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FIELD-ALIGNED ELECTRON DENSITY IRREGULARITIES NEAR 500 KM - EQUATOR TO POLAR CAP TOPSIDE SOUNDER Z MODE OBSERVATIONS

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ABSTRACT

Striking evidence, in addition to spread F, for field-aligned electron density irregularities is commonly observed on Alouette 2 topside sounder ionograms recorded near perigee (500 km). This evidence is provided by distinctive signal returns from sounder-generated Z mode waves. At low latitudes these waves become guided in wave ducts caused by field-aligned electron density irregularities and give rise to strong long-duration echoes. At high latitudes, extending well into the polar cap, these Z mode waves (and stimulated electrostatic waves at the plasma frequency) produce a series of vertical bars on the ionogram display as the satellite traverses discrete field-aligned density structures.

INTRODUCTION

This work is the outgrowth of an investigation to predict noise levels to be expected at orbital altitudes covered during Space Shuttle missions. In particular, a major question in the Waves in Space Plasmas (WISP) program concerns the RF noise environment to be expected in the 400-500 km altitude region from low to high latitudes. WISP [Fredericks and Taylor, 1981] is one of the prime experiments to be represented on the Space Shuttle/Spacelab flight designated as Space Plasma Lab which is planned for a 1988 launch. WISP will include a highly flexible ionospheric sounder with doppler and bistatic capability (the bistatic operation involves the use of a subsatellite). In order to address the noise environment question, an investigation of perigee (~500 km) Alouette 2 topside sounder data was initiated. All observed noise bands were scaled on nearly 200 topside sounder ionograms recorded near perigee at low (Quito), mid (Ottawa) and high (Resolute Bay) latitude telemetry stations. The minimum and maximum frequencies of each noise band were entered into a data base for computer analysis in a manner similar to the recent investigation of auroral kilometric radiation (AKR) using nighttime auroral zone ISIS 1 ionograms recorded near apogee (3500 km) [Benson, 1983]. In contrast to the results of this AKR investigation, where the signals of primary interest are of natural origin and are very common (see Figures 1 and 2), the signals of primary interest in the perigee study are found to be sounder generated.

OBSERVATIONS

Ionogram examples revealing the presence of field-aligned electron density N_e irregularities in low, mid and high latitudes are presented in Figures 3a, 3b and 3c, respectively.

The series of sounder-stimulated electrostatic electron cyclotron harmonic wave resonances extending up to $14f_H$, where f_H is the electron cyclotron frequency, together with the electrostatic plasma frequency resonance at f_N near $14f_H$ are very prominent in the low latitude example of Figure 3a. The large number of harmonic resonances following a weak fundamental in this ionogram is very typical of low latitude Alouette 2 ionograms [Benson, 1972]. These electrostatic features are more dominant than the electromagnetic ionospheric reflection traces which are confined mainly to the first 200 km of virtual range in the 8-9 MHz frequency range. There is a very prominent feature extending from 200 to 1000 km virtual range in the frequency range between the Z mode cutoff at f_z and the plasma frequency f_N. This feature is attributed to sounder-generated Z mode waves which are ducted along field-aligned N_e irregularities. Such Z mode ducting takes place in plasma troughs in the frequency range just above the cutoff frequency f_z and in plasma enhancements in the frequency range just below the Z wave resonance at f_N for propagation parallel to the ambient magnetic field direction (W. Calvert, private communication, 1984). The lack of ordinary (O) and extraordinary (X) wave ducting which are associated with N_e troughs and are common at higher altitudes [see, e.g., Muldrew, 1969] indicate that the field-aligned irregularities near perigee and near the magnetic equator are more suitable for Z mode ducting in enhancements than X, O or Z

