# U.S. Antarctic Research Program, 1974-1975

## Review of year-round activities

This section of *Antarctic Journal of the United States* comprises the second part of a review of U.S. antarctic projects that were active in 1974 and 1975. Included are descriptions of data analysis done at home institutions and reports on year-round observations made in the Antarctic. The first part of this review, in the July/August 1975 issue, describes field activities that took place in the 1974-1975 austral summer.

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## VLF wave injection experiments at Siple Station

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From Siple Station's 100-kilowatt transmitter, very low frequency (VLF) (≃5 kilohertz) waves are injected into the magnetosphere to stimulate new waves or emissions and to modify the earth's radiation belts. Figure 1 shows schematically the region of space probed by the Siple signals as they travel along paths that reach the conjugate station, Roberval, Quebec, Canada, or are intercepted by satellites. The immediate purpose of the experiments is to advance our understanding of wave-particle interactions in the magnetosphere and other plasmas. Monitoring and controlling the ionosphere and magnetosphere is a long-range objective. Another is to develop a better means of VLF and ultra low frequency (ULF) communication.

Siple (76°S. 84°W.) offers a rare combination of advantages for these experiments: (1) its thick (2-kilometer) ice sheet provides an electrically low-loss platform for the 23-kilometer-long dipole antenna (Raghuram, in press), (2) its latitude is at the mean position (L≃4) of the plasmapause (the outer boundary of the relatively dense plasma region surrounding the earth) (Carpenter, 1966), (3) it is in one of the world's most active whistler and emission regions, (4) its geomagnetic conjugate point at Roberval (48°N. 72°W.) is accessible year-round.

Associated with the Siple transmission experiments are several passive experiments involving VLF whistler and emission monitoring, ionospheric absorption (riometer), magnetic field, magnetic

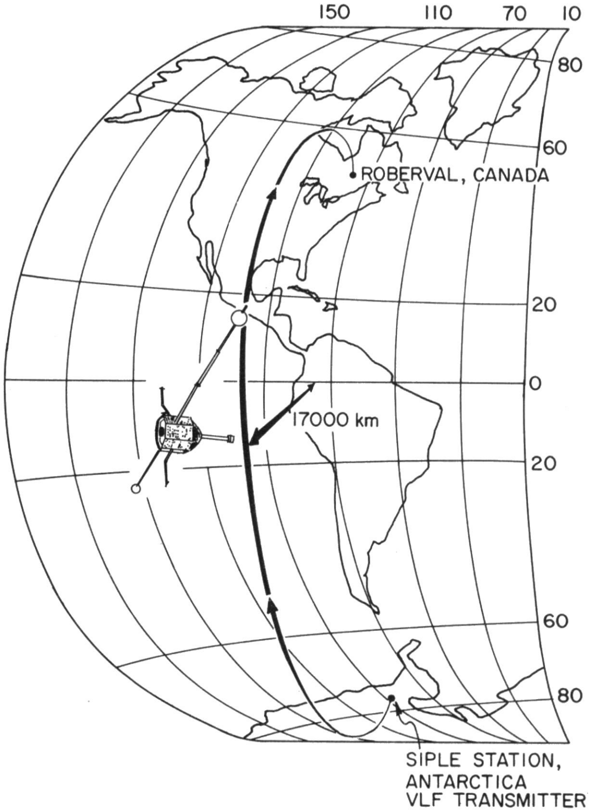

**Figure 1. Sketch of a geomagnetic field-alined path through the earth's magnetosphere. The path is followed by signals propagating from the Siple Station, Antarctica, very low frequency transmitter to the Northern Hemisphere conjugate station at Roberval, Quebec, Canada.**

pulsations, VLF phase path, light emissions, and balloon X-ray (austral summer only). Planned studies in the future include VLF direction finding, auroral backscatter, and auroral television. At or near Roberval are experiments in passive VLF, riometer, magnetic field, magnetic pulsations, and short-term balloon and direction finding. Supporting measurements in the magnetosphere have been or are provided by such satellites as ISIS-2, Explorer 45, IMP-6, and AE-C. Future ISEE and electrodynamics Explorer satellite programs will use Siple signals in their *in situ* studies of wave-particle interactions. During the International Magnetospheric Study (IMS), from 1976 to 1978, Siple is expected to join with other antarctic and subantarctic stations (Halley Bay, General Belgrano, Argentine Islands or Palmer, Sanae, Kerguelen, and Campbell Island) in worldwide whistler studies of magnetospheric plasma structure and motions.

