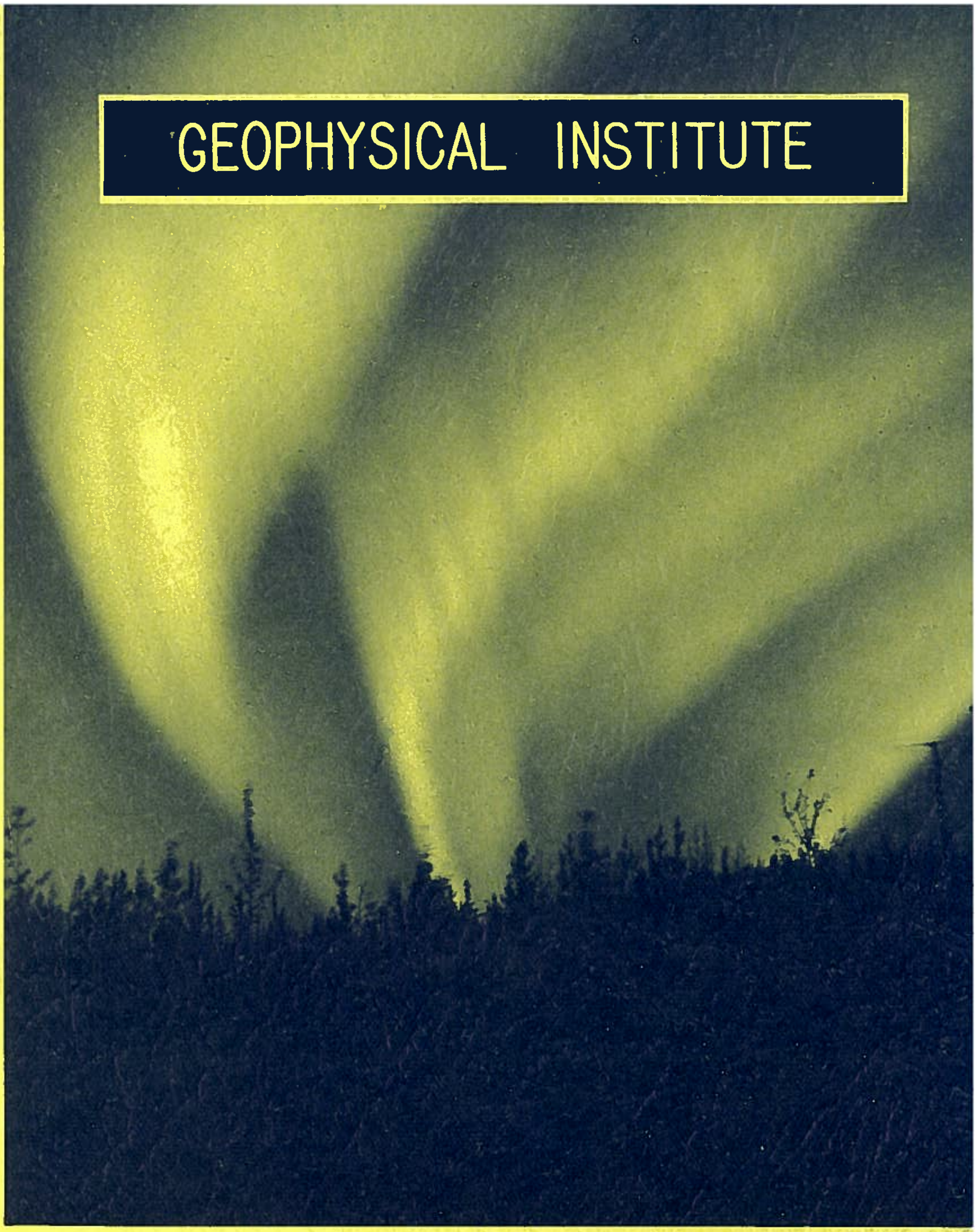

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HF/VHF AURORAL AND POLAR ZONE FORWARD SOUNDINGS

by

H. F. Bates and R. D. Hunsucker

Scientific Report No. 3
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1. INTRODUCTION

HF/VHF oblique backscatter and synchronized forward soundings of the polar ionosphere are being routinely made by the Geophysical Institute at College, Alaska under the sponsorship of various agencies. This report will present preliminary forward sounding results obtained during the Winter 1963-1964.

Although each figure may combine data for various paths, we shall discuss each polar path separately.

Basic parameters of the Granger Mod. 902 "Skipfinder" are shown in Table I.

TABLE I

Power Output	30 kw (rated) 15 kw (measured)
Freq. Range	4-64 mc/s
Short Pulse Mode	PRF 50 pps, PL 100 μsec, BW 16 kc/s, 4 pulses/channel 12.8 sec/sweep
Long Pulse Mode	PRF 20 pps, PL 1000 μsec, BW 4 kc/s, 2 pulses/channel 16 sec/sweep

The antennas used are Granger Mod. 726-4/64 log-periodic vertical monopoles (LPA) directed toward true bearings of 015°, 105°, 210°, 270° and 325°. Backscatter soundings are made every 10 to 30 minutes on all five antennas. Forward soundings are received from Johnston Island; Palo Alto; Ft. Monmouth; Thule, Greenland; Andöya, Norway and Okinawa. Figure 1 shows the great-circle paths for the forward-sounding circuits in relation to the visual auroral zone [Vestine, 1944].

The data utilized in this analysis were obtained during the period November 1963-February 1964 and thus represent conditions during the winter night and at sunspot minimum.

2. FORWARD-SOUNDING RESULTS

2.1 Thule-College Path

The Thule-College great circle path is 2860 km and the most probable propagation modes are 1, 2, and 3-hop F-modes; 2, 3, and 4-hop E modes or combination E-F modes. Fig. 2 shows typical winter long and short pulse records from Thule. The upper long pulse record displays a common winter Es mode with an LOF at 5 mc/s and an MOF of 17 mc/s. The short pulse record below illustrates another common mode with an Es LOF of $\sim$4 mc/s and an MOF of 20 mc/s. Very spread F modes are present between 5 and 10 mc/s.

