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Effect of magnetic storm intensity on Pc1 activity at high and mid-latitudes

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Abstract

We study the properties of structured and unstructured Pc1 pulsations at a high-latitude station (Sodankylä; $L = 5.1$) and a mid-latitude station (Nurmijärvi; $L = 3.3$) during 18 storms occurring in low solar activity years. The storms were divided into two groups according to their intensity as measured by the minimum value of the D_{st} index. Pc1 activity was studied from the day of the storm sudden commencement onwards during six consecutive days. Having recently published the average results for all 18 storms [Kerttula et al., J. Geophys. Res. (2000) in press], we concentrate here on the effect of magnetic storm intensity on wave properties. The source of structured Pc1s was found to be at lower latitudes during intense storms, in agreement with the lower latitude of the ring current during intense storms. Also, the source of unstructured Pc1s, the plasmasheet ions, was found to shift to lower latitudes during intense storms but this change was only observed in the early recovery phase. The great depletion of structured Pc1s on ground during the storm main and early recovery phase, which is in apparent disagreement with space observations and model calculations, is even more dramatic for intense storms. This further emphasizes the significance of the ionospheric conditions for wave observations on ground, and suggests that the depletion is due to deterioration of the ionospheric Alfvén resonator during the storm main phase. Moreover, the results support the idea [Kerttula et al., J. Geophys. Res. 62 (2000) 299–309] that Pc1 occurrence maximum during late recovery phase is related to the improved ionospheric amplification and propagation conditions, rather than the outward expansion of the plasmapause. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Energetic ions of sufficient temperature anisotropy can give rise to ion cyclotron instability in the equatorial magnetosphere, leading to the generation of electromagnetic ion cyclotron (EMIC) waves (Cornwall, 1965; Kennel and Petschek, 1966). The EMIC waves can propagate from the equatorial source region to the ground, where the waves in the frequency range 0.2–5.0 Hz are called Pc1 pulsations. On ground, Pc1 pulsations have often been divided into two main groups according to their dynamic spectra. One group contains events whose amplitude is periodically modulated. They are called structured or “pearl” pulsations. The large majority of all other events forms the second group called unstructured pulsations.

Pearl pulsations are the most common Pc1 type at low- and mid-latitudes (Benioff, 1960; Fraser-Smith, 1970; Kawamura, 1970; Kuwashima et al., 1981) but are fairly often observed even at high latitudes (Fukunishi et al., 1981; Mursula et al., 1994a). The diurnal occurrence of pearls is concentrated in morning hours. It has been found that pearls, on an average, are generated fairly close to the plasmapause region (Roth and Orr, 1975; Lewis et al., 1977; Webster and Fraser, 1985; Mursula et al., 1994b; Erlandson and Anderson, 1996). On the other hand, unstructured Pc1 pulsations are mainly seen at high latitudes

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in the noon–afternoon sector (Troitskaya and Guglielmi, 1970; Kuwashima et al., 1981; Mursula et al., 1994a).

There are several studies of Pc1 pulsations during magnetic storms. Structured Pc1 activity has been observed to be greatly enhanced during the storm recovery phase at low- (Wentworth, 1964), mid- (Plyasova-Bakounina and Matveyeva, 1968; Gupta, 1983) and at high-latitudes (Heacock and Kivinen, 1972). However, the occurrence rate of unstructured pulsations has shown little dependence on storm evolution (Kuwashima et al., 1981). Recently, we (Kerttula et al., 2000; to be called P1) studied Pc1 observations on ground during 18 storms in low sunspot activity years. We found, e.g., that the structured pulsations are strongly concentrated in the dusk sector during the main and early recovery phase, in agreement with space observations (Bräysy et al., 1998) and model calculations (Jordanova et al., 1997; Kozyra et al., 1997). However, the ground Pc1 activity was found to be rather weak in view of the fact that both space observations (Bräysy et al., 1998) and model calculations (Jordanova et al., 1997; Kozyra et al., 1997) indicate that the wave source has maximum activity at this time. In P1 we argued that this reflects the deteriorated resonator conditions of the ionosphere, suppressing coherent wave activity. During later storm recovery, the structured Pc1 activity on ground is greatly enhanced, attaining the maximum occurrence on the fourth day after the storm main phase. On the other hand, no related enhancement is found in space (Bräysy et al., 1998) or in model calculations (Jordanova et al., 1997; Kozyra et al., 1997). In P1, we argued that the increase of structured Pc1s with storm recovery is due to the improvement of ionospheric conditions for Pc1 wave amplification and ducting. The occurrence of maximum activity of structured Pc1s in the morning sector is also related to the respective ionospheric conditions.

