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ULF Geomagnetic Pulsations at High Latitudes: the Italian Contribution

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A b s t r a c t

The study of geomagnetic field variations in Antarctica is important in that local field lines are close to extreme magnetospheric regions, such as the polar cusp, where several generation mechanisms for ULF waves are active.

Since the eighties, the Italian scientific community developed a research activity in Antarctica at Mario Zucchelli Station (TNB, CGM latitude 80°S), where magnetic facilities are continuously operating. In this review we present the experimental results obtained by a number of investigations conducted in the last years on geomagnetic pulsations in the Pc3-Pc5 frequency range. We also show compared analyses with measurements from other Antarctic and low latitude stations, and, in particular, a statistical analysis of propagation characteristics of low frequency geomagnetic field fluctuations between the two Antarctic stations, TNB and Scott Base.

1. Introduction

Geomagnetic field measurements at very high latitudes are important for the understanding of several dynamical processes which control the energy transfer from the solar wind (SW) to the Earth's magnetosphere. Indeed, local field lines reach magnetospheric regions close to the extreme magnetosphere boundary, the magnetopause,

and to the polar cusp, which separates sunward, closed magnetospheric field lines from tailward, open field lines.

The Antarctic Italian geomagnetic observatory Mario Zucchelli Station (formerly Terra Nova Bay, international geomagnetic observatory code TNB, geomagnetic latitude 80°S, magnetic local time MLT = UT-8 hours) was installed in the austral summer 1986-87. Due to the Earth's rotation, through the day TNB has a variable distance from the cusp. Around magnetic midnight and during the major part of the day, it is in the polar cap at the footpoint of open field lines, while at noon it approaches the cusp. Taking into account that the cusp latitude depends on interplanetary parameters (Zhou *et al*. 2000), in particular, conditions TNB can be located at the footprints of closed field lines.

The ULF geomagnetic pulsations are magnetic field fluctuations with periods ranging from seconds to minutes, which obtain their energy from the SW. We show the results obtained in the last few years in the mid (Pc3-Pc4, f = 7-100 mHz) and low frequency range (Pc5, f = 2-7 mHz).

Generation mechanisms of Pc3-5 pulsations can be basically related to: (a) Kelvin-Helmholtz instability along the flanks of the magnetopause (Atkinson and Watanabe 1966), (b) upstream waves generated by SW ions in the foreshock region through a ion-cyclotron instability mechanism (Greenstadt *et al*. 1981) (schematically shown in Fig. 1) and (c) local phenomena in the cusp region (Engebretson *et al*. 1986).

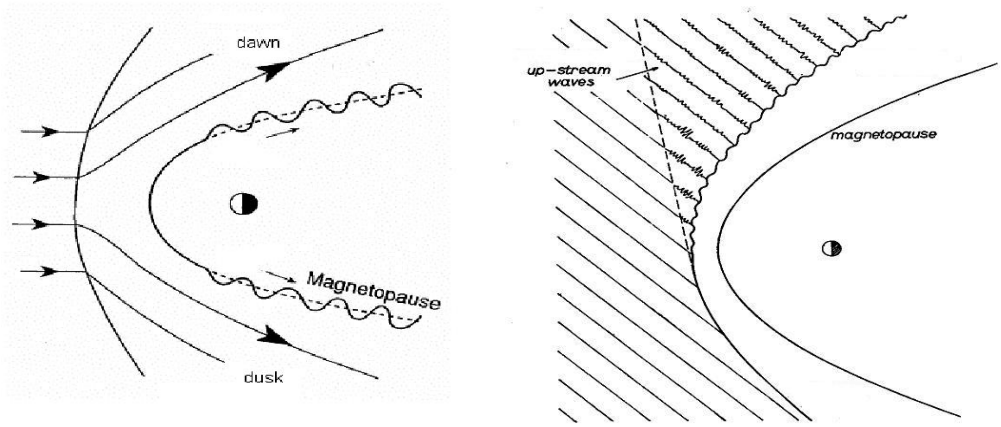

Fig. 1. Schematic view, in the equatorial plane, of the Kelvin-Helmholtz instability (left side) generated on the magnetopause by the SW flux, indicated by arrows, and of upstream waves (right side) generated along the interplanetary magnetic field lines, indicated by the 45° inclined lines.

Interplanetary shocks impacting on the magnetopause can be an additional source of low frequency pulsations in that they may generate magnetospheric cavity/waveguide modes (Kivelson and Southwood 1985) between an outer boundary, such as the magnetopause, and an inner turning point (Fig. 2). Such modes at discrete frequencies have a global character in the magnetosphere and have been observed at

auroral (Walker *et al.* 1992), low latitudes (Francia and Villante 1997) and even in the polar cap (Villante *et al*. 1997).

