oduce less output, changes in the th ınt advantage of ra multipath effects

VLF signals can tri VLF transmissions recordings made :al association has 'raser-Smith and still uncertain. Fu ol of ULF wave ge open up new ave lsations and might

Figure 4. Roberval spec grams illustrating "q bands" immediately b the 5,950- and 5,050-h transmitter frequenc The transmissions te nated at 1152 Unive Time (lower right).

Figure 5. Roberval trograms illustrating variable nature of growth and emissio tivity during a seque frequency ramps a second pulses. Each shows the same tra sion format.

a basis for new ULF communications techues.

ure program

The Siple experiments have led magnetospheric arch into an exciting new stage. A major task is to develop new theories to explain the re-s. Classical plasma physics has not dealt with erent wave generation, although the evidence gests that the phenomenon should be found in tually all plasmas. An important objective is to ect the effects of precipitation induced by Siple nals, as has been done with natural VLF waves senberg *et al.*, 1971; Helliwell *et al.*, 1973). Space sions of this experiment would combine electron d wave injection to further extend control of perimental parameters. Plans are being made for such an experiment to be performed on a entific payload (AMPS) of a forthcoming space ttle or spacelab. In the meantime, much remains be done from the ground.

Ultimately the Siple experiments should aid in derstanding how the delicate outer fringe of our osphere moderates the sun's influence on the er atmosphere. Such understanding will have a e in predicting and adapting to climatic changes.

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Siple transmitter signals as diagnostic probes of the magnetosphere

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Natural very low frequency (VLF) whistlers from lightning propagate on magnetospheric field-alined paths from hemisphere to hemisphere. A well established theory relates the observed frequency-time or dispersion characteristics of a whistler to the electron density along its path and to the path equatorial radius (e.g., Helliwell, 1965). This theory enables us to obtain much detailed information on the distribution and dynamic behavior of the magnetospheric plasma. The area of Siple and Eights stations possesses exceptional properties as a whistler-receiving location (e.g., high conjugate lightning rates, low local noise). For example, the data acquired there have provided much knowledge of the important geophysical boundary known as the plasmapause (Carpenter, 1966). At this field-alined boundary, typically four earth radii distant at the equator, the plasma density may drop by from one to two orders of magnitude within a fraction of an earth's radius (Angerami and Carpenter, 1966). Figure 1 shows two equatorial profiles of electron density deduced from Siple whistlers. Dashed curves provide estimates of the general trends shown in the data. One example (circles) involves quiet magnetospheric conditions; the profile extends relatively smoothly to ≈5.5 earth radii and the plasmapause is not defined. The other case (triangles) involves moderately disturbed conditions; the plasmapause is present near four earth radii, which is near the field lines connecting Siple, Antarctica, and Roberval, Quebec (Canada).

What role can the Siple transmitter signals play as diagnostic probes of the magnetosphere? A study has been made of the circumstances of transmitter signal reception at Roberval. Travel time versus frequency characteristics of the Siple signals were compared to those of whistlers. Figure 2 shows frequency (1.5 to 3.5 kilohertz) versus time records of frequency ramps transmitted at Siple (above) and received ≈3.2 seconds later at Roberval (below). The double ramp structure at Roberval (lower left) shows evidence of propagation on more than one path, while the curvature of the received ramps

