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MODULATED IONOSPHERIC ABSORPTION UNACCOMPANIED BY SIGNIFICANT GEOMAGNETIC PULSATIONS

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Abstract: Long-period (Pc 4–5) modulations of ionospheric cosmic noise absorption (CNA) at Siple, Antarctica ($L=4.2$) are rarely seen unaccompanied by pulsations in the local geomagnetic field. Conjugate modulations of ~2 min period lasting about one hour were recorded near local noon by riometers at Siple and Roberval on October 30, 1983. The Siple magnetometer records show little evidence of pulsations at this time. The absence of a ground magnetic signature implies that if such events are caused by ULF hydromagnetic waves (*e.g.*, a field line resonance), the waves are highly localized and effectively screened by the ionosphere.

In addition, the possible existence of a recurrent particle precipitation structure in space was suggested by observations of absorption modulations with periods of 10–15 min which occurred on several days at about the same time of day. These modulations were also generally unaccompanied by magnetic pulsations.

1. Introduction

Auroral zone observations of simultaneous long-period (Pc 3–5) pulsations in the geomagnetic field (monitored by ground magnetometers) and in ionospheric absorption (measured by riometers) have been made for many years and the correlation between the two is well established (*e.g.*, OLSON *et al.*, 1980). The geomagnetic variations are believed to be hydromagnetic waves which also modulate energetic electron precipitation to produce the pulsations observed in riometer cosmic noise absorption (CNA) data. Similar results are also obtained at sub-auroral latitudes (*e.g.*, OKSMAN *et al.*, 1986).

Pulsations often may appear in magnetometer records but not in the riometer signal at the same location. This can usually be explained by the limited field of view of the riometer antenna in comparison with the magnetometer's spatial range of response. The reverse situation in which ionospheric modulations are not accompanied by geomagnetic pulsations is relatively rare and may imply an ionospheric screening mechanism of the kind proposed by HUGHES and SOUTHWOOD (1976a, b) for highly localized waves.

In this paper, we report on observations of an unusual type of event, not previously described, characterized by strong ionospheric absorption modulations with weak or non-existent ground magnetic signatures, describe some other interesting aspects of this event and discuss their implications. We also give examples of several other events of this unusual nature which appear to have a preferred time of occurrence in the local afternoon and occurred on three days over a 4-day interval.

2. Observations

As part of the U.S. upper atmospheric research program in Antarctica, the University of Maryland operated a 30 MHz riometer at Siple station (75.6°S, 83.6°W geographic, L=4.2, 60.8°S, 3.2°E corrected geomagnetic) during 1983. A similar riometer was also operated simultaneously at the nominal conjugate point, Roberval (48.5°N, 72.2°W geographic, 60.0°S, 4.5°E corrected geomagnetic) in Canada, for the study of conjugate phenomena. The riometer antennae consisted of two half-wave dipoles separated horizontally by approximately half a wavelength, connected to form a zenith-pointing beam with an effective half-power (full) beamwidth of 60°. The riometers monitored the cosmic radio flux continuously; the data were sampled every second and written to digital magnetic tape. The raw data were converted to absorp-

