Geophysica (1985), Vol. 21, No. 1, pp. 19–37.
Printed in Finland

550.388.8:551.594.5

AURORAL AND MAGNETIC PULSATIONS IN THE MORNING SECTOR OF THE AURORAL ZONE

by

S.A. CHERNOUSS and V.R. TAGIROV

Polar Geophysical Institute, Apatity, U.S.S.R.

M.A. CHERNOUSS

Institute of the Physics of the Earth, Moscow, U.S.S.R.

J. KANGAS and J. LEINONEN

Department of Physics, University of Oulu, Oulu, Finland

M. KIVINEN

Finnish Meteorological Institute, Nurmijärvi Geophysical Observatory, Nurmijärvi, Finland

Abstract

We have analysed a great number of auroral and magnetic observations to study pulsation phenomena associated with auroral activity. We show that it is important to make a distinction between irregular, burst-like auroral pulsations (*Pi*(*A*)) and continuous auroral pulsations (*Pc*(*A*)). *Pi*(*A*)'s are a low-latitude phenomenon during high magnetic activity but *Pc*(*A*)'s appear at high latitudes during low magnetic activity. Irregular auroral pulsations occur during patchy auroras whereas *Pc* auroral pulsations are connected with diffuse auroras. The period of *Pc* auroral pulsations increases with latitude. The relationship of auroral luminosity pulsations to magnetic pulsations seems to be more direct in the *Pi* regime than in the *Pc* regime. These observations are discussed in the frame of existing models.

1. *Introduction*

DAVIS (1978) gives a definition of pulsating aurora: »A pulsating aurora is one with maximum intensity never exceeding ~10 kR in 4278 Å and which undergoes at least one full cycle wherein there is first a rapid increase, then a rapid decrease in intensity. The pulsations are usually repetitive and often quasi-periodic». Davis reviews also main characteristics of pulsating auroras. We repeat some of them here: »Pulsating forms are usually immersed in a uniform or irregular background emission. The altitude of the pulsating form is lower than that of the background emission. Pulsating periods range from 0.3 s to 30 s».

Pulsating aurora is one of the pulsating phenomena observed during auroral activity. Variations of the Earth's magnetic field are also typical in the same period range and it is evident that simultaneous observations of auroral and magnetic pulsations are one of the key methods to study the auroral pulsation physics.

A good correlation is usually observed between auroral luminosity pulsations and magnetic pulsations (see reviews by CAMPBELL, 1970, CAMPBELL, 1978, RASPOPOV *et al.,* 1978, and references therein, see also HEACOCK and HUNSUCKER, 1981 and WARD *et al.,* 1982). It is known that when auroral pulsations are observed concurrent magnetic field variations are observed simultaneously at the same location. The converse is not true and magnetic pulsations can be registered without any local auroral luminosity pulsations. This is at least partly due to different scales of the phenomena as observed on the ground.

Magnetic pulsations associated with auroral activity in the morning sector of the auroral zone are termed *Pi*-pulsations or *PiC* pulsations (see HEACOCK, 1967). It has been established that these *Pi* pulsations can be divided into two distinct groups: broad-band *Pi 1* pulsations and narrow-band *Pc 3*-type pulsations (ARTHUR *et al.,* 1973, 1975, 1977). These works also show that broad-band pulsations do not appear at geosynchronous orbit though they are observed at the conjugate area on the ground.

There are reports that also auroral pulsations observed in the morning sector of the auroral zone can be classified into two groups: the first one is characterized by a burst-like structure and the second one by more continuous and regular oscillations of luminosity (see RASPOPOV *et al.,* 1978 and references therein). In this paper, it is shown that this division of auroral pulsations can be based on several photometric observations.

Recently, ENGEBRETSON *et al.* (1983) reported an unusual class of correlated irregular magnetic pulsations and optical emissions which can be related to the burst-like structures mentioned above. As long series of observations are available in this study our aim is to extend the correlation studies between auroral and magnetic pulsations. We conclude that the division of pulsations into two characteristic classes is useful to understand their generation and interconnections between auroral and magnetic pulsations.

2. *Experimental*

Auroral and magnetic measurements were made at the stations shown in Table 1. Zenith photometers with the field of view of 70° were used, except at Loparskaya where the field of view was only 5°. Recordings were made at the speed of 180–760 mm/h. Auroral pulsations were identified when the amplitude of intensity variations was more than 10 % of the background intensity.

Magnetic field variations were recorded by the fluxgate magnetometer, except at Sodankylä where the induction coil magnetometer was operated. Analog recordings, either on paper or on magnetic tape have been available.

Table 1. Locations of the observation sites and periods of both photometric and magnetic measurements.

Station	Corrected geomagnetic		Observation periods	
	Latitude	Longitude	Photometer	Magnetometer
Heiss Island	74.1	144.5	1972–73	1980
Zhelaniya	70.3	147.1	1972–73	1980
Dikson	68.6	154.4	1976–77	–
Molodesnaya	–68.2	77.8	1976	1980
Loparskaya	64.0	114.8	1980–81	1978
Lovozero	63.8	118.0	–	1978
Sodankylä	63.5	109.0	1981–82	1981–82
Apatity	63.0	114.0	1981	1981
Kem	60.7	113.7	1968	–
Sogra	58.1	128.0	1970–71	1970–71

3. *Auroral pulsations and auroral forms*

Two types of auroral pulsations can be identified in photometric measurements in the morning sector as shown in Figs. 1a and 1b. In Fig. 1a the enhancements of auroral intensity appear as bursts of irregular structure. The bursts are about 10 seconds apart, on the average. These auroral intensity variations are called here as *Pi*(*A*) pulsations.

