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POLARIZATION OF SMALL-SCALE MAGNETIC PERTURBATIONS IN THE TOPSIDE AURORAL IONOSPHERE IN THE EVENTS OF BROADBAND ELF TURBULENCE

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Abstract. Magnetic perturbations in the topside auroral ionosphere registered by the FAST satellite at frequencies 0.5-8 Hz (scales from 14 km down to 0.9 km) in the events of broadband ELF turbulence are investigated. It is demonstrated that their polarization features, along with large amplitudes and power-law scaling, is strongly inconsistent with the approximation of plane linear waves often used for their description.

Introduction

With a few exceptions it is widely believed that electric and magnetic perturbations registered in the topside ionosphere and lower magnetosphere during the events of the BB ELF turbulence are intrinsically related to shear Alfvén waves or their dispersive modifications. To explain the observed characteristics of the perturbations, such as phase and group velocities, the ratios of field components, electromagnetic or electrostatic perturbation type, the predictions of linear analysis are often used, where the perturbations are considered as small-amplitude plane waves of the form $\sim\exp(ik_z z - i\omega t)$ for shear Alfvén waves propagating along $\boldsymbol{B_0}$ or $\sim\exp(i(\boldsymbol{k}_\perp \boldsymbol{r}_\perp + k_z z) - i\omega t)$ for dispersive Alfvén waves, which propagate obliquely to $\boldsymbol{B_0}$.

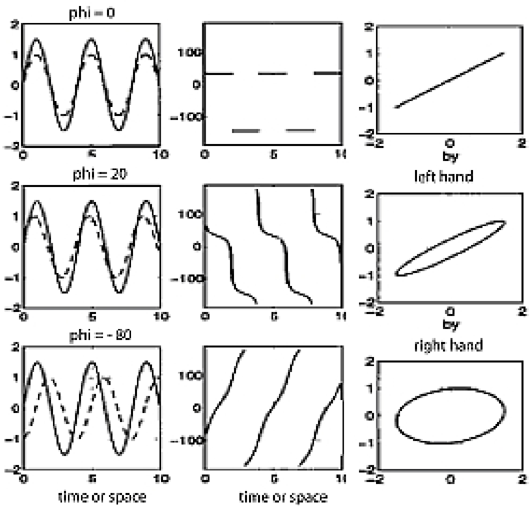

Figure 1. Transverse to $\boldsymbol{B_0}$ magnetic perturbations b_y (solid) and b_x (dashed) (b_z is assumed zero in the incompressible case) in the form of sine waves with different amplitudes and phase shifts, x pointing northward, and y eastward (left column); the phase angle of the transverse magnetic perturbation computed as atan2(b_x/b_y) (middle column); hodograms of the perturbations on the left (right column); [*Stasiewicz and Potemra*, 1998].

On the other hand, polarization patterns expected for propagating or standing plane linear Alfvén waves have never been demonstrated for the fields observed in the BB ELF turbulence events. Instead, highly disordered patterns with changeable sense of polarization and unsteady phase relations, as those shown in Figure 2 from [*Stasiewicz et al.*, 1998], were presented. This is not surprising, since large amplitudes and power-law scaling of the perturbations under study suggest non-linear processes involved.

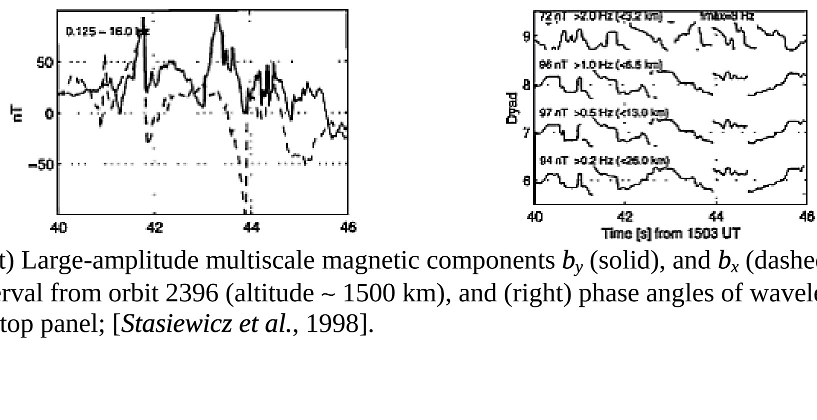

Figure 2. (left) Large-amplitude multiscale magnetic components b_y (solid), and b_x (dashed) observed by FREYA in a 6 s time interval from orbit 2396 (altitude ~ 1500 km), and (right) phase angles of wavelet decomposed magnetic signals in the top panel; [*Stasiewicz et al.*, 1998].

