SECULAR BEHAVIOUR OF GEOMAGNETIC INDICES IHV, C9, *aa* SINCE 1901 AND PRESUMED RISING OF SOLAR OPEN MAGNETIC FIELD FLUX

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We examine long-term series of IHV and C9 geomagnetic indices calculated from the data derived during the 20th century in St.-Petersburg, Pavlovsk, Swider, Cheltenham, Fredericksburg, Kakioka, and Honolulu in order to verify the conclusion of Lockwood *et al.* [8] that the total magnetic flux leaving the Sun increased by a factor of 2.3 since 1901. It was supported on the analysis of *aa* geomagnetic index which shows a drift upward from the 12th–13th solar cycle to the 22nd cycle. The mean level of the annual averages of indices used here have been approximately constant or showed the clearly smaller rising than *aa* drift upward from 1901 till 1960. We conclude that the double rising of solar magnetic flux during the 20th century is questionable.

INTRODUCTION

The interplanetary space is dominated by originating at the solar plasmas and magnetic field which is controlling the state and behaviour of the medium. It is so-called solar wind, a supersonic flow of plasma resulting from the continual heating of the solar corona up to temperatures of about one million K. Solar magnetic fields from the corona are frozen into the solar wind plasma and carried outward through the Earth's orbit to the termination shock. It is the heliospheric magnetic field (HMF) which carries the solar magnetic flux. Due to the solar wind and HMF embedding into the wind, the long and short term changes of the magnetic conditions in the Sun and the solar corona have implications for the magnetosphere and the Earth's atmosphere. The solar activity causes geomagnetic activity. It is believed that the major mechanism of energy transfer from the solar wind to the magnetosphere is the magnetic reconnection, *i.e.*, the merging of oppositely directed magnetic fields, the HMF and the Earth's field [3]. For the estimation of solar activity level one can use, for example, the sunspot number or 10.7 cm solar radio flux. The geomagnetic variability can be determined by means of different geomagnetic indices calculated from the Earth's magnetic field components horizontal H, vertical Z, and declination D registered at magnetic observatories. Some stations have begun systematic registration in the middle of the 19th century. The large data base of hourly values of magnetic components is collected at WDC-C2 at the Kyoto University [15].

The longest and most usable solar time series, called as the Wolf or Zurich sunspot number [4], calculated from the 18th century and based on the formula $R = k\,(10\,G + N)$, where G is the number of sunspot groups, N is the number of individual sunspots, and k denotes an individual correction factor, is in doubt as a measure of solar activity, especially during early periods of observations when there were not much observations, because they contain some elements of subjective estimations (for longer discussion see, *e.g.*, [14]). The second above-mentioned time series known from 1947, Ottawa/Penticon radio flux seems to be more precious and homogeneous because it is based on the stable method of calibration without interference of non-objective observers. The similar situation is in the topic of the geomagnetic field variability where the most popular indexes are constructed with some admission of subjective estimations of observer or author of the index. Therefore, performing studies with such old data series, everybody would cautiously approach to conclusions. Construction of the continuous time series from the interrupted data of stations when one station is replaced by another also requires an extraordinary intent attention.

GEOMAGNETIC INDICES

J. Bartels [2] in 1938 introduced K-index calculated from magnetic elements data (H, Z, or D) registered at every observatory. The K-index is quasi-logarithmic local index of the 3-hourly range in magnetic activity relative to an assumed quiet-day curve for a single geomagnetic observatory site (Table 1). It consists of a single-digit 0 through 9 for each 3-hour interval of the universal time (UT). The planetary 3-hour-range index Kp introduced by J. Bartels in 1949 was the mean standardized K-index from 13 geomagnetic observatories between 44 degrees and 60 degrees northern or southern geomagnetic latitude. The scale was 0 to 9 expressed in thirds of a unit, *e.g.*, 5– is 4 2/3, 5 is 5, and 5+ is 5 1/3. This planetary index is designed to measure geomagnetic variability in mean latitudes.

