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Evidence for a global disturbance with monochromatic pulsations and energetic electron bunching

M. R. Lessard,[1,2] M. K. Hudson,[1] B. J. Anderson,[3] R. L. Arnoldy,[4] H. Lühr,[5] G. D. Reeves,[6] N. Sato,[7] and A. T. Weatherwax [8]

Abstract. We present data from a number of ground stations and satellites that reveal an example of a previously unreported type of global event. The event is characterized by the occurrence of monochromatic pulsations of widely varying frequencies in different regions of local times and L shells. The pulsations appear to be modulated with a ~45 min periodicity. Simultaneously, energetic particle fluxes observed at geosynchronous orbit (with energies resulting in a drift period of ~45 min) appear to become phase bunched and the pulsations are observed to occur coincident with minima in the particle bunching. Corresponding data from GOES 5 show an increase in the compressional component of the magnetic field with this period. Data from South Pole Station show fluctuations in the east–west component of the magnetic field at half this period, along with a weak auroral signature and riometer absorptions. We conclude that the data show the existence of a global disturbance with a compressional magnetic field signature, and we suggest that this compression induces a radial electric field, based on Faraday's law. Phase bunching of energetic electrons (due to the induction electric field) and monochromatic pulsations are consequences of the global disturbance, although the mechanism responsible for exciting the pulsations is not clear.

1. Introduction

A number of authors have investigated various properties of radially polarized monochromatic pulsations. *Arthur and McPherron* [1981] concentrated on a study of Pc4 (7 to 22 mHz) waves and showed that these waves have a strong peak in occurrence rate near dusk. *Singer et al.* [1982] determined the extent of the resonant regions of radially polarized waves to be 0.2 to 1.6 L shells for three events and showed that the waves were second harmonic standing waves. *Takahashi and McPherron* [1984] studied radially polarized waves from 0 to 100 mHz and determined that they were predominantly second harmonic standing waves, likely excited by wave–particle interactions, with a peak in occurrence rate just after magnetic noon. *Kokubun et al.* [1989] considered Pc4 pulsations and obtained similar results. *Engebretson et al.* [1988] and *Engebretson et al.* [1992] reported radially polarized events in the Pc3-4 period range observed by AMPTE/CCE and GOES 5 and 6. These events were localized near the equator during quiet times characterized by warm, strongly trapped light ions, often with streaming low–energy plasma. They suggest that plasma density increases, associated with plasmaspheric refilling, are the cause of local instabilities leading to wave onset, although they also point out that the possibility exists for either a drift–bounce resonance or a drift Alfvén ballooning mode. The events they studied occurred from late morning to dusk, and their results are consistent with those of *Anderson et al.* [1990], who showed a broad peak in occurrence distribution in the afternoon sector.

In spite of the diverse and varied reports of these pulsations, the data we present appear to be similar to other studies in only a couple of instances. *Hughes and Grard* [1984] discussed a second harmonic field line resonance observed by three satellites that had characteristics much like those reported here, although no mention was made in their work of the possibility of a global occurrence of their observations. They concluded that a bounce resonance involving medium–energy ions was the most likely source of the waves. *Engebretson et al.* [1992], using events observed on the dayside, de-

[1]Department of Physics and Astronomy, Dartmouth College, Hanover, New Hampshire.

[2]Now at Institute for Space Research, Department of Physics and Astronomy, University of Calgary, Canada.

[3]Applied Physics Laboratory, Johns Hopkins University, Laurel, Maryland.

[4]Institute for the Study of Earth, Oceans and Space, Space Science Center, University of New Hampshire, Durham.

[5]GeoForschungsZentrum Potsdam, Germany.

[6]Los Alamos National Laboratory, Los Alamos, New Mexico.

[7]National Institute of Polar Research, Tokyo, Japan.

[8]Institute for Physical Science and Technology, University of Maryland, College Park.

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scribed pulsations with similar characteristics to those reported here. However, the large data set used in our study leads to different conclusions than they obtained. In particular, the event discussed here has the fortunate advantage that data were available from many different stations, exposing its global character.

In this paper, we present data showing monochromatic pulsations that are predominantly radially polarized and whose frequencies vary sharply with local time. The pulsations appear to be modulated with a ~45 periodicity that is also seen as phase bunching of energetic electrons at geosynchronous orbit.

2. Data presentation: May 10, 1985

The event we consider occurred on May 10, 1985, under quiet geophysical conditions. The *AE* index peaked at approximately 310 nT about 8 hours before the event but remained near 40 nT for the 3 hours preceding the event and had a secondary peak at only 60 nT just as the event began. *Dst* did not exceed ±10 nT, and *Kp* remained at 0 for several hours preceding the event and during its observation. During this interval, the B_z and B_y components of the solar wind magnetic field measured by the IMP 8 satellite fluctuated positive and negative with a magnitude of less than 2 nT.

Figure 1 shows the locations of the relevant satellites and ground stations for this event, mapped to the equatorial plane for reference. Each station was mapped using an International Geomagnetic Reference Field (IGRF) model, except Active Magnetospheric Particle Tracer Explorers/Ion Release Module (AMPTE/IRM) and Charge Composition Explorer (CCE), which were mapped using a dipole model. Just as the pulsations began to be detected, South Pole Station was located near 22.0 magnetic local time. Figure 2 shows data from this station and provides an overview of activity for this period, which begins near 0030 UT. As is shown below, the event described in this section appears to have been triggered about this time, although the data in Figure 2 do not show this clearly. The presence of aurora can be seen along with low-level riometer absorptions, although there is no sign of a negative bay in the H component of the magnetometer and no sign of Pi2 pulsations in the induction coil data (labeled MICROPULSE X in the plot), two reliable substorm signatures. It appears, then, that no substorm was occurring at the time of this event, although magnetic activity is clear. The large oscillations in the D component of the magnetometer are discussed below.

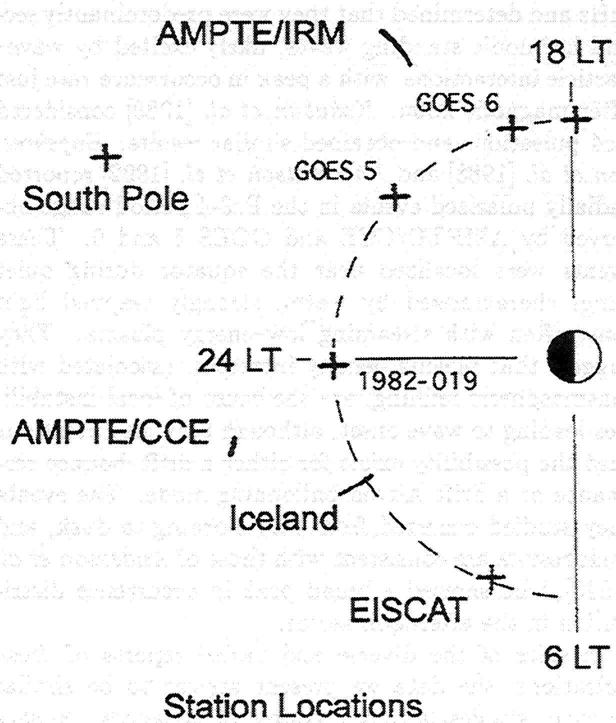

Figure 1. The equatorial projection of the locations of the various ground stations and satellites at the time of event 1. The line segments for AMPTE/IRM and CCE represent their approximate trajectories during the course of the event. The mapping of South Pole Station was done using an IGRF model, although the station is located near the polar cap and open field lines. Because wave packets are detected there, however, it appears that the field lines are closed in this case.

