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Spectral Analysis of Pc3 and Pc4 Pulsations With Regard to the Dayside Plasmapause Position

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Abstract. Based on the observational data obtained simultaneously at 12 stations (most of them along a north-south profile crossing the projection of the plasmapause), the characteristics of pc3–4 pulsations are investigated. Data analysis of selected pulsation events reveals that the power spectra are influenced especially by the magnetic activity and by the positions of the auroral belts and the plasmapause. A shift of power density is observed in H between adjacent spectral bands near the plasmapause position which could be estimated at any time of day by the method of Orr and Webb.

For low magnetic activity (Kp < 1o) spectral bands corresponding to periods of $T = 25$–60s are observed. Of these, the shorter period pulsations dominate outside the estimated plasmapause position, the longer period dominate inside. At Kp > 2o the contrary is observed: spectral bands centered on $T = 50$–60s occur predominantly at the southern stations (Wingst, Enköping) whereas spectral bands corresponding to periods of $T = 70$–150s -with pc3 usually superposed on pc4 – are observed at the north of the profile with an amplitude maximum between 65° and 67° geomagnetic latitude. At moderate magnetic activity (Kp ~ 2o) a minimum in the distribution of spectral amplitudes appears with adjacent maxima at 62° and 65° geomagnetic latitude.

The polarization properties of the magnetic disturbance vector, projected on the *H-D* plane, are very complex; sometimes the sense of polarization does not change along the profile at all and in other cases there are several reversals of the rotational sense. Some events showing reversals in the region of the plasmapause agree with results of pulsation theories.

Key words: Pc3 and pc4 pulsations – Spectral amplitude distribution – Polarization properties – Dayside plasmapause position.

Introduction

At 11 European observatories between the auroral zone and Italy pulsations are recorded by induction-type variometers described by Voelker (1963). Al-

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Table 1. List of observatories (O) and recording sites with tape equipment (T) and film equipment (F) during 1970 and 1971 in Scandinavia

Abbreviations	Station	Type	Geograph. Coordin.		Geomagn. Coordin. (centered dipole 1945 model)		L-value
			Lat.	Long.	Lat.	Long.	
HEI	Heiss	O	80.70	58.00	71.37	156.33	14.28
TR	Tromsø	O	69.68	19.00	67.14	116.80	6.30
REP	Repparfjord	T	70.37	24.50	66.77	121.81	6.42
ABI	Abisko	T	68.35	18.50	66.02	114.96	5.69
KI	Kiruna	O	67.80	20.40	65.24	115.56	5.41
ÅLL	Ålloluokta	F	67.08	19.50	64.78	114.05	5.18
POR	Porjus	F	66.97	19.85	64.61	114.21	5.13
MES	Messaure	T	66.65	20.53	64.21	114.44	5.01
ARJ	Arjeplog	F	66.00	17.90	64.11	111.58	4.85
SO	Sodankylä	O	67.38	26.58	63.79	120.00	5.10
MAL	Malå	F	65.22	18.83	63.24	111.58	4.57
LYC	Lycksele	T(F)	64.62	18.73	62.71	110.90	4.40
ÅSE	Åsele	F	64.18	17.33	62.59	109.31	4.31
JUN	Junsele	F	63.72	16.87	62.25	108.47	4.21
HAM	Hammarstrand	T(F)	63.12	16.45	61.80	107.58	4.06
FRN	Fränsta	F	62.45	16.08	61.26	106.68	3.90
DEL	Delsbo	T(F)	61.80	16.57	60.57	106.56	3.74
EDS	Edsbyn	F	61.37	15.82	60.32	105.55	3.66
SVJ	Svärdsjö	F	60.80	15.88	59.78	105.15	3.55
GAR	Garpenberg	T	60.30	16.22	59.26	105.05	3.45
ENK	Enköping	O	59.50	17.28	58.31	105.42	3.29
WN	Wingst	O	53.75	9.07	54.46	94.47	2.54

though five of these stations (Reykjavik, Tromsø, Kiruna, Sodankylä, and Enköping) are in Scandinavia, in the analysis of the data as well as in the interpretation of the results the station distribution is not entirely satisfactory. In particular, the distance between Enköping and Kiruna is too large to correlate pulsation events at the northern stations with those in Enköping. And Sodankylä, Tromsø and Reykjavik are at such different longitudes that it is difficult to decide whether the observed properties depend on latitude or longitude.

The aim of this experiment was to investigate the distribution of geomagnetic pulsations on a north-south profile by means of closely spaced mobile stations, and to study how this distribution can be interpreted to reveal some properties of the magnetosphere. Therefore, during August and September 1970 and from May to October 1971 a chain of six field operating pulsation stations was installed on a profile between the North Cape and Stockholm. The magnetic field measurements were made at 16 different sites to supplement the 5 existing instruments with similar characteristics working at Scandinavian observatories. Table 1 lists the names, the geographic and geomagnetic coordinates and the corresponding L-values of the stations used. Figure 1 shows the distribution of the stations along the profile. Wingst and Sodankylä are far from the profile on either side.

