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Solar wind control of polar chorus

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Abstract. The intensity of chorus as observed at several high latitude ground stations in the Antarctic is highly correlated with the solar wind dynamic pressure exerted on the magnetopause boundary. In two different cases, intense chorus and associated precipitation measured as riometer absorption were abruptly interrupted by several minutes of deep quieting. Satellite measurements of solar wind dynamic pressure showed the intensity of chorus to rapidly respond to magnetospheric compression and relaxation over an extended region as evidenced by the fact the effect was observed at multiple sites.

Introduction

Chorus is an intense plasma wave that permeates magnetospheric regions between the plasmapause and the magnetopause and can be observed on the ground over a range of latitudes. It typically consists of repeating, usually rising and often overlapping coherent tones, occurs regularly in association with disturbed magnetospheric conditions and in conjunction with microburst electron precipitation [*Rosenberg et al.*, 1981], and is known to be a driver of pulsating aurora and maybe even the morningside diffuse aurora [*Inan et al.*, 1992 and references therein]. Chorus is thought to be generated via cyclotron resonance with energetic electrons in the 5 to 150 keV range [*Sazhin and Hayakawa*, 1992 and references therein].

Chorus that is generated within 1–2 R_E of the magnetopause may originate in local regions of minimum magnetic field strength that occur off the magnetic equator as a result of solar wind compression of the dayside magnetosphere [*Tsurutani and Smith*, 1977] and subsequently propagate to the ground in the polar regions. Consequently, polar chorus as measured on the ground is typically the most intense in the local noon sector, occurring in the frequency range of 400–1500 Hz [*Sazhin and Hayakawa*, 1992 and references therein]. Previous studies have shown that the compression of the magnetosphere during sudden commencement geomagnetic storms triggers chorus or increases its intensity [*Gail et al.*, 1990].

New evidence for direct association of chorus (observed in-situ) with solar wind parameters during an intense coronal mass ejection (CME) event was recently reported [Lauben et al., 1998]. In this paper, we report further evidence of direct control of the intensity of chorus (observed on the ground) by the dynamic pressure exerted on the magnetospheric boundary by the solar wind, with emissions literally turning on/off in response to increases/decreases in pressure. Observations of the effect at multiple distributed ground sites indicate that the solar wind control takes place in a large magnetospheric region. Simultaneous turn-offs of riometer absorption confirm that much of the precipitation in this region is indeed driven by chorus.

We focus on results from two study periods, February 23, 1997 and April 11, 1997, the latter being a CME disturbance. On both days, intense chorus activity was interrupted by periods of deep quieting lasting several minutes and associated with reductions in dynamic pressure.

Data Sets Used

The network of Automatic Geophysical Observatories (AGO) in Antarctica with coverage from the auroral zone to the polar cap is well positioned for ground-based observations of polar chorus. Figure 1 shows the locations of AGO stations P1–P4 and South Pole station with respect to the International Geomagnetic Reference Field (IGRF–1995). The location of the auroral oval when the stations are near magnetic noon is also shown [*Feldstein and Starkov*, 1967]. At each site, an ELF/VLF receiver system records, continuously in multiple narrowbands as well as in broadband snapshots, wave activity incident upon North/South and East/West crossed loop antennas [*Shafer et al.*, 1994]. Complementing the ELF/VLF recordings at each site are IRIS imaging riometers [*Detrick and Rosenberg*, 1990] which provide a sky map of the ionospheric absorption of cosmic noise that results from energetic particle precipitation into the lower ionosphere. The AGO array typically observes the diurnal pattern of ELF/VLF events as reported by *Morozumi* [1967] with chorus being observed for many hours around magnetic noon and associated with ionospheric absorption.