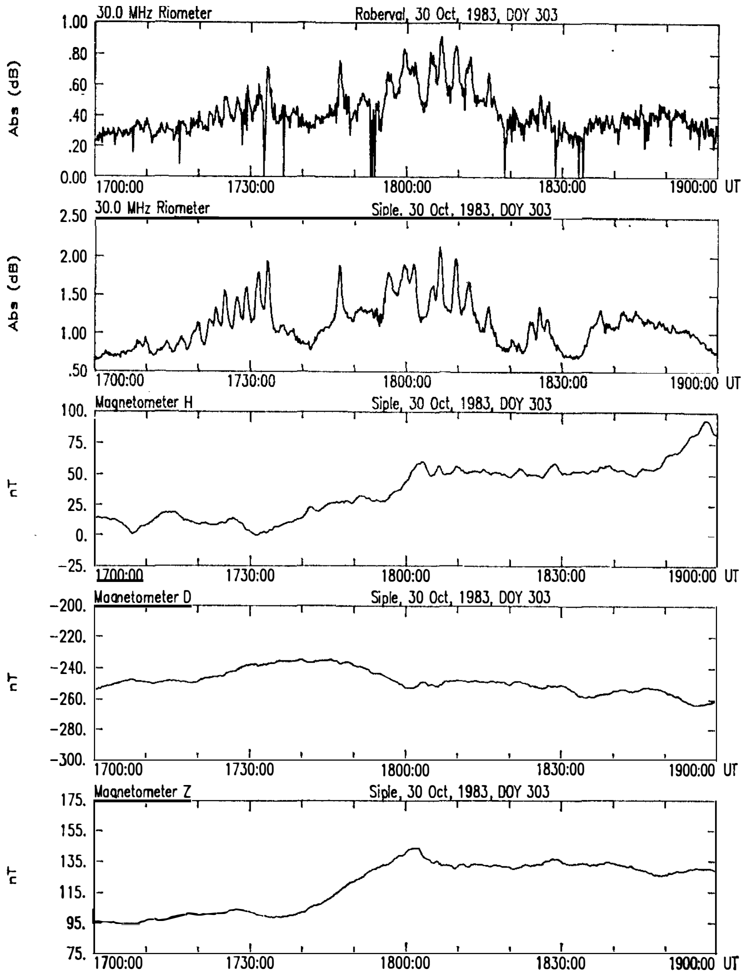

Fig. 1. Large amplitude Pc 4–5 modulations in conjugate riometer data from Siple and Roberval. Note the almost complete absence of magnetic pulsations at Siple, especially during the early part of the event (1710–1735 UT).

tion values after computing the so-called quiet day curve using the technique described by KRISHNASWAMY *et al.* (1985a).

The top two panels in Fig. 1 show the cosmic noise absorption measured at Roberval and Siple on October 30, 1983 during 1700–1900 UT. The value of the planetary *Kp* index during this interval was 4 to 4−. Strong ionospheric modulations (up to ~1 dB in amplitude at Siple) with a period of about 2 min appear in the 30 MHz riometer signals near local noon (≃1700 UT). There is detailed correlation between the temporal structures of the event at the two locations, testifying to the high degree of conjugacy of the two stations at that time. The lower three panels in Fig. 1 show the records of the AT&T Bell Laboratories' 3-component fluxgate magnetometer at Siple. The almost complete absence of a ground magnetic signature at Siple, especially during the early part of the event (1710–1735 UT), makes this a rather extraordinary event. This is confirmed by Fig. 2 which shows the data of Fig. 1 bandpass filtered in the 1.5–4.0 min period range; wave activity in the magnetometer records is essen-

