CORRELATED PULSATIONS IN AURORAL LIGHT INTENSITY AND VLF HISS

D. D. DUTHIE, J. P. S. RASH and M. W. J. SCOURFIELD

Department of Physics, University of Natal, King George V Avenue, 4001 Durban, South Africa

Abstract: Observations at Sanae, Antarctica of a pulsating aurora with a low light level T. V. system have been combined with simultaneous recordings of VLF hiss on a broad band receiver. Both auroral light and hiss intensities display a significant peak at 1.3 Hz in the power spectrum. The peaks in the auroral light intensity variations lead those in the VLF hiss by times between zero and 0.2 s, as revealed by cross-spectral analysis. These results are explained in terms of cyclotron resonance in the equatorial plane between the auroral electrons and echoing VLF hiss.

1. Introduction

Auroral VLF hiss has been correlated with auroras in both satellite and ground observations (*e.g.* OGUTI, 1975). This type of hiss is believed to be generated by Cerenkov radiation (JØRGENSEN, 1968).

Correlations have also been observed between discrete VLF emissions and auroral electron precipitation (*e.g.* ROSENBERG *et al.*, 1971; HELLIWELL *et al.*, 1980). The mechanism responsible, as for mid-latitude hiss (BULLOUGH *et al.*, 1969), is believed to be the cyclotron resonance interaction (HELLIWELL, 1967; RYCROFT, 1972).

In this paper we report on the simultaneous observation, at $L=4.1$, of variations in auroral light intensity and VLF hiss intensity, showing a common period of 0.75 s. The delay times of the peaks in auroral light intensity with respect to those in VLF hiss are 0–0.2 s. We will discuss these results in terms of a cyclotron resonance interaction in the equatorial plane.

2. Data Description and Analysis

At Sanae ($L=4.0$) we record images of auroral emissions using a low light level T. V. system and video recorder. The data set used here was recorded on 10 September 1975, 0342–0358 UT ($Kp=5+$); the T. V. camera lens had a 25° field of view and a blue filter was used to include the N_2^+1 NG band at 391.4 nm but exclude the OI line at 557.7 nm. Broadband (0–15 kHz) VLF recordings were made simultaneously; both recordings were made with NASA time code.

The pulsating auroral form appeared near zenith ($L=4.1$) during the post-breakup phase of an auroral display. The form had dimensions $\sim$10 s of km and drifted slowly eastwards ($v<50\ \mathrm{ms}^{-1}$). It pulsated quasi-periodically ($\tau \cong 0.75$ s) and was