Table 1. Conversion between maximum deviation from diurnal run in nT and K-index for Niemegk

K	0	1	2	3	4	5	6	7	8	9
Dev. (nT)	0–5	5–10	10–20	20–40	40–70	70–120	120–200	200–330	330–500	500+

The *aa* index time series was derived by Mayaud [9] using the data from two nearly antipodal observatories (Table 2), where magnetograms were available since 1868. For each three hour interval, K indices are measured at two stations and converted back into amplitude; an individual *aa* index is the average of the northern and southern values, weighted to account for a small difference in latitude of two stations, or for the slight changes in the place of the observatory. The *aa* index is in n anotesla (nT) and it represents the activity level at an invariant magnetic latitude of about 50. Data sets of *aa* are available at WDCs, *e.g.*, [4]. Another index devised to express geomagnetic activity in the daily time scale is the C9 which converts the algebraic differences between the greatest and the least deviations from the daily curve of the magnetic element to the one digit scale between 0 and 9. The long time series of C9 data are collected in the paper of Zosimovich [16].

Table 2. The list of pairs of stations used by Mayaud to calculate *aa* indices

Station	Geog. Lat.	Geog. Long.	Operating period	Station	Geog. Lat.	Geog. Long.	Operating period
Greenwich	51.48	0.00	1868–1925	Melbourne	−37.83	144.98	1868–1919
Abinger	51.18	359.61	1926–1956	Toolangi	−37.53	145.47	1920–1978
Hartland	50.98	355.52	1957– ...	Canberra	−32.30	149.00	1979– ...

It would be pointed out that these conversions from nT to K and back to *aa* and from nT to C9 digits insert some subjective determinations into the results. Recently introduced InterHour Variability Index (IHV) by Svalgaard *et al.* [13] has no such a fault. It is defined as the sum of the differences, without regard to the sign, of hourly means for a geomagnetic component from one hour to the next over six-hour interval around local midnight where the S_q variation is absent or minimal. As the authors have written *"the index is objective in the sense that it is derived from simple hourly averages without any problematic attempt to eliminate the variations not caused by the solar wind"*.

HAS THE SUN'S MAGNETIC FLUX DOUBLED DURING THE LAST 100 YEARS?

Lockwood *et al.* [8] considered the annual means of *aa* index and radial component of near-Earth HMF B_r for 1964–1996 and found some increase in these parameters. A least-squares linear fit has yielded 41 percent to B_r. On the faith of the empiric relationship obtained by them for this period between the magnetic field, solar wind speed and *aa* index and basing on *aa* rise from 1901 to 1960 they have extrapolated the conclusion to the whole Sun's sphere and to this long period. They have claimed that the total magnetic flux F_m leaving the Sun has risen since 1901 by a factor of 2.3. According to them, in 1901 $F_m = 2.308 \cdot 10^{14}$ Wb and rose to a peak value of $5.325 \cdot 10^{14}$ Wb in 1992.

This result was negated in [6, 7, 10–12]. Ponyavin [10] has pointed out that the annual means of the data of the planetary C9 index derived by Zosimovich [16] do not show such increase as it is observed in *aa* index. Kotov and Kotova [7] have considered measurements of the general magnetic field of the Sun as a star at four observatories from 1968 until 1999 and have shown that the mean strength of the photospheric magnetic field has not changed over the last 32 years. Stozkov [11] has estimated the average interplanetary magnetic field (IMF) from the measurements of ionization chambers (from 1937) and monitor neutrons (from 1953) and obtained that the average IMF strength was constant in the limits of 5–7 percents. In extensive and comprehensive study Svalgaard *et al.* [12] have used geomagnetic data of H component at Chektenham/Fredericksburg station from

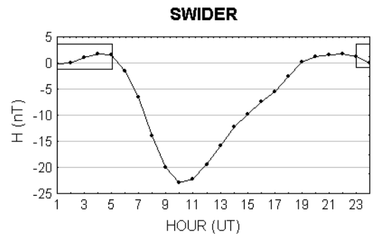

Figure 1. The daily S_q variation of the H component at Swider for the years 1921–1967. The zero-level was taken as the value at 2 UT. The box shows the local night time interval used for calculation of IHV index