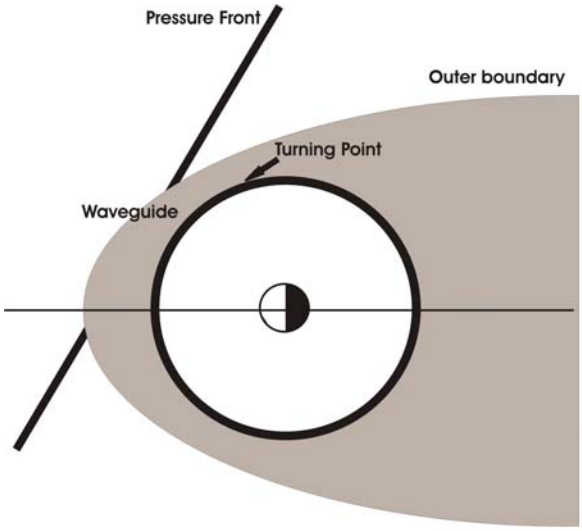

Fig. 2. Schematic view in the equatorial plane of the impact of a shock front on the magnetopause.

2. Experimental Results

In Fig. 3 we show the MLT dependence of Pc3 and Pc4 pulsation power. It is evident that power maximizes at noon, when TNB approaches the cusp; this result suggests that a main source related to local phenomena can be active.

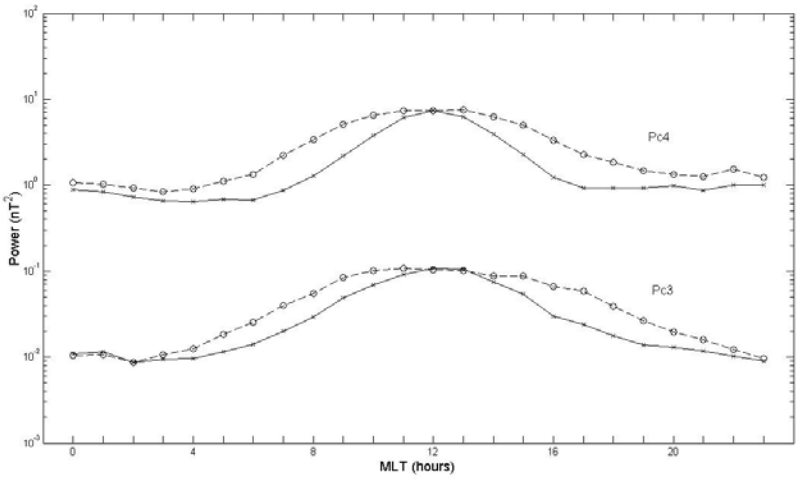

Fig. 3. The diurnal variation of Pc3 and Pc4 pulsation power for the north-south H (solid line) and east-west D (dashed line) horizontal components (from Villante *et al*. 2000).

We also show in Fig. 4 the MLT dependence of the correlation coefficient *r* between the pulsation power and the SW speed. It can be seen that for Pc3 pulsations *r* is higher in the morning indicating an upstream wave source while for Pc4 pulsations *r* higher in morning and afternoon as expected for pulsations generated by the Kelvin-Helmholtz instability.

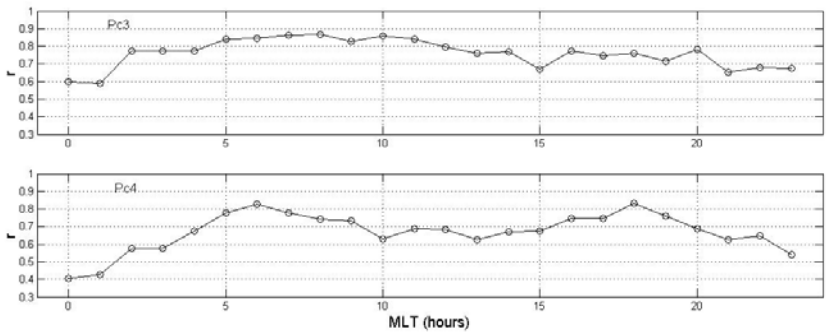

Fig. 4. Daily variation of the correlation coefficient r between Pc3 and Pc4 power and SW speed (from Villante *et al*. 2000).

The analysis of selected Pc3 wave packets observed during a period of variable interplanetary magnetic field (IMF) conditions has shown a linear relation between the pulsation frequency and the IMF strenght clearly indicating an upstream waves source (Fig. 5).

