Whistler-triggered VLF noise bursts observed on the DE-1 satellite and simultaneously at Antarctic ground stations

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ABSTRACT. Whistler-triggered bursts of very low frequency chorus in the 5-7 kHz range, occurring quasi-periodically every 3-5 min, have previously been observed at ground stations under conditions of relatively deep quieting following moderate magnetic disturbance. It was found that these wave bursts propagate outside the plasmapause and that they can induce detectable electron precipitation at ionospheric *D*-region altitudes. In this paper we report simultaneous observations of such wave events on the ground at Antarctic stations Halley and Siple ($L = 4.3$) and on the high altitude satellite DE-1. In a case study from 25 June 1982 the satellite data were recorded near 25° south magnetic latitude and the $L = 4.7$ magnetic shell. Analysis indicated that the waves detected on DE-1 were predominantly the result of downward ducted propagation from a triggering region followed by reflection at low altitudes, with the signals reaching the satellite in a nonducted mode. Comparisons of nonducted signals from the Siple transmitter received on DE-1 and simultaneously observed discrete periodic emissions provided a means of estimating the propagation characteristics of the wave bursts. Direct wave propagation from the generation region of the noise bursts to the satellite was not observed. The ducted-nonducted mode conversion process provides a means by which signals generated, triggered or amplified in small localized ducts can spread into much larger regions of the inner magnetosphere. The DE-1 data provided evidence of a strong interaction between whistler-triggered noise bursts and prevailing hiss levels. However, this hiss was not detected at the available ground station (Halley).

Key words : whistler-triggering, chorus, ducted propagation.

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1. INTRODUCTION

One of the aims of the Dynamics Explorer Mission was to « study wave, particle and plasma interactions in the ionospheric and magnetospheric plasmas » (Hoffman and Schmerling, 1981). A powerful technique for this study is the wave injection experiment involving VLF transmissions from Siple station and reception by the Linear Wave Receiver (LWR) on the DE-1 satellite. (Shawhan *et al.*, 1981 ; Inan and Helliwell, 1982). Wave injections were carried out during May-August 1982 when the apogee (23400 km) of the high altitude polar orbiting satellite was in the vicinity of the magnetic equator, so that its orbit was almost parallel to geomagnetic field lines in the range $L = 4\text{-}5$. During this time the satellite was also very well placed for investigating natural plasma wave phenomena in the inner magnetosphere, especially in coordination with ground stations located near $L \sim 4.3$, such as Siple or Halley stations in Antarctica. (During wave injection experiments from Siple, passive VLF recordings could be made at Halley but not at Siple.)

DE-1 provides a particularly favourable opportunity to study the $L = 4\text{-}5$ region of the magnetosphere at high altitudes. Most previous satellites carrying wave experiments have been at lower altitude, or in geostationary orbit, or in the case of high altitude satellites have passed through this region relatively quickly.

In this paper we present the results of a case study involving simultaneous wave data from DE-1 and ground stations, principally Halley. The interval of study was chosen by first sampling DE-1 data acquired during the period 19 June-18 July 1982 (when conjugate VLF recordings were made at Halley and St Anthony, Newfoundland) at times when the satellite was in the Halley/Siple longitude sector. DE-1 was typically at least 20 degrees of magnetic longitude west of Halley at these times, as shown in figure 1(*b*), since the data acquisition intervals were scheduled for conjugacy with Siple. In 9 out of the 12 samples there was little or no similarity between the ground and satellite data. In the other 3 cases, one of which is discussed in detail here, correlated bursts of chorus-like noise, triggered by whistlers propagating outside the plasmasphere, were observed. Ground observations of such bursts have been described before (Carpenter, 1978), and have been associated with burst precipitation of energetic electrons into the lower ionosphere (e.g. Helliwell *et al.*, 1980; Dingle and Carpenter, 1981). The phenomenon has not, to our knowledge, been previously reported in high-altitude satellite data, though a somewhat similar case has been identified in Explorer-45 data and will be reported in a separate paper.

Analysis suggests that the chorus bursts were triggered in whistler ducts, in which they subsequently travelled downwards to low altitudes in the ionosphere (and thence to the ground); propagation to DE-1 was by upward reflection into a nonducted mode. The degree of spreading of the nonducted wave energy can be inferred from the relative duration times of the burst activity as observed on the ground and along the DE-1 trajectory.

