OBSERVATIONS OF LOW FREQUENCY TERRESTRIAL TYPE III BURSTS BY GEOTAIL AND WIND AND THEIR ASSOCIATION WITH ISOLATED GEOMAGNETIC DISTURBANCES DETECTED BY GROUND AND SPACE-BORNE INSTRUMENTS

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Abstract

The low frequency (LF) terrestrial type III radio burst is a plasma wave emission that typically below 60 to 100 kHz has a smooth time profile and a negative frequency drift. After reviewing past observations, we will examine two LF burst events observed by both the GEOTAIL Plasma Wave Instrument and the WIND WAVES experiment while both spacecraft were in the solar wind and upstream from the Earth's bow shock but at widely separated locations. In both cases enhanced auroral kilometric radiation (AKR) was observed simultaneously with the LF burst by the spacecraft with the least obstructed view of the nightside magnetosphere. The CANOPUS ground magnetometer data and magnetograms from the National Geophysical Data Center (NGDC) show that the LF burst events are well correlated with the expansive phase onsets of intense isolated substorms detected by observing stations near local midnight. In the magnetometer data for GOES 8 we have found enhanced field aligned currents and magnetic field dipolarization observed simultaneously with a strong LF burst event. The recent launch of POLAR has allowed us to detect the AKR very near the source region. Details of the wave observations from WIND, GEOTAIL, and POLAR along with the ground and space magnetometer data indicate an intimate relationship between AKR, geomagnetic substorms, and LF bursts. We suggest that the dynamics of the substorms may be responsible for some of the observed time dispersion in the LF bursts.

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1 Introduction

A new type of low frequency (typically tens of kHz) terrestrial radio emission with a smooth time profile and a negative frequency drift was first studied by Steinberg et al. [1988, 1990] from ISEE-3 and ISEE-1 observations in the solar wind. The phenomenon was called isotropic terrestrial kilometric radiation (ITKR) because of its characteristics and apparent association with auroral kilometric radiation (AKR). Kaiser et al. [1996] used data from the WAVES experiment [Bougeret et al., 1995] on the WIND spacecraft to determine that the emissions also have a bursty high-frequency component which has much less frequency drift and extends up to 500 kHz. They preferred calling the phenomena LF (Low Frequency) bursts due to their similarity to Jovian "type III" bursts and their observation that the bursts often appeared isolated from AKR. All of the data used in their study came from the period November 12, 1994, to July 31, 1995, when WIND was predominantly in the solar wind and upstream from the Earth's bow shock. Using the list of LF bursts identified by the WIND WAVES team, we have examined the GEOTAIL Plasma Wave Instrument (PWI) [Matsumoto et al., 1994] data for the same time periods. From November 12, 1994, until late February 1995, GEOTAIL mainly traversed the downstream tail region with apogee extending out to about 50 R_e. In late February 1995 GEOTAIL was moved into a 10 R_e by 30 R_e inertial orbit with the initial apogee near dusk and moving towards noon at a rate of two hours of local time per month.

LF bursts have been identified in the GEOTAIL PWI data for nearly all of the cases on the WIND WAVES list. Many additional LF bursts have been identified in the GEOTAIL data prior to the WIND launch and even more have been identified in both the GEOTAIL and WIND data since the time of the original WIND WAVES study. The lower frequency portion of many of the bursts have the diffuse falling-tail characteristic of solar "type III" radio bursts except the LF bursts have a much shorter duration. These bursts typically have a five to ten minute duration above about 100 kHz and tens of minutes duration from about 100 kHz down to 30 kHz, the average solar wind plasma frequency near the Earth. The lower frequency part of the LF bursts shows almost no spin modulation which indicates a very large source. All other characteristics suggest that they are either a part of AKR emissions or intimately associated with them. Almost all of the GEOTAIL events were associated with active or enhanced AKR. Frequently the LF bursts would occur among a series of AKR bursts with progressively decreasing and then increasing lower frequency cutoffs. Several LF burst events have been clearly identified with strong isolated moving geomagnetic substorms detected by the CANOPUS ground magnetometers. The POLAR PWI [Gurnett et al., 1995], after its launch on February 24, 1996, has been able to provide AKR spectra near the source region simultaneously with the observations of LF bursts by GEOTAIL and WIND. We have also found indications of enhanced field aligned currents and magnetic field dipolarization observed by the GOES 8 magnetometer data simultaneously with a strong LF burst event. Using two or more appropriately located spacecraft we will show that the frequent isolation from AKR reported in the WIND WAVES study is most likely a propagation effect and not related to the generation of the LF bursts.

