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Spectral analysis of geomagnetic data from Kandilli Observatory, Istanbul

Ayşe Hümeyra Bilge (1) (*) **and Yurdanur K. Tulunay** (2) (°)
(1) *Department of Mathematics, TÜBİTAK, Marmara Research Center, Research Institute for Basic Sciences, Gebze, Kocaeli, Turkey*
(2) *Department of Aeronautical Engineering, METU/ODTÜ, Ankara, Turkey*

Abstract
The geomagnetic field variation spectra for periods longer than 2 h are analysed using the data obtained at the Kandilli Observatory in Istanbul, Turkey. Among the deterministic components, only the harmonics of the solar daily variation (S_i) and the second harmonic of the lunar daily variation (L_2) were observed. The seasonal dependence of the D component is analysed; the first harmonic of the solar daily variation (S_1) has maximum power in summer, decreasing symmetrically towards the winter; the second harmonic (S_2) has equal power in spring, summer and fall, while the third harmonic (S_3) has maximal power in spring and fall.

Key words *Kandilli data – geomagnetic field – spectral analysis*

1. Introduction

In this paper we study the geomagnetic field data obtained at the Kandilli Observatory in Istanbul, Turkey for the years 1973-1977, using spectral analysis. The coordinates of the Kandilli Observatory are given below:

$$\phi = 41°03.8\,\mathrm{N}, \qquad \lambda = 29°03.7\,\mathrm{E},$$

$$h = 130\,\mathrm{m}, \qquad \Phi = 38°5, \qquad \Lambda = 107°5,$$

where h is the elevation, $\{\phi, \lambda\}$ are geographical latitudes and longitudes and $\{\Phi, \Lambda\}$ are corresponding geomagnetic coordinates at 1976. The geomagnetic observation department in Kandilli has been in operation since 1947. The hourly mean values of D, H and Z components are regularly published in the observatory yearbook which also describes instruments and data acquisition.

In our analysis we used the hourly mean values of the D, H and Z components for the years 1973-1977. Hence our analysis is necessarily directed to the study of the periodicities longer than the Nyquist frequency, 2 h.

The short-term variations of the geomagnetic field are mainly due to the changes in the atmospherical current systems and the best known «quiet day» variations are the solar daily variations S with a 24 h period and the lunar daily variation L with a 24 h 50 min period. The S variation is dominant and it can be seen from the magnetograms as an increase in the field intensity during daylight hours. This variation is far from a regular sine curve

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(*) *Present address*: Department of Mathematics, Istanbul Technical University, 80626 Maslak, Istanbul, Turkey; e-mail: bilge@mam.gov.tr

(°) *Present address*: Faculty of Aeronautics and Astronautics, Istanbul Technical University, 80626 Maslak, Istanbul, Turkey.

even for quiet days, there is an increase in the amplitude from winter to summer and its shape also depends on the latitude. The amplitude of L variation is around 1/10 of S variation and is usually masked by the latter (for example, Mitra, 1952, section 7.2). Using time domain averaging techniques it has been observed that the main constituent of the L variation is a semi-diurnal component very close to a regular sine curve.

Further details of the classical time domain methods for the analysis of the solar and lunar daily variations are described for example in Mitra (1952).

In the frequency analysis we applied the Fast Fourier Transform (FFT) to zero mean data. In our analysis we used either $N = 2^m$ (m = integer) data points with a 4-term Blackman-Harris window (Harris, 1978), or a data length which is a multiple of the first harmonic of the solar daily variation (S_1) or of the second harmonic of the lunar daily variation (L_2) without windowing.

Preliminary investigations showed that the harmonics of the solar daily variation were dominant, and the analysis was directed to the study of any seasonal dependence of these variations and to separating the deterministic from the random variations.