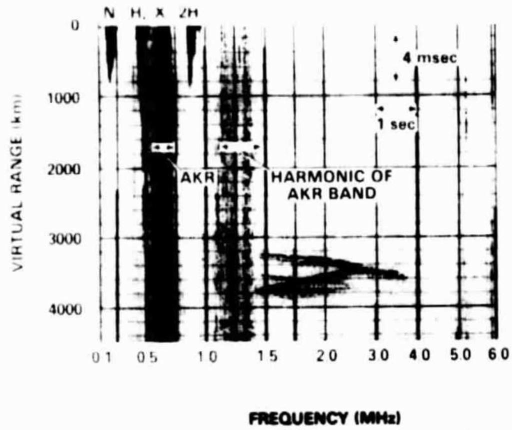

Figure 1. An ISIS 1 ionogram revealing AKR together with sounder-stimulated electrostatic wave plasma resonances (the dark stalactite-like signals tied to the zero time-delay baseline, i.e., zero virtual range, at the top) and electromagnetic wave ionospheric echoes (the nearly horizontal signals between 3000 and 4000 km virtual range and between the 1.5 and 4.0 MHz frequency markers). The symbols on this and later figures have the following meaning: N for the plasma resonance at f_N, H for the electron cyclotron resonance at f_H (and nH, or simply n on later figures, for those at nf_H) and X for the extraordinary mode cutoff f_x (and on later figures, Z for the Z mode cutoff f_z). (After Benson [1982].)