2.1.1 Sporadic-E Modes

The relative occurrence of sproadic-E modes on the Thule-College circuit is shown in Fig. 5 (lower graph). The histogram peaks around 20-24 UT (10-14 150° WMT) and shows a minimum around 11-14 UT (01-04 150° WMT). The histogram gives the fraction of time that sporadic-E is present on the Thule-College circuit and shows that the dominant winter mode on this path is, in fact, Es-supported.

The diurnal variation of the sporadic-E MOF for the same period is shown in Fig. 6 (lower graph). The histogram shows the diurnal variation of the average MOF for each hour and the upper curve gives the highest MOF observed during each hour for the period 27 November 1963-12 February 1964. A maximum is indicated between 0730-1230 UT (2130-0230, 150° WMT) in the average MOF curve for Thule.

It is interesting to note that this time corresponds to the diurnal peak of aurora at the College end of the propagation path, (Davis, 1961), but in light of the Norway-College results discussed in Sec. 2.2, this agreement may be fortuitus. The average MOF for this period was 18 mc/s.

2.1.2 Delayed Modes

In addition to the great-circle propagated direct mode, several long-delayed modes are also seen on most of the circuits monitored at College. The Thule-College path shows the typical direct signal component plus other signal modes at delays of from 3 to 11 m/sec from the direct mode. Fig. 8 (lower record) shows the Thule direct mode plus several other modes, one delayed from the direct mode by 11 m/sec. Another typical delayed mode record from Thule is shown in the upper ionogram of Fig. 8. The Thule-College great circle propagation time is 10.5 m/sec. The upper display is a good example of discrete modes while the lower record shows much more diffuse or spread signals. At times, the Thule delayed modes are spread almost continuously from the direct mode up to 10 or 11 milliseconds.

The relative occurrence of delayed modes on the Thule-College circuit is shown in the lower plot of Fig. 9. The occurrence of these long-delayed modes for each hour during the period 27 November 1963 to 12 February 1964 is plotted vs U.T. A maximum occurs between 09-14 UT (23-04 150° WMT) which appears to coincide with the diurnal peak of auroral activity at the College end of the transmission path. The delayed signals had an average LOF of 4.9 mc/s and an MOF of 8.8 mc/s.

2.1.3 Other Winter Modes

In addition to the predominant Es modes during the winter period on the Thule-College path, various other modes are observed. Fig. 2 (lower record) shows the typical Es mode along with what appears to be a very spread F mode at lower frequencies. Short pulse (100 $_u$sec) records of the Thule signal taken in late February and March (daytime) show the normally expected F modes (upper record of Fig. 4) with a subsequent decrease in occurrence of the Es mode. That this is the expected behavior is discussed in Sec. 3.1.

2.2 Andöya-College Path

2.2.1 Sproadic-E Modes

The most prominent winter night mode on the Andöya-College transpolar path (5000 km) appears to be at least partially Es-supported. The signal shows the Es constant-range discrete-signal characteristics. Occasionally some retardation is present at the upper frequency end of the trace, but in most cases the signal appears similar to that shown in Fig. 3. The relative occurrence of Es on the Andöya-College path has two diurnal peaks as shown in Fig. 5, one peak is centered around 0400 UT (1800 150° WMT) and another peak near 1700 UT (0700-150° WMT). Sporadic-E MOF's as high as 32 mc/s and an average MOF of 18 mc/s are observed on this circuit as shown in Fig. 6. There are two diurnal peaks in average MOF on the Andöya circuit as opposed to the single maximum on the Thule path. MOF maxima occur at the following times:

U.T.	150°WMT
06-09	20-23
19-21	20-23

2.2.2 Delayed Modes

Signals delayed up to 6 m/sec from the great-circle direct mode were observed on the Andöya-College path. The frequency of occurrence of off-path modes on the Andöya circuit was considerably less than on the Thule circuit

(Fig. 9) but the multipath modes were observed on higher frequencies (Avg. LOF = 7.2 mc/s, MOF = 12.5 mc/s). The diurnal peak of Andöya multipath occurs at 1200 UT (0200, 150° WMT).

2.3 Delayed modes on other paths

Delayed modes have been observed from Palo Alto and Johnston Island as well as on the polar paths. Although the log periodic antennas used at College have a very broad horizontal beamwidth (110° between half power points), some indication that the delayed modes from Johnston Island (true bearing 210° from College) were non-great-circle propagated was obtained by an antenna switching experiment. The antennas were alternately switched between 210° and 105° when the delayed mode was observed, and the Johnston Island signal was always stronger on the 105° antenna. Typical delayed modes from Johnston Island and Palo Alto are shown in Fig. 7. The lower ionogram is Palo Alto with delayed modes at 3 and 5 m sec, and the upper ionogram shows modes delayed from the Johnston Island direct mode by 4 and 11 m sec. The transmissions from both Johnston Island and Palo Alto are not directed toward College. The Johnston Island antenna is pointed to the northeast, and the Palo Alto log periodic antenna azimuth is 060° true bearing; thus most of the rf energy from both sites is beamed into the northern U.S. and central Canada. Thus, we would expect off-path signals to predominate from the east from those sounders.

3. DISCUSSION OF FORWARD SOUNDING RESULTS

3.1 Sporadic-E Propagation

It appears that during the winter months polar HF propagation is predominantly supported by sporadic-E ionization. The importance of Es in polar propagation during winter nighttime conditions was reported by Hunsucker and Stark [1959]. Results obtained on transpolar paths monitoring HF pulse transmissions and fixed-frequency backscatter soundings to the north revealed that Es activity peaks during the period 1800 to 0600, 150° WMT. Folkestad [1963] reported that signal strengths of 18 mc/s pulse transmissions on the transpolar College to Kjeller, Norway path during January and February 1961 peaked between 2100-0600 AST, further illustrating the role of Es in transpolar propagation during the winter night. The high percentage occurrence of fEs > 5 mc/s in the polar regions during the winter night was also emphasized by Leighton, et al [1960] using IGY results. Chadwick [1962] found that there was a negative correlation coefficient of 0.68 between fEs > 5 mc/s vs yearly average sunspot number for College and that the diurnal peak of fEs > 5 mc/s occurred between 2000-0600 AST.