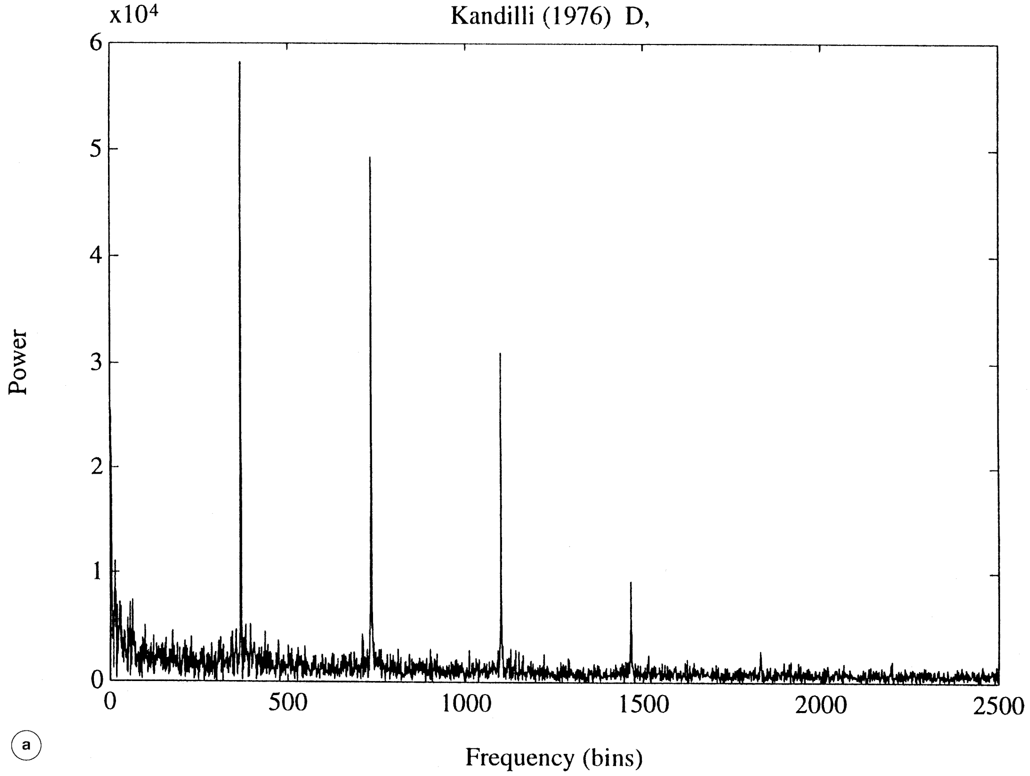


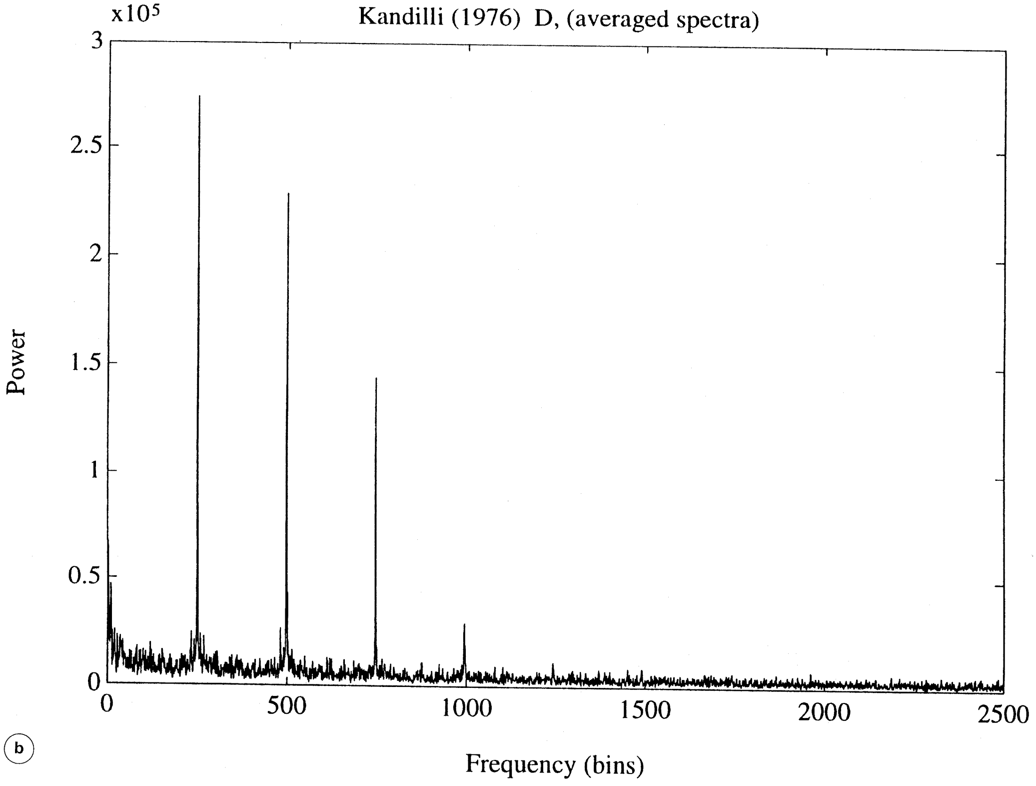
Fig. 1a,b. a) Power frequency spectrum of the D component. The total observation time is one year (1976) and FFT is obtained using $8784 = 24 \times 366$ data points. The vertical axis is the power of the frequency components (dimensionless) which is proportional to the total power of the time series. The units on the horizontal axis are «bins» which can be converted to hours by $T = 8784/(n-1)$. For example the periods corresponding to 500, 1000, 1500 and 2000 bins are respectively 17.603, 8.793, 5.860 and 4.394 h. b) Average of six power

