On the Absence of Plasma Wave Emissions and the Magnetic Field Orientation in the Distant Magnetosheath

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Abstract. in early September, 1983 ISEE-3 made a long traversal of the distant dawnside magnetosheath starting near x = -150 R_E downstream. The distant magnetosheath often contains moderately intense plasma wave emissions at frequencies from several hundred to 5 kHz. However, over time scales of many days, a clear correlation exists between the occurrence of the plasma waves and the cone angle (θ_{xB}) between the magnetic field and the plasma flow velocity (x-direction). For θ_{xB} large (small), the plasma wave amplitudes arc near background (high). Sudden (< 1 minute) changes in the local magnetic field orientation produce a correspondingly sudden change in the wave amplitudes. Statistically, the wave amplitudes decrease continuously with increasing θ_{xB}.

introduction

The Earth's bow shock excites a moderately intense band of plasma wave turbulence with frequencies between the ion and electron plasma frequencies, which extends throughout the subsolar region of the magnetosheath [*Rodriquez*, 1978; *Anderson* et al., 1982; *Onsager et al.*, 1989]. In September, 1983 the ISEE-3 spacecraft made a traversal of the distant dawnside magnetosheath starting about x = -150 R_E and moving eastward [*Greenstadt et al.*, 1990] and detected many long intervals of wave excitation even at these large distances from the bow shock, in this paper we report on a striking and rather curious correlation between the absence of plasma waves and the orientation of the magnetosheath magnetic field.

Observations

The ISEE-3 measurements by the TRW/n. Iowa electric field wave detector and the JPL magnetometer were made from 0000 to 1200 UT on September 10 and 12, 1983. During these intervals the spacecraft was continously in the magnetosheath moving from x = -158 R_E, y = -28 R_E to x = -146 R_E, y = -33 R_E (GSE). On September 10 (12), the magnetosheath flow speed varied from 500 to 600 km/s (400 to 500 km/s), the electron temperature was steady at 1.6 x 10^5 K, and the plasma densit y was in the range of 4 to 5 cm^{-3} (measurements from the 1.ANI, plasma analyzer). Figure 1 presents the measurements fo September 12, 1983. "l'he top panels display the 60-second average magnetic field components and magnitude. The central color panel presents the peak electric field amplitude (volts/meter) in the frequency channels from 1001IZto31 kI *17,* which occurred during successive 60-second intervals. The next panel shows the magnetic field cone angle (θ_{xB})- the angle bet ween the x-axis (nominal magnetosheath flow direction) and the magnetic field. The bottom two panels display the magnetic field longitude (defined so that 00 to 90° (-900 to 0°) corresponds to B_x and B_y having the same (opposite) signs), and the magnetic latitude.

Throughout this twelve hour interval plasma waves were almost continously excited in the frequency band between 178 Hz and 3.1 kHz with the strongest signals occurring bet ween 1.0 and 3.1 kHz. in addition intermittent bursts of electron plasma oscillations arc evident in the 17 kHz channel. However, there are definite intervals of a fcw minutes duration when the peak electric field amplitude is near the background level of the wave instrument; clear examples arc near 0020 UT , 0440 UT, 0650 UT, 0900 UT, and 1155 UT. in the magnetosheath and solar wind, the average (over 60 s) electric field amplitude can be mar background while the peak amplitude will remain high; thus , a zero peak amplitude indicates the virtual absence of plasma waves.

The disappearance of the 178117, to 3.1 kHz wave emissions occurs when the magnetic cone angle exceeds 60° and is typically above 75°. From the top panels in Figure 1, large cone angles correspond to intervals in which B_x is small, while B_y and B_z have varying and comparable values. in particular the magnetic field latitude did not exceed 45° to 60° during the wave dropouts; since the ISEE-3 electric field antenna is in the ecliptic plane, a parallel polarized electric field signal will not be detected if the magnetic latitude was near 900 "l"he first four and sixth dropouts occurred during small to moderate depresions in the magnetic field strength; however for the fifth and seventh dropouts, the field magnitude was steady.