This ducted to nonducted mode conversion process (Thomson and Dowden, 1978; Bell *et al.*, 1983) is closely related to the duct-duct coupling responsible for mixed-path whistler effects (Smith and Carpenter, 1982). It is believed to be a potentially important mechanism for the large scale spreading into the magnetosphere of coherent whistler mode wave energy which has been generated, amplified or triggered in small localised ducts. A possibly related result was reported by Molchanov *et al.* (1983), who studied data on 10.2-13.6 kHz Omega signals from Aldra, Norway, recorded at 500-1000 km altitude over Europe on Interkosmos 19. On occasion they found that two-hop signals, apparently propagating in a nonducted mode after reflection in the conjugate hemisphere, were observed over a larger spatial region than were the direct upgoing signals.

2. DATA DESCRIPTION

In our case study of 25 June 1982 we have made use of analogue broadband VLF wave data acquired at three Antarctic ground stations and with the plasma wave instrument on board the DE-1 satellite. The magnetic conditions were ones of relatively abrupt quieting following moderate disturbance.

The ground stations involved were Halley (76° S 27° W, $L = 4.3$), Siple (76° S 84° W, $L = 4.3$) and Palmer (65° S 64° W, $L = 2.3$). Continuous data were available from Halley for the entire period of the study (2030-2140 UT), whereas at Siple the transmitter was switched on at 2038 UT and passive recordings were made only until that time. Plasmaspherically propagating whistlers observed at Palmer helped to estimate the plasmapause radius, and we referred to data from the northern hemisphere stations Roberval (48° N 72° W, $L = 4.3$) and St Anthony (52° N 56° W, $L = 4.3$) for assistance in identifying the source atmospherics for the whistlers which triggered noise bursts.

The plasma wave instrument on DE-1 has been described in detail by Shawhan *et al.* (1981). We use data from the Stanford University Linear Wave Receiver (LWR) operating in its 3-6 kHz passband mode and connected to the magnetic loop antenna which was oriented so as to respond to the wave magnetic field components perpendicular to the spacecraft spin axis (the spin period was 6 s, about an axis normal to the orbit plane). For the case discussed here the LWR was operated in its automatic gain mode in which the receiver gain varied in discrete steps of 10 dB, with gain changes possible at 8 s intervals.

During the time of the reported observations, DE-1 was in the southern hemisphere and was moving northwards towards apogee, which occurred at 2230 UT when the spacecraft was at : latitude = 6.9° S (magnetic dipole latitude 3.8° N), longitude = 90.2° W, $L = 4.7$, $LT = 16.5$ h. The orbit of DE-1 was such that when apogee was near the equator, as in this case, the spacecraft remained close to the 4.65 L-shell for about 4 hrs; this is illustrated in figure 1(*a*). Furthermore, the high inclination and slow precession of the orbit meant that DE-1 remained at almost constant local time (on time scales of a few hours) and thus moved steadily westward in longitude. This is shown in figure 1(b), in which the satellite trajectory, mapped along dipole magnetic field lines into the geostationary magnetic equatorial plane, is shown in relation to the intersection with this plane of field lines through the ground stations.

The point « S » in figures 1(*a*) and (*b*) marks the start at 2040 UT of data acquisition from the satellite. Precise measurement of arrival time differences between ground and satellite receivers required the use of time codes recorded on the data tapes; in the case of the DE-1 data, a small correction (70 ms) was necessary to allow for the telemetry propagation delay.

3. DE-1 AND GROUND OBSERVATIONS ON 25 JUNE 1982

Whistler-triggered noise bursts

Figure 2 shows the LWR data in a compressed time scale format from the start of data acquisition at 2040 UT until 2058 UT. The upper panel is a 2-7 kHz spectrogram, and the lower panel shows the wave amplitude in a 2 kHz wide passband centred on 5.5 kHz, plotted on a linear scale. The reduced signal levels near the upper and lower edges of the spectrogram are mainly due to the passband of the receiver (3-6 kHz). The 10 dB gain steps are indicated by G_+ and G_-.

