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Average Diurnal Variations of the Intensity of Geomagnetic Pulsations in the Period Ranges of pc 2–pc 5 Observed at Fürstenfeldbruck During the Years 1960–1971

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Abstract. Geomagnetic pulsation analogue records from the geophysical observatory at Fürstenfeldbruck near Munich (Germany, $L=2.0$) were statistically analyzed for the twelve years 1960–1971. The analysis was performed by estimating the average peak-to-peak amplitude for every quarter hour of UT, separately for the two horizontal components H (toward local magnetic north) and D (toward local magnetic east), and for any one of the four period ranges 5–10 s, 10–45 s, 45–150 s, and 150–450 s. The estimate of amplitude was made by subjective comparison of the film record with different master curves engraved on a glass scale. From the estimated single values, average daily variations of pulsation intensity were derived for quiet days ($Ap \leqq 8$), moderately disturbed days ($8 < Ap \leqq 25$), and disturbed days ($Ap > 25$). The character of these average daily variations of intensity seems to be remarkably independent of geomagnetic activity though their level increases when the geomagnetic field is more disturbed. The ratio between the average intensity on disturbed days and the average intensity on quiet days increases from 1.6 for the 5–10 s period range to 9.1 for 150–450 s. However there are indications that the results for the 5–10 s period range are somewhat contaminated by the presence of some artificial disturbances of hitherto unknown origin.

Key words: Geomagnetic pulsations – Geomagnetic indices – Solar-terrestrial relationships – Statistics of extended time series

Introduction

Since December 1959 geomagnetic pulsations in the period range from about 2 s to about 500 s have been recorded continuously at the Fürstenfeldbruck observatory (geographic coordinates 48°9′N; 11°36′E; geomagnetic coordinates 48,8°N, 93,3°E, L=1.97). The three-component set of induction variometers of the Grenet-type (an improved version developed at the Geophysical Institute of the University at Göttingen (Voelker, 1963) installed at Fürstenfeldbruck, is part of a north-south chain of similar stations reaching from Kiruna in Northern Sweden to Fürstenfeldbruck in Southern Germany. A detailed description of the variometers (including a description of resonance characteristics and recording technique) has been given by Voelker (1963). The present paper presents results of processing the complete set of photo-optical records (recording speed 6 mm/min) from the years 1960–1971 on a quarter-hourly basis, by subjective reading of activity indices which will be defined below.

In the early fifties, Angenheister (1954) applied the technique of assigning activity indices to geomagnetic pulsations, utilizing rapid-run records from a similar but earlier H-component instrument operated at Göttingen (Germany). He subdivided the range of periods between 7.5 s and 480 s into six intervals of equal length on a logarithmic scale i.e. into six octaves. For each band of periods separately he determined one-hourly activity indices. Continuous records from January 1952 to March 1953 were analyzed in this way and gave mean diurnal variations of pulsation activity dependent on period. Later on, the same approach to the evaluation of pulsation records from Göttingen was undertaken for the years 1953–1958 by Angenheister and von Consbruch (1961).

A similar first statistical analysis of H-component geomagnetic pulsations recorded at Fürstenfeldbruck was made for the years 1960–1962 (Korschunow 1966). However, in this case the period band (octave) from 3.75 s to 7.5 s was also included and the basic time interval was changed from one hour to 15 min in order to improve time resolution (cf. the well-known Q-index of geomagnetic activity introduced by Bartels and Fukushima (1956)).

Modified Fürstenfeldbruck Method of Analysis of Horizontal Pulsation Records for Statistical Purposes

The results of the paper by Korschunow (1966) indicated that a subdivision of the full period range from 3.75 s to 480 s into seven octaves seemed to be too fine i.e. neighbouring period bands yielded mean diurnal variations which were too similar to each other. After some tests, the following ranges of period were introduced for the final analysis: 5–10 s, 10–45 s, 45–150 s, 150–450 s. Though the decision was made rather independently, these ranges correspond almost perfectly to the period intervals defining pc 2, pc 3, pc 4, and pc 5 pulsations according to a well-known 1963 IAGA resolution (see Jacobs et al. 1964). Note, however, that in the present analysis the different period ranges denote (semi-quantitatively, see below) the application of corresponding band-pass filters to every 15 min interval of

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time, whereas a pulsation train with a main period of about 120 s may be classified as a pc 4 or a pi 2 event according to the IAGA resolution, for example, because this classification takes into account also the general shape of the event.