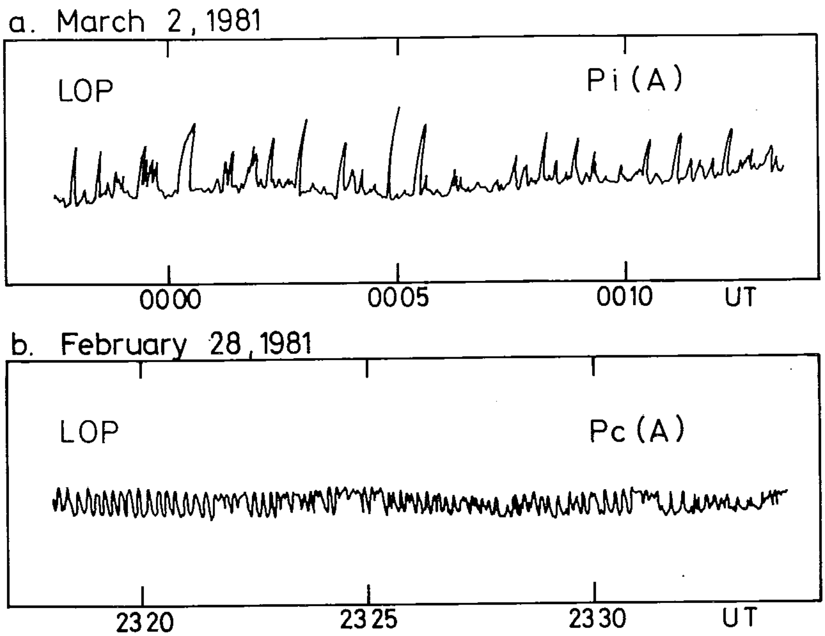

Fig. 1. Two examples illustrating type *Pi*(*A*) and type *Pc*(*A*) auroral pulsations (λ = 557.7 nm).

More regular intensity variations are shown in Fig. 1b. These pulsations are called here as *Pc*(*A*) pulsations. The period depends on the latitude of observation as will be shown later but it is usually between 10 and 40 seconds. The amplitude is typically smaller than that of *Pi*(*A*) pulsations.

Most often the observed auroral pulsations can be considered as a mixture of *Pi*(*A*) and *Pc*(*A*) pulsations. This is demonstrated in Table 2 where the occurrence

Table 2. Occurrence probability of different types of auroral pulsations at 7 photometer stations.

Station		Number of 15 min intervals	Occurrence probability (%) *Pc*(*A*)	*Pi*(*A*)	Mixture
Heiss Island	(HIS)	3918	2.9	0.3	7.9
Zhelaniya	(ZHE)	3558	2.1	0	10.1
Dikson	(DIK)	4581	1.5	1.4	10.4
Molodesnaya	(MOL)	1764	2.4	12.5	27.4
Loparskaya	(LOP)	2658	1.6	6.8	13.5
Kem	(KEM)	2063	0.5	3.9	5.0
Sogra	(SOG)	1055	0	8.5	6.8

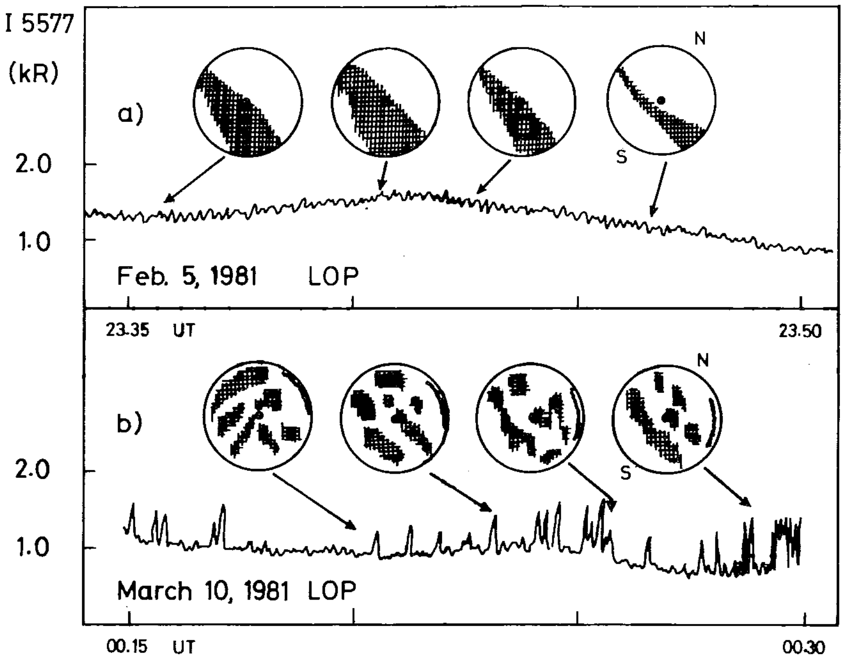

Fig. 2. *Pc*(*A*) type auroral pulsations observed during diffuse auroras (a) and *Pi*(*A*) type pulsations associated with auroral patches (b).

probability of different types of pulsations at several stations is given. In order to estimate the occurrence probability the observation time has been divided into the intervals of 15 minutes. Table 2 shows that *Pi*(*A*) pulsations are more common than *Pc*(*A*) pulsations but the latter type of pulsations is dominating at high latitude stations.

In Fig. 2 two events of auroral pulsations are related with auroral forms. It is seen that *Pi*(*A*)-type irregular pulsations can be associated with auroral patches. On the other hand, *Pc*(*A*)-type pulsations seem to bear a relation to diffuse auroras.

On the basis of the analysis of a more extended data sample the above-mentioned relations seem to be valid. 14 cases with *Pi*(*A*) pulsations have been analysed together with all-sky photographs and in all cases *Pi*(*A*) pulsations appear together with auroral patches. In 5 cases of 7 events with *Pc*(*A*) pulsations diffuse surfaces or diffuse bands have been identified.