As shown in figure 2, six noise bursts were observed, each characterised by a sudden intensification and spectral broadening of the noise centered at 5.5 kHz. The bursts occurred roughly three minutes apart, at times which are marked by the star symbols. Closer examination reveals that the bursts were triggered by whistlers. This is illustrated in figure 3(*a*), a spectrogram of the event which occurred at 2041 : 28 UT. Two somewhat diffuse whistler components were followed by a 20-30 s long chorus-like burst consisting of closely spaced rising elements in the frequency range 4.5-

6.5 kHz. A pre-existing hiss band was seen at 5-6 kHz but the additional wave energy released by the triggering process resulted in sudden enhancement (by a factor of 2 in amplitude) of the total intensity seen by the satellite receiver, together with a slight increase in bandwidth. During the most intense burst, at 2051 : 48 UT, the wave intensity integrated across the band 4.5-6.5 kHz reached 0.4 pT rms.

A somewhat different triggered burst was seen at nearly the same time on the ground at Halley (fig. 3(*b*)). The characteristics of the bursts as observed from the ground are best discussed by reference to a slightly earlier event at 2035 : 08 UT, illustrated in figures 3(*c*) and (3(*d*), which was very similar to the 2041 UT event as far as Halley was concerned, but for which data from Siple were also available. There were, however, no DE-1 data acquired at that time.

On the Siple record, figure 3(*c*), we see what appear to be two whistler traces, with separation and dispersion in the 3-6 kHz band similar to those of the DE-1 whistler traces of figure 3(*a*), followed by a long enduring chorus burst similar to that observed by the satellite. The hiss band, prominent in the DE-1 data, was not detected at either ground station.

Differential time delay measurements showed that the whistlers were detected on the ground ~ 350 ± 20 ms earlier than on the satellite. The significance of this in terms of propagation paths will be discussed in Section 5.

High resolution spectrograms (not shown) indicate that the first whistler trace consists of three closely spaced « knee » components, inferred to have been propagating just outside the plasmapause at an L-value of about 3.7. The second trace is composed of about ten individual whistler components each of which is detectable only in a narrow frequency range near its nose frequency; these components propagated on paths outside the plasmapause in the range $L = 4.0\text{-}5.2$. It is not clear from the data which of these paths was associated with the triggering.

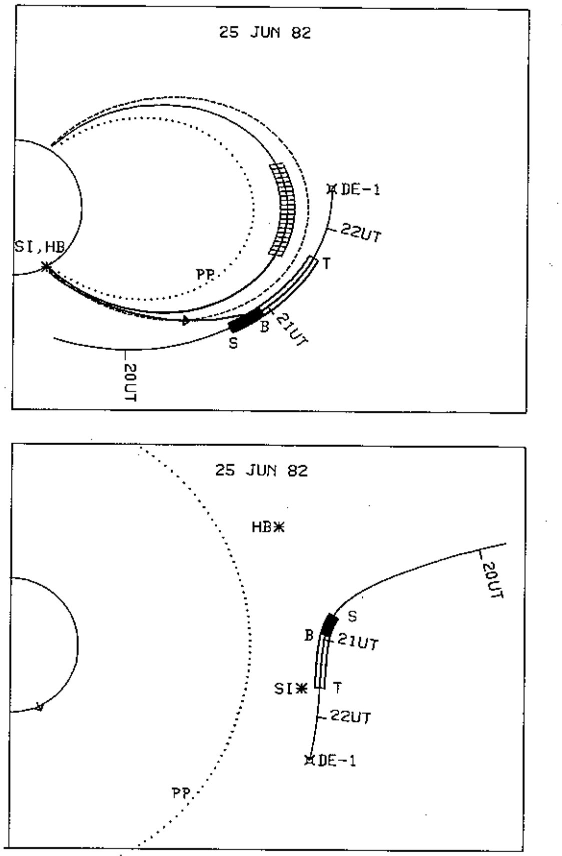

Figure 1

(a) Sketch showing in a meridional plane the orbital track of the DE-1 *satellite on* 25 *June* 1982, 20-22 UT. « S » *marks the start of the data acquisition. The noise bursts discussed in the text were observed on* DE-1 *until the point marked* « B », *and transmissions from Siple were seen until the point marked* « T ». *We show a possible path to the satellite from the triggering region (shaded), which involved a combination of ducted and nonducted propagation. The plasmapause* (PP) *is shown dotted, and the Halley/Siple L-shell (in a dipole field model) is shown dashed. (b) Similar to (a) but showing the projection in the magnetic equatorial plane, produced by mapping along dipole field lines. This shows that the satellite moved westward at almost constant L, passing the longitude of Siple somewhat after the noise bursts were observed.*