The pulsations investigated in this section (not visible in Figure 2) are observed to have a wave train or "wave packet" structure, typically lasting approximately 20 min. In the subsections that follow, data are presented from a number of satellites and ground stations that show the simultaneous observation of wave packets at different local times with different frequencies. Not all stations and satellites observed every wave packet, but we concentrate on one that is observed everywhere in an attempt to identify its mode and origin.

2.1. Satellite Magnetometer Observations

The AMPTE/IRM satellite was launched on August 16, 1984 into an elliptical orbit with an apogee of approximately 18.8 R_E and a perigee of 557 km. The orbit, with a period of 44.3 hours, was inclined 28.6° from the geographic equator and precessed westward 23.0 hours in local time per year (0.95° per day). Data used for this study were obtained when the satellite was outbound near 20.0 magnetic local time.

Figure 3 shows IRM observations of the arrival of two of the wave packets. The first packet is detected near 0115 UT on May 10, 1985, but we focus on one centered at approximately 0200 UT. The coordinate system used is a spherical one, with its polar axis aligned with Earth's magnetic dipole and the data presented in radial, eastward, and compressional coordinates. In this system, compressional perturbations $\mathbf{B_N}$ are directed along the calculated background magnetic field, which is nominally northward. Radial oscillations $\mathbf{B_R}$ are directed radially outward from the center of Earth in the direction of the satellite, and $\mathbf{B_E}$ is azimuthally eastward. The data, while in a solar magnetic (SM) coordinate system, were first detrended by subtracting a background field, calculated point by point as follows [*Zhu and Kivelson*, 1991]. For each data point, a seg-

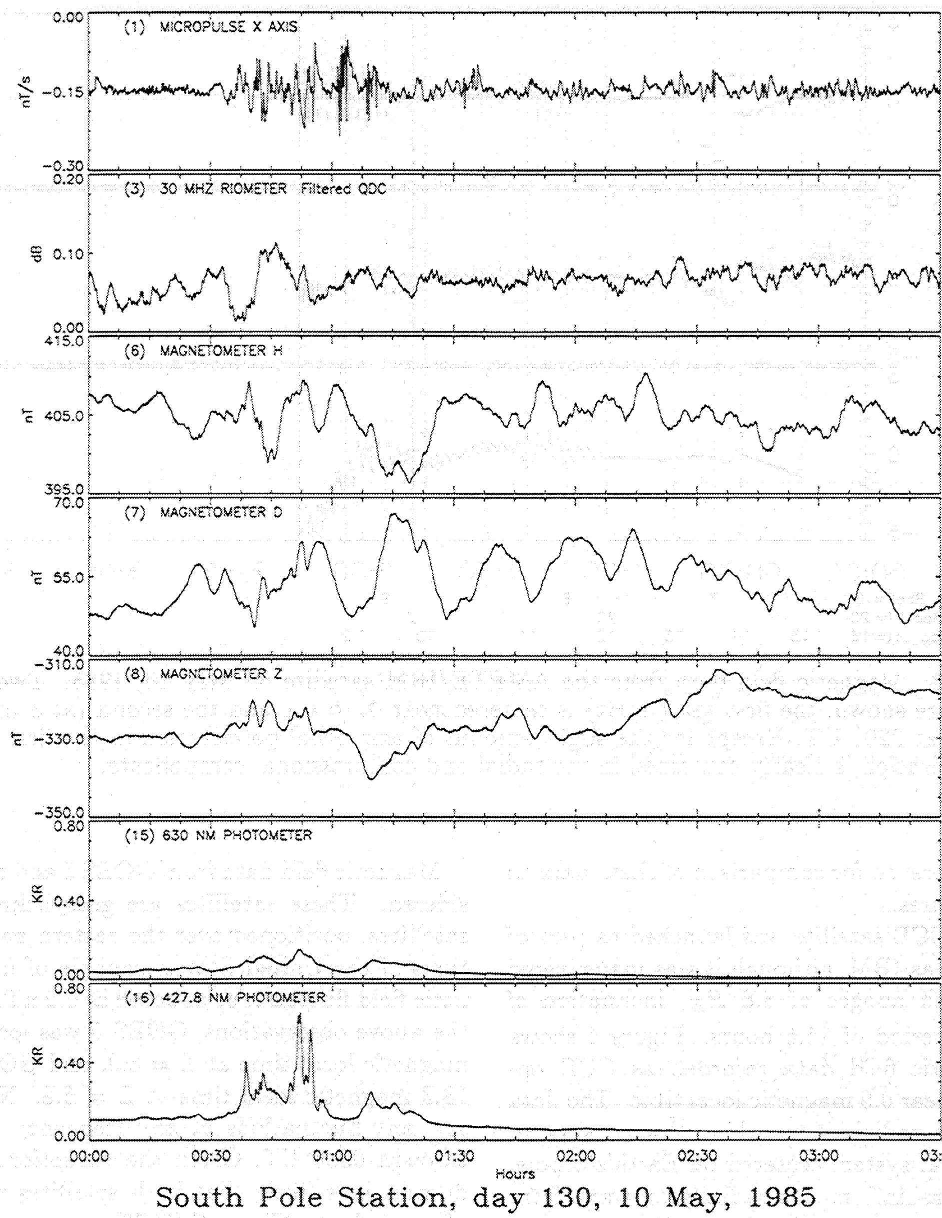

Figure 2. Observations recorded at South Pole Station. The occurrence of aurora can be seen in the photometer and riometer data, but no sign of a negative bay is present in the H component of the magnetometer and no Pi2 pulsations are present in the induction coil data.

ment consisting of approximately 30 min worth of data (400 data points), whose midpoint occurs at the time of the data point, was fitted with a straight line. The value of the midpoint of the fitted line was taken to be the value of the background field at the time corresponding to the data point. The calculated background field was then used to calculate the compressional component $\mathbf{b} \cdot \mathbf{B}/B$, where $\mathbf{B}$ is the background field and $\mathbf{b}$ is the magnetic field data in the SM system. The unit vector for the eastward component was then calculated by crossing the unit vector in the compressional direction into that of the radial direction (the satellite position).

