ANNALI DI GEOFISICA, VOL. 42, N. 4, August 1999

The temporal and spatial variations of low frequency geomagnetic pulsations at polar cusp and cap latitudes

Natalia G. Kleimenova (¹), **Patrizia Francia** (²), **Umberto Villante** (²), **Olga V. Kozyreva** (¹),
Jacques Bitterly (³) and **Jean-Jacques Schott** (⁴)
(¹) *Institute of the Physics of the Earth, Moscow, Russia*
(²) *Dipartimento di Fisica, Universita' dell'Aquila, Coppito, L'Aquila, Italy*
(³) *Institute de Physique du Globe, Chambon-la-Foret Observatoire, Paris, France*
(⁴) *Ecole et Observatoire des Sciences de la Terre, Strasbourg, France*

Abstract
Geomagnetic field measurements at two Antarctic stations are compared during two weeks in the local summer (January 1-15, 1992). Low frequency (0.6-6 mHz) pulsations are observed at each station near local magnetic noon. The same wave packets appear in some cases also at the other station, although with a significant attenuation, more clearly in the morning sector; the waves show a near noon reversal of the polarization sense from counter-clockwise in the morning to clockwise in the afternoon indicating a westward and an eastward propagation, respectively.

Key words *geomagnetic pulsations – Antarctica*

1. Introduction

As it is well known, the area near the dayside cusp latitudes is characterized by the occurrence of broadband ULF magnetic pulsations (Troitskaya and Bolshakova, 1977; Troitskaya *et al.*, 1980; Bolshakova and Troitskaya, 1982; Troitskaya, 1985; Kleimenova *et al.*, 1985, 1989; Olson, 1986; Dunlop *et al.*, 1994; Engebretson *et al.*, 1995; McHang *et al.*, 1995; Clauer *et al.*, 1997). The continuous irregular pulsations with frequencies, on average, from 1.1 to 5.5 mHz have also been called ipcl (Troitskaya and Bolshakova, 1977). They occur either as bursts or persist continuously from 2 to 10 h, depending on geomagnetic activity, with amplitudes from several to tens of nT. Troitskaya (1985) showed that ipcl amplitude appears to depend mainly on the solar wind velocity and on the southward orientation of the interplanetary magnetic field; more recently, Villante *et al.* (1997) found major evidence for low frequency pulsations near cusp latitudes during time intervals characterized by high solar wind speed.

As a consequence of the Earth's rotation, a polar cap station approaches the cusp for a relatively short time interval around the local magnetic noon. Data from two ground stations located at about the same high geomagnetic latitude and separated in longitude can then provide useful information on the local and/or temporal extent of individual events. In this paper we analyzed simultaneous geomagnetic meas-

---

Mailing address: Dr. Patrizia Francia, Dipartimento di Fisica, Università dell'Aquila, Via Vetoio 10, 67010 Coppito, L'Aquila, Italy; e-mail: patrizia.francia@aquila.infn.it

urements at Dumont D'Urville and Terra Nova Bay (hereafter DRV and TNB) in Antarctica, during two weeks in the local summer (January 1-15, 1992) and found that low frequency waves are observed at each station near local magnetic noon: in some cases the same pulsations also appear at the other station, mainly in the local morning, and show a counterclockwise polarization before local noon and a clockwise polarization in the early afternoon.

Daytime spectra of low frequency geomagnetic pulsations at DRV during local summer are usually characterized by a main enhancement in the 1.5-2.5 mHz band (Kleimenova *et al.*, 1989). Villante *et al.* (1997), who conducted a statistical analysis of 0.7-5.0 mHz geomagnetic field fluctuations at TNB during three austral summers close to the maximum of solar activity, found that the daytime power spectra show, in addition to some discrete maxima at 3.3, 3.9 and 4.5 mHz, power enhancements at lower frequencies (1.2, 1.9 and 2.7 mHz) during higher solar wind speed conditions. As they remarked, the observed peaks are close to the frequencies expected for magnetospheric compressional/waveguide modes. Recently several papers have been published concerning the theoretical and observational aspects of these pulsations (Walker *et al.*, 1992; Samson *et al.*, 1992; Harrold and Samson, 1992; Ziesolleck and McDiarmid, 1994). The energy source is assumed to be related to the solar wind through Kelvin-Helmholtz instability or impulsive disturbances on the magnetopause which may generate compressional oscillations of the magnetosphere. Further, such compressional modes may drive shear Alfven resonances on field lines with matching eigenfrequencies.