2. Analysis of the Kandilli data

2.1. *Spectral analysis*

A clear resolution of the *S* harmonics is obtained by using FFT with 8784 = 366 × 24 data points. The power spectra for 1976 (chosen as it is a magnetically quiet year in the period 1973-1977) shows clearly the S_i harmonics for $i = 1, ..., 4$ (fig. 1a); S_5 and even S_6 are also visible. The L_2 variation is observable, but it cannot be distinguished from neighboring peaks of similar power. In order to confirm that the observed peak really corresponds to the L_2 variation, we obtained the power spectra for 6 overlapping intervals each 5960 data points long (which corresponds to an exact multiple of the L_2 periodicity), shifted by 500 data points. The average of these spectra is given in fig. 1b, where the peak corresponding to the L_2 periodicity is enhanced, while other peaks previously of similar power are smeared out.

In order to decide which periodicities are deterministic, we worked with 58 monthly observation periods (excluding the first and the last months of the total observation period) for the *D* component as its variations were observed to be more accentuated.



spectra for *D* component obtained from FFT using $5960 = 40 \times \frac{149}{12}$ data points. This procedure enhances the L_2 peak. The vertical axis is the power of the frequency components (dimensionless) which is proportional to the total power of the time series. The units on the horizontal axis are «bins» which can be converted to hours by $T = 5960/(n-1)$. For example, the periods corresponding to 500, 1000, 1500 and 2000 bins are 11.944, 5.966, 3.976 and 2.981 h respectively.

2.2. *Separation of determistic and random variations*

We consider the power spectra for the D components for 58 monthly samples. The number of occurrences of the peaks in the frequency spectrum of the samples is plotted as a histogram in fig. 2.

In this analysis the S_1 periodicity occurs at frequency points corresponding to 24.09, 24.23 and 24.38 h in 15, 39 and 3 samples respectively. We assume that there is a ± 1 frequency point uncertainty in the determination of a peak, *i.e.*, a peak that occurs at the $n+1$'th or $n-1$'th frequency point in the power spectrum, will be considered as having occurred at the n'th point. Thus as S_1 peak occurs on 57 out of 58 samples we say that the «percentage of occurrence» of S_1 is 98%. With similar considerations we obtain table I.

Hence we clearly conclude that only the S_i, $i = 1, ..., 4$ are observed. The 50% occurrence of L_2, together with the enhanced peak in the averaged spectrum given in fig. 1b allows us to claim that L_2 also is observed.

2.3. *Seasonal dependence of the solar daily variation*

The seasonal mean values of the D component *versus* universal time are plotted in fig. 3 for the year 1976 as an example. From the figure, it can be seen that the daily variation is