The extension of pulsating patches is typically 10–100 km (Davis, 1978) and therefore *Pi*(*A*) pulsations are quite localized. *Pc*(*A*) pulsations are a more wide-

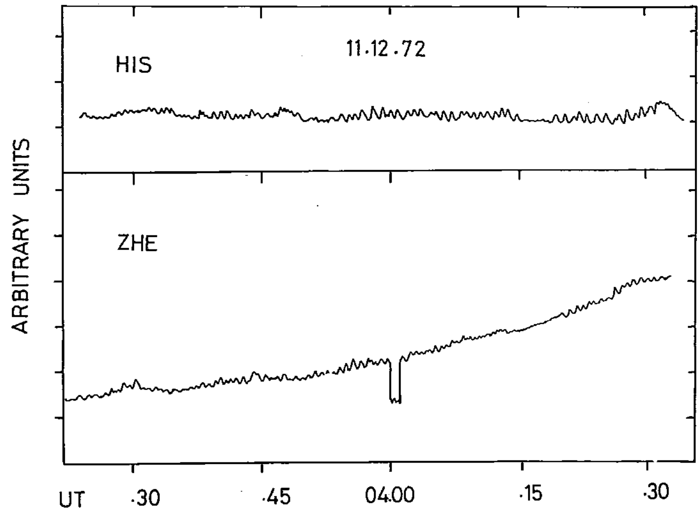

Fig. 3. Simultaneous photometric measurements of *Pc*(*A*) auroral pulsations at Heiss Island and Zhelaniya on 11 December, 1972.

spread phenomenon. During the observation period of 1972–73 26 simultaneous *Pc*(*A*) pulsation events were recorded at Heiss Island and Zhelaniya which are about 4 degrees apart in latitude. One example of such recording is shown in Fig. 3. Thus the extension of pulsating diffuse auroras may be 400–500 km in N–S direction. The coherency of these pulsations is not studied in this paper.

4. *Statistical analysis of the two types of auroral pulsations*

In above, it has been shown that auroral pulsations can be divided into two distinct groups. In this shapter, this conclusion will be further established by presenting some statistical results. Here we are able to use photometric observations from 7 stations which are located between 58.1° and 74.3° in geomagnetic latitude (Table 2).

15 min intervals with auroral observations have been analysed. Pulsations have been identified if the amplitude has been more than 10 % of the background level. The probability distributions have been made on the basis of these scalings.

The local time distributions of the *Pi*(*A*) and *Pc*(*A*) type pulsations are presented in Fig. 4 for all seven stations. Hatched areas refer to *Pc*(*A*) pulsations. The maximum occurrence of these pulsations shifts to earlier local times as the observation site moves to a lower latitude. The most probable time to observe

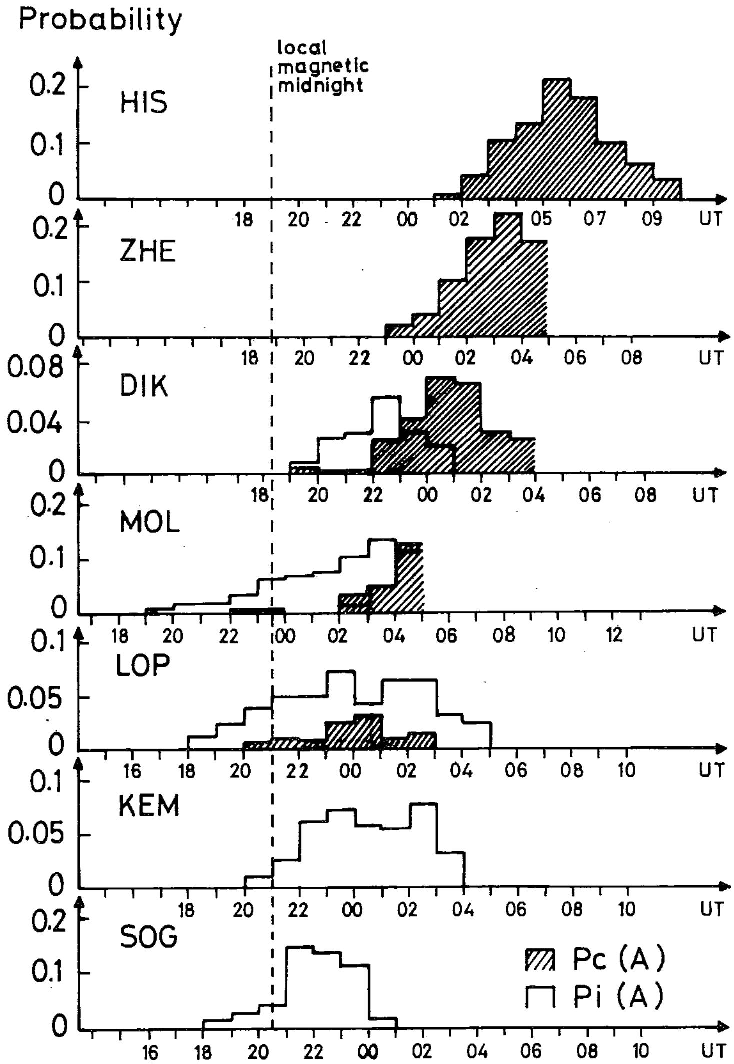

Fig. 4. Local time probability to observe the two types of auroral pulsations at seven stations.

irregular *Pi*(*A*) pulsations seems to be 01–05 LT without any systematic variation with respect to latitude. It has to be noted that 24 hour photometric observations have been possible only at Heiss Island; at other stations data have not been available from about 05 UT on.

Pi(*A*) auroral pulsations bear a more direct connection to magnetic activity than *Pc*(*A*) pulsations. Fig. 5 shows the probability to observe both types of

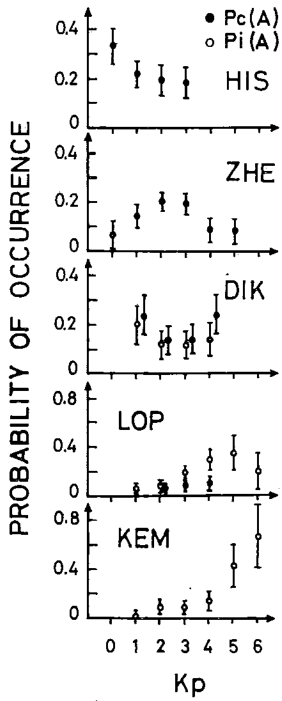

Fig. 5. Occurrence probability of the two types of auroral pulsations observed at five stations at different level of geomagnetic activity.