Results

The FAST magnetic experiment incorporated a tri-axial fluxgate magnetometer for dc and low-frequency magnetic field measurements, and a searchcoil system for measurements of ELF-VLF wave fields. For the purposes of the present study only fluxgate magnetometer observations are suitable, since the search coils have low sensitivity at frequencies below ~ 100 Hz [*Elphic et al.*, 2001]. The frequency range here considered is restricted by ~ 0.5 Hz from below to avoid contamination from residual spin harmonics, and by ~ 8 Hz from above, which is dictated by low-pass filtering of fluxgate magnetometer data on FAST.

Figures 3 shows three events of the BB ELF turbulence with typical duration of 50-100 s observed by FAST in traversals above the early morning auroral zone (Figure 3a), the afternoon auroral zone (Figure 3b), and the dayside cusp (Figure 3c) in the Northern Hemisphere. The despun along-track (b_N) and across-track (b_E) magnetic components, pointing, respectively, nearly northward and nearly eastward, are measured by the fluxgate magnetometer with a sample rate of 128 s^{-1} [***Ergun et al.***, 2001]. It can be seen from the figures that the magnetic perturbations are polarized in the plane normal to the background magnetic field (the parallel magnetic component b_Z is small in all cases). Therefore, further we will focus on the b_N and b_E magnetic perturbations, which are relatively large in all three events (from tens of nT to a hundred of nT). Also shown is the along-track electric field component E_N measured by the double probes on FAST with 512 s^{-1} sample rate. It is seen that intense electric perturbations tend to develop in the regions of magnetic field gradients.

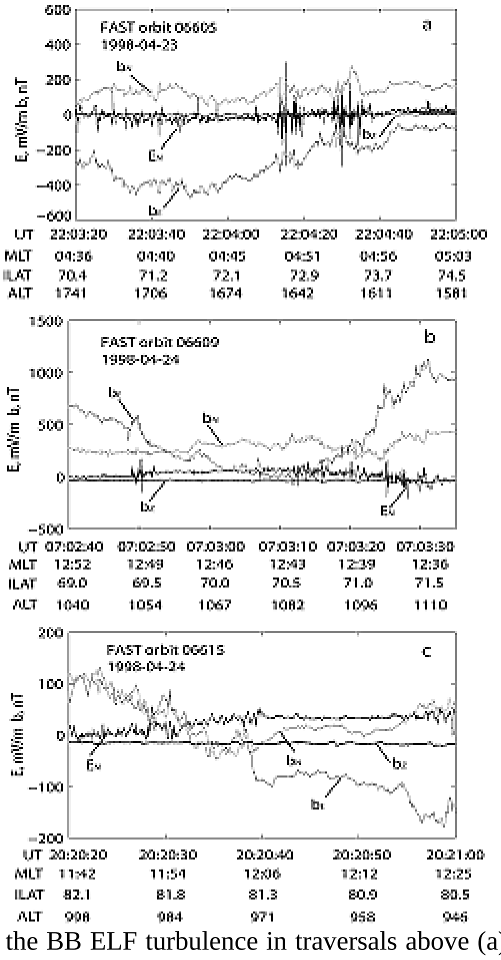

Figure 3. FAST observations of the BB ELF turbulence in traversals above (a) the early morning auroral zone; (b) the afternoon auroral zone, and (c) the dayside cusp; [*Golovchanskaya et al.*, 2011].

To gain insight of polarization of magnetic perturbations under study, the hodograms of perpendicular magnetic fields $b_\perp = (b_N, b_E)$ have been constructed. Figure 4 displays those for $b_\perp = (b_N, b_E)$ observed in the event of BB ELF turbulence displayed in Figure 3b and filtered in different passbands. One can see that the polarization patterns are highly disordered, with changeable sense of polarization and unsteady phase relations. They have little in common with a repetitive, regular pattern expected for perturbations in the form of a plane linear wave [see ***Stasiewicz et al.***, 1998 for discussion].