Another important change as compared to the method applied earlier by Korschunow (1966), is the inclusion of the magnetic *D* (i.e. local magnetic east) component in the analysis, in addition to the *H* (local magnetic north) component.

In view of the fact that the records to be statistically analyzed were photo-optical traces on paper film, and that digitizing the records was beyond the resources of the observatory, the analysis was done by eye in the following way: A glass-scale of a length corresponding to 15 min of time on the film was used to estimate the average peak-to-peak amplitude in each period band. In fact, the estimations were made by comparing corresponding oscillations in the record to oscillating master curves of certain frequencies and constant amplitude which were engraved on the glass. As a first step in this estimation, integers – called indices – from 0 to 9 were assigned to the 15 min time interval and period band considered, the figures from 0 to 8 being proportional to average amplitude as far as possible. If the amplitude of the oscillations surpassed a certain upper limit depending on period, the index 9 was estimated. Finally, the indices were transformed into average peak-to-peak amplitude values, in nT, taking into consideration the known dynamic response of the magnetometer. A more detailed description of the procedure of analysis and particularly of index estimation has been given by Korschunow (1969), Holló and Korschunow (1974), and Korschunow (1976, 1982).

Compared to more exact methods, such as analogue or digital filtering, for example, the subjective reading applied will yield peak-to peak amplitudes which may be affected with rather large errors, in single cases. On the other hand, it may be expected that these errors will largely average out if the estimated data are used for statistical purposes. In fact, different tests – analyses of records done by different persons, repeated analysis of the same record after some time, for example – showed that the estimated amplitudes were reliable enough to serve as a basis for long-term statistics such as in the present case (Korschunow, 1976).

Results

In general, in investigations of geomagnetic variations it is advisable to distinguish between quiet and disturbed intervals of time because results of any analysis may be very different in the two cases. Correspondingly, and because derivation of average daily variations of pulsation activity was the aim of the present work, the whole set of estimated indices and corresponding amplitudes was subdivided according to the following three classes of days in UT:

q-days	(quiet)	$Ap \leqq 8$
m-days	(moderately disturbed)	$8 < Ap \leqq 25$
d-days	(disturbed)	$25 < Ap$.

Here, Ap is the daily planetary activity index defined by Bartels (see, for example, Siebert, 1971). Note, that at Fürstenfeldbruck the local solar day approximately coincides with the UT day. The classification of days mentioned was adopted by studying the statistical properties of Ap indices for the years 1960–1968. It was found to be in agreement with particulars given later on by Siebert (1971).

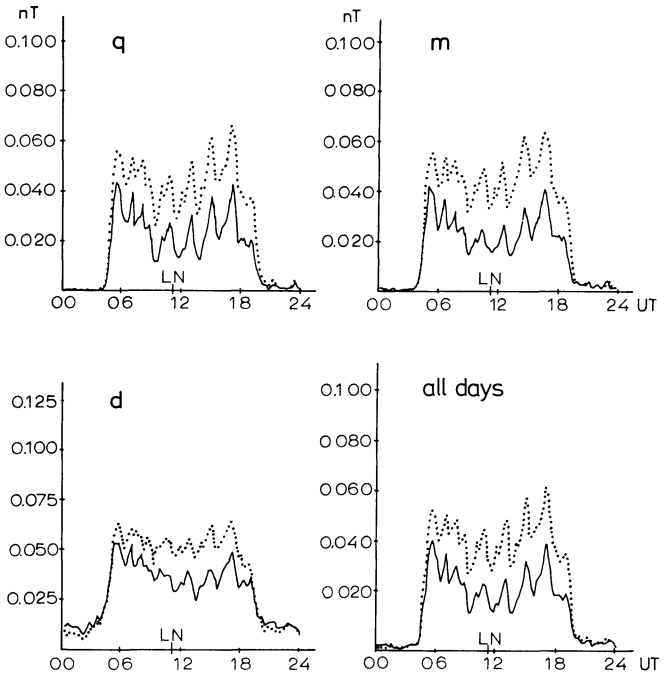

Fig. 1. Average daily variations of geomagnetic pulsation intensity in *H* (*full lines*) and *D* (*broken lines*) on a quarter-hourly time basis for quiet days (*q*), moderately disturbed days (*m*), disturbed days (*d*), and all days, for the period range 5–10 s corresponding to the pc 2 range of periods. LN denotes average local noon at Fürstenfeldbruck