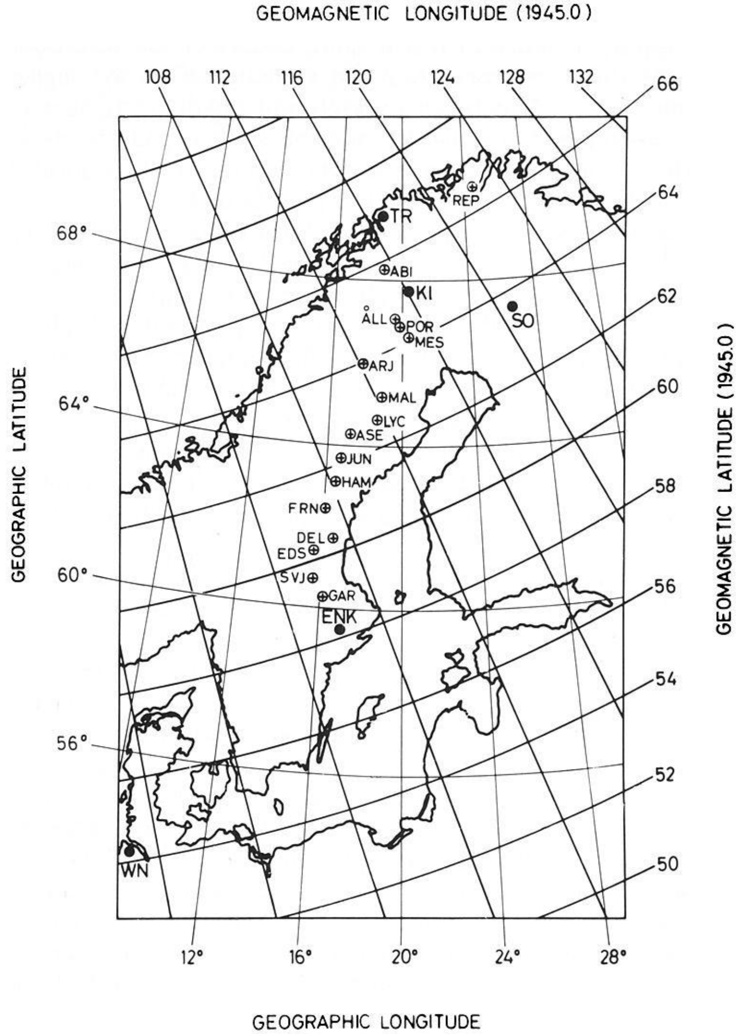

Fig. 1. ⊕ : Sites in Scandinavia where the pulsation instruments were set up during 1970 and 1971. ● : Observatories in Scandinavia and Northern Germany (WN) with Grenet type pulsation systems whose records were used in data analysis. (Heiss in USSR is located outside this area)

The (1945) coordinates used in this study differ only slightly from more recent representations (1965) of the dipol field. The difference to the (1945) coordinates is nearly the same (−0.1°, 0.5°) for all stations listed in Table 1.

Experiment and Data Analysis

The measurements were carried out in three stages. During the first period the instruments, with average spacings of 100 km, recorded between the North Cape (Repparfjord) and Lycksele. Then a longer profile was installed between

Abisko and Fränsta. The distance between the working stations in this case was about 200 km. Finally, in order to reveal more details of the behaviour of the pulsations in the transition zone from the midlatitudes to the higher latitudes, measurements were made between Lycksele and Enköping again with shorter spacings of about 80 km. Altogether the portable systems and the observatories (including Heiss, the northernmost Soviet station, which is located far from the profile) yielded simultaneous data from 12 stations.

Each pulsation system consists of three Grenet Variometers recording the magnetic components *H, D,* and *Z*. At the observatories the variometer signals are recorded optically by galvanometers on photo sensitive paper. In order to improve the sensitivity, three mobile field systems were provided with photo electric amplifiers consisting of galvanometers and differential photo resistors. For three further portable systems the output voltages (approximately 10μV/nT) were directly amplified by DC amplifiers and then recorded by slow speed FM-tape recorders (15/320 ips) which allowed 10 days continuous recording. The amplitude responses of *H, D* and *Z* components at all stations differ only by constant calibration factors. The phase responses are similar at all stations.

The magnetic activity was generally low during the period of measurement. The Kp indices ranged from Kp=0 to 6 with a maximum of occurrence frequency between Kp=1+ and 2+.

In order to establish the spectral behaviour of the pc3 and pc4 between auroral and mid-latitudes and to study the properties of the pc3–4 frequency bands near the plasmapause, power density spectral analysis was used in which both the autocovariance functions and the power spectra were calculated. Cross-spectral analysis was utilized to determine phase differences between similar components at different stations and between components at the same location. Moreover, wave hodograms as well as the Multiple-Filter-Method (Dziewonski et al., 1969) were used to study the characteristics of the wave polarization. The amplitudes and phase differences are presented in a frequency-time diagram, so the sense of polarization and the orientation of the wave ellipses can be evaluated for any frequency band of interest and for any time interval of the record being examined. The determinations of the polarization quantities were generally made within those intervals (mostly 3–4 min) of the record where the maximum amplitudes of the pulsation event occurred.

Spectral Properties of Pc3, 4 Events

An event occuring during a period of moderate magnetic activity (Kp=2o) is shown in Fig. 2. The *H* and *D* component field data were plotted from top to bottom in order of decreasing geomagnetic latitude. The calibration factor at WN and ENK is represented by the longer bar at the right hand side of the plots, and the shorter bar for the other stations. Each bar equals 3nT. The high coherencies, especially between *D* components of different stations, are remarkable. At WN and ENK the dominant period of the *H* component ($T \sim 40$s) is shorter than at the northern stations ($T > 60$s), where, in

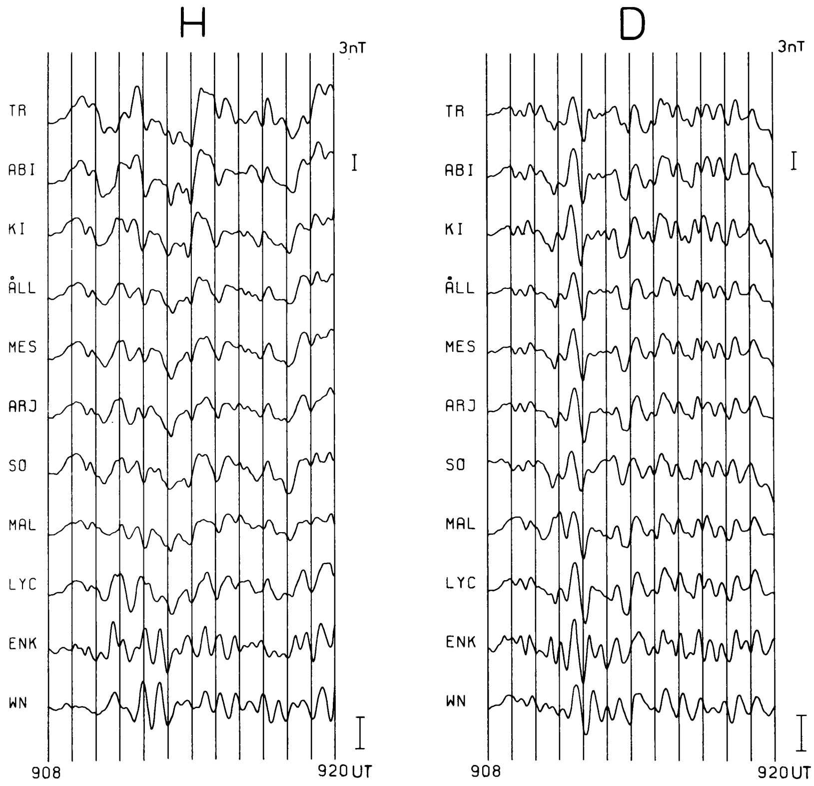

Fig. 2. Example of a pulsation event on June 3, 1971, at Kp=2o. The calibration factor at WN and ENK is represented by the longer bar at the right hand side of the plots, and the shorter bar for the other stations. Each bar equals 3nT

