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Signature of Hale and Gleissberg solar cycles in the geomagnetic activity

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[1] The *aa* index, designed to describe the geomagnetic activity at global scale, has been shown to have increased in the twentieth century by about 65%. The increase in the case of a corrected *aa* is about 38%, similar to the ones of the recently introduced interhour variability (IHV) and interdiurnal variability (IDV) indices of geomagnetic activity. In terms of 11-year running averages, there is a long-term similarity between *aa*, *R* (the sunspot number), *x, y, z,* and *r* (geomagnetic indices designed to characterize the solar quiet daily variation, controlled by the solar UV radiation), and S (the solar irradiance). We show that the variation depicted by 11-year running averages of *aa* and *R* (and by consequence also of the other parameters mentioned) results from the superposition of Hale and Gleissberg cycle signatures in the corresponding time series. The IHV and IDV indices are included in the analysis. The two signals have a substantial contribution in *R* (10–30% and 20–34%, respectively, of the amplitude of the solar cycle 22) and *aa* (<12–27% and ~30%, respectively, of the corresponding cycle 22 in *aa*). Characteristics of the two signals in the solar and geomagnetic activity and several implications of the geomagnetic activity and the solar quiet daily variation relationship with various solar outputs at the Hale and Gleissberg timescales are discussed.

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1. Introduction

[2] It has long been recognized that the solar activity is at the origin of the geomagnetic activity. The latter is the result of variable current systems formed in the magnetosphere and ionosphere as a consequence of the interaction of the solar wind with the magnetosphere and is described quantitatively by means of so-called geomagnetic indices [see, e.g., *Campbell*, 2003]. Among the indices designed to provide a global picture of the degree of disturbance level the *aa* index [*Mayaud*, 1972, 1980] covers the longest time span (the time series starts in 1868) and is well suited as a proxy of geomagnetic activity in long-term studies. This index has been compiled from the range of variations of the geomagnetic field over periods of 3 h (the *K* index) at two near-antipodal observatories in England and Australia; by definition, the solar quiet time variation, S_q, is removed from the data.

[3] The long-term behavior of the geomagnetic activity and its resemblance to the long cycle in the solar activity, as well as peculiarities of the 11-year cycle of *aa*, such as the second peak in the declining phase of the sunspot cycle and the increase of the minimum values during the twentieth century, have been discussed by several authors. In terms of 11-year running averages the long-term similarity between *aa* and *R* was pointed out, for instance, by *Feynman and Crooker* [1978], *Feynman* [1982], *Silverman* [1992], and *Cliver et al.* [1998]. Such studies were reviewed by *Stamper et al.* [1999] in an attempt to analyze the causes of the century-long increase in geomagnetic activity using near-Earth interplanetary measurements made during the solar cycles 20–22 (1964–1996). Their main conclusion was that the upward drift in geomagnetic activity is caused by heliospheric conditions at 1 AU, represented by the interplanetary magnetic field (IMF) strength, the solar wind speed, and the solar wind density. A latitudinal dependence of the geomagnetic activity was found by *Mursula et al.* [2004] and *Mursula and Martini* [2005] on the basis of the interhour variability index (IHV), introduced by *Svalgaard et al.* [2004] to avoid certain calibration problems related to *aa*. *Svalgaard and Cliver* [2007] developed a global (composite) IHV index, linked to the product BV^2, where *B* is the IMF strength and *V* is the solar wind velocity at 1 AU. Recently, a new global geomagnetic activity index, the interdiurnal variability (IDV) index, which is linked only to the IMF strength, has been devised by *Svalgaard and Cliver* [2005]. The IHV index is defined as the sum of differences, without regard to sign, of hourly means for a geomagnetic component from one hour to the next over the 6-h interval around local midnight where the solar daily variation is absent or minimal. The global (composite) IHV index is obtained from IHV given by about 70 individual observatories equatorward of 55°, grouped in longitudinal sectors, as a mean over 27-d Bartels rotations, ultimately normalized to the IHV series from the German station Potsdam-Seddin-Niemegk, covering the 1890 to present

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time interval. The IDV index is defined as the unsigned difference between two consecutive days of the average value of the geomagnetic component for the first hour after local midnight. While *aa* and similar indices (e.g., *am*) are geomagnetic range indices, IHV and IDV are variability indices. It has been shown [*Svalgaard and Cliver*, 2007] that IHV can be used as a long-term proxy for *am*, which is available only from 1959, considered as the best range index. A comparison of IHV with *aa* [*Svalgaard and Cliver*, 2007] shows that *aa* is too small by about 3 nT before 1957. The *aa* and *am* indices react to heliospheric conditions the same way as IHV.