Onset of the first wave packet occurs near 0100 UT. Its duration is approximately 25 min, although the wave power never goes to zero before the arrival of the second wave packet, centered at 0200 UT. The data recorded for this orbit end at 0215 UT, preventing any further observations. The first wave packet exhibits power mainly in the radial and compressional components, with some power also present in the eastward component. The second packet, however, contains power only in the radial and compressional components, the signature of a meridionally polarized wave. It should also be noted that these observations occur at 10° magnetic latitude at $L = 9$. The power spectrum, estimated using a Fourier transform with a Bartlett window, indicates the frequency of the first wave packet to be approximately 7 mHz and that of the second wave packet to be 8 mHz. Bold vertical lines are drawn at 0148 and 0215 UT in

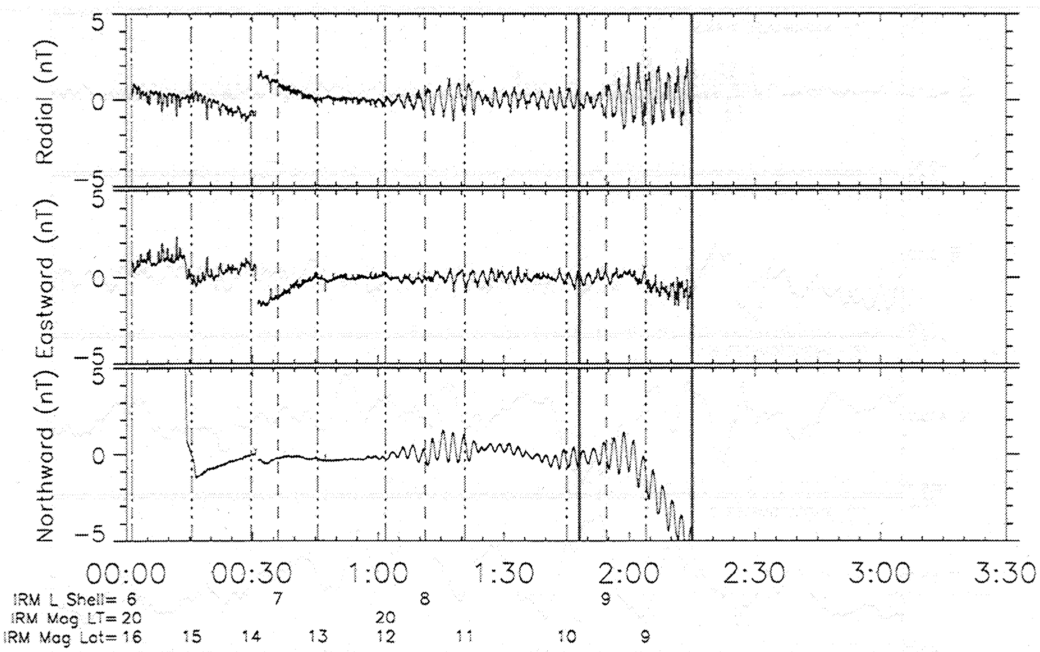

Figure 3. Magnetic field data from the AMPTE/IRM satellite on May 10, 1985. Two wave packets are shown, the first (at 7 mHz) is centered near 0115 UT and the second (at 8 mHz) is centered at 0200 UT. Except for the slight amount of azimuthal polarization in the first event, the polarization is clearly contained in the radial and compressional components.

the figure as a reference for comparison of these data to those in other figures.

The AMPTE/CCE satellite was launched as part of the same package as IRM, although it was maneuvered into an orbit with apogee of 8.8 R_E, inclination of 4.8° and orbital period of 15.6 hours. Figure 4 shows detrended magnetic field data recorded as CCE approached apogee near 0.9 magnetic local time. The data are presented in a radial–eastward–northward system, which is a spherical system centered on Earth's dipole. In this system, "radial" means radially outward from the center of Earth, "eastward" points azimuthally eastward, and "northward" points perpendicular to these components, toward the north magnetic pole. In the figure, two wave packets can again be seen, although the arrival of the first begins earlier than in the IRM data. The second packet, however, coincides well with the second observed by IRM, although the satellites are separated by more than 4 hours in local time.

Power in both the radial and eastward components is present in the first wave packet, although the second contains power only in the radial component. Figure 4 shows that the amplitude of the radial component for the second packet must be at least a factor of 3 greater than that of the other components. The lack of compressional power in both packets suggests that they are transverse waves, although it may be the case that the satellite, near the equator at this time, could be at a node of an even mode compressional wave. Both packets observed by AMPTE/IRM showed significant compressional power at 10° magnetic latitude.

Magnetic field data from GOES 5 and 6 were also considered. These satellites are geosynchronous weather satellites, positioned over the eastern and western portions of the United States, capable of measuring magnetic field fluctuations as small as 0.2 nT. At the time of the above observations, GOES 5 was located near 20.5 magnetic local time at $L = 6.9$, and GOES 6 was near 18.3 magnetic local time at $L = 6.8$. Neither satellite saw any fluctuations at any frequency from 0000 UT through 0330 UT. Given the exceptionally quiet conditions, it is likely that both satellites were inside the plasmasphere. *Chappell* [1972] presents data from Ogo 5 that show the plasmapause can extend to as far out as $L = 9$ under the conditions present during this event.

2.2. Ground–Based Magnetic Field Observations

Several ground–based observatories also recorded the events described above. Data are first presented from induction coil magnetometers in Husafell, Isafjordur and Tjornes in Iceland along with Syowa in Antarctica. Figure 5 shows the H (northward) and D (eastward) components from these stations. The first wave packet, centered at 0115 UT, is just above the noise level but can be seen in the H component of Husafell and Tjornes. The frequency of this packet is 13 mHz. The second wave packet, marked by the bold vertical lines, shows power in the H component at all stations. The frequency of this packet is estimated to be 10.5 mHz. Note also that waves of similar frequency and amplitude recur through 0300 UT. It is shown below

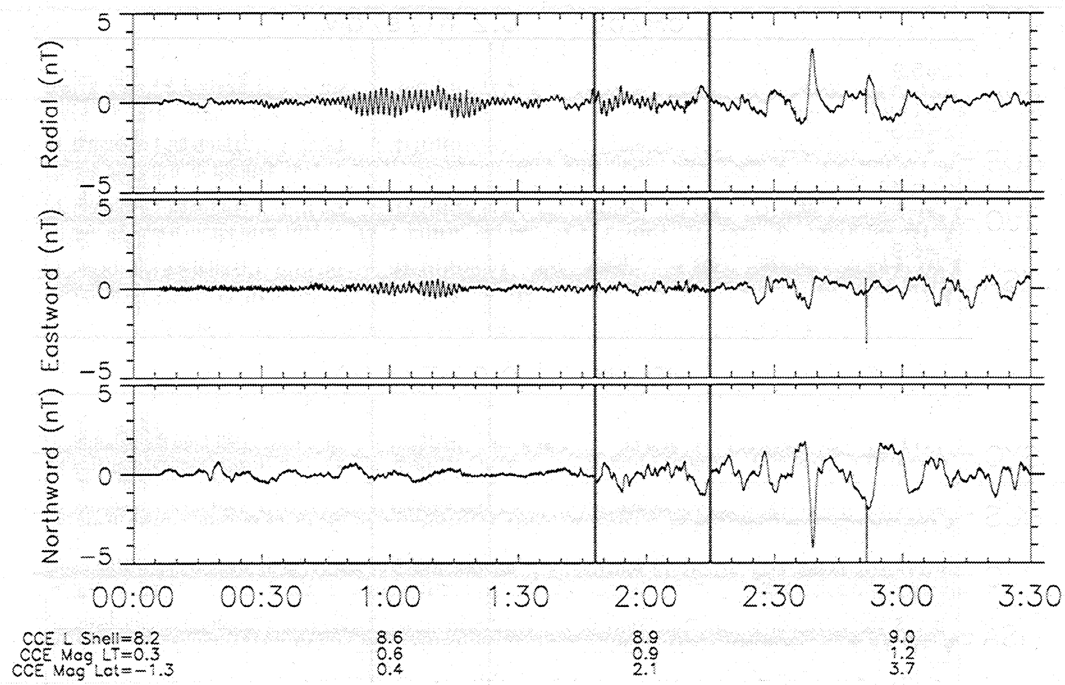

Figure 4. Magnetic field data from the AMPTE/CCE satellite on May 10, 1985. Wave packets can be seen at approximately the same times as in AMPTE/IRM, except that the first wave packet in this case begins earlier. Note the lack of power in the compressional component in this case. As in the IRM data, the first packet also contains power in the azimuthal component. Both wave packets in this case occur at 13 mHz.

that these stations continue to detect wave packets for several hours afterward.