## First results

The first results were obtained shortly after Siple Station began transmitting, which was during the 1973 austral winter. It was found that coherent triggering signals generally grow exponentially with time until saturation is reached or until the triggering pulse ends, whichever occurs first. The growth rate was found to vary with time, ranging from 25 to 250 decibels per second. According to current ideas, there should have been a corresponding variation in the flux of energetic electrons (order of 10 electron-volts) trapped on the field line connecting Siple with Roberval (see figure 1). Growth effects are usually observed a day or two after the onset of a magnetospheric substorm, during which a fresh supply of energetic electrons is injected into the midnight sector of the magnetosphere.

One of the persistent features of the growth process is the generation of narrowband variable-frequency emissions. These emissions frequently last longer and contain more total energy than the amplified trigger pulse itself. Contrary to earlier observations, the more detailed Siple experiments showed that the spectra of the emissions connect smoothly to the trigger signal instead of starting at a higher, "offset" frequency (Stiles and Helliwell, 1975). All initial frequency changes with time were positive, but the continuation of the emission could either rise or fall in frequency.

A curious feature of many stimulated emissions is their frequent sudden changes in amplitude or in frequency slope. The repeatable nature of the Siple-Roberval experiments revealed that these perturbations often occur at Siple transmitter frequencies and at harmonics of the local (Canadian) powerline currents. Many simultaneous spectra from Siple and Roberval were compared, and it was found that power system radiation frequently excites magnetospheric lines that are observed simultaneously at both ends of the path (Helliwell *et al.*, in press). Surprisingly, these lines were often found at frequencies 20 to 30 hertz higher than the nearest powerline harmonic, even though their spacings were often near 120 hertz. This effect is thought to be related to a positive frequency offset of emissions seen on key-down signals from the Siple transmitter. The presence of coherent radiation from powerlines provides a natural explanation for many observed anomalies in the spectra of artificially stimulated and naturally occurring emissions. Calculations of pitch angle scattering of electrons by these lines suggest that power system radiation may contribute significantly to the precipitation of electrons from the radiation belt.

## Recent results

Work on the properties of stimulated emissions has continued during the past year. Interesting new phenomena have been identified in a first look at the data, including the following:

(1) The growth process is frequently inhibited by the presence of an echo, a signal that propagates back and forth one or more times along the same magnetospheric path. The effect is illustrated in figure 2, which shows a time average of the observed signal intensity at Roberval over a sequence of 17 30-second-long transmitted pulses. The first 4.1-second portion of the transmitted pulse is amplified ≃10 decibels above the noise level. After ≃4.1 seconds, the three-hop echo arrives at Roberval and the intensity of the total signal is reduced by 3 decibels. The echo, which contains many off-frequency emission components, is thought to destroy the phase-locking capability of the "clean" primary signal, thus reducing the growth. According to a theory being developed at Stanford (Helliwell and Crystal, 1973), the triggering wave must be coherent in order to organize or "bunch" the phases of these magnetospheric electrons whose velocity along the field lines is sufficient to put them in "cyclotron resonance" with the waves. The phase-bunched electrons constitute a current that radiates energy at the triggering wave frequency, causing the signal to grow in time. Given the opportunity, the magnetosphere seems to prefer generating narrowband emissions of short duration. We might call this the coherent wave instability of the magnetosphere.

