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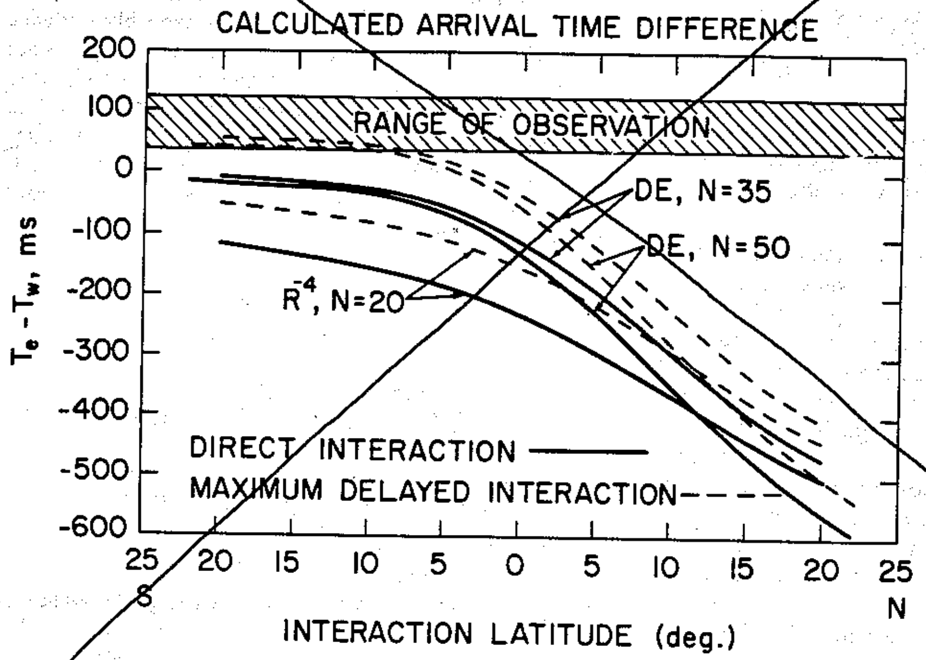

~~**Figure 3. Dependence of the calculated electron-wave arrival time difference on dipole latitude. *N* refers to the equatorial electron density. DE: "Diffusive equilibrium" density model. R-4: "Collisionless" density model.**~~

Observations of Siple transmitter signals on the ISIS satellites

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Since February 1979, through arrangements between the Communications Research Centre of Canada and Stanford University, VLF transmissions have regularly been made from Siple, Antarctica, to the ISIS-1 and -2 satellites in the northern hemisphere conjugate region. Both satellites are in polar orbit, with ISIS-2 at approximately 1,400-kilometer altitude and ISIS-1 at altitudes ranging from 600 to 3,500 kilometers. In earlier experiments in 1975, transmitter signals were received on the satellites but the number of cases observed was relatively small. In the recent and longer campaign, strong Siple signals have been received on a large fraction of the orbits, apparently because of the approximately 7-decibel higher power achievable with the new Jupiter transmitter at Siple.

This new data set provides a strong basis for studying magnetospheric very-low-frequency (VLF) propagation and associated wave-growth phenomena. We present here spectrographic illustrations from some of the first data tapes surveyed.

Figure 1, second and third panels, shows spectrograms of signals received on ISIS-2 during a northbound pass near local noon (15 August 1979) and a southbound pass near local midnight (23 August 1979). The transmitted format is shown at the top; the approximately 2-second offset between it and the receptions is due to propagation delay along the magnetospheric paths. A striking feature of the records is the Doppler shifts of approximately 100 hertz on both sides of the transmitted frequency. These are particularly well defined near t = 16 seconds in the middle panel. The frequency offsets are due to the occurrence of nonducted propagation, in which the wave normal is bent away from the direction of the magnetic field according to the distribution of gradients in the plasma and geomagnetic

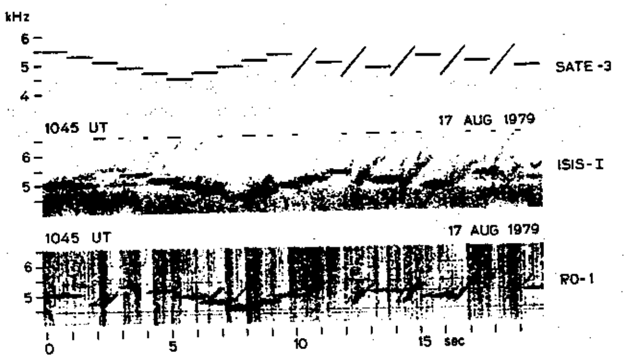

Figure 1. Frequency-time records of Siple Station VLF transmitter signals received in the northern hemisphere on the ISIS-2 satellite. The transmitted format is at the top.