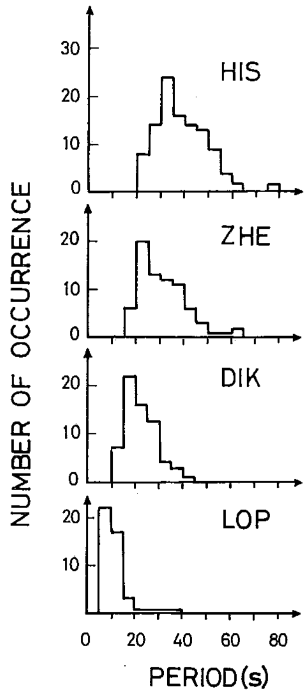

Fig. 6. Occurrence frequency of $Pc(A)$ pulsations of different periods at four stations.

pulsations for different values of the geomagnetic activity index Kp. It is noted that $Pc(A)$ pulsations typical for high latitude stations occur mainly during weak magnetic activity. $Pi(A)$ pulsations dominating at lower latitudes are most often observed during high magnetic activity.

A distinct period can be determined only for $Pc(A)$ pulsations. The period strongly depends on the latitude as shows in Fig. 6. The typical period is 10 seconds at $\phi = 64^\circ$ but 20–30 seconds at $\phi = 70^\circ$. The variation of the period as a function of magnetic activity is studied for the stations Heiss Island and Zhelaniya. It is seen in Fig. 7 that the period of $Pc(A)$ pulsations is typically greater during low Kp values than during high ones when the period does not depend very much on magnetic conditions.

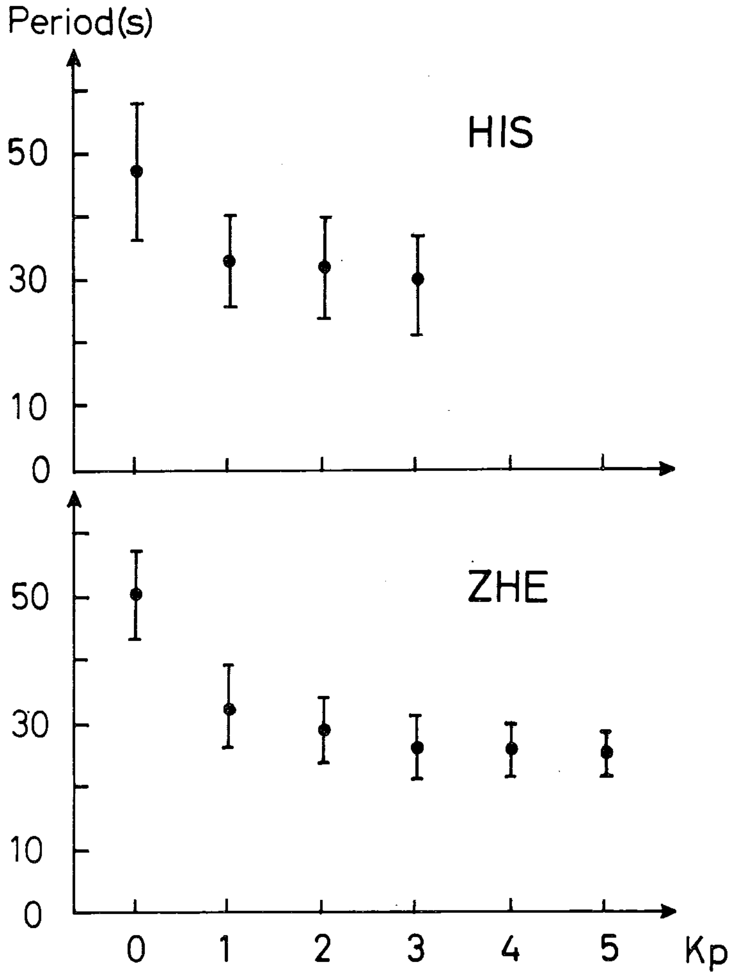

Fig. 7. Period of $Pc(A)$ pulsations as a function of Kp at Heiss Island and Zhelaniya.

5. *Auroral and magnetic pulsations*

In order to study the connections between auroral luminosity pulsations and magnetic field variations some important facts have to be taken into account. The field of view of magnetometers is typically much greater than that of photometers. On the other hand, non-identical characteristics of recording systems make the comparisons between stations difficult. We may demonstrate these matters using the data from two Soviet-Finnish recording campaigns. The first set of data is

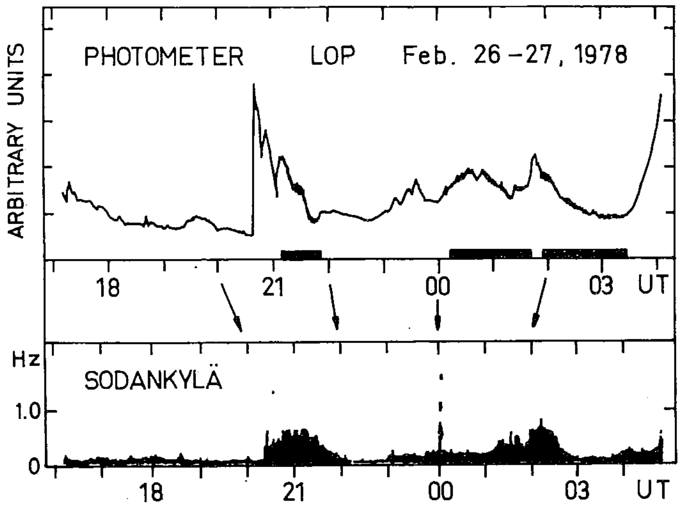

Fig. 8. Dynamic spectrum of magnetic pulsations observed at Sodankylä on 26–27 February, 1978 together with simultaneous photometer recordings made at Loparskaya.

