DOES THE MAGNETOSPHERE BEHAVE DIFFERENTLY ON WEEKENDS?

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ABSTRACT

Global geomagnetic activity has been suggested to be enhanced during weekends above the weekly average after 1940s. Before 1940s weekends and weekdays were found to be equally active. This so-called "weekend effect" was suggested to be due to VLF range harmonics of the radiation emitted by electric power lines (power line harmonic radiation, PLHR). Since the consumption of electric power is different on weekends and weekdays leading to different PLHR intensities, this could possibly cause the "weekend effect" in global geomagnetic activity.

In the present paper we reanalyze the suggested "weekend effect" in global geomagnetic activity using the 69-year planetary geomagnetic *Ap* index and the 133-year antipodal *aa* index. We conclude that there is no statistically significant "weekend effect" during the interval covered by these geomagnetic activity indices. Although global geomagnetic activity is slightly enhanced on weekends from 1940s to 1980s, the more recent data show rather a decrease of global geomagnetic activity on weekends, contrary to the expected increase of the "weekend effect" due to increasing power consumption

1. INTRODUCTION

The power line harmonic radiation can propagate from ground into space and thus may, in principle, have effects on the global behaviour of the magnetosphere. The propagation of PLHR through the magnetosphere was first observed by Helliwell and Katsufrakis (1974). Subsequent studies verified that man-made VLF waves can propagate from ground into the magnetosphere (Helliwell and Katsufrakis, 1974; Helliwell et al., 1975; Park, 1977; Parka and Helliwell, 1978; Fraser-Smith and Coates, 1978). During the past decade, low-altitude satellites have been used to study the anthropogenic PLHR in space. AUREOL 3 satellite (Parrot, 1994) was the first to observe PLHR at mid-latitudes.

Fraser-Smith (1979) reported that global geomagnetic activity had increased on weekends since 1940s. He studied global geomagnetic activity by the superposed epoch (SPE) method using the daily values of the *Ap* and *aa* indices in the 46.5-year (Jan 1, 1932 - June 6, 1978) and 110-year (Jan 1, 1868 - Dec 31, 1977) intervals, respectively. No increase was observed before 1940s, but thereafter activity on weekends was enhanced. Fraser-Smith (1979) suggested that this so-called "weekend effect" is due to the consumption of electrical power which is larger on weekdays than on weekends, and which is greatly increased since 1940s. According to Fraser-Smith (1979), global geomagnetic activity is smaller on weekdays because the strong PLHR affects the magnetospheric processes so that natural disturbances are suppressed. On weekends, the activity would be higher because the smaller level of PLHR would have a smaller suppressing effect.

In this paper we repeat the study of Fraser-Smith (1979) and extend it by 20 years of additional, more recent data on global geomagnetic activity. With the ever increasing power consumption one could expect the "weekend effect" to be strengthened during this time. We examine the "weekend effect" in the *Ap* index in Section 2 by the superposed epoch method and in Section 3 by spectral methods. In Section 4 we present a detailed time profile for the "weekend effect" using both *Ap* index and the 130-year *aa* index. Section 5 presents our conclusions.

2. SUPERPOSED EPOCH ANALYSIS OF THE AP INDEX

We have calculated the weekly variation by the superposed epoch method from the daily *Ap* indices for the time interval studied by Fraser-Smith (1979) and for the time interval Jan 1, 1932 - Dec 31, 2000 (the whole *Ap* interval until recently). Table 1 lists the average *Ap* values and their standard errors for each day of the week for these two time intervals, and Figure 1 depicts them visually. Our results for the years 1932-1978 are the same as those reported by Fraser-Smith (1979).

