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Satellite measurements during Siple Station VLF wave-injection experiments

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One of the primary functions of the Siple Station very-low-frequency (VLF) transmitter is to inject coherent VLF waves into the magnetosphere in order to stimulate nonlinear gyroresonance interactions between the waves and the energetic particles that populate the Earth's radiation belts. In these interactions the perturbing waves may be amplified by as much as 30 decibels, VLF emissions may be produced, and the resonant energetic electrons may be scattered into the atmospheric loss cone, eventually precipitating into the lower ionosphere to produce bremsstrahlung X-rays, optical emissions, and plasma density enhancements (Helliwell and Katsufrakis 1974).

The main goal of the Siple Station VLF wave-injection experiments it to gain understanding of the physics that governs the nonlinear gyroresonance interaction in the magnetosphere. This knowledge is essential if we are to understand the mechanisms that determine the lifetime of energetic particles in the magnetosphere of the Earth, as well as in the magnetospheres of other planets in our solar system.

Each wave injection experiment begins with the injection of VLF waves from the Siple transmitter into the ionosphere. A small fraction of these waves travel in ducts of enhanced ionization along the Earth's magnetic field. Near the magnetic equatorial plane, these waves interact with energetic electrons to produce wave amplification (up to 30 decibels), triggering of VLF emissions, and scattering of energetic electrons. The ducted signals and associated triggered emissions travel to the ionospheric regions conjugate to Siple Station and enter the Earth-ionosphere waveguide to be observed on the ground near Roberval, Canada.

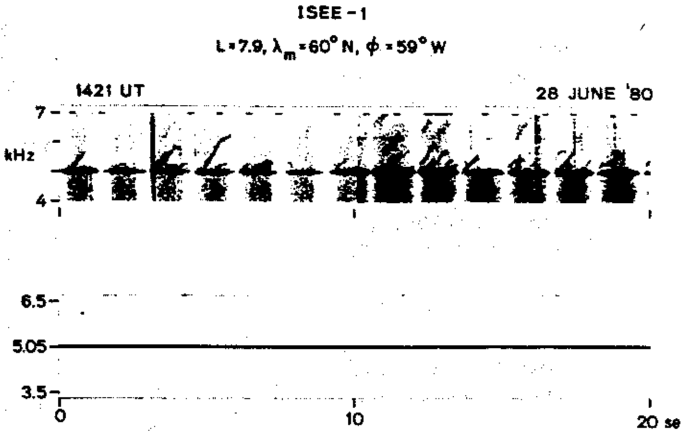
Although ground-based measurements can determine a number of important features of the interactions involving ducted waves, most of the waves injected by the Siple Station transmitter propagate in the magnetosphere in a nonducted mode, and the output of these interactions is not observable on the ground (Bell, Inan, and Helliwell 1981). Thus, the only means of observing the output of wave-particle interactions involving nonducted injected waves is through the use of satellites or rockets.

During the past year, three satellites have been used to obtain correlative measurements during Siple Station wave-injection experiments: the EXOS-B, the ISIS II, and the ISEE-1 spacecrafts. The Japanese high-altitude EXOS-B spacecraft has been uniquely valuable in providing both VLF wave and energetic particle measurements during Siple wave-injection experiments. A few of the new discoveries (Bell et al. in preparation; Kimura et al. in preparation) credited to the EXOS-B/Siple Station experiments are:

1. In the local noon sector, the triggering of VLF emissions by Siple signals took place only in the aftermath of a large magnetic storm.
2. The probability of Siple signals triggering VLF emissions was an order of magnitude higher in the local dawn sector than in the local noon sector.
3. Emission-triggering by Siple signals appears to depend more strongly on the magnitude of the energetic particle flux than on the pitch angle distribution of the flux.

The Canadian low-altitude satellite ISIS II has obtained valuable data above Roberval concerning the Doppler shift of nonducted Siple signals and associated VLF emissions. This information has been used to determine the raypath along which the emissions were generated and to determine the wave normal of the waves in the interaction region.

The National Aeronautics and Space Administration high-altitude satellite ISEE-1 has been uniquely valuable in obtaining comprehensive measurements of Siple transmitter signals and associated emissions both inside and outside the plasmasphere. The figure shows a portion of the VLF wave data acquired by the ISEE-1 satellite on 28 June 1980 during an hour-long interval in which Siple signals and associated VLF emissions were present in the data.



Portions of very-low-frequency (VLF) wave data acquired on the ISEE-1 satellite on 28 June 1980. Upper panel shows a spectrogram of wave data in the 4–7 kilohertz range. Lower panel shows the transmitter format. The presence of VLF emissions and signal bandwidth increase is clearly in evidence.