[4] *Le Mouël et al.* [2005] introduced simple geomagnetic indices, *x, y, z*, and *r*, defined as the daily ranges based on hourly means of the three components of the geomagnetic field, *X* (north), *Y* (east), and *Z* (vertical). These indices are dominated by S_q, caused by the ionospheric dynamo controlled by the solar UV radiation. They showed that in terms of 11-year running averages the long-term variation of *x, y, z*, and *r* at 11 observatories is very similar to the corresponding variation in *aa*, *R*, and total solar irradiance, TSI. *Le Mouël et al.* [2005] concluded this would imply that both electromagnetic radiation and corpuscular flux in the vicinity of the Earth are subject to the same time variations on the timescale considered.

[5] A 22-year variation in *R* and *aa* has been discussed by several authors (see, for instance, the review by *Kuklin* [1976] and the paper by *Mursula et al.* [2001], concerning solar activity, and the papers by *Chernosky* [1966], *Russell* [1974], *Russell and Mulligan* [1995], and *Cliver et al.* [1996], concerning the geomagnetic activity). It appears that this variation is ultimately linked to the magnetic field of the Sun and its changing polarity via the interaction with a relic constant magnetic field in the convection zone, in the case of the Sun [*Mursula et al.*, 2001], and via a polarity reversal/geometrical-coupling effect [*Russell*, 1974] plus an intrinsic variation of the polar magnetic field of the Sun [*Russell and Mulligan*, 1995; *Cliver et al.*, 1996], in the case of geomagnetic activity. Consequently, we shall refer to the 22-year variation, both in *R* and in *aa*, as the ''Hale-cycle-related'' or ''solar-magnetic-cycle-related'' variation (MC signal, MC signature).

[6] Studies on a longer-term cycle in the solar activity, namely, the Gleissberg cycle (GC) (also named the ''secular'' or ''80- to 90-year'' cycle), are reviewed by *Kuklin* [1976]. This cycle manifests itself as a modulation of the amplitude and frequency of the 11-year solar cycle and is empirically defined, and its physical meaning is not clear as yet. As a matter of fact, the term ''cycle'' is not properly used in this case, as the length of the GC varies between 60 and 120 years [*Mouradian*, 2002], and a better term might be ''variation.'' However, in the following we shall stick to the traditional term and refer to the Gleissberg variation effects in the parameters we analyze as the GC signal or GC signature. Spectral analysis techniques applied to the sunspot number time series indicate peaks at various frequencies in the GC range. For instance, *Rozelot* [1994] reports peaks at 58.5 and 97.2 years, while *Prestes et al.* [2006] find a peak at 100.7 years, and M. L. Rogers et al. (Long-term variability in the length of the solar cycle, 2006; available at http://arxiv.org/abs/astro-ph/0606426) indicate peaks at 87, 97.5, and 102 years, depending on the method used. Analyzing auroral data of *Siscoe* [1980] going back to 450 A.D., *Feynman and Gabriel* [1990] found a robust 88-year period for the GC before the Maunder Minimum (MM). This oscillation changed its phase by about 35 years after the MM. They interpreted this behavior as being compatible with the model of quasiperiodic state interrupted by chaotic state episodes of the solar dynamo. In the quasiperiodic state, subharmonics of the fundamental period of 11 years (or 22 years if the MC is considered as fundamental) are present (here, the 88-year cycle). When the system is close to the chaotic state, the spectral lines of the periodic regime still appear, but they are broadened (see *Feynman and Gabriel* [1990, and references therein] for a detailed discussion, which is beyond the scope of this paper). *Duhau* [2006] shows that a monochromatic wave, as Fourier formalism assumes, cannot be sustained by a system in a state close to the transition between period doubling and chaos; instead, the waves are well represented by resonant functions centered at the proper frequencies, and the long-term behavior in the GC range can be described by successive episodes with a quasiperiodic behavior (a quasiperiod of 90 years between 1740 and 1923, 145 years after 1951, and 35 years before 1705).