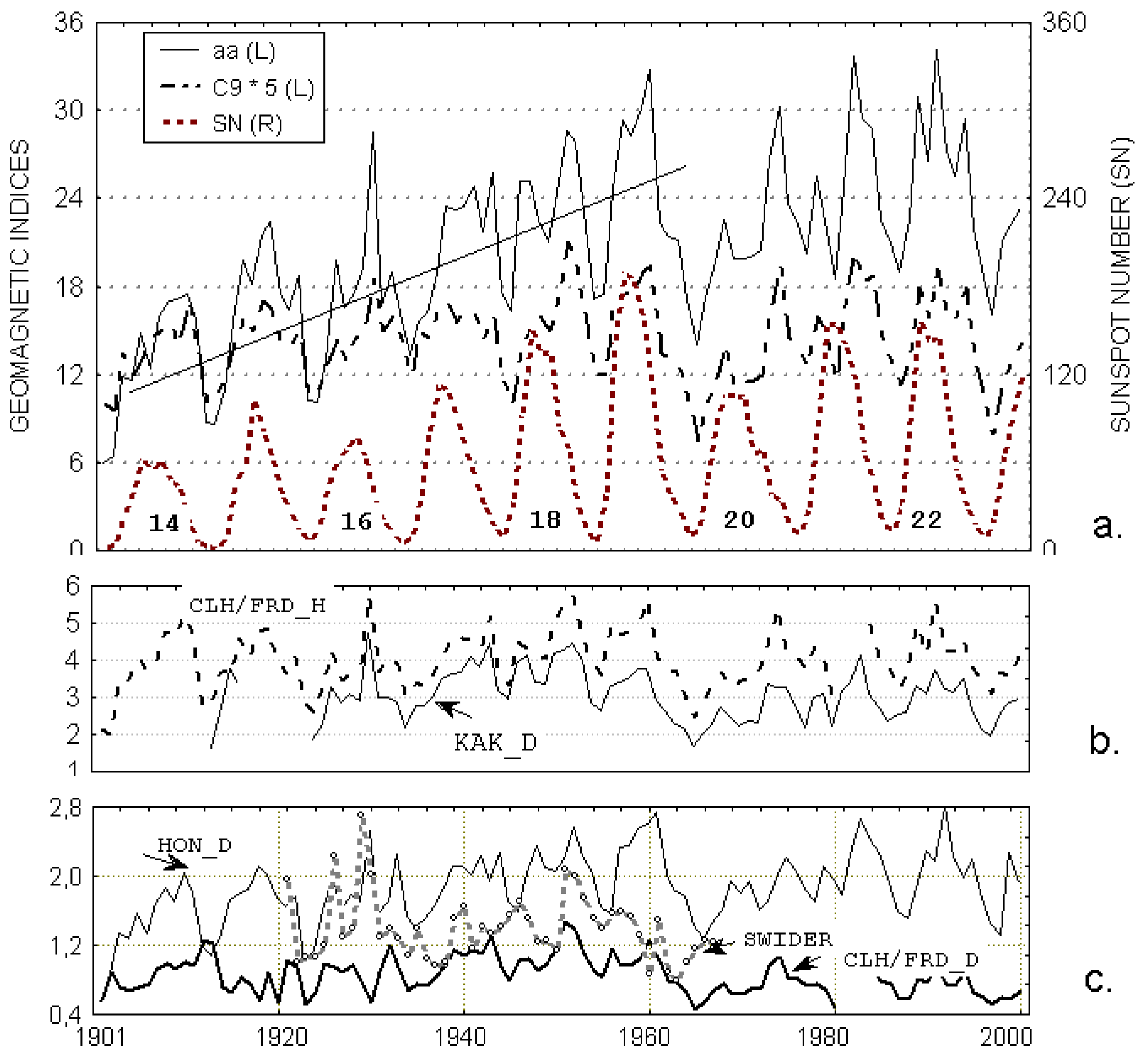

Figure 2. Yearly averages of geomagnetic indices for the interval 1901–2000: (a) sunspot numbers, index *aa* together with its trend during 1901–1960, index C9 multiplied by 5, cycle numbers are marked; (b) IHV indices calculated from declination at Kakioka (KAK_D), and from H component at Cheltenham till 1956 and at Fredericksburg (CLH/FRD_H) after 1956; (c) IHV from declination for these stations (CLH/FRD_D) and for Honolulu (HON_D), and from H component for Swider station during 1921–1967 divided by 4

1901 to 2000 and calculated the new geomagnetic index IHV. This index and other analyses have also indicated that there was no doubling of the Sun's coronal magnetic flux during last 100 years. Kobylinski and Izdebska [6] have analysed old geomagnetic indices and have come to the conclusion that during the time interval from 1841 to 1964 the mean level of the geomagnetic indices other than *aa*, as C9 (planetary), C9 from St.-Petersburg and Finish indices A_k have been approximately constant.