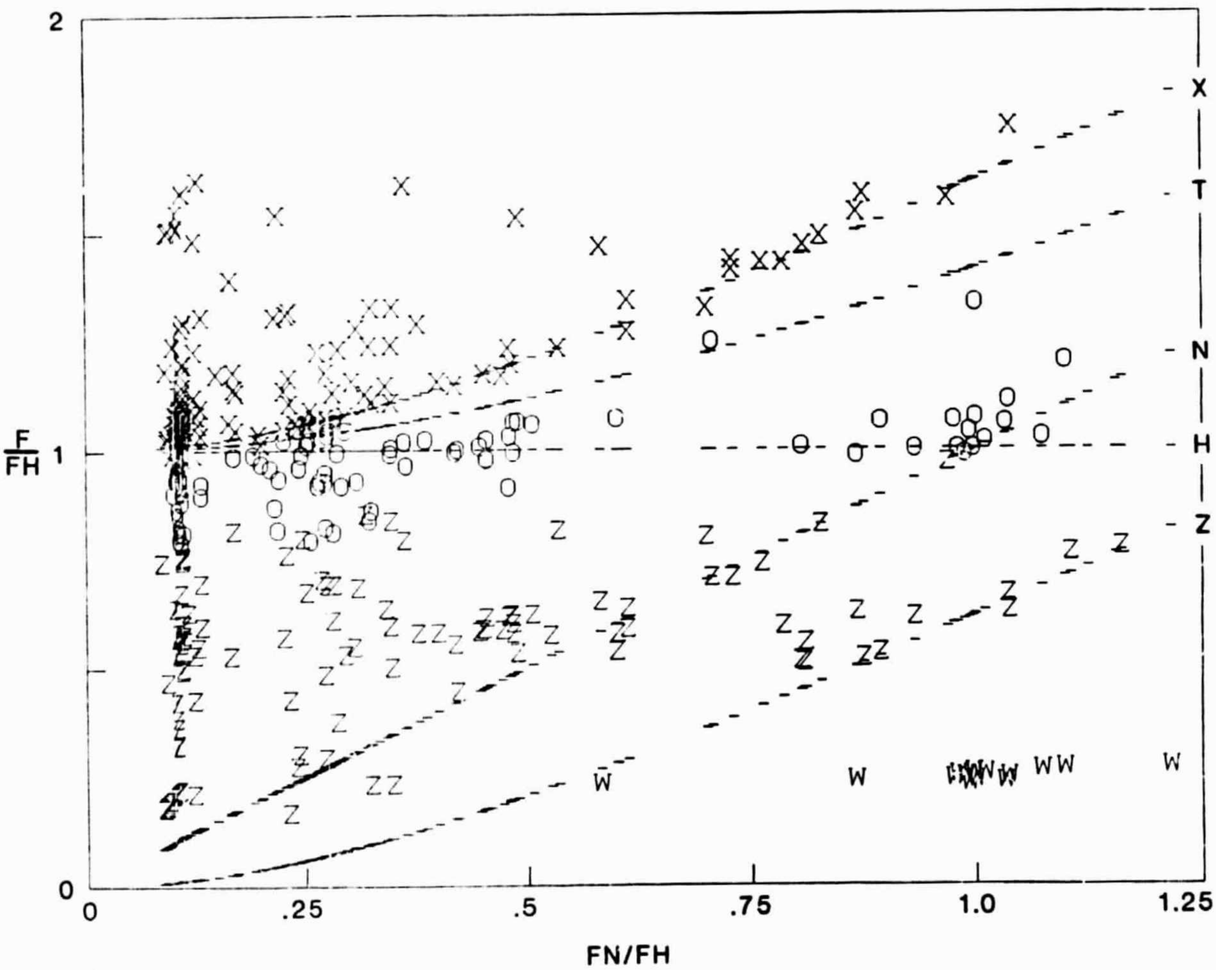

Figure 2. Normalized minimum frequencies of AKR of all intensities identified as extraordinary (X), ordinary (O), Z or whistler (W) mode organized according to the value of f_N/f_H at the point of observation. The horizontal dashes identify scaled or