details. Particularly well defined in both data sets is a negative excursion of the fields near 0830 universal time (UT). This event coincided with a magnetospheric substorm disturbance and reveals a number of characteristic features that have been described in previous whistler-based analyses (Carpenter, Park, and Miller 1979). The lack of agreement in amplitude near 04 UT may be due to distortions of the real magnetic field that are not taken into account in mapping the whistler data to the ionospheric level.

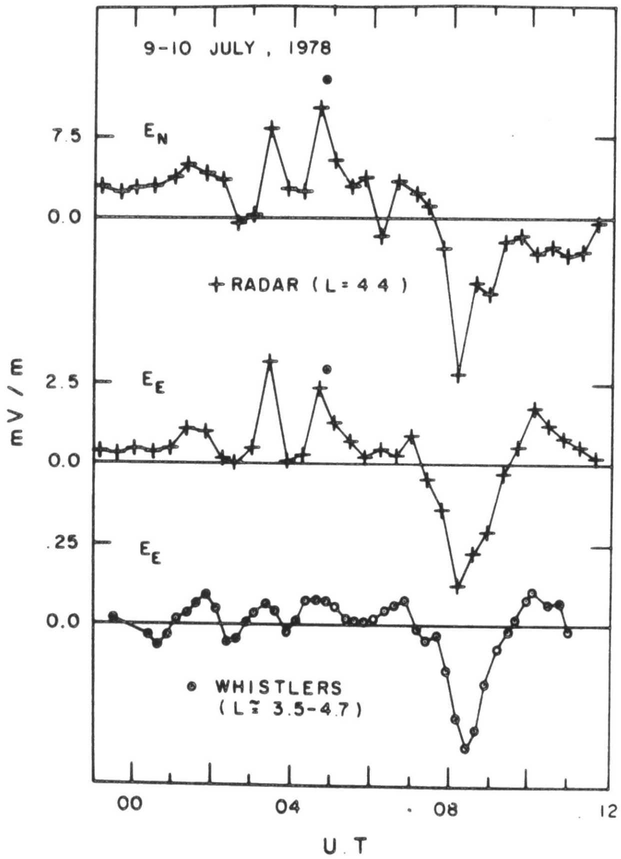

Figure 2. Comparison of radar and whistler data on plasma drifts, plotted in terms of electric fields perpendicular to the local magnetic field in the north direction (E_N) and in the east direction (E_E).

The comparison near 0830 UT provides evidence that the compared electric fields were largely potential in nature, at least on the 20-minute time scale of the measurements. These results are providing a basis for further whistler-radar studies of the high and low altitude drift activity.

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References

Carpenter, D. L., Park, C. G., and Miller, T. R. 1979. A model of substorm electric fields in the plasmapause based on whistler data. *Journal of Geophysical Research*, 84(A11), 6559.

Gonzales, C. A., Kelley, M. C., Carpenter, D. L., Miller, T. R. and Wand, R. H. 1980. Simultaneous measurements of ionospheric and magnetospheric electric fields in the outer plasmasphere. *Geophysical Research Letters*, 7(7), 517.

Photometrically detected precipitation bursts at the conjugate point of Siple Station

J. H. Doolittle

Radioscience Laboratory
Stanford University
Stanford, California 94305

The precipitation of energetic electrons from the Van Allen radiation belts can result from interactions with electromagnetic waves. Very-low-frequency (VLF) waves generated by terrestrial lightning can propagate along field-alined ducts in the magnetosphere and scatter trapped electrons through cyclotron resonance. Some of the scattered electrons follow trajectories which carry them into the ionosphere where they can collide with ions or neutral constituents, causing further ionization, heat, optical emissions, and bremsstrahlung X-rays.

Observational evidence for wave-induced electron precipitation was first seen as correlations between bursts of VLF noise and X-rays occurring at balloon altitudes over Siple Station (Rosenberg, Helliwell, and Katsufrakis 1971). Precipitation has also been found to cause amplitude perturbations in subionospherically propagating VLF signals (Helliwell, Katsufrakis, and Trimpi 1973) as a result of localized enhancements in ionization.

Correlations between discrete VLF waves and ionospheric optical emissions were first observed at Siple Station in 1977 (Doolittle, Armstrong, Katsufrakis, and Carpenter 1978). The relative arrival times of the waves and precipitating electrons in those events suggested that northgoing whistler echoes scattered southgoing electrons near the equator. It follows that a similar effect involving southgoing waves and northgoing electrons should cause precipitation in the northern hemisphere. While the one-hop whistlers were seen to arrive before the optical emissions at Siple Station, a two-hop whistler should lag optical emissions at the conjugate point. In order to verify this, a photometer was placed in the field at Roberval, Quebec, in 1978.