In this paper, we continue the analysis of Pc1 activity observed at high- and mid-latitudes during the 18 magnetic storms included in P1, concentrating on the storm intensity effects on the properties of Pc1 pulsations as observed on ground. As in P1, the structured and unstructured Pc1 pulsations are studied separately. In Section 2, we present the data and methods used in the study. Section 3 presents our observations. In Section 4, we discuss the main observations and compare them with earlier results. Finally, Section 5 concludes the paper.

2. Data and method

In P1, we described the conditions used when selecting the storms included in the two studies. All the storms were from low solar activity years, were triggered by a verified SSC signal, had to develop systematically and had to be of a suitable intensity and length. These conditions select a fairly homogeneous set of storms. Moreover, the first condition favours a recurrent high-speed stream as the heliospheric cause of the storm, and the second condition requires that a shock front was included in the process. The storms included in this study, and the values of D_{st} minima are presented in Table 1. In order to study the effect of storm intensity on Pc1 activity, we have divided the storms into two groups according to the minimum D_{st} value. The average (median) D_{st} minimum value was −172 nT (−160 nT) for nine most intense storms and −95 nT (−99 nT) for nine weakest storms. As in P1, we have used the superposed epoch method. The zero time is set at 00 UT on the day of SSC occurrence (denoted by day 0). Note that the interpretation of results for day 0 is limited because the storms can be in different phase (initial, main or early recovery) during this day. (In order to keep the total measurement time equal to 24 h even for day 0, we have collected Pc1 data for the whole day of SSC occurrence, i.e., Pc1 events appearing even before SSC have also been included.) However, we note that other methods of defining the zero day (e.g. as the minimum D_{st} day) would lead to essentially similar results as obtained now.

Table 1
The analyzed storm intervals and the D_{st} minimum values

Storm interval			D_{st} minimum
Year	Month	Day	Value (nT)
1976	Jan	10–15	−156
1976	Mar	26–31	−226
1976	Apr	1–6	−218
1977	Jul–Aug	29–3	−94
1978	Feb	15–20	−108
1978	Mar	8–13	−99
1978	Aug–Sep	27–1	−226
1984	Jul–Aug	31–5	−112
1985	Jun	9–14	−77
1986	Jan	6–11	−79
1986	Sep	11–16	−170
1986	Oct	13–18	−101
1986	Nov	4–9	−100
1987	Jul–Aug	28–2	−100
1987	Aug	24–29	−97
1988	Jan	14–19	−147
1988	Feb	21–26	−130
1988	May	6–11	−160

Pc1 data is collected from the search-coil magnetometers of the high-latitude Sodankylä station (SOD, 67.4° GGLat, 26.6° GGLong, 63.9° CGMLat, 109° CGMLong, $L = 5.1$) and the mid-latitude Nurmijärvi station (NUR, 60.5° GGLat, 24.7° GGLong, 57.0° CGMLat, 103° CGMLong, $L = 3.3$). The observed Pc1 events were divided into three groups: structured, unstructured (mainly Pc1-2 band and hydromagnetic chorus; see the classification by Fukunishi et al., 1981), and the rest (e.g., IPDP and unclear events). The first two groups form most of Pc1 activity (about 94%) at both stations. The properties of each Pc1 event (which may last from a few minutes to several hours) were studied for each UT hour separately. We registered the type, start time, intensity and duration for each such UT sample. Moreover, for each sample we noted the highest and lowest frequency as well as the average frequency at the time of maximum intensity. Possible simultaneous bands (multiband events) were analyzed as separate events.

3. Observations

3.1. Average occurrence probabilities and frequencies

During the 18 storms the total Pc1 activity was about 24.5% of the measurement time at SOD and 20.6% at NUR. Structured pulsations dominated at both stations. At SOD (NUR) more than 63% (70%) of Pc1 activity was classified to be structured, and 31% (23%) of the activity was unstructured. As shown in Table 2, higher structured Pc1 activity was found at SOD during weak (16.6% of time) than intense storms (14.3%). The opposite effect was observed at NUR where structured Pc1s occurred 13.2% (15.8%) of time during weak (intense) storms. Interestingly, the changes observed in unstructured Pc1 activity were reversed. At SOD, unstructured Pc1s occurred 6.6% (8.7%) of time during weak (intense) storms but at NUR 5.3% (4.3%) of time.

As noted in P1, the average frequency of structured Pc1 activity is higher at NUR, implying that the source of waves observed at NUR is typically at a lower latitude than at SOD. Table 2 shows that at both stations the average frequency of structured Pc1 pulsations is considerably higher during intense than weak storms. The average frequency of structured Pc1s during weak (intense) storms is 0.83 Hz (1.07 Hz) at SOD and 0.94 Hz (1.25 Hz) at NUR. Note that although the average frequency is higher at NUR for both storm groups, the frequency at SOD for intense storms is higher than at NUR for weak storms, underlining the changes in source location with storm intensity. Similarly, the average frequency of unstructured Pc1s was slightly higher during intense than weak storms at both stations (see Table 2).