[7] *Mouradian* [2002] extends the GC information back to 1500 and points to a period of 207 years and to a higher-order cycle with a half-period greater than 500 years, present in the GC time evolution. At much longer temporal scales the solar activity was discussed by *Usoskin et al.* [2003] (the last millennium) and by *Solanki et al.* [2004] (the last 11,000 years). Their reconstructions, based on ^{10}Be and ^{14}C data, show that the increase trend of the activity in the twentieth century led, for the past 70 years, to an exceptional level of solar activity as compared to the last 8000 years.

[8] Measured data on solar irradiance variations are only available since 1978 [e.g., *Frölich*, 2003]. Information on longer timescales (the so-called secular variation) is retrieved by means of models linking the solar radiative output with the contributing features of the photosphere (sunspots and faculae) [*Lean et al.*, 1995; *Lean*, 2000] or with the solar surface magnetic flux (which also includes the network and the open flux contribution) [*Solanki et al.*, 2002; *Krivova et al.*, 2003, 2007].

[9] In the present paper we go beyond averaging out sunspot cycle variations by showing that the variation depicted by 11-year running averages of the quantities discussed, defining an ''overall magnetic trend,'' as pointed out by *Le Mouël et al.* [2005], results from the superposition of MC and GC signatures in the corresponding solar-cycle-free time series and attempt to quantitatively characterize these signatures or signals. Both the MC and the GC appear in the sunspot number (and sunspot group number) time series (the only long-term proxy, based on measurements, available for the solar activity) as modulations of the 11-year activity, hence the terms signal and signature used throughout this paper. In our analysis we do not attempt to prove the existence of these cycles or to decide on physical processes behind them but to find some of their properties and some characteristics of the relationship between the solar activity and the geomagnetic field variations (geomagnetic activity and the diurnal variation), at the corresponding timescales, from sunspot number and geomagnetic indices. We also

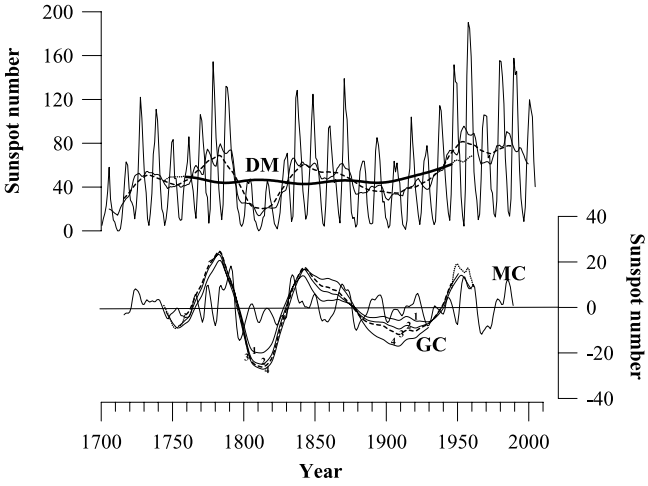

Figure 1. (top) Successive averages with running windows of 11 (thick curve), 22 (dashed curve), and 88 (short, thick curve) years on the sunspot number time series (thin curve). Dotted curve, extension of R88 (see text). DM, Dalton Minimum. (bottom) Signals of the Hale (solid curve, MC for R11-R22) and Gleissberg (dashed curve, GC for R22-R88) cycles in the sunspot number time series. Dotted curve, extension of GC signal (see text). Numerals 1, 2, 3, 4, GC signals corresponding to 60-, 78-, 88-, and 120-year running windows, respectively.

discuss some implications of the observed variations at the MC and GC timescales at 1 AU. Our analysis links heliospheric conditions at 1 AU as well as ionospheric geomagnetic variations controlled by the UV radiation to processes in various zones in the Sun and its atmosphere at both the MC and the GC timescales. The available *aa* (1868–2004), IHV (1890–2006), IDV (1872–2004), TSI (1700–2004), and *R* (1700–2004) time series are used for this purpose together with simple averaging procedures.

2. Data and Method

[10] Details of our approach will be illustrated in this section for the case of *R* and *aa* time series. The results for all studied parameters will be discussed in section 3.