The azimuthal wave number m of the second wave packet was calculated using the method of *Tonegawa and Sato* [1987]. The method assumes that the spatial phase shift of pulsations is linear among stations and calculates the wave number based on the phase difference between stations. The following relation holds between the propagation vector $\mathbf{k}$ and the phase difference between the i th and j th stations:

$$\phi_j - \phi_i = \mathbf{k} \cdot (\mathbf{r}_j - \mathbf{r}_i) \qquad (1)$$

where $\mathbf{r}_i$ and $\mathbf{r}_j$ are the positional vectors of the ground stations. Using the observed phase difference, the $\mathbf{k}$ vector can be obtained for H and D components independently, where the east–west component of $\mathbf{k}$ is the azimuthal wave number m. Data were used between 0150 and 0210 UT with a center frequency of 10.5 mHz to calculate phase differences. Pulsations with northward polarization at this frequency were determined to have an azimuthal wave number of $m = 1.6$ with westward propagation. If these waves were excited at the magnetopause by the solar wind, the propagation direction might be interpreted as tailward propagation, although we have no evidence to support this idea.

Figure 6 shows data recorded by the European Incoherent Scatter Radar (EISCAT) cross of fluxgate magnetometers in Scandinavia. Geographic components are used where X is north, Y is east, and Z is downward. Only the second wave packet (centered near 0200 UT) is visible in the Y component. The signal in the X component (not shown) was not above the noise level. The frequency of the second wave packet is estimated to be 10 mHz for these stations.

Hughes [1974] showed that pulsations observed on the ground will have a magnetic field component that is rotated 90° relative to its magnetospheric signature. The Iceland/Antarctic data show most of the power to be in the northerly direction which means that the pulsations are azimuthally polarized in the magnetosphere. Data from the EISCAT chain, however, indicate that pulsations observed there are radially polarized in the magnetosphere.

Finally, induction coil data obtained at the South Pole are presented again in Figure 7. Although the data are contaminated somewhat by noise spikes near 0130 UT and a calibration pulse at 0201 UT, the same wave packet character can be seen centered at 0200 UT in the X component (azimuthally polarized in the magnetosphere). The frequency in this case is near 10 mHz.

2.3. Satellite Observations of Energetic Particles

Finally, energetic particle data are presented in Figure 8. These data were recorded by the Charged Particle Analyzer (CPA) and Synchronous Orbit Particle Analyzer (SOPA) instruments on the suite of geosynchronous satellites maintained by the Los Alamos Na-

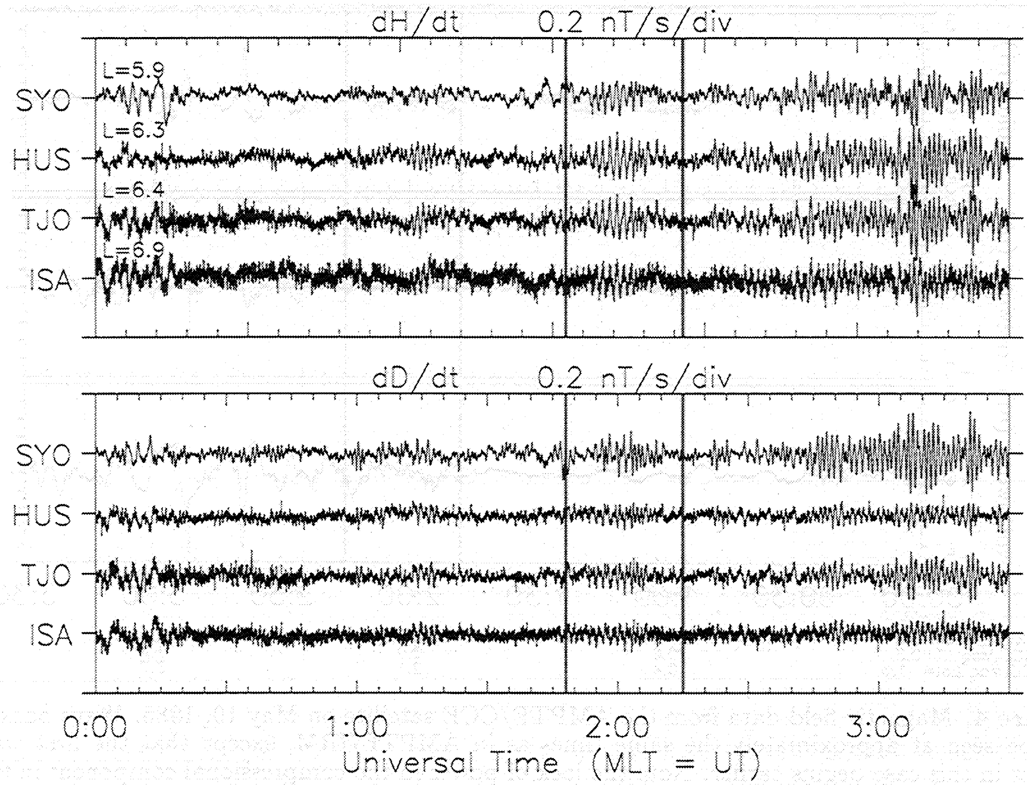

Figure 5. Induction coil data from the Iceland and Syowa stations. Wave packets are detected at the same times as those by the AMPTE/IRM and CCE satellites. In this case, however, the first packet is at 13 mHz, while the second is 10.5 mHz. Also, note that the Syowa data show the wave packet at 0200 UT is polarized in the H direction (north–south) while the one that follows at 0300 UT is polarized in the D direction (east–west).

tional Laboratory [*Reeves et al.*, 1997]. Oscillations in electron flux with a period of approximately 45 min can be seen in the 140-200 keV channels of all three satellites beginning at 0030 UT. Electron fluxes in the energy channels immediately above and below the 140-200 keV channel show weaker oscillations but with a slightly decreased period for the next highest energy channel (200-300 keV) and an increased period for the next lowest energy channel (94-140 keV). These oscillations are nearly sinusoidal and do not have the character of drift echoes due to substorm injection [*Arnoldy and Chan*, 1969; *Pfitzer and Winckler*, 1969; *Reeves et al.*, 1990]. Substorm–injected particles appear with a distinct onset and an abrupt increase in count rate, followed by a relatively gradual decrease in count rate. Echoes resulting from gradient–curvature drift motion usually follow the injection, but velocity dispersion results in any subsequent peaks having decreased amplitude and a broadening of the signature with each echo. In contrast, the oscillations in Figure 8 are wave–like and appear to provide evidence for drift phase bunching. The drift period of electrons in this energy range in a dipole field is approximately 45 min at geosynchronous orbit. If the oscillations are due to phase bunching occurring at the drift period, then the bunching observed by 1979-053, positioned 6.2 hours west of 1982-019, should lead that of 1982-019 by approximately 12 min, which is consistent with the data. Likewise, the bunching observed by 1984-037, positioned 7.0 hours east of 1982-019, should lag that of 1982-019 by 13 min. The observed lag is closer to 7 or 8 min, which is probably within the error that results from assuming a dipole field.