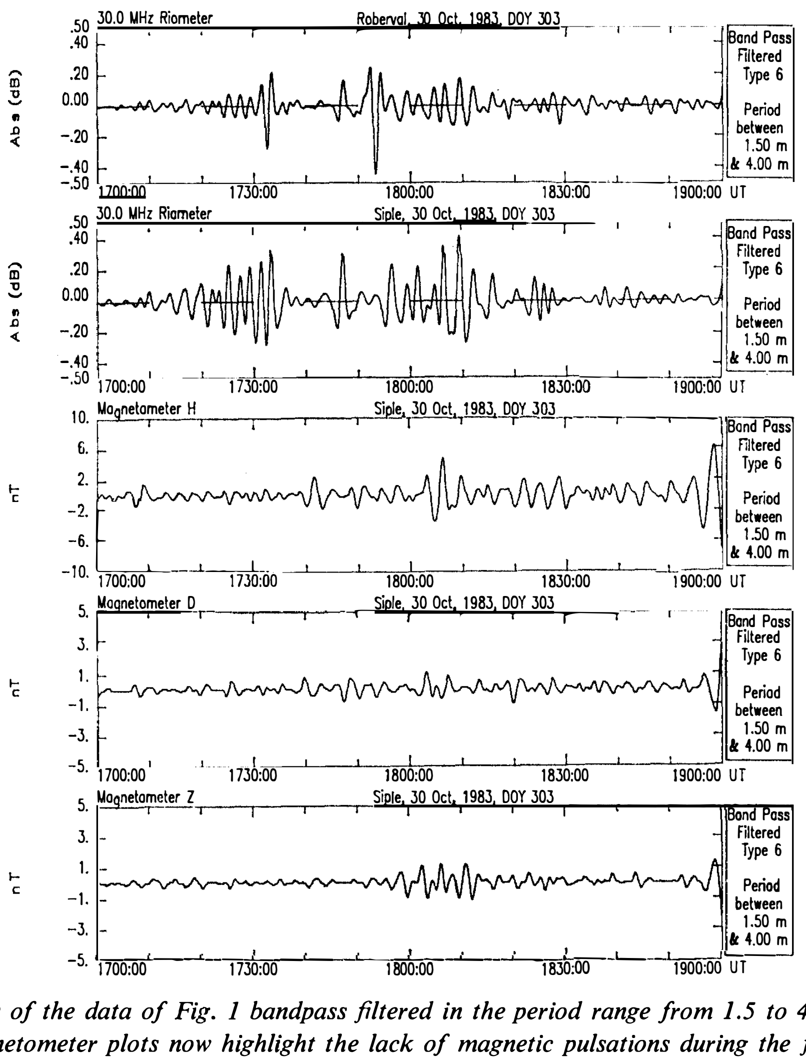

Fig. 2. Plots of the data of Fig. 1 bandpass filtered in the period range from 1.5 to 4.0 min. The magnetometer plots now highlight the lack of magnetic pulsations during the first sequence of absorption pulsations and also show some evidence of wave activity during the later part of the event.

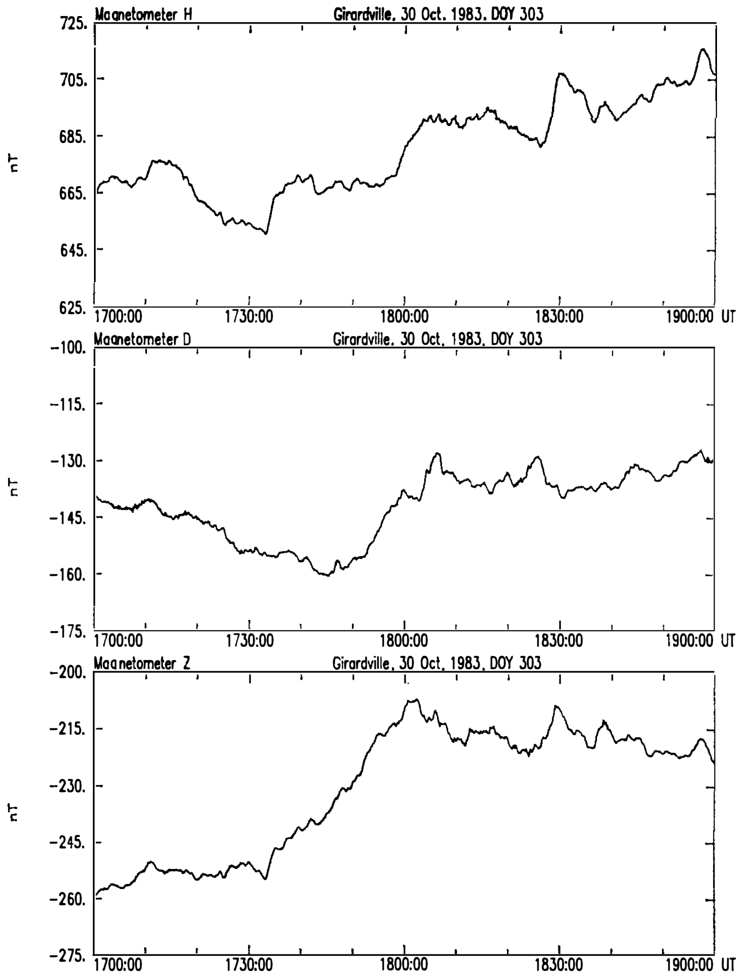

Fig. 3. Ground magnetometer data from Girardville, a station in the vicinity of Roberval confirm the lack of a clear magnetic pulsation signature in the northern hemisphere. Again, there is a hint of some pulsations, especially in the H-component, around 1805–1815 UT.

tially nonexistent during the early part of the event although there appears to be a weak signal around 1800–1810 UT.

Magnetometer data from Roberval are unavailable but Fig. 3 shows data from Girardville, one of the stations in the AT&T Bell Laboratories magnetometer chain in the vicinity of Roberval. Again, except for some suggestion of weak wave-like features around 1805–1815 UT, there is practically no indication of magnetic pulsation activity during this event in the northern hemisphere also.

Particle data from ISEE-1 provided by G.K. PARKS (private communication) show modulations of similar period in the dayside magnetosheath plasma, suggesting the involvement of ULF waves (KRISHNASWAMY *et al.*, 1985b).