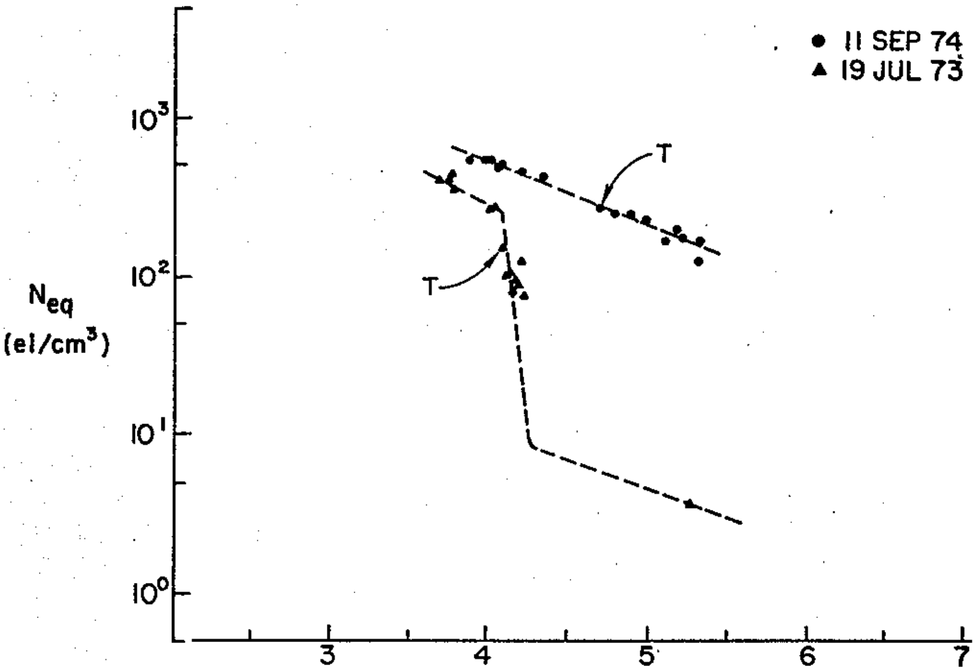

Figure 1. Magnetospheric equatorial profiles of electron density versus geocentric distance in earth radii, as deduced from whistlers recorded at Siple during two periods of very low frequency (VLF) transmitter operation. The data points corresponding to the magnetospheric path followed by the transmitter signals are marked by a T.

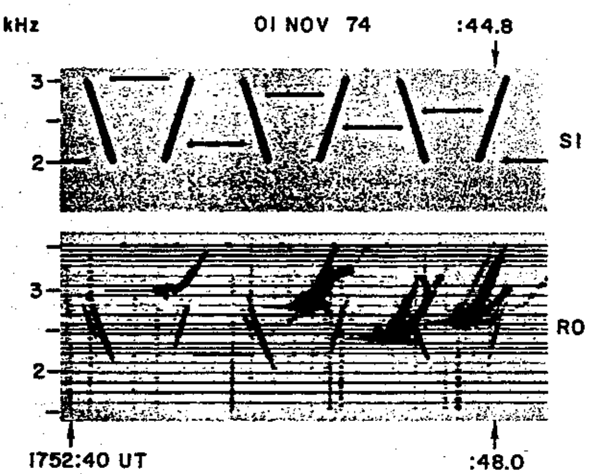

Figure 2. Frequency-time records showing frequency ramps as transmitted at Siple (above) and received ≈3.2 seconds later at the conjugate station Roberval (below). Horizontal lines on the Roberval record are due to local power system currents.

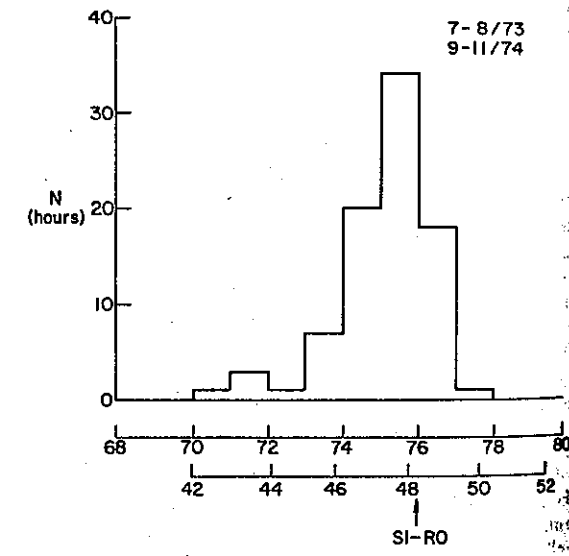

Figure 3. Histogram of number of observing hours versus geographic latitude of the endpoints of the Siple transmitter signal path. The positions of Siple and Roberval in southern and northern latitude are indicated below.

permits reconstruction of the key propagation features of the paths.