The average all-day *Ap* value for the years 1932-2000

	1932-1978		1932-2000	
	m	σ_m	m	σ_m
Mon	14.66	0.33	14.96	0.28
Tue	14.16	0.31	14.44	0.26
Wed	14.28	0.31	14.49	0.26
Thu	14.18	0.33	14.39	0.26
Fri	14.21	0.34	14.51	0.27
Sat	14.74	0.35	14.78	0.28
Sun	14.73	0.36	14.70	0.28
Weekend	14.73	0.25	14.74	0.20
Weekday	14.30	0.15	14.56	0.12
All days	14.42	0.13	14.61	0.10

Table 1. Mean values (m) and standard errors (σ_m) of Ap index for each day of the week in 1932-1978, and 1932-2000.

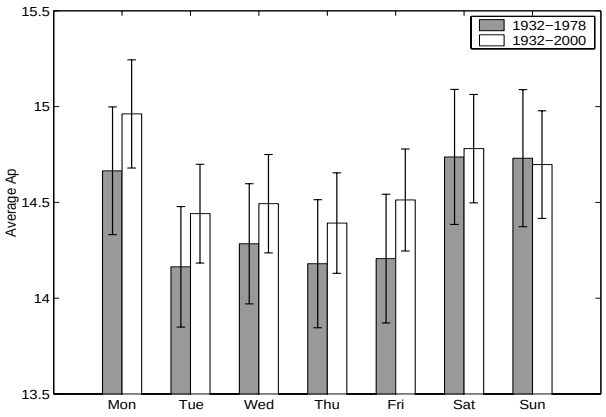

Figure 1. Mean values and standard errors of Ap index for each day of the week in 1932-1978, and 1932-2000.

(see Table 1) is larger than for the years 1932-1978, reflecting the increasing trend of global geomagnetic activity (see, e.g., Clilverd et al., 1998; Lockwood et al., 1999). However, this increase has mainly taken place on weekdays while the weekend mean value in 1932-2000 is roughly the same as in 1932-1978. Accordingly, global geomagnetic activity is smaller on weekends than on weekdays since 1980's, indicating that the "weekend effect" was reversed during this time. Actually, while the interval studied by Fraser-Smith (1979) depicts roughly a 2 σ_m signal of enhanced weekend activity, the same signal in 1932-2000 is within the 1 σ_m error.

Consequently, the significance of the "weekend effect" during the more recent, larger *Ap* interval has decreased considerably since the time of Fraser-Smith (1979). This development is contrary to the idea that the "weekend effect" would be further enhanced during the last 20 years due to enhanced consumption of electric power. The small overall level of the "weekend effect" in 1932-2000 and the variation of weekend activity above and below the weekly average strongly suggest that the "weekend effect" is only due to statistical fluctuation.

3. SPECTRAL ANALYSIS OF THE AP INDEX

Fraser-Smith (1979) pertinently noted that the spectral analysis of lengthy intervals of the *Ap* (e.g. Fraser-Smith, 1972) and *aa* indices (e.g. Delouis and Mayaud, 1975) do not show a well-defined 7-day spectral line. He suggested that this could be reconciled with the results of the SPE method if the weekend increase only occurs intermittently in time.

We have studied the temporal occurrence of spectral power in Figure 2 which depicts the dynamic FFT spectrum of the *Ap* index for periods from 6 to 8 days. The *Ap* data were split into successive annual sections, detrended and zero-padded, and the average FFT power spectral density was calculated for each annual section. The 6-8-day period part of the resulting annual spectra have been depicted along the vertical axis in monochrome (black and white) intensity scale. The plot verifies that there are isolated enhancements of geomagnetic activity within the 6-8 day period range but no continuous 7-day variation.

Figure 2 shows that in the years 1939-42, 1946-52 and especially in 1957-62 there were large variations in global geomagnetic activity at periods from 6 to 8 days. We note that most of these do not have a period of exactly 7 days and that spectral power is fairly evenly distributed over the depicted period range. However, some of the enhancements, for instance the one in 1953, has a period close to 7 days (see Figure 2).

Overall, the power of geomagnetic activity variations between 6 to 8 days has become weaker after early 1960s. The power in the 6-8 day period range was especially weak from early 1960s to late 1970s. During the years 1979-83 a few enhancements appeared mostly close to the period of 8 days. Also some weak variations at the period of about 7 days occurred during those years. In 1992-93 strong spectral lines occurred with periods between 6 and 7 days. In 1999 there was a clear 7-day spectral line.