DATA, ANALYSIS, AND CONCLUSION

Here we use the following data: daily *aa* time series from [4]; daily C9 indices calculated from registrations in the period 1901–1910 at the Pavlovsk and St.-Petersburg observatories (geographic latitude is 59.57) by Zosimovich [16], the daily planetary index C9 collected by the same author for the period 1910–1932 and the daily planetary C9 from [5] for the period 1932–2000; hourly means of magnetic components registered by observatories at Kakioka (1913–2000, geographic latitude 36.23), Honolulu (1901–2000, 21.23), Cheltenham (1901–1956, 38.70), and Fredericksburg (1956–2000, 38.20), obtained from [15]; hourly components registered at the Polish Station Swider (1921–1967, 52.12) from [1]. Time series of magnetic components were averaged in order to obtain the mean daily variation for the whole periods of existing observations at determined observatory. We have chosen only these components for which S_q variation was small or absent during the night hours (as an example, S_q variation for H component at Swider is shown in Fig. 1) and calculated IHV indices which were later averaged. The annual means of every data are presented in Fig. 2.

The mean level of the annual averages of indices used here have been approximately constant or showed the clearly smaller rising than *aa* drift upward from 1901 to 1960. We conclude that the double rising of solar magnetic flux during the 20th century is questionable.

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[1] Annual Magnetic Reports.–Prace Obs. Geof. im. St.-Kalinowskiego w Swidrze, PWN, Warsaw, 1921–1967.

[2] *Bartels J., Heck N. M., Johnson H. F.* The three-hour-range index measuring geomagnetic activity // J. Geophys. Res.–1939.–**44**.–P. 411.

[3] *Dungey J. W. et al.* Interplanetary magnetic field and the auroral zones // Phys. Res. Lett.–1961.–**6**.–P. 47.

[4] [`ftp://ftp.ngdc.noaa.gov/STP`].

[5] [`http://www.gfz-potsdam.de/pb2/pb23`].

[6] *Kobylinski Z., Izdebska J.* Presumed rising trend of solar magnetic flux and old geomagnetic data sets // Solar variability as an input to the Earth's environment: Proc. of ISCS.–2003.

[7] *Kotov V. A., Kotova I. V.* Uvielichivajetsja li magnitnoje pole Solntsa? // Pis'ma Astron. Zh.–2001.–**27**, N 4.–P. 302–309.

[8] *Lockwood M., Stamper R., Wild M. N.* A doubling of the Sun's coronal magnetic field during the past 100 years // Nature.–1999.–**399**.–P. 437–439.

[9] *Mayaud P. N.* A hundred year series of geomagnetic data, 1868–1967, indices *aa*, storm sudden commencements // IAGA Bull. 33, Intern. Union of Geodyn. and Geophys. Publ. Off., Paris, 1973.

[10] *Ponyavin D.* Geomagnetic tracing of the inner heliosphere // Space Sci. Rev.–2001.–**97**.–P. 224–228.

[11] *Stozkov Yu. I.* Magnitnyj potok Solntsa v proshlom stoletii // Geomagnetizm i Aeronomija.–2002.–**42**, N 6.–P. 746–751.

[12] *Svalgaard L., Cliver E. W., Le Sager P.* No doubling of the Sun's coronal magnetic field during the last 100 years // Unpublished manuscript.–2002.

[13] *Svalgaard L., Cliver E. W., LeSager P.* IHV: a new geomagnetic index // Adv. Space Res.–2003.

[14] *Usoskin I. G., Mursula K.* New standpoints in long-term solar cycle evolution: a review // Solar variability as an input to the Earth's environment: Proc. of ISCS.–2003.–P. 25–36.

[15] World Data Center C2, Kyoto.–[`http://www/swdcwww.kugi.kyoto.ac.jp`].

[16] *Zosimovich I. D.* Geomagnetic activity and corpuscular stability of the Sun.–Moscow: Nauka, 1981. (in Russian).