At Halley, figure 3(*d*), an essentially similar version of events was observed, except that the knee traces were barely discernable on the record, and the triggered chorus burst was less intense and of shorter duration than at Siple. The latter suggests that the triggering region was closer in longitude to Siple than to Halley. We also note, beginning at 2035:18 UT, periodic

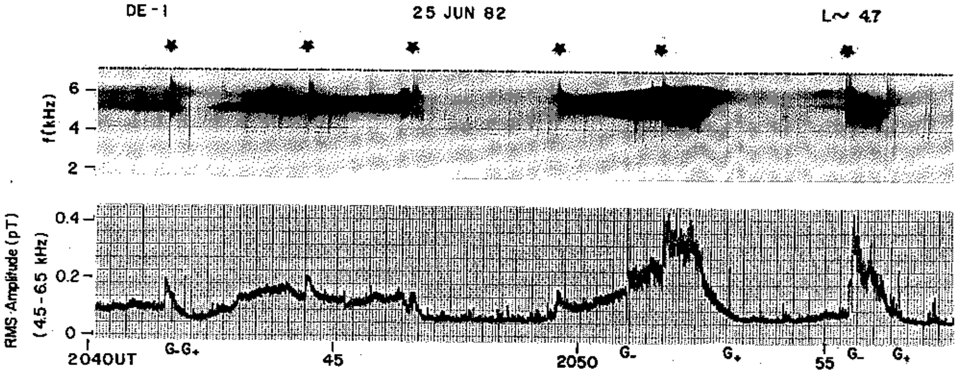

Figure 2

Compressed time scale record, covering the period when the noise bursts were observed on DE-1 *on* 25 *June* 1982; *each burst is marked by a star. (*10 dB *steps in receiver gain, marked by* G_+ *and* G_-, *have been compensated by* 10 dB *gain changes in the playback system gain, resulting in spurious transients at these times.) (a)* 2-7 kHz *spectrogram. The nominal receiver passband was* 3-6 kHz *though strong signals extended beyond this, e.g. the whistler at* 2041 :28 UT. *Besides the whistlers and the bursts which they triggered we also see on the record an intermittent hiss band at* 5-6 kHz, *often double banded. This hiss band was sometimes suppressed by the bursts, e.g. those at* 2041 : 28 UT *and* 2046 : 33 UT. *(b)* RMS *wave amplitude, integrated over the frequency range* 4.5-6.5 kHz.

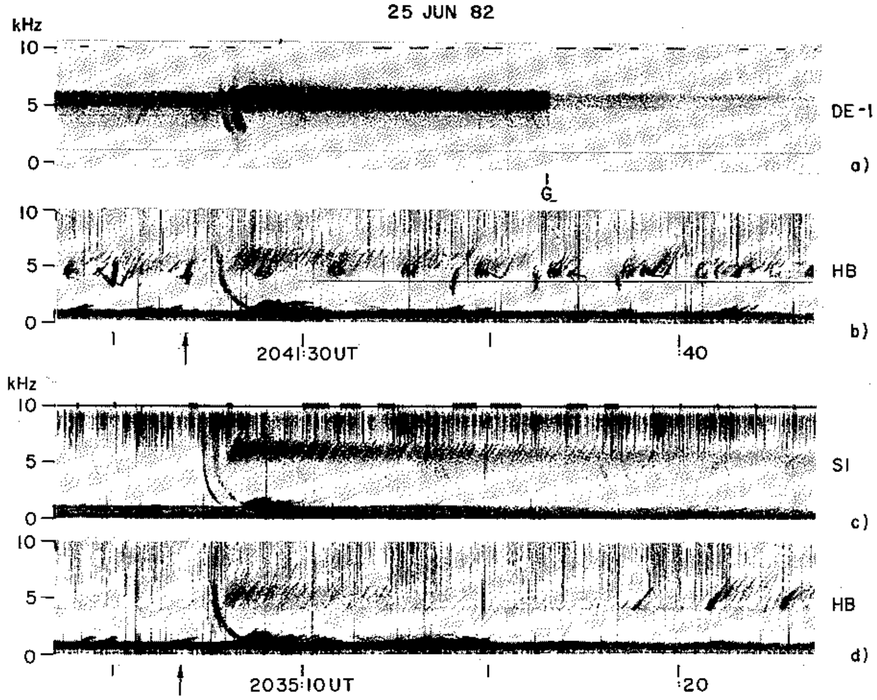

Figure 3

Examples of the triggered noise bursts, shown in 0-10 kHz *spectrogram format. (a) The* 2041:28 UT *event observed on* DE-1. *(b) The same event at Halley. (c) The* 2035:08 UT *event observed at Siple. (d) The same event at Halley. Note also periodic risers beginning at* 2035:18 UT *and not seen at Siple.*

emission activity (period ~ 2 s) in the same frequency range but on a path nearer to Halley.

