ISEE-1 Observations of VLF Emissions Triggered by Nonducted Coherent Waves in the Magnetosphere

T. F. Bell and U. S. Inan

Radioscience Laboratory
Stanford University, Stanford, California 94305

1. Introduction

New observations of nonducted coherent VLF waves from ground-based transmitters and associated VLF emissions in the magnetosphere are reported. The data were acquired by the Stanford University VLF wave receiver on the ISEE-1 satellite [Bell and Helliwell, 1978]. The purpose of this experiment is to study VLF propagation and wave particle interactions. The coherent waves are injected into the magnetosphere by ground transmitters such as that at Siple Station, Antarctica and those of the worldwide Omega Navigation Network.

The experiment is illustrated in Figure 1, where we show these two classes of wave-injection experiments, (a) Siple-to-Roberval transmission through a field-aligned duct of enhanced ionization, with the waves and particles interacting in a region (shaded) close to the equator to produce wave amplification and emission triggering. A spectrogram of a typical emission triggered by a one-second long transmitter pulse is shown below. The distinguishing characteristics of such emissions are a frequency-time slope of ~2-4 kHz/sec and coherent and discrete spectral shapes, (b) Ground-to-satellite transmission along nonducted paths. Both direct and indirect waves can intersect the interaction region (shaded), where wave amplification and emission triggering can be produced. A spectrogram of a typical emission-triggered by a 10.2 kHz pulse is shown below. The emissions consist of a distribution of discrete elements, with a rate of change of frequency of up to ~40 kHz/sec.

The details of these results are given elsewhere [Bell et al., 1981]; in this discussion we show a few outstanding examples.

2. VLF Emission Characteristics

Figures 2 and 3 show examples of emissions triggered by nonducted waves. The fact that the waves are nonducted is separately determined by time delay measurements and raytracing analysis done in model magnetospheres. Figure 2 shows an example of receptions of Omega, North Dakota transmitter signals on the ISEE-1 satellite. The transmitter format consists of ~1 sec pulses alternating between 5 different frequencies in the 10.2-13.6 kHz range. The data samples of the two panels are four minutes apart in time and are representative of receptions during a period of triggering that lasted ~10 minutes. Note that the durations of the received signal and triggered emissions are much longer than that of the direct pulse (~1 second). Figure 2 shows the wave spectrum at the beginning of the event.

Arrows along the time axis indicate the instant at which the strong direct pulses at 10.2 kHz reach the satellite. The magnetospherically reflected echoes [Edgar, 1977] and emissions arrive approximately one second later, producing a continuous signal of approximately 4 seconds duration (see Appendix). At this time the emissions consist of short rising tones of small bandwidth and relatively low intensity.

The situation is reversed a few minutes later, as shown in Figure 2. Here the amplitude of the direct pulses at 10.2 and 11-1/3 kHz is only slightly above the noise level, whereas the echoes are strong and trigger intense multi-emission noise bursts. Arrows along the time axis indicate the arrival time of the echo and associated emissions. The time delay between the direct pulse and the echo pulse is ~2 seconds. The emissions consist of discrete tones which rise rapidly in frequency across a 5-kHz band above the transmitter frequency. The rate of change of frequency of these rising tones approaches 40 kHz/sec, a value much larger than the ~1-10 kHz/sec rate for natural emissions observed on the ground (presumably ducted) [Allcock and Mountjoy, 1970] and natural emissions observed outside the plasmasphere [Burtis and Helliwell, 1976]. The discrete nature of the rising tones is obscured because of the large number of emissions triggered by the echo; thus they appear noise-like in character.

Another example of emissions triggered by nonducted waves is shown on a compressed time scale in Figure 15. The data displayed are characteristic of ISEE-1 receptions over a ~20-minute period. Again, the signals at 10.2 kHz consist of a superposition of multipath pulses.

Examination of amplitude plots shows that the initial two seconds of each signal group consist of two separate overlapped pulses of 1.2 seconds' duration, with the second pulse delayed 800 ms with respect to the first. Each double pulse group is followed after 300-500 ms by a diffuse hiss-like noise burst of approximately 4 seconds' duration, which has a sharp lower cutoff frequency of 10.2 kHz. Analogus noise bursts are triggered by the pulse groups at 11.05 and 11-1/3 kHz. Unlike previous examples of triggered emissions, these noise bursts contain no detectable structure; they are similar in spectral form to quasi-periodic noise bursts [Ho, 1974]. Since no emissions or noise are triggered during the first two seconds of the pulse group, it is reasonable to conclude that the noise is produced by longer time delay pulses which accompany, but are obscured by, the noise bursts. However we cannot positively rule out the possibility that the unusual noise bursts were generated through some unknown delayed triggering mechanism activated by the earlier pulses.