3.2. Daily Pc1 activity

Figs. 1a and b depict the daily activity of structured pulsations at SOD and NUR for the two storm groups separately. During weak storms the daily activity at SOD (Fig. 1a) increases fairly smoothly from day 0 to a maximum on day 5. During intense storms the structured activity at SOD is lower on days 0–2 but increases fast to a higher maximum on day 4 with a subsequent decrease on day 5. At NUR (Fig. 1b), the activity of structured Pc1s is slightly lower on day 0 during intense than weak storms but higher on all subsequent days. For both storm groups, maximum activity is observed on day 4 with subsequent decrease on day 5, as observed at SOD for intense storms.

Figs. 2a and b show correspondingly the daily activity of unstructured Pc1s at SOD and NUR for the two storm groups. While the activity level at SOD remains rather constant for weak storms, it is enhanced during days 1–3 for intense storms. On day 1 of intense storms, the amount of unstructured Pc1s at SOD even exceeds that of structured Pc1s despite the overall dominance of structured Pc1s at SOD during intense storms (see Table 2). In accordance with overall statistics, the unstructured Pc1 activity at NUR is lower than at SOD on each day in both storm groups.

Table 2
The occurrence probability of Pc1 activity, number of events, average durations and average frequencies during weak and intense storms at SOD and NUR for structured and unstructured pulsations

	Occurrence probability (%)	Number of events	Average duration (min)	Average frequency (Hz)
SOD				
Weak storms				
Structured	16.6	161	80	0.83
Unstructured	6.6	75	69	0.43
Intense storms				
Structured	14.3	152	74	1.07
Unstructured	8.7	87	78	0.50
NUR				
Weak storms				
Structured	13.2	174	59	0.94
Unstructured	5.3	74	56	0.33
Intense storms				
Structured	15.8	205	60	1.25
Unstructured	4.3	63	53	0.40

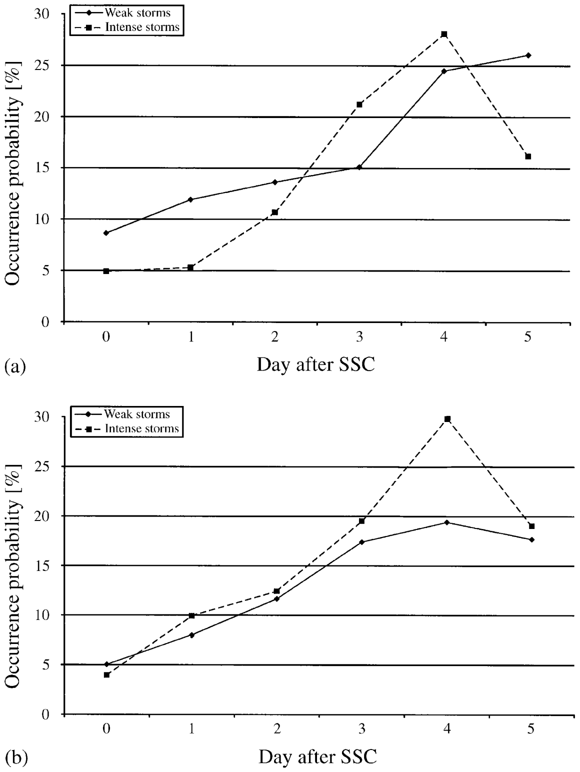

Fig. 1. The daily occurrence probability of structured pulsations at SOD (a) and NUR (b) for weak and intense storms.

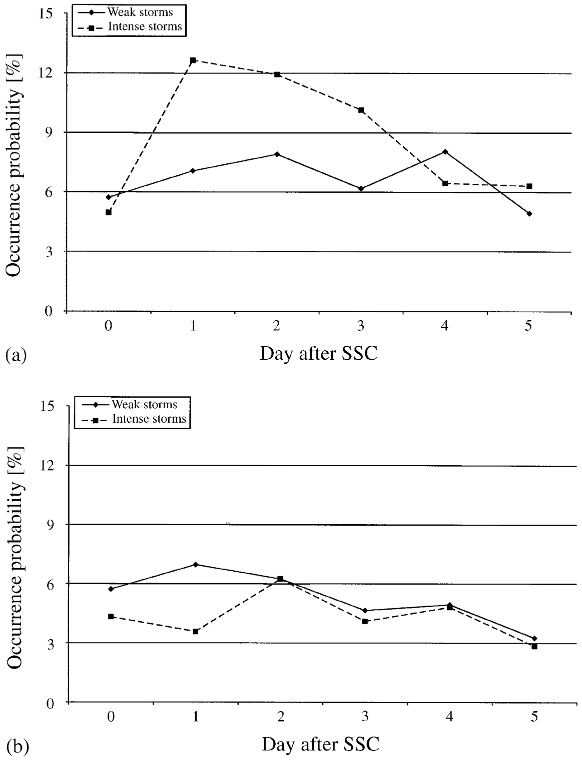

Fig. 2. The daily occurrence probability of unstructured pulsations at SOD (a) and NUR (b) during weak and intense storms.