Figure 4 shows the event at 2046:33 UT, illustrating more clearly the structured nature of the bursts, though in this case the whistler traces are less well defined. Here three whistler traces are seen on the DE-1 record (fig. 4(*a*)) : the first two correspond to the two seen in figure 3(*a*), while the third is a unique trace seen only in this event. The two traces seen at Halley, figure 4(*b*), correspond to the second and third DE-1 traces. We also show here the record from Palmer (fig. 4(*c*)), which exhibits several lower latitude plasmaspheric whistler traces originating from the same atmospheric (marked by the arrow) as the components seen by Halley and DE-1 which travelled in the plasma trough. The plasmaspheric paths extend out to $L = 2.8$, consistent with the plasma pause radius $L_{pp} \simeq 3.5$ estimated from the Siple whistlers.

Narrow band emissions and echoing effects

Periodic activity in the form of discrete narrow band risers and hooks, mentioned above in connection with figure 3(*d*), also exhibited a high degree of correlation between the ground and the satellite. An example is shown in figures 5*a*) and 5(*b*); the discrete elements seen on DE-1 are an almost exact replica of those seen at Halley.

VLF signals from the Siple station transmitter were also received on DE-1 at this time. (The transmitter format is evident on the record from Halley, where the subionospheric signal is received ~ 5 ms after transmission.) For example, the 500 ms long 3.77 kHz pulse transmitted at 2057:24 UT was received with a well defined beginning and end. This permitted a precise measurement of the ground-to-satellite propagation time of the Siple signal at this frequency. The result,

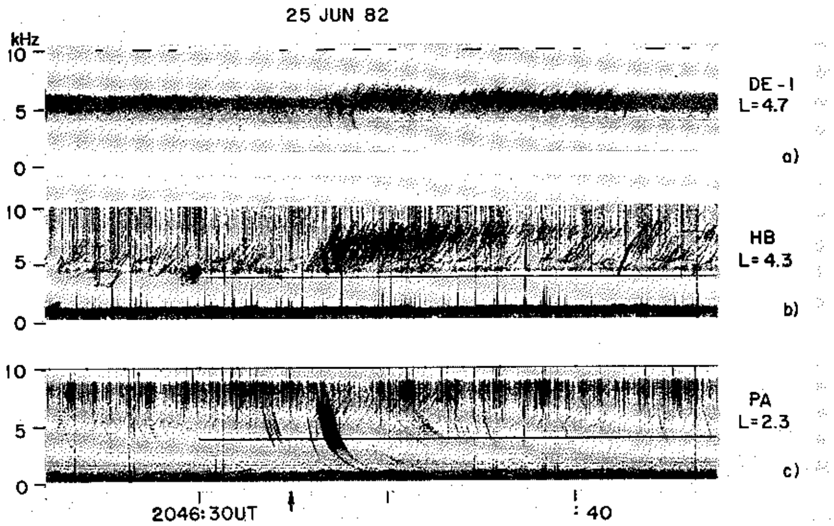

Figure 4

The same format as figure 3, *showing the* 2046:33 UT *burst, as observed at. (a)*DE-1, *(b) Halley, (c) Palmer.*

