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The solar daily geomagnetic variation and its dependence on sunspot number

Cengiz Çelik*

Kandilli Observatory and Earthquake Research Institute, Bogazici University, Istanbul, Turkey

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ABSTRACT

A detailed spherical harmonic model of the solar daily geomagnetic variation, *S*, is presented. The model is based on a data-set that is much more extensive in distribution, both geographically and temporally, than hitherto. The dependence of the spherical harmonics on sunspot number is investigated and is shown to be dependent on frequency.

1. Introduction

The geomagnetic field shows regular variations, *S*, with periods of submultiples of a solar day. These are the principal periodic variations and are due to electric currents in the ionosphere generated by gravitational and thermal movements of the atmosphere across the main geomagnetic field. There is a secondary component of *S* of internal origin, due to currents induced in the earth and oceans. *S* may sometimes be masked by magnetic storms: larger, irregular variations that originate further out in the magnetosphere and the ring current. Here we are concerned only with *S*, so we omit the five international disturbed days (IDDs) of each month from our data. We choose not to go the whole way towards S_q, the solar quiet-time variation revealed in the five international quiet days of each month, as we later intend to compare the *S* variations with the much-smaller *L*, the lunar daily variation, derived from the same data. For the determination of *L* we cannot afford to discard 5/6 of the data. The omission of the five IDDs of each month is common practice in such studies; see, for example Malin (1973).

The reason for studying *S* and its variation with Zurich Sunspot Relative Number, *R*, is partly for its intrinsic interest, but also for its use in deep induction studies, the correction of survey data to the mean of the day, and for the light it sheds on processes in the ionosphere. *S* is strongly dependent on season and some authors, e.g. Parkinson (1971) have considered each season separately and ignored the annual mean effect. However, *S* can be considered as the sum of pure harmonics with the seasonal variation resulting from independent variations with frequencies that differ from the principal daily harmonics by small multiples of one cycle per year. That is why we consider here only the principal harmonics with frequencies of 1, 2, 3 and 4 cycles per mean solar day. The seasonal harmonics are also of interest, but are not considered here. They may be discussed in a future paper.

S may be seen in most of the daily geomagnetic records (magnetograms), but it can be masked or even completely obscured by disturbance variation, originating well outside the ionosphere. Also it is distorted by the presence of day-to-day variability and contributions from seasonal variation and *L*. Much of the disturbance variation is removed by the omission of the five IDDs and most of the rest is removed by averaging over very many days. Similarly seasonal variation, *L* and day-to-day variability average out if a long enough interval of data is considered. For this reason, the most reliable estimates of *S* are obtained from long series of data.

There have been many previous studies of *S*, both for individual observatories, e.g. Chapman and Gupta (1968) for Greenwich, Cain (1957) for Sitka and De Mayer (2003) for Dourbes, and also as worldwide models. The history of such global modelling has been well described by Chapman and Bartels (1940). Since then the tendency has been towards more detailed models based on larger data-sets. One of these was by Malin (1973) for 1957.5–1960.0 (the International Geophysical Year and the subsequent International Year of Geophysical Cooperation, denoted IGY/C) for which the mean value of *R* was 178 – an exceptionally high maximum. It was based on hourly mean data from 100 magnetic observatories with an unprecedentedly widespread distribution. In all it incorporated 250 observatory-years of data. Another such model was that of

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* Tel.: +90 2247576020.
E-mail addresses: celikc@boun.edu.tr, cengizcel@gmail.com

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Table 1
Additional data used in the analysis in order of colatitude.

