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ANALYSIS OF SIMULTANEOUS POLAR FOX II BACKSCATTER AND IONOSPHERIC SOUNDING DATA

G. J. Gassmann   J. Buchau

Air Force Cambridge Research Laboratories
Bedford, Massachusetts

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ABSTRACT

Backscatter data from the northward-looking POLAR FOX II radar were simultaneously taken with airborne and ground-based ionospheric soundings and optical data supplemented by satellite observations. The detailed ionization contour lines in the region from 0 to 2000 km north of POLAR FOX II, obtained for a period of about 2 hours before local midnight in December, explain why only a small range section of ground could be seen during this period. Aspect-sensitive direct backscatter echoes from field-aligned laminae both in the E- and F-layer were dominant and were found to be reflected from latitudes where vertical soundings show spread-E and -F. Those regions appear to be identical to the auroral E (night E) layer and "plasma ring" F layer known to be associated with the auroral oval.

I   INTRODUCTION

A joint measuring program was conducted in December 1971 after agreement between the Lincoln Laboratory of MIT and the Air Force Cambridge Research Laboratories. The object was to operate the POLAR FOX II

backscatter station, located in northern Maine, in an appropriate mode
while at the same time the ionosphere north of the station was to be
explored in as much detail as possible. For the latter purpose airborne
ionospheric soundings and optical observations were scheduled in conjunc-
tion with satellite paths. The analysis of the data covers about two
hours before local midnight, a period when the auroral activity approaches
its southernmost latitude during the course of a day. During the period
covered, an auroral substorm took place.

II THE IONOSPHERE NORTH OF POLAR FOX II
DURING A SELECTED PERIOD

The joint measurements took place on 9 December 1971 from
02:30 to 04:30 UT. The airborne laboratory flew during this period from
Goose Bay, Labrador in a northwesterly direction and accomplished by this
track a single traverse of the predicted auroral oval. In the coordinate sys-
tem of the auroral oval, which is corrected geomagnetic latitude and cor-
rected geomagnetic (local) time (CGL/CGT) and under which the earth ro-
tates, the aircraft track versus UT appears as a heavy zigzag line in
Figure 1. The thin line from top to bottom indicates the track and po-
sition of satellite ISIS II. Also marked is the position of POLAR FOX II
versus both UT and local magnetic time (bottom scale). For each position
the azimuths $0°$ (true north), $-12°$, and $+6°$, and the radar ground ranges
are indicated.