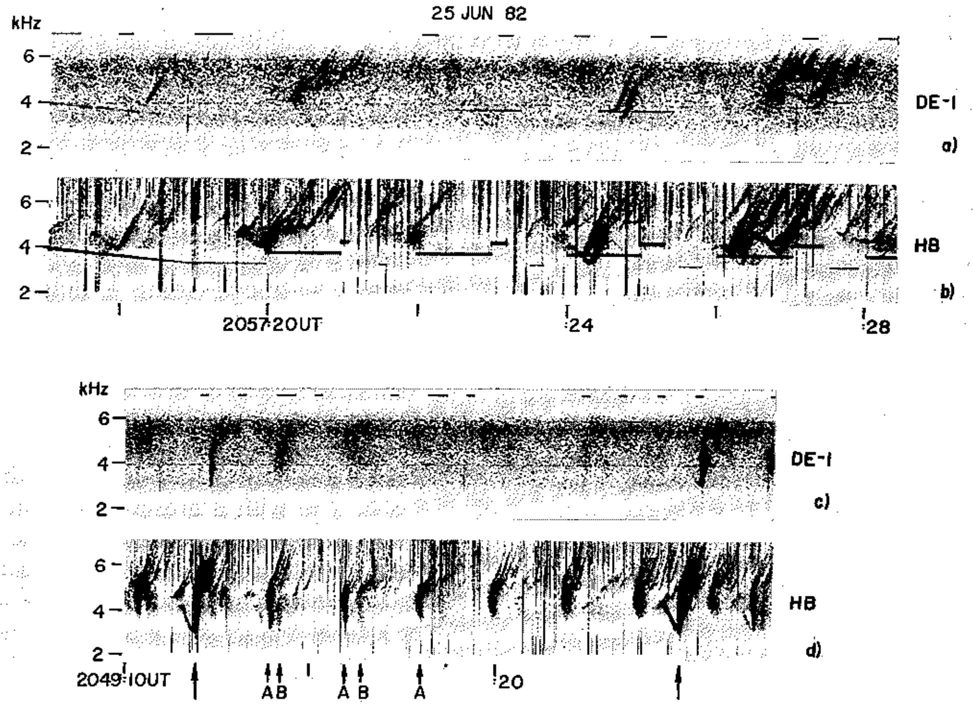

Figure 5

Correlated signals seen on DE-1 *and the ground on* 25 *June* 1982, *shown in* 2-7 kHz *spectrograms. (a) Hooks and Siple transmissions on* DE-1 *around* 2057:20 UT. *(b) The simultaneous record from Halley. (c) Periodic activity around* 2049:20 UT *on* DE-1, *and (d) Halley. A hook (arrow) initiates two echo trains (marked « A » and « B ») of different periods.*

385 ± 10 ms, was the same, to within the limits of measurement error, as the time difference between correlated signals on the ground and the satellite found for the riser/hook activity (at 3.77 kHz); at 5.5 kHz the satellite-ground time difference for the risers was 340 ± 10 ms — the same as that measured for the whistlers which triggered the noise bursts. This is illustrated in the case of the 2057:24 UT pulse by the two closely spaced rising elements which occurred at the same time relative to the beginning of the pulse in figures 5(*a*) and 5(*b*). (The Halley record shows that the elements were part of a double hook, the weak falling part being undetectable by the DE-1 receiver.)

Figure 5(*d*) exemplifies the strong periodic emission activity which was seen on the ground throughout the period of interest, and in this case was also detected on DE-1. An intense hook, seen at Halley at 2049:12 UT (first arrow), initiated two echo trains (marked « A » and « B ») with two-hop periods of 1.95 s and 2.20 s (measurement error ± 50 ms). The former persisted strongly until the end of the record, with some retriggering on each hop, whereas the latter rapidly became diffuse and disappeared after the third echo. (The traces following the hook within less than a second are from a preceding echo train.) Another hook at 2049:25 UT (second arrow) initiated a similar sequence of events.

The rising part of the first hook was seen on the satellite and was followed by echoes which, in spite of their diffuseness, had a periodicity measurably different (1.80 s) from either of the series observed on the ground. This suggests that a third path, not revealed by the Halley record, was also excited by the original hook.

Amplitude modulation at twice the spacecraft spin frequency, i.e. having a 3 s period, is noticeable in much of the data used here; it can be seen clearly near the beginning of the compressed spectrogram of figure 2. This may to some extent mask any periodicities due to echoing effects. However in figure 5(*c*) the echo period is sufficiently different from 3 s that it can be clearly identified as unrelated to spacecraft spin.

4. DISCUSSION

Noise bursts with a several minute quasi-periodicity such as those described above are a phenomenon observed outside the plasmapause by ground stations such as Siple and Halley during conditions of sudden, deep quieting following geomagnetic disturbance. They have been observed to be triggered by whistlers propagating slightly beyond the plasmapause (Dingle and Carpenter, 1981) and in one rare case by Siple transmitter signals (Carpenter and Miller, 1983). The triggering by whistlers may be either direct, as in the DE-1 case reported here, or indirect where the whistler echoes several times between hemispheres before inducing the triggering (Carpenter, 1978). The triggering signal is usually much less intense than the noise which it triggers, and may be barely detectable on the spectrogram.