Solar wind conditions were assessed using data from the three-dimensional plasma (3DP) [*Lin et al.*, 1995] and the magnetic field (MFI) [*Lepping et al.*, 1995] instruments aboard the WIND satellite in conjunction with similar measurements by the comprehensive plasma (CPI) [*Frank et al.*, 1994] and magnetic field (MGF) [*Kokubun et al.*, 1994] instruments on Geotail. The satellites provide two independent measurements of the prevailing conditions in the solar wind as well as verification of event timing.

Case 1: 23 February 1997

On February 23, 1997, low level chorus activity began around 1000 UT at three stations, P2, P3, and SP, and gradually increased in intensity for several hours. Broadband

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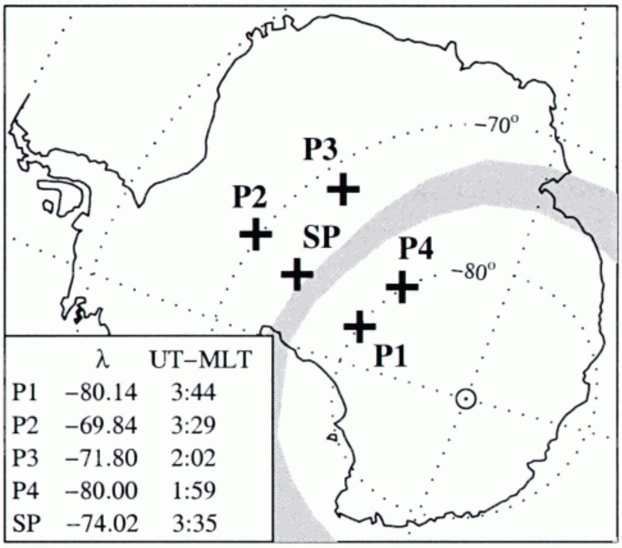

Figure 1. Locations of the AGO stations P1–P4 and South Pole. The legend shows the magnetic latitude, λ, and the difference between universal and magnetic local time, UT–MLT. The antenna orientation is identified at each site, with the vertical line representing the North/South antenna and the horizontal line the East/West antenna.

measurements for 1 minute each 15 minutes from South Pole, Figure 2, show the overall chorus activity for this day. Chorus was not detected at P1 and P4 until about noon UT and stayed at much lower levels throughout the period of interest. The peak intensity of 50 μV/m at P2 represented some of the most intense chorus measured at these sites, especially during the austral summer. At each of the sites, the chorus intensities on the two antennas were relatively equal. However, at P1 and P3 the chorus recorded on the N/S antenna was accompanied by VLF hiss, with the levels at P1 being quite intense until 1400 UT.

Starting at 1330 UT there were several sudden decreases in chorus activity that were evident at all five stations, the most dramatic occurring several minutes after 1400 UT (Figure 3). At P2 the signal level dropped 20 dB in 10 minutes, remained at a low level for 5 minutes, then recovered rapidly to the previous intense value. Similar signatures were measured at the other stations. Figure 4 shows the dropout effect as observed in AGO broadband snapshot data, also confirming that the waves involved were indeed chorus emissions.

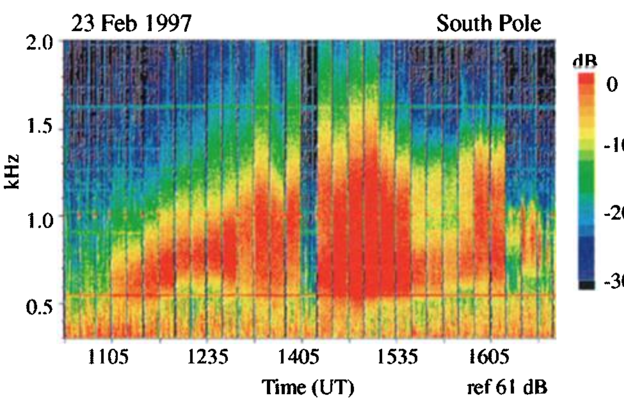

Figure 2. South Pole broadband recordings show the entire duration of chorus activity for February 23, 1997. The system records for 1 minute each 15 minutes on the N/S antenna.

