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. projects that were active in 1974 and 1975. Included are descriptions of data analysis done by institutions and reports on year-round observations made in the Antarctic. The first part of a review, in the July/August 1975 issue, describes field activities that took place in the 1974-1975 summer.

LF wave injection experiments at Siple Station

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

Figure 1. Sketch of a geomagnetic field-aligned 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.

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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 VLF and electrodynamics Explorer satellite programs will use Siple signals in their situ studies of wave-particle interactions. During the International Magnetostrichic 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, Sanæ, 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 storm, 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 Hellwell, 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 (Hellwell et al., in press). Surprisingly, these lines were often found at frequencies 20 to 30 hertz higher than the nearest powerline harmonic, even though the spacings were often near 120 hertz. This effect is thought to be related to a positive 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 artificially stimulated and naturally occurring emissions. Calculations of pitch angle scattering 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 emission has continued during the past year. Interesting 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 magnetic 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. At 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 frequency emission components, is thought to be due to the phase-locking capability of the "clean" primary signal, thus reducing the growth. According to an theory being developed at Stanford (Helliwell Crystal, 1973), the triggering wave must be coherent in order to organize or "bunch" the phase of these magnetospheric electrons whose pitch along the field lines is sufficient to put them on the "cyclotron resonance" with the waves. The bunched electrons constitute a current that radiates energy at the triggering wave frequency, thus the signal to grow in time. Given the opportunity, the magnetosphere seems to prefer generation of narrowband emissions of short duration. We 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 primary signal. Sometimes this reversal greatly attenuated the output, as shown in the upper margin of figure 2. Phase reversals at the upper margin had little effect. The opposite occurred at the lower margin. Other experiments show that waves is generated for independent bands of 20 to 30 hertz. (3) Natural magnetic field effects, as measured by amplifiers and observed by two omnidirectional antennas, are much as 6 decibels at 200 hertz wide local conditions.

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stimulated emissions in the past year. Interestingly, it is observed in a first look at the following:

- The stimulated emissions are inhibited by a continuous signal that propagates hundreds of times along the path. This effect is illustrated in the average of the stimulated emissions over a sequence of 500 pulses. The stimulated emissions are significantly reduced, even though the stimulated emissions contain many effects.

- A second effect is observed in the "clean" region of the noise. According to [1], the stimulated emissions contain many effects, and it is thought to be the result of the stimulated emissions. The effect is observed in the average of the stimulated emissions over a sequence of 500 pulses. The stimulated emissions are significantly reduced, even though the stimulated emissions contain many effects.

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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 spectograms 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 Collin, 1975), but the relationship is still uncertain. Further tests are in progress. Control of VLF wave generation by VLF signals would open up new avenues for the study of magnetic pulsations and might provide a basis for new research.

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

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

\(^*\)Rate of changes of frequency with time.

The Siple experiment is part of a research program to develop new scientific payloads. As has been previously suggested, the phases of this experiment are to conduct an experiment to inject waves and measure changes in such an experimentally controlled manner and to understand the effects of these waves on the plasmasphere and on the magnetosphere. The ultimate goal is to understand how the magnetosphere interacts with the plasmasphere and then predict and control these interactions.

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References

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-aligned 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-aligned 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 A=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 A=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...