3. Conclusions

Analysis of the large bulk of VLF data from the ISEE-1 satellite has shown that the VLF transmitter signals propagating in the nonducted mode are observed continuously over large regions of the plasmasphere, and that VLF emissions triggered by those nonducted waves often are found to have spectral characteristics different from those of emissions triggered by ducted signals.

Furthermore it has been found that VLF emissions are rarely triggered by those transmitter signals that reach the satellite along the raypath of shortest time delay. We conclude that the triggering of VLF emissions can proceed under much more general conditions than heretofore believed.

References

Allcock, G. McK., and J. C. Mountjoy, Dynamic spectral characteristics of chorus at a middle-latitude station, J. Geophys. Res., 75, 2503, 1970.

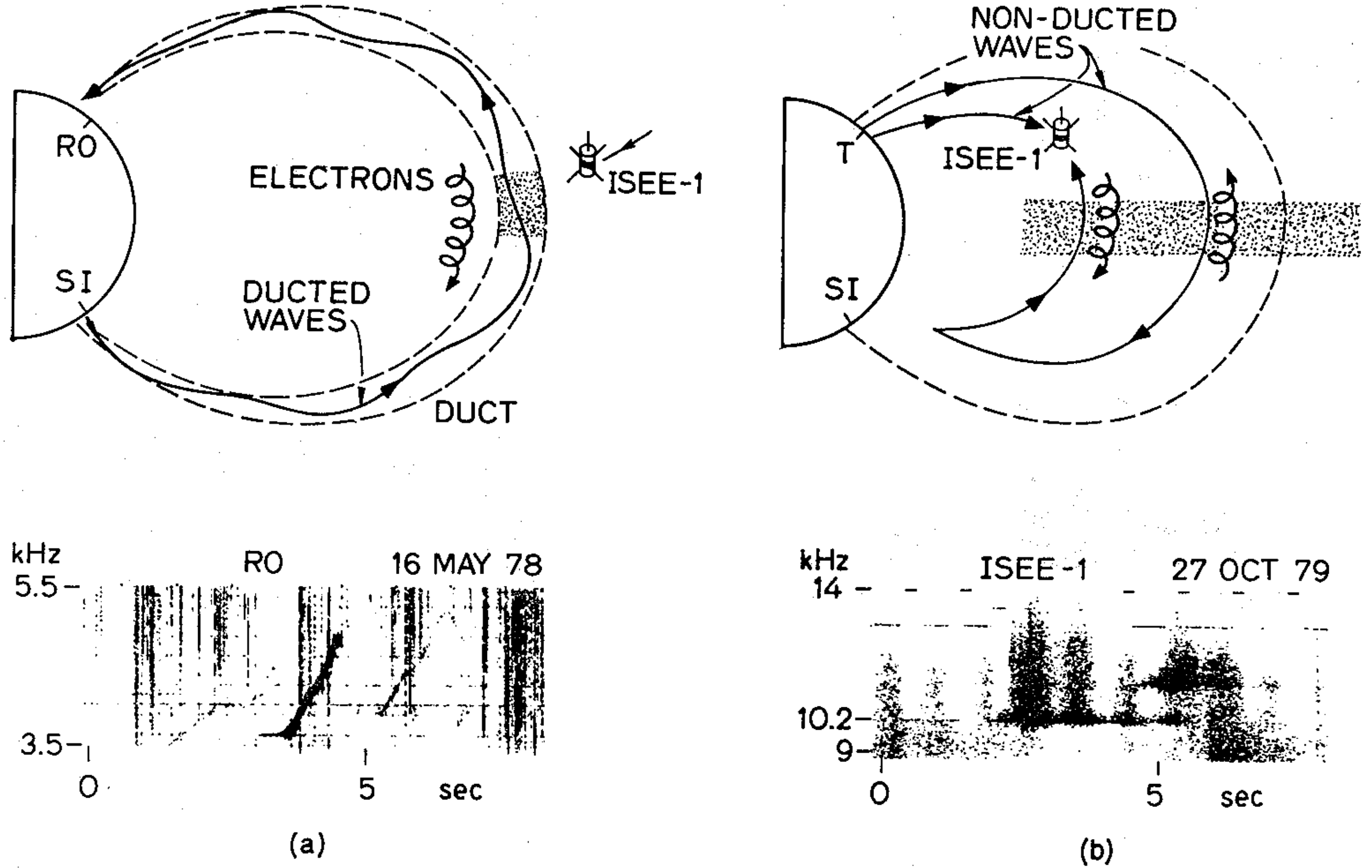
Bell, T. F., U. S. Inan and R. A. Helliwell, Nonducted coherent VLF waves and associated triggered emissions observed on the ISEE-1 satellite, J. Geophys. Res., in press, 1981.

Bell, T. F., and R. A. Helliwell, The Stanford University VLF wave injection experiment on the ISEE-A spacecraft, IEEE Trans. Geosci. Electron. GE-16(3), 248, 1978.