Figure 2 presents the magnetic field and plasma wave measurements for 0000- 1200 UT on September 10, 1983. From 0000 UT to 0400 UT and again from 0800 UT to 12(XJ UT, the magnetic cone angle was often near 90° or rapidly varied between 60° and 90°. Plasma wave emissions between 178 Hz and 3.1 kHz are virtually absent during these intervals except for brief isolated bursts which occur when the cone angle drops below 60°. Between 0420 UT and 0450 UT, the cone angle decreased to about 40°, and fairly continuous wave emissions developed. From 0600 UT to 0800 UT, the cone angle remained below 45° and strong plasma wave signals were detected; the continuity of the wave emissions was broken at 0715 UT by a brief increase of the cone angle to 80°. For this twelve hour period intermittent electron plasma oscillations at 17 kHz were present during intervals of both high and low cone angles, and their occurrence did not exhibit any clear correlation with the magnetic field direction.

Figure 3 presents higher resolution measurements for the interval 0150 UT to 0230 UT on September 12, 1983; the magnetic field is averaged over 3 seconds, and the electric field spectral amplitude is unaveraged with a resolution of 0.5 s. At 0154 UT the wave amplitudes drop to background as B_x decreases to approximately 1 nT and θ_{xB} increases above 60°. During the wave dropout, the field magnitude stays constant, B_y changes sign, and a strong $B_z > 0$ results in a high field latitude (approximately 700). The wave dropout developed simultaneously in the frequency channels from 316 Hz to 3.1 kHz, and there was no evidence that the wave amplitudes swept downward (upward) in frequency as B_x decreased (increased). At 0200 UT, a sharp drop of B_x to near zero (θ_{xB} = 750), again at constant field strength, produced a rapid decrease in the wave amplitudes. The cone angle remained high (θ_{xB} = 75 to 90°) and wave amplitudes remained low from 0200 to 0208 UT, except for brief low frequency wave burst and θ_{xB} <600 dip at 0202:30 UT. Between 0208 and 0211 UT, θ_{xB} varied in the range 60° to 75°, and weak low frequency waves were observed. Except for a short burst at 0212 UT, these emissions terminated as B_x decreased to near zero at 0211 UT. From 0212 to 0220 UT, the field magnitude dropped to quite low values, B_x remained near zero, and all wave amplitudes were at background. At 0220 UT, the field strength recovered, B_x jumped to become the dominant field component, θ_{xB} decreased to 10°, and the 1.0 kHz to 3.1 kHz wave amplitudes started to increase. The wave amplitudes reached their previous (before 0154 UT) high levels after 0222 UT.

The temporal variations in the cone angle and plasma wave intensities on September 12, 1983 were sudden, radical changes from moderate to high θ_{xB} (Figure 1). Hence the question arises as to whether the plasma wave amplitudes vary continuously with θ_{xB} or simply cut-off for angles above some threshold, Figure 4 presents a scatter plot of wave amplitude in the 1.78 kHz channel *versus cone* angle. The graph shows clear agreement with the general nature of the day's events, with most points at high intensity when θ_{xB} was usually below 40° and a much smaller number of points at low intensity, or instrument sensitivity limit, when θ_{xB} was less commonly above 500

The apparent declining trend of intensity with angle, however, implies a continuous physical relationship between the two quantities for all angles. The wide scatter could be caused by several factors. Much of it is probably accounted for by the impulsive character of the plasma wave signals and the rapid fluctuations of the cone angle.

Discussion

The above examples have clearly demonstrated that in the distant dawnside magnetosheath the occurrence of plasma waves in the 316 Hz to 3.1 kHz band is tightly controlled by the local magnetic field direction. We have also observed the same anti-correlation between wave amplitude and high values of θ_{xB} in the duskside magnetosheath, but not in the upstream solar wind. l-he anti-correlation is so distinct that the first inclination is to seek an instrumental explanation, "l'he ISEE-3 antenna is in the ecliptic plane, and thus electric fields which arc perpendicular to the ecliptic arc not measured. However, even if the waves were polarized exactly parallel to the magnetic field, which is not at all clear or even likely, the large cone angles, which imply B_x was small, usually occurred when B_y was quite finite so that the magnetic field latitude did not exceed 45° to 600' therefore, the cosine reduction in the measured field amplitudes cannot explain the virtual disappearance of the wave emissions.

If the wave polarization is strongly -field aligned, another conceivable explanation involves the Doppler shift frequency $\omega_D = \mathbf{k}\cdot\mathbf{v}$, which would vary as $\cos\theta_{xB}$. If the observed frequencies are domnated by ω_D, the reduction of $\cos\theta_{xB}$ would shift the peak spectral amplitude to lower frequencies; thus on the higher frequency falling part of the spectrum, the amplitudes would decrease, and the waves would appear to drop-out. 1 Iowever, in examining the temporal behavior of the amplitudes in the various frequency channels during changes in θ_{xB} (as in Figure 3), the spectral peak does not shift to lower (higher) frequencies as θ_{xB} increases (decreases). Hence we conclude that the dropouts are not due to θ_{xB} variations in the Doppler shift frequency.