4. LONG-TERM EVOLUTION OF THE "WEEKEND EFFECT"

Long-term variations and trends can greatly affect an SPE analysis. Since global geomagnetic activity is known to have increased fairly systematically during the last 100 years, this might have led to a "weekend effect" when weekly averages are compared with the values of the subsequent weekend. In order to avoid the effect of long-term variations and trends, we have subtracted the running 13-day mean from the daily *Ap* index series to form the high-pass filtered *Ap* series. All periods longer than 13 days (e.g., solar cycle changes and 27-day variations) are thereby effectively removed from the *Ap* index.

Also, in order to avoid the artefact of the weekend

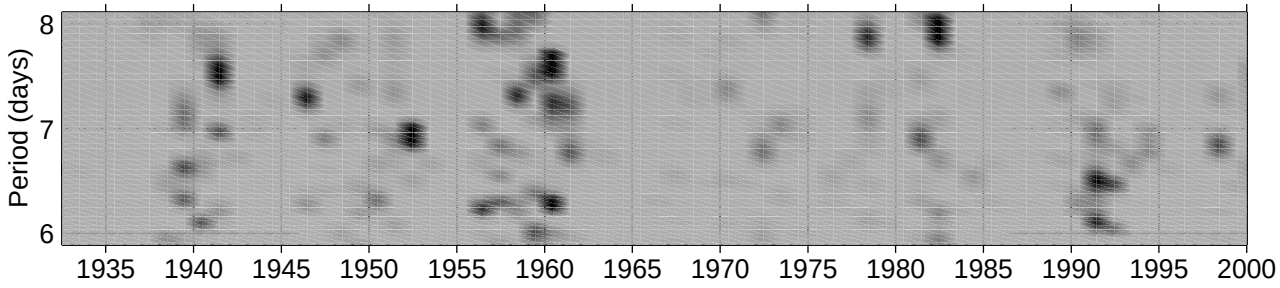

Figure 2. Dynamic FFT spectrum for the daily Ap series in 1932-2000. Black colour represents large intensities.

being at the end of the week, we have compared the (filtered) *Ap* values for the weekend with the average level of the two adjacent 5-day working weeks. Each weekend (Saturday and Sunday) is combined with the 5-day working week before and after it to form a 12-day segment. Finally, we subtracted the mean 10-day weekday average from the mean weekend value to form the series representing the weekend-weekday difference. In order to study the detailed time evolution of the "weekend effect", we have computed the cumulative sum of weekend-weekday differences from the *Ap* indices for the years 1932-2000, and plotted this curve in Figure 3. The cumulative sum can directly depict the time evolution of any possible weekend enhancements.

Figure 3 shows that the cumulative sum has experienced a major increase from early 1940s to about 1980. This increase corresponds to enhanced geomagnetic activity during weekends during this time, as found by Fraser-Smith (1979) using the SPE method. Accordingly, this increase forms the basis of his evidence in favour of the "weekend effect". However, as seen in Figure 3 the subsequent evolution of the cumulative sum is completely different, decreasing from 1980s until today. This implies that the global geomagnetic activity has been weaker on weekends than on weekdays since 1980s. This decrease is against the idea of a persistent "weekend effect" and, in particular, against the idea of the effect being due to the PLHR.

Note also that some detailed features that were found in the dynamic spectrum of the *Ap* index (see Figure 2) are also seen in the cumulative sum for the *Ap*. For instance, within the years 1939-42, 1960-62 and 1979-82 the cumulative curve has a rapidly increasing section, corresponding to simultaneous spectral enhancements.