3. Discussion

HUGHES and SOUTHWOOD (1976a, b) have put forward a mechanism by which horizontal structures in the magnetosphere can be smoothed out or even totally shielded from the ground if they are sufficiently localized ($\lesssim$100 km), whereas large-scale structures are unaffected. If the observed lack of ground magnetic signature is due to this screening effect, it would imply that the horizontal structures associated with this event were significantly smaller than about 100 km during the earlier part of the event described above but may have increased somewhat in size later during this event when a weak magnetic signature was able to penetrate to the ground.

This event also has a number of similarities to an ELF emission and relativistic electron precipitation event described by WEST and PARKS (1984) (occurrence near local noon; possibly localized in the L=4.5–5 range; periods of 1–3 min; associated with 1-kHz ELF emission) and also to compressional waves studied by TONEGAWA (1982) (occurrence near local noon; large azimuthal wave number, and therefore likely to be screened by the ionosphere).

Quasi-periodic (QP) ELF-VLF emissions unaccompanied by magnetic pulsations on the ground have been discussed by SATO and KOKUBUN (1981), SATO and FUKUNISHI (1981) and SATO and MATSUDO (1986). However, these emissions generally had much shorter periods (between 10 and 60 s, mostly around 20 s) and a different physical mechanism may be involved. VLF data recorded at the time of the event reported here are being examined to explore its relation to VLF emissions.

WEST and PARKS (1984) have suggested that simultaneous ground monitoring of magnetic pulsations and ELF/VLF emissions can remove some of the uncertainty involved in interpretation. The event described above demonstrates that this may not always be the case.

From Fig. 1, there is a strong suggestion that the structure of the event is such that the amplitude of the modulations increases as the background absorption level rises and that the modulation disappears when the absorption falls below a certain value. Figure 4 shows a plot for each station of the pulse amplitudes as a function of the background (mean) absorption level at the time of the pulse during this event. Also shown are the least-squares fitted lines to the data, treating the background absorption as the independent variable. The results confirm the visual impression from Fig. 1 that the pulse amplitude is directly proportional to the background absorption with a high degree of correlation (about 0.9 at both Siple and Roberval). A similar linear relationship has been reported by OLSON *et al.* (1980) from a study of a number of Pc 4–5 pulsation events seen at L=6–8, using an array of magnetometers and riometers in western Canada operated by the University of Alberta during the IMS period. This has been interpreted as evidence of the modulation of the loss rate of an electron plasma distribution which is at or near the stable trapping limit. Following the notation of OLSON *et al.* (1980), the relationships found for this event between the pulse amplitide, δA, and the mean background absorption, A, are, for Siple,

$$\delta A=(0.68\pm0.13)A-(0.44\pm0.16), \quad (1)$$

and for Roberval,

$$\delta A=(0.55\pm0.14)A-(0.09\pm0.07), \quad (2)$$

where both δA and A are in decibels and the errors in the determination of the slopes