The absence of an instrumental or Doppler shift explanation leaves the possibility that the wave missions are controlled by the global connection of the magnetic field to the bow shock and/or magnetosphere. Since ISEE-3 was within 20-30 R_E of the tail magnetopause, the local magnetosheath field lines could be influenced by the location, shape, and/or reconnection state of the magnetotail. We have checked on whether the plasma wave dropouts and turnons depend on the signs of B_y and B_z, which could indicate a sensitivity to reconnection-related magnetotail strucutre and By-twist of the tail's orientation, and found no obvious relation. Since dropouts occur when $B_y = 0$, the intersection of the field lines with the magnetotail is not essential to produce the amplitude decreases. Thus we conclude that the wave dropouts are not obviously produced by connection to the magnetosphere.

The wave dropouts can persist for many minutes to hours, which indicates that the large scale structure of the magnetic field, not the small scale or local wiggles, is responsible for the absence of wave emissions. When θ_{xB} is large, the nose region bow shock is in a quasiperpendicular configuration over most of the region sunward of the terminator. Thus most of the magnetosheath ions which flowed past the ISEE-3 spacecraft on September 10 and 12, 1983 crossed a quasiperpendicular shock, and thus might be expected to possess at least the remnants of a reflected ion or ring-type phase space distribution. Downstream of the terminator, the field lines would typically intersect the weak flank shock surface in the quasiparallel configuration. Since the magnetosheath electrons (ions) have thermal speeds of about 20 R_E/min (0,5 R_E/min) the local electrons (ions) would (not) have passed through a quasiparallel shock. Furthermore the shock strength at the two intersection points of the field line would be about equal, so that the distribution function of the shocked electrons would tend to be symmetric with respect to the parallel velocity. Thus the absence of plasma waves when θ_{xB} is large may be caused by the symmetry of the electron distribution in parallel velocity even if the local ion distribution contains remnants of the ring-type structure produced by ion reflection.

When θ_{xB} is small, the dawnside shock in the nose region is quasiparallel (quasiperpendicular) if the magnetic field is in a Parker (anti-Parker) spiral configuration. We found that the plasma wave emissions in the distant magnetosheath occur independently of the relative sign between B_x and B_y; thus the waves are present for local magnetosheath ion distributions which have passed through either a quasiparallel or quasiperpendicular shock. For small θ_{xB}, both the shock strengths and shock type at the two locations where the magnetic field line intersects the shock surface are very different. Thus the local electron distribution, which is in thermal contact with the bow shock, is likely to be asymmetric with respect to the parallel velocity.

in conclusion, the only explanation for the observed anti-correlation of θ_{xB} and plasma wave emissions, which we have been able to identify, is that when θ_{xB} is small, the expected asymmetry in the local electron distribution leads to plasma wave exictation, and when θ_{xB} is large, the field line connection to similar strength and type bow shocks results in a more symmetric electron distribution which is stable to wave emissions. Clearly GEOTAIL electron and ion plasma measurements will be able to test this possible explanation and/or provide a better one.

Acknowledgments

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References

Anderson, R. R., C. C. Harvey, M. M. Hoppe, B. T. Tsurutani, T. E. Eastman, and J. Etcheto, Plasma waves near the magnetopause, *J. Geophys. Res.*, 87, 2087, 1982.

Greenstadt, E. W., D. P. Traver, F. V. Coroniti, E. J. Smith, and J. R. Slavin, observations of the flank of Earth's bow shock to -110 R_E by ISEE 3/ICE, *Geophys. Res. Lett.*, *1* 7, 753, 1990.

Onsager, T. G., R. H. Holzworth, H. C. Koons, O. H. Bauer, D. A. Gurnett, R. R. Anderson, H. Luhr, and C. W. Carlson, High frequency electrostatic waves near Earth's bow shock, *J. Geophys. Res.*, 94, 13,397, 1989.

Rodriquez, P., Magnetosheath electrostatic turbulence, *J. Geophys. Res.*, 84,917, 1979.