Burtis, W. J., and R. A. Helliwell, Magnetospheric chorus: Occurrence patterns and normalized frequency, Planet. Space Sci., 24, 1007, 1976.

Edgar, B. C., The upper- and lower-frequency cutoffs of magnetospherically reflected whistlers, J. Geophys. Res., 81, 205, 1976.

Ho, D., Quasi-periodic (QP) VLF emissions in the magnetosphere, Tech. Rep. 3464-2, Radioscience Lab., Stanford Electron. Lab., Stanford University, Stanford, Calif., 1974.



(a) (b)

FIG. 1

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(a) 5 sec (b)

FIG. 1

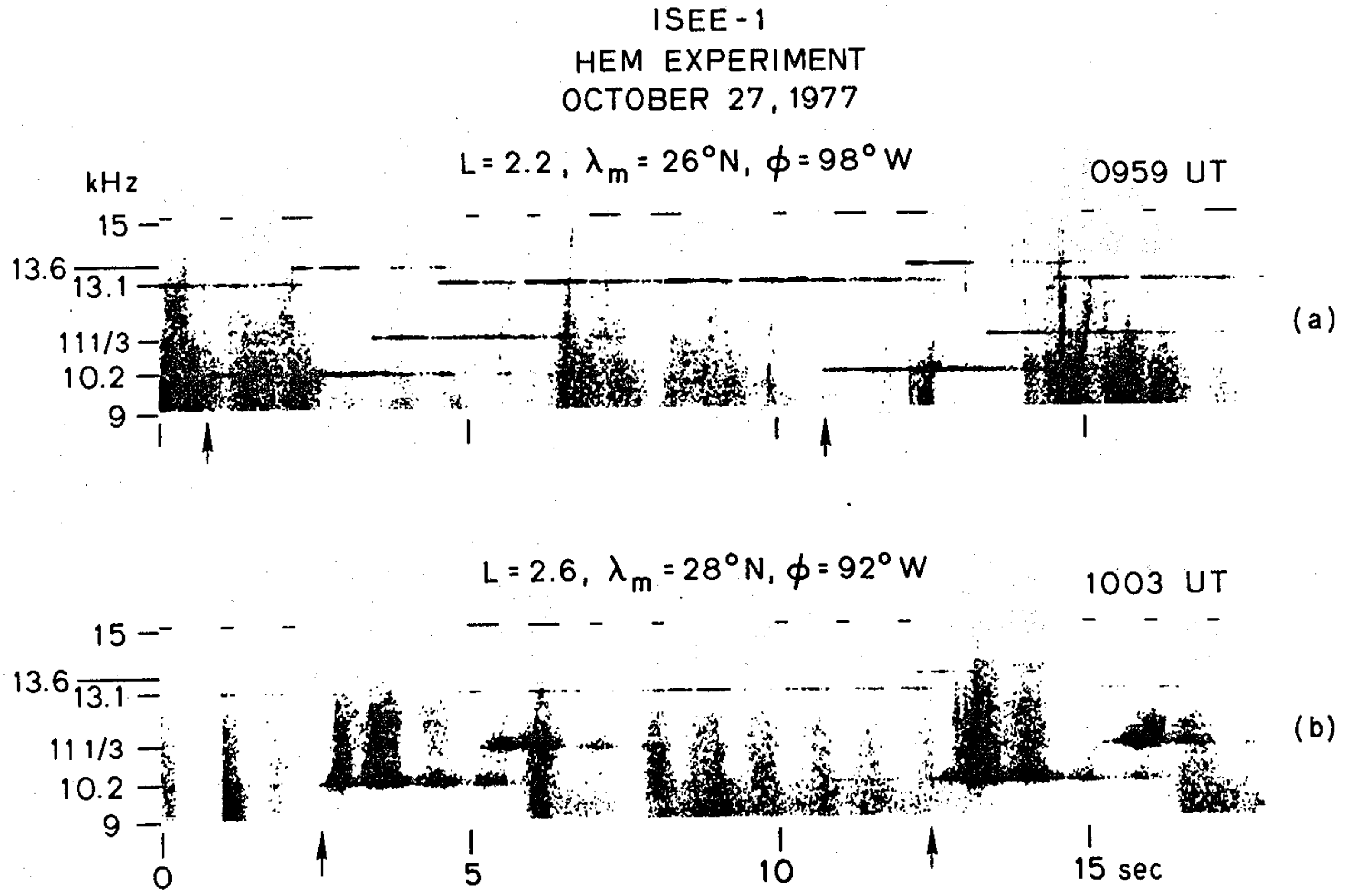

FIG. 2

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HEM EXPERIMENT
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$L = 3.3$, $\lambda_m = 5°S$, $\phi = 87°W$

FIG. 3

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