We will first examine in detail a LF burst event which was observed on April 14, 1996, by both GEOTAIL and WIND while both spacecraft were in the upstream solar wind but at widely separated locations. At the same time POLAR was at 6 R_e over the northern auroral zone. These observations from three spacecraft will also be compared with the CANOPUS ground magnetometer data and the GOES 8 magnetometer data while both the CANOPUS network and GOES 8 were near local midnight. The spacecraft and ground observing networks which provided data for this study are all parts of the International Solar Terrestrial Physics/Global Geospace Science (ISTP/GGS) program described by Acuna et al. [1995]. Another LF burst event observed by GEOTAIL and WIND that is well correlated with magnetograms from the National Geophysical Data Center (NGDC) will also be discussed.

2 Observations of the April 14, 1996, LF Burst Event

The first LF burst event we will study was detected around 0545 UT on April 14, 1996. GEOTAIL was slightly upstream in the solar wind just outside the subsolar bow shock at a radial distance, R, of 19.6 R_e (GSE X = 18.8 R_e, GSE Y = 4.6 R_e, and GSE Z = −1.6 R_e). The solar wind speed measured by the GEOTAIL Comprehensive Plasma Instrument (CPI) [Frank et al., 1994] was steady at about 430 km/sec (K. L. Ackerson, personal communication). Panel A of Figure 1 shows the two highest frequency bands of the PWI Electric Sweep Frequency Analyzer (SFA) data from 0500 UT to 0700 UT in a 50 dB dynamic range. The SFA has five bands and the frequency steps within each band are linearly spaced. The top two bands cover 12.5 kHz to 100 kHz, and 100 kHz to 800 kHz. The two roughly horizontal narrow bands near 30 kHz and 60 kHz identify the solar wind plasma frequency, F_p, and its second harmonic, $2F_p$. The local plasma frequency is the lower limit of the quasi-thermal noise line (the lower band). Reiner et al. [1996] have used WIND observations from a perigee pass in August 1995 to confirm that the $2F_p$ emissions (the upper band) are emitted from the Earth's electron foreshock region along a line tangent to the contact point. The sporadic band of emissions with a lower cutoff near 200 kHz at the beginning of the plot and reaching down to around 100 kHz at the end of the plot is AKR. Throughout the two hour time interval there are several instances when the lower cutoff (or a lower component) of the AKR extends below 100 kHz to near $2F_p$. The upper cutoff of the AKR observed during this two-hour interval by GEOTAIL ranges from 300 kHz to 400 kHz.

The LF burst is most prominent in the 60 kHz to 200 kHz range beginning about 0540 UT. A weak dispersed low frequency portion of the LF burst is evident from about 60 kHz ($\sim 2F_p$) near 0540 UT down to 30 kHz ($\sim F_p$) near 0545 UT. The LF burst somewhat above 60 kHz and especially above 100 kHz shows time dispersion in the opposite sense. The higher-frequency intensification (which may be AKR) begins around 100 kHz at 0540 UT and continues up to 400 kHz at 0545 UT. This prolonged rising feature of the LF burst is a new phenomenon we are just beginning to study.