[11] In order to extract the MC and the GC signals from the data, we averaged the *R* and *aa* annual mean time series (http://www.ngdc.noaa.gov/stp/SOLAR/ftpsunspotnumber.html and http://isgi.cetp.ipsl.fr/des_aa.htm, respectively), shown in Figure 1 (top) and Figure 2 (top), with running windows of 11, 22, and 88 years, applied successively to the measured data, to the 11-year filtered R11 and aa11, respectively, and to the 22-year filtered R22 and aa22 time series, respectively. The *aa* index annual means were corrected by adding 3 nT to all values prior to 1957 [*Svalgaard and Cliver*, 2007]. The obtained R11, R22, and R88 and aa11, aa22, and aa88 time series are depicted in Figures 1 and 2. The differences, R-R11 and aa-aa11, R11-R22 and aa11-aa22, and R22-R88 and aa22-aa88, would depict the 11-year sunspot cycle (SC), the MC, and the GC signal in *R*, respectively, and in *aa*, respectively. These signals are plotted in Figure 1 (bottom) and Figure 2 (bottom) for *R* and for *aa*, respectively. The SC signal in *R* is not shown in order to allow a clearer image of the MC and GC signals. In all differences and all plots the shift by 0.5 year in the case of an even number of window points has been taken into account. We mention at this point that *Mursula et al.* [2001], who showed the presence of the MC cycle in the sunspot activity, used monthly group sunspot numbers (GSN) and a somewhat different method to isolate that cycle: They standardized the monthly GSN by subtracting a 30-year trend and then suppressed the dominant 11-year cycle by calculating the running 11-year average intensity. The latter is very similar to our R11-R22 series, except the interval 1735–1755, when the difference in quality between *R* and GSN data is probably showing up. We are aware of the fact that, in principle, R11-R22 and a11-aa22 might contain, besides the 22-year variation, any other signal with periods between 11 and 22 years. However, in the case of the data we analyzed, the variations with periods between 11 and 22 years that contaminate the 22-year signal, originating from the variability of the SC (8–13 years) or from combination tones of certain oscillations, have a small power in comparison to the 22-year signal. This can be seen in the MC signal we derived. That the signal in the case of geomagnetic activity is indeed a 22-year signal was checked by fitting a sinusoid to the MC time series of *aa* (see Figure 2). The best fit was obtained for a period of

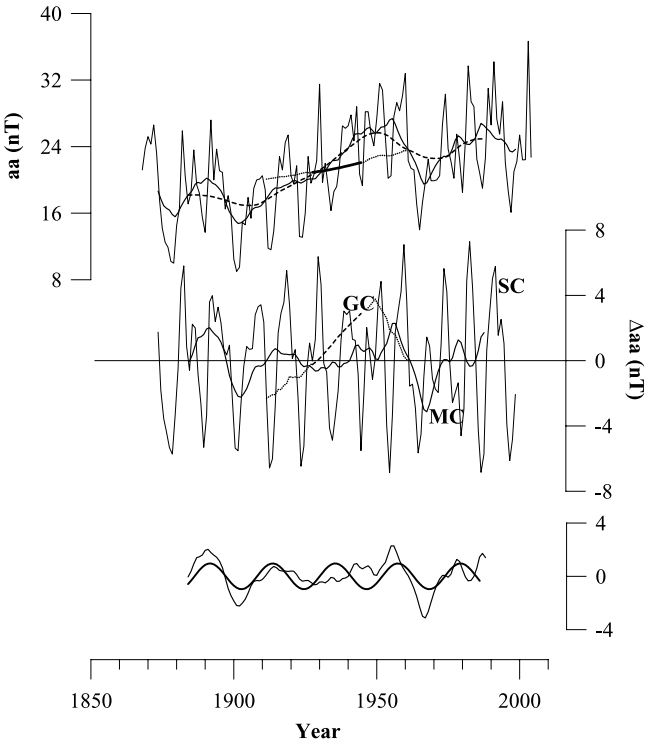

Figure 2. (top) Successive averages with running windows of 11 (thick curve), 22 (dashed curve), and 88 (short, thick curve) years on the *aa* time series (thin curve). Dotted curve, extension of aa88 (see text). (middle) Signals of the sunspot (thin solid curve), Hale (thick solid curve, MC for aa11-aa22), and Gleissberg (dashed curve, GC for aa22-aa88) cycles in the *aa* time series. Dotted curve, extension of the GC signal (see text). (bottom) Sinusoidal fit to the MC signal (the best fit period, 21.88 years).