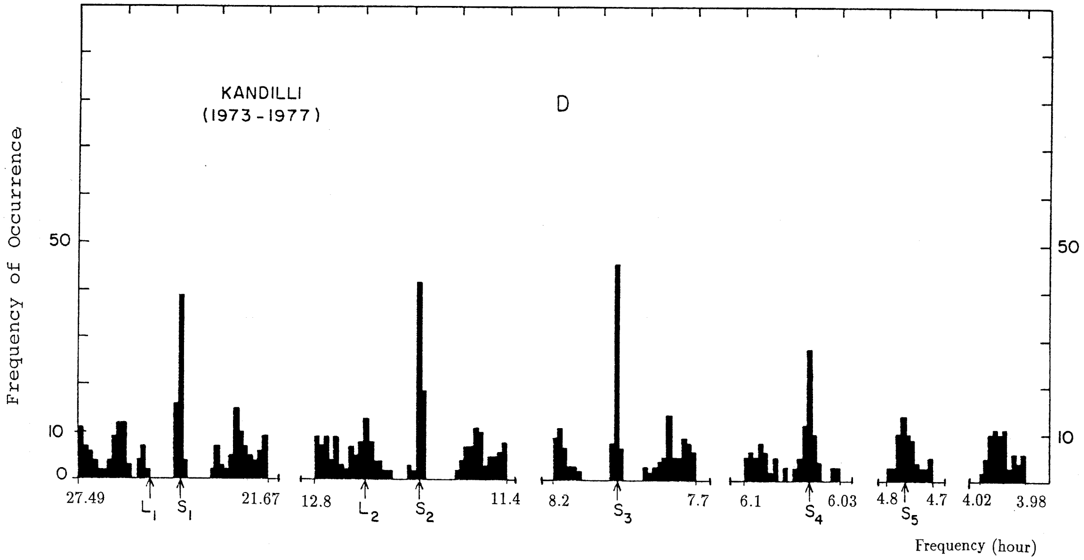


Fig. 2. Histogram of the frequency components in 58 samples with one-month observation periods; the vertical axis shows the number of occurrences of a given frequency in the FFT of 58 samples. The lower frequency portion of the spectrum is covered only.

Table I. Percentage of occurrences of the S and L harmonics.

Harmonic	L_1	S_1	L_2	S_2	S_3	S_4	S_5	S_6
Percentage of occurrence (%)	0	98	50	98	79	69	41	17