Mathematically, the lack of coherence between two orthogonal components b_x and b_y of vector $\boldsymbol{b}_\wedge$ can be verified by a transition to analytical signals $b_{x,r}$ + i $b_{x,i}$ and $b_{y,r}$ + i $b_{y,i}$ via Hilbert transform and calculations of correlation coefficients $r_l = r(b_{x,r}, b_{y,r})$ (testing for linear polarization) and $r_c = r(b_{x,r}, b_{y,i})$ (testing for circular polarization).

Table 1 contains coefficients r_l and r_c calculated with applying the Spearman rank correlation procedure to the magnetic components b_N and b_E observed in the event of BB ELF turbulence displayed in Figure 3b at UT = 07:03:10-07:03:14 that were filtered in three pass bands. We note that Spearman rank correlation coefficient r is a conventional measure of correlation between two arbitrarily distributed samples. With correlation coefficients r_l and r_c known, we tested the null hypothesis that the considered magnetic components are not correlated (H = 0) against an alternative that they are correlated (H = 1). The significance level p was taken 0.01, which corresponds to one false decision against 99 true decisions. It is seen from Table 1 that a suggestion of circularly polarized signal must be rejected (H_c = 0 in all cases). As for the linear polarization, while in two of three cases H_l = 1, indicating statistically significant value of coefficient r_l, the coefficient itself is low. Therefore, we conclude that only a minor part of the signal is linearly polarized.

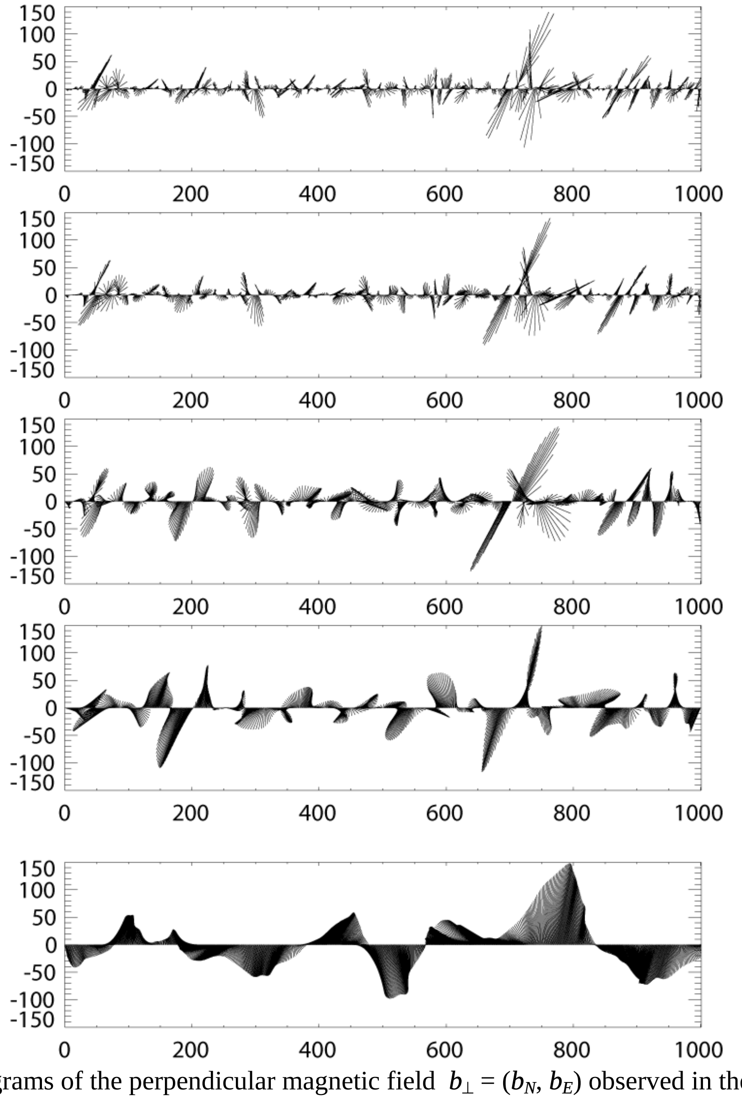

Figure 4. Hodograms of the perpendicular magnetic field $b_\perp = (b_N, b_E)$ observed in the event of BB ELF turbulence shown in Figure 3b and filtered in different passbands. The vector lengths are in relative units.

Table 1. Results of testing the observed magnetic signal $b_{\perp}$ for linear (l) and circular (c) polarization

f, Hz	r_l	H_l	r_c	H_c
4-8	0.28	1	-0.04	0
2-4	0.26	1	0.07	0
1-2	0.09	0	-0.07	0

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