2. Experimental observations

The corrected (according to the Tsyganenko magnetic field model IGRF95) geomagnetic latitude of both DRV and TNB is 80.5°S; the longitude of DRV and TNB is 235°E (MLT $\approx$ UT + 11) and 307°E (MLT $\approx$ UT – 8), respectively; so, the DRV geomagnetic noon occurs approximately at 01 UT while the TNB noon at $\approx$ 20 UT. It means that the noon time at TNB corresponds to the early morning at DRV, while when DRV is located near noon, TNB is in the late afternoon. The time period January 1-15, 1992 was moderately disturbed, the average K_p values being about 2-3 (only during January, 11-14 the K_p values increased to 5-6). During moderate geomagnetic activity, around local noon both stations move progressively toward closed field lines; conversely, when the magnetic activity increases, the cusp shifts to lower latitudes and DRV and TNB stay in the polar cap during the whole day.

We analyzed the 1 min measurements of the geomagnetic field horizontal components H and D in the time interval 15-06 UT, corresponding to 07-22 MLT at TNB and 02-17 MLT at DRV, in order to include daytime hours at both stations. The signal was filtered out by applying sixth order Butterworth type band pass filter between 0.6-6 mHz (Otnes and Enochson, 1978). Then amplitude spectra were calculated by means of direct Fourier transform. Several examples of the H component daytime spectra at DRV (solid lines) and TNB are shown in fig. 1. In general, at low frequency ($f < 2$ mHz) they are typically characterized by a relative broadband activity with amplitude sharply decreasing with frequency. At higher frequencies the amplitude more slowly decreases from 2 mHz to 5 mHz, showing in some cases remarkable enhancements mainly in the 2-3 mHz frequency band (for instance on January 9-10, 12-13 and 13-14).

Figure 2 shows three examples of the filtered signal (H component). As can be seen, sharp pulsations were detected at each station close to the local magnetic noon (dashed lines in the figure). In some cases this wave activity seems to be accompanied by the occurrence of pulsations also at the other station, although with much lower amplitude (January 6-7, 18-21 UT; January 10-11, 19:30-22 UT) while in other cases (January 12-13) it is hard to find any clear correspondence between the wave packets observed at the two stations.

To make these aspects clearer, we examined the experimental data in two frequency bands (1-2 mHz and 2-3 mHz), also performing a polarization analysis. Figure 3 shows, as an example, the filtered signals on January 6-7 in the