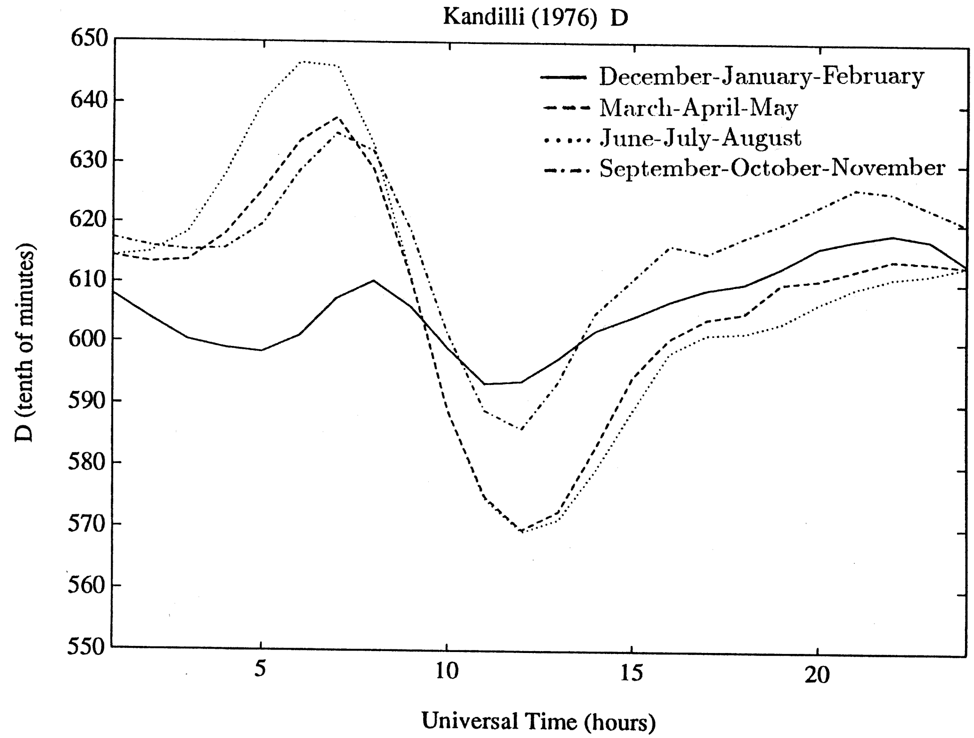


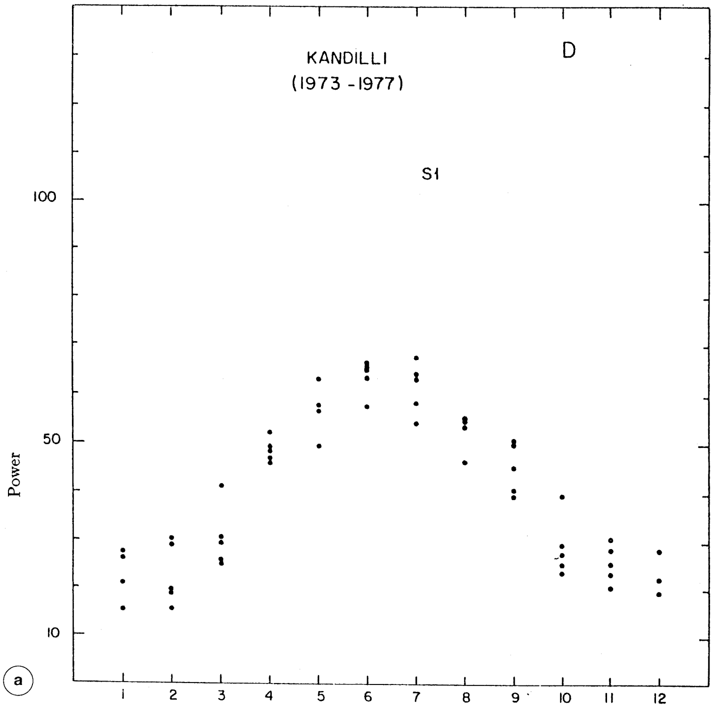
Fig. 3. Seasonal mean values of D daily variations *versus* Universal Time (UT); Local Time (LT) is given by LT = UT+2 h. The baseline values to be added to the values on the vertical axis is 2°. The nice dip around noontime is evident, which is typical of middle latitudes (Mitra, 1952; Risbeth and Garriot, 1969). The behaviour of D concerning the phase change between solstices around local noon is similar to H (not shown here). A more symmetrical oscillation is evident in the summer solstice.

confined mostly to the daylight hours. The same applies to the other two components not shown here. As the shape is far from a regular sine curve, strong higher harmonics are expected in the frequency analysis. The seasonal dependence of the solar daily variation is observed in all three components but mostly in the D component. During summer, the daily variations have larger amplitudes for all components.

The power spectra of the D variation for 5 years were analyzed. The variations of the amplitudes of the S_i for $i = 1 \ldots 3$ harmonics *versus* months are plotted in fig. 4a-c. As it can be seen, the S_1 harmonic reaches its maximum in summer and its power decreases symmetrically towards winter. The S_2 harmonic has more or less equal power during spring, summer and fall but it decreases again towards winter. The S_3 and S_4 harmonics are accentuated only during spring and fall. The power of the S_4 harmonic is considerably less than the others and it is almost ineffective in summer. As its seasonal variations is minor, the graph is omitted.