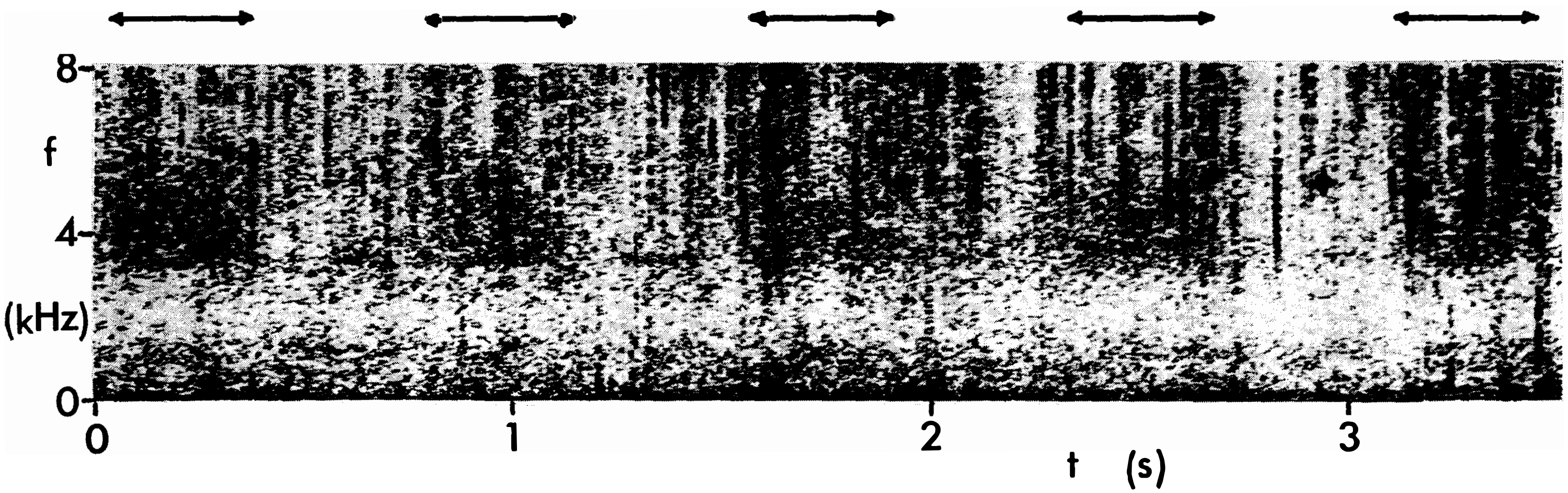

Fig. 1. *A typical VLF frequency-time (f-t) spectrogram showing the observed band-limited (2.7 to 5.2 kHz) hiss occurring in 'bursts' with period 0.75 s, as indicated by the arrows above the spectrogram.*

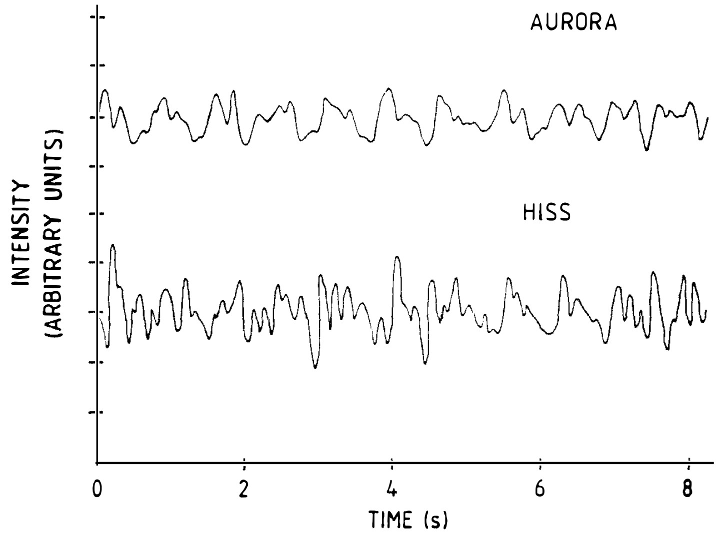

Fig. 2. A typical 8 s data segment showing the simultaneous variations in intensity of auroral light and VLF hiss in a narrow band at 3.9 kHz.

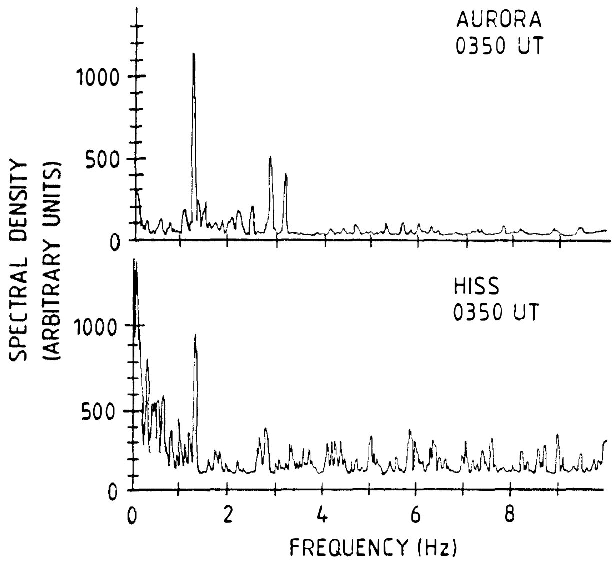

Fig. 3. Results of power spectral analysis of a 50 s data segment of integrated auroral light intensity and VLF hiss band intensity.

modulated down to the background level.