At 0545 UT WIND was in the solar wind upstream of the Earth at R = 64.3 R_e (GSE X = 48.1 R_e, GSE Y = 42.5 R_e, GSE Z = −4.6 R_e). The solar wind speed measured by the WIND Solar Wind Experiment (SWE) [Ogilvie et al., 1995] was steady at about 440 km/sec. Panels B and C of Figure 1 are spectrograms from the WIND WAVES experiment's Radio Receiver Band 1 (RAD1) and Thermal Noise Receiver (TNR), respectively, for the 0500 UT to 0700 UT time period. The RAD1 spectrogram is plotted with a 50 dB dynamic range above the RAD1 noise level. The intense band extending from slightly above 50 kHz to about 500 kHz from about 0525 UT to about 0620 UT is AKR. The TNR spectrogram covers a 30 dB dynamic range above the TNR noise level. It clearly shows the F_p and $2F_p$ lines as well as the enhanced LF burst which began around 0540 UT. The portion of the LF burst above $2F_p$ is stronger than both the AKR around it and the lower frequency portion between F_p and $2F_p$. The lower frequency portion of the LF burst has the distinctive disperse falling tail. The positive frequency drift for the higher frequency portion of the LF burst is also evident. Please note that a very weak diffuse tail is also observed below the $2F_p$ band for about five minutes beginning around 0523 UT.

The electric field data from the POLAR PWI Sweep Frequency Receiver (SFR) for 0500 UT to 0700 UT are plotted over a 100 dB dynamic range in Panel D of Figure 1. Several enhancements of AKR are evident including one beginning about 0523 UT and another at 0540 UT. At 0545 UT POLAR was at 6.2 R_e over the Earth's northern polar region near local midnight at an invariant latitude of 72.5 degrees. The AKR burst beginning around 0523 UT extends down to 40 kHz and the one at 0540 UT extends down to near 30 kHz. Both extend up to over 500 kHz.

The 24-hour plot of the CANOPUS [Rostoker et al., 1995] key parameter CL data for April 14, 1996, is shown in Figure 2. CL is the lower trace of the envelope (extrema) of all magnetograms for the CANOPUS array. CL is the CANOPUS equivalent of the AL index except that the CANOPUS array is not world-wide. We have found that LF bursts are usually associated with strong narrow negative bays. Many were as deep as −800 to −1000 nT and some were deeper than −2000 nT. The negative bay observed in Figure 2 reached a minimum of about −970 nT between 0540 and 0545 UT.

The geographic north-south (X) component of the CANOPUS ground magnetometers from 0400 UT to 0800 UT on April 14, 1996, is plotted in Panel A of Figure 3. Panel B shows the high-pass filtered (f_c = 7 mHz) X-component data which highlights Pi2 oscillations associated with expansive phase onsets. Data showing examples of expansive phase onsets, can be found in Rostoker et al. [1995]. Full-scale for each station in Panel A is 850 nT and 130 nT in Panel B. In the time period from 0500 UT to 0700 UT we see that the Pi2 pulsations show an intensification shortly after 0500 UT, larger ones around 0523 UT and a huge intensification at 0540 UT. The unfiltered magnetometer data show that the associated geomagnetic disturbances, such as the sudden decreases in

Figure 1: (plate, next page) The time period for all four panels is 0500 UT to 0700 UT on April 14, 1996. Panel A is the GEOTAIL PWI SFA electric field data plotted on linear scales from 12.5 kHz to 100 kHz and from 100 kHz to 800 kHz. Panel B is the WIND WAVES RAD1 data plotted on a linear scale from 20 kHz to 1040 kHz. Panel C is the WIND WAVES TNR data plotted logarithmically from 4 kHz to 256 kHz. Panel D is the POLAR PWI SFR electric field data plotted logarithmically from 10 kHz to 800 kHz.