Finally, from the quarter-hourly estimated single values, diurnal variations of the average peak-to-peak amplitude of geomagnetic variations at Fürstenfeldbruck were determined for the three different classes of days (1994 *q*-days, 1947 *m*-days, 460 *d*-days) as well as for the whole set of 4401 days from 1960 to 1971, for the two horizontal field components, and for the four period ranges defined above. The results are shown in the Figures 1–4. Note that the ordinate scales are different from case to case.

One point seems to be particularly evident when regarding these results: For any particular period range chosen, the character of the curves remains rather similar for the different classes of days (*q, m,* or *d*), for each horizontal component, whereas this character changes considerably going from one period range to another. This feature implies that the mutual interplay of the *H*- and *D*-components in each period range remains strikingly constant i.e. unaffected by the state of magnetic activity.

A second point should also be mentioned. If one carefully observes and compares the curves presented one may notice certain non-statistical properties in the fine structure of the curves. This is especially true for the period range of pc 2 (Fig 1) where, during daytime, all the curves exhibit large quasi-periodic oscillations with a periodicity of 2 h, the maximum values appearing at about 10,45, 12,45, 14,45, 16,45, and – though somewhat faint – at 18,45 UT, for all classes of days and both field components. The origin of this persistent effect is open to discussion. However, it should be mentioned that the observatory of Fürstenfeldbruck is situated about 25 km from the center of Munich, and that since the installation of the pulsation magnetometers a continuously increasing level of man-made electromagnetic noise, which seems to affect particularly the

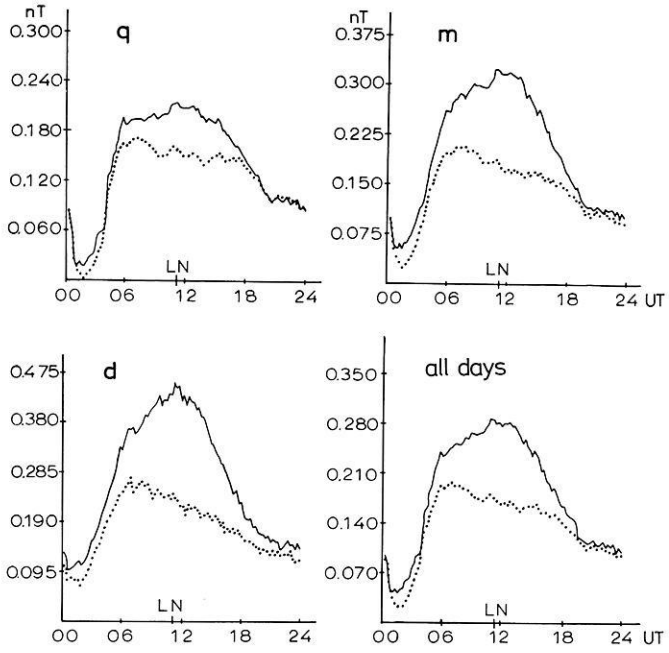

Fig. 2. Same as Fig. 1 but for 10–45 s corresponding to the pc 3 range of periods