Note that 1979-053, located near 18.0 MLT, is in close proximity to GOES 6 and that, as discussed above, both are likely inside the plasmasphere. GOES 6 did not observe the wave packets, but 1979-053 did observe the electron bunching, reinforcing the suggestion that although the wave packets are well–correlated with the electron bunching, they are separate phenomena.

The enhanced electron fluxes observed by the geostationary satellites occur at 45 min intervals, suggesting the presence of a driver with this period. Since the drift period of the 140-200 keV electrons is also 45 min, the data in Figure 8 indicate that enhanced fluxes occur only in a single region in local time at any instant (that only a single "bunch" of electrons evolves). Bunching as described here would occur if an oscillating radial electric field (of global scale) with a 45 min period was imposed on the drifting particles, resulting in an $\mathbf{E} \times \mathbf{B}$ force that would resonate with the particle drift motion and cause the bunching. Such an electric field would result from Faraday induction associated with a mag-

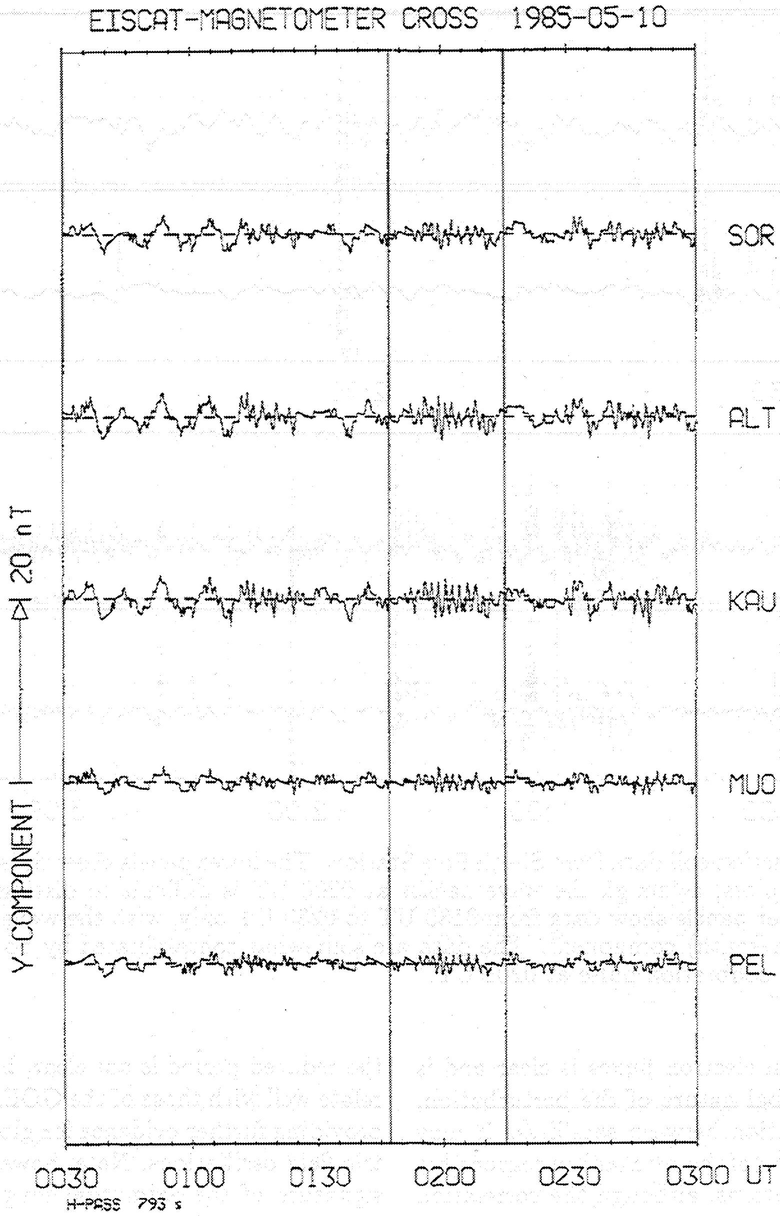

Figure 6. Fluxgate magnetometer data from the EISCAT chain in Scandinavia. Although the signal is barely detectable with these magnetometers, the presence of the wave packets at 0120 UT and 0200 UT in the Y (geographic east–west) component is clear. The frequency of both is estimated to be 10 mHz.

netic disturbance in the azimuthal and compressional directions.

Another feature visible in Figure 8 is an increase in the period of flux bunching with each transit around Earth. While velocity dispersion may be responsible in some way for this increase (faster electrons get ahead of the slower electrons in the drift phase bunch), the precise mechanism is not clear. It may be the case that the period of the driver is increasing for some reason, but it should also be noted that if an overdamped system is perturbed impulsively, the period of the disturbance will increase as the system relaxes. In other words, if a transient perturbation is imposed on the magnetosphere and is overdamped, the period of the perturbation will increase with time. If this is the case here, such a scenario suggests that the event described is triggered by an impulsive disturbance as opposed to a steady state one.

Figure 9 again shows the observation of wave packets by AMPTE/IRM but plotted with the electron bunching observed by 1982-019, the northward component of the magnetic field observed by GOES 5 and the D component of the fluxgate magnetic field data recorded at the South Pole. Recall that AMPTE/IRM was located near 20.0 MLT and that 1982-019 was near magnetic midnight. The observation of wave packets that corre-