The associated VLF hiss was band limited, in the frequency range 2.7–5.2 kHz. It appears in the form of 'bursts' on the spectrograms, as shown in Fig. 1. A video analyser (ALPORT and SCOURFIELD, 1975) was used to obtain the integrated light intensity within the optical field of view. The hiss intensity was obtained using a filter with centre frequency 3.9 kHz and bandwidth 100 Hz. A typical 8 s period of data showing the variations in both intensities is given in Fig. 2.

The results of power spectral analysis of a typical 50 s segment, sampled at 500 Hz, of both the auroral light intensity and VLF hiss intensity are shown in Fig. 3. Both show a prominent peak in spectral density at 1.3 Hz. This peak (with $\sigma=0.3$

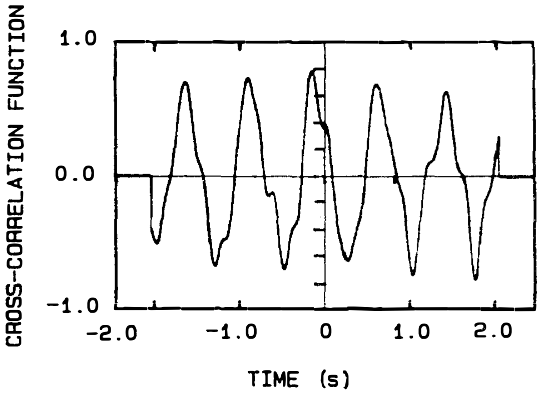

Fig. 4. Results of cross-correlation analysis between the two data sets shown in Fig. 2, with a sample period of 2 ms. The first peak to the left of zero occurs at a delay time of 0.135 s.

Hz) is present throughout the analysis period (16 min) in both data sets.

Cross-spectral analysis of the two data sets shows a coherency of $\cong$0.8 at the common spectral frequency of 1.3 Hz. The cross-correlation function (Fig. 4) shows a minimum time delay of $\cong$0.135 s of the auroral light intensity peaks with respect to those of the VLF hiss. This time difference (varying from ~ zero to 0.2 s) is also present throughout both data sets, although it is not apparent on the coarse time scale of Fig. 2.

We can thus summarize the results as follows:

(i) There is a prominent peak at f=1.3$\pm$0.3 Hz (*i.e.* τ=0.75 s) in both auroral light and VLF hiss power spectra.

(ii) There is a time delay of the auroral light intensity peaks with respect to those of the VLF hiss of 0–0.2 s.

3. Interpretation and Discussion

The common spectral frequency and high coherency in the two data sets suggest a common modulation by means of a wave-particle interaction. The similarity of these results to those of ROSENBERG *et al.* (1971) and HELLIWELL *et al.* (1980) lead us to consider cyclotron resonance as the interaction mechanism.

Cyclotron resonance occurs between circularly polarised whistler-mode waves and oppositely-travelling auroral electrons. The electrons lose energy to the waves, which then grow in amplitude; transverse energy is lost preferentially so that electrons with pitch angles just outside the loss cone will be scattered into it (RYCROFT, 1972). These electrons then precipitate into the ionosphere to produce the auroral light emissions.

HELLIWELL *et al.* (1980) used this interaction to explain their observations of peaks in VLF wave intensity leading those in photometer output by 1–2 s. In their scenario, shown in Fig. 5, northward-going VLF waves interact in the equatorial plane with southward-going electrons. The electrons are scattered directly into the loss cone and produce an increase in light intensity detected by the photometer at Siple. The VLF waves grow, travel northwards to te reflected in the northern ionosphere, and return to be detected at Siple.