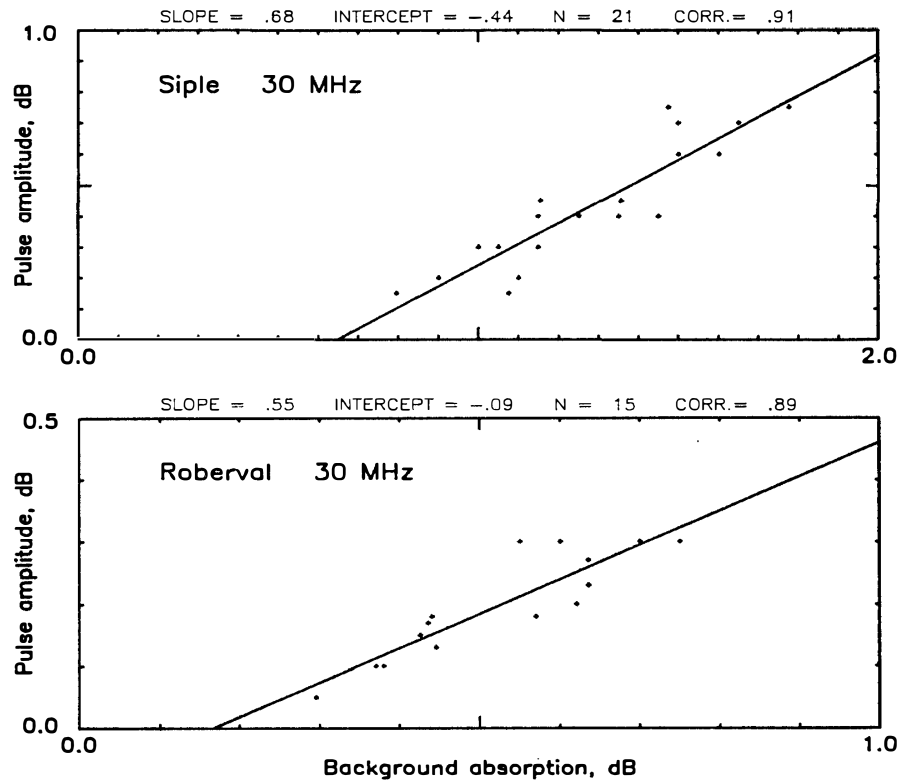

Fig. 4. A plot of the ionospheric absorption pulse amplitudes versus the background absorption level at the time of the pulse, along with the least-squares fit lines. The values of the slopes, y-intercepts, number of data points and correlation coefficients are indicated.

and y-intercepts are the 90% confidence limits calculated using Student's t-test (see, *e.g.*, DRAPER and SMITH, 1966).

A number of points can be made here. First, although the errors in the slopes are such that equality of the two slopes cannot be ruled out, the value of the slope for the Siple data appears to be somewhat higher than that for the Roberval data, suggesting that the pulse amplitude is more sensitive to the background absorption at Siple than at Roberval. Since the solar zenith angle during the event was roughly the same (~65°) at both places, this difference may be related to the proximity of Siple to the South Atlantic anomaly, in whose neighborhood precipitated particle fluxes would tend to be enhanced due to the lowering of the mirror point. Second, the OLSON *et al.* (1980) study, which also used riometers operating at the same frequency (30 MHz), obtained a value of 0.22 ± 0.04 for the slope of the line relating δA to A; this is significantly smaller than the value obtained at either Roberval or Siple and may be related to the higher latitude of the Alberta array. This would imply that the pulse amplitude is much less sensitive to the background absorption at higher latitudes. It should be kept in mind, however, that the Alberta study involved (mostly pre-noon) events with concurrent riometer and magnetometer pulsations, possibly suggesting that these events were associated with spatial structures insufficiently localized for the ionospheric screening mechanism to be effective. Third, the relations (1) and (2) imply that pulsations occurred only above a threshold level of the background absorption (0.65 dB at Siple, 0.17 dB at Roberval) and suggest that some minimum level of steady precipitation has to be present in order for electron precipitation to be modulated by magnetic pulsations, with the minimum level being greater near the South Atlantic anomaly. (In their study, OLSON *et al.* (1980) were unable to obtain a meaningful value for the threshold absorption level because of systematic errors introduced into their data by the presence of unwanted noise.)

It is clear from Fig. 1 that the level of absorption at Siple is generally much higher than at Roberval. Again, this is consistent with effect of the lowering of the mirror points near the South Atlantic geomagnetic anomaly resulting in electrons being deposited more readily from the trapping regions in the vicinity of the anomaly. The approximate equality of the solar zenith angle at the two sites during the course of the event implies that the difference in the level of absorption at the two locations must essentially reflect the difference in the flux of precipitated electrons. This in turn depends on the details of the equatorial pitch angle distribution of the trapped particle population.

The remarkable similarities in the temporal structure of the absorption variations