Obs.	Lat.	Long.	Elem.	Mean *R*			Interval	Source
				L	*M*	*H*		
ALE	82.5N	62.5W	*XYZ*	18	61	101	1963–1972	Gupta (1983)
MBC	76.2N	119.4W	*XYZ*	16	49	110	1962–1979	Gupta (1983)
RES	74.7N	94.9W	*XYZ*	14	48	133	1954–1976	Gupta (1980)
CBB	69.1N	105.0W	*XYZ*	19	36	124	1973–1979	Gupta (1983)
CMO	64.9N	147.8W	*XYZ*	14	48	129	1948–1976	Gupta (1980)
BLC	64.3N	96.0W	*XYZ*	19	51	100	1966–1979	Gupta (1983)
BDH	64.0N	145.8W	*DHZ*	–	–	187	1957–1958	Malin (pers. comm.)
HEA	63.9N	149.0W	*DHZ*	–	–	187	1957–1958	Malin (pers. comm.)
NUR	60.5N	24.6E	*XYZ*	15	50	100	1953–1973	Gupta and Sucksdorff (1981)
FCC	58.8N	94.1W	*XYZ*	19	52	110	1967–1979	Gupta (1983)
SIT	57.1N	135.3W	*XYZ*	12	50	117	1905–1976	Gupta (1980)
GWC	55.3N	87.8W	*XYZ*	19	52	110	1967–1979	Gupta (1983)
MEA	54.6N	113.3W	*XYZ*	13	47	122	1932–1975	Gupta (1980)
WIT	52.8N	6.7E	*DHZ*	–	–	187	1957–1958	Malin (pers. comm.)
GRW	51.5N	0.0E	*DHZ*	12	57	104	1916–1925	Leaton et al. (1962)
ABN	51.2N	0.4W	*DHZ*	11	54	117	1926–1957	Leaton et al. (1962)
DOU	50.1N	355.4 W	*D*	–	70	–	1960–1999	De Meyer (2003)
VIC	48.5N	123.4W	*XYZ*	19	51	102	1966–1977	Gupta (1983)
STJ	47.6N	52.7W	*XYZ*	19	52	113	1968–1979	Gupta (1983)
MMB	43.9N	144.2E	*DHZ*	–	37	118	1958–1973	Shiraki (1977)
AGN	43.8N	79.3W	*XYZ*	12	45	127	1932–1965	Gupta (1980)
CHL	38.7N	76.9W	*DH*	7	37	69	1901–1916	Gupta and Chapman (1970)
FRD	38.2N	77.4W	*XYZ*	16	49	133	1956–1976	Gupta (1980)
SFS	36.4N	6.2W	*DH*	9	38	91	1911–1960	Chapman and Fogle (1968)
KAK	36.2N	140.2E	*DHZ*	16	52	119	1913–1976	Shiraki (1979)
TUC	32.2N	110.8W	*XYZ*	12	49	117	1909–1976	Gupta (1980)
KNY	31.4N	130.9E	*DHZ*	–	37	118	1958–1973	Shiraki (1977)
HLW	29.9N	31.3E	*XYZ*	7	32	73	1909–1934	Gupta and Chapman (1970)
HON	21.3N	158.0W	*XYZ*	14	47	126	1939–1976	Gupta (1980)
SJG	18.4N	66.1W	*XYZ*	13	49	119	1926–1976	Gupta (1980)
TRD	8.5N	75.0W	*D*	–	42	–	1853–1859	Malin (pers. comm.)
PAB	5.8N	55.2W	*DHZ*	–	–	187	1958	Malin (pers. comm.)
WAT	30.3S	115.9E	*DHZ*	9	32	104	1919–1958	Green and Malin (1971)
HER	34.4S	19.2E	*XYZ*	14	47	128	1941–1973	Gupta (1980)
TOO	37.5S	145.5E	*DHZ*	9	31	108	1924–1933	Green (1972)

Winch (1981) for the sunspot minimum period (mean $R=13$) of 1964 and 1965. It included 130 observatories and a total of 260 observatory-years of data (see also Stening and Winch, 2013).

The individual-observatory studies have shown that S is dependent on R, but, in general, global studies have ignored this effect. However Malin et al. (1975) have examined the dependence of both S and L on R for a widespread distribution of observatories. They draw the surprising conclusion that S and L originate largely at different levels in the ionosphere, based on the different responses of the two phenomena to R. In the present paper, and in a subsequent one for L, we hope to shed some light on this subject. We shall do this by considering a much larger data-set than hitherto, and by using a more sophisticated modelling method than previously, determining all the required parameters simultaneously rather than analysing the horizontal and vertical components separately and then comparing them to obtain internal and external parts. We also incorporate the dependence on R into the same analysis.

2. Data

The main body of data for this analysis consists of hourly mean values in computer-readable form from the World Digital Data Centre (WDDC) for the interval 1932 to 1990 (comprising 3808 observatory-years of data) and similar INTERMAGNET data for the interval 1991 to 2010, comprising a further 2761 observatory-years. For each element at each observatory, the four principal Fourier harmonics, with frequencies of 1, 2, 3 and 4 cycles per day, were determined as described in the next section. Before proceeding to the global analyses these harmonics were supplemented with those determined by other workers as detailed in Table 1, adding a further 867 observatory years. Care was taken to avoid overlaps between the data-sets, so that no data were used twice. This additional source improved the geographical coverage and considerably extended the temporal range. In all cases, standard deviations were included, so that the quality of the determinations could be taken into account. The magnetic elements listed in the table are: X north intensity; Y east intensity; Z vertical intensity, positive downwards; H horizontal intensity and D east declination.

The geographical distribution of the data is shown in Fig. 1. As is inevitable with studies based on observatory data, the southern hemisphere and oceans are poorly covered, while there is a great density in Europe. The temporal range is from 1853 (Trevandrum) to 2010 (INTERMAGNET). Selleck (1980) has shown that there is a small, but detectable secular variation in S, but we consider it to be too small to be of significance for the present study.

The need for the best possible geographical coverage is obvious, but it might be questioned why such long runs of data are required. While S could be determined adequately from relatively short (a few years) runs of data, we later plan to examine L, for which the longest possible runs of data are required, and wish to do so from the same data-set to permit accurate comparison. Also we are investigating the variation of S with R, so require data over a number of sunspot cycles. For this latter investigation, the WDDC and INTERMAGNET data have been grouped according to sunspot number: high ($R>100$), medium ($20<R<100$) and low ($R<20$). Most of the longer analyses listed in Table 1 had been similarly divided.