Gnevyshev peaks in geomagnetic indices

R.P. Kane*

Instituto Nacional de Pesquisas Espaciais, C.P. 515 São José dos Campos, 12201-970 SP, Brazil

A R T I C L E   I N F O
Article history:
Received 18 May 2009
Received in revised form 1 December 2009
Accepted 2 December 2009
Available online 21 December 2009

Keywords:
Gnevyshev peaks
Geomagnetic indices
Cycle 23
Dst

A B S T R A C T
Sunspots have a major 11-year cycle, but the years near the maximum show two or more peaks called Gnevyshev peaks. It was noticed that in cycle 23, the double peaks in sunspot numbers are reflected in the electromagnetic radiations and coronal mass ejections (CMEs) in the solar atmosphere. But, in the interplanetary space, the ICMEs (interplanetary CMEs) show peaks not all coinciding with the peaks of sunspot numbers. Also, there are stream interaction regions (SIR), including co-rotating interaction regions (CIR), which evolve quite differently from sunspot numbers. In the geomagnetic indices, the peaks are related mainly to the peaks in SIRs, indicating that geomagnetic indices have no direct relationship with most of the phenomena at the Sun but are responding only to the interplanetary blobs due to SIRs, which are more predominant in the declining phase of sunspot activity.

© 2009 Elsevier Ltd. All rights reserved.

1. Introduction

Sunspots have a major 11-year cycle. However, the maximum is not smooth but structured. Two or more peaks can be identified during the solar maximum years. This splitting of activity was identified for the first time in the green corona line intensity data by Gnevyshev (1967, 1977) and later for several solar and interplanetary phenomena (details in the review by Storini et al., 2003). In recent publications (Kane 2006, 2007; 2008a, 2008b, 2008c), it was pointed out that these Gnevyshev peaks have a solar latitude dependence, with peaks shifting with time from higher to lower latitudes as in the Maunder butterfly diagram, and the peaks in sunspots are similar to those in other electromagnetic radiations (2800 MHz flux, X-ray background, etc.), but may differ in number and time location for some other parameters like coronal mass ejections (CMEs), solar open magnetic flux, etc.

In the present communication, the geomagnetic indices Dst, Ap, AU, AL, AE are examined to see whether these show multiple Gnevyshev peaks during years around sunspot maximum of cycle 23. Most of the data are obtained from the NOAA website, but some others are obtained from other sources as mentioned at appropriate places.

2. Plots

Since monthly values varied erratically, 12-month running means were evaluated. Fig. 1 shows the plots of the 12-month running means, four values per year, centered at January, April, July and October. The following is seen:

1. The top plot is for sunspot numbers Rz and shows two distinct peaks, one at April 2000 and another at January 2002. These are marked by vertical lines.
2. The next three plots are for solar electromagnetic radiations, namely, Lyman-α (121.6 nm, chromospheric, data in ftp://lasftp.colorado.edu/pub/solstice/composite_lya.dat), the 2800 MHz radio emission F10 (10.7 cm), and the coronal green light (530.3 nm, Rybansky et al., 2005, data in http://www.ta3.sk/data/coronal/index). The F10 shows double peaks like sunspots, but Lyman-α and Coronal green show only the second peak prominently, while the first peak is obscure, marked on a set of constant values with no clear minimum between the first and the second peak.
3. The next two plots are for CME (coronal mass ejections, all CMEs as well as their subset halo CMEs (Gopalswamy, 2006). Both these show Gnevyshev peaks similar to those of sunspot numbers.
4. When CMEs travel from the Sun to the Earth, a considerable distortion and modification occurs. The plot of ICME (interplanetary CME, private communications from Hilary Cane and Nat Gopalswamy) shows only the first Gnevyshev peak (http://cdaw.gsfc.nasa.gov/CME_list/UNIVERSAL/2005_02/univ2005_02.html)
5. Besides the CMEs, another solar emission is from coronal holes. These are fast solar wind streams unrelated to CMEs or sunspots. When these impinge on the ambient slow solar wind in interplanetary space, shock fronts are formed. These are termed stream interaction regions (SIRs; Jian et al., 2006). Because of solar rotation, these fronts get distorted and a subset of these, those that survive more than one solar
rotation of 27 days, are termed co-rotating interaction regions (CIRs). As can be seen, their solar cycle evolution is very different from that of sunspot numbers. The maximum does not occur near sunspot maximum but much later, in the declining phase. This is because the coronal holes start in the polar regions and their effect on interplanetary space is seen more when they move to the solar equatorial plane in the declining phase of solar activity.

(6) The next plot is for open magnetic fields (Wang and Sheeley, 2002). The plot does show two peaks but these are slightly displaced, one occurring before the first peak in sunspot numbers and the other occurring later than the second peak of sunspot numbers.

(7) Further plots are for geomagnetic indices, AU, AL, AE in the auroral region and the conventional Dst and Ap indices (data from the website http://swdcwww.kugi.kyoto-u.ac.jp/dstae/index.html). For indices having all negative values, for example Dst and AL, the vertical scale is reverse, so that troughs look like maxima). These do show peaks but for AU, AE, Ap, Dst, the first one occurs earlier than sunspot numbers, while the second one occurs much later than the second peak of sunspot numbers. (For Ap and Dst, the first peak is somewhat obscure.) For AL, the peaks are split. The second peak occurs simultaneously with a peak in SIR in the middle of 2003. Also, there is a third peak, occurring simultaneously with a peak in halo CMEs at the end of 2004.