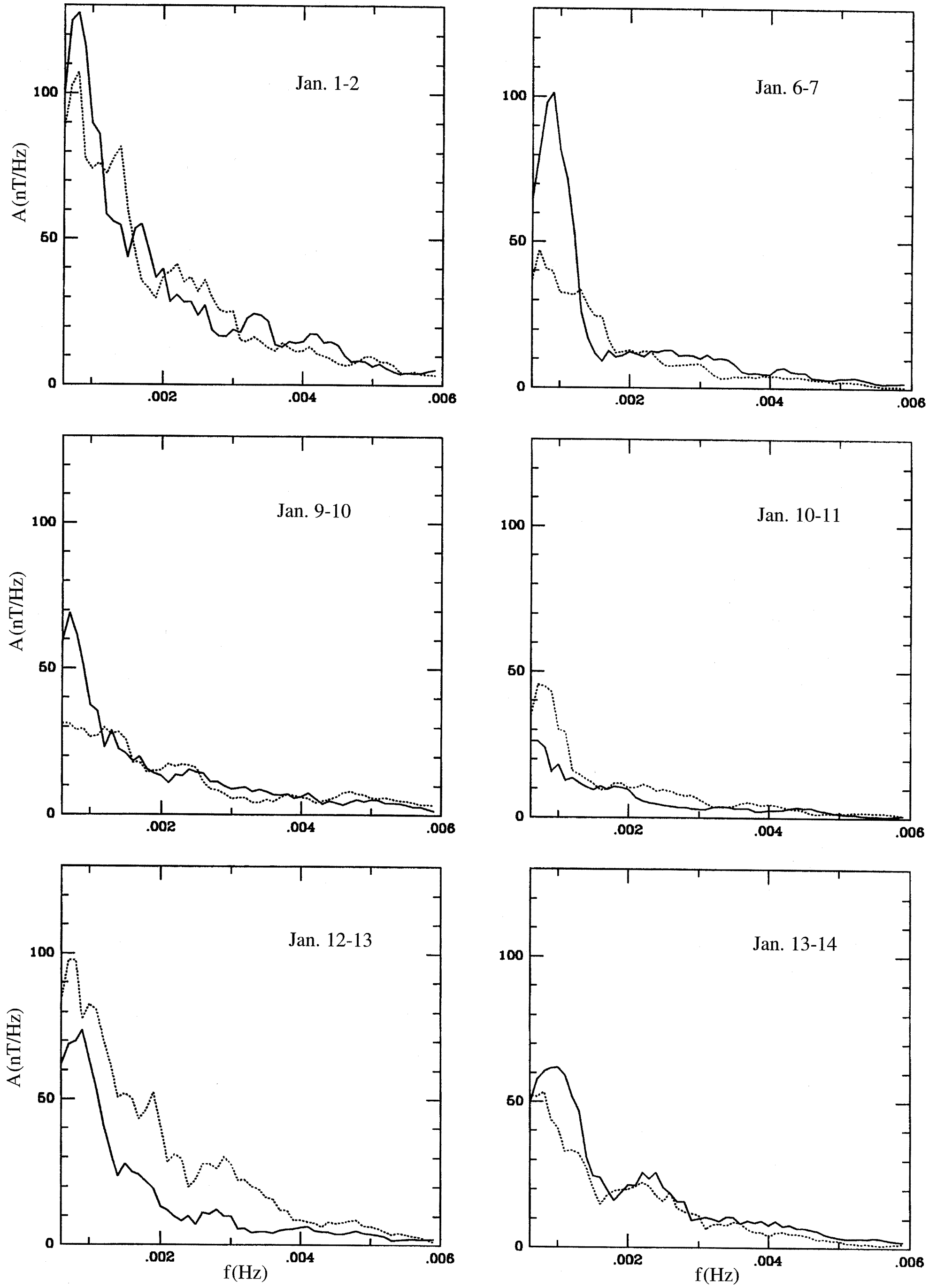

Fig. 1. *H* component amplitude spectra in the frequency band 0.6-6.0 mHz at DRV (solid line) and TNB.