In an early study of the relationship between visual aurora and vertical ionosonde observations, Heppner, Byrne and Belon [1952] found a high correlation between certain zenithal auroral forms and the value of fEs. In particular, rayed bands at the zenith gave the highest correlation with fEs (the sporadic-E cutoff frequency), while complete absorption was indicated 100 per cent of the time when pulsating auroral forms were overhead. Another study of the relation between visual aurora and vertical ionosonde fEs data was made at an auroral zone station by Hunsucker and Owren [1962]. Using all-sky camera pictures they found that the motion of an auroral arc or band from a low elevation angle to a position near the zenith was accompanied by an increase in the value of fEs by a factor of 2 or greater. With discrete auroral forms near the zenith, values of fEs from 8 to 10 mc/s were common with a maximum observed value of 13 mc/s.

The results of this investigation are in good agreement with the foregoing findings concerning the occurrence and behavior of auroral zone sporadic-E during winter night and sunspot minimum conditions. The MOF peak on the Thule-College circuit coincides with the period of maximum auroral activity near the College end of the circuit (2130-0230, 150° WMT). Sporadic-E propagation on the Andöya-College path is a much more complicated phenomenon, displaying several diurnal activity peaks. This is to be expected, since the 5000 km propagation path traverses the auroral zone twice and shows sunrise/sunset effects twice as compared to once on the Thule-College path.

It is sometimes helpful to transform ionospheric data into the magnetic time scale, taking 70°W as the reference longitude. When the Es-occurrence on the Andöya-College path (Fig. 5) is plotted vs "magnetic time" the diurnal peaks occur near magnetic noon and magnetic midnight, while no well defined peak can be identified on the MOF curve in Fig. 6. Investigation of this is continuing.

The transition from the winter, 'night-modes' (Es propagation) to the F-propagated 'day-modes' for the polar paths investigated takes place about the middle of February. As the reflection points on the Thule-College and Andöya-College paths become sunlit, the normal multi-hop F-modes propagate, as shown in the records for 22-23 February in Fig. 4.

3.2 Delayed or "off-path" modes

Very strong evidence of "off-path" propagation associated with the auroral zone was presented by Egan and Peterson [1960]. The 12 and 18 mc/s pulse signals from Thule and College monitored at Stanford revealed very strong delayed modes with time delays up to 12 m/sec between the direct mode and the "sidescatter" modes. Ortner and Owren [1961] and Owren [1963] presented evidence for the existence of such modes on the 18 mc/s transpolar propagation path between College and Kiruna, Sweden. Additional evidence for the existence of "off-path" modes was given by Hunsucker [1964a & b] for a synchronized step-frequency circuit between College and Öya, Norway and for the 18 mc/s College-Thule circuit.

The present investigation confirms these long delayed or "off-path" modes on polar and non-polar HF propagation paths. Delays up to 11 m/sec on the Thule-College, and the Johnston Island-Palo Alto circuits were observed. When the College antennas were switched on the Johnston Island transmission, the signal was always stronger in the off-path direction (105° T). College and Palo Alto utilize log-periodic antennas (LPA's) with horizontal half-power beam widths of 110°.

4. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

The importance of sporadic-E ionization for winter-night sunspot-minimum conditions on polar propagation paths is quite apparent. During the period 27 November 1963-12 February 1964 the average per cent occurrence of Es on the Thule-College and Andöya-College circuits was over 50 per cent. Sporadic-E MOF's as high as 46 mc/s with typical values of 18 mc/s were observed on the Thule-College path and MOF's as high as 32 mc/s with typical values of 16 mc/s were observed on the Andöya-College path. (It suggests that long-haul HF traffic may be routed over polar paths during winter-night sunspot-minimum periods when the mid-latitude MOF's are quite low.)

The MOF maxima for both the Thule-College and the Andöya-College paths appear to coincide with the period of maximum visual auroral occurrence at the College end of the circuit (1800-0600, 150° WMT).

It appears that the long-delayed modes observed on the Thule, Andöya, Palo Alto, and Johnston Island records were off-path modes which were laterally deviated. Antenna switching experiments at College and at Palo Alto indicate that the off-path signal comes from the east. The characteristics of the off-path modes are summarized in Table 2.

TABLE 2

Path	Period of Max. occurrence (150°WMT)	Avg. LOF (mc/s)	Avg. MOF (mc/s)	Rel. occurrence of diurnal peak
Thule-College	2300-0400	4.9	8.8	1%
Andöya-College	0200-0400	7.2	12.5	0.5%

Toward the end of February as the polar paths become more sunlit, the Es and off-path modes tend to disappear and the normal F-mode structure is evident on the records.

Analysis of the forward sounding data is continuing in an effort to determine the seasonal variation of the sporadic-E and off-path modes on both polar and non-polar propagation paths. A direction-finding experiment is being proposed jointly with Kiruna Geophysical Observatory in order to determine the horizontal direction-of-arrival of the off-path modes. This experiment will be of the "Pinwheel" type, utilizing a 5 element braodside array on a 60 meter rotating boom at Kiruna and a rotating receiving yagi at College.