Figure Captions

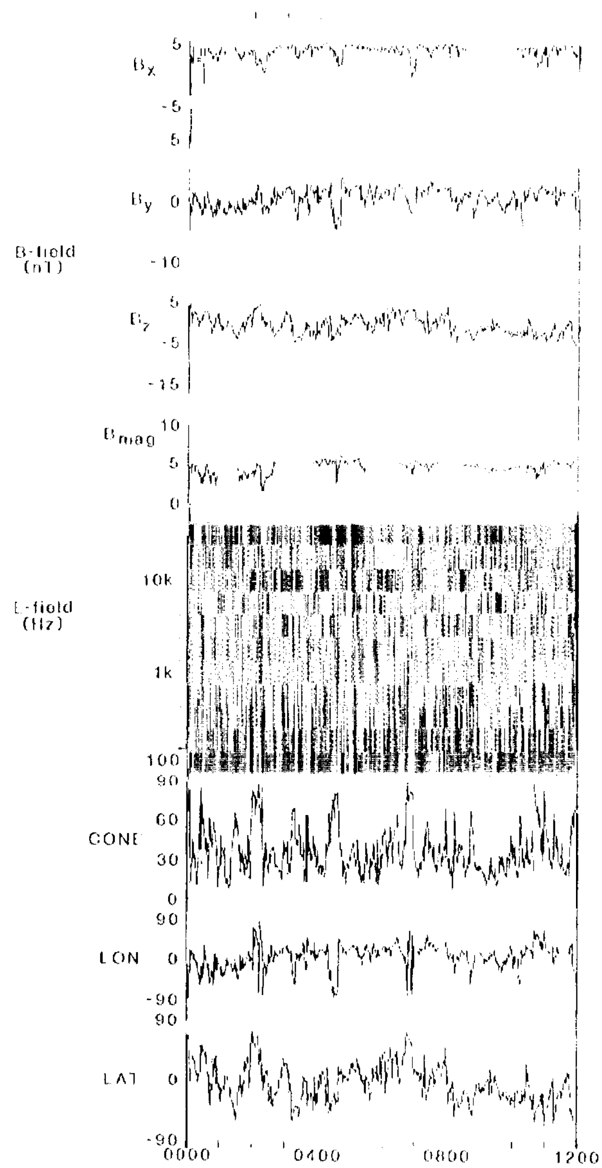
Figure 1. ISEE-3 measurements on 0000 UT to 1200 UT cm September 12, 1983. The upper panels present the one-minute average components and magnitude of the magnetic field. The center panel is a color-coded display of the plasma wave electric field amplitudes (volts/m) from 100 Hzto 31.6 kHz. The bottom panels present the calculated magnetic field cone angle (θ_{xB}) and the longitude and latitude of the field as defined in the text. Clear dropouts in the plasma wave amplit udes occur when θ_{xB} approaches 90°.

Figure 2. ISEE-3 measurements on 0000 UT to 1200 UT on September 10, 1983, in the same format as Figure 1. Plasma wave amplitudes are high only when the cone angle is below 400

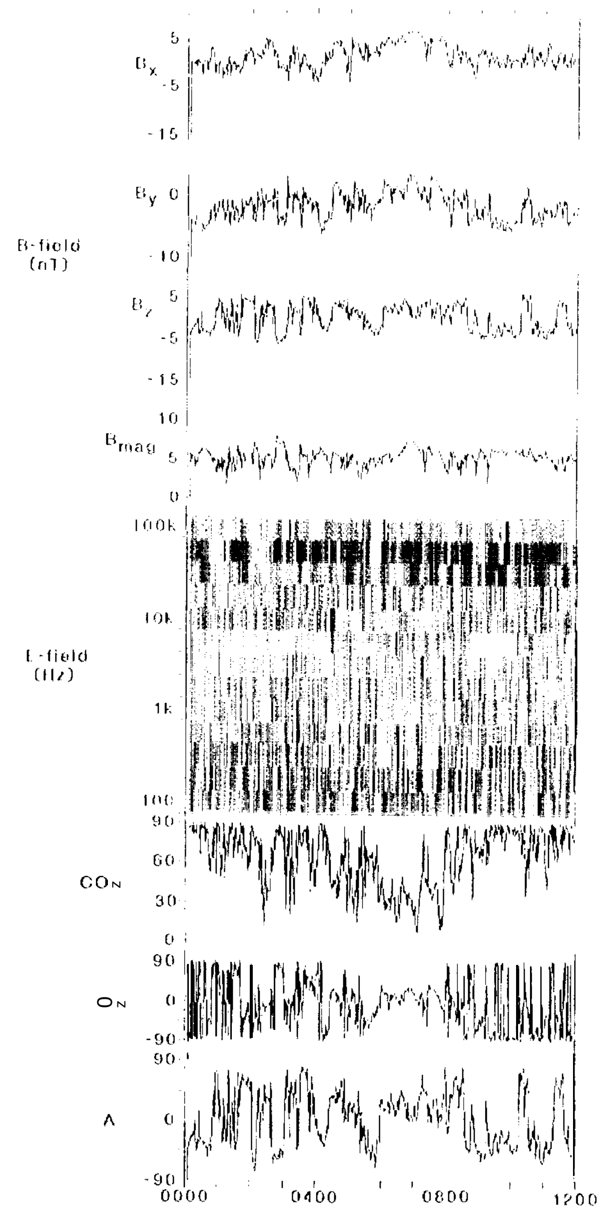
Figure 3. High time resolution measurements from0150U"l'to02301)'1' on September 12,1983. The bottom (top) panels display the measured (calculated) magnetic field components and magnitude (magnetic angles). The center panel shows the plasma wave spectral amplitude from 178 Hz to 3.16 kHz. Sudden changes in θ_{xB} result in sudden changes in the wave amplitudes.