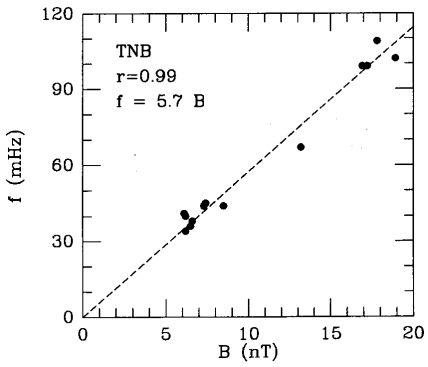

Fig. 5. Dependence of the frequency of Pc3 waves on the IMF strenght B (from Villante *et al.* 1999).

The arrival of interplanetary structures characterized by SW pressure pulses can trigger quasi monochromatic pulsations in the Pc5 frequency range. In Fig. 6 it is shown the pulsation event during the Earth's passage of the April 11, 1997 magnetic cloud. In order to ascertain the global character of the observed pulsations, the analysis was extended also to a low latitude station (AQ, corrected geomagnetic latitude 36.2°N) and to geosynchronous spacecraft (GOES 8 and 9). It can be seen that the

power spectra are characterized by common peaks, in particular at 3.6 mHz, and the filtered data by simultaneous wave packets, suggesting a common SW source.

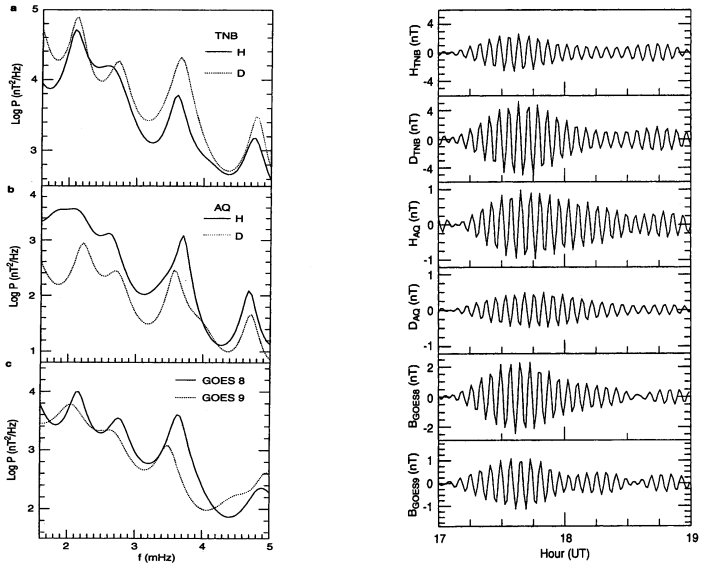

Fig. 6. Left panels: power spectra of the H and D components at TNB and AQ and of the total field from GOES spacecraft in the time interval 17-19 UT on April 11, 1997. Right panels: 3.6 mHz filtered data (from Lepidi *et al*. 1999).

In order to investigate the propagation characteristics of Pc5 pulsations we statistically analyzed the phase difference between coherent pulsations at TNB and Scott Base (SBA) during 2001-2002. The two Antarctic stations are at the same geomagnetic latitude but with one hour difference in MLT. Then, the phase difference indicates an azimuthal propagation: it is positive (negative) for SBA (TNB) leading, i.e. for signals propagating westward (eastward). We can see in Fig. 7 a phase difference

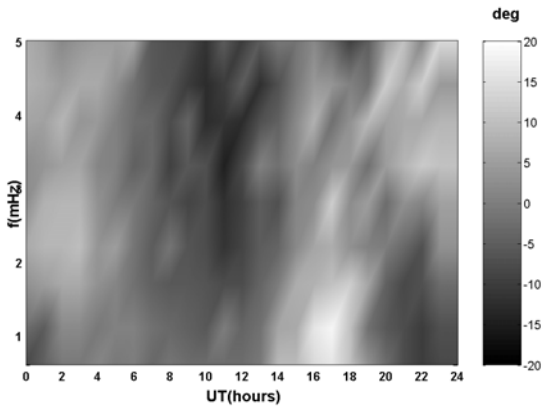

Fig. 7. Phase difference between coherent pulsations at TNB and SBA during 2001-2002.

reversal at ~19 UT for f < ~2.5 mHz, indicating a longitudinal propagation away from noon, and a second reversal at ~7 UT for f > ~2 mHz, indicating a longitudinal propagation away from midnight.

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