the interval 9.16–9.17 h UT, note that pc3 ($T \sim 20$s) are superposed on pc4, especially at MAL, SO, ARJ, MES, and ÅLL. The spectral behaviour of this event is shown in Fig. 3. In the following the spectral range corresponding to periods greater than $T = 150$s is not referred to, due to poor spectral resolution. The spectra of H show that at WN and ENK the dominant spectral peak is centered on $T = 38$s. This peak is significant at the higher latitude stations, too, but with somewhat less power between LYC and KI. The adjacent peak centered on $T = 55$s is also consistent along the profile. At WN the period is shorter ($T = 50$s). Perhaps this is due to the fact that WN is far from the profile. The power of this spectral band increases strongly from ENK to LYC, has a minimum between MAL and ÅLL and reaches the maximum power again at KI, ABI and TR. Significant peaks with high power centered on $T \sim 150$s appear only at the northern stations, especially at ABI and TR. Also the pc3 spectral range centered on $T \sim 25$s occurs predominantly at those stations situated north of ENK.

In *D* all spectral peaks show a remarkable consistency along the profile. The dominant peaks are centered on $T = 86$s, $T = 55$s, $T = 38$s and $T = 24$s. The

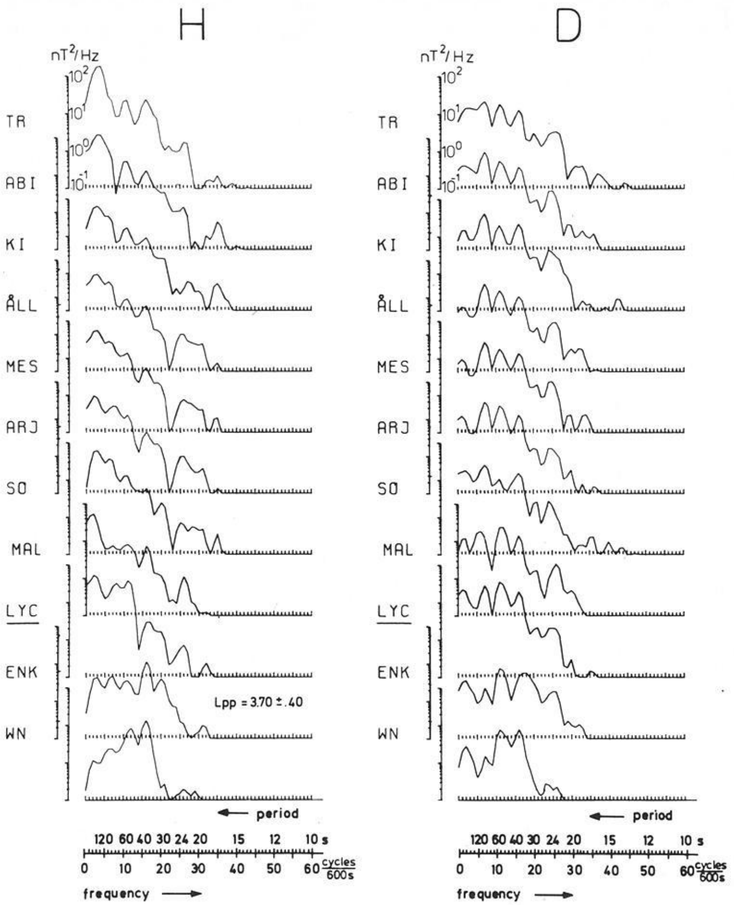

Fig. 3. Power spectra of the pulsation event plotted in Fig. 2. The *underlined symbol* of the station LYC at the left hand side of the spectra indicate that this station corresponds to the region of the plasmapause which has been estimated by the method of Orr and Webb (1975)

peak centered on $T = 86$s does not appear in H, i.e., the longer period frequency range of D is different from H, but the power of this spectral band increases strongly from ENK to LYC and has its maximum power at the stations north of LYC.

Another example of a pulsation event at Kp = 3+ is shown in Fig. 4, and its power spectra are represented in Fig. 5. Again D is very consistent for all significant spectral bands along the profile. The dominant peaks of D are centered on $T = 60$s, $T = 33$s, and $T = 23$s. The pc3 range on $T = 23$s appears to be significant at those stations which are north of ENK. The maximum peaks at WN and ENK are centered on $T = 60$s, at LYC on $T = 50$s, at SO on $T = 86$s, at ARJ on $T = 50$s and at MES, ÅLL, KI, ABI, and TR again on $T = 86$s. It is obvious from these spectra that the dominant periods of the