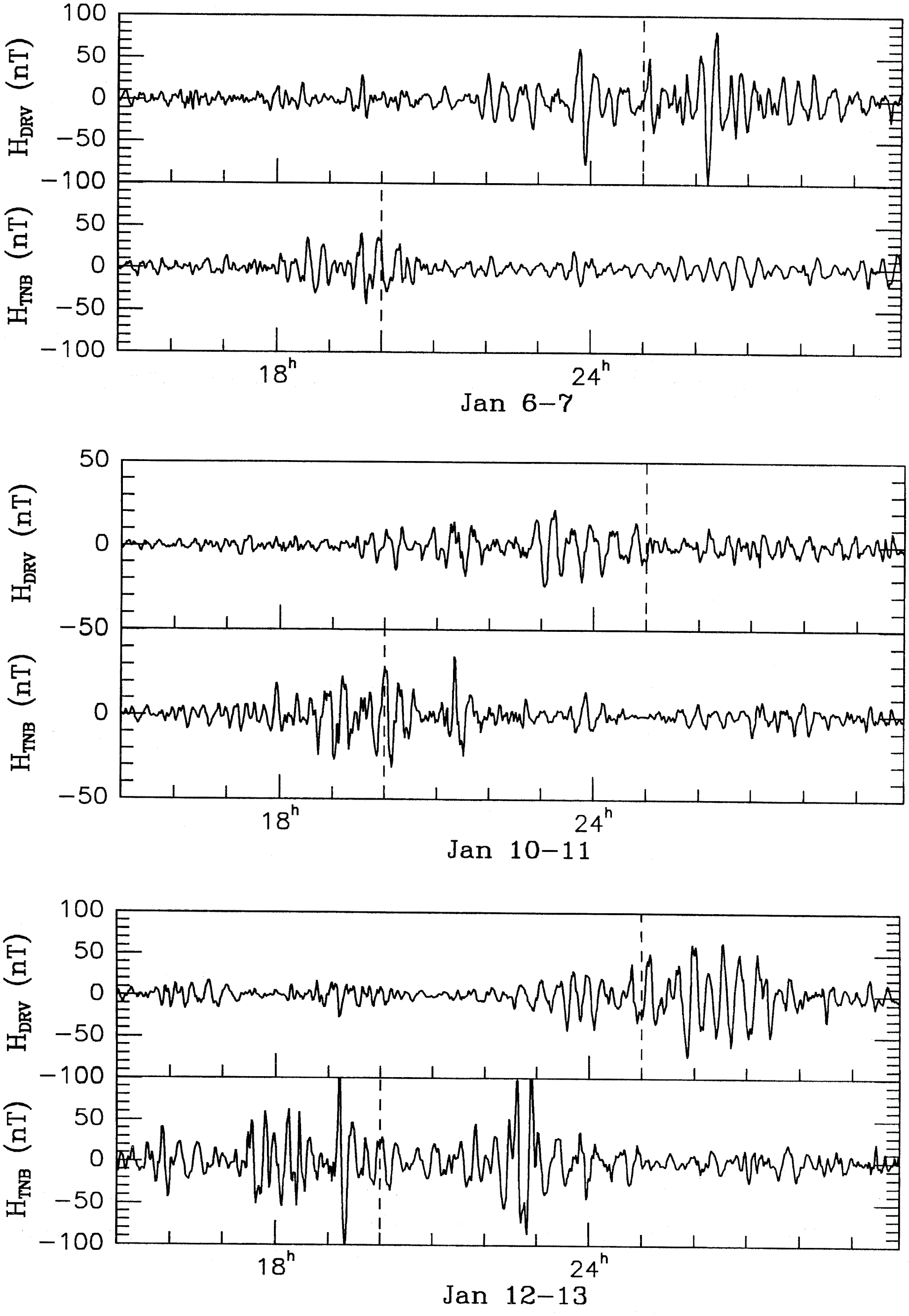

Fig. 2. Three examples of the 0.6-6.0 mHz filtered pulsations at DRV and TNB. Dashed lines show the magnetic noon at DRV and TNB.