3.3. Diurnal distributions of Pc1 activity

Figs. 3a and b depict the diurnal distributions of structured Pc1 pulsations at SOD for each day of the storm for weak and intense storms, respectively. The overall change of the diurnal distributions with storm evolution is roughly the same for both weak and intense storms and follows the pattern found in P1 for the total data set of 18 storms. On day 0, the activity is concentrated in late morning hours. A dramatic change in the distribution is seen from day 0 to 1, with nearly all events on day 1 occurring in the afternoon-dusk sector. On day 2, structured Pc1s appear in the morning sector but the dusk sector still remains more active. The relative fraction of activity in the morning continues to increase on day 3. On day 4, when the overall activity maximum is observed at SOD during intense storms (see also Fig. 1a), the occurrence is clearly concentrated in the dawn sector for both storm groups. On day 5, the distributions mainly resemble the diurnal distribution based on long-term statistics at SOD (see e.g. Mursula et al., 1994a).

However, despite this overall similarity in the storm evolution of the diurnal distributions, there are some interesting differences between weak and intense storms at SOD. On day 0, no structured Pc1 activity was found in the evening sector during intense storms although some activity appeared there during weak storms. On days 0 and 1, a higher activity level is observed for weak storms (see also Fig. 1a). Moreover, the activity of weak storms on day 1 is concentrated in the late evening sector, clearly later than for intense storms. These differences can naturally be understood by the fact that the disturbances in the ionosphere, in particular at the nightside, are larger during the main phase of intense than weak storms.

The observations at NUR (Figs. 4a and b) verify the above-discussed overall change of the diurnal distributions with storm evolution for both storm groups. Moreover, we find similar differences in the diurnal distributions at NUR between the weak and intense storms as discussed above for SOD. E.g., more events are found at NUR during weak than intense storms on day 0 (see also Fig. 1b), particularly in the afternoon/evening sector. Also, the diurnal distribution on day 1 is concentrated to the afternoon during intense storms while a later (evening) maximum is found for weak storms.

At both stations and in both storm groups, unstructured pulsations (not shown here) are strongly concentrated around the noon each day, in accordance with P1 and earlier long-term results (Fukunishi et al., 1981; Kuwashima et al., 1981; Mursula et al., 1994a).