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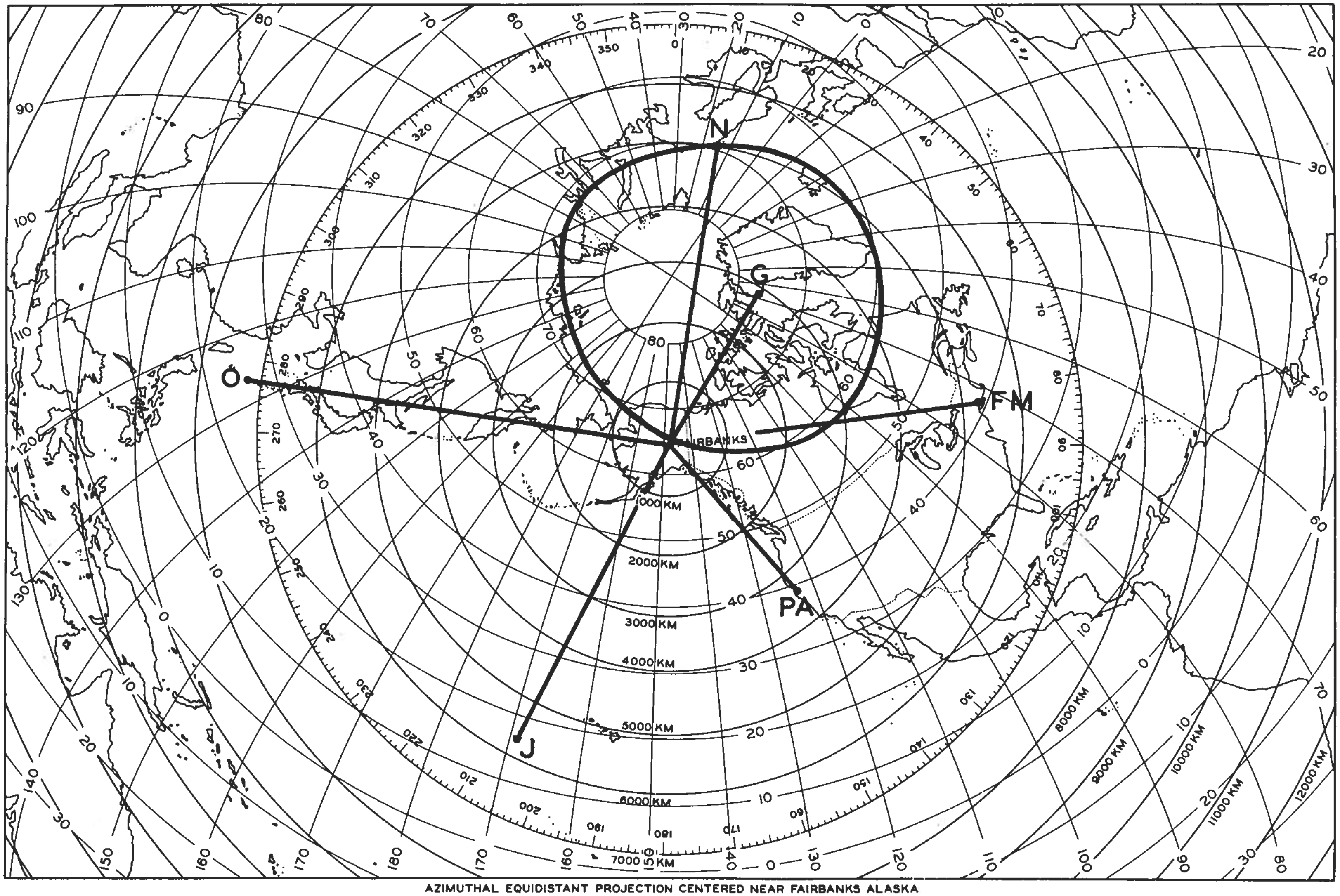


Fig. 1 Map showing forward sounding paths recorded at College and their relation to the auroral zone.

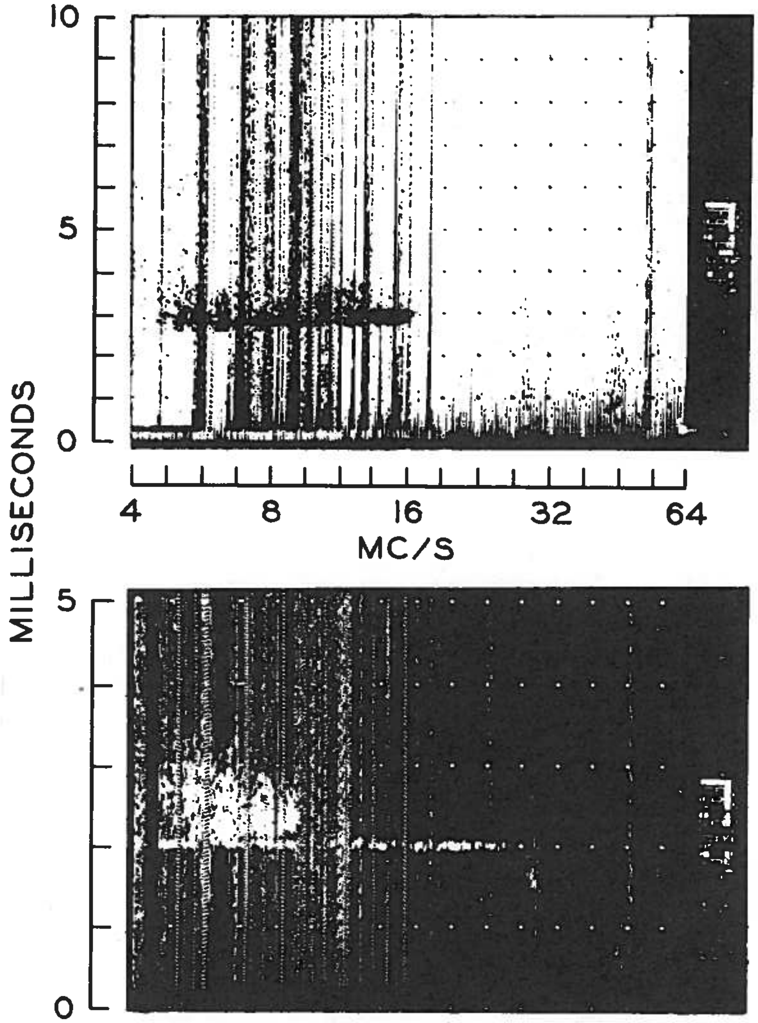


Fig. 2 Typical Winter records from Thule, Greenland. Long pulse record above and short pulse record below.