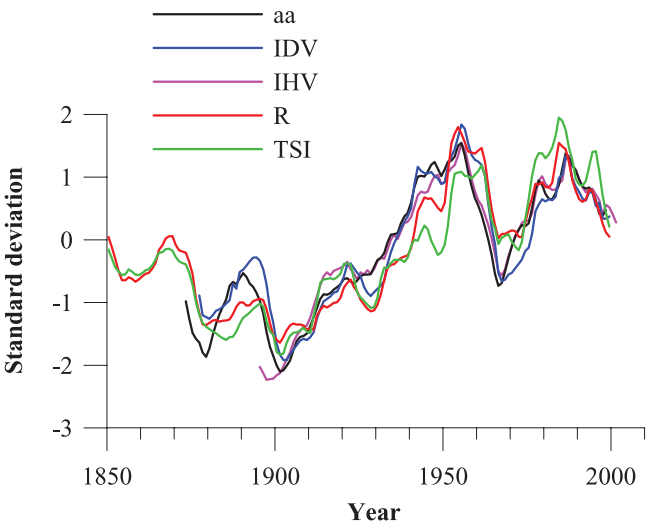

Figure 3. The 11-year running averages of *R*, *aa*, interdiurnal variability (IDV) index, interhour variability (IHV) index, and total solar irradiance (TSI). Curves are reduced to their means over the common time interval (1895–1998) and scaled with their standard deviations about the mean as a unit.

21.88 years. In comparison with the MC signal in *R* the one in the geomagnetic activity shows details (Figure 3, section 3) related to the different nature of the processes they represent.

[12] As regards the GC the running window of 88 years, suggested by the doubling period model of solar activity [*Feynman and Gabriel*, 1990], could be replaced, with similar results, by a 78-year window, suggested by the spectral analysis of *aa* [*Currie*, 1976] and of long observatory annual mean time series [*Demetrescu and Dobrica*, 2005]. An experiment with shorter (60 years) and longer (120 years) running windows, to cover the variations observed in the length of the GC [e.g., *Kuklin*, 1976; *Mouradian*, 2002], is shown in Figure 1 (bottom). The shape of various GC signatures corresponding to the 60-, 78-, 88-, and 120-year running averages of R22 is similar as regards the time of peaks' occurrences, but there are minor differences in amplitude (8–12 units at most, between the 60- and the 120-year running averages in intervals of GC minima, 1800–1820 and 1880–1930). The main characteristics of the GC transpire directly from R22, but we feel that a certain reference line is needed to better define the GC, considering longer-term variations in the solar activity [*Mouradian*, 2002; *Usoskin et al.*, 2003; *Solanki et al.*, 2004] mentioned in section 1. They affect R22 and could be seen, for instance, in R88: The mean level to 1900 is ~45 units; the level in 1945 is 61 units. To render evident the GC in the sunspot number time series, *Kuklin* [1976] used a 23-year sliding summation, obtaining the secular cycle for the interval 1720–1940, similar to R22 except the 11-year signal was present too. Variations with periods between 22 and 88 (or 78, 60, and 120, according to the filter used) years might be present in R22-R88 (or 78, 60, and 120, respectively) as small wiggles, but they have negligible amplitudes when compared to the Gleissberg cycle amplitude, as can be seen in Figure 1.

[13] Because of averaging with running windows of 11, 22, and 88 years the successive filtered time series are shorter than the original time series by 10, 31, and 118 years, respectively. Longer time series for GC can be obtained by 88-year smoothing directly on original time series (R88*), but they will include, of course, reminiscent 11- and 22-year signals, originating from the variability of the SC and 22-year cycle length. If the R22 and aa22 are calculated by correspondingly smoothing the original time series with a 22-year running window (R22* and aa22*), the time series of differences R11-R22* and aa11-aa22* would be longer by 10 years than the corresponding time series calculated by successive averaging. R22*-R88* and aa22*-aa88* would be longer by 31 years but would still contain a reminiscent 11-year signal. The extended time series are also shown in Figures 1 and 2.

[14] The same treatment was applied to IHV [*Svalgaard and Cliver*, 2007, Table 2], IDV [*Svalgaard and Cliver*, 2005, Table 3], and TSI (*Lean et al.* [1995]; *Lean* [2000], http://www1.ncdc.noaa.gov/pub/data/paleo/climate_forcing/solar_variability/lean2000_irradiance.txt, annual means to 2000; and *Krivova et al.* [2007], http://www.mps.mpg.de/projects/sun-climate/data/tsi_1700.txt, daily values in the interval 2000–2004) data. The IHV time series was too short to obtain Gleissberg cycle information for a significant time interval.