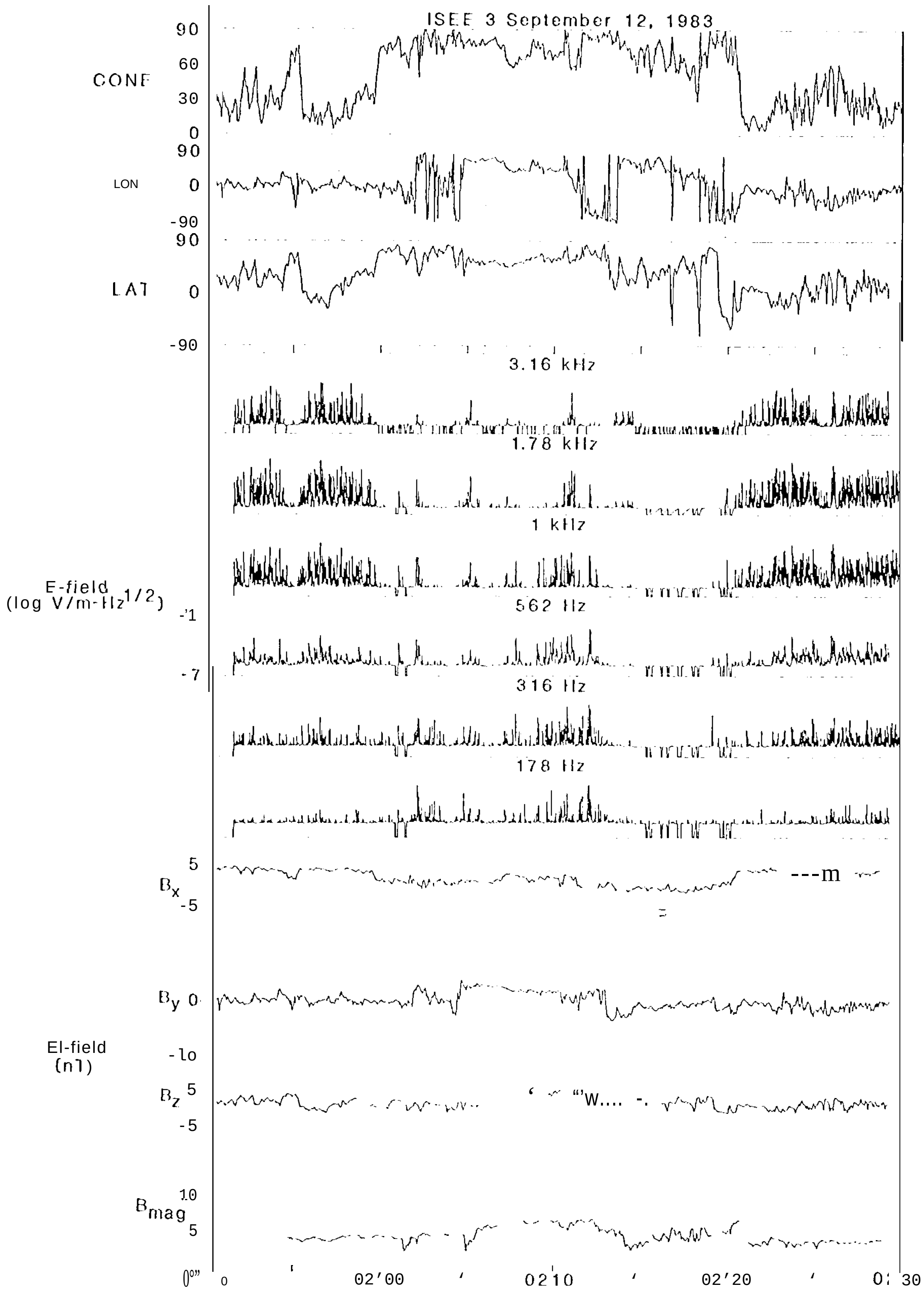
Figure 4. A scatter plot of the plasma wave electric field amplitude (volts/m) *versus cone* angle for the 0000- 1200 UT interval on September 12, 1983. Although the scatter is large, the decrease of wave amplitudes with increasing cone angle is clear.