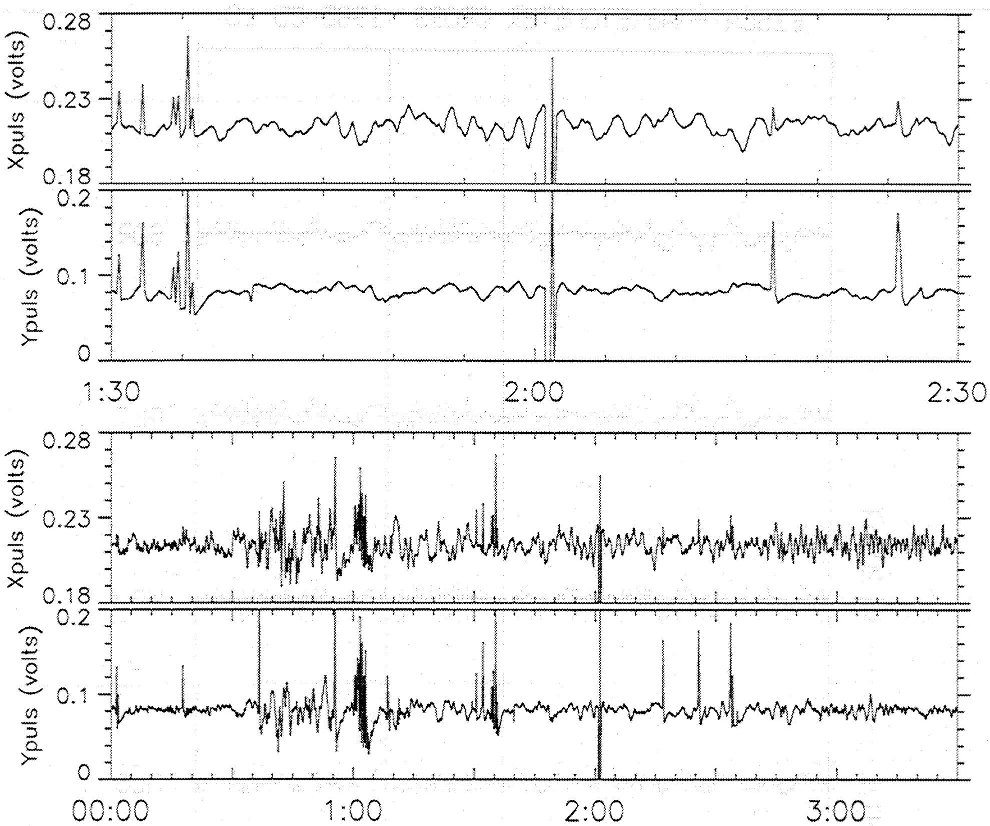

Figure 7. Induction coil data from South Pole Station. The lower panels show the same timescale as in previous plots, although the wave packet at 0200 UT is difficult to distinguish from the noise. The upper panels show data from 0130 UT to 0230 UT only, with the wave packet visible in the X (north–south) component. The data are somewhat contaminated by noise spikes near 0130 UT and a calibration pulse at 0201 UT.

late well with minima in electron fluxes is clear and is consistent with the global nature of the perturbation, given the 4 hour separation between satellites. It may also provide an indication of the mechanism responsible for generating the pulsations, although the correlation does not necessarily imply a cause and effect relationship. Also, note that the relative density of energetic electrons is small compared to the background plasma. Oscillations of these particles, then, would not be associated with a significant change in plasma beta or be responsible for a temperature anisotropy, features commonly associated with MHD instabilities. Instead, if these particles play a role in the excitation of the pulsations, then the mechanism involved is likely to be associated with a kinetic instability.

The GOES 5 data shown in Figure 9 have not been detrended or processed in any way but show modest increases in the strength of the northward component at times when electron flux minima occur at 1982-019, consistent with the suggestion that the electron flux bunching results from a globally imposed disturbance with a radial electric field resulting from Faraday's law, as discussed above. The D (east–west) component of the magnetic field at the South Pole shows oscillations with half the period of the electron bunching. The reason for the reduced period is not clear, but the oscillations correlate well with those of the GOES 5 and 1982-019 data, providing further evidence for global magnetic and electric field oscillations. Note, however, that the expected signature of the azimuthal magnetic field that would induce a radial electric field should be rotated 90° and appear in the H component of the ground–based data.

2.4. Further Observations

In this section, we list observations related to the event that may provide information regarding the processes responsible for its occurrence. For reference, Figure 1 shows the locations of the relevant satellites and ground stations, mapped to the equatorial plane.

1. There are two instances in these observations where stations are positioned within an hour of the same local time. For the wave packet occurring near 0115 UT, Iceland is located at 1.25 MLT and AMPTE/CCE is at 0.7 MLT and both observe a wave packet frequency of 13 mHz, although the Iceland chain spans from $L = 5.9$ to 6.9 and AMPTE/CCE is at $L = 8.7$. In the second instance, EISCAT observes a frequency of 10 mHz at 0200 UT and 4.6 MLT. The Iceland chain reaches 4.6 MLT at approximately 0436 UT, when it observes activity near 17 mHz, suggesting that the ex-

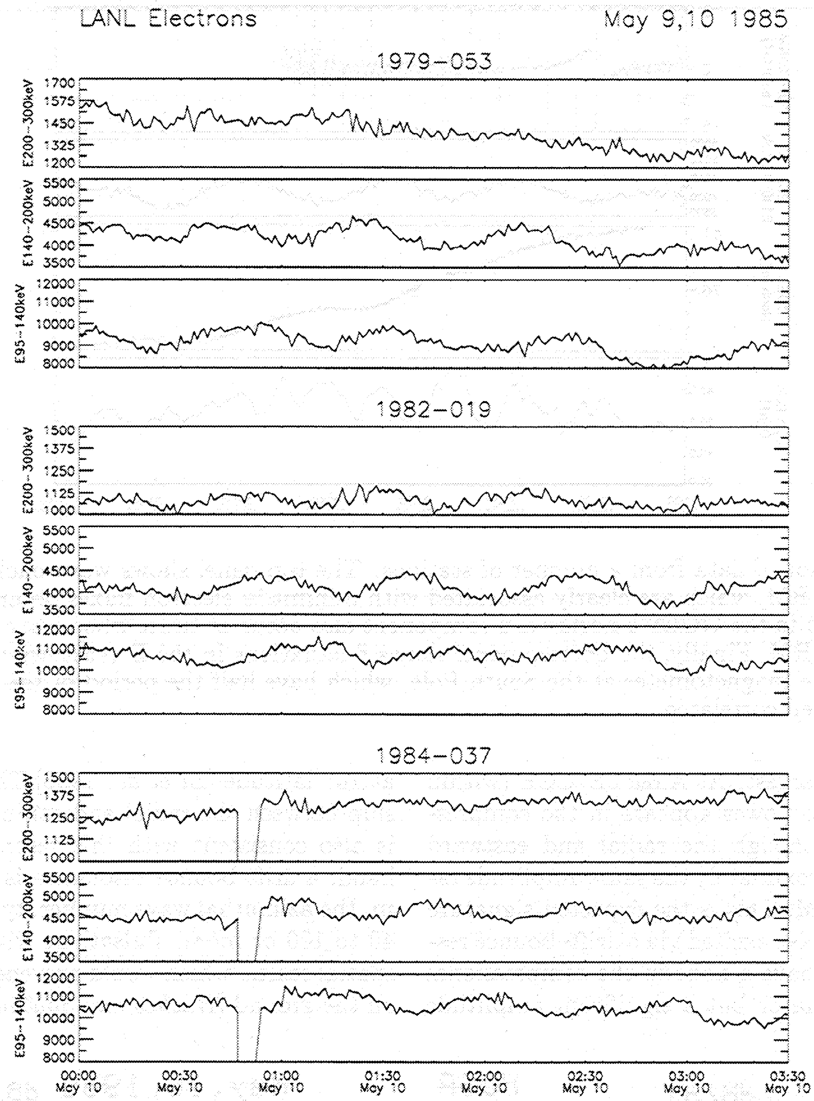

Figure 8. Energetic electron data from the Los Alamos satellites. Electron bunching is apparent in each satellite beginning at approximately 0040 UT, most prominently in the 140-200 keV energy channels. These electrons have a drift period of approximately 45 min, the same period as the bunching. This also appears to be the time between the detection of the wave packets. See Figure 9.

citation mechanism of these waves may not be stationary. These data also indicate that the events being observed are not field line resonances, which have frequencies that depend on L shell and show power primarily in the azimuthal component of the magnetic field [*Anderson et al.*, 1989, 1990; *Engebretson et al.*, 1986; *Zanetti et al.*, 1987]. It should also be noted that the periodically repeating wave packet structures shown here are not typical of field line resonance observations.