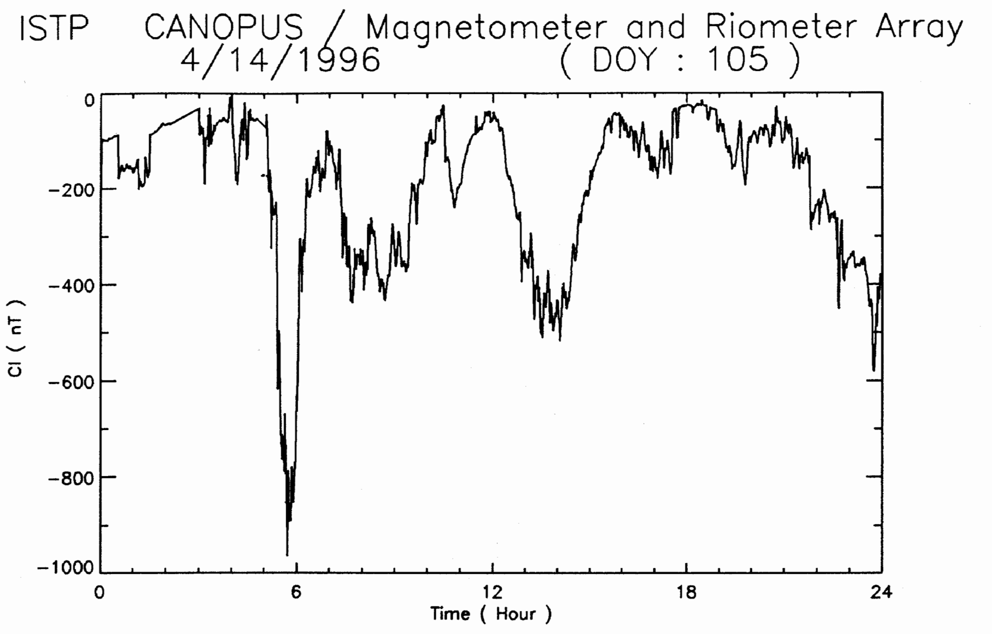

Figure 2: The CANOPUS magnetometer array Key Parameter CL index for the full 24 hours on April 14, 1996. Full scale is 1000 nT. The LF burst being studied was most intense between 0540 UT and 0545 UT.

the X-component data, are indicative of expansive phase onsets. The disturbances beginning around 0502 UT are primarily confined to only Island Lake (gmlat = 64.9°) and Gillam (gmlat = 67.4°) which are next to the lowest latitude stations on the Churchill line of magnetometers. The Churchill line consists of the first seven stations shown in Figure 3 which are located at geographic longitudes of 266 ± 2 degrees which is where local midnight occurs shortly after 0600 UT. The disturbances around 0523 UT are strongest at Gillam and Rabbit Lake (gmlat = 67.8°) which is near the same geomagnetic latitude but about one hour in magnetic local time west of the Churchill line. The disturbances at 0540 UT are the most intense at Fort Churchill (gmlat = 69.7°) and Rabbit Lake. The Fort Churchill X-component magnetometer data decreases 850 nT in about two minutes. Shortly thereafter a 500 nT decrease was measured at Eskimo Point (gmlat = 71.7°). The observation of the LF burst between 0540 UT and 0545 UT occurs when the geomagnetic disturbances are most intense and most poleward.

GOES 8 is a geosynchronous satellite which was located at 75 degrees west longitude. Figure 4 shows the high-time resolution GOES 8 magnetometer data for 0400 UT to 0700 UT on April 14, 1996. At 0500 UT GOES 8 was at about local midnight. The Hp axis is perpendicular to the orbital plane and thus is parallel to the Earth's spin axis. The He axis is perpendicular to the Hp axis and lies parallel to the satellite-Earth center line and points toward the Earth. The Hn axis is perpendicular to both Hp and He and points eastward. Ht is the total field. Details of the GOES 8 magnetometer experiment and information on interpreting its results can be found in Singer et al. [1996]. The first most notable features in Figure 4 are the two dramatic increases in the Hn-component shortly after 0500 UT and just before 0523 UT. Increases in the Hn-component are indicative of field-aligned currents (FACs). A second notable feature is the increase in