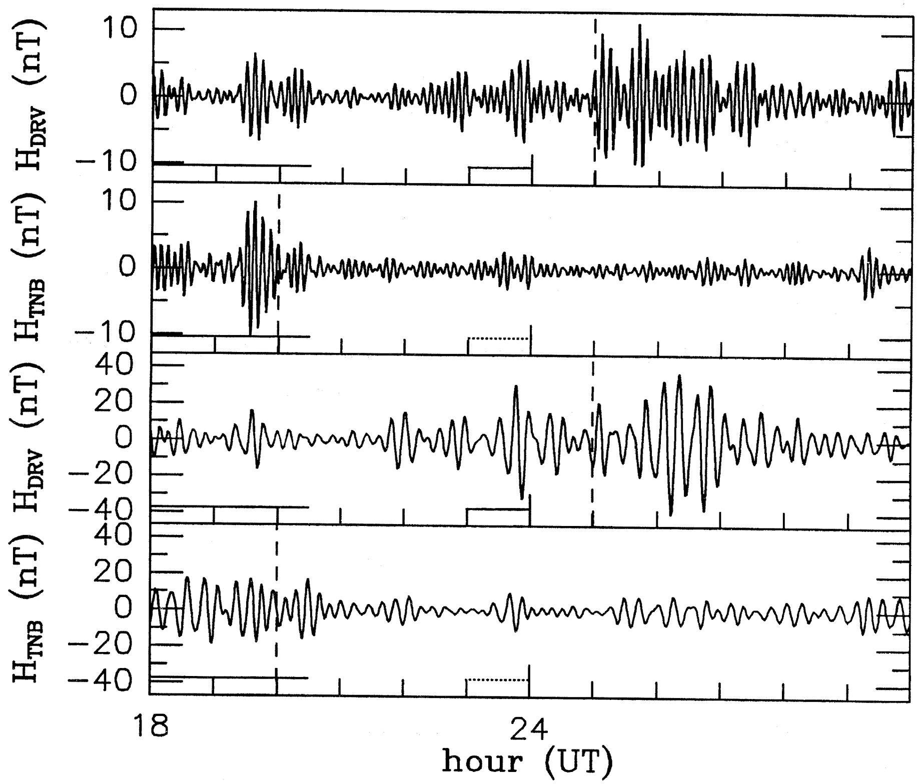

Fig. 3. The 1-2 mHz (lower panels) and 2-3 mHz (upper panels) filtered pulsations on January 6-7, 1992. Solid (dotted) lines indicate counterclockwise (clockwise) polarization sense. Dashed lines show the magnetic noon at DRV and TNB.

time interval 18-06 UT. As can be seen, the higher frequency pulsations occurring between 18-20:30 UT were observed both at TNB around local noon and at DRV in the local early morning, with an amplitude approximately a factor of 1.5 stronger at TNB. The analysis of the polarization of these pulsations showed that it is counterclockwise at both stations; taking into account the field line resonance effects, at southern polar latitudes and for morning hours these features are consistent with waves propagating westward (Southwood, 1974) with a significant attenuation. Conversely, in the same frequency band, the pulsations observed between 01-03 UT at DRV, *i.e.* just after the local noon, were not accompanied by wave activity at TNB in the late afternoon. Similar conclusions can also be drawn for the lower frequency signal. Indeed, the pulsations observed near local magnetic noon at TNB were also detected, although damped, at DRV in the morning sector and they also showed the expected counterclockwise polarization at both stations; on the other hand, the strong wave packet occurring between 01-03 UT at DRV found a poorer correspondence at TNB. Note also that, in both frequency bands, a short wave packet was observed at both stations in the time interval 23-00 UT: it had a greater amplitude at DRV which was closer to the local magnetic noon. Moreover, it is interesting to remark that the wave packets had a counterclockwise polarization at DRV in the late morning and a clockwise polarization at TNB, after the local noon: this feature may be considered consistent