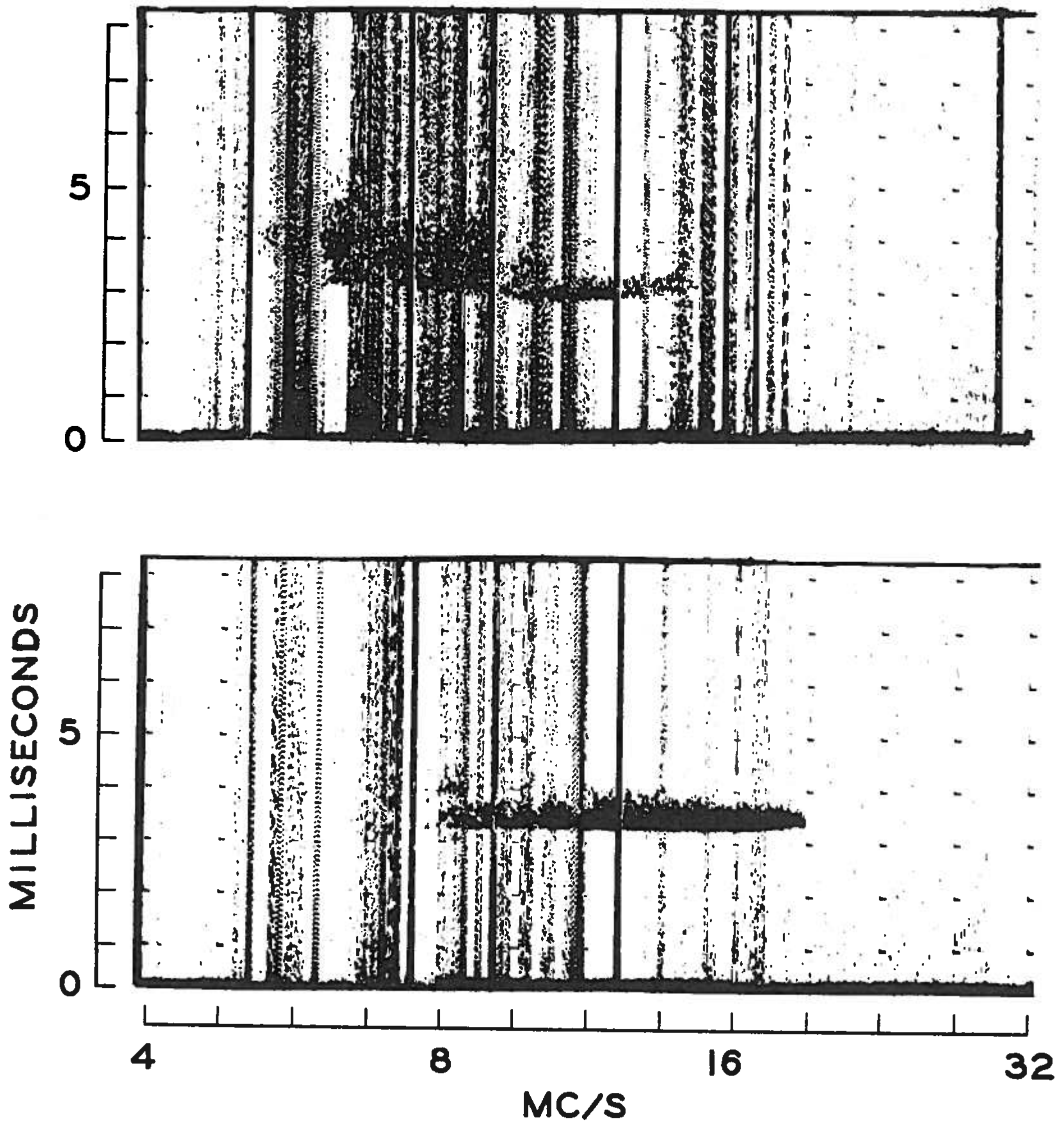


Fig. 3 Typical Winter short pulse records from Andöya, Norway.

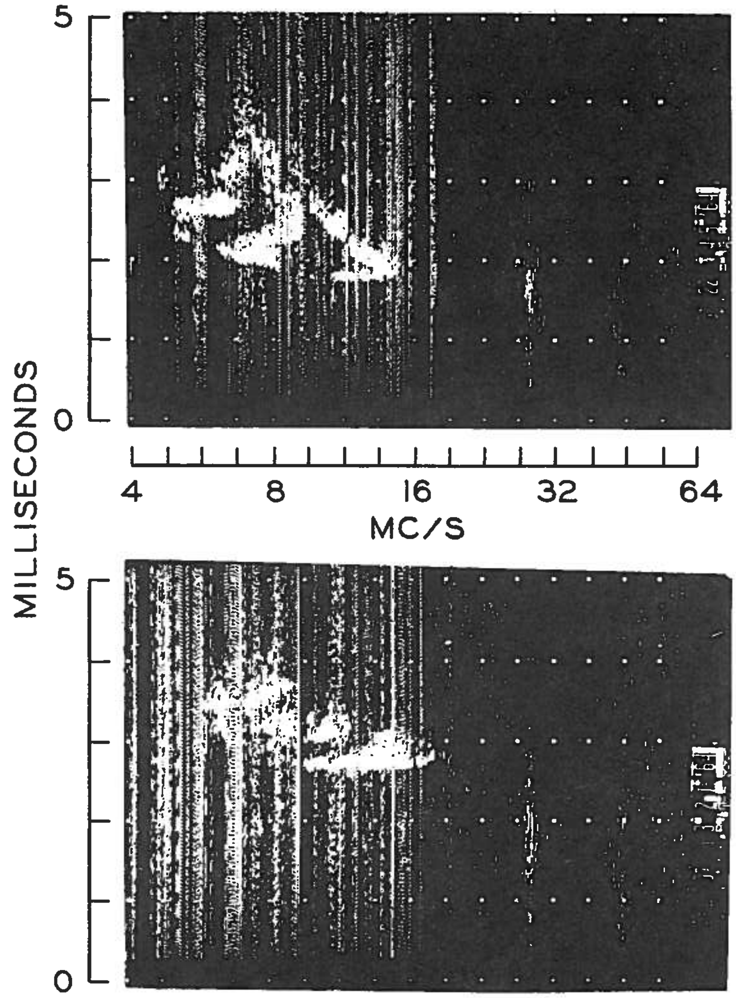


Fig. 4 Normal F-modes from Thule (above) and Andöya (below).