3. Results and Discussion

[15] The 11-year averages of *R*, *aa*, IHV, IDV, and TSI are superimposed in Figure 3 in order to emphasize the common long-term trend, 11-year solar cycle free, in various solar outputs and geomagnetic indices of the present study. The curves are reduced to their means over the common time interval (1895–1998) and scaled with their standard deviations about the mean as a unit.

[16] When the top and bottom plots in Figures 1 and 2 are compared, it immediately appears that the general increase of sunspot and geomagnetic activity in the twentieth century, as seen in the 11-year running average time series, is the expression of the Gleissberg cycle ascendant branch. Superimposed on this, the MC variation is responsible for shorter-scale variations present in the R11 and aa11. The peak at 1891 followed by the minimum in 1902, the peak in 1955 followed by the minimum in 1967, and the peak in 1987 (~40 units in *R* and 4–5 nT in *aa*, maximum to minimum) are producing the pronounced changes in the temporal variation of *R* and *aa* evidenced by the 11-year averages of this study, R11 and aa11, plotted again in Figure 3 (and also in the study of *Le Mouël et al.* [2005]), or by the double segment representation of *Mursula et al.* [2004]. In the case of *aa*, however, the aa22 curve is too short to show the higher peak at 1987 seen in the aa11, R11, and R22 time series. In comparison with the amplitude of the solar cycle 22 in *R* and with the amplitude of the corresponding cycle in *aa*, respectively, calculated as the difference between the peak value and the average of the minimum value at the beginning and end of the cycle, the variations above amount to ~27%. The minor variations present in R11 and aa11 are also well reproduced by the MC signals in *R* and in *aa*, respectively. Between 1911 and 1953 the amplitude of the

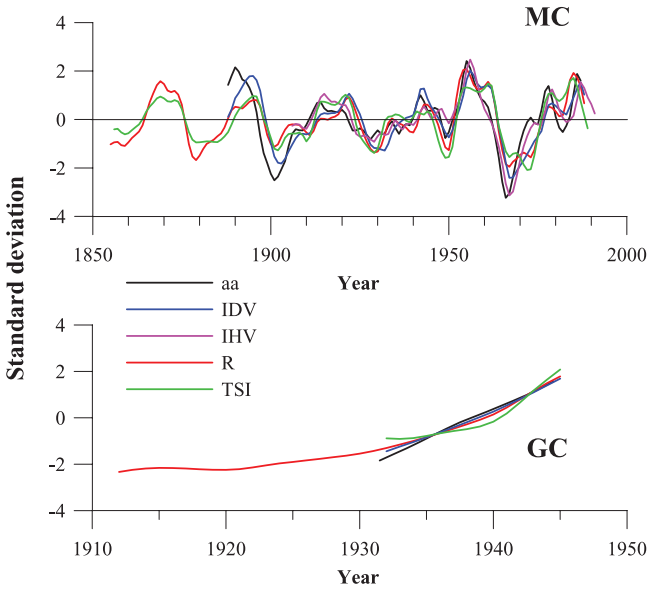

Figure 4. The (top) MC and (bottom) GC signals in *R*, *aa*, IDV, IHV, and TSI. Curves are reduced to their means over the common time interval (MC, 1906–1988; GC, 1932–1945) and scaled with their standard deviations about the mean as a unit.

MC signal is lower (12 units in average in *R*, <2 nT in *aa*, representing ~9% and <12%, respectively).

[17] The Gleissberg cycle signal in *R* shows, in the time interval 1759–1945, in which it could be defined, two maxima at 1783 and 1842 and two minima at 1813 (the well-known Dalton Minimum) and 1909. Another maximum is to be expected around 1950, and a secondary minimum is possible around 1752, as shown by the extended signals in Figure 1. It is interesting to note that the secular cycle activity shows periods with higher amplitude of the variation and shorter duration (1763–1830, ~50 units from the 1783 maximum to the 1813 minimum, representing ~34% of the amplitude of the solar cycle 22) and periods with lower amplitude and longer duration (1830 to ~1950, ~30 units from the 1842 maximum to the 1909 minimum, representing ~20% of the amplitude of the solar cycle 22). According to *Mouradian* [2002] the successive Gleissberg cycles are determined by the years of minimum activity (GC0 before 1835, length 122 years, GC1 between 1835 and 1905, length 91 years, and GC2 after 1905, length ≥61 years). From the shape of the GC curve in Figure 1 (bottom) one could choose to define a cycle using the intercept with the zero line, including in a cycle a maximum and the next minimum (GC0* between 1763–1830, 67 years long, GC1* between 1830–1939, 109 years long, and GC2* after 1939).