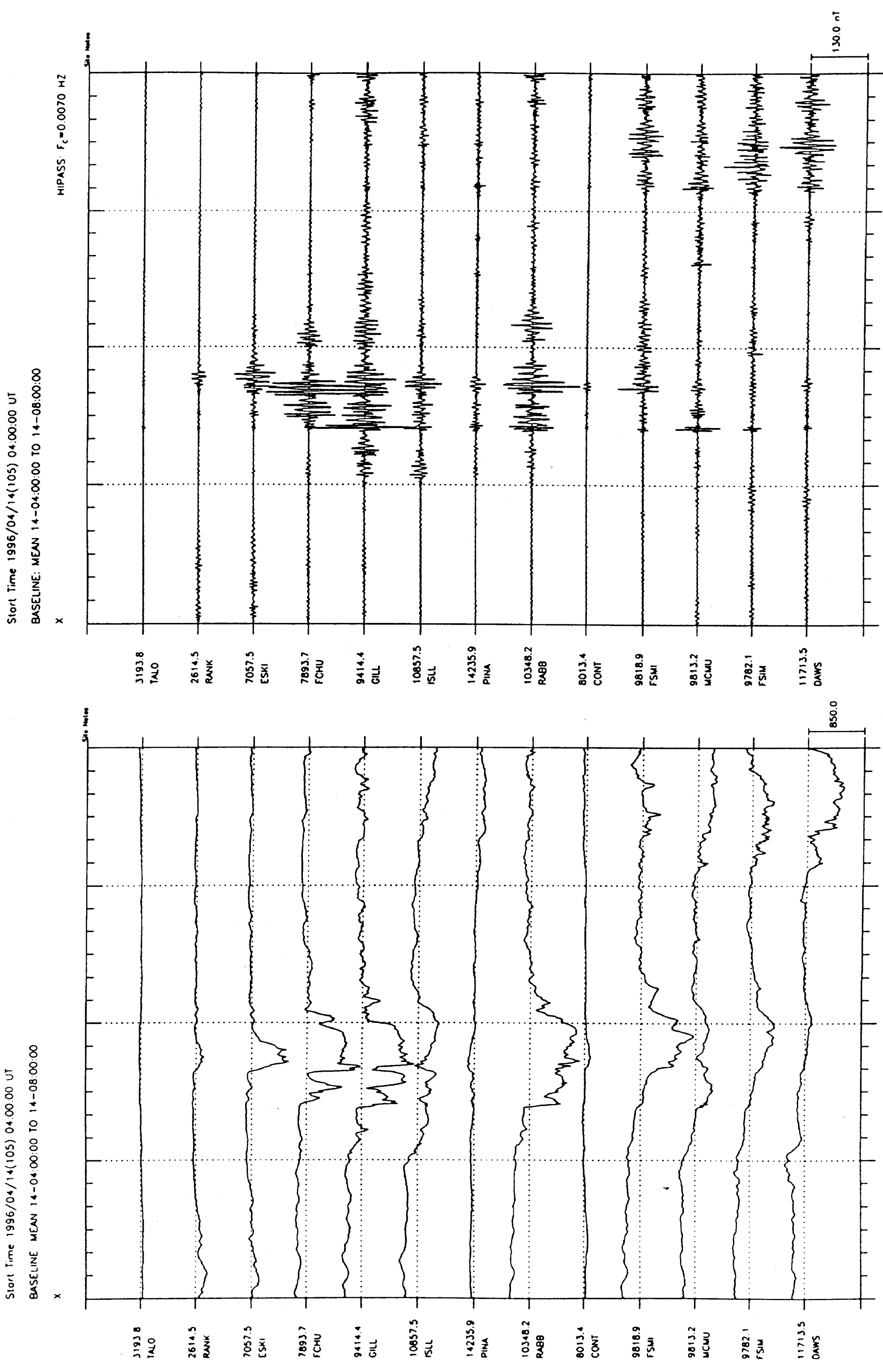

Figure 3: The CANOPUS array magnetometer north-south (X) component data for 0400 UT to 0800 UT on April 14, 1996. Panel A is unfiltered and Panel B is high-pass filtered with f_c = *7 mHz.*