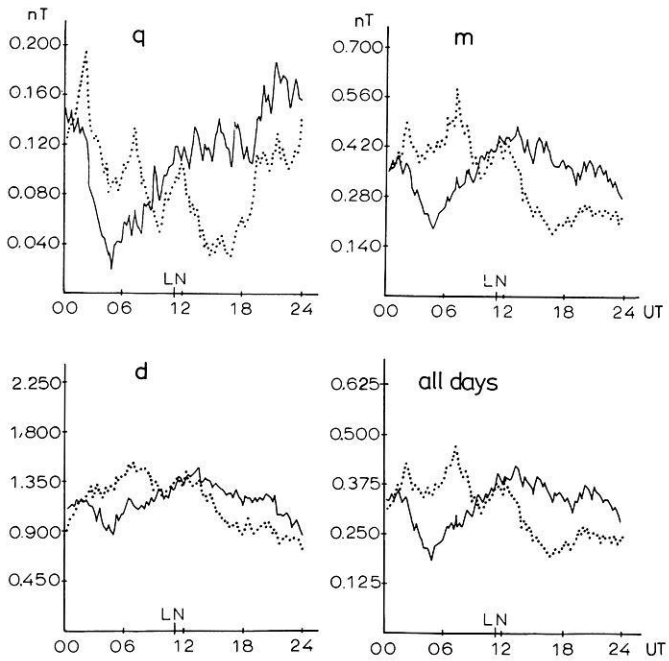

Fig. 4. Same as Fig. 1 but for 150–450 s partly corresponding to the pc 5 range of periods

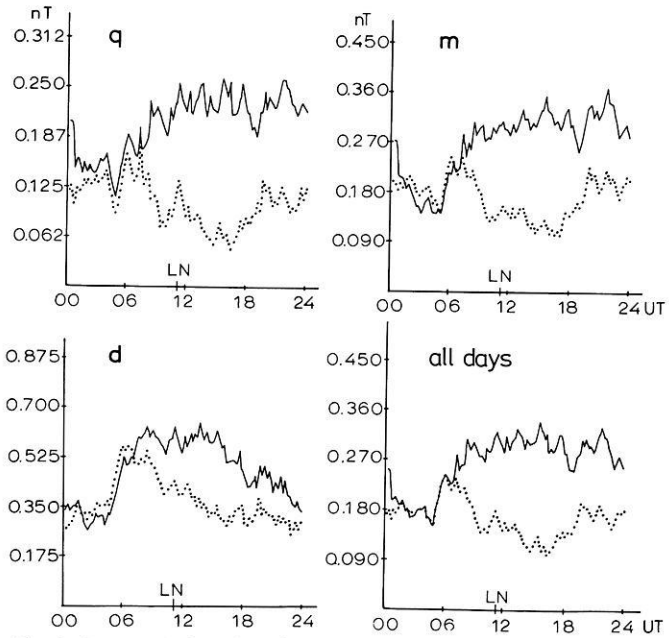

Fig. 3. Same as Fig. 1 but for 45–150 s corresponding to the pc 4 range of periods

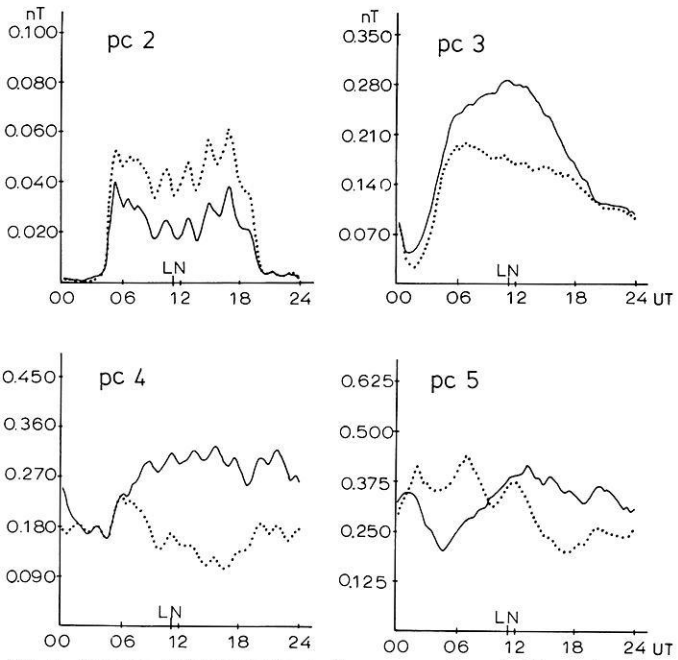

Fig. 5. Average daily variations of geomagnetic pulsation intensity as shown in Figs. 1–4 for all days but smoothed (see text)

pc 2 period range, in our case, has been observed. On the other hand, it has not as yet been possible to identify any clear artificial source which might result in the oscillations mentioned above.