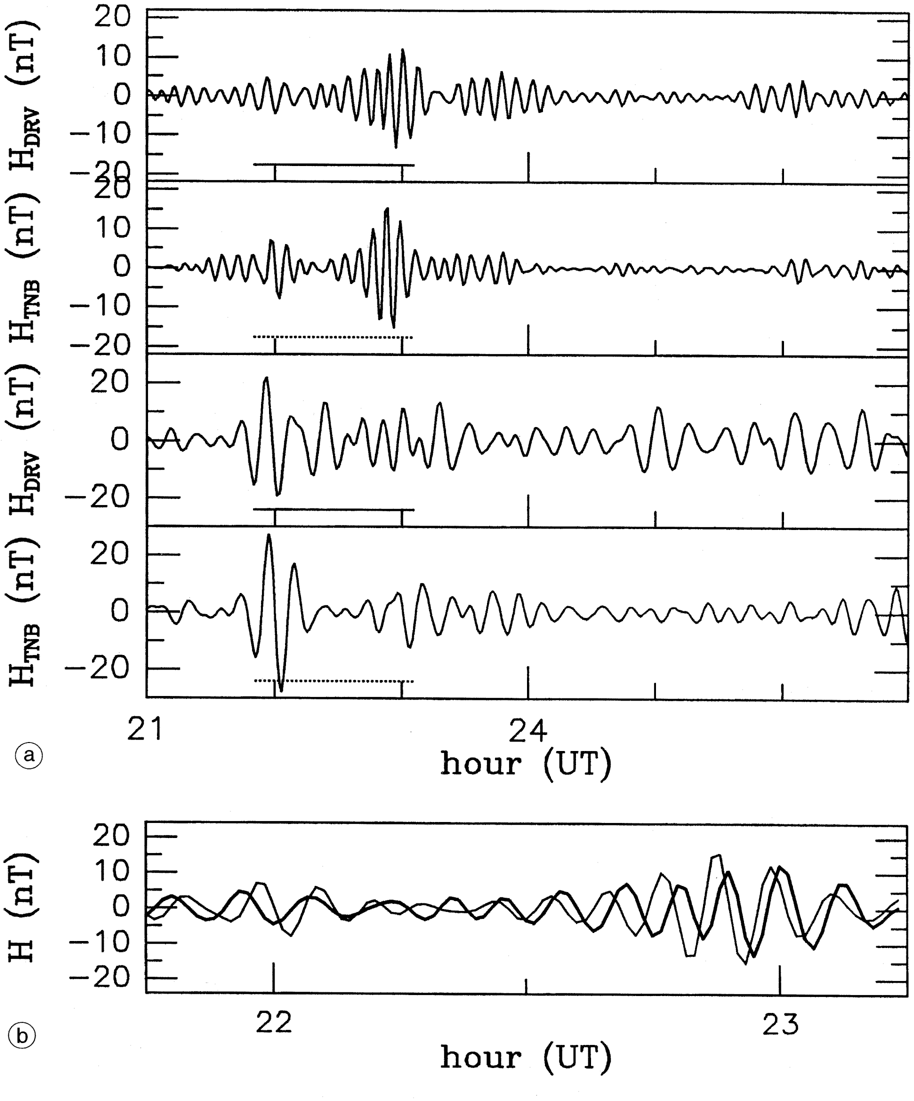

Fig. 4a,b. a) The same as fig. 3 for the SSC on January 9-10, 1992; b) the 2-3 mHz filtered *H* component for the time interval 21:45-23:15 UT at the two stations (thick line at DRV).

with waves propagating westward and eastward respectively from a source located close to the subsolar point on the magnetopause (Southwood, 1974).

Figure 4a,b examines the pulsations observed in correspondence with an SSC which occurred on January 9 at 21:52 UT, when DRV was located in the morning and TNB in the afternoon sector. The SSC effect at both stations was very similar despite the different local time. The amplitude of the 1-2 mHz field oscillations at TNB, which was located closer to the local noon (≈ 14 MLT), was a little stronger than at DRV (≈ 09 MLT); the sense of polarization at

DRV was counterclockwise while at TNB the waves showed a clockwise rotation. At both stations after the SSC there was an intensification of the 2-3 mHz pulsations which were also characterized by the opposite sense of polarization, consistently with a westward and eastward wave propagation from the source. As shown in greater detail in fig.4b, it can also be noted that at DRV the higher frequency waves first led the TNB packet by about 2 min. Considering the observed polarization pattern, this result seems to indicate that the source of these pulsations was located between the stations, late in the morning, closer to DRV than to TNB. About 40 min later, a new sharply defined 2-3 mHz wave packet at DRV and TNB appeared, also with the opposite sense of polarization but with the TNB signal leading DRV by about 2 min. It suggests that, in this case, the 2-3 mHz pulsations source was also located between the two stations but in the early afternoon, nearer to TNB than to DRV.

3. Summary and discussion

In this paper we analyzed two weeks in austral summer of low frequency geomagnetic pulsation measurements at two ground stations in Antarctica. The stations are located at the same geomagnetic latitude of 80.5°S with a longitudinal separation of about 5 h.

The daytime 0.6-6.0 mHz spectral power at both stations showed a sharp decrease with frequency in the range 1-2 mHz and a broad enhancement between 2-5 mHz, often with remarkable maxima in the 2-3 mHz frequency band; in these frequency ranges, the pulsations were observed at each station mainly near local magnetic noon, as reported by many investigators (Troitskaya and Bolshakova, 1977; Olson, 1986; Kleimenova *et al.*, 1989; Engebretson *et al.*, 1995; Villante *et al.*, 1997; Ballatore *et al.*, 1998). The enhancement of the wave activity around noon can be explained considering that, close to the local magnetic noon, the high latitude stations are expected to approach the cusp or, during quiet magnetospheric conditions (low K_p), to be even located on closed field lines.