The 2-5 min quasi-periodicity of the bursts may be related to the time constant for the replenishment of resonant particle flux by diffusion or drift processes following depletion by wave-induced pitch angle scattering during the preceding burst (Francis *et al.*, 1983; Dingle and Carpenter, 1981). It is apparently not related to the occurrence of whistlers, since whistlers with dispersion characteristics identical to those which do trigger are observed between bursts and induce no effect.

Whilst effects of precipitation were detected on the ground during Explorer-45 observations of similar burst activity on 11 September 1973 (Carpenter *et al.*, 1984), none were observed in association with the DE-1 event. From whistler evidence the *L*-value of initial propagation of the bursts was probably in the range 4.1-4.6. Thus the invariant latitude (close to that of Siple) and local time (afternoon) of any associated precipitation region were likely to be unfavourable for remote detection by perturbations of subionospheric signals from VLF transmitters to the north, while its longitude may have been out of range of any local ground sensors (e.g. riometers).

A puzzling feature of the DE-1 data on 25 June 1982 is the occasional presence on the satellite of a hiss band (5-6 kHz) which was not detected on the ground. Figures 2, 3 and 4 show this hiss band, which sometimes exhibited a double-banded structure. The compressed spectrogram of figure 2 strongly suggests the presence of some kind of interaction between the hiss and the highly structured chorus bursts. Interactions between quasi-coherent and diffuse VLF wave phenomena have been reported, examples being the « quiet band » induced in background hiss at frequencies just below that of the Siple transmitter signal (Raghuram *et al.*, 1977) and the suppression of hiss bands by whistlers (Gail and Carpenter, 1984). In the present case, the hiss seen at the start of the record at 2040 UT continued at a fairly constant level until a whistler triggered the first burst; after about 20 s the structured emission decayed but the hiss had been suppressed below its previous level of intensity (see the amplitude plot). The third burst at 2046 UT cut off the hiss band in a similar way, as did the last two bursts although to a lesser extent. On the other hand, the fourth burst seemed to be followed by the onset of a hiss band. The apparent interactions suggest that both hiss and chorus bursts propagated initially in a ducted mode, and one might expect to have observed both on the ground. However, as suggested by the results on periodic emissions and by the noted differences between details of the ground and satellite chorus bursts, multiple ducts were probably involved. The principal chorus burst-hiss interaction may have taken place along a duct or ducts whose output was not transmitted efficiently to the Halley receiver.

5. DUCTED AND NONDUCTED WHISTLER MODE PROPAGATION

A variety of ducted signals were observed at the two $L = 4.3$ ground stations, Halley and Siple, namely : multi-component whistlers, noise bursts triggered by one or more of these components, and periodic emissions. The one-hop travel times of typically 1 s are indicative of propagation outside the plasmapause, determined in this case by whistler analysis to lie near $L = 3.5$, well inside both the ground stations and the satellite position. Evidence from whistler nose frequency measurements, relative amplitude measurements, and direction finding measurements, suggests that propagation occurred on a range of paths widely spaced in both *L*-value and longitude.

Our time-delay analysis suggests that downcoming ducted waves were scattered back upwards at low altitudes in the southern hemisphere, and reached the satellite in a nonducted mode, as illustrated schematically in figure 1(*a*). Since DE-1 was also in the southern hemisphere at the time of the observations it seems probable that such waves could reach it from somewhat lower *L*-shells provided they had a sufficient spread of upward wave normal directions after reflection. This was confirmed by two-dimensional ray tracing using a diffusive equilibrium model for the electron density, constrained to match the equatorial density profile derived from whistler analysis. The ray tracing showed that model rays in the frequency range 3.5-5.5 kHz, starting at dipole latitude 61° S and altitude 500 km, with wave normal direction 10 degrees equatorward of the field direction, reached the satellite with a group travel time of 0.30 s, a value consistent with the measured value of 0.35 s after a correction has been made for propagation through the ionosphere up to 500 km altitude.

The lack of any signals observed earlier on DE-1 than on the ground implies that the satellite never passed either through any of the several ducts known to be present or close enough to one for leakage of ducted energy to be received. In fact, reports of direct observations of ducts by high altitude satellites are extremely rare (Angerami's (1970) paper using OGO-3 data is one such case). This supports a concept of a very localised nature of whistler ducts, making them difficult to be intercepted by a satellite, even one such as DE-1 with an orbit specifically designed to remain for most of each orbital period in the *L*-range where ducts are known to be common.