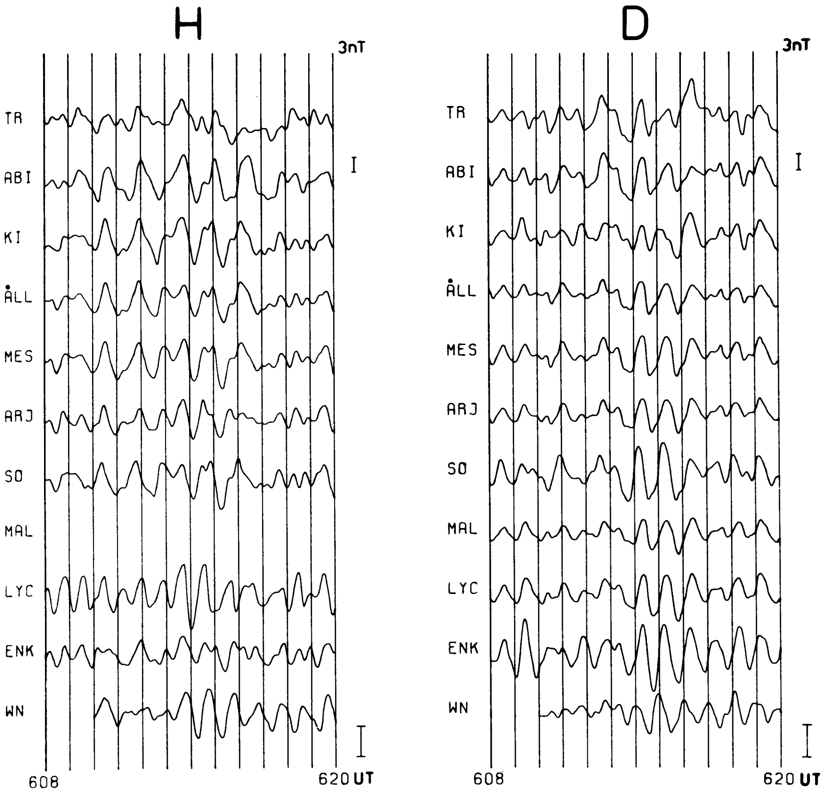

Fig. 4. Example of a pulsation event on June 4, 1971, at Kp=3+

pulsation change between LYC and MES, i.e., a distinct shift of spectral power density appears in this region.

Figure 6 shows the power spectra of a pulsation event under quiet magnetic conditions (Kp=1−). In *D* there is only one dominant frequency band, centered on $T=46$s. The same period is seen in *H* at WN, ENK, LYC, and MAL. A shift of power density between spectral bands centered on $T=46$s and $T=35$s is observed at SO, ARJ, MES, and ÅLL. At the northernmost stations KI and TR only the peak centered on $T=35$s appears.

The pulsation event in Fig. 7 (Kp=4o) is typical of the strong attenuation of the amplitudes at higher Kp values when going along the profile from north to south. The maximum amplitudes with values up to 30nT are limited to a range in latitude near the auroral belts. Moreover this event shows in H an obvious increase of period with increasing latitude.

It is important to know if the region where the sudden shift of pulsation event spectral maximum is observed correlates with the position of the plasmapause. For this purpose the method of Orr and Webb (1975) was used to estimate the statistical plasmapause position, using their equation $L=6.52-1.44\text{Kp}+0.18\text{Kp}^2$ with Kp in the range 0–4. This is in accordance with

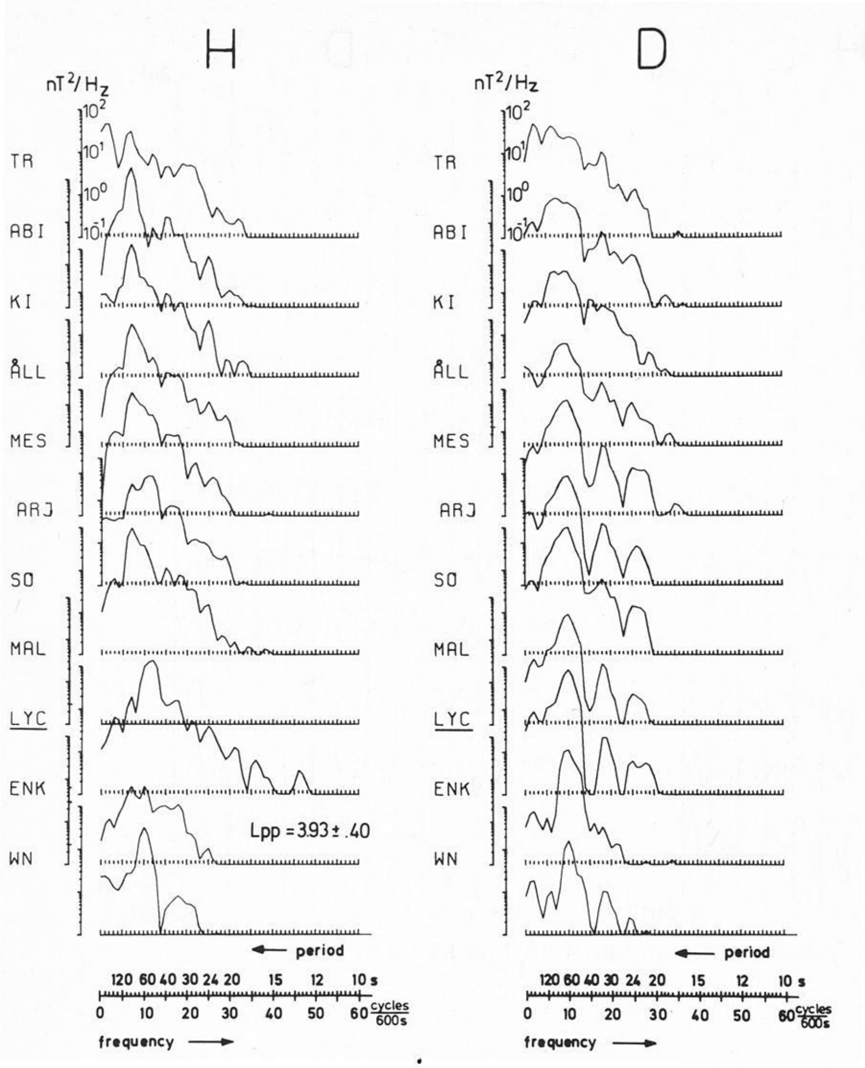

Fig. 5. Power spectra of the pulsation event plotted in Fig. 4

data from OGO-5 (Chappel, et al., 1970). For their fit of formula to data the rms residual of 0.4 is interpreted as equivalent scatter of ±0.4 earth radii in the equatorial plane of the estimated position of the plasmapause. The underlined symbols of the stations at the left hand side of the power spectra in Fig. 3, 5, and 6 indicate that these stations correspond to the region of the estimated plasmapause. This procedure, estimating the plasmapause position and comparing its L-value with the corresponding L-values of the stations along the profile, was performed for each wave event being analyzed. It was found that under quiet magnetic conditions ($\mathrm{Kp} \leqq 1+$) only one or two dominant frequency bands appear in the spectra. The corresponding periods range from $T = 25$s to 60s. A systematic increase of period with increasing latitude is not seen. However, tracing the projection of the statistical plasmapause position onto the earth surface a shift of power density is observed between adjacent spectral bands in its region of influence. The shorter period (25s–40s) occurs