field along the ray path. The orbital motion of the satellite is nearly parallel to the direction of the wave normals with largest angles, so that relatively large Doppler shifts can be observed in such cases. Multiple shifts are believed to be caused by multiple ray paths from the source to a point in the conjugate region, each with characteristic wave normal angle and group delay. Unshifted signals probably have wave normals that are near the magnetic field direction, either because of special properties of a nonducted ray path or because of a ducting process that constrains the wave normals. The separate nature of the ray paths of the three signals is suggested by the differences in their respective group delays.

In the lower panel there is an apparent drift in frequency with time of individual pulses. The pulses at the upper and lower frequencies are clearly much longer than the transmitted pulses, indicating propagation on multiple paths with an extended range of travel times. The apparent change in Doppler shift with time may reflect the successive arrival times of waves with different wave normal angles.

Figure 2 illustrates a case in which the signals observed on ISIS-1 (middle panel) resembled those observed simultaneously at the ground station Roberval, Canada (lower panel). Their travel times are in good agreement, and the similarity in spectral forms suggests that both sets of signals traveled on ducted paths of the type required for reception at the ground station. Differences in the records may be due to the coupling of energy to the satellite from a number of ducted paths not seen on the ground and also to nonducted propagation.

The general type of relationship illustrated in figure 2 is shown again in figure 3, which includes an ISEE-1 satellite recording in the southern hemisphere (below the transmitter format). The transmitter signal first appears near t = 1 second on the spin-modulated ISEE record. It is then received nearly simulteneaously at ISIS-2 and Roberval. After its termination in the north, the signal continues to be seen in a multi-hop mode on ISEE, but there is no evidence of stimulated emissions. The ISIS record shows similarities to a number of features of the ducted signals received on the ground, but also contains a large number of discrete rising tones, falling tones, hooks, etc., that are not detected at Roberval Station. These have the characteristics of emissions triggered by ducted signals and are probably evidence of propagation to the satellite from ducts whose signals are not being detected at the ground station. These and many other features of the ISIS data are now under investigation.

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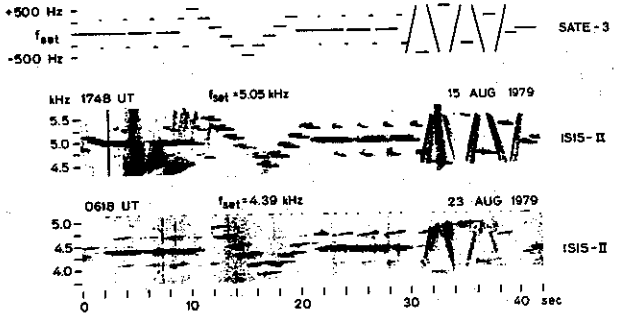

Figure 2. Comparison of Siple transmitter signals and stimulated emissions received in the northern hemisphere on the ISIS-1 satellite and on the ground at Roberval, Canada.

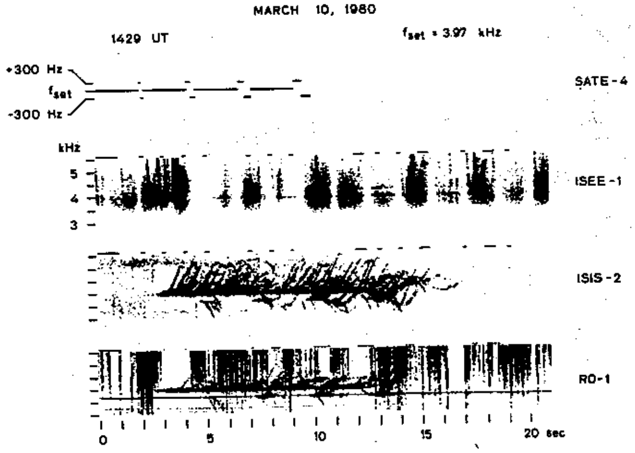

Figure 3. Comparison of Siple transmitter signals and emissions received on the ISEE-1 satellite in the southern hemisphere and at the ISIS-2 satellite and Roberval Station in the northern hemisphere.