GROUND-BASED ELF/VLF OBSERVATIONS AT HIGH LATITUDES DURING PASSES OF GEOS-1 AND ISEE-1 AND -2

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Abstract. Recordings of ELF/VLF radio signals were made, as a contribution to the International Magnetospheric Study, in Iceland (17 August to 5 September 1977) and Norway (21 October to 15 December 1977; and 11 January to 27 February 1978) by the Space Radio Physics group. The equipment used at each of three sites was a goniometer (direction finding) receiver. As an example of the results obtained, recordings of risers, occurring at a rate up to \( \sim 10 \text{ min}^{-1} \) and with frequencies (\( \sim 1.0 \) to \( 1.5 \) kHz) just greater than those of simultaneous hissy chorus signals, made between 10:20 and 11:00 UT on 31 August 1977, are discussed. These risers (downcoming whistler mode signals) are shown to have well defined exit points from the ionosphere which are located, to within an uncertainty of typically \( \pm 40 \) km, by triangulation. The observations are broadly consistent with there being a single exit point which, on this occasion, happens to be almost on the flux tube through the geomagnetic observatory at Leirvogur. Simultaneous ground-based magnetometer observations, and also wave and energetic charged particle observations made aboard GEOS-1, have been studied. The electron spectra and pitch angle distributions are as required for the operation of the electron cyclotron instability in which whistler mode signals are amplified.

1. Introduction

It is well known that whistlers constitute an important diagnostic tool for studying the distribution of thermal plasma in the magnetosphere. Discrete ELF/VLF radio emissions are a manifestation of an interaction between energetic electrons trapped in the magnetosphere’s radiation belts and whistler mode radiation, which require further study before they can – by ‘remote sensing’ – provide detailed information on parameters of the Van Allen belts.

As part of a research programme centred on the International Magnetospheric Study, the Space Radio Physics group at Southampton University has made ELF/VLF observations at auroral latitudes. Signals in the band 0.5 to 16 kHz have been recorded using goniometer (direction finding) receivers. At each remote recording site, the equipment used consisted of an aerial (two electrostatically screened vertical loops, of area \( 60 \text{ m}^2 \), mounted in the N-S and E-W planes), a preamplifier and a goniometer receiver. The signals from the two loops are combined electronically to simulate the output from a single loop rotating about a vertical axis with a frequency \( \sim 27.5 \text{ Hz} \), and recorded on one channel of a stereo magnetic tape recorder. A stationary source gives a tape recorded signal with two maxima and two minima per simulated rotation. The phase difference between this modulation of the input signal and a calibration pulse occurring once per rotation period at a known orientation, say \( N \), gives the azimuthal bearing of the source, with an ambiguity of 180°. This ambiguity is removed by triangulation from two or more stations. The
region in space where a particular downcoming whistler mode signal emerges into
the earth-ionosphere waveguide (termed its exit point) is thus located within a
quadrilateral of uncertainty (see also Rycroft et al., 1975).

2. Chorus and Risers Observed on 31 August 1977, and Discussion

Recordings made in Iceland on 31 August 1977 were subjected to detailed study.
Selected tapes were studied at Sheffield University using their Semi-Automatic
Whistler Analyser (Bullough et al., 1975). Having calibrated the systems using
signals from a small radiating coil mounted at a known angle at the centre of the large
loop aerials, the azimuthal bearings of interesting naturally occurring signals could
be determined.

As an example of the types of signals received at high latitudes, and of the
procedure and the results obtained, Figure 1 shows the dynamic spectra of signals
received at all three stations at 10:49:23 UT during a particularly active period. At
the time of these signals, geomagnetic activity had been steady ($K_p \sim 2$) for 24 hr
previously. Evident are two rising frequency emissions, between 0 and 1 s and
between 3 and 4 s, with frequencies increasing from ~1.0 to ~1.5 kHz. These
signals, with a sweep rate ~100 Hz s$^{-1}$, emerge from a band of hissy chorus near its
upper frequency limit.

The right hand side of Figure 1 shows spectra obtained with the narrow band
(22.5 Hz) filter of a Sonagraph. The bandwidth of the emission is well resolved to be
~200 Hz. By contrast, the left hand side of Figure 1 shows spectra of identical signals
obtained with the wide band (150 Hz) filter in which the temporal variations are well
resolved. Below 0.5 kHz the Sonagrams show the spectra of the calibration pulses.
Just evident in the left hand part of Figure 1 are two maxima and two minima of the
received signal per interpulse period, not only for the risers, but also for the hissy
chorus.

Figure 2 shows this goniometer modulation much more clearly; it is the dynamic
spectrum of the earlier riser in Figure 1. The improved temporal resolution neces-
sitates a worsening of the frequency resolution, the bandwidth of the wideband
setting on this 0 to 16 kHz range being 600 Hz. Particularly in the upper (Husafell)
and lower (Siglufjördur) Sonagrams, the modulation of the riser is evident. Also
evident in Figure 2 are strong atmospherics at ~0.2 s, by which the identification of
the same signal at the three stations is aided. For this purpose also, signals from VLF
transmitters are helpful; these include signals of ~1 s duration from the Omega long
range navigation system at 10.2, 11.3, 13.6 kHz and other frequencies. Also shown
here are signals of ~0.4 s duration at ~12.6 kHz, presumed to be from the U.S.S.R.
version of Omega (Klass, 1971).

Returning to the risers, these occurred at a rate not exceeding 10 min$^{-1}$ from
10:20 to 11:00 UT. Rather than perform triangulations on each individual riser,
mean bearings from both Husafell and Skaftafell were calculated for all risers
observed in 5 min intervals. In each case, an estimate of the standard error of the