In the period range of pc 4 (Fig. 3) the curves also seem to exhibit some degree of periodicity, of 2 h and 20 min, in this case. This is shown more clearly if smoothed curves are considered (Fig. 5).

Such daily variation curves were derived from the unsmoothed quarter-hourly values x_i represented in Fig. 1–4, using the smoothing process $\bar{x}_i = (x_{i-1} + 2x_i + x_{i+1})/4$. The smoothed curves are shown in Fig. 5, for all days, for the four period ranges, and for the two field components. According to these curves, any noticable periodicity seems to be absent in the cases of the period ranges of pc 3 and pc 5. Again, explanation of the phenomenon in the pc 4 period range remains open, especially since inspection of the records suggests that artificial disturbances are absent for periods larger than about 10 s.

Figure 5 represents the main results of this paper which may be compared to similar results from other observatories. The curves shown exhibit the average daily behaviour

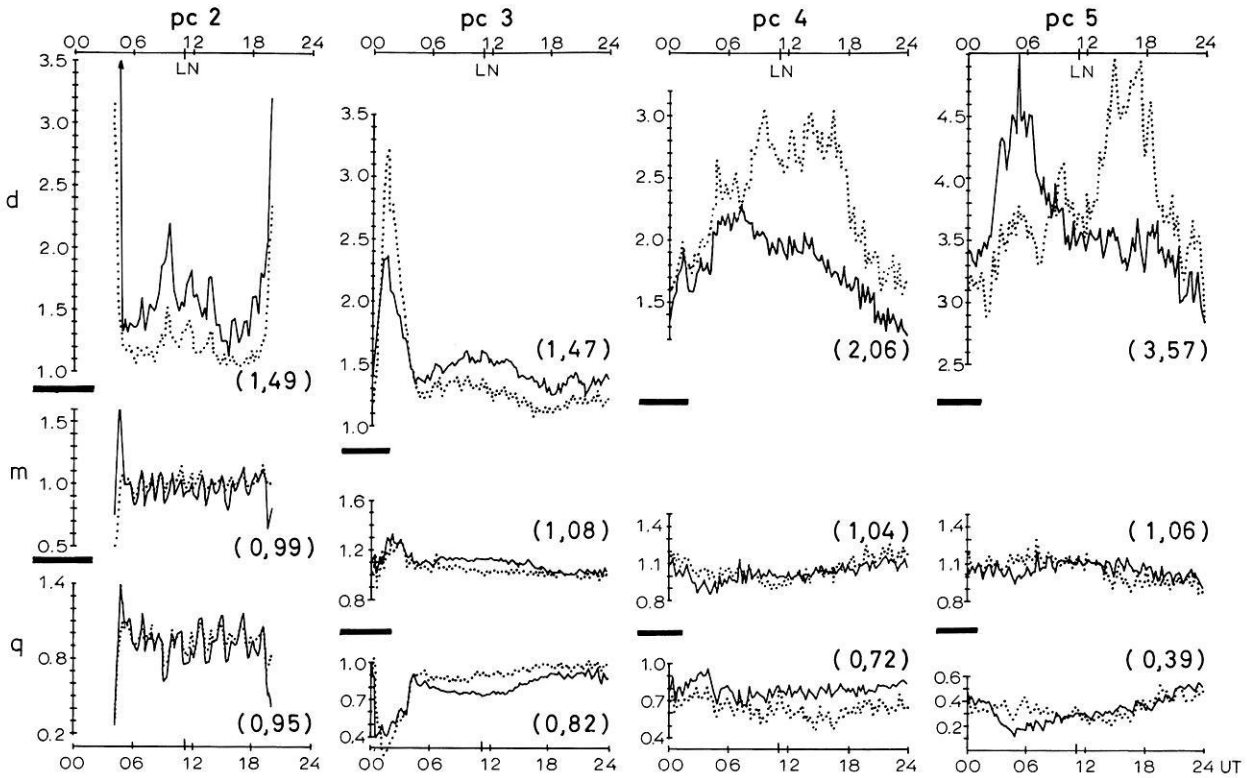

Fig. 6. Ratios of quarter-hourly average values shown in Fig. 1–4 for quiet (*q*), moderately disturbed (*m*), and disturbed (*d*) days to corresponding values shown in Fig. 5, as functions of UT. The results of averaging the ratios over 00–24 UT are given in *brackets*

of peak-to-peak amplitude of geomagnetic pulsations for the different ranges of period and the two horizontal field components, and may serve as master curves for different purposes.