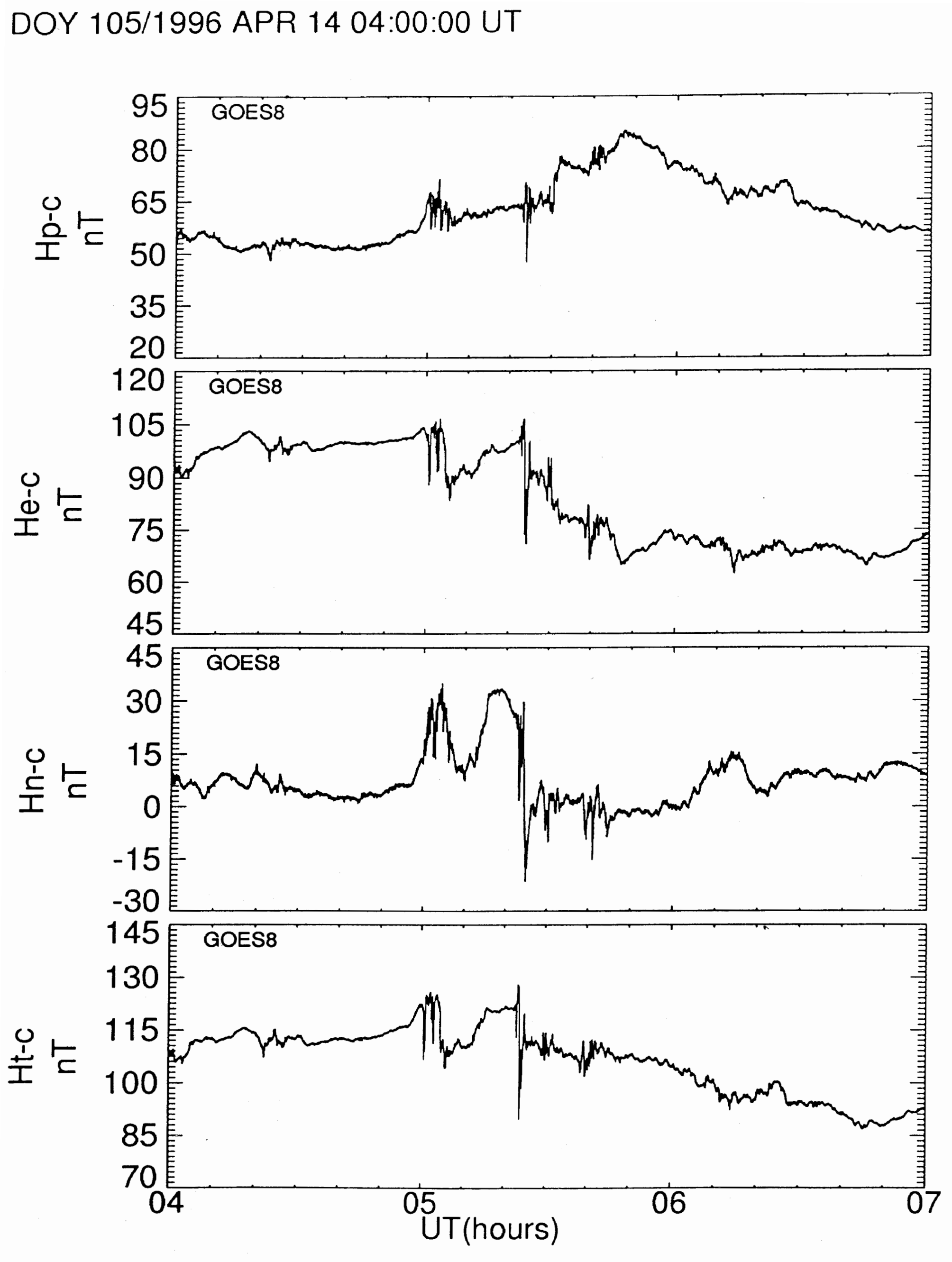

Figure 4: The GOES 8 magnetometer data for 0400 UT to 0700 UT on April 14, 1996. GOES 8 is in geosynchronous orbit at 75 degrees west longitude where local midnight occurs at 0500 UT. The axes are described in the text. Ht is the total field. Increases in the Hn-component are indicative of field aligned currents and increases in the Hp-component are indicative of magnetic field dipolarization.

the Hp-component which indicates a dipolarization of the magnetic field. The maximum dipolarization occurs between 0540 UT and 0550 UT, coincident with the observation of the LF burst. The third notable feature is the increase in high frequency structure in all the components that occurs between 0500 UT and 0545 UT.

3 Observations for March 5, 1995, LF Burst Event

We have primarily concentrated on LF bursts that occurred while the CANOPUS network was near midnight. Now we are able to retrieve ground magnetometer data from around the world from the NOAA National Geophysical Data Center (NGDC) site on the World Wide Web. The first case we examined was for the March 5, 1995, event around 2032 UT shown in Figure 1 of Kaiser et al. [1996]. The top panel of Figure 5 shows the GEOTAIL SFA data from 12.5 kHz to 800 kHz for the 45-minute time period beginning at 2000 UT. The middle panel shows the WIND WAVES TNR data from 20 kHz to 200 kHz for the same time period. The LF bursts beginning around 2003 UT and 2032 UT as well as the F_p and $2F_p$ emission lines are quite apparent in both the GEOTAIL and WIND data. The bottom panel shows the relative locations of GEOTAIL and WIND in the X-Y plane. WIND was very near the Earth-sun line 206 R_e directly upstream of the Earth. GEOTAIL was at R = 26.0R_e (GSE X = 8.4 R_e, GSE Y = 24.4 R_e, and GSE Z = 3.0 R_e) in the solar