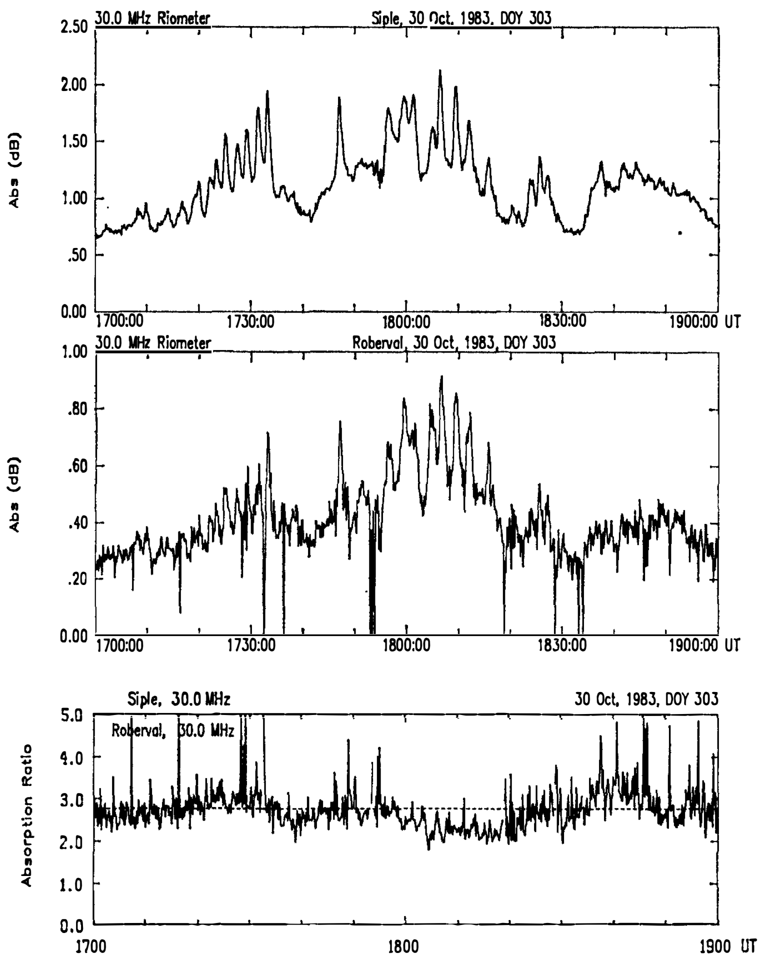

Fig. 5. The riometer data from Fig. 1 along with a plot of the time variation of the Siple/Roberval absorption ratio. The dashed line is the mean value of this ratio during the entire 1700–1900 UT interval. Note the significant deviation of the values in the 1800–1820 UT interval, when some evidence of wave activity was seen from the ground (Fig. 2).

at Siple and Roberval are clear from Fig. 1. These data are shown again in the top two panels of Fig. 5. The bottom panel in this figure shows the ratio of absorption at Siple to the absorption at Roberval during the course of the event. (The large spikes in this plot are caused by unwanted noise due to propagated interference in the Roberval data and should be ignored). The dashed line is the average value of this ratio during the interval shown (1700–1900 UT), and illustrates that the absorption at Siple was almost 3 times as great as the absorption at Roberval during much of the event. Deviations from this line represent quantitative changes in the inter-hemispheric relationship of the precipitated electron fluxes as the event progresses. Despite the high degree of similarity in the event profile at the two locations, it is evident that there are significant changes in the quantitative relationships during the event. By comparing this plot with the filtered plots in Fig. 2, one sees that the absorption ratio is somewhat above the mean value during the early part of the event (1715–1735 UT) when there was no ground magnetic signature, implying almost complete ionospheric screening, while the ratio is significantly below the mean value during the latter part of the event (1800–1820 UT) when some evidence of wave activity was seen on the ground, suggestive of some weakening of the screening effect.

If the decrease in the shielding effect is assumed to be due to an increase in the spatial scale of the pulsation structure, and the variation in the Siple/Roberval absorption ratio is interpreted as due to changes in the precipitated electron flux between the two hemispheres, then one is led to postulate a connection between changes in the magnetic pulsation structure sizes (or azimuthal wave numbers) and changes in the inter-hemispheric ratio of the precipitated electron fluxes responsible for modulated ionospheric absorption. The inter-hemispheric absorption ratio may itself be influenced by the direction of the interplanetary magnetic field (HARGREAVES, 1969). Thus, all three factors—the IMF direction, the inter-hemispheric asymmetry of the electron precipitation flux and magnetic pulsation structure size—may be interrelated.

Finally, a search for other events of this unusual nature revealed a repeating pattern of conjugate ionospheric absorption modulations with periods of about 15 min which were seen at Siple and Roberval over a number of days at about the same time of day, around 1300–1600 local time (1800–2100 UT), on September 19, 21 and 22, 1983. The Siple riometer data are shown in Fig. 6, along with the data for September 20 on which day the modulations were much weaker. Figure 7 shows the Siple riometer data and the H-component of the magnetometer signal on September 21, as well as the data from the 30 and 51 MHz riometers at Roberval and the H-component of the magnetometer at the nearby station, La Tuque, which is also part of the AT&T Bell Laboratories' chain. Again, the amplitude of the absorption modulations are quite large ($\sim$1 dB at Siple) but the magnetic signature is not obvious. The events on the other days also show similar behavior.