[18] The GC signal in *aa* could be defined only for the time interval 1927–1945, when an increase of 3 nT is seen. An 88-year running average directly on *aa*, which would give a longer time series (Figure 2), affected, however, by the SC signature, seems to indicate a possible maximum around 1950, similar to the corresponding one in *R* mentioned above. Between 1912 and 1950 the GC signal increases by ~5 nT (30% of the amplitude of the cycle 22 in *aa*).

[19] The IHV index [*Svalgaard et al.*, 2004], originally calculated from the records of the Cheltenham/Fredericksburg observatory, challenged the long-term increase in geomagnetic activity shown by *aa* and, consequently, the conclusion of *Lockwood et al.* [1999], based on *aa* data, that the solar coronal field doubled in the past 100 years. Later works by *Mursula et al.* [2004] and *Mursula and Martini* [2005], who calculated the index for several observatories and corrected the IHV index for quiet time daily variation and for the changing of the registration method from hourly samples to hourly mean values at the beginning of the twentieth century, and by *Clilverd et al.* [2005], who reconstructed the *aa* time series on the basis of Sodankylä and Niemegk data, confirmed the robustness of the centennial trend in the *aa* index. Moreover, *Mursula et al.* [2004] showed that IHV has the same qualitative long-term pattern during the last 100 years as *aa*, namely, an increase of activity from about 1900 to 1960, then a drop in the early 1960s and a weaker increasing activity thereafter. This is also seen in the 11-year running averages presented by *Le Mouël et al.* [2005]. The IDV data [*Svalgaard and Cliver*, 2005, Figure 1 and Table 3] are characterized by the same long-term pattern. However, the amount of the general increase of the three indices in the twentieth century is not the same. Following *Mursula et al.* [2004], who compared IHV for individual geomagnetic observatories and *aa*, we quantified this increase in *aa*, global IHV, and IDV by calculating the average values of the indices during the last (1979–2000) and the first (1901–1922) 22 years of the century and the corresponding percentage increase. The figures are 38% for corrected *aa*, 36% for IHV, and 39% for IDV. These differences might come from the different nature of the processes the three indices respond to (product BV^2 or B) being a matter of scaling, as is shown in Figure 4.

[20] To compare the geomagnetic and solar activity at MC and GC timescales, in Figure 4 (top) we superimpose the MC signals in *aa*, IHV, IDV, and *R*, and in Figure 4 (bottom) we superimpose the GC signals in *aa*, IDV, and *R* (the IHV time series was too short to derive a significantly long signal). In order to make the signals comparable the curves are reduced to their means over the common time interval (1906–1988 and 1932–1945, respectively) and scaled with their standard deviations as a unit. To include in the discussion the solar radiative output, the MC and GC signals in TSI are plotted as well.

[21] The correlation between signals in the sunspot numbers and the geomagnetic activity is extremely good, confirming the visual impression produced by Figures 1–4 as well as a previous result concerning the *aa*/*R* ratio in the case of MC [*Cliver et al.*, 1996]. The correlation coefficients for the common time interval are given in Table 1.

[22] The conclusion of *Le Mouël et al.* [2005] that the good correlation, in terms of 11-year averages, between *R*, *x, y, z, r*, TSI, and *aa* implies that both electromagnetic radiation and corpuscular flux in the vicinity of the Earth are subject to the same time variations is extended here to the MC and GC timescales. Moreover, our conclusion would be that, more general, this implies that at both the MC timescale and the GC timescale the coronal source field (as reflected by heliospheric conditions at 1 AU, namely, the product BV^2, described in turn by the IHV, *aa*, and *am* indices, and/or as reflected by the IMF strength at 1 AU,

Table 1. Correlation Coefficients Between Analyzed Parameters in the Case of MC and GC Signals

Correlation Coefficient	*aa*	IDV	IHV	*R*	TSI
		MC			
aa	1	0.62	0.95	0.72	0.58
IDV	...	1	0.70	0.79	0.75
IHV	...	...	1	0.75	0.68
R	...	...	...	1	0.90
TSI	...	...	...	...	1
		GC			
aa	1	0.99	...	0.98	0.91
IDV	...	1	...	0.99	0.95
R	...	...	...	1	0.97
TSI	...	...	...	...	1

described in turn by the IDV index), the photospheric magnetic field (as reflected by *R*), and the solar radiative output (as given by TSI) have a similar temporal behavior, intrinsic to processes developing in the Sun.

