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A new type of very-low-frequency emission triggered at altitudes below 1,400 kilometers by signals from Siple Station

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A new type of triggered very-low-frequency (VLF) emission has been discovered in ISIS-2 satellite data acquired at Siple Station for the period of April through October 1983 during joint VLF wave-injection experiments involving the Communications Research Centre at Ottawa, Canada, and the Stanford University STAR Laboratory. The joint wave-injection experiments have four main components: (1) broadband VLF/extremely-low-frequency (ELF) receivers on the ISIS-1 and ISIS-2 satellites; (2) a broadband (1 to 20 kilohertz) controllable VLF transmitter located at Siple Station, Antarctica (Helliwell and Katsufrakis 1974); (3) various VLF navigation and communication transmitters, such as those of the world-wide Omega network; and (4) ground stations in the Antarctic and Canada.

The main goal of these and similar experiments is to understand interactions between coherent VLF waves and energtic particles in the magnetosphere and ionosphere (Helliwell and Katsufrakis 1974; McPherson et al. 1974; Dowden et al. 1978; Bell, Inan, and Helliwell 1981; Bell et al. 1983-a; Kimura et al. 1983). Sources of the coherent waves involved in these studies include VLF transmitters, large-scale power grids, whistlers, and other natural coherent VLF signals.

The new type of VLF emission is triggered by Siple transmitter pulses as they propagate through the ionosphere and low-altitude magnetosphere up to the ISIS-2 satellite at 1,400 kilometers altitude. It is the only type of emission known to be triggered at low altitudes by manmade signals. Other triggered VLF emissions apparently are generated at high altitudes (greater than 6,000 kilometers) near the magnetic equatorial plane (Helliwell and Katsufrakis 1974; Bell et al. 1981).

Figure 1 shows high time-resolution data of the frequency and amplitude of a Siple Station transmitter pulse during typical emission events. The upper panel shows a 1.5- to 4.5-kilohertz spectrogram of the pulse. The middle panel shows the pulse amplitude in a 300-hertz bandwidth centered on the instantaneous frequency of the pulse. The lower panel shows the frequency-time format of the pulse. Arrows along the time axis of the spectrogram in the upper panel show the location of four emission events. (A few others, somewhat weaker, are not marked.) The events are characterized by impulsive increases in signal bandwidth and amplitude which endure for roughly 20 to 30 milliseconds (based on a 10-decibel amplitude decrement). In general, bandwidth increases can reach as much as 1 kilohertz, and amplitude increases can exceed 20 decibels. In the examples shown, the maximum bandwidth increase of the pulse is roughly 700 hertz, and the amplitude of the emission is roughly 10 to 20 decibels above the signal level immediately preceding and following the events. During the duration of each of the emission events (20 to 30 milliseconds), the satellite moved approximately 150 to 200 meters.

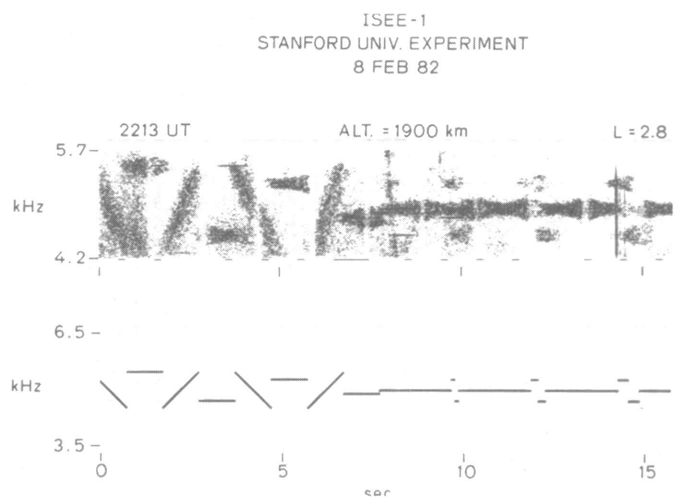

Figure 1. Typical example of a Siple Station transmitter signal triggering impulsive very-low-frequency emissions. ("UT" denotes "universal time." "f" denotes "frequency." "kHz" denotes "kilohertz." "A" denotes "amplitude." "dB" denotes "decibel.")

Another unique feature of the new type of triggered emission is that it has been observed to occur only in the subauroral region outside the plasmapause where the cold plasma density is relatively low. Most other VLF emissions triggered by signals from ground-based transmitters occur within the plasmasphere where cold plasma densities are relatively high. The new type of emission may be generated by a rapidly evolving plasma instability which is driven by precipitating energetic electrons within magnetic field aligned density irregularities. The Siple Station signals are thought to couple to quasi-electrostatic plasma modes in the irregularities, and these modes are subsequently amplified by the instability.