The absorption modulations at Siple and Roberval are less well correlated during these events than during the event shown in Fig. 1. This difference can probably be explained by the fact that the degree of conjugacy of a pair of fixed stations varies from time to time since conjugate points may wander in a somewhat random manner. Although there are similarities, exact correspondence in auroral absorption between conjugate points is apparently not very common and correlation coefficients for ex-

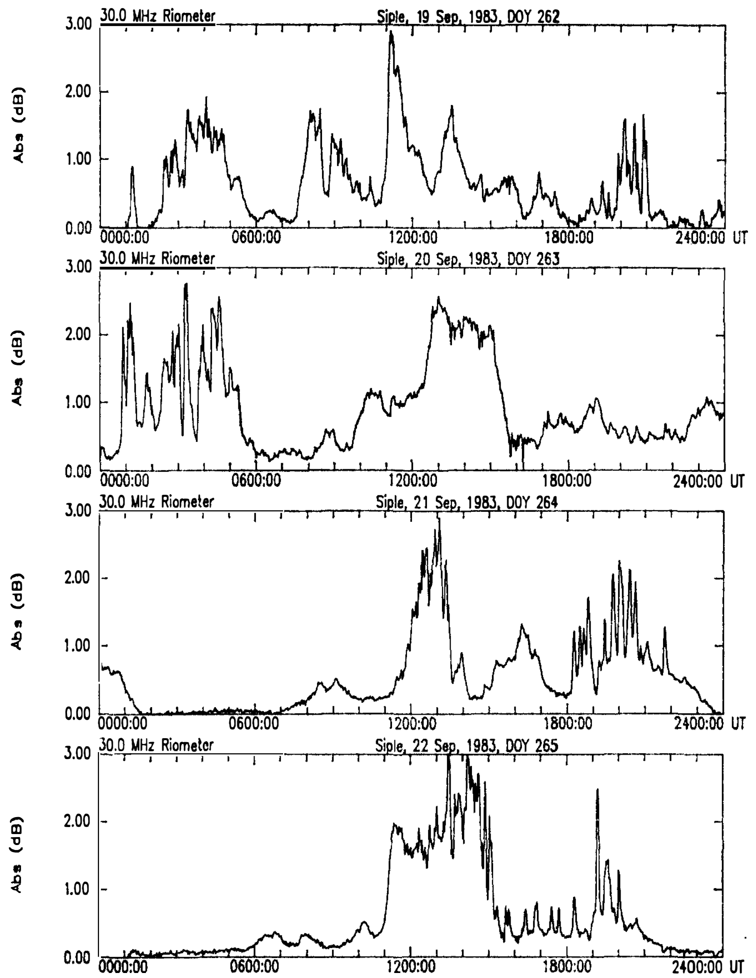

Fig. 6. 24-hour plots showing the ionospheric absorption over Siple during the period September 19–22. Note the repeating pattern of large-amplitude, comb-like, modulated absorption features with periods of about 15 min seen around 1800–2100 UT (1300–1600 local time) on September 19, 21 and 22. Similar features, although smaller in amplitude, were also seen at Roberval. (Notice also the overall similarities in the daily pattern of absorption between September 19 and 20 and between September 21 and 22.)

tended conjugate observations generally do not exceed about 0.7; hemispheric asymmetry of particle precipitation or moving events and displaced conjugate points may also be involved (HARGREAVES, 1969). Moreover, the second class of events described here had much longer pulsation periods than the event of Fig. 1 (15 min rather than 2 min) and also lasted much longer (4 h instead of 1 h) thus increasing the probability that the correspondence may be smeared out by variations in the degree of conjugacy during the course of these events.

In addition to the ionospheric screening mechanism, the possibility that these events may involve phenomena other than hydromagnetic waves is also being investigated. As pointed out by JUNGINGER *et al.* (1984) and KOKUBUN (1985), in order to clarify the mechanisms involved in such events, it is important to have simultaneous measurements of magnetospheric electric and magnetic field fluctuations.