Though the *character* of the curves does not depend much on magnetic activity, as discussed above, the *level* of peak-to-peak amplitude generally increases going from q-days to d-days. It is of interest to note how this increase depends on time of day. Accordingly, Fig. 6 shows the ratios of the quarter-hourly values from Fig. 1–4 to the corresponding smoothed values represented in Fig. 5. In addition, daily averages of these ratios, combined for both field components, are also given in Fig. 6. This figure shows that the relative increase of peak-to-peak amplitude from q-days to d-days becomes appreciably larger going from the pc 2 period range to the range of pc 5, for example from 1.6 (=1.49/0.95) to 9.1 (=3.57/0.39) if daily averages of the ratios are considered, combined for both field components. With increasing period, the ratios decline for *q*-days, whereas the opposite is true for *d*-days. Note, that no ratios are given in Fig. 6 for night time between 20 UT and 04 UT for the pc 2 range of periods because the nominators are very small and are considered to be unreliable in this case. Similarly, the ratios exhibited for *d*-days in the pc 3 period range between about 00 UT and 06 UT should be regarded with reservation.

The Fürstenfeldbruck Method of Statistical Analysis of Pulsation, Records in Relation to Other Work

Several good reviews exist in the literature concerning the wide field of geomagnetic pulsation analysis (for example, Saito, 1969; Jacobs, 1970). Troitskaya et al. (1972) gave a review on different indices of geomagnetic pulsations in use, stating that "only the practice of long term exploitation of an index can answer the question of its utility". In his review on geomagnetic activity indices Bouška (1977) discussed several methods to derive pulsation indices from analogue records. Among those particular workers who introduced geomagnetic pulsation activity indices Saito (1965), Auld and Caner (1971), Frey et al. (1971), Holló et al. (1972), Holló and Verö (1972), Verö (1972), and Tátrallyay and Verö (1973) should be mentioned. Such work should be distinguished clearly from another type of statistical analysis of long term geomagnetic pulsation records, namely the investigation of the occurrence of clearly sinusoidal trains of pulsations (i.e. pc type pulsations) (see, for example, Kato and Watanabe, 1956; Saito 1964; Münch, 1965; Usher and Stuart, 1966; Hirasawa, 1969; Kato et al., 1967; Gupta and Stening, 1971; Gupta, 1976; Olson and Rostoker, 1978).

In comparison to this and other similar work, the Fürstenfeldbruck set of geomagnetic pulsation activity indices is unique in the following respects:

a) A total time interval of 12 years, i.e. of a complete solar activity cycle, is covered without gaps.

b) Both horizontal components have been analyzed in the same way.

c) A high time resolution (15 min) has been preserved throughout the whole process of analysis.

d) The indices derived are suitable for direct conversion into average peak-to-peak amplitude, at different frequencies. This will facilitate future comparison with other results from the statistical analysis of pulsations, at other observatories, or for other solar cycles, for example.

Conclusions

The most remarkable result of the present analysis seems to be that the character of the daily variation of the average peak-to-peak amplitude of geomagnetic pulsations within the four period ranges considered does not seriously depend on magnetic activity. Accordingly, it may be concluded that the magnetospheric generation of pulsations in the period range 5 s–450 s certainly increases in strength when the magnetosphere is disturbed but at the same time seems to preserve its character.

This homogeneous analysis of geomagnetic pulsations covering several years should be regarded as a pilot experiment. With modern electronic equipment a much more sophisticated and somewhat better defined permanent analysis of pulsations should be possible. Promising efforts in that direction have recently been reported by Auster et al. (1973), Auster and Schiller (1975), and Auster and Linthe (1979), for example.

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