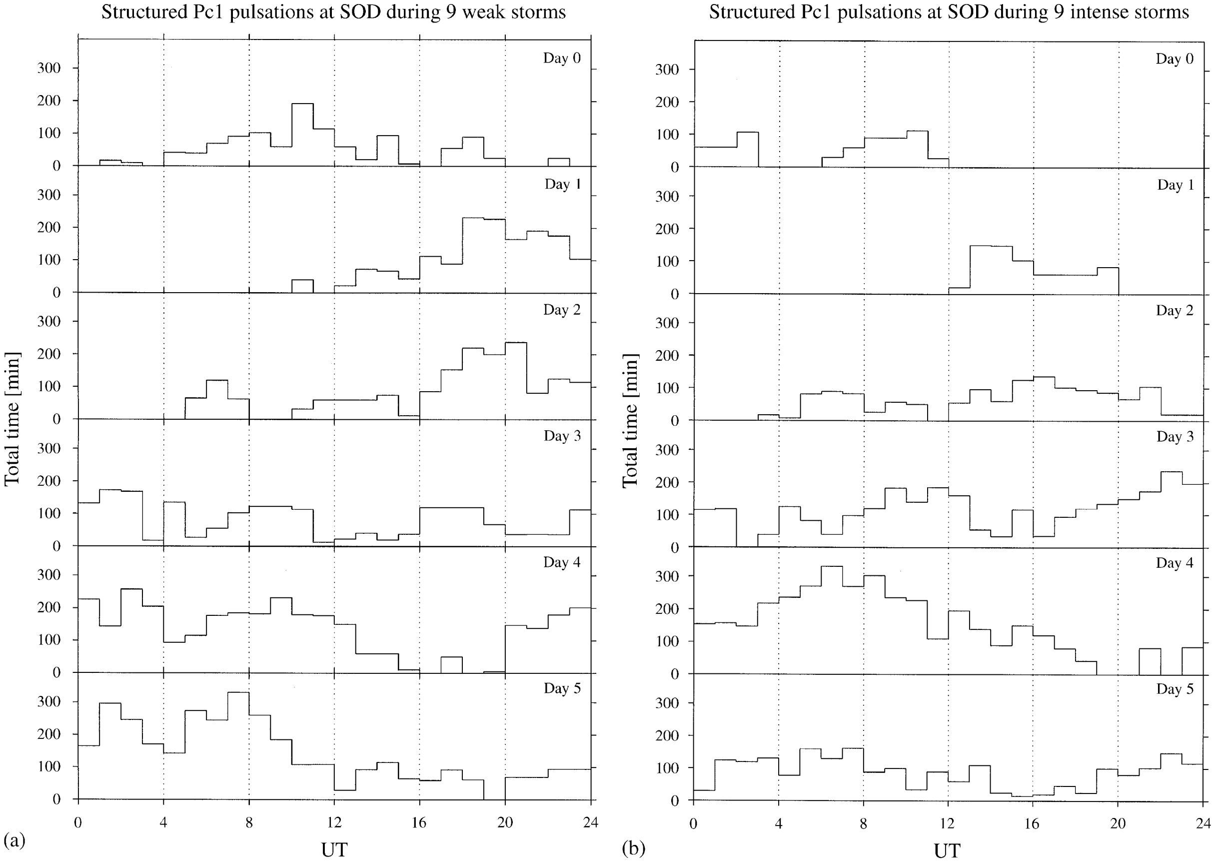

Fig. 3. Diurnal distributions of structured pulsations at SOD on days 0–5 during weak (a) and intense (b) storms.

3.4. *Frequency distributions of Pc1s*

Figs. 5a and b present the overall frequency histograms of structured Pc1s for the two storm groups at SOD and NUR, respectively. At SOD structured Pc1s during weak storms are concentrated at frequencies 0.3–1.5 Hz, with a maximum (median) at 0.7 Hz (0.83 Hz). For intense storms, the distribution is slightly shifted and extended to higher frequencies (0.4–2.1 Hz) with a maximum (median) at 1.0 Hz (1.04 Hz). At NUR, the frequency range in each storm group is almost the same as at SOD. During weak (intense) storms the wave frequencies range from 0.3 to 1.7 Hz (0.4–2.2 Hz, respectively), with only minor activity at other frequencies. However, the distribution at NUR is more weighted to higher frequencies than at SOD, leading to the higher average frequencies in both storm groups, as already listed in Table 2. The frequency median value at NUR was 0.91 Hz (1.23 Hz) for weak (intense) storms.

The daily frequencies of structured and unstructured Pc1s for the two storm groups at SOD and NUR are presented in Figs. 6a and b, respectively. At SOD, the average frequency of structured Pc1s during weak storms remains roughly constant, reaching a low maximum on day 3. During intense storms the frequency rises rather systematically to a maximum on day 4. On days 0–1 the average frequency of structured Pc1s at SOD is almost the same for both storm groups, but on all subsequent days the frequency is clearly higher for intense storms.

At NUR, the evolution of the daily average frequency of structured Pc1s during weak storms is somewhat unsystematic but a maximum is reached on day 3, as observed at SOD. During intense storms the average frequency increases strongly from day 0 to a maximum on day 2, remaining at a high level thereafter. The average frequency of structured Pc1s is every day higher during intense than weak storms. Also, during intense storms the frequency at NUR is clearly higher every day than at SOD.

The daily frequencies of unstructured Pc1s remain rather constant through the storm at both stations and for both storm groups. At NUR, the frequency is clearly higher than average on day 1 during intense storms. Similarly, the frequency difference between intense and weak storms at SOD is largest on day 1.