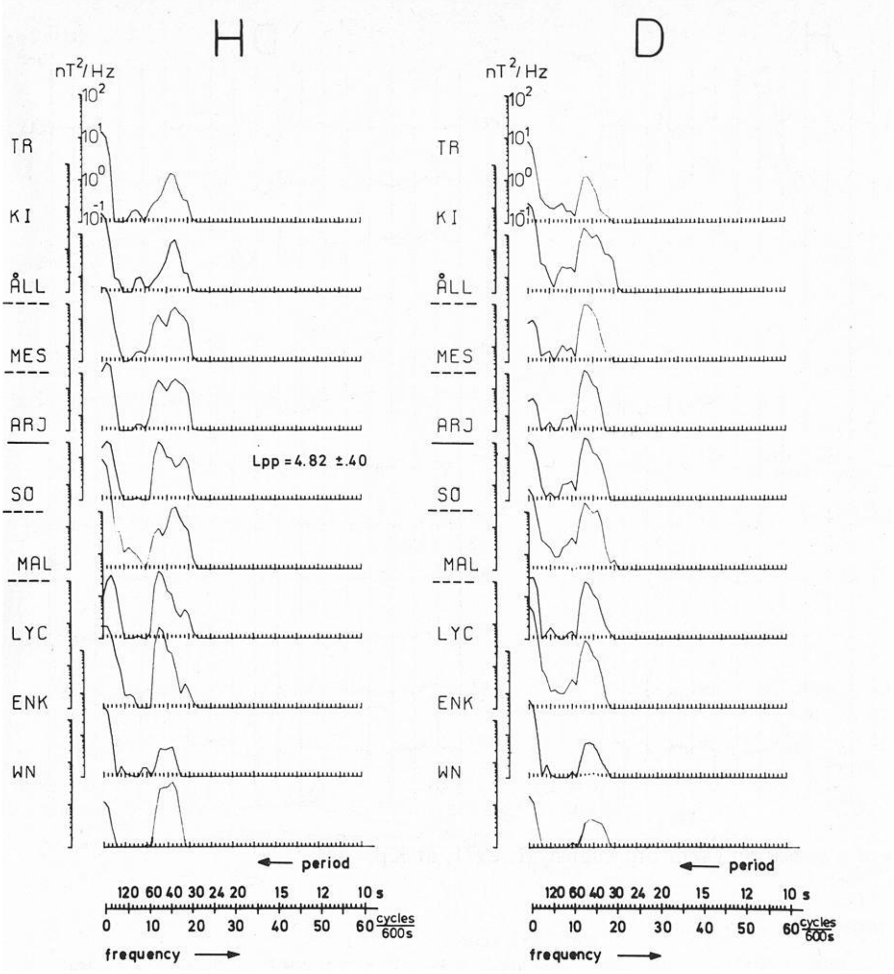

Fig. 6. Power spectra of a pulsation event under quiet magnetic conditions on June 19, 1971, Kp = 1−. The stations *MAL, SO, ARJ, MES*, and *ÅLL* correspond to the estimated plasmapause $L_{pp} = 4.82 \pm 0.4$, as indicated by the *underlined symbols*

outside and the longer period (40s–60s) inside the plasmapause. This behaviour is mostly observed in H. Similar results have been found by Lanzerotti et al. (1974; 1976) at somewhat different spectral bands. They reported that the latitude of the *H*-component peak power in the 15 to 27mHz band (37s–67s) is generally higher than the latitude of the H-component peak power in the 10 to 15kHz band (67s–100s).

In the Scandinavian data when the magnetic activity increases the number of significant frequency bands grows too, and the mean power shifts to the longer period pc4 range; e.g., for the range $2o \leqq Kp \leqq 3+$ the main power is found in spectral bands corresponding to periods from $T = 50$s to 90s. The shorter period bands ($T = 50$s to 60s) dominate at the southern stations, especially at WN and ENK. In the region where the profile is crossing the projection of the plasmapause position, a clear discontinuity is observed in the spectral behaviour of *H*: Outside the plasmapause the main power is concentrated in the lower frequency bands corresponding to periods of $T = 80$s–90s and ampli-

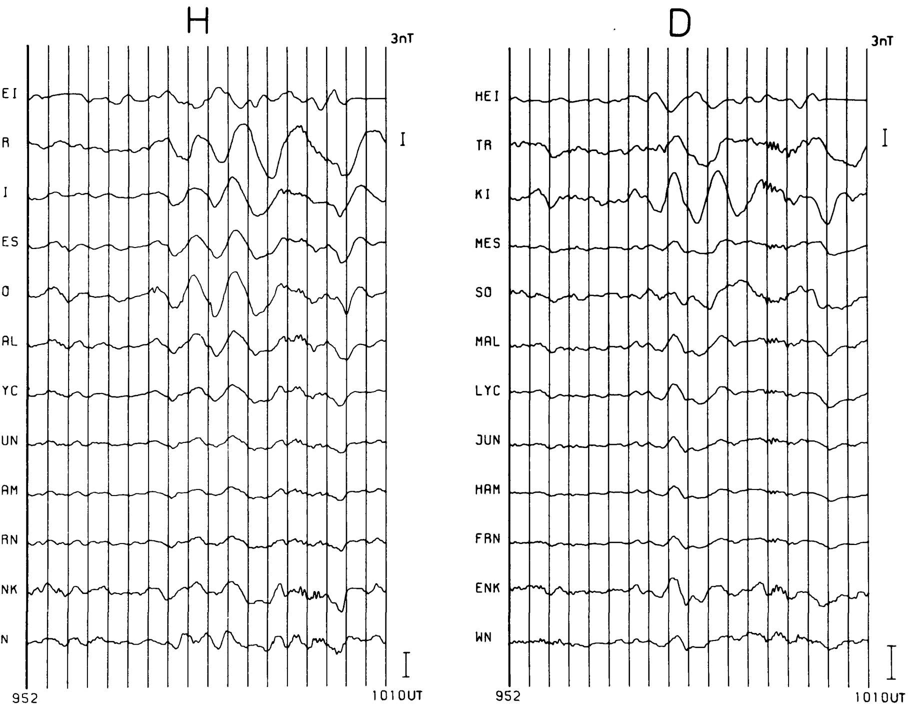

Fig. 7. Example of a pulsation event on August 31, 1971, at Kp=4o

tudes of about 10nT; the power inside the plasmapause is concentrated in the higher frequency range centered on $T=50\mathrm{s}$–$60\mathrm{s}$.