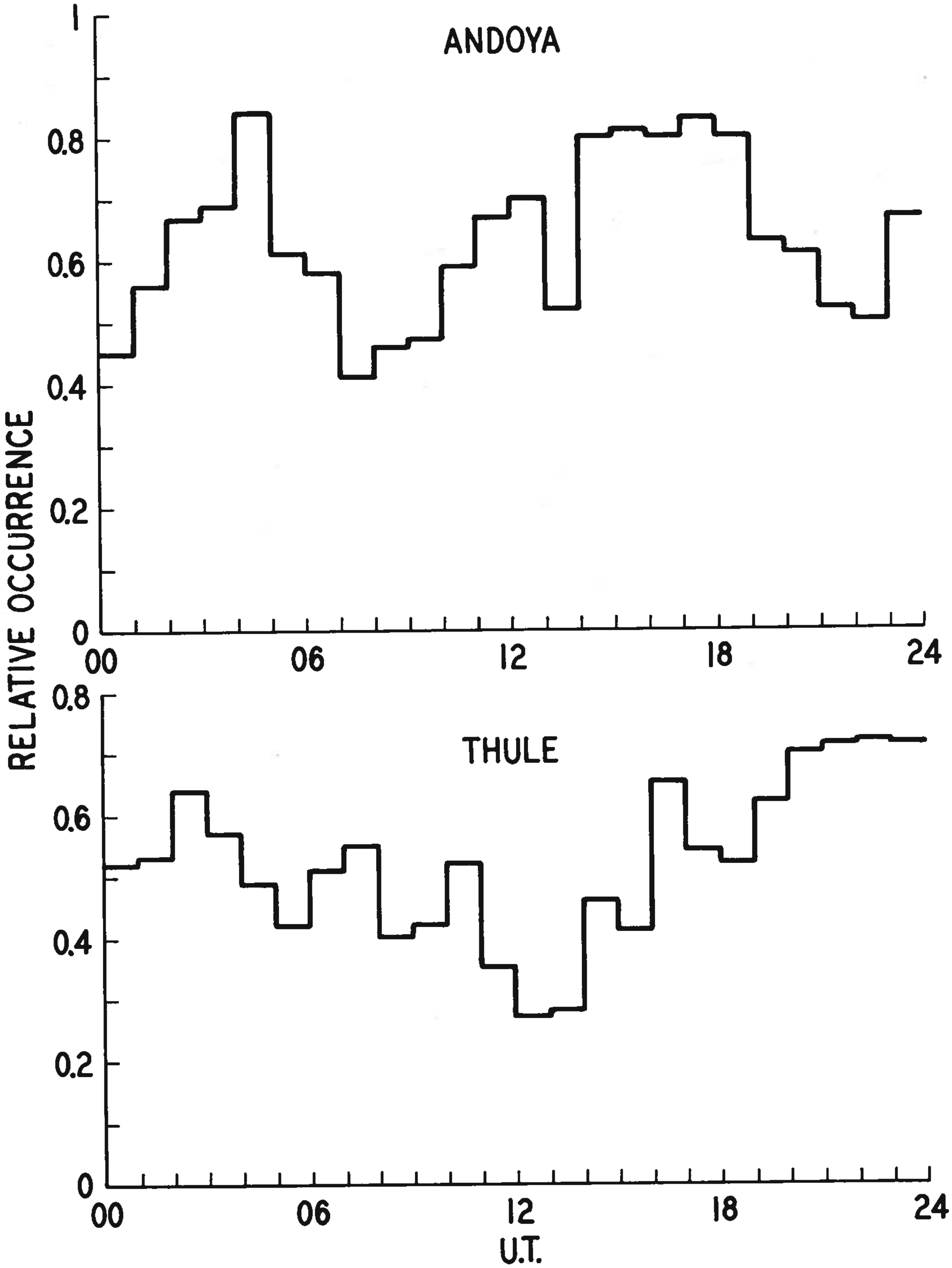
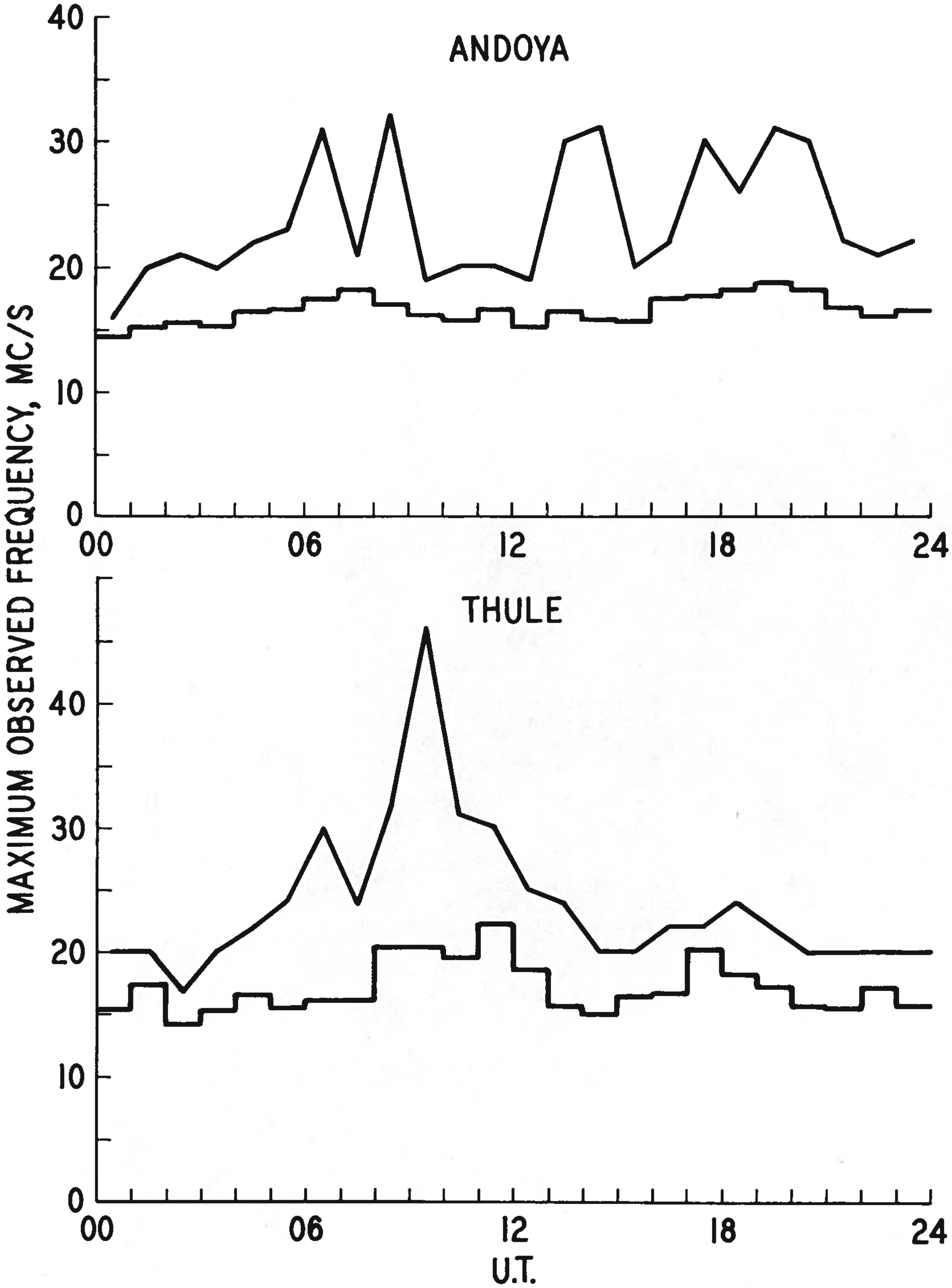