In some cases the pulsations also appeared at the other station (although with a strong attenuation), more clearly in the morning sector. The correspondence between the wave packets observed at the two stations and their polarization patterns are consistent with a solar wind related origin and a tailward propagation of the waves. In particular, the observed polarization pattern with the near noon reversal for both the 1-2 mHz and 2-3 mHz pulsations is in agreement with the high latitude polarization pattern of low frequency waves found by Samson (1972) and interpreted by Southwood (1974) on the basis of the field line resonance theory. As regards the origin of the observed wave activity, compressional waves excited by solar wind pressure pulses or transient dayside reconnections can be involved. Such waves as well as waves generated on the surface of the magnetopause by the Kelvin-Helmholtz instability may couple with resonances of shear Alfven modes where the field lines are closed (Matthews *et al.*, 1996).

Previous works showed that at auroral latitudes *Pc*5 pulsations have a higher occurrence frequency in the morning than in the afternoon (Samson *et al.*, 1971; Olson and Rostoker, 1978; Lam, 1980; Pilipenko *et al.*, 1997). At higher latitude our results seem to indicate that in the afternoon there is less evidence of simultaneous occurrence of the waves detected around local noon. Some authors (Rostoker and Sullivan, 1987) have tentatively interpreted the auroral local time dependence in terms of a stronger damping of the Kelvin-Helmholtz instability on the dusk side of the magnetosphere. They also suggested that afternoon events might originate mainly from solar wind pressure pulses associated with corotating regions. This interpretation can be considered consistent with our observation of SSC related pulsations both in the morning and afternoon sectors.

Acknowledgements

This work was partially supported by INTAS project (grant 93-412) and by the Russian Fundamental Research Foundation under grant 98-05-64776. The research activity at TNB is supported by PNRA (National Italian Antarctic Research Program).

REFERENCES

BALLATORE, P., M. ENGEBRETSON, C. MCLENNAN and M. CANDIDI (1998): Ground based observations of *Pc*3-*Pc*5 geomagnetic pulsation power at Antarctic McMurdo station, *Ann. Geofis.*, **41** (2), 141-149.

BOLSHAKOVA, O.V. and V.A. TROITSKAYA (1982): Impulse reconnection as a possible source of ipcl pulsations, *Geomagn. Aeron.*, **22**, 877-879.

CLAUER, C.R., A.J. RIDLEY, R.J. SITAR, H.J. SINGER, A.S. ROGER, E. FRIIS-CHRISTENSEN and V.O. PAPITASHVILI (1997): Field line resonant pulsations associated with a strong dayside ionospheric shear convection flow reversal, *J. Geophys. Res.*, **102**, 4585-4596.

DUNLOP, I.S., F.W. MENK, H.J. HANSEN, B.J. FRASER and R.J. MORRIS (1994): A multistation study of long period geomagnetic pulsations at cusp and boundary layer latitudes, *J. Atmos. Terr. Phys.*, **56**, 667-679.

ENGEBRETSON, M.J., W.J. HUGHES, J.L. ALFORD, E. ZESTA, L.J. CAHILL, R.L. ARNOLDY and G.D. REEVERES (1995): Magnetometer array for cusp and cleft studies observations of the spatial exent of broadband ULF magnetic pulsations at cusp/cleft latitudes, *J. Geophys. Res.*, **100**, 19371-19386.

HARROLD, B.G. and J.C. SAMSON (1992): Standing ULF modes of the magnetosphere: a theory, *Geophys. Res. Lett.*, **19**, 1811-1814.

KLEIMENOVA, N.G., O.V. BOLSHAKOVA, V.A. TROITSKAYA and E. FRIIS-CHRISTENSEN (1985): Two types of long period geomagnetic pulsations near equator border of dayside polar cusp, *Geomagn. Aeron.*, **25**, 163-164.

KLEIMENOVA, N.G., O.V. KOZYREVA, J. BITTERLY and J. FOLK (1989): Spectrum of long period geomagnetic pulsations (np) at dayside polar cusp region, *Geomagn. Aeron.*, **29**, 846-848.