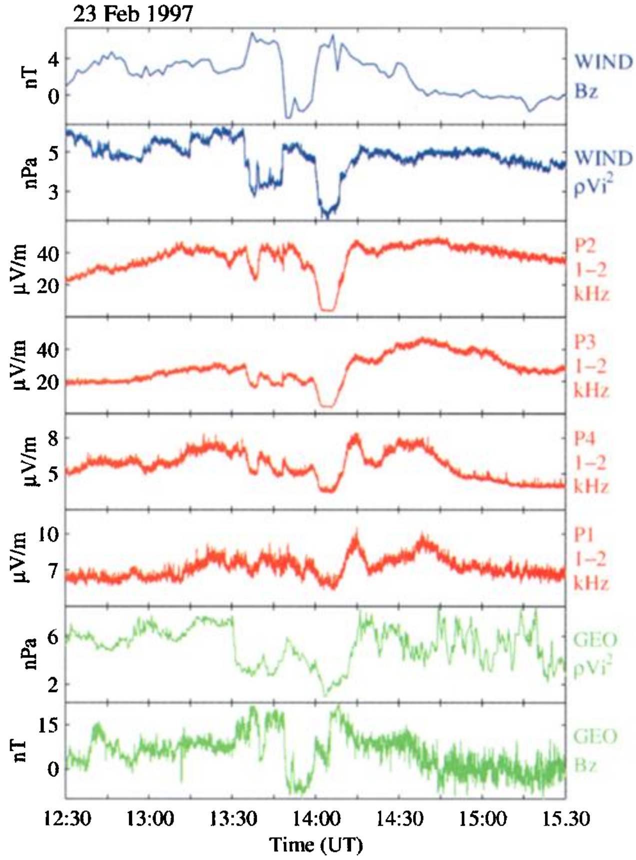

Figure 3. Narrowband recordings from the 1–2 kHz E/W channel are shown with time aligned solar wind data for the February 23, 1997 case.

During this period the WIND satellite was located at 213 R_E sunward of the Earth while Geotail was located 13.5 R_E behind the earth in the nightside magnetosheath region. Figure 3 shows the dynamic pressure and the magnetic field B_z component measured by the satellites, time aligned with the ground station data. The measurements at Geotail are distorted with respect to those measured at WIND due to its position in the turbulent magnetosheath; however, prominent features are still visible. The travel time delay between the satellites was estimated to be 55 minutes, and for alignment with ground data the WIND measurements were shifted +47 minutes and the Geotail measurements −8 minutes consistent with alignment of visible features and satellite measurements of solar wind velocity.

The chorus intensity was correlated with the solar wind dynamic pressure, and the deep quieting in chorus at 1400 UT, as well as the smaller drops, were associated with pressure relaxation. For the one hour period from 1330 to 1430 UT, the correlation coefficient between WIND dynamic pressure and each of the AGO 1–2 kHz channels lies between 0.66 and 0.76, and for Geotail, from 0.62 and 0.67. The interplanetary magnetic field was northward throughout most of the period except for a brief interval just prior to the largest chorus dropout.

Next we examine the relationship between the ELF chorus activity and electron precipitation. First, we note that no measurable absorption was detected at the highest latitude sites (P1, P4). However, absorption at the level of 0.1–0.2 dB was measured at P2 and P3 (Figure 5), the lowest latitude sites, where the ELF chorus intensity (Figure 3) was also at its highest. Some weaker precipitation was also detected at the intermediate location of SP (not shown). Depicted in Figure 5 are riometer absorption data in riogram format (distance at 90-km altitude along the geomagnetic meridian versus time) and 1–2 kHz narrowband ELF recordings for P2 and P3, showing a correlation between particle precipitation and polar chorus. In particular, the dramatic decrease in chorus at 14 UT corresponded to a turn off of particle precipitation, as the absorption decreased to its lowest value. Several smaller decreases in absorption were also evident during other decreases in chorus activity.