The Roberval photometer monitors ionospheric optical emissions of ionized molecular nitrogen at 4,278 angstroms in a 10° field of view centered on the zenith. The system turns on automatically after sunset and records the sky brightness on a chart recorder running at a slow speed. During synoptic intervals of 1 minute in every 15 the chart speed is increased by a factor of 10 to give better time resolution. VLF audio recordings are also made during the synoptic intervals, both at Roberval and at Siple Station.

Subvisual optical bursts which are correlated with VLF wave events are often small compared to slow variations in the background sky brightness. It is necessary to remove the slowly varying component of the photometer analog output, using a high-pass filter with a 2-minute time constant, so that the gain may be increased to resolve the precipitation events. The photometer signal is recorded both before the filter to show the background intensity, and after the filter with an additional gain of 20 to show bursts of ionospheric optical emissions.

Obvious one-to-one correlations between optical emissions and whistler-triggered noise events were recorded at Roberval on 30 August, 1979, between 0735 and 0851 universal time (UT). The photometer chart record during the 0750 UT synoptic interval is shown in panel (a) of figure 1 where bursts of optical emissions of about 1.5-second duration are labeled using letter designations. The integrated 2-3 kilohertz VLF amplitudes obtained from audio recordings made at Siple Station and Roberval are shown in panels (b) and (c). Conjugate VLF spectrograms for the interval appear in figure 2 where the subscripts on the event labels indicate the lightning source (e.g., A_o), the one-hop whistler (A_1), and the two-hop whistler (A_2).

The sequence of a typical event (e.g., F) begins with a lightning source in the northern hemisphere (F_o) which launches a VLF wave into the magnetosphere. The whistler-mode wave is ducted along the Siple-Roberval field line and resonates with counter-streaming electrons. Wave growth results from the interactions and therefore the wave becomes more efficient in scattering electrons as it travels past the equator. North-going electrons which are scattered into the loss cone continue spiraling along the field line toward Roberval while the wave travels south and is seen at Siple Station (F_1) as a one-hop whistler. The precipitating electrons then cause the ionospheric optical burst (F) seen at Roberval and finally the two-hop whistler (F_2) arrives after the expected delay.

The new Roberval results support the model used to explain the 1977 VLF-photometer correlations seen at Siple Station. In the 1980 campaign at Roberval, the photometer output will be recorded on the VLF audio tapes to give better resolution of the relative timing of correlated events.

The Stanford Radioscience Laboratory VLF experiment at Roberval was supported by National Science Foundation grant DPP 78-05746. The assistance of Richard Taillefer for field operation of the photometer is gratefully acknowledged.

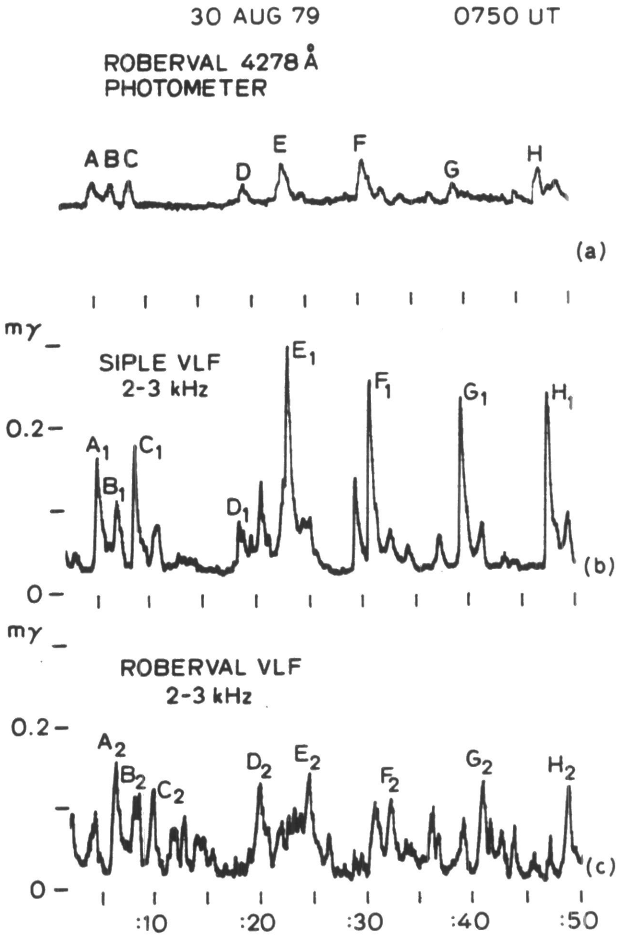

Figure 1. Chart records showing 4,278 angstrom optical emissions at Roberval (a) correlated with VLF amplitude peaks in milligammas (mγ) at Siple Station (b) and Roberval (c).