The new emission may possibly be the transient analog of the recently reported spectral broadening effect (Bell et al. 1983-b). In the spectral broadening effect, initially narrow-band (approximately 1 hertz) signals from ground-based VLF transmitters undergo a significant steady-state frequency bandwidth increase as they propagate through regions where energetic electron precipitation is thought to take place. The effect has been observed at satellite altitudes in the range 600 to 4,000 kilometers, and both upgoing and downgoing signals can show the effect. The affected transmitter signals lie in the range of 4 to 20 kilohertz, and the frequency bandwidth increase can reach a value as high as 10 percent of the nominal frequency of the input signal. The bandwidth increase occurs only in the presence of impulsive VLF hiss and/or a lower-hybrid-resonance (LHR) noise band (Laaspere, Johnson, and Semprebon 1971) with an irregular lower cutoff frequency, and only for signals whose frequency lies above the local LHR frequency at the satellite location. Dispersion in the components of the affected pulses suggests that the bandwidth increases may be due to a Doppler-shift effect in which the initial signal scatters from plasma density irregularities at low altitude and couples into quasi-electrostatic modes of short wavelength. The large Doppler shift associated with these short-wavelength modes produces a significant increase in the bandwidth of the signal as observed on a moving satellite. Since impulsive VLF hiss and irregular LHR noise bands have been linked to energetic (less than 1 kiloelectronvolt) electron precipitation in the past, it appears likely that the irregularities which scatter the injected signals are produced by the precipitating electrons.

An example of the steady-state spectral broadening of Siple Station transmitter signals is shown in figure 2. The upper panel shows the broadened signals as received on the ISEE-1 satellite, while the lower panel shows the format of the signals as actually transmitted. The received pulses have a bandwidth in the range 100 to 200 hertz, approximately two orders of magnitude larger than their original bandwidth when transmitted.

The discovery of the new type of triggered VLF emission is important, because it shows that coherent VLF signals can act as catalysts to trigger natural plasma instabilities in the subauroral ionosphere and low-altitude magnetosphere. Thus controlled studies of these instabilities may be possible.

Further controlled wave-injection studies of low-altitude plasma instabilities and triggered emissions are planned for 1986 – 1987 at Siple Station. These joint studies will involve workers from Nagoya University, the Japanese National Institute of Polar Research, the Canadian Communication Research Centre, and Stanford University. The studies will concern data acquired on the three spacecraft, ISIS-2 (Canada), ISEE-1 (USA), and DE-1 (USA), and on the ground at Siple and Syowa Stations.

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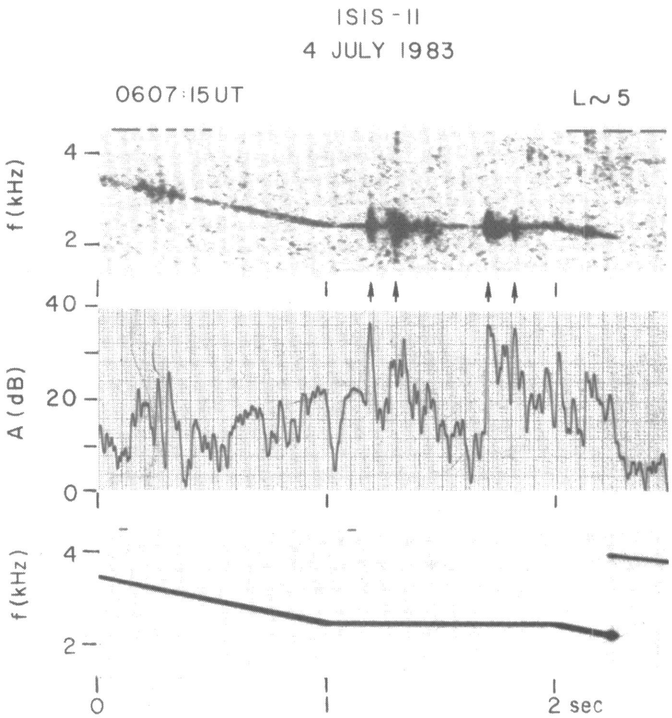

Figure 2. Example of the frequency-bandwidth increase effect as observed in Siple Station transmitter signals. The data were acquired on the ISEE-1 spacecraft on 8 February 1982. The upper panel shows a spectrogram of the received signals, and the lower panel shows the format of the signals as actually transmitted. ("UT" denotes "universal time." "KHz" denotes "kilohertz." "Km" denotes "kilometer.")

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