Briefly, it was found that Siple signals reproduce many features of whistlers, but in a way that complements the conventional whistler experiment. For example, the received transmitter signals frequently propagate on only one or two of the many paths followed simultaneously by whistlers. This is shown in figure 1; for each case the data point corresponding to the path followed by the transmitter signals is marked by a T. Further, the Siple paths tend to have endpoints within ±≈200 kilometers of Siple-Roberval in the north-south direction. Figure 3 shows a histogram of hours of reception versus geographic latitude of the inferred path endpoints. The concentration of paths is believed to depend on a number of factors, including signal losses due to spreading beneath the ionosphere and the frequent presence along field lines near Siple-Roberval of energetic electrons suitable for the amplification of VLF waves.

The path concentration should facilitate experiments in which path location is of particular importance, such as the search (using balloon-borne x-ray counters, riometers, etc.) for the effects of wave-induced precipitation of energetic electrons into the lower atmosphere. Further, magnetospheric phenomena of interest tend to move in a way that permits the various important states of the system to be scanned through sufficiently long-enduring observations near given field lines; this is illustrated in figure 1. In one case (circles) the Siple signal probes conditions well inside the plasmapause, while in the other case it probes the region of steep plasmapause density gradients.

The transmitter signals have been used to advantage in a recent (June and July 1975) test of VLF direction finding on signals emerging from the ionosphere in the vicinity of Roberval. Participants from Japan, the United Kingdom, and the United States benefited from the availability of signals of known frequency in a known signal format, propagating within an expected north-south range.

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Satellite observations of nonducted signals from the Siple transmitter

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In a circular region with a radius of about 500 kilometers, a substantial portion of the energy radiated by the Siple transmitter enters the ionosphere and propagates into the magnetosphere in the whistler mode. The path of propagation in the magnetosphere may be either ducted or nonducted. Ducted signals follow geomagnetic field-alined paths and may emerge from the ionosphere and be observed at ground stations (Helliwell, 1965). Nonducted waves follow more complicated paths: they tend to remain above the lower boundary of the ionosphere, and are not usually observed on the ground (Smith and Angerami, 1968).

The properties of ducted signals are by far the best understood; most of our knowledge about whistlers, very low frequency (VLF) emissions, and wave-particle interactions in the magnetosphere derives from their study. The nonducted mode nonetheless is important; about 90 percent of the energy radiated by a VLF ground transmitter will propagate through the magnetosphere in this mode.

It generally can be expected that the nonducted waves from the Siple transmitter will interact with energetic particles in the magnetosphere and will produce VLF emissions and particle scattering in the same manner as ducted waves. The nonducted

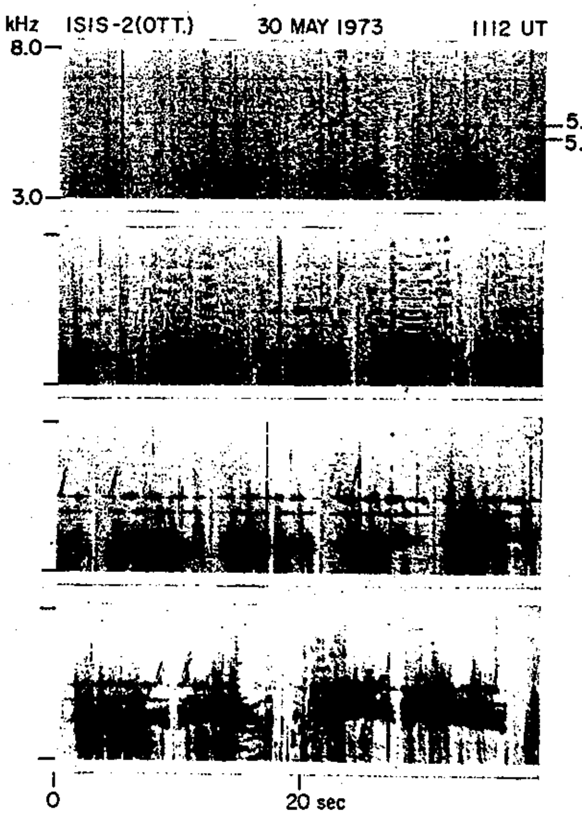

Figure 1. Very low frequency (VLF) spectrogram showing Siple transmitter pulses and stimulated emissions as observed over the Northern Hemisphere by the polar-orbiting satellite ISIS-2.