Fig. 5 Hourly occurrence of Es propagated signals from Andöya and Thule for period 27 November 1963 to 12 February 1964.



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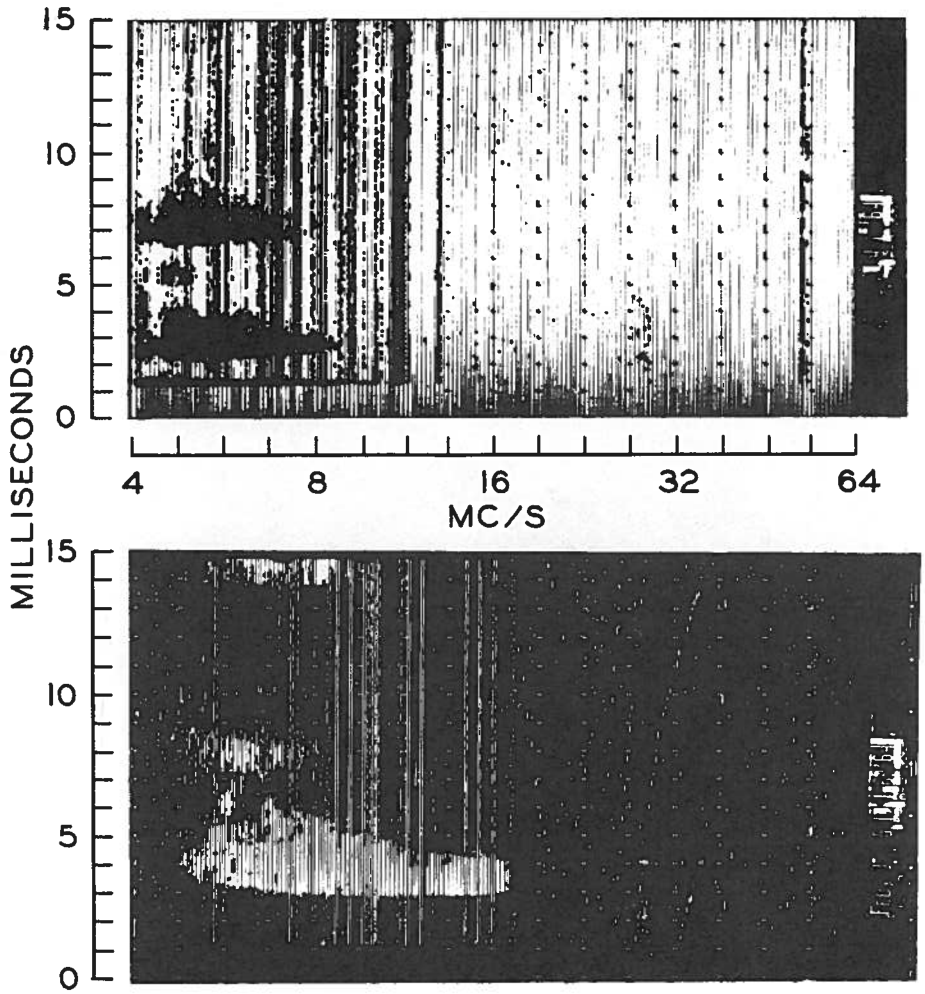