calculated values of f_x, $f_T = (f_N^2 + f_H^2)^{1/2}$, f_N, f_H and f_z for each ionogram and are designated on the right hand side by X, T, N, H and Z, respectively. (Adapted from Benson [1983].)

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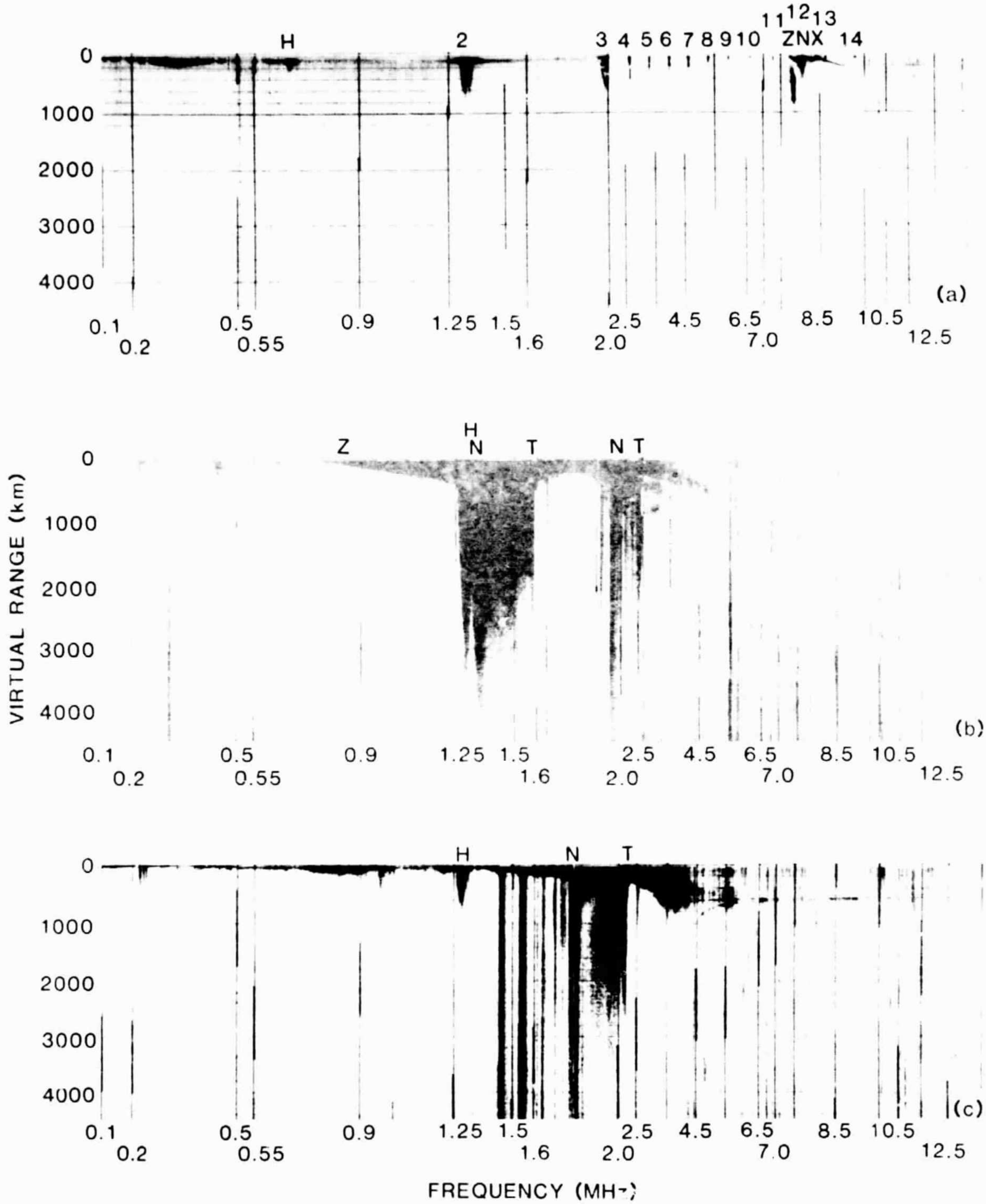

