagnetic disturbances in both sunspot minimum and sunspot maximum are generated by CMEs (Richardson et al. 2001), and their number and the velocity of the solar wind associated with them follow the sunspot cycle (Gopalswamy et al. 2003), so the sunspot number can be considered a good measure of the solar wind originating from closed magnetic field regions. Especially geoeffective are magnetic clouds (MCs) - a subclass of CMEs distinguished by the high magnetic field magnitude and the smooth magnetic field rotation inside the structure (Georgieva and Kirov 2005). CMEs, however, are not the only source of high speed solar wind. Early in the 20^{th} century it was noticed that many geomagnetic storms occur without any visible solar disturbance. Such storms tend to recur every 27 days - the period of solar rotation, therefore they originate from long-living regions on the Sun which come back into geoeffective position rotation after rotation. Only when X-rays telescopes were flown above the atmosphere it was found out that are large regions of open magnetic field geometry, and sources of high speed solar wind. They are now known as Coronal Holes (CHs) because, due to their lower density and temperature compared to the surrounding corona, they look darker in X-rays.

3. CMEs, MCs and CHs

We will now compare the properties and geoeffectiveness of the two types of solar drivers - Hight Speed Streams (HSSs) from coronal holes, and CMEs, additionally dividing the CMEs into two types - MCs and non-MC CMEs (which we will further denote as simply CMEs). Our study covers 11 years, from 1992 to 2002. In this period we have 92 MCs (Georgieva et al. 2005) and 128 CMEs from the list of Cane and Richardson (2003) from which all events identified as MCs have been removed and 126 CHs identified in the OMNI database (http://nssdc.gsfc.nasa.gov/ omniweb). Figure 2 presents a comparison of the mean solar wind speed for the three types of solar drivers while Figure 3 shows the solar cycle variation of their speed.

Figure 2 demonstrates that the speed of the solar wind originating from CHs is much higher than of the solar wind associated with CMEs and MCs. The yearly averaged speed of solar wind from CHs and MCs are comparable around sunspot maximum, and higher than the speed of CMEs, and everywhere outside sunspot maximum the fastest solar wind orig-

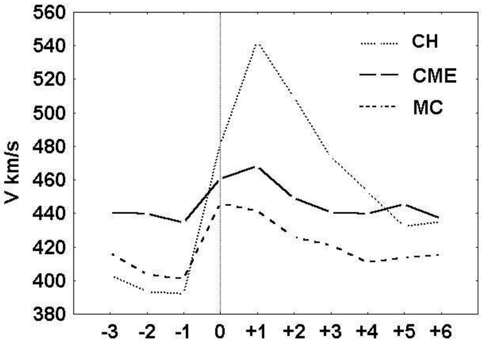

Fig. 2. Average solar wind speed relative to the days of registration at the Earth's orbit of CH, CME and MC.

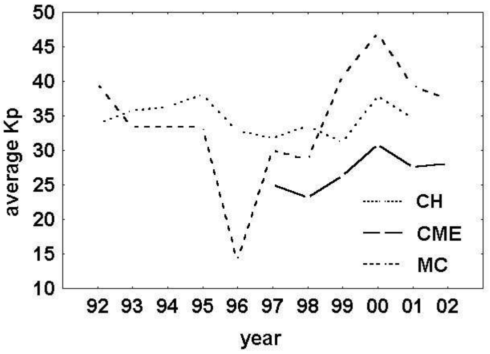

Fig. 4. Solar cycle variations of the average geo-effectiveness of solar wind from CHs, MCs and CMEs.

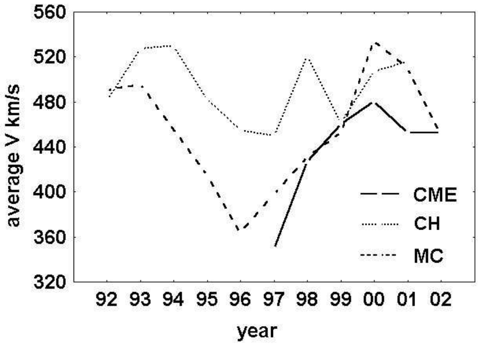

Fig. 3. Solar cycle variations of the speed of solar wind associated with CHs, CMEs and MCs.