The spectral range centered around $T=150\mathrm{s}$ reveals high peaks of power in *H* at the northern stations TR, ABI, and KI if the Kp index is ≧4o. These peaks do not appear at the southern stations because of the strong attenuation of the amplitudes in southward direction. The demarcation line is at about 62° geomagnetic latitude. Toward HEI, the northernmost Soviet station, which is located far from the profile and probably outside the range of closed magnetic lines, the power is strongly attenuated, too. The peaks in the pc3 range centered on $T=25\mathrm{s}$ occur predominantly outside the estimated plasmapause position and there the spectral power decreases exponentially from the lower frequency pc4 domain to the higher frequency pc3 domain. The pc3 spectra show no latitude dependence of period; this is consistent with the results of Kopytenko et al. (1975).

The spectra of *D* generally have a more regular behaviour than those of *H*. In particular the midfrequencies of the main power peaks in *D* do not change along the profile.

A more detailed examination of the spectral peaks reveals that the longer period pc4's ($T=80\mathrm{s}$–$150\mathrm{s}$) have their maximum power between 65° and 67° geomagnetic latitude, when Kp is ≧3+. Up to 62° the distribution of spectral

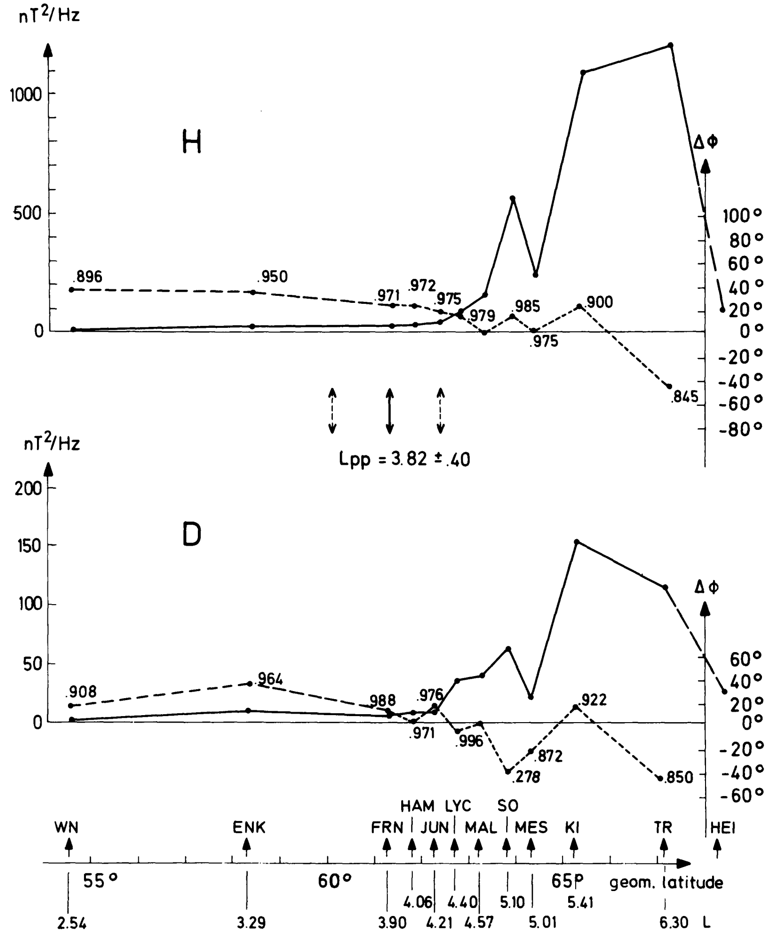

Fig. 8. Spectral amplitude distribution for the frequency band of 4/600 cycles/*s* = 6.67 mHz. The pulsation event is shown in Fig. 7. Also shown are the phase difference (*interrupted lines*) and coherency with respect to the reference at *MAL*. For this example the plasmapause is estimated to be $L_{pp} = 3.80 \pm 0.4$ and is indicated by arrows in the middle of the figure

amplitudes is nearly constant and generally does not exceed values of 10nT²/Hz. From 64° to 65° an increase of power density is observed sometimes up to 1000nT²/Hz and more. It seems that the latitude gradient of power is a sensitive function of magnetic disturbance. The same conclusion is given with regard to the 2 to 5mHz band (200s–500s) in the study of pc3, 4 and pc5 pulsations, presented by Lanzerotti et al. (1976). Moreover they found that the latitude gradients of the power levels change with local time and from day to day within their latitude range of observation ($L = 3.2$–4.4), and, with only minor exceptions, the maximum power levels occur at the highest latitudes of observation (Girardville $L = 4.4$ corresponds to Lycksele $L = 4.4$) for essentially all local times and all days. In the region of maximum power the power in D is normally two to five times lower than in *H* in the Scandinavian data. The maximum in *H* of the shorter period pc4's ($T=45$s to 60s) is located inside the plasmapause, south of 60° to 62° geomagnetic latitude; the corresponding maximum in *D* is found between 65° and 67°.

Figure 8 is a typical example of spectral amplitude distribution for longer pc4's when Kp is $\geqq 4$o. The pulsation event is shown in Fig. 7. Also shown are the phase difference $\Delta\,\phi=\phi$ (MAL) $-\,\phi$ (station) and coherency with respect to the reference at MAL. A positive phase difference means the signal arrives later at MAL than at the station. The plasmapause is estimated to be $L=3.8\pm 0.4$ and is indicated by arrows in the middle of Fig. 8. The phase differences vary smoothly in *H*, and also in *D* except in the region of increasing power. The coherencies are high, nearly reaching 1 in most cases, except at SO. Notice also that the *H* and *D* amplitudes at SO deviate from the general profile distribution. Since this station lies well off the profile meridian the deviation of coherency and amplitude may reflect a longitudinal dependence.

Those events occurring during moderate magnetic activity (Kp$\sim$2) often have a minimum in the amplitude distribution. The adjacent maxima are located at $\sim$62° and 65°, respectively. An example showing this behaviour is given in Fig. 9. The wave trains corresponding to this example are shown in Fig. 2. The minimum in *H* amplitude is quite clear, and there is also a definite minimum in *D*. But, unlike the previous case for Kp=4o, the station SO is an exception from the profile distribution only in *D*, not in *H*.