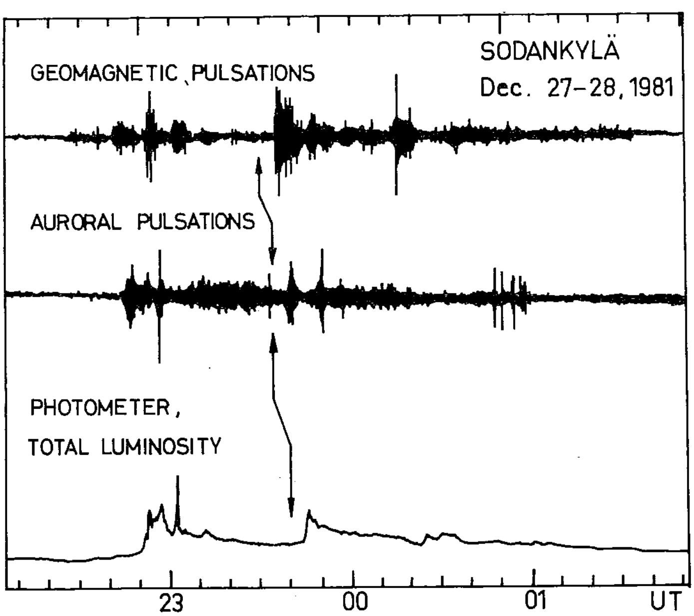

Fig. 9. Simultaneous recordings of auroral and magnetic pulsations at Sodankylä.

from the campaign during the winter 1977–78 when the observations of magnetic pulsations were made at Sodankylä and the auroral pulsations were recorded at Apatity. Simultaneous data are available from 75 days. The distance between the stations is about 300 km. The second campaign was organized during the winter 1981–82 when simultaneous auroral and magnetic pulsation recordings were made at Sodankylä. Data have been collected during 34 nights.

Figs. 8 and 9 present one example from both data sets. In Fig. 8 the dynamic spectrum of the Sodankylä magnetic variations shows that *Pi*-type magnetic pulsations occur always during auroral pulsations but also when no auroral pulsations are identified in Loparskaya photometer recordings. In Fig. 9 where both data are from the same station a high correlation between the two pulsation phenomena is seen.

The conclusions presented above are confirmed by Fig. 10 where the statistics

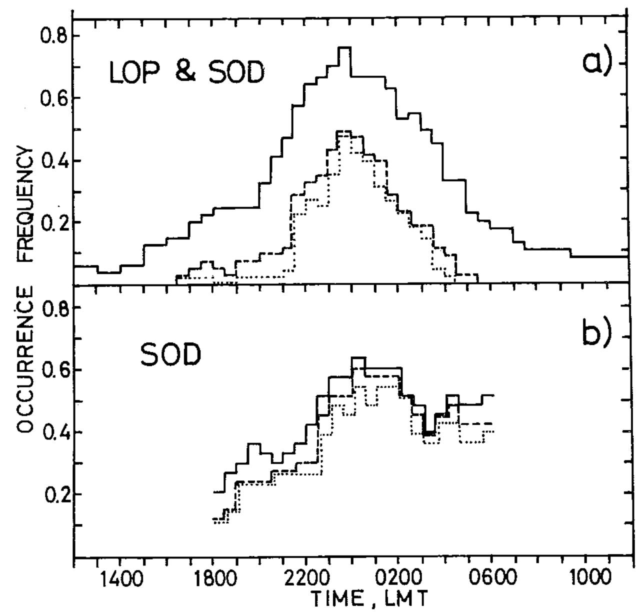

Fig. 10. Comparison of auroral and magnetic records:
a) —— *Pi* magnetic pulsations at Sodankylä in 1977–78,
- - - - - auroral pulsations recorded at Loparskaya in 1977–78,
········ magnetic pulsations observed at Sodankylä simultaneously with auroral pulsations at Loparskaya.
b) Same for the data set from 1981–82 when also auroral pulsations were recorded at Sodankylä, *i.e.* - - - - - illustrates the occurrence probability of auroral pulsations at Sodankylä.

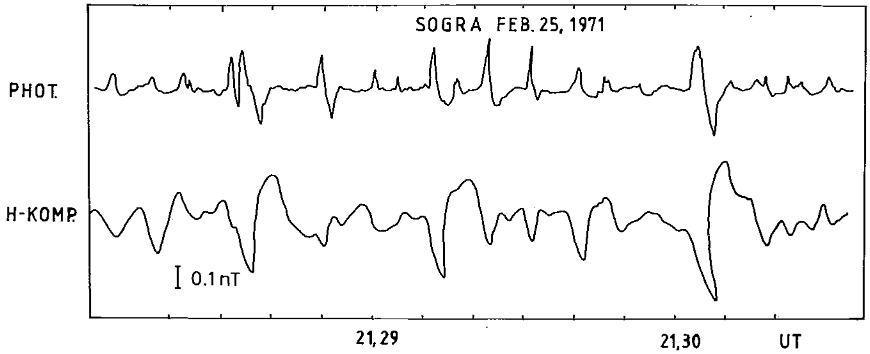

Fig. 11. Simultaneous records of *Pi* type magnetic and auroral pulsations at Sogra.

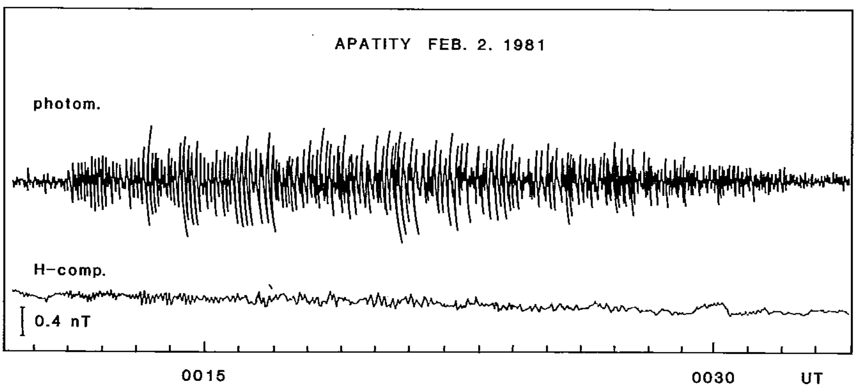

Fig. 12. Comparison of *Pc*-type magnetic and auroral records at Apatity.

on the basis of the two data sets is shown. In Fig. 10a we compare the magnetic pulsations recorded at Sodankylä with simultaneous observations of auroral pulsations at Loparskaya. One notes that magnetic pulsations at Sodankylä are about twice more frequent than auroral pulsations at the near-by station Loparskaya. On the other hand, Fig. 10a shows also that almost all auroral pulsation events observed at Loparskaya are accompanied with *Pi* type magnetic pulsations at Sodankylä. The correlation between the two pulsation phenomena increases when both of them are recorded at the same station as illustrated in Fig. 10b.