2. The persistence of this particular event is clear in Figure 10, which shows dynamic spectra of the northward component at Husafell, one of the stations in the Iceland chain, for a 24 hour period. The bursts at 0115 and 0200 UT are clearly visible, as are many others until approximately 0800 UT. Recalling that the local time of these stations is approximately equal to universal time, these data reinforce the suggestion that these pulsations are observed over a global scale and that they can persist for many hours. It is not clear whether this is the case with the energetic electrons observed by the Los Alamos satellites. Although all three satellites detect phase bunching around 1230 UT, the bunching only remains until approximately 0400 UT. In addition, the decreasing period of the bunching suggests the source may be impulsive and so the mechanism responsible for the bunching may not be directly responsible for the pulsations.

3. While the data in Figure 10 clearly show the global and persistent character of the bursts, the wave mode of the pulsations remains uncertain. However, a number of features can be extracted from the numerous observations. The wave packet detected by AMPTE/IRM at 0200 UT while at 10° latitude shows power in all three components, but the radial and compressional ampli-

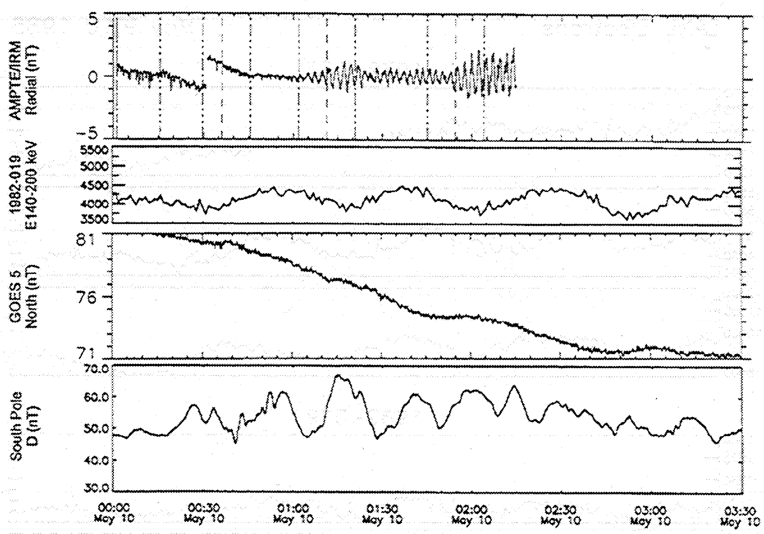

Figure 9. Plot of data from a number of stations. The top panel shows wave packets observed by AMPTE/IRM, which are clearly associated with minima in electron fluxes observed by 1982-019. Increases in the GOES 5 northward component also occur at times when wave packets were observed by IRM. Finally, the bottom panel shows fluctuations in the D (east–west) component of the fluxgate magnetometer at the South Pole, which have half the period of the other signals but remain well correlated.

tudes are clearly the largest. At AMPTE/CCE (within 2° of the equator), no power appears in the compressional component, although the radial and eastward components have approximately the same amplitude ratio as in AMPTE/IRM. This is the expected signature of an antisymmetric wave excited via a drift–bounce resonance, which would have a node in the compressional component at the equator but a significant amplitude at 10° latitude [*Li et al.*, 1993].The antiphase relationship between the radial and compressional components is also consistent with this resonance. On the other hand, a drift bounce resonance is associated with high m, the azimuthal wave number, typically of the order of 40 to 100 or more. Pulsations with high m have small spatial scales, which would prevent their being observed on the ground [*Hughes and Southwood*, 1976], as is true

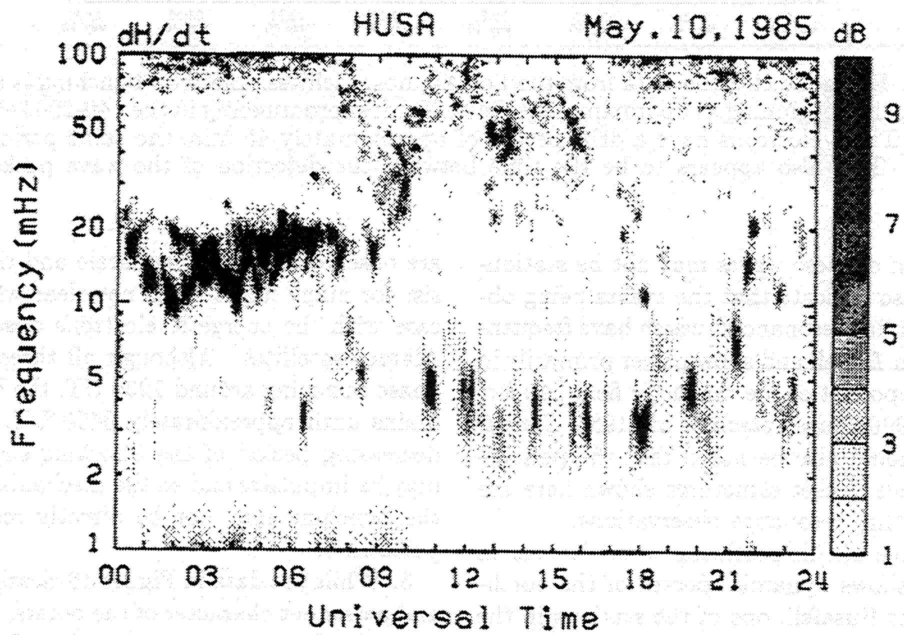

Figure 10. Induction coil data showing persistence of event 1. The bursts at 0115 and 0200 UT are clearly visible, as are many others until approximately 0800 UT. Since universal time is approximately equivalent to magnetic local time for these stations, these data reinforce the suggestion that the wave packets are observed over a global scale and that they can persist for many hours.

for the wave packets in this event. In addition, the azimuthal wave number determined from the Iceland data is 1.6, much less than what would be expected for pulsations resulting from a drift–bounce resonance. We note that the pulsations reported by *Hughes and Grard* [1984], similar in character to those reported here, were attributed to a bounce resonance involving medium energy ions, although they had no way of calculating the azimuthal wave number. If the pulsations presented in this study were in fact excited via a bounce resonance, their observation on the ground with a low azimuthal wave number would be a new and very interesting problem (assuming that the wave mode observed in space is the same as that observed on the ground).

4. The wave packets presented here have a number of features in common with so–called giant pulsations (Pg's). Such pulsations are noted for their distinct sinusoidal waveform, although they have a number of other established characteristics including east–west polarization as observed on the ground and azimuthal wave numbers of 16–35 with westward propagation [*Glassmeier*, 1980; *Rostoker et al.*, 1979]. While the wave packets in our data set have the appearance of Pg's, induction coil data from Iceland (Figure 5) and the South Pole (Figure 7) show larger amplitudes in the north–south component. We also showed above that the azimuthal wave number of the pulsations observed in Iceland was $m = 1.6$, significantly lower than expected for Pg's. In addition, the data from AMPTE/CCE (Figure 4) show that the signal is almost purely transverse when observed very near the equator. This property indicates that the pulsations do not have a node at the equator, meaning that their structure is antisymmetric. This result is opposite to the findings of *Takahashi et al.* [1992], who concluded that Pg's are due to symmetric standing waves. Based on these arguments, we conclude that the wave packets discussed here are not giant pulsations.