3. Discussion and conclusions

The main objective of this work is to introduce the geomagnetism community to the data from Kandilli Observatory. We presented the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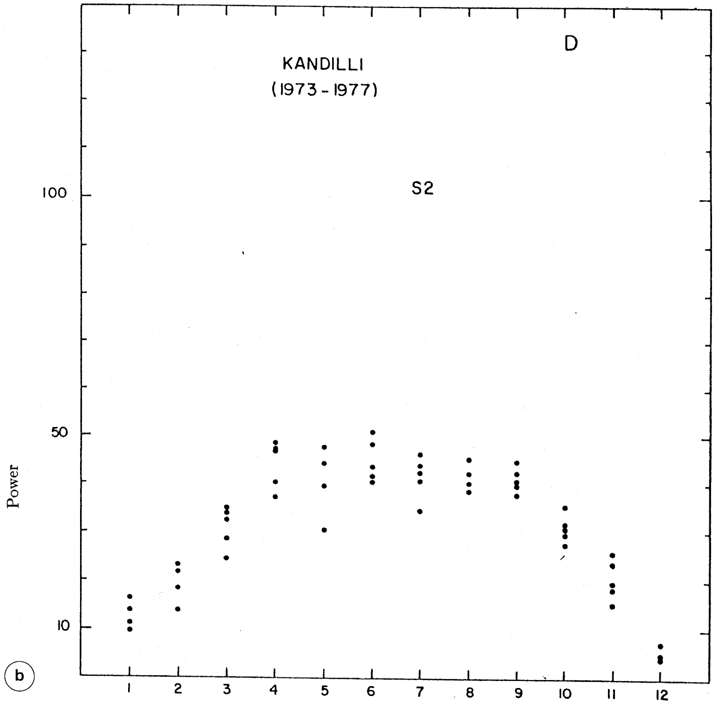
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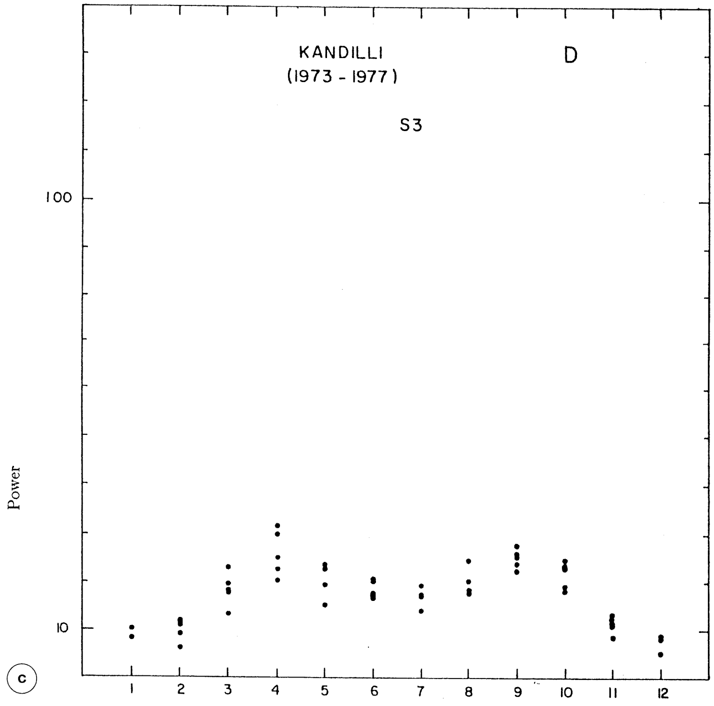

Fig. 4a-c. The seasonal dependence of the S harmonics in the D variation. The vertical axis is the power of the corresponding harmonic. The units on the horizontal axis are months (see text for explanation).

diurnal and seasonal behaviour of the Kandilli D, H and Z data sets for a relatively magnetically quiet period with particular attention to D. The S_i harmonics for $i = 1, 2, 3$ were clearly distinguishable, and we obtained the seasonal dependence of these harmonics using the spectra of one-month observation periods over five years. The enhancement of the S_1 variation in summer is well known, but to our knowledge the seasonal dependence of S_2 and S_3 and the observation that the higher harmonics are more effective in spring and fall is new. The seasonal variation of diurnal variations was also studied recently in Rastogi (1993) using time domain methods. As our time domain analysis is only qualitative, we can only say that the D and H fields have concurrent midday *extrema* (except for winter), and this observation agrees with Rastogi's findings.

The power spectra and the histogram study revealed a number of low power peaks including the L_2 variation. Among these we claim to have «observed» the L_2 variation because it was enhanced in the averaged spectra using a total observation period which is an exact multiple of the L_2 period. Further investigation is needed in order to decide whether other peaks of similar power are deterministic or not. In this context we mention that a quasi 2-day periodicity was studied in Takeda and Yamada (1989).

We conclude with two remarks concerning future directions for research. Firstly, the location of the Kandilli Observatory is interesting for the change of phases of the average pressure at high latitudes in the troposphere and a correlation between meteorological pressures and the strength of geomagnetic activity has been observed (Tulunay *et al.*, 1988; King, 1974). Secondly, the observatory is located near the Bosphorus, where a high speed southward current system is dominant. However the effects of such shallow (80-90 m) current systems are expected to be reflected at higher frequencies (about 2.5 min) than those investigated here. Thus the available magnetogram data is not suitable for this purpose and studies in this direction might necessitate new experiments.

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