Our observations can also be interpreted in terms of this model. The model

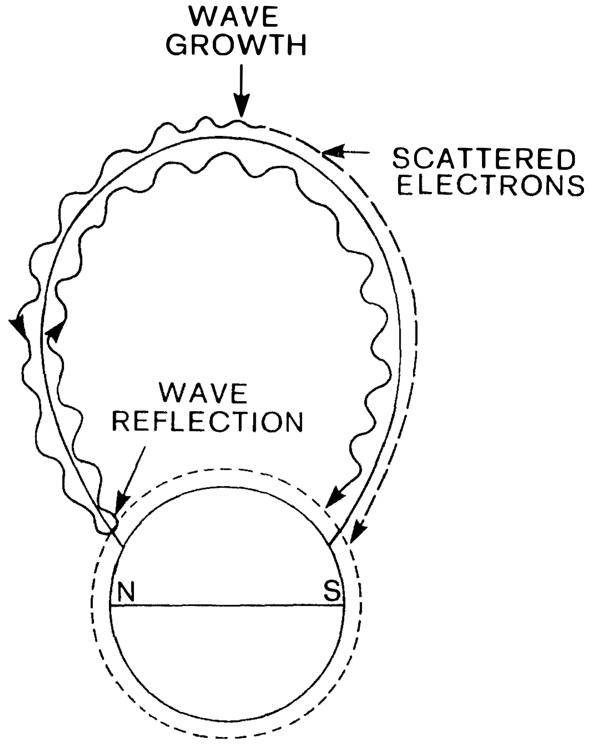

Fig. 5. A schematic diagram of the interaction between north-going VLF waves and south-going auroral electrons, used to explain the observations (after HELLIWELL *et al., 1980).*

suggests that the difference in arrival time ($\Delta\tau$) of the VLF hiss and auroral light emission is equal to the 3/2-hop travel time of the VLF minus the 1/2-hop travel time of the electrons. (Here $\Delta\tau>0$ means the electrons lead the VLF).

We follow the method of ROSENBERG *et al.* (1971) in calculating these times. We determine the VLF travel time at $f=3.9$ kHz. The electron travel time is a function of their energy; the resonant energy is a function of the thermal plasma density. Figure 6 shows the resulting $\Delta\tau$ as a function of N_{eq}, the electron density in the equatorial plane, in the range 1–20 cm^{-3}, using both DE-1 and R-4 plasma models (PARK, 1972). The rectangle in Fig. 6 encloses the range of observed $\Delta\tau$; this indicates N_{eq} of 1–7 cm^{-3} (corresponding to resonant electron energies of 50–200 keV).

The observed periodicity in the data sets may be interpreted as due to echoing VLF hiss (HELLIWELL, 1965). The bounce time for 3.9 kHz VLF waves is shown as a function of equatorial electron density, for the same two plasma models, in Fig. 7. The rectangle here encloses the observed range of period, *viz.* 0.6–1 s (corresponding to $f=1.3\pm0.3$ Hz); this indicates an N_{eq} of ~ 5 cm^{-3}, essentially the same as that deduced from the $\Delta\tau$ data. These densities are, however, somewhat low for within the plasmasphere.

The regular periodicity shown in Fig. 4 suggests that we should consider a particular peak in auroral light intensity to be associated with any peak in VLF hiss intensity, not necessarily that closest to it in time. This would give $\Delta\tau=0$–0.2 s, or $\Delta\tau=0.75$–0.95 s, etc. (*i.e.* the minimum $\Delta\tau$ plus multiples of the bounce period).

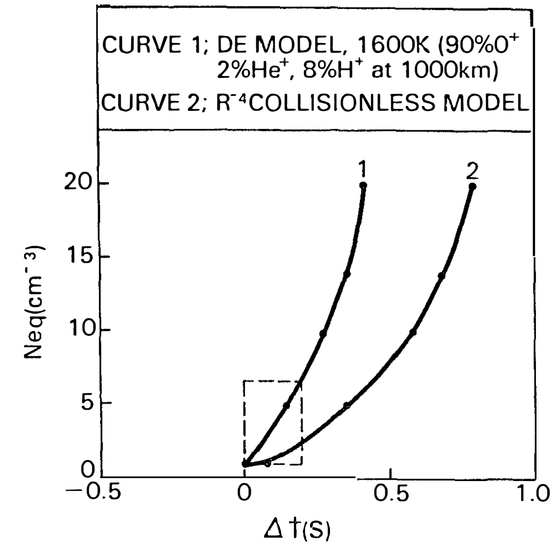

Fig. 6. Difference in arrival time $\Delta\tau$ versus equatorial electron density N_{eq} for the DE-1 (curve 1) and R-4 (curve 2) model plasma distributions. The observed range of $\Delta\tau$ is enclosed in the rectangle.