The observation in space of whistler mode waves which have been initially ducted and subsequently scattered at low altitude into a nonducted mode is, however, not uncommon (e.g. Bell *et al.*, 1982), even though particularly favourable ionospheric conditions for reflection and scattering may be necessary for it to occur. Quieting conditions following a period of geomagnetic disturbance also seem to be favourable. Bell *et al.* (1983) suggested this mode of propagation to explain the characteristics of Siple transmissions detected on the EXOS-B satellite during the recovery period following a large geomagnetic storm on 13 August 1979. As in the present case, triggering was often observed to have occurred in the ducted segment of the path. The phenomenon is closely associated with the low altitude coupling of waves between ducts, recently discussed by Smith and Carpenter (1982). The latter effect was also observed in the present case; see for example figure 5(*d*) showing a hook which coupled, at the southern end of its path, into at least two ducts with different two-hop echo periods.

Some information about the extent of spreading of the wave energy once it has become nonducted may be derived by noting the duration of burst activity seen on the satellite. Whistlers and associated noise bursts were detected by the DE-1 receiver from the beginning of the data acquisition at 2040 UT until they cut off abruptly after the 2056 UT burst. At Siple the triggered bursts were received for at least four hours, beginning about 2000 UT (15 MLT). During the period 2040-

2056 UT, DE-1 moved through 4.0 degrees of longitude (westward) as well as 6.4 degrees of (dipole) latitude and 0.14 in *L*. The point at which bursts ceased to be observed (marked « B » in fig. 1) was presumably that at which the satellite left the region into which the nonducted waves had spread. By contrast, signals from the Siple transmitter continued to be received until 2137 UT (marked « T » in fig. 1), indicating that they spread further to the west than the natural signals. However, signals originating from a ground source may be capable of entering the ionosphere over a wide region and thus may begin to propagate upwards from a wider distribution of starting points than signals which are initially travelling downwards in a localised duct.

Chorus emissions with intensities 30-40 dB higher than the maximum reported here (~ 0.4 pT) have been observed on many other occasions on DE-1, in general agreement with typical chorus intensities in the range 1-100 pT as previously reported by Burtis and Helliwell (1975). The statistics of these measurements are beyond the scope of this paper and will be reported separately. Whilst the higher observed intensities probably relate mainly to direct observations of chorus near the source region, for the indirect propagation proposed in the present case considerable attenuation would be expected both from absorption in the ionosphere and by defocusing in the nonducted segment of the path.

There is evidence from the whistler data on 25 June 1982 of longitudinal variations in plasma density of order 20 % within the viewing area of the ground stations at $L = 4\text{-}4.5$, i.e. whistlers with almost the same nose frequency had nose travel times varying by $\sim 10\,\%$. Longitudinal density gradients undoubtedly affect the extent to which nonducted waves spread longitudinally through the magnetosphere from a localised region. However, three-dimensional ray tracing computations would be needed to assess this effect quantitatively.

6. CONCLUSIONS

Whistler-triggered bursts in the 5-7 kHz range, occurring quasi-periodically every 3-5 min, have previously been observed at ground stations under conditions of relatively deep quieting following moderate magnetic disturbance. There is evidence that these wave bursts propagate outside the plasmapause and that they induce detectable electron precipitation at ionospheric *D*-region altitudes. In this paper we have reported observations of such wave events on the DE-1 high-altitude satellite. Analysis of this case study indicates that the observed waves are predominantly the result of downward ducted propagation from the triggering region followed by reflection at low altitudes, with the signals reaching the satellite in a nonducted mode. Comparisons of nonducted signals from the Siple transmitter and simultaneously observed discrete periodic emissions provided a means of estimating the propagation characteristics of the wave bursts. Direct wave propagation from the generation region of the noise bursts to the satellite was not observed.

While high altitude satellites only rarely appear to observe whistler-mode signals by virtue of passing through or close to a duct, the ducted-nonducted mode conversion process provides a means by which signals generated, triggered or amplified in small localised ducts can spread into a much larger region of the inner magnetosphere. Combined ground and satellite wave data can be used to estimate the size of such regions.

The DE-1 observations indicated an evidently strong interaction between whistler-triggered noise bursts and prevailing hiss levels. However, this hiss was not detected at the available ground station (Halley). The occurrence and mechanism of this type of interaction, as well as the details of subsequent propagation to receivers on the ground and in space, need further investigation.

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