wind upstream of the Earth and far to the side of the Earth-sun line. While WIND shows very little AKR at the time of the LF bursts, GEOTAIL shows strong AKR amidst and surrounding each of the bursts. Both the wind SWE and the GEOTAIL CPI experiments measured steady solar wind velocities below 450 km/s. The University of Tromso, Norway, magnetograms from Tromso (Lat.: 69.6°, Lon.: 19.0°) and Bear Island (Lat.: 74.5°, Lon.: 19.2°) display very large deflections in the geomagnetic declination which begin around 2032 UT. Only a tiny deflection at least a factor of ten smaller was evident for the 2003 UT LF burst.

4 Discussion

We have identified a LF burst amidst AKR that was observed by both the GEOTAIL PWI and WIND WAVES experiments when they were in the solar wind. The POLAR PWI which was over the northern auroral zone detected the full AKR spectrum which included the upper and lower frequency limits of the observed LF burst. Since AKR is generated near the local electron cyclotron frequency, the higher the AKR frequency, the lower the altitude where it is generated. AKR at 400 kHz is generated near a geocentric radial distance of 1.6 R_e and 30 kHz AKR is generated near 3.7 R_e [Gurnett and Anderson, 1981]. The very highest frequency portion of the AKR spectrum was missing or attenuated at GEOTAIL.

The Earth and dense plasmasphere totally blocked or severely attenuated the AKR above 400 kHz from reaching GEOTAIL for this event since GEOTAIL was so close to the

Figure 5: (plate, next page) The time period for the two spectrograms covers 2000 UT to 2045 UT March 5, 1995. The top panel shows the GEOTAIL SFA data from 12.5 kHz to 800 kHz. The middle panel shows the WIND/WAVES TNR data from 20 kHz to 200 kHz. The bottom panel shows the relative location of GEOTAIL and WIND in the X-Y plane.