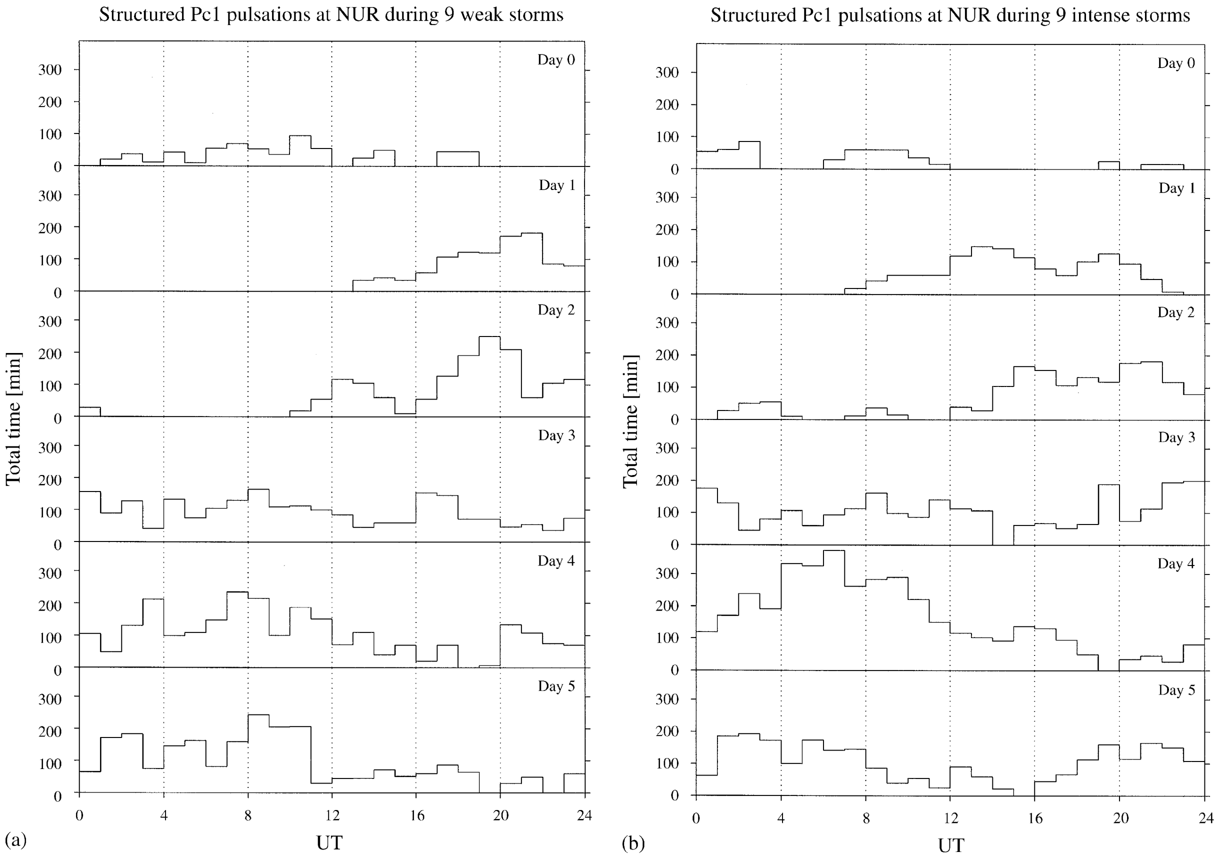

Fig. 4. Diurnal distributions of structured pulsations at NUR on days 0–5 during weak (a) and intense (b) storms.

4. Discussion

4.1. *Effect of storm intensity on Pc1 source location*

The present results indicate that the latitudinal distribution of structured Pc1s depends on magnetic storm intensity. During intense storms, the activity level of structured pulsations was found to decrease at high and increase at mid-latitudes compared to their respective levels during weak storms (see Table 2). Moreover, the average frequency of structured Pc1s is higher during intense than weak storms at both stations. These observations imply that the source region of structured pulsations is at lower latitudes during intense storms. This is in accordance with Heacock and Akasofu (1973), who suggested that the high-frequency events observed during intense storms are generated at lower latitudes.

The location of the energy density maximum of the ring current depends on storm intensity. E.g., for a storm with D_{st} minimum = $-$ 140 nT it is at $L = 3.5$ (Korth and Friedel, 1997) but for a storm with D_{st} minimum = $-$ 300 nT at $L = 2.5$ (Hamilton et al., 1988). The average D_{st} minimum of weak (intense) storms included in this study is -95 nT (-172 nT). Since the energetic ions of the ring current form the energy source of structured Pc1s, this supports the above result that the average source region is at lower latitude during intense storms. Moreover, it is very likely that the average source region during intense storms is considerably closer to NUR ($L = 3.3$) than SOD ($L = 5.1$).

While the average source region of structured Pc1s is, at least during storm times, equatorward of SOD, the unstructured Pc1s have their source at latitudes higher than SOD (e.g., Mursula et al., 1994a). This is also reflected in the lower average frequencies of unstructured pulsations (see Table 2). Moreover, the average frequency of unstructured Pc1s was higher during intense storms at both stations, suggesting for the wave source being at lower latitudes during intense than weak storms, similarly to the source of structured pulsations. However, the frequency difference for unstructured Pc1s between weak and intense storms was, especially at NUR, strongest on day 1 (see Fig. 6b), contrary to structured pulsations. Unstructured Pc1s are produced by plasmasheet ions located on open drift shells. Both plasmasheet and ring current ions are driven to lower L shells by the enhanced convection electric field which is mostly

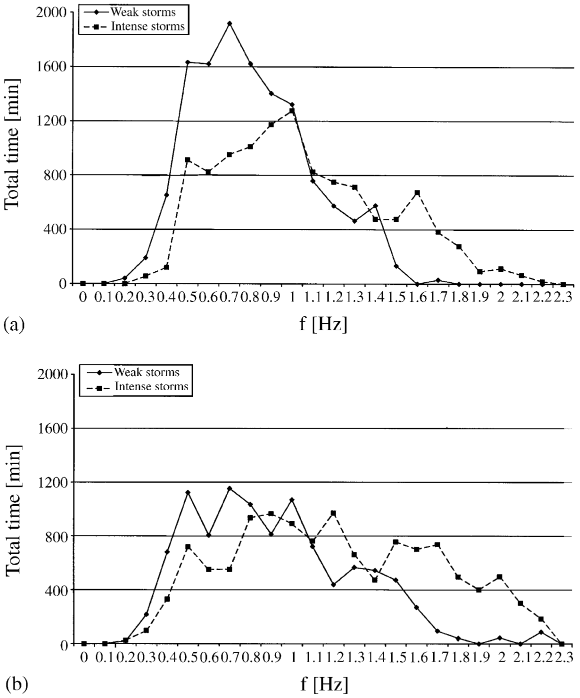

Fig. 5. Frequency histograms of structured pulsations at SOD (a) and NUR (b).