Polarization Properties of Pc3, 4 Events

The wave polarization of about forty significant frequency bands (evaluated from fifteen pulsation events) centered on periods ranging from $T=25$s to 150s have been investigated. The shorter period range is discussed first, the longer second, for events occurring at more disturbed magnetic activity (Kp$\geqq$3o).

It was found that the wave ellipses for the shorter period range ($T=25$s–55s) have predominantly LH (left hand) polarization in the morning, i.e., the disturbance vector rotates anticlockwise viewed in the direction of a line of force, whereas the ellipses for events occurring between 11.00 and 15.00 h LT often show reversals (1) in the south of the profile, (2) between 65° and 67° geomagnetic latitude and (3) sometimes at stations at the plasmapause position. For these reversals the change can be either LH to RH (right hand) or RH to LH, varying from event to event.

In the lower frequency range of period $T=70$s–150s the ellipses have predominantly RH polarization for events around local noon (10.30–15.00 h LT), but for morning events the polarization changes several times along the profile. In some cases the magnetic disturbance vector of morning events of longer period pc4's is LH north of the line of maximum amplitude (65°–67°) and RH south of it. In other cases the reverse behaviour is observed as was also found by Samson and Rostoker (1972) for pc4 and pc5 pulsations; there is RH polarization north and LH south of a demarcation line characterized by maximum amplitudes and linear polarization. The events being investigated

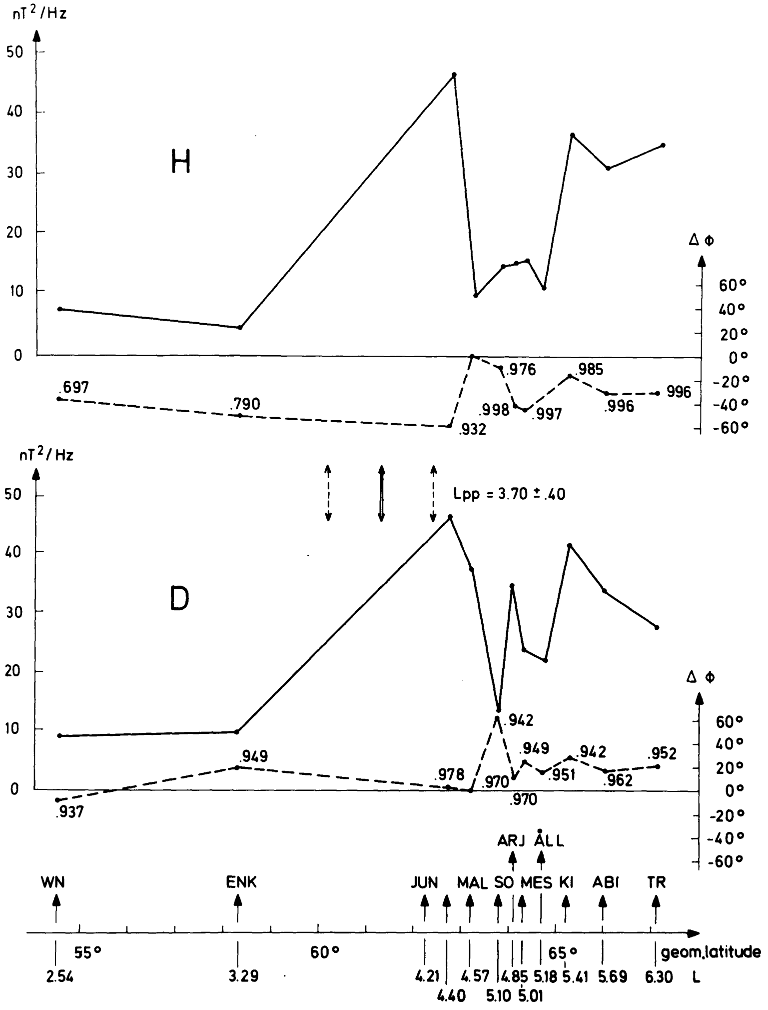

Fig. 9. Spectral amplitude distribution, phase difference and coherency for the frequency band at 10/600 cycles/$s = 16.67$ mHz with respect to the reference at *MAL*. The corresponding pulsation event and the power spectra are shown in Figs. 2 and 3, respectively

in this study show that the major axis of the polarization ellipses are preferentially oriented in the NE-direction.

Figure 10 shows some examples of the latitudinal distribution of polarization ellipses in the *H*-*D* plane. These ellipses have been evaluated from five wave events which occurred on different days and under low to moderate magnetic activity ($1- \leqq \mathrm{Kp} \leqq 2+$). Station, geomagnetic latitude and *L*-value are given along the right hand side of the diagram. The polarization has been evaluated for the bands whose periods are noted at the top of each column. For each event the time (LT), Kp index and the projection of the estimated plasmapause