Figure 3. Alouette 2 ionograms recorded near perigee at Quito (a), Ottawa (b) and Resolute Bay (c). See captions for Figures 1 and 2 for symbol definitions. The time and position information for these ionograms are as follows: 20 June 1968 2349 UT, 1842 magnetic local time (MLT), 519 km altitude, 18.8° invariant latitude Λ in (a); 14 November 1967 0307 UT, 2054 MLT, 525 km and 62.1° Λ in (b); 13 October 1966 0435 UT, 1730 MLT, 520 km and 84.3° Λ in (c).

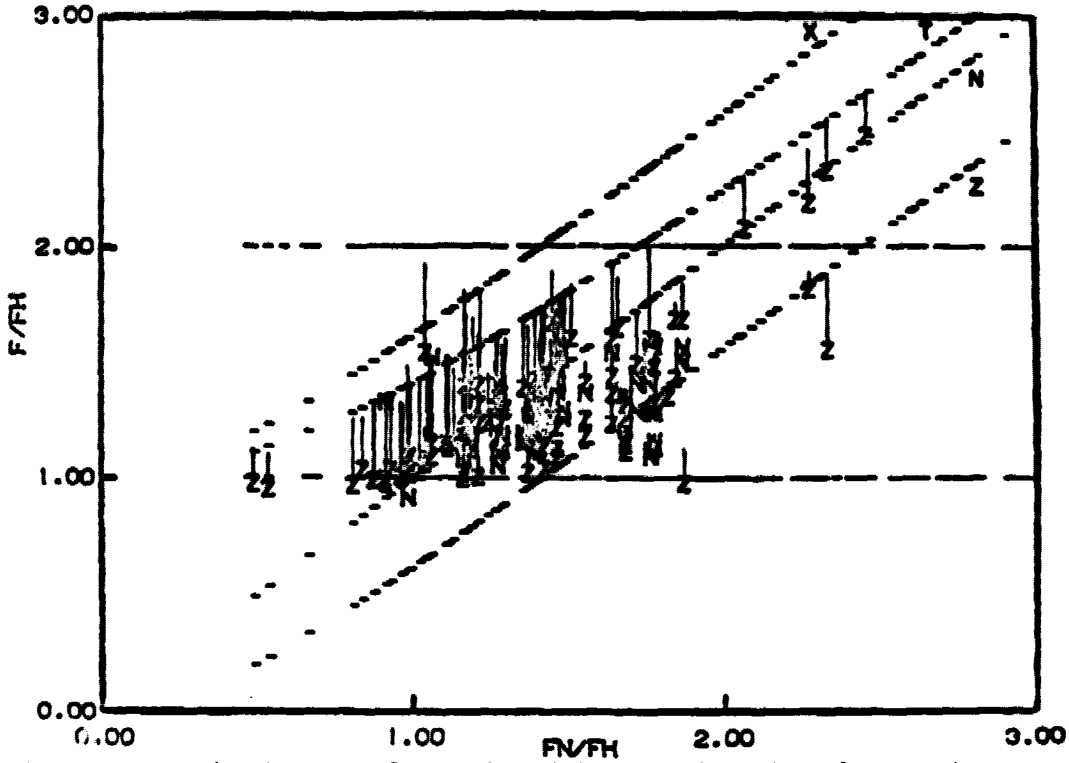

Figure 4. Normalized minimum frequencies of long-duration echoes from sounder-generated Z mode signals (Z) and plasma resonance signals (N). The vertical line above each symbol represents the normalized frequency bandwidth for the corresponding signal. See Figure 2 for a description of the background grid.

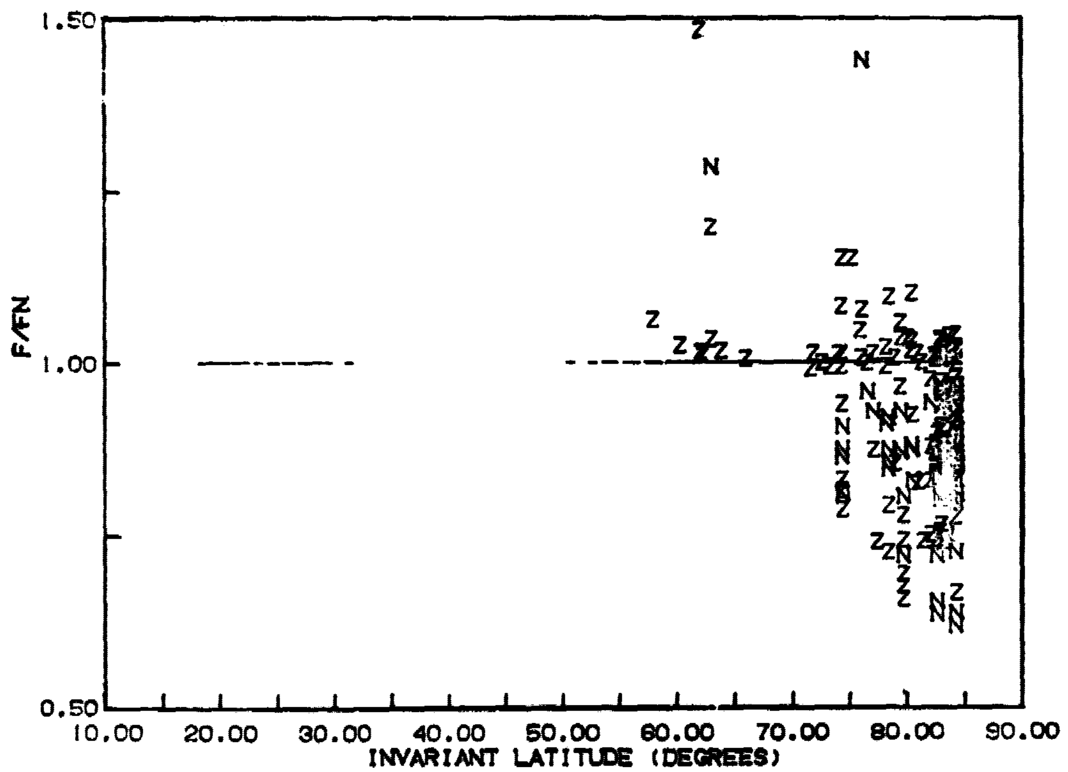

Figure 5. The minimum frequency of the Z and N signals of Figure 4 with $f_N/f_H > 1$ normalized by f_N (rather than f_H) plotted against the invariant latitude of Alouette 2 at the point of observation.

mode ducting in troughs. (It is unlikely that the differences are due to temporal changes in the ~1 sec f_z to f_x sweep time since examples such as the one in Figure 3a are very common in this region.)