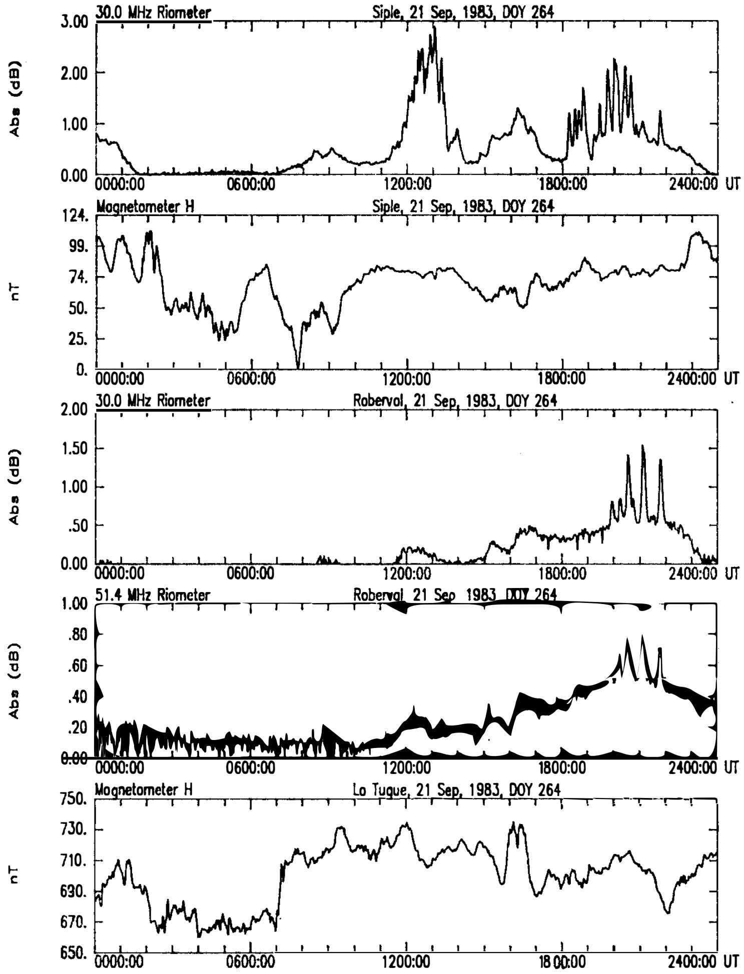

Fig. 7. *The September 21 event of Fig. 6 is shown here along with the data from the Siple magnetometer (H-component), the two riometers at Roberval (30 and 51 MHz), and the H-component of the magnetometer at La Tuque (a station in the vicinity of Roberval). The absorption modulations around 2000–2200 UT can be seen at both frequencies at Roberval. Neither of the magnetometer records shows any definite sign of corresponding magnetic pulsation activity. The events on September 19 and 22, shown in Fig. 6, also have similar properties.*

4. Summary

An unusual type of event characterized by strong ionospheric absorption modulations with weak or non-existent ground magnetic signatures was observed at the sub-auroral (L=4.2) conjugate pair of stations, Siple and Roberval, on October 30, 1983 between 1700 and 1900 UT. The event occurred near and shortly after local noon and consisted of large amplitude absorption pulsations in the Pc 4–5 range with periods of about 2–3 min, and lasted for about an hour. There was essentially no indication of associated magnetic pulsations during the early part of the event and only a weak magnetic signature later during the event.

If this event was caused by ULF hydromagnetic waves, as suggested by particle data from the ISEE-1 spacecraft, then the waves must have been highly localized and effectively screened by the ionosphere, thus precluding the ground-based magnetometers from detecting them. The weak ground magnetic signature seen during the later part of the event implies that the wave structure became less localized at this time, resulting only in partial screening of the magnetic pulsation signature. This apparent change in ionospheric screening was matched by a change in the Siple/Roberval absorption ratio, suggesting that changes in magnetic pulsation structure sizes may be a factor in the variation of the inter-hemispheric ratio of the precipitated electron flux at sub-auroral latitudes.

The time profile of the event shows that the amplitude of the absorption pulses is linearly proportional to the mean level of the background absorption at the time of the pulse, possibly suggesting that the electron distribution must be near or above the threshold for diffusion into the loss cone. There is also evidence to suggest that some minimum level of steady precipitation is required for magnetic pulsations to modulate electron precipitation.

Properties in common with other events described in the literature also suggest similarities between this event and those involving relativistic electron precipitation or compressional Pc 4–5 waves observed from satellites.

Finally, other examples have been found in the Siple/Roberval data of strong ionospheric pulsations in the absence of associated magnetic activity seen from the ground. These events had periods of about 15 min, occurred in the local afternoon and were seen repeatedly over a number of days, suggesting the existence of a long-lasting precipitation structure in space.

Acknowledgments

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