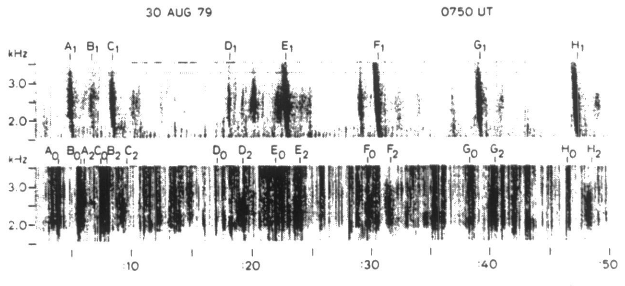

Figure 2. Conjugate spectrograms of the correlated VLF events shown in figure 1. Subscripts on event labels refer to the causative spheric (e.g., A_o), the one-hop whistler (A_1), and the two-hop whistler (A_2).

References

Doolittle, J. H., Armstrong, W. C., Katsufrakis, J. P., and Carpenter, D. L. 1978. Wave-induced particle precipitation effects at Siple Station. *Antarctic Journal of the U. S.*, 13(4), 204–206.

Helliwell, R. A., Katsufrakis, J. P. and Trimpi, M. L. 1973. Whistler-induced amplitude perturbations in VLF propagation. *Journal of Geophysical Research*, 78(22), 4679.

Rosenberg, T. J., Helliwell, R. A. and Katsufrakis, J. P. 1971. Electron precipitation associated with discrete very-low-frequency emissions. *Journal of Geophysical Research*, 76(34), 8445.

Direct observation of microburst electron characteristics

D. L. MATTHEWS

Institute for Physical Science and Technology
University of Maryland
College Park, Maryland 20742

Electron microbursts are fluxes of precipitating energetic electrons (tens to hundreds of kiloelectron volts) of duration approximately 50 to 500 milliseconds. Microbursts are a well-defined phenomenon, as yet poorly understood, expected to be observed in the Siple Station rocket-balloon program that was postponed to summer 1980–81. Here and in another paper in this volume we outline progress made by the University of Maryland group in understanding microbursts and related events.

In the companion paper, Siren, Rosenberg, Detrick, and Carpenter (*Antarctic Journal U.S.*, this volume) discuss new results on the relationships between microbursts and VLF chorus. The present note outlines some characteristics of the precipitating particles themselves as directly observed from a sounding rocket. A brief report of these observations was published by Matthews and Simons (1973), and Rosenberg, Foster, Matthews, Sheldon, and Benbrook (1977) reviewed what is known about microbursts; the latter paper should be consulted for further references.

The rocket observations were made in May 1972 from the Andöya Rocket Range, Norway, in the auroral zone. The observed properties should also be characteristic of bursts in the lower geomagnetic latitude of Siple Station and its magnetic conjugate point, Roberval, Canada.

In the rocket data about 80 microbursts were found, typically distributed in duration and grouping. What follows is a summary of those features of the observations which I consider both new and typical.

1. Maximum energy. Electrons up to at least 600 kiloelectron volts (keV) are precipitated in strong microbursts.

2. Energy spectrum. The measurable spectrum (50 to 300 keV) cannot be described by a single power law or exponential but hardens at the higher energies. Up to about 200 keV an e-folding energy of 50 keV fits the strongest bursts; in these the integral flux from 50 to 300 keV approaches 10^8 per square centimeter per second. The bursts emerge from a background flux with an e-folding energy of approximately 20 keV. The background is about half the burst intensity at 50 keV and zero above 200 keV. The integral flux at background is still considerable at approximately 2×10^7 per square centimeter per second.

3. Pitch-angle distribution. The angular distribution of downcoming electrons can be described by a flatness parameter which increases with the flux. At background this parameter, which is (flux (30°)/flux (85°)), is less than 0.3, but at maximum flux it equals or exceeds unity, even at the highest energy (300 keV), that is, the flux becomes very nearly isotropic.

These results show that an approach to strong diffusion is occurring in the microburst process up to surprisingly high energies, corresponding to low resonant frequencies. (No radiowave data are available.)

Cross-correlation analysis has yielded two results. In a comparison of burst components of the same energy but different pitch angles, hence different parallel velocities, the bursts are found to have originated at an altitude greater than about one earth radius. However, when one compares different energies at the same pitch angle, one finds that the more energetic component arrives significantly *later* than the less, and is of shorter duration. This implies a growth rate for the operative instability that decreases with increasing energy.

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References

Matthews, D. L., and Simons, D. J. 1973. Observation of relativistic electron precipitation at $L=6$. *Journal of Geophysical Research* 78, 7538–7542.

Rosenberg, T. J., Foster, J. C., Matthews, D. L., Sheldon, W. R., and Benbrook, J. R. 1977. Microburst electron precipitation at $L \approx 4$. *Journal of Geophysical Research* 82, 177–180.

Siren, J. C., Rosenberg, T. J., Detrick, D., and Carpenter, D. L. 1980. Characteristics of the common origin of electron microbursts and VLF chorus. *Antarctic Journal of the U.S.*, 15(5).