Table 1 gives the inter-correlation matrix.

### Table 1: Inter-correlation matrix for the various parameters plotted in Fig. 1

<table>
<thead>
<tr>
<th></th>
<th>Sunspots</th>
<th>Lyman α</th>
<th>F10</th>
<th>Cor. green</th>
<th>CME</th>
<th>ICME</th>
<th>SIR</th>
<th>Open mag</th>
<th>AU</th>
<th>− AL</th>
<th>AE</th>
<th>Ap</th>
<th>− Dst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunspots</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lyman α</td>
<td>0.96</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F10</td>
<td>0.98</td>
<td>0.98</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cor. green</td>
<td>0.96</td>
<td>0.97</td>
<td>0.98</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CME</td>
<td>0.87</td>
<td>0.90</td>
<td>0.91</td>
<td>0.87</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICME</td>
<td>0.63</td>
<td>0.56</td>
<td>0.53</td>
<td>0.50</td>
<td>0.38</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIR</td>
<td>−0.15</td>
<td>−0.09</td>
<td>−0.03</td>
<td>−0.06</td>
<td>0.19</td>
<td>0.75</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open mag</td>
<td>0.71</td>
<td>0.64</td>
<td>0.73</td>
<td>0.68</td>
<td>0.78</td>
<td>0.04</td>
<td>0.51</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AU</td>
<td>0.22</td>
<td>0.16</td>
<td>0.25</td>
<td>0.16</td>
<td>0.43</td>
<td>−0.24</td>
<td>0.68</td>
<td>0.75</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>− AL</td>
<td>−0.13</td>
<td>−0.11</td>
<td>−0.06</td>
<td>−0.09</td>
<td>0.16</td>
<td>−0.52</td>
<td>0.73</td>
<td>0.44</td>
<td>0.82</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AE</td>
<td>0.05</td>
<td>0.01</td>
<td>0.10</td>
<td>0.03</td>
<td>0.30</td>
<td>−0.38</td>
<td>0.72</td>
<td>0.64</td>
<td>0.96</td>
<td>0.93</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ap</td>
<td>0.03</td>
<td>−0.01</td>
<td>0.07</td>
<td>0.01</td>
<td>0.26</td>
<td>−0.34</td>
<td>0.66</td>
<td>0.58</td>
<td>0.93</td>
<td>0.94</td>
<td>0.99</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>− Dst</td>
<td>−0.25</td>
<td>−0.26</td>
<td>−0.20</td>
<td>−0.28</td>
<td>0.08</td>
<td>−0.50</td>
<td>0.71</td>
<td>0.36</td>
<td>0.78</td>
<td>0.88</td>
<td>0.87</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

3. Conclusions and discussion

The double Gnevyshev peaks in sunspot numbers are seen in the electromagnetic radiations and coronal mass ejections (CMEs) in the solar atmosphere up to the lower and middle corona. The correlation is high (0.90 ± 0.03).

In the interplanetary space, the ICMEs show a first peak coinciding with the first peak of sunspot numbers, but there is no ICME peak corresponding to the second peak of sunspot numbers. Instead, ICME has its second peak much later, in the end of 2004, when sunspot activity declined considerably. The correlation for ICME with other parameters is moderate (0.63 ± 0.11).

There are stream interaction regions (SIR) (including co-rotating interaction regions CIR), which evolve quite differently from sunspot numbers and have a peak in the middle of 2003 during the declining phase of sunspot numbers. The correlation of SIR with other solar parameters is almost zero, and with ICME, even negative.

Open magnetic field is moderately well related to other solar parameters (0.70 ± 0.09), but zero correlated with ICME and poorly correlated with SIR (0.51 ± 0.13).

Geomagnetic indices have a first peak before the first sunspot peak, no peak corresponding to the second peak of sunspot numbers, a second peak in the middle of 2003 coinciding with a peak in SIR, and a third peak coinciding with a third peak in halo CMEs, at the end of 2004, well into the declining phase of sunspot numbers. The correlation is good with SIR (0.70 ± 0.09) and with open magnetic field (−0.60 ± 0.11).

Thus, the peaks in the geomagnetic indices are well related only to the peaks in SIRs. This shows that geomagnetic indices
have no direct relationship with most of the phenomena at the Sun, and are responding only to the interplanetary blobs, mainly of the stream interaction regions SIRs, when these engulf the Earth predominantly in the declining phase of sunspot activity. As such, fine structures like the Gnevyshev double peaks and gaps near sunspot maximum are not expected to be seen in geomagnetic indices unless the Gnevyshev peaks are reflected in ICMEs and/or SIRs, which they are not. ICMEs have only one prominent peak coinciding with the first peak of sunspots, etc., while SIR activity is in the declining phase of sunspot activity and geomagnetic indices are responding mainly to the SIRs.

Acknowledgement

This work was partially supported by FNDCT, Brazil, under contract FINEP-537/CT.

References