(2) A further test of signal coherence effects was made by reversing the phase of the transmitted signal. Sometimes this reversal greatly attenuated

the output, as shown on the spectrograms of figure 3. Phase reversals are indicated by the symbol ≈ in the upper margin. In other cases the reversal had little effect. These results are not yet understood. Other experiments in which a line spectrum of waves is generated show that the minimum separation for independent growth of two signals is about 20 to 30 hertz.

(3) Natural magnetospheric noise is sometimes suppressed by amplified Siple signals. Reductions of as much as 6 decibels are observed in a band 50 to 200 hertz wide located just below the transmitter frequency. Figure 4 shows the reduction of noise below two frequency-shift-key transmitter frequencies, 5,950 and 5,050 hertz. Onset and disappearance of this "quiet" band are typically delayed several seconds with respect to the transmitted signal. A possible explanation of the quiet band is a reduction in electron flux caused by pitch angle scattering of electrons by the amplified Siple signals in a region off the equator. The change in resonant conditions between this scattering region and the equator is such that the affected electrons are those that resonate with the suppressed noise at the equa-

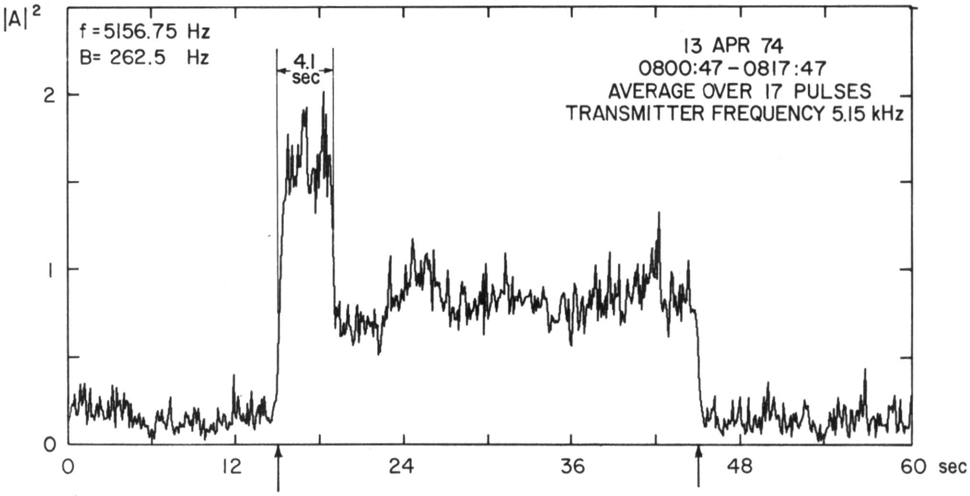

**Figure 2. Average of the squared amplitude of 17 successive 30-second Siple transmitter pulses received at Roberval.**

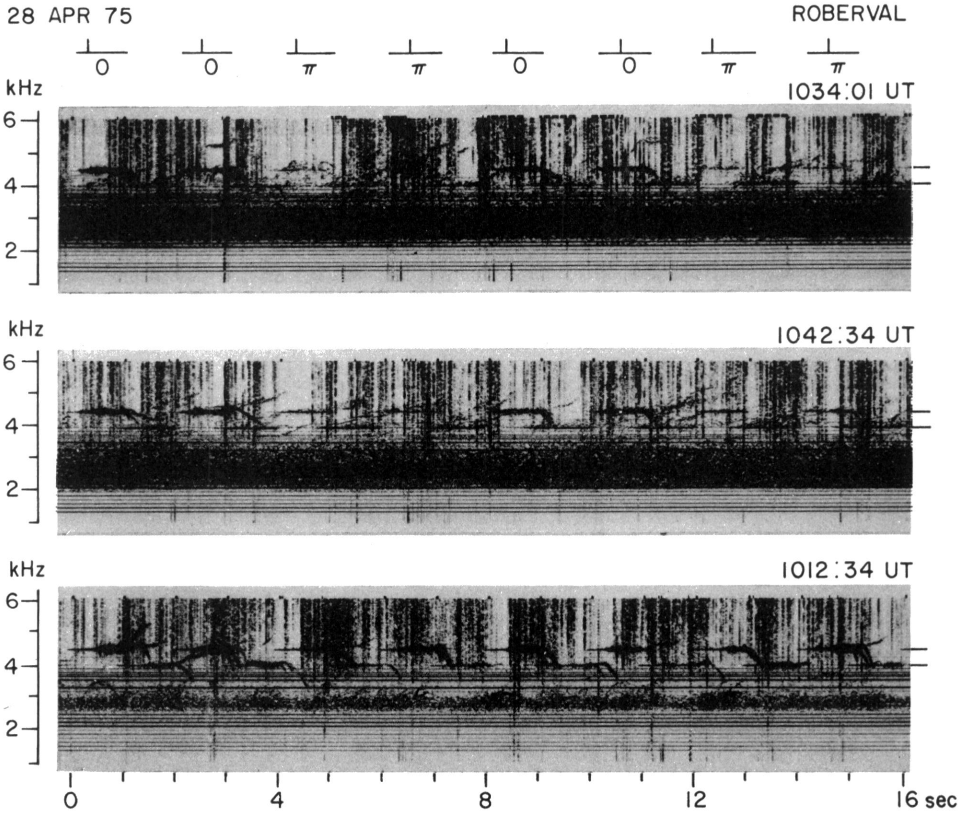

