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Polarization pattern of low and mid-frequency magnetic pulsations in the polar cap: A comprehensive analysis at Terra Nova Bay (Antarctica)

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Abstract

The polarization pattern of ULF pulsations ($f \approx 1$–100 mHz) at Terra Nova Bay (Antarctica, CGM $\lambda \sim 80°$) has been determined for the entire 2003, soon after the solar maximum. A comparison with the results of previous investigations, conducted at the same station close to the solar minimum (1994–96), allows to focus common elements and major differences among different frequency bands which persist through the entire solar cycle. Basically, between $f \sim 1.5$ and 5 mHz, the day can be divided into four sectors with alternate polarizations. The local time and latitudinal dependence of the observed pattern can be tentatively interpreted in terms of a latitude of resonant field lines reaching $\lambda \sim 80°$ in the noon sector; on the other hand, resonance effects of lower latitude field lines can be clearly identified also far from the noon meridian when the station moves into the deep polar cap. Moreover, in the morning sector the resonance region would extend to lower latitudes than in the evening sector. The proposed profile of the resonant region can interpret also the results obtained at other cusp/auroral stations and appears consistent with that one inferred in the northern hemisphere at smaller latitudes. The resonance region progressively shifts toward lower latitude with increasing frequency; correspondingly, the four-sector pattern progressively disappears at TNB. Above $f \sim 20$ mHz, the experimental observations might suggest an additional contribution from Sunward propagating waves, possibly via the magnetotail lobes.

Keywords: ULF waves; Antarctica; Polarization pattern

1. Introduction

As it is well known, important information on the generation and propagation mechanisms of ULF waves in the magnetosphere can be obtained from their polarization characteristics. For example, waves generated by the Kelvin–Helmholtz instability (KHI) at the magnetopause are expected to propagate antisunward through the magnetosphere, i.e. westward in the local morning and eastward in the afternoon. As a consequence, at northern ground stations, counterclockwise (CCW, looking downward on the Earth) and clockwise (CW) polarizations should be expected in the morning and afternoon sector, respectively. The opposite situation is expected in the southern hemisphere, with CW and CCW polarizations in the morning and afternoon, respectively. On the other hand, according to theoretical models, the polarization pattern can be modified by the resonant coupling between compressional waves and Alfven modes (Southwood, 1974; Chen and Hasegawa, 1974). In particular, for a given frequency, theory predicts a polarization reversal at the latitude (Λ_r) of the resonant field line and an additional reversal at the latitude (Λ_{min}) corresponding to the wave amplitude minimum between the magnetopause and the resonant field line (the region extending between Λ_r and Λ_{min} is referred as "resonance region").

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At low frequencies ($f \sim$ 1–10 mHz), early observations of the Pc5 characteristics ($f \sim$ 1.7–6.7 mHz) highlighted the MLT (MLT being the Magnetic Local Time) and latitudinal dependence of the wave polarization at auroral/cusp latitudes. In the northern hemisphere, above $\lambda \sim 60°$, Pc5 events showed the expected CCW polarization before ~11 MLT, while 8–10 h of CW polarizations were observed in the afternoon and evening sector (Kato and Utsumi, 1964; Campbell, 1967). Samson et al. (1971) found at $\lambda \sim$ 59–78° ($f \sim$ 5 mHz) a polarization reversal at ~13 MLT; for lower frequency events ($f <$ 4 mHz, Samson, 1972), the reversal between opposite polarizations occurred earlier, namely at ~11:30–12:30 MLT; some evidence for an additional reversal was proposed at ~18:30–19:30 MLT. Polarization reversals in latitudinal sense were reported by Rankin and Kurtz (1970) in a wide frequency band. Samson et al. (1971) and Samson (1972) found at $\lambda \sim 78°$ ($f <$ 5 mHz) a reversed sign of polarization as compared with lower latitude observations. Samson and Rostoker (1971) identified a clear tendency for the latitude of reversal to decrease with increasing frequency ($\lambda \sim$ 78°–59°; $f \sim$ 1–22 mHz). More recently, Baker et al. (2003) conducted a comprehensive analysis of Pc5 pulsations at auroral latitudes and confirmed polarization reversals both in latitude and across noon.