The lack of measurable absorption at P1 and P4 is consistent with the fact that these higher latitude sites are likely to lie under open field lines. Chorus is typically generated on closed field lines which connect to equatorward ionospheric regions and was likely observed at P1 and P4 as a result of propagation in the Earth-ionosphere waveguide.

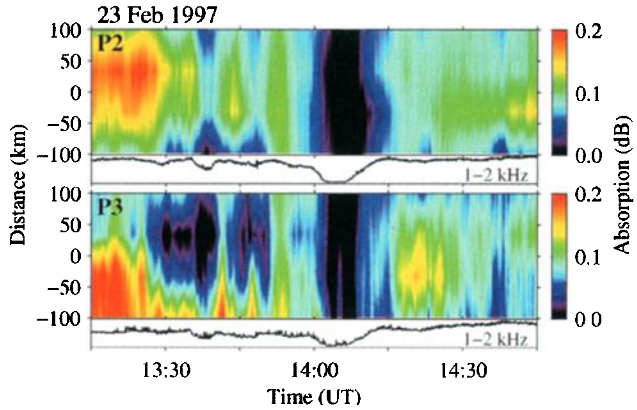

Figure 5. Riometer absorption and 1–2 kHz narrowband ELF data recorded at P2 and P3. The riometer data are displayed in riogram format, where the ordinate is depicted as meridional distance at a 90-km altitude range (D region) with south (north) at the top (bottom), UT time is along the abscissa, and color as given by the bar is proportional to absorption in decibels (dB).

Case 2: 11 April 1997

During a CME-induced disturbance on April 11, 1997, chorus was observed at P2, P3 and SP for over eight hours with unusually variable intensity. The wave activity was quiet at P1 and no data were available from P4. Both WIND and Geotail were in the interplanetary medium upstream from the Earth at 230 R_E and 16 R_E respectively. Figure 6 shows a high correlation between the chorus intensity and solar wind conditions over a period of several hours. Identical features in the solar wind dynamic pressure seen by the two satellites allowed for precise alignment of the satellite and ground data. The average time delay between WIND and Geotail throughout this period was approximately 54 minutes, with another 5 minute delay before features were seen on the ground. The correlation coefficient was calculated for the entire five hour period and was found to be from 0.63 to 0.74 between each of the satellites and the 1–2 kHz channel at P2 and P3.

In this study period the B_z component was northward, but its magnitude did not appear to affect chorus activity. From 1400 to 1600 UT, B_z remained nearly constant while the time adjusted dynamic pressure fluctuated in synchronism with the chorus intensity.

As on February 23, 1997, the decreases in chorus intensity at P3 and SP stations correlated well with precipitation drops (not shown), particularly the sharp drop at 1500 UT. Data from P2 was inconclusive for this case, due to high levels of background noise.

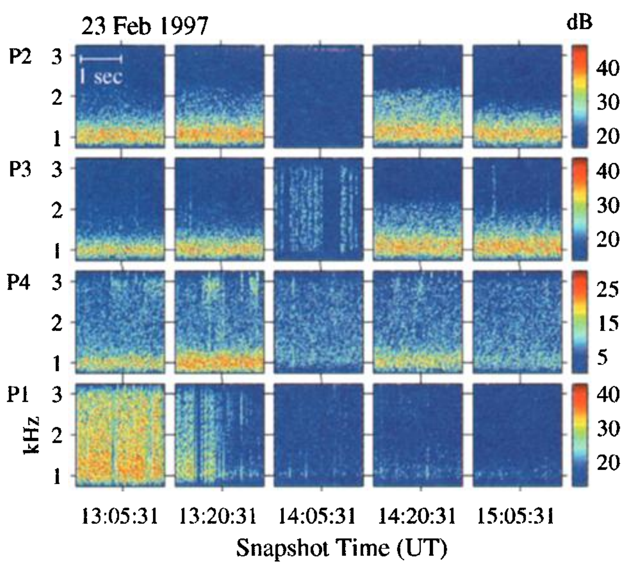

Figure 4. Broadband snapshot recordings from the N/S antenna capture the chorus dropout at 1405 UT. Intense hiss was detected at P1 on the N/S channel until 1405 UT.