**Figure 3. Roberval spectrograms illustrating effect of reversing the phase during transmission of 1-second pulses. Upper diagram shows the transmission program for the upper frequency. An offset-frequency phasing pulse 10 milliseconds in duration is introduced at either 200 or 400 milliseconds. For pulses labeled "0" there is no change in phase at the main pulse. For pulses labeled "π" there is a 180° change in phase. The same program applies to the lower frequency (delayed 1 second).**

tor. A possible use for this wave-induced quiet band would be to improve the signal-to-noise ratio of an ordinary VLF communication channel centered in the band.

(4) Our model of the growth process predicts that the growth rate should be independent of df/dt*, to the first order. To test this prediction, frequency ramps were transmitted as shown in the spectrograms of figure 5. In most cases, growth and triggering are not sensitive to df/dt, in accord with the model. However, the higher values of df/dt (>2 kilohertz per second), usually produce less output, suggesting that extensions or changes in the theory may be required. An important advantage of ramps is their ability to separate multipath effects, as shown in figure 2.

To test suggestions that VLF signals can trigger ULF (≃1 hertz) waves, Siple VLF transmissions have been compared with ULF recordings made at Roberval. A positive statistical association has been found in one set of data (Fraser-Smith and Cole, 1975), but the relationship is still uncertain. Further tests are in progress. Control of ULF wave generation by VLF signals would open up new avenues for the study of magnetic pulsations and might pro-

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*Rate of changes of frequency with time.