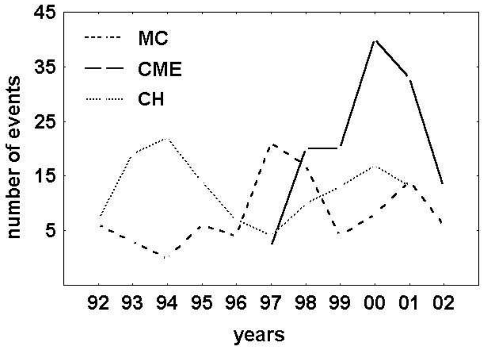

Fig. 5. Yearly number of CHs, MCs and CMEs.

inates from CHs (Figure 3). Similarly, the average geoeffectiveness of solar wind from CHs is highest outside sunspot maximum (Figure 4) while around sunspot maximum the most geoeffective solar driver are MCs.

The real terrestrial impact of the different solar drivers depends not only on the average geoeffectiveness of a single event but also on the number of events. Figure 5 presents the yearly number of CHs, CMEs and MCs in the period 1992-2002. On the descending phase of the sunspot cycle, the greatest part of high speed solar wind streams affecting the Earth comes from coronal holes (Figure 5), in this period their speed is higher than the speed of the solar wind originating from other regions, and their geoeffectiveness is the highest. Therefore, when speaking about the influence of solar activity on the Earth, we cannot neglect the contribution of the solar wind originating from coronal holes. However, these open magnetic field regions are not connected in any way to sunspots, so their contribution is totally neglected when we use the sunspot number as a measure of solar activity.

4. Discussion

The geomagnetic activity reflects the impact of solar activity originating from both closed and open magnetic field regions, so it is a better indicator of solar activity than the sunspot number which is related to only closed magnetic field regions. It has been noted that in the last century the correlation between sunspot number and geomagnetic activity has been steadily decreasing from - 0.76 in the period 1868-

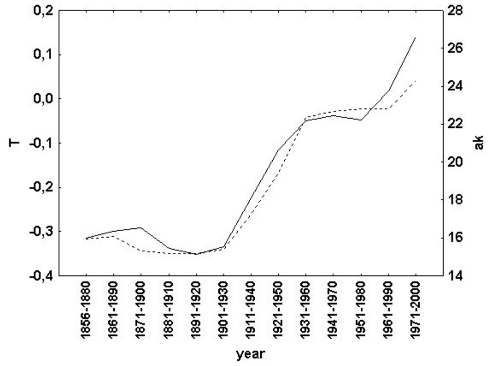

Fig. 6. Global temperature anomalies *T* (solid line) and *ak* index of geomagnetic activity (broken line) for the period 1856-2000; climatic normals.

1890, to 0.35 in the period 1960-1982, while the lag has increased from 0 to 3 years (Vieira et al. 2001). According to Echer et al. (2004), the probable cause seems to be related to the double peak structure of geomagnetic activity. The second peak, related to high speed solar wind from coronal holes, seems to have increased relative to the first one, related to sunspots (CMEs) but, as already mentioned, this type of solar activity is not accounted for by the sunspot number. In Figure 6 the long-term variations in global temperature are compared to the long-term variations in geomagnetic activity as expressed by the ak-index (Nevanlinna and Kataja 2003). The correlation between the two quantities is 0.85 with $p<0.01$ for the whole period studied.It could therefore be concluded that both the decreasing correlation between sunspot number and geomagnetic activity, and the deviation of the global temperature long-term trend from solar activity as expressed by sunspot index are due to the increased number of high-speed streams of solar wind on the declining phase and in the minimum of sunspot cycle in the last decades. So the sunspot number is not a good indicator of solar activity, and using the sunspot number leads to the under-estimation of the role of solar activity in the global warming.

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