In order to study the temporal evolution of the "weekend effect" for even earlier times, we have calculated the cumulative sum also for the *aa* index (see Fig. 4). Figure 4 shows that the cumulative sum has experienced three major, increasingly large and mostly positive fluctuations during the 130-year interval. The first fluctuation (1870-1890) lasted only 20 years and returned the sum roughly to zero value. The second, longer fluctuation (1890-1935) stopped with the cumulative sum retaining a small positive

Figure 3. Cumulative sum of weekend-weekday differences calculated from the Ap indices (solid curve). Running 10-year mean is depicted as a dashed curve.

value. The third fluctuation started in 1940's and is obviously not yet finished. Note also how closely the curves of the two indices of geomagnetic activity (see Figs. 3 and 4) follow each other during the overlapping time interval.

Despite the fact that the weekend-weekday difference is positive nearly continuously throughout the 130-year interval it does not give solid evidence for the existence of a "weekend effect". In particular, the small size of the positive fluctuations is below statistical significance, as concluded earlier. Moreover, the fluctuating nature of the weekend-weekday difference, in particular the decreasing sections in 1910-1940 and from 1985 until now, are against a persistent "weekend effect" and the idea that the effect would be due to the PLHR. Note also that the decrease since 1985 also excludes the possibility that the "weekend effect" was active only in 1940-1985. Such a scenario could be envisioned if the weekly variation of power consumption was reduced since recently, e.g. due to increased automation of the industry.

5. CONCLUSIONS

In this paper we have reanalyzed the evidence found earlier (Fraser-Smith, 1979) in favour of a higher level

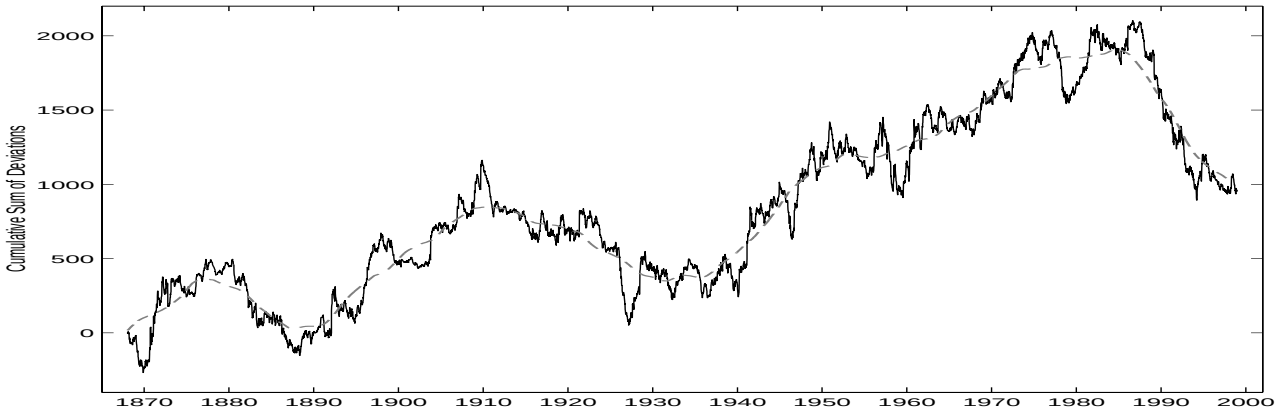

Figure 4. Cumulative sum of weekend-weekday differences calculated from the aa indices (solid curve). Running 10-year mean is depicted as a dashed curve.

of global geomagnetic activity on weekends since 1940s. The reason for this so-called "weekend effect" was suggested to be the different amount of power line harmonic radiation between weekends and weekdays.

We have calculated the temporal evolution of the weekend-weekday difference during the last 130 years and find no systematic or statistically significant enhancement of geomagnetic activity on weekends either during the overall 130-year interval studied, or during the more recent decennia. Instead of the expected systematically increasing trend, the weekend-weekday difference only depicts fluctuations which are, however, below statistical significance. The earlier evidence in favour of the "weekend effect" was based on the rising part of the so far largest statistical fluctuation of the weekend-weekday difference. During the last 15-20 years the activity is even weaker on weekends than weekdays, contrary to the behaviour expected for the "weekend effect" due to power line harmonic radiation. These results suggest that the weekend-weekday difference is of purely statistical nature.

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