The mid-latitude ionogram of Figure 3b is from a series of ionograms where large N_e fluctuations were observed from ionogram to ionogram. The double recording of f_N and f_T resonances indicates severe N_e changes along the satellite path during the recording of this particular ionogram (the upper-hybrid frequency f_T is given by $f_T^2 = f_N^2 + f_H^2$). In particular, the average N_e change from the f_T resonance near 1.6 MHz to the f_N resonance near 1.9 MHz was 18%/km. The sounder-generated Z mode waves between f_N and f_T, which are so common on high latitude ionograms (see, e.g., Figure 14 of Muldrew [1969] and Figure 9 of James [1979]) highlight these frequency domains and also indicate (by their continuous presence) that there were no severe N_e changes during the f_N to f_T sweep time.

Field-aligned N_e irregularities with a much smaller spatial separtion are indicated in the high latitude ionogram of Figure 3c. Here the sounder-generated Z mode waves are not continuous over the f_N to f_T frequency domain. In addition, a series of "vertical bars" are observed between f_H and f_N. This bar phenomenon, and its relation to N_e irregularities, has been discussed by Muldrew and Hagg [1970]. The solid black bars are most likely due to f_N resonance signals whereas the lighter ones resemble thin frequency samples of Z mode signals between f_N and f_T. In either case, if the spacing on the frequency axis is interpreted in terms of the satellite motion at ~8 km/sec during the 0.1 to 0.4 sec sweep time between bars, the satellite is crossing a series of N_e fluctuations (of 10's of percent) over the polar cap with typical spacings of hundreds of meters to a few kilometers. Similar N_e structures in the topside auroral ionosphere have been vividly demonstrated in the ISIS 1 satellite/Chatanika Radar correlative investigation of Muldrew and Vickrey [1982].

The distribution of Z mode signals which cover this entire ionogram virtual range scale, and solid black vertical bars attributed to f_N resonances, of the type illustrated in Figures 3b and 3c are presented in Figure 4 using the same format as in Figure 2. Unlike the case of Figure 2, however, the data represented in Figure 4 correspond to sounder-generated signals rather than the naturally occuring signals. (Very few signals of natural origin were observed in the present data set.) The vertical lines above each symbol in Figure 4 designate the normalized frequency bandwidth of the sounder-generated signal. If there were no significant horizontal N_e gradients, the sounder-stimulated Z mode signals extending over the full ionogram virtual range scale would be confined to the frequency domain between f_N and f_T when $f_N/f_H > 1$ and there would be no entries for "vertical bars" (other than for those along the slanting distribution corresponding to the f_N resonance). The abundance of Z mode signals outside the f_N to f_T range and of N's removed from the f_N distribution when $f_N/f_H > 1$, however, indicates the common occurrence of N_e gradients along the satellite path which are attributed to field-aligned N_e irregularities.

In order to obtain information on the location of these field aligned irregularities, the minimum frequencies of the Z mode and f_N signals when $f_N/f_H > 1$ of Figure 4 were normalized by f_N and plotted against the invariant latitude of Alouette 2 corresponding to the time when the f_H resonance was recorded. The results are presented in Figure 5. If the ionosphere contained no horizontal N_e gradients, all of the Z's and N's should fall on the $f/f_N = 1$ line. The results of Figure 5 indicate that this is not the case, however, and that field-aligned irregularities are common in the polar cap. As mentioned earlier, these irregularities have separations of 100's of meters to a few kilometers. Their wide distribution over the polar cap could be the result of plasma instabilities operating at the edges of larger scale irregularities (> 10 km) which can convect over the polar cap [Kelley et al., 1982].

SUMMARY

Sounder-generated Z mode waves can be employed as a sensitive diagnostic tool for high latitude field-aligned irregularities with scale sizes in the range from 100's of meters to several kilometers. An inspection of Alouette 2 perigee data (~500 km) indicate that such irregularities are a common feature of the polar cap. In addition, field-aligned irregularities capable of producing ducted Z mode echoes near 500 km are common at low magnetic latitudes.

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