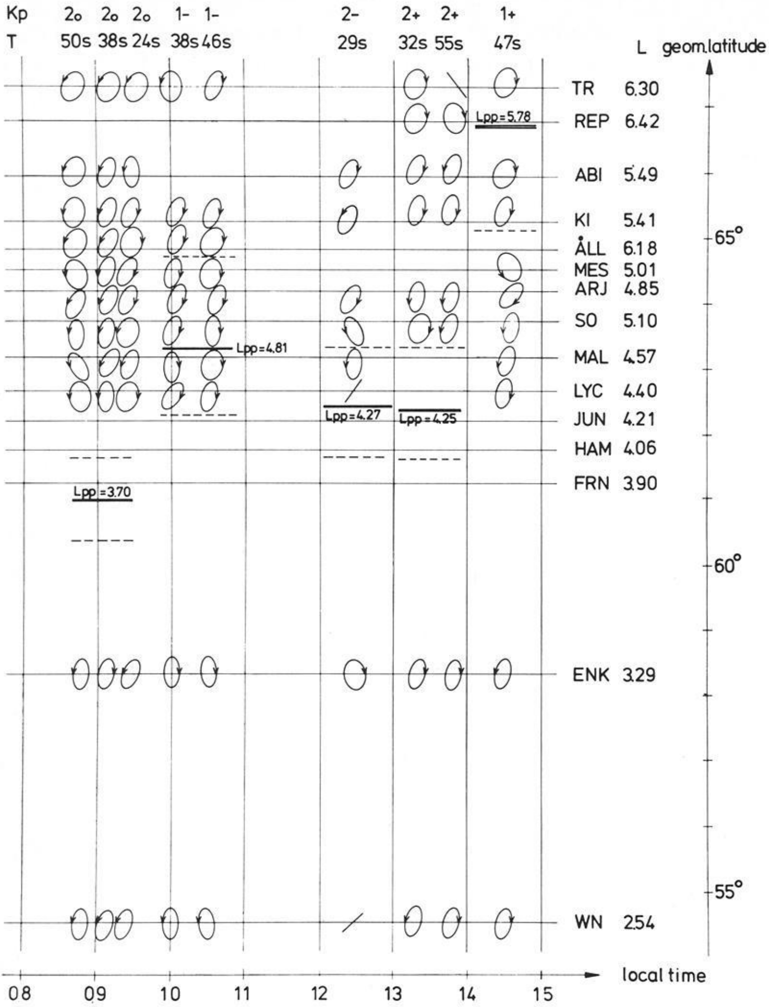

Fig. 10. Examples of the latitudinal distribution of polarization ellipses in the *H-D* plane. Further details of this figure are described in the text

position, indicated by the dashed lines, are given. For the earlier of the two morning events (9.00 h LT) – the corresponding wave train is seen in Fig. 2. – the polarization is predominantly LH in the longer period bands of $T=50$s and $T=38$s, but variable for the short period band $T=24$s. The polarization of the 10.00 h LT event is RH north of WN ($T=38$s and 46s at Kp$=1-$). The behaviour of polarization for events from 12.00 to 15.00 h LT is more complicated. For example, for the event at 14.30 h LT there occur 6 polarization reversals, and 3 for the event at 12.30 h LT (6th column of Fig. 10). One of the reversals in the former event occurs in the estimated plasmapause position, and, although no reversals occur in the plasmapause position in the latter event, there is a change of major axis orientation.

Summary and Discussion

In summary several points can be made about the analysis of amplitude spectra and of polarization of the magnetic disturbance vector. The latitude dependence of D and H spectra is complex. For this study the following points are noted.

1. There are a few cases in this study of more disturbed magnetic activity for which the dependence at latitude $>63°$ to 70° is similar to that observed by Voelker (1963) at midlatitude observatories Fürstenfeldbruck, Göttingen, and Wingst. And the few pse's (pulsation single effects, which occur predominantly in connection with sudden impulses and storm sudden commencements) observed in this study confirm earlier investigations of Hillebrand et al. (1973). These results do not, however, favor conclusively one theory over another.

2. For low activity, $\mathrm{Kp} < 2$, the present results are similar to those of Lanzerotti et al. (1974; 1976). Stations with dominant peaks at pc4 frequency tend to be at lower latitude than stations with dominant pc3 frequency peaks (Lanzerotti's data is for northern latitude stations with $L = 3.2$–4.4).

3. At higher activity, $\mathrm{Kp} \geqq 2\mathrm{o}$, however, the opposite effect is observed. The shorter period bands ($T = 50\mathrm{s}$–$60\mathrm{s}$) dominate in spectra from southern stations of the profile, while the longer period bands ($T = 70\mathrm{s}$–$150\mathrm{s}$) dominate at the higher latitude stations.

4. In both cases (2) and (3) the transition between high and low latitude behaviour occurs at the estimated plasmapause position, and is especially clear in H spectra.

The latitude dependence of polarization is also complex, and the sense of polarization is found to depend on frequency and time of day, too. Thus, in this study (1) there is a tendency for LH polarization in the morning at higher frequencies ($T = 25\mathrm{s}$–$55\mathrm{s}$) with reversals of polarization sense at lower frequencies ($T = 70\mathrm{s}$–$150\mathrm{s}$), and (2) there is a tendency for RH around noon (10.30–15.00 h LT) at lower frequency, but no clear pattern at the higher frequencies.

This may be compared with the polarization characteristics observed by Lanzerotti et al. (1976).

(1) In the 2 to 5mHz band (200s–500s) all stations ($L = 3.2$–4.4) exhibited similar characteristics on day to day basis, as well as on the average over several days. There was RH polarization between 12.00 and 18.00 h LT, and LH otherwise, and near local noon the major axis of polarization switched from NW-SE to NE-SW.

(2) In the 10 to 15mHz band (66.7s–100s) the same tendency for reversal of polarization and change of axis direction at local noon was found only in the average.

(3) In the 15 to 27mHz band (37s to 66.7s) the polarization character varied with latitude. From 12.00 to 18.00 h LT RH polarization was observed, and LH otherwise, but whereas this was observed on a day to day basis for $L = 3.2$–3.5 it was found only in the average for $L = 4.0$–4.4.

A few fundamental results from current theoretical work with resonance models of pulsations can now be compared with observational results.

(1) Southwood (1974a and b) and Chen and Hasegawa (1974) showed that (a) the sense of polarization changes across the resonant region, (b) the polarization is linear at the resonant field line, and (c) the major axis does not switch across the resonant region.

(2) Lanzerotti et al. (1974) used a specific model of plasmapause-type density distribution, and considered the polarization characteristics at latitudes away from the resonant region. At these latitudes they showed that the major axis direction can also switch.

(3) Hughes and Southwood (1976a and b) have extensively studied the ionospheric modification of pulsation. They found that the atmosphere and ionosphere alter the magnetospheric signal so as to smooth the amplitude and phase variation at ground level. They conclude that because of this smoothing polarization reversals may not be observed, and they suggest that disagreements of observational results with theoretical results may be explained by observing that the magnetosphere NS-field and EW-field at ground level show a relatively larger peak at resonance than is indicated by the models the authors used.

Although some observations of the present studies of Scandinavian data tend to fit the resonance models others do not, as, especially, the polarization ellipses which are more variable then would be expected. Some of the disagreement may be due to the ionospheric modification suggested by Hughes and Southwood (1976a and b). Future work with magnetometer networks and synchronous data from satellites will tell us more about the excitation and propagation of magnetohydrodynamic waves. These topics are under active investigation in the international magnetospheric study (IMS) project at present.

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