A more detailed picture of the relationship of auroral pulsations to magnetic pulsations is shown in Figs. 11 and 12. Typical *Pi*(*A*) pulsations observed at Sogra occur simultaneously with irregular non-periodic field variations. We conclude that these pulsations are identical with those reported by ENGEBRETSON

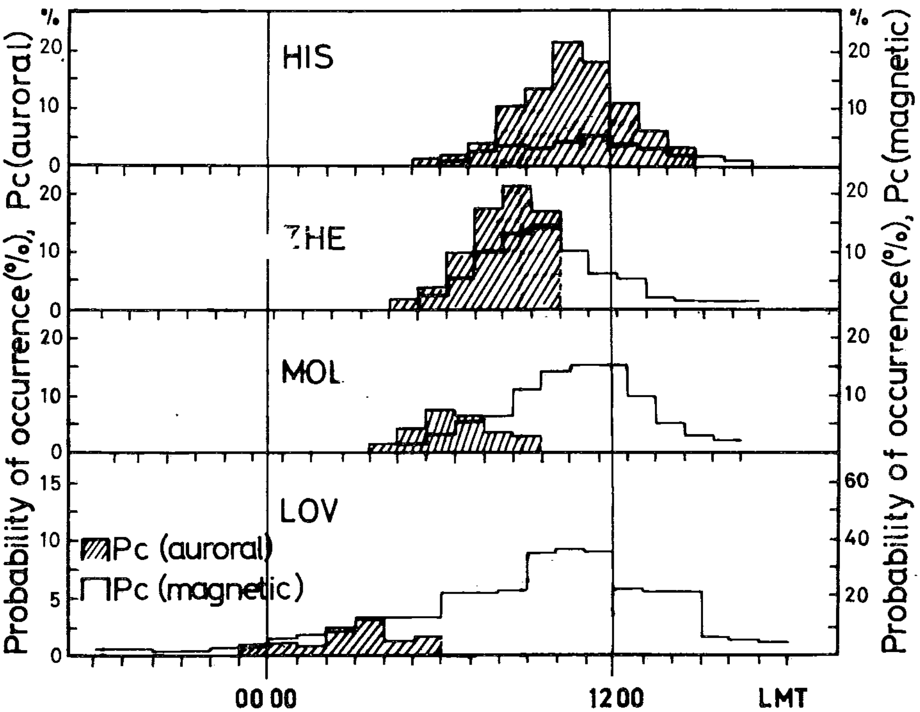

Fig. 13. Probability of both *Pc* (auroral) and *Pc* (magnetic) pulsations as a function of local magnetic time at four stations.
Note: Molodesnaya magnetic pulsations are compared with Dikson auroral data. These two stations are located at about the same latitude.

et al. (1983). On the other hand, *Pc*(*A*) type auroral pulsations shown in Fig. 12 appear at Apatity together with weak, continuous type magnetic pulsations.

We have shown in Fig. 4 that the occurrence probability of the two types of auroral pulsations depends on latitude and local time. Figs. 13 and 14 illustrate how the correlation between magnetic and auroral pulsations may vary. Fig. 13 shows that the maximum of the occurrence of *Pc* type magnetic pulsations is late in the local morning sector and the corresponding distribution of *Pc* type auroral pulsations agrees with it only at the northernmost stations (Heiss Island and Zhelaniya). It has to be pointed out that the observations of auroral pulsations do not extend to the late morning sector at southern stations. In any case, it is important to note that the maximum occurrence of *Pc*(*A*) pulsations at Dikson is well before the corresponding maximum of *Pc* magnetic pulsations at Molodesnaya.

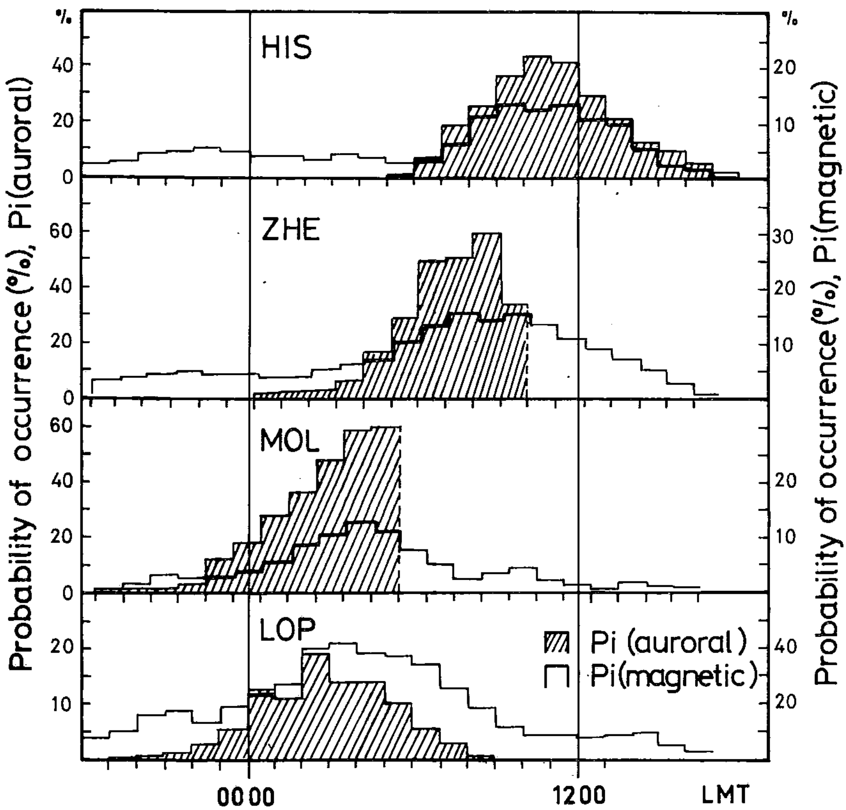

Fig. 14. Same as in Fig. 13 but for *Pi* type pulsations.

In Fig. 14 where *Pi* type pulsation phenomena are compared, all *Pi* auroral pulsations are included (see Table 2). This figure demonstrates that a strong relationship exists between auroral and magnetic pulsations in the *Pi* regime.