3. Summary and Discussion

The character and scale of the event can be inferred from the combination of satellite and ground–based data. Pulsations with a wave packet appearance are observed to occur simultaneously with frequencies from 8 to 13 mHz (77 to 125 s period), spanning more than 8 hours in local time and from $L = 5.9$ to $L = 9.6$ and perhaps beyond. In addition, spectral analysis of the Iceland data shows that the wave packets have a bursty nature and tend to occur with an apparent ~45 min periodicity. Data from AMPTE/IRM and AMPTE/CCE also show the ~45 min periodicity, implying that the pulsations are excited or modulated temporally over a large spatial scale. Table 1 summarizes observations of the wave packets that occurred near 0200 UT. Figure 11 shows the distribution of their frequencies as a function of magnetic local time, which shows a monotonic variation, although there is no evidence that this is the case for wave packets that occur at other times (e.g., 45 min later). The mechanism responsible for the pulsations is not clear.

Although the wave packets provide important information about this type of event, it appears that their occurrence is a consequence of a larger scale perturbation. Figure 9 shows data suggesting that a global perturbation (visible as a magnetic field oscillation in the GOES 5 data) induces a radially polarized electric field that results in the flux modulation or "bunching" of energetic electrons at geosynchronous orbit, all with a period of 45 min (which, perhaps, slowly increases). Simultaneously, the monochromatic pulsations are also observed to occur, coincident with minima in electron flux oscillations and with a repetition rate that matches the period of these oscillations. Because of the lack of adequate solar wind data, it is not possible to determine whether the source of the 45 min fluctuations is in the solar wind or whether this frequency is intrinsic to the magnetosphere. We also note that the event appears to be triggered in some manner (the first wave packet is observed just after a brief period of visible aurora is observed at the South Pole), although the details of the mechanism are not clear.

Of the significant number of studies of radially polarized monochromatic pulsations, only those of *Hughes and Grard* [1984] and *Engebretson et al.* [1992] discussed features that are similar to those presented here,

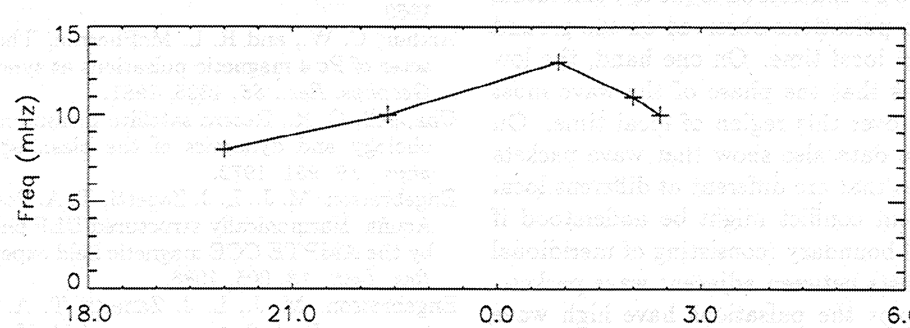

Figure 11. The frequency distribution versus position in local time of observed wave packets for packets observed at 0200 UT. The simultaneous observations over an 8 hour span in local time are indicative of the global nature of this event.

Table 1. Summary of Observations for Event 1 at 0200 UT.

Station	L Shell	Magnetic Local Time	Frequency
AMPTE/CCE	8.9	0.9	13
AMPTE/IRM	9.1	20	8
Ice/Syowa	5.9-6.9	2	11
EISCAT	6	4.6	10
South Pole	13	22.4	10

although neither study considered energetic particle bunching. Most of the studies, including that of *Engebretson et al.* [1992], noted that such pulsations are more often observed on the dayside. The fact that those presented here occur on the nightside during exceptionally quiet times may simply mean that a dipolar field is a requirement for these pulsations to exist. Both *Hughes and Grard* [1984] and *Engebretson et al.* [1992] concluded that the pulsations must be associated with localized effects, suggesting a high azimuthal wave number, in contrast to the low wave number noted in this study.

Lanzerotti et al. [1973] reported observations of pulsations that they attributed to excitation of MHD surface waves at the plasmapause. The data they presented showed that a magnetic disturbance observed as an impulsive change at higher latitudes was associated with a damped sinusoidal oscillation at lower latitudes with typical frequencies in the range of ~9 to ~12.5 mHz, similar to those reported here. The oscillations also appeared to have a very narrow spectral signature, and the authors concluded that they were associated with eigenmodes of the plasmapause. The pulsations in their case were observed only at very low latitudes ($L = 3.2$) and did not have the repetitious wave packet characteristic of the events reported here. On the other hand, the monochromatic signature in the range of ~9 to ~12.5 mHz in the vicinity of the plasmapause is similar to the data shown here, suggesting that the same (or similar) processes may be occurring in each case.

Of all the information that can be derived from the many and varied data sets, perhaps the most important feature that needs to be understood is the low azimuthal wave number of the pulsations observed on the ground over small ranges in local time. On one hand, the low wave number means that the phase of the wave must be nearly constant over this region of local time. On the other hand, the data also show that wave packets can have frequencies that are different at different local times. This apparent conflict might be understood if some sort of spatial boundary (consisting of meridional current sheets?) exists between adjacent wave packets. Alternatively, perhaps the pulsations have high wave numbers in space but their transmission through the ionosphere has a filtering effect that results in low wave numbers on the ground.

The data presented in this work show a number of features that have not been discovered in previous works. A thorough understanding of the process involved will require analysis of more events like these in order to characterize the event more completely. Once a number of events have been analyzed, statistics may be used to reduce the number of parameters associated with this type of event, after which it may be possible to isolate its essential features.

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B. J. Anderson, Applied Physics Laboratory, Johns Hopkins University, Laurel, MD 21218.

R. L. Arnoldy, Institute for the Study of Earth, Oceans and Space, Space Science Center, Morse Hall, University of New Hampshire, Durham, NH 03824.

M. K. Hudson, Department of Physics and Astronomy, Dartmouth College, 6127 Wilder Laboratory, Hanover, NH 03755-3528.

M. R. Lessard, Institute for Space Research, Department of Physics and Astronomy, University of Calgary, 2500 University Dr. NW, Calgary, Alberta, Canada, T2M 1N4. (lessard@phys.ucalgary.ca)

H. Lühr, GeoForschungsZentrum, Telegrafenberg, Potsdam D-14473, Germany.

G. D. Reeves, NIS-2, Mail Stop D-436, Los Alamos National Laboratory, Los Alamos, NM 87545.

N. Sato, National Institute of Polar Research, Itabashi–ku Tokyo, 173 Japan.

A. T. Weatherwax, Institute for Physical Science and Technology, Computer and Space Sciences Building, University of Maryland at College Park, College Park, MD 20742-2431.

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