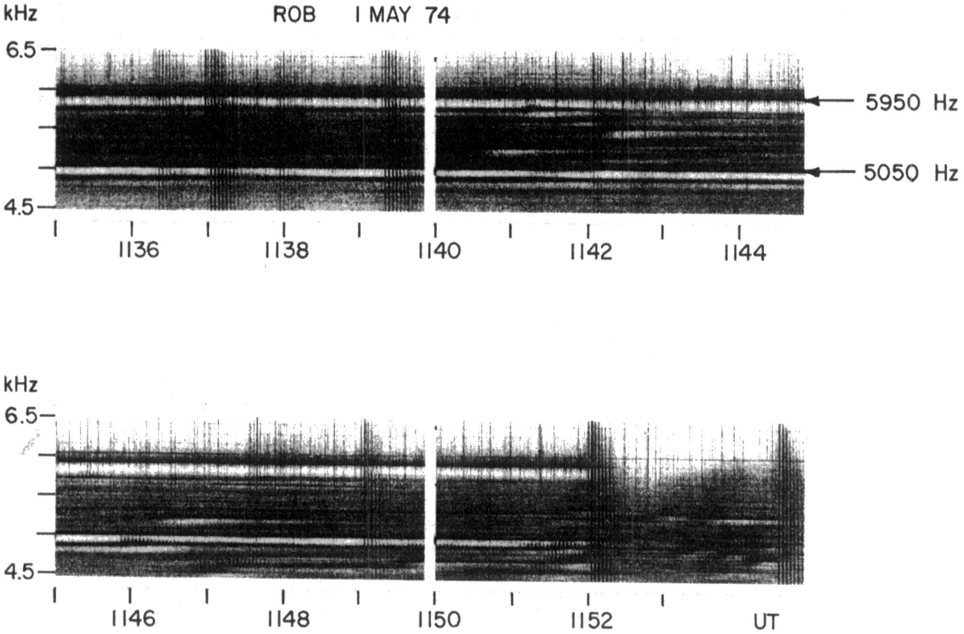

Figure 4. Roberval spectrograms illustrating "quiet bands" immediately below the 5,950- and 5,050-hertz transmitter frequencies. The transmissions terminated at 1152 Universal Time (lower right).

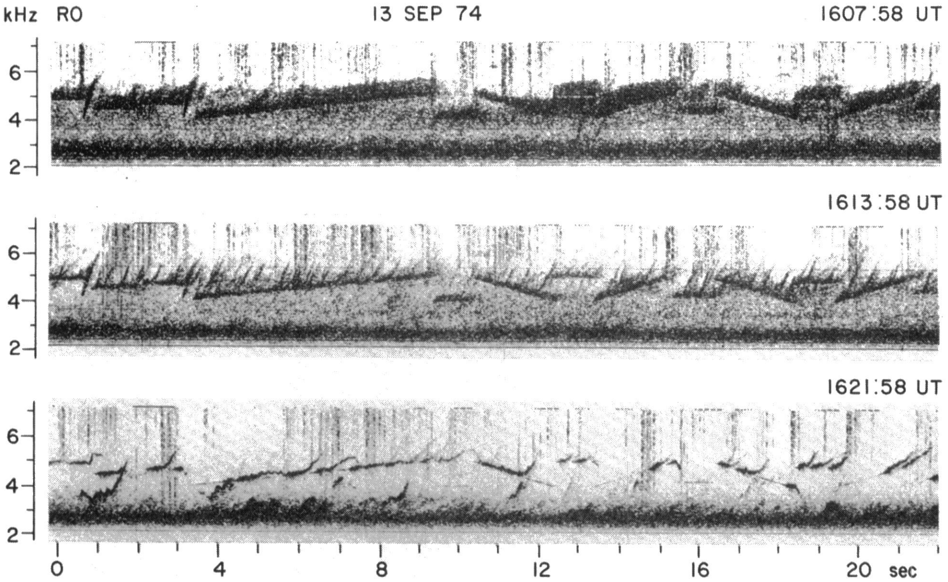

Figure 5. Roberval spectrograms illustrating the variable nature of wave growth and emission activity during a sequence of frequency ramps and 1-second pulses. Each panel shows the same transmission format.

vide a basis for new ULF communications techniques.

## Future program

The Siple experiments have led magnetospheric research into an exciting new stage. A major task now is to develop new theories to explain the results. Classical plasma physics has not dealt with coherent wave generation, although the evidence suggests that the phenomenon should be found in virtually all plasmas. An important objective is to detect the effects of precipitation induced by Siple signals, as has been done with natural VLF waves (Rosenberg *et al.*, 1971; Helliwell *et al.*, 1973). Space versions of this experiment would combine electron and wave injection to further extend control of experimental parameters. Plans are being made for just such an experiment to be performed on a scientific payload (AMPS) of a forthcoming space shuttle or spacelab. In the meantime, much remains to be done from the ground.

Ultimately the Siple experiments should aid in understanding how the delicate outer fringe of our atmosphere moderates the sun's influence on the lower atmosphere. Such understanding will have a role 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