6. *Summary of observations*

The main observational results of this study can be summarized as follows:

1) Auroral pulsations observed in the morning sector of the auroral zone can be divided into two groups: *Pi*(*A*) and *Pc*(*A*) pulsations.
2) *Pi*(*A*) pulsations occur in connection with auroral small-scale patches whereas the appearance of regular pulsations is related with diffuse, large-scale auroras.
3) The period of regular auroral pulsations depends on the latitude and Kp.
4) Statistical analysis shows that *Pc*(*A*) pulsations are typically a quiet-time, high-

latitude phenomenon whereas *Pi*(*A*) pulsations are typical for active magnetospheric conditions in auroral and sub-auroral zones.

5) We have established that *Pi*(*A*) variations bear a close relationship to irregular *Pi* magnetic variations.
6) In the *Pc* regime, the relationship of auroral luminosity pulsations to magnetic pulsations seems to be complicated. However, it is evident that most often both pulsation phenomena co-exist.

7. *Discussion*

The experimental results summarized above demonstrate that it is important to make distinction between *Pi*(*A*)- and *Pc*(*A*)-type pulsation phenomena. After this conclusion it is possible to understand *e.g.* the results reported by ENGEBRETSON *et al.* (1983) that at Siple (L = 4.2, geomagnetic latitude 64.4°) there was no evidence of large amplitude sinusoidal magnetic variations when correlated irregular magnetic pulsations and optical emissions were observed. Our statistical data suggest that such a situation should not be probable at a sub-auroral station.

To understand the link between the auroral and magnetic pulsations is a problem which has not been solved. It has been a common opinion that magnetospheric ULF waves determine the periodicity of the pulsating aurora (see CORONITI and KENNEL, 1970). Recently, a different approach has been proposed where the magnetic pulsations are the result of the electron precipitation modulating the ionospheric conductivity (see LUHMANN, 1979, DAVIDSON, 1979, CORNWALL and CHIU, 1982). The observations reported by ENGEBRETSON *et al.* (1983) provide support of this approach, see also HEACOCK and HUNSUCKER (1977). In the following we discuss these two views in the frame of the present observations.

Correlated Pi magnetic and auroral pulsations

ENGEBRETSON *et al.* (1983) conclude that the irregular magnetic pulsations with asymmetric and nonsinusoidal waveform are of ionospheric origin. They propose that these pulsations are generated by transient currents resulting from the precipitation of energetic electrons. The primary precipitation pulsations may be *e.g.* due to relaxation oscillations generated by electrostatic turbulence and magnetic mirror forces as proposed by CORNWALL and CHIU (1982).

This model for correlated *Pi* magnetic and auroral pulsations as summarized in Fig. 15 remains a good candidate at present. This is supported by satellite meas-

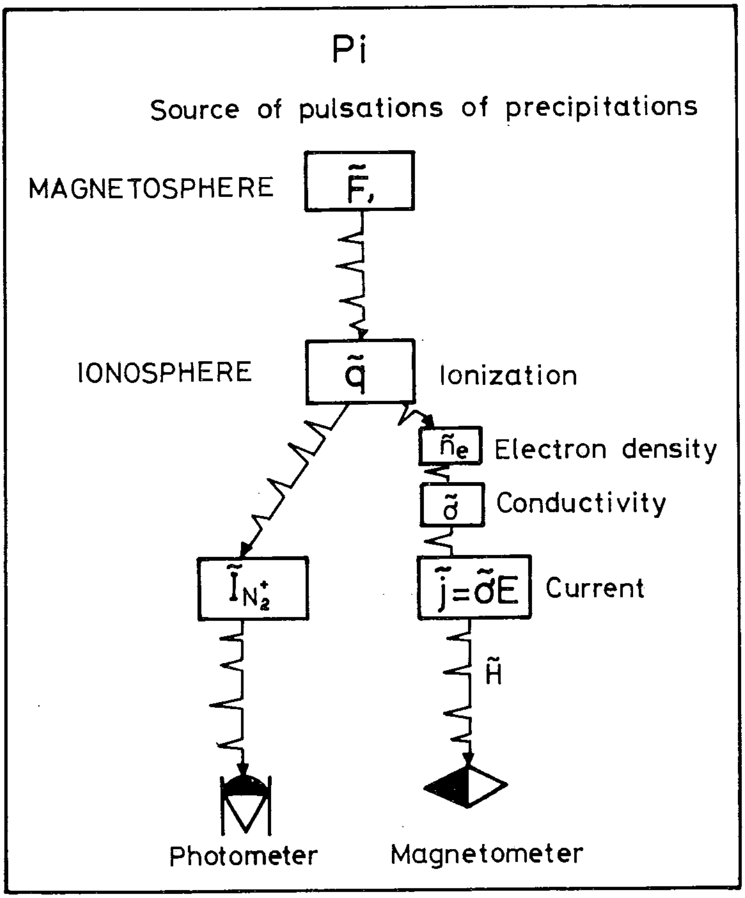

Fig. 15. Schematic presentation to illustrate the inter-connections between *Pi* magnetic and auroral pulsations.

urements which show that *Pi* magnetic pulsations do not appear in the geostationary orbit when they have been observed on the ground. However, it is most probable that other mechanisms are involved: *e.g.* much of the mixed mode pulsation activity as listed in Table 2 has not been classified in the present study.

Pc-type pulsation phenomena

One of the most advanced theory of auroral pulsations has been developed by Coroniti and Kennel (1979). According to this theory micropulsations modulate the pitch angle scattering of energetic electrons in the magnetosphere. Equatorial