[23] In Figure 4 the MC and GC signals in *R* are plotted also for some years before the common period to suggest, in view of the correlation shown during the common period, the possible evolution of the geomagnetic activity before the instrumental interval. However, reconstructing past information on the geomagnetic activity and related parameters of solar and heliospheric conditions at the MC and GC timescales is beyond the scope of the paper.

[24] The existence of the MC and GC signals in the geomagnetic activity, discussed in the present paper, would suggest that such signals should also be present in the annual mean time series of geomagnetic elements determined at geomagnetic observatories, as it has long been recognized that annual averages do not completely eliminate external variations. The MC and GC signals would have significant contributions, amounting to about 30% of the 11-year cycle one (5–6 nT). When discussing the main geomagnetic field, i.e., the field produced by the geodynamo process in the outer core of the Earth, geomagnetic observatory data should be cleaned from external contributions at all three temporal scales discussed here, not only for the sunspot cycle effects, as is done at present [e.g., *Sabaka et al.*, 2004]. A recent study by *Demetrescu and Dobrica* [2005] shows that the long-term variation of the geomagnetic field, dominated by the presence of geomagnetic jerks separating intervals of a relatively smooth variation of the field, is produced by an ~80-year variation combined with a 22-year variation, both of internal origin, on which the SC-related variation is superimposed. The temporal scale of the ~80- and 22-year variations in the main field is similar to cyclicities or variations observed in the solar activity and in the external geomagnetic field, which might be confusing and lead to speculations beyond the scope of the present paper. The external contribution to the ~80- and 22-year variations in the main geomagnetic field of about 5–6 nT would, however, be of marginal importance when compared to the internal variations of several hundred and several tens of nT, respectively, but might become important, as improvement of measurement accuracy and of modeling fine details of the geomagnetic field is constantly being looked for. The 11-year variation is decisive though in establishing the very short timescale characterizing jerks and, to some extent, also the amplitude and timing of the jerk.

4. Conclusions

[25] Signatures of the magnetic Hale cycle and the Gleissberg cycle of the solar activity have been evidenced in the sunspot number time series, in the geomagnetic activity depicted by the *aa*, IHV, and IDV indices, and in the solar radiative output, as represented by the total solar irradiance by simple averaging procedures (successive 11-, 22-, and 88-year running averages and differences between them). The long-discussed centennial increase of geomagnetic activity in the twentieth century, seen in *aa*, IHV, and IDV indices, and the so-called overall trend of the geomagnetic field evolution in the same time interval, defined in terms of 11-year running averages of *aa*, *x, y, z*, and *r* indices, have been shown to be the result of the superposition of the MC and GC signatures in the data.

[26] The contribution of MC and GC to the *R* series is not constant in time: Variations between 9% and 27%, in the case of MC, and between 20% and 34% of the amplitude of the solar cycle 22, in the case of GC, have been found. The MC and GC signals in *aa* have a substantial contribution, amounting to 27% and to ~30%, respectively, of the 11-year cycle 22 amplitude. However, between 1911 and 1953 the MC signal in *aa* is under 2 nT.

[27] When scaled by the standard deviation from the average value for the common interval covered by the data, the MC and GC signals are quite similar in *R*, *aa*, IHV, IDV, and TSI. This implies that at both the MC and the GC timescales processes in various zones of the Sun, characterized by outputs such as (1) the coronal source field (as reflected by general heliospheric conditions at 1 AU: IMF strength, solar wind speed, and density, represented by the product BV^2, described in turn by the *aa* and IHV indices, and/or as reflected by the IMF strength at 1 AU, described in turn by the IDV index), (2) the photospheric magnetic field (as reflected by the *R* index), and (3) the solar radiative output (as reflected by *x, y, z, r*, and TSI), have a similar behavior, intrinsic to processes developing in the Sun. The present analysis points to the possibility of reconstructing the past evolution of the geomagnetic activity and related parameters of solar and heliospheric conditions at the MC and GC timescales on the basis of correlations seen for the common instrumental period, with consequences in solar physics studies and in better defining the "space climate" concept.

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