The upper panel of the figure shows a spectrogram of the satellite wave data in the range of 4–7 kilohertz for a 20-second period near 1421 universal time when the spacecraft was near the northern auroral zone on a magnetic shell of number L = 7.9, a magnetic latitude of 60°N, and a geographic longitude of 59°W. The transmission format at this time consisted of a signal of constant frequency at 5.05 kilohertz, and this format is depicted in the spectrogram in the lower panel of the figure.

The fading with 1.5-second period evident in the top spectrogram is caused by the rotation of the satellite dipole antenna during reception. Comparison of the two panels of the figure shows that the Siple transmitter signal has triggered a number of VLF emissions somewhere along its path of propagation to the satellite. In addition, the bandwidth of the signal has been increased significantly by its interaction with energetic electrons along its propagation path.

It is planned that new satellite wave and particle measurements will be carried out during future Siple VLF wave-injection experiments.These measurements will be of great value in expanding our knowledge of how waves and particles interact in the Earth's environment.

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~~ULF-associated particle precipitation at Siple Station~~

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~~The correlation of ultra-low-frequency (ULF) waves with particle precipitation has long been recognized as a very interesting geophysical phenomenon that apparently results from the interaction between waves and particles in the magnetosphere. Although the integrated wave energy in the magnetosphere is small compared with that in the particle population, wave-particle interactions could be significant in particle acceleration and losses, in wave growth, and in the modification of such plasma parameters as collision frequency and resistivity.~~

~~This report presents two different types of ULF-photometer correlations. The first type is a prompt (within a few seconds) correlation between Pi 1 (irregular pulsation category 1) and auroral light bursts. Figure 1 gives the horizontal components of dB/dt (i.e., the derivative of magnetic field B with respect to time); the component along B was negligible. Also given is the output from the 5577-ångstrom Lockheed photometer viewing vertically with a 10° entrance aperture for 4 minutes on 21 August 1979. The vector direction of the horizontal dB/dt signal is given by the angle ϕ measured positive north of west. The figure clearly shows that only when the direction of dB/dt was southwest, or when the disturbance field ΔB was directed to the southwest, were the pulsations correlated with light bursts. Equally large ΔB directed to the northwest occurred but was not accompanied by a light burst. This rather unique association of particle precipitation with a disturbance field in one direction is a consistent feature seen in approximately a dozen such events recorded in 1979 with the favored direction always southwest or west. We would like to make brief comments about possible interpretations of this type of photometer-Pi 1 correlation.~~

~~1. Local current model. In this model the micropulsations are the ground-level magnetic signature of an ionospheric current system enhanced or generated either as a result of an impressed electric field or an increased ionospheric conductivity due to particle precipitation. The origin of the particle precipitation and/or electric field is not addressed in this model. For events like the one discussed here, one needs an ionospheric current directed toward the north-northwest. Such a current system has been attributed to the quasi-periodic poleward propagation of on-off switching aurora as observed with auroral TV by Oguti and Watanabe (1976). These poleward-propagating auroral particles were observed by Oguti and Watanabe in the dawn post-breakup aurora and were concurrent with magnetic pulsations having approximately a 10-second period. The date of figure 1 are inconsistent with this model in at least one respect. If the auroral light burst is responsible for the local ionospheric current, then the ground ΔB field will rise with time approximately as the light burst. The micropulsation signal is the time derivative of ΔB; hence, it would not track the light burst as it is observed to do in figure 1.~~

~~2. Equatorial wave-particle interaction. In this model, wave growth in the equatorial plane is at the expense of particle energy; hence, particles are moved into the loss cone and precipitated. Pi 1 (SIP) has been observed by satellite sensors in the equatorial plane at synchronous orbit associated with the onset of substorms (Shepard et al. 1980). Because the wavelength of the observed Pi 1 is only a fraction of the distance from the ionosphere to the equator, it is unlikely that the wave is a standing mode. However, for a propagating wave, there should be a delay of a few tens of seconds between the particle precipitation and the arrival of the wave at the ionosphere, and this is not observed.~~

~~3. Local particle precipitation. In this model, the magnetospheric waves incident on the ionosphere lower the mirror point of local particles. A similar model involving ionospheric current feedback has been suggested by Maehlum and O'Brien (1968). The serious problem with this mechanism is that the ground ΔB measured is only a few gamma in amplitude. Even allowing large ionospheric attenuation, the signals above the ionosphere still would be very small compared with the magnitude of the local field and would be of questionable effectiveness in the precipitation of particles. The ULF-photometer~~