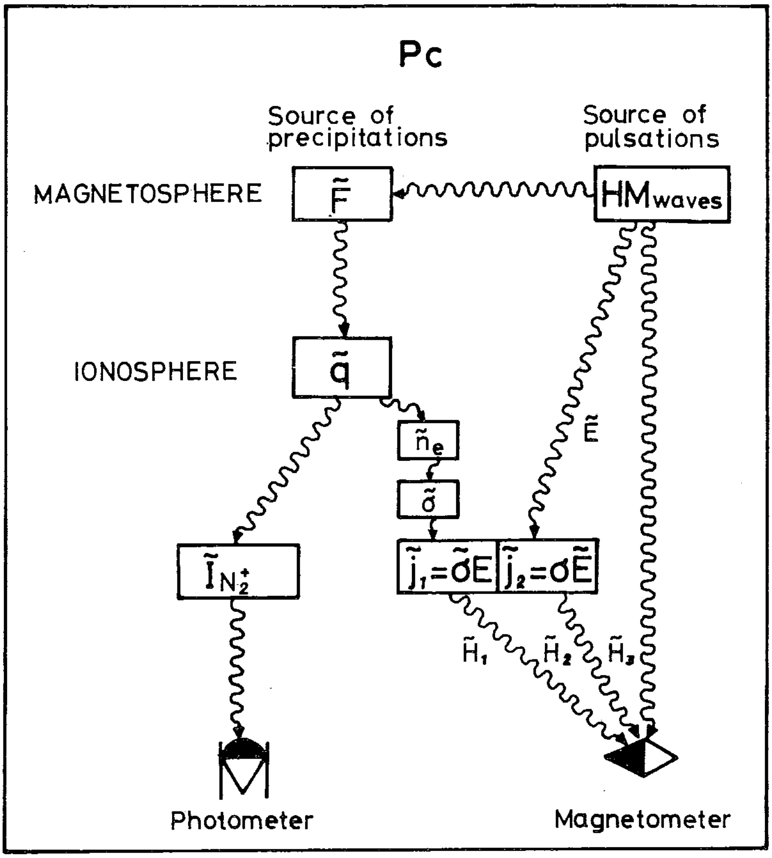

Fig. 16. Same as in Fig. 15 but for *Pc* pulsations.

location for the source of such modulations has been deduced from the velocity dispersion of pulsations (see *e.g.* BRYANT *et al.*, 1975).

We realize that the observed increase in the period of pulsations with latitude is an important boundary condition for possible mechanisms. THOMAS and ROTHWELL (1979) assume that the precipitating electrons are modulated at the bounce period of electrons. Another explanation might take into account the well-known fact that the period of long-period continuous magnetic pulsations depends on latitude. This should introduce a modulation of particle fluxes in the frame of the theory by CORONITI and KENNEL (1970) which depends on latitude.

The relationship of *Pc* auroral pulsations to *Pc* magnetic pulsations as reported in the present study is weaker than that expected from the above-mentioned theoretical considerations. This is partly due to hydromagnetic waves which introduce directly magnetic pulsations by modulating the electric field in the ionosphere as shown by the summary in Fig. 16.

Acknowledgements: The authors are grateful to many colleagues who have participated in the recording campaigns. We express our thanks especially to Dr. T. Turunen, Geophysical Observatory, Sodankylä. The work has been financially supported by the Finnish-Soviet Committee on co-operation in Science and Technology.

REFERENCES

ARTHUR, C.W., McPHERRON, R.L., and P.J. COLEMAN, Jr., 1973: Micropulsations in the morning sector: 1. Ground observations of 10- to 45 second waves Tungsten, Northwest territories, Canada. *J. Geophys. Res.*, **78**, 8180–8192.

ARTHUR, C.W. and R.L. McPHERRON, 1975: Micropulsations in the morning sector: 2. Satellite observations of 10- to 45-s waves at synchronous orbit, ATS 1. *Ibid.*, **80**, 4621–4626.

–»– , 1977: Micropulsations in the morning sector: 3. Simultaneous ground – satellite observations of 10- to 45-s period waves near L = 6.6. *Ibid.*, **82**, 2859–2866.

BRYANT, D.A., SMITH, M.J., and G.M. COURTIER, 1975: Distant modulation of electron intensity during the expansion phase of an auroral substorm. *Planet. Space Sci.*, **23**, 867–878.

CAMPBELL, W.H., 1970: Rapid auroral luminosity fluctuations and geomagnetic field pulsations. *J. Geophys. Res.*, 75, 6182–6208.

–»– , 1978: Highlights in the studies of relationship of geomagnetic field changes to auroral luminosity. *J. Geomagn. Geoelectr.*, **30**, 315–325.

CORNWALL, J.M. and Y.T. CHIU, 1982: Ion distribution effects to turbulence on a kinetic auroral arc model. *J. Geophys. Res.*, 87, 1517–1527.

CORONITI, V.E. and C.F. KENNEL, 1970: Electron precipitation pulsations. *Ibid.*, 75, 1279–1289.

DAVIDSON, G.T., 1979: Self-modulated VLF wave-electron interactions in the magnetosphere: A cause of auroral pulsations. *Ibid.*, **84**, 6517–6523.

DAVIS, T.N., 1978: Observed characteristics of auroral forms. *Space Sci. Rev.*, **22**, 77–113.

ENGEBRETSON, M.J., CAHILL, L.J. Jr., ARNOLDY, R.L., MENGE, S.B., and T.J. ROSENBERG, 1983: Correlated irregular magnetic pulsations and optical emissions observed at Siple station, Antarctica. *J. Geophys. Res.*, 88, 4841–4852.

HEACOCK, R.R., 1967: Two subtypes of type *Pi* micropulsations. *Ibid.*, 72, 3905–3917.

–»– , and R.D. HUNSUCKER, 1977: A study of concurrent magnetic field and particle precipitation pulsations, 0.005 to 0.5 Hz, recorded near College, Alaska. *J. Atmos. Terr. Phys.*, 39, 487–501.

–»– , 1981: Type *Pi* 1–2 magnetic field pulsations. *Space Sci. Rev.*, **28**, 191–221.

LUHMANN, J.G., 1979: Auroral pulsations from atmospheric waves. *J. Geophys. Res.*, **84**, 4224–4228.

RASPOPOV, O.M., CHERNOUSS, S.A., ROLDUGIN, V.K., and O.A. POCHOTELOV, 1978: *Pulsating particle precipitation in ionosphere and magnetosphere.* Leningrad, Nauka.

THOMAS, R.W. and P. ROTHWELL, 1979: A latitude effect in the periodicity of auroral pulsating patches. *J. Atmos. Terr. Phys.*, **41**, 1179–1184.

WARD, I.A., LESTER, M., and R.W. THOMAS, 1982: Pulsating hiss, pulsating aurora and micropulsations. *Ibid.*, **44**, 931–938.