LAM, H.L. (1980): Longitudinal characteristic of *Pc*5 magnetic pulsations, *Planet. Space Sci.*, **28**, 1035-1050.

MATTHEWS, D.L., J.M. RUOHONIEMI, J.R. DUDENEY, C.F. FARRUGIA, L.J. LANZEROTTI and E. FRIIS-CHRISTENSEN (1996): Conjugate cusp-region ULF pulsations responses to the solar wind event of May 23, 1989, *J. Geophys. Res.*, **101**, 7829-7841.

MCHANG, M.G., J.V. OLSON and P.T. NEWELL (1995): ULF cusp pulsations: diurnal variations and interplanetary magnetic field correlations with ground-based observations, *J. Geophys. Res*, **100**, 19729-19742.

OLSON, J.V. (1986): ULF signature of the polar cusp, *J. Geophys. Res.*, **91**, 10055-10062.

OLSON, J.V. and G. ROSTOKER (1978): Longitudinal phase variations of *Pc*4-5 micropulsations, *J. Geophys. Res.*, **83**, 2481-2488.

OTNES, R.K. and L. ENOCHSON (1978): *Applied Time Series Analysis. V.1 Basic Techniques* (Wiley-Interscience, New York).

PILIPENKO, V.A., N.G. KLEIMENOVA, O.V. KOZYREVA, K. YUMOTO and J. BITTERLY (1997): Longitudinal characteristics of geomagnetic pulsations *Pc5* in morning and evening sectors, *Geomagn. Aeron.*, **37**, 64-68.

ROSTOKER, G. and B.T. SULLIVAN (1987): Polarization characteristics of *Pc*5 magnetic pulsations in the dusk hemisphere, *Planet. Space Sci.*, **35**, 429-438.

SAMSON, J.C. (1972): Three-dimensional polarization characteristics of high-latitude *Pc*5 geomagnetic micropulsations, *J. Geophys. Res.*, **77**, 6145-6160.

SAMSON, J.C., J.A. JACOBS and G. ROSTOKER (1971): Latitude-dependent characteristics of long-period geomagnetic micropulsations, *J. Geophys. Res.*, **76**, 3675-3683.

SAMSON, J.C., B.G. HARROLD, J.M. RUOHONIEMI, R.A. GREENWALD and A.D.M. WALKER (1992): Field line resonances associated with MHD waveguides in the magnetosphere, *Geophys. Res. Lett.*, **19**, 441-444.

SOUTHWOOD, D.J. (1974): Some features of field line resonances in the magnetosphere, *Planet. Space Sci.*, **22**, 483-491.

TROITSKAYA, V.A. (1985): ULF wave investigations in the dayside cusp, *Adv. Space Res.*, **5**, 219-229.

TROITSKAYA, V.A. and O.V. BOLSHAKOVA (1977): Diurnal latitude variation of the location of the dayside cusp, *Planet. Space Sci.*, **25**., 1167-1169.

TROITSKAYA, V.A., O.V. BOLSHAKOVA and E.T. MATVEEVA (1980): Geomagnetic pulsations in the polar cap, *J. Geomagn. Geoelectr.*, **32**, 309-313.

VILLANTE, U., S. LEPIDI, P. FRANCIA, A. MELONI and P. PALANGIO (1997): Long period magnetic field fluctuations at Terra Nova Bay (Antarctica), *Geophys. Res. Lett.*, **24**, 1443-1446.

WALKER, A.D.M., J.M. RUOHONIEMI, K.B. BAKER, R.A. GREENWALD and J.C. SAMSON (1992): Spatial and temporal behavior of ULF pulsations observed by Goose Bay HF radar, *J. Geophys. Res.*, **97**, 12187-12202.

ZIESOLLECK, C.W.S. and D.R. MCDIARMID (1994): Auroral latitude *Pc*5 field line resonances: quantized frequencies, spatial characteristics and diurnal variations, *J. Geophys. Res.*, **99**, 5817-5830.

(received January 11, 1999;
accepted July 10, 1999)