ISEE 3 September 12, 1983



ISEE 3 September 10, 1983

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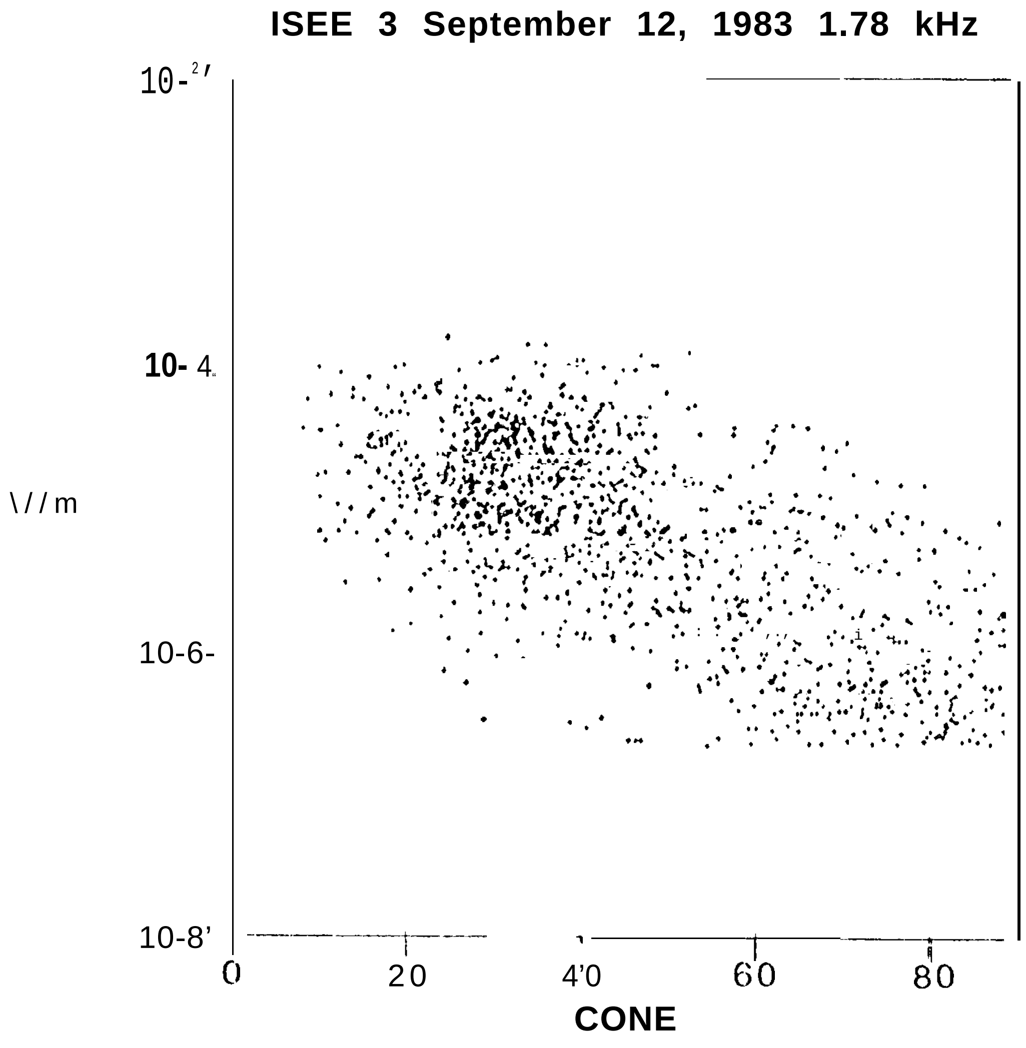

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