Earth-Sun line. Being far to the side of the Earth-Sun line, WIND was in a much more favorable position to intercept direct radiation from the AKR source region even though it was farther away. The complete AKR spectrum observed by POLAR was nearly fully detectable by WIND.

These observations showed that the LF burst occurred during a period of strong AKR activity and that the AKR showed enhancement in intensity and an increase in both the upper and lower frequency limits at the time of the LF burst. The LF burst occurred when the CANOPUS CL index reached its most negative value during a period of isolated but intense substorm activity. Excellent correlation was observed for the CANOPUS CL index and the AKR intensity detected at WIND. In the high resolution data from the various CANOPUS stations intensifications indicative of substorm expansive phase onsets were observed beginning around 0502 UT at a limited number of the lower latitude stations and progressively moved northward to around 0540 UT. The LF burst between 0540 UT and 0545 UT occurred when the geomagnetic disturbances were most intense and most poleward.

In the GOES 8 magnetometer data the high frequency structure began when the CL index first began to drop and continued until about 0545 UT when the CL reached its most negative value. The magnetic field dipolarization indicated by the Hp-component maximized about the same time that CL minimized. It was also during this time that the field-aligned currents inferred from the Hn-component were largest and fluctuating indicative of much spatial structure. The GOES 9 magnetometer located at 135 degrees west longitude several hours away in local time showed no deviations at the time of the LF burst in agreement with the CANOPUS observations that the geomagnetic disturbances were isolated. It should be noted that increased geomagnetic disturbances were also observed in the CANOPUS data and GOES 8 magnetometer data around 0523 UT when a weak dispersive tail characteristic of a LF burst was observed in the WIND WAVES data below $2F_p$. At the same time enhanced AKR was observed by the POLAR PWI.

The March 5, 1995, event further demonstrated that the lack of AKR being observed by WIND during a LF burst event was due to the AKR being blocked by the Earth and dense plasmasphere. Excellent correlations with isolated substorm activity detected by two high-latitude University of Tromso stations when they were near local midnight was also shown for this event.

We suggest that substorm dynamics may be responsible for some of the observed time dispersion. The time dispersion for both the high and low frequency portion of the LF bursts may be due to the movement and/or expansion of the AKR source region. If the more poleward excursion also corresponds to the disturbance moving to field lines that extend farther out into the magnetosphere, the local AKR frequency will decrease. Being further out from the Earth and dense plasmasphere allows more probability that the radiation can be detected. However, in order to make its way through the magnetosheath, it still may have to depend on reflections or scattering further downstream when the magnetosheath density becomes comparable to the solar wind density. The high frequency dispersion could also result from poleward movement of the geomagnetic disturbance. The magnetic field strength at a given altitude increases as one moves to a higher latitude. If the auroral particles generating AKR are able to reach the location with higher magnetic field strength, the AKR frequency will increase. Another possibility is that the AKR source region moves to lower altitudes at higher latitudes.

Desch et al. [1996] found that the occurrence of LF bursts were well correlated with the solar wind speed and somewhat less correlated with the azimuthal direction of the IMF. The LF bursts tended to occur in the sectors when the IMF was pointed towards the sun. They concluded that the LF bursts were a signature of a large-scale process of magnetospheric energy dissipation. They suggested a viscous-like interaction between the solar wind and the magnetosphere. Both of the LF burst events we have examined here did occur in a toward sector but the solar wind velocity of less than 450 km/s was definitely not higher than average.

5 Summary

The two cases we have discussed here show a strong correlation of the LF bursts with strong and isolated geomagnetic disturbances and enhanced AKR even during moderate solar wind velocities. We have offered a plausible explanation for the time delays due to the movements of the geomagnetic disturbances and the locations of where AKR is generated. We will continue to study multiple spacecraft and ground observations of the global activity that leads to observations of the LF bursts.

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