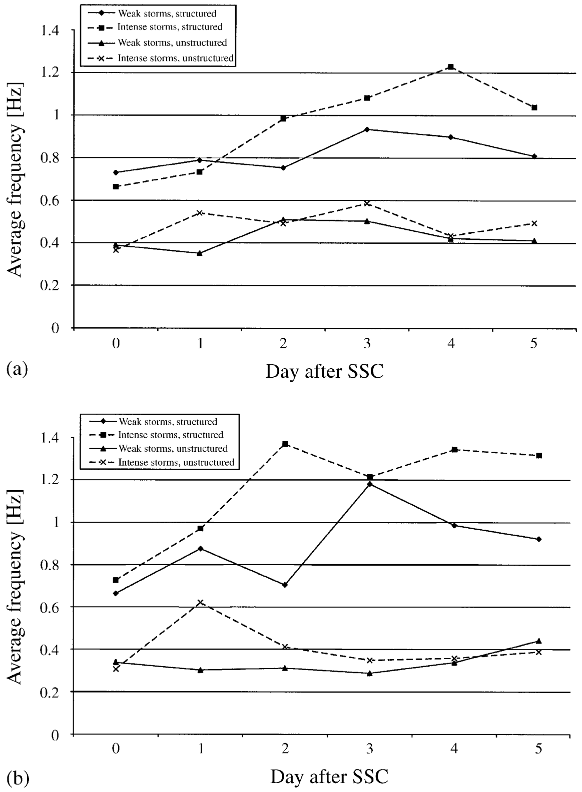

Fig. 6. The daily average frequencies of structured and unstructured pulsations at SOD (a) and NUR (b).

effective during the storm main and early recovery phase. However, since the plasmasheet ions on open drift shells are lost at the dayside, the frequency rise of unstructured pulsations decreases after day 1. The lower latitude of unstructured wave source during the first days of intense storms is also reflected in the higher activity of unstructured Pc1s at SOD on days 1–3 during intense than weak storms (see Fig. 2a), leading also to a higher overall activity at SOD during intense storms (see Table 2).

4.2. *Storm intensity and IAR effects*

As noted in P1, structured pulsations are practically not seen on ground during the main phase and the first few hours after D_{st} minimum despite significant Pc1 activity in space above the ionosphere (Bräysy et al., 1998) and the maximum wave activity found in model calculations at this time (Jordanova et al., 1997; Kozyra et al., 1997). In P1 we suggested that this difference can be understood in terms of the ionospheric Alfvén resonator (IAR) (Polyakov and Rapoport, 1981). During the storm main phase, the wave amplification and ducting properties of the IAR are strongly disturbed, resulting in minor wave activity on the ground. This is in accordance with Belyaev et al. (1999), who found that the spectral resonance structures produced by the IAR in the Pc1 frequency range, are reduced by increasing geomagnetic activity due to enhanced local particle precipitation. It was also recently shown (Mursula et al., 2000) that the frequency of structured Pc1s observed on ground corresponds to the calculated IAR eigenfrequency, emphasizing the role of the ionosphere for Pc1 observations on the ground.

This view is further supported by the daily and diurnal distributions of structured Pc1s at SOD and NUR. On day 0, no structured Pc1s were observed at SOD (see Fig. 3) in the afternoon/evening sector during intense storms while some activity existed there during weak storms. The daily activity of structured Pc1s at SOD (see Fig. 1a) on day 0 (1) is 76% (125%) higher during weak than intense storms. These differences suggest that the annihilation of waves in the resonator is more complete for intense storms. On day 1, there was no Pc1 activity at SOD in the late evening sector during intense storms, contrary to weak storms, indicating that the ionospheric disturbances were strongest in that sector where the most intense particle precipitation is taking place. As a result, the diurnal distribution on day 1 is shifted to earlier MLT hours during intense storms. At NUR (see Fig. 4), similar changes occur but less dramatically, indicating that the storm effects on ionospheric conditions exist even at mid-latitudes but are weaker than at SOD. E.g., the Pc1 activity in the afternoon/evening sector on day 0 was clearly less during intense than weak storms. The evening drop of Pc1 activity on day 1 was seen also at NUR but later in the evening and less dramatically than at SOD.