In the mid-frequency range ($f \sim$ 10–100 mHz) the polarization reversal at local noon (or few hours before) was reported at low and mid-latitudes in a number of investigations (for example, Lanzerotti et al., 1981; Saka and Kim, 1985). Ziesolleck et al. (1997) compared Pc3-4 pulsations ($f \sim$ 6.7–100 mHz) detected by GOES 7 with simultaneous observations at ground stations ($\lambda \sim$ 61°–73°): in correspondence with transverse waves at geosynchronous orbit, ground observations revealed a prevailing CCW (CW) in the pre-noon (post-noon) sector. Vellante et al. (2002) conducted a long term analysis of the polarization pattern during 15 years ($\lambda \sim 36°$; $f \sim$ 40–100 mHz) and considered the experimental observations consistent with a wave source located 1–2 h before noon and an additional source located around midnight. More particularly, the earlier occurrence of the pre-noon reversal at higher frequencies was interpreted in terms of a more significant contribution of upstream waves generated on the morning side of the magnetosphere. The additional midnight reversal was imputed to substorm related waves propagating Sunward. As for lower frequencies, polarization reversals in latitude were observed also for Pc3 and Pc4 events (for example, at $\lambda \sim$ 42°–44°, for $f \sim$ 25–40 mHz; Ziesolleck et al., 1993).

The basic elements of the polarization pattern of polar cap pulsations at Terra Nova Bay in Antarctica (TNB; CGM $\lambda = 80°$S; MLT = UT-08:11) in different frequency ranges and for different time intervals close to the minimum of the solar cycle (1994–96) have been discussed in previous investigations, mostly in terms of general comparisons with the results obtained at other sites (Lepidi et al., 1999; Villante et al., 2000; Francia et al., 2005). In the present paper we conduct a long term investigation on the entire 2003, soon after the solar maximum, and present a joint analysis of older and new observations, focusing attention on the progressive appearance of interesting elements with the increasing frequency. For this scope, before presenting the results of the new analysis, we found interesting to discuss, for each frequency range, some interesting aspects of the polarization pattern which emerge from a visual inspection of the results of previous investigations and gain importance as common elements which persist for the entire solar cycle. Such careful analysis of common elements and significant differences among different frequency ranges allows a better identification and understanding of the polarization pattern at low and mid-frequencies in the polar cap and suggests a global profile of the resonance region able to interpret also the results obtained at other cusp/auroral stations. The experimental measurements presented by Lepidi et al. (1999) and Francia et al. (2005) were obtained by a triaxial fluxgate magnetometer (1 min measurements); those of the present analysis and by Villante et al. (2000) have been obtained by a search-coil instrument (1 s measurements). As for previous investigations, the data processing was performed through cross-spectral analyses between the H and D components using the technique for partially polarized waves as proposed by Fowler et al. (1967). In particular, the polarization ratio R (i.e., the ratio between the polarized and total intensity of the horizontal signal) and the ellipticity eps (i.e., the ratio between the minor and the major axis of the polarization ellipse in the horizontal plane) were evaluated over each hour and then averaged over the 3-h intervals. In order to consider only intervals characterized by a negligible noise and by a well identified polarization sense, this analysis was restricted to intervals with $R > 0.7$ and $|eps| > 0.2$.

2. The polarization pattern

2.1. The low frequency band ($f \sim$ 1–8 mHz)

As shown in Fig. 1a ($f \sim$ 0.8–3.6 mHz; 1995; Lepidi et al., 1999), CW polarizations are clearly dominant between ~0 and 5 MLT; they become CCW between ~6 and 10 MLT, and newly CW between ~11 and 17 MLT. A less definite situation emerges between ~18 and 23 MLT, where a prevailing CW polarization still persists, although with percentages much smaller than in adjacent sectors. Peak percentage values greater than 75% are observed in both polarization senses around noon. At higher frequencies (Fig. 1b, $f \sim$ 4–8 mHz; austral summer 1994–95; Villante et al., 2000), CW polarizations are dominant between ~0 and 6 MLT, CCW polarizations dominate between ~7 and 11 MLT; they become newly CW between ~12 and 17 MLT; unlike lower frequencies, slightly prevailing CCW polarizations emerge between ~18 and 21 MLT.

Fig. 1c shows the frequency distribution of the percentage of CW events ($f \sim$ 0.8–7 mHz; Jan.–Oct., 1996; Francia et al., 2005). As can be seen, at lower frequencies the results