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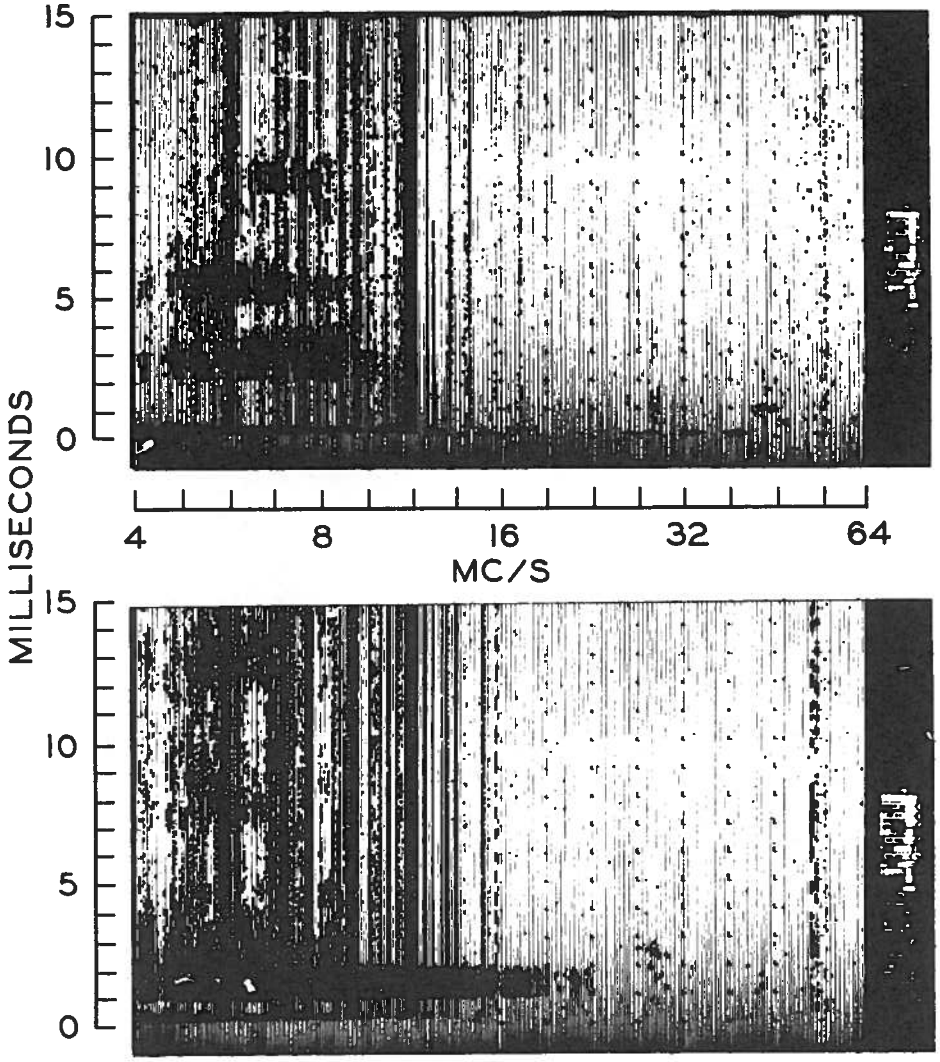

Fig. 8 Direct and off-path modes from Thule long pulse records. In lower ionogram maximum off-path delay is 11 milliseconds.

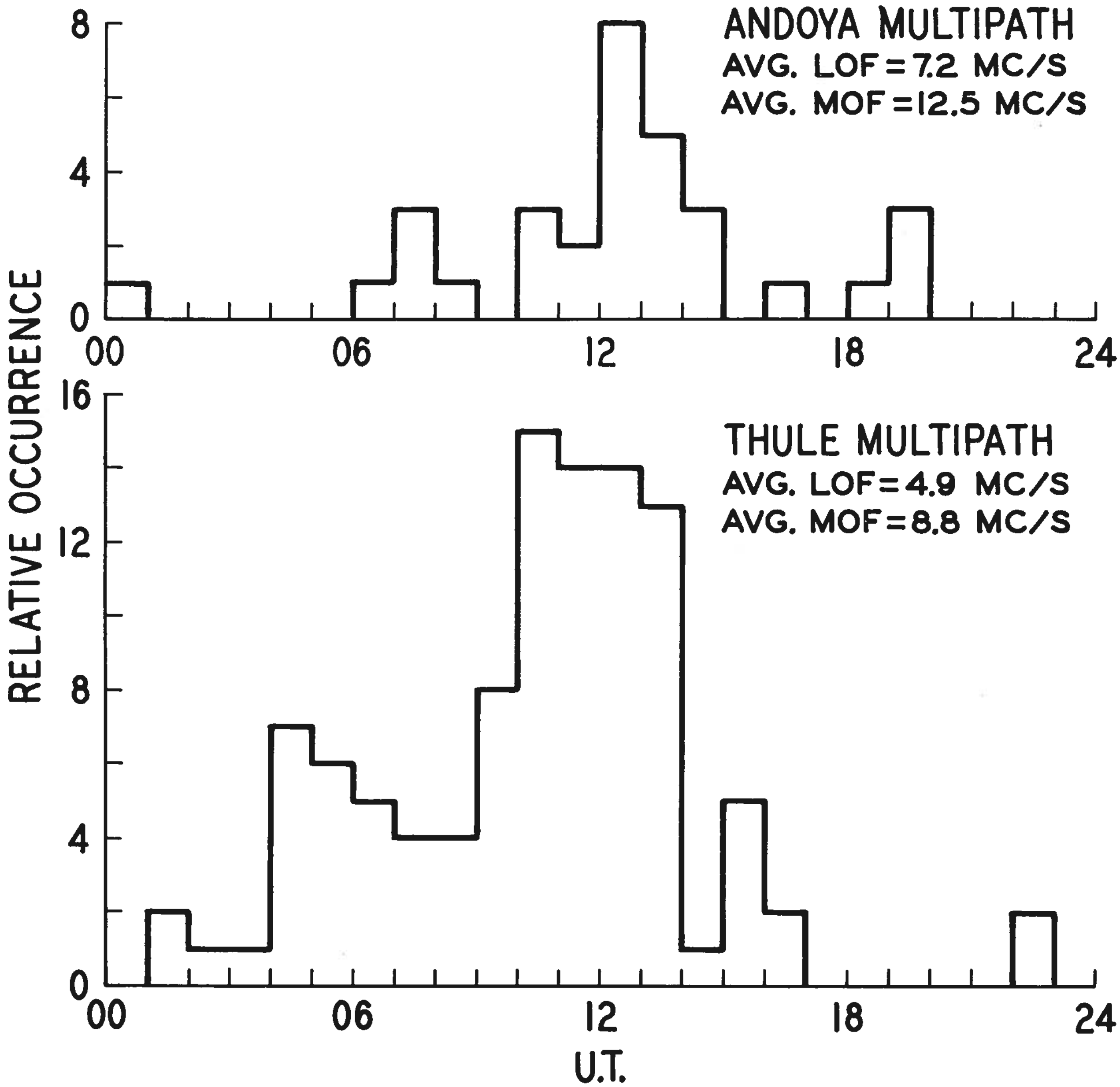

Fig. 9 Hourly occurrence and average LOF and MOF values of off-path modes from Andöya and Thule for period 27 November 1963 to 12 February 1964.