Note also that while the activity of structured Pc1s at SOD on days 0–2 was higher during weak than intense storms, the activity at NUR is higher during intense storms already from day 1 onwards. This may partly be due to the smaller storm disturbances in the ionosphere at lower latitudes, in agreement with the above discussion. However, it may also partly be due to the lower L shell and a larger intensity of the wave source during intense storms. Moreover, the higher level of structured Pc1 activity at SOD on days 3–4 and at NUR on days 1–5 during intense than weak storms can hardly be explained purely by ionospheric effects but rather reflects the higher source intensity (stronger ring current) during intense storms.

Contrary to SOD, the overall amount of unstructured Pc1 activity at NUR was slightly lower during intense than weak storms (see Table 2). This difference is only observed on days 0 and 1 (see Fig. 2b), suggesting that it is also due to the ionospheric conditions, which are more disturbed during intense storms.

Fraser-Smith (1970) suggested that the increase of structured Pc1 activity during storm recovery is related to the outward expansion of the plasmapause. This model implies a time delay of a few days for the maximum occurrence between low and high latitudes. Kuwashima et al. (1981) found a maximum of structured Pc1 activity at a low-latitude station ($L = 1.5$) 2–3 days and at a high-latitude station ($L = 6.1$) 4–5 days after the D_{st} minimum, supporting the time delay related to the outward expansion of the plasmasphere. However, as discussed in P1, the daily distributions of structured Pc1s averaged over all 18 storms did not show such a time delay between NUR and SOD. Moreover, the average daily frequencies were found to increase at both stations with storm recovery, contrary to the expectations based on the expanding plasmapause model. If the daily increase of structured Pc1 activity with storm recovery was indeed related to this model, the corresponding changes should be particularly clearly seen during intense storms when the storm effects on plasmasphere are more dramatic. However, we find the Pc1 maximum on day 4 at both stations during intense storms, in accordance with the results presented in P1 and, e.g., the low-latitude observations by Wentworth (1964). Moreover, the average daily frequency either stays constant (at NUR) or increases (at SOD) on days 2–4 of intense storms. No decrease of frequency is found, contrary to the plasmapause model. These results support the view presented in P1 that the daily activity of structured Pc1s during the storm recovery phase is not related to the outward expansion of the plasmasphere. Rather, it is related to the improved wave amplification and propagation conditions in the ionosphere. The ionospheric explanation is further supported by the fact that the wave activity in space was not increased during storm recovery (Bräysy et al., 1998), contrary to the expectations based on the plasmapause expansion model.

5. Conclusions

We have studied the effect of magnetic storm intensity on the properties of structured and unstructured Pc1 pulsations at high and mid-latitudes comparing the observations during 9 weak and 9 intense storms. During intense storms, the structured Pc1 activity increases at mid-latitudes and decreases at high latitudes when compared to the corresponding activity levels during weak storms. Moreover, the overall average frequencies of both structured and unstructured Pc1s were higher during intense than weak storms at both stations. These observations indicate that the source region of both types of pulsations is at lower latitudes during intense than weak storms. Since the ring current ions are the energy source of structured pulsations, this is in agreement with the change of the energy density maximum of the ring current to lower latitudes during intense storms (Hamilton et al., 1988; Korth and Friedel, 1997). The source of unstructured Pc1s existed at lower latitudes on days 1–2 only. This reflects the connection of the unstructured Pc1s with the plasmasheet ions on open drift shells.

Practically, no structured pulsations were seen on ground during the main phase and the first few hours after the D_{st} minimum despite significant wave activity in space observed earlier (Bräysy et al., 1998) and the modelled maximum wave activity at this time (Jordanova et al., 1997; Kozyra et al., 1997). Also, the occurrence rate of structured Pc1s at SOD on days 0–2 was lower during intense than weak storms. This difference cannot mainly be due to the lower latitude of wave source during intense storms since the maximum wave occurrence on day 4 during intense storms exceeded that during weak storms. Instead, this difference is due to a larger depletion of structured Pc1s in the late evening-premidnight sector during intense storms. We have earlier suggested (Kerttula et al., 2000) that the depletion of structured Pc1s during the main and early recovery phase is due to deteriorated amplification and ducting properties of the ionospheric Alfvén resonator. The above-discussed results support this suggestion and demonstrate that depletion of the IAR properties is more dramatic during the more intense storms, especially in the late evening-premidnight sector at high latitudes.

The present results also give an additional evidence against the view (Fraser-Smith, 1970) that the maximum activity of structured Pc1s during the late storm recovery is due to the outward expansion of the plasmapause. Contrary to this view, during intense storms, when changes in the plasmapause are expected to be most significant, the structured Pc1 maxima are observed on day 4 at both stations. Also, the daily average frequencies were found to increase at both stations, contrary to the plasmapause model. Rather, the results further support the view (Kerttula et al., 2000) that the great enhancement of structured pulsations on ground during late storm recovery phase is closely related to the improved ionospheric conditions for wave amplification and ducting.

Acknowledgements

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