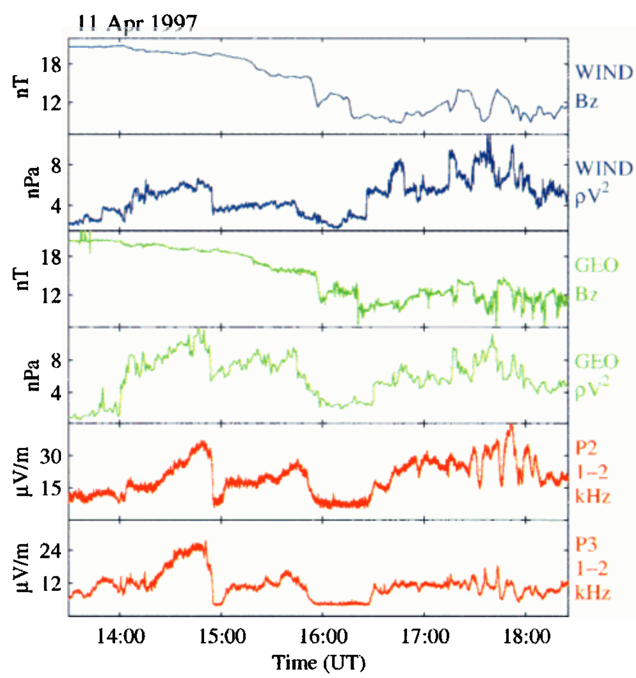

Figure 6. Time aligned solar wind and ground-based chorus data for the April 11, 1997 case.

Discussion

There have been a number of past studies of the association between chorus and precipitation bursts, as measured via x-rays, riometers or by optical methods. In particular, *Rosenberg et al.* [1981] detailed the correlation between chorus and x-ray bursts in opposite hemispheres to conclude that chorus drives the precipitation via cyclotron resonant pitch angle scattering, and also discussed the possibility that the chorus wave growth region might be separate (and involve different electron energy and pitch angle distributions) from the pitch angle scattering region out of which electrons precipitate to cause the x-rays or riometer absorption. Thus, elevated dynamic pressure could lead to enhanced (trapped) electron flux which drives chorus wave growth. The chorus then scatters electrons of the appropriate energy. Relaxation of the pressure then cuts off the conditions for wave growth, and precipitation ceases.

In this study, riometer absorption decreased simultaneously with chorus indicating that the particle precipitation observed at the auroral stations, P2, P3 and SP was driven by chorus. At the high latitude stations, P1 and P4, chorus amplitudes were significantly reduced and did not correlate with precipitation. Chorus observed at these sites was likely generated on closed field lines terminating at ionospheric points equatorward of the sites and subsequently propagated to P1 and P4 within the Earth-ionosphere waveguide.

When the stations P2, P3 and SP are in the magnetic noon sector, they are connected to field lines containing source regions of chorus. Propagation to the ground is assumed to be ducted, since the wavenormal angle must be small in order for the signal to penetrate the sharp lower ionospheric boundary. Directional antennas indicate that chorus penetrated to the ground over a large area. Results from these two study periods indicate that ELF chorus intensity can be controlled directly by the solar wind dynamic pressure confirming similar in-situ observations [Lauben et al., 1998]. The response of chorus is fast with respect to sudden changes in pressure and control apparently takes place over an extended magnetospheric region as implied by the fact the effect is observed at multiple stations. Solar wind control can persist for extended periods as evidenced by the fact that for the CME disturbance case, correlation between chorus and solar wind dynamic pressure existed for over five hours.

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