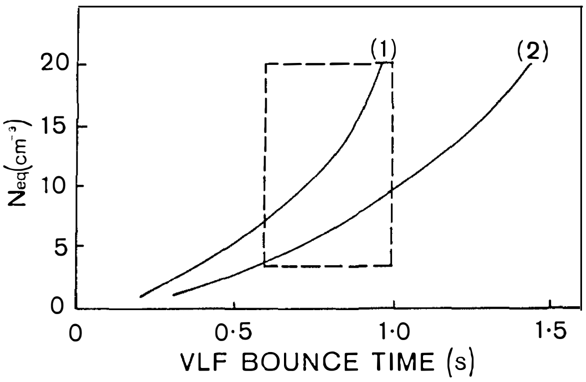

Fig. 7. Bounce time of VLF waves versus equatorial electron density N_{eq} for the same plasma distributions as in Fig. 6. The observed range of echo period is enclosed in the rectangle.

If the VLF hiss emissions were three-phase (HELLIWELL, 1965) rather than single phase, then the true bounce period for each 'bunch' of waves would be 3×0.75 s= 2.25 s. By extension of the curves in Fig. 7 this corresponds to $N_{eq}=110$ cm^{-3} for the DE-1 plasma model (or 45 cm^{-3} for the R-4 model). Extension of the curves in Fig. 6 gives a corresponding $\Delta\tau$ of 0.9 s for the DE-1 model (or 1.2 s for the R-4 model). This value fits into the second range of $\Delta\tau$ given above; this corresponds to a particular 'bunch' of electrons being associated with the VLF 'burst' not immediately following it, but just over one bounce period later.

By invoking echoing VLF hiss as the driving mechanism of the observed periodicity, we are assuming the existence of ducts of enhanced plasma density. We might further consider the pulsating auroral form to be the 'footpoint' of a duct, as suggested by SCOURFIELD *et al.* (1983). The electron density should then be a typical plasmasphere value, *viz.* $\sim$100 cm^{-3} and the DE-1 model should apply.

Approximately 30 minutes before the data period a few whistlers of poor quality were recorded. These gave equatorial electron densities of approximately 700 ± 100 cm^{-3} at $L=3.6\pm0.1$. Using RYCROFT and THOMAS's (1970) empirical relation to estimate the plasmapause position, we obtain $L=3.8\pm0.3$ for $Kp=5+$, the value at the time of these observations. This is consistent with the idea that the duct described above has 'peeled off' the plasmasphere in the manner suggested by SCOURFIELD *et al.* (1983).

All this then tends to support the view that the electron density should be $\sim$100 cm^{-3}, so that the value of 110 cm^{-3} obtained by assuming that the echoing VLF hiss is three-phase appears to be the most reasonable.

4. Conclusion

We conclude that the most likely scenario to explain our observations of correlated auroral light intensity and VLF hiss pulsations (with a consistent N_{eq} of 110 cm^{-3}) is the following:

Three-phase VLF waves echo backwards and forwards between the northern and southern hemisphere with a period of 2.25 s. While travelling northwards through the equatorial region they undergo cyclotron resonance with southward-going electrons with auroral energies. These electrons feed energy to the waves, are scattered into the loss cone and precipitate to produce the observed luminosity above Sanae. The amplified waves continue northwards, are reflected in the northern hemisphere and return to arrive at Sanae approximately 0.9 s later, after the arrival of the VLF hiss 'burst' associated with the previous 'bunch' of electrons.

Acknowledgements

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