For the analysis the airborne data together with the tabulated
ionograms of St. John's and Resolute Bay (Canadian Ionospheric Data,
Dec. 1971)[1] have been used. Satellite observations provided supplemen-
tary information. From this a single vertical-ionization cross section
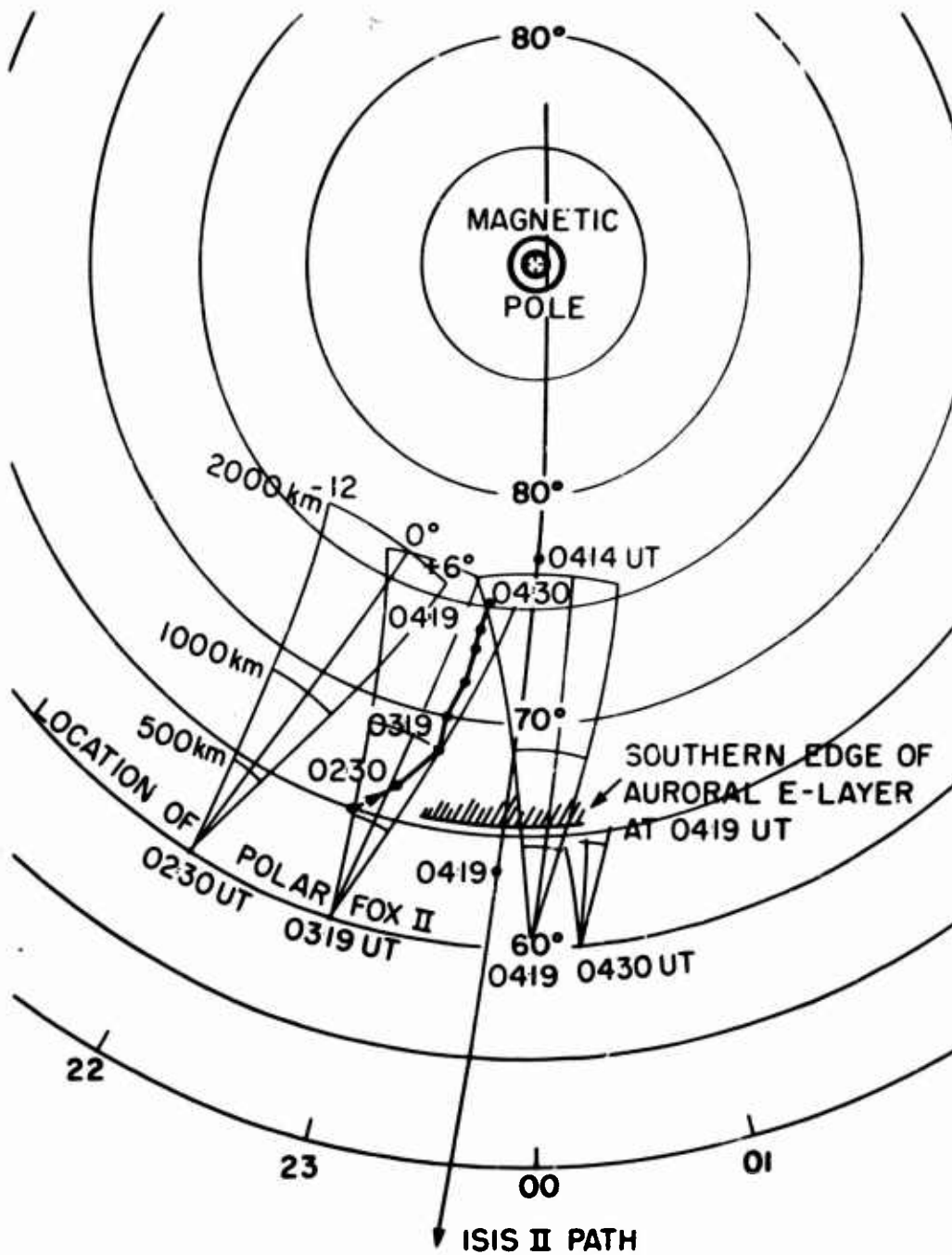along the geomagnetic meridian with some indications of its temporal

FIGURE 1   POLAR FOX II, AFCRL AIRCRAFT, AND ISIS II SATELLITE vs.
UT ON 9 DECEMBER 1971 IN AURORAL OVAL COORDINATES —
CORRECTED GEOMAGNETIC LATITUDE AND CORRECTED
GEOMAGNETIC (local) TIME (CGL/CGT)

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variation has been derived. This cross section is reproduced in Figure 2. It shows plasma-frequency contour lines in the corrected geomagnetic-latitude-versus-altitude space along the geomagnetic longitude through the POLAR FOX II site. The station is located at the 0-km mark, which coincides with 60° CGL. Since the airborne data and those from the other sources were not taken exactly at this longitude, the derivation of this profile depended to some degree on inference. The latter was mainly based on our experience that many arctic ionospheric features extend in east-west directions along constant CGL.

The profile is representative for the hours from approximately 03:05 to 04:30 UT, with modifications near 04:19 UT marked by dotted con-tour lines. During the hour prior to 03:05 UT the profile was probably very similar except that the sharp bump of an auroral E-layer between 68^{c} and 69° CGL was less distinct. The latter was probably augmented after 03:05 UT in conjunction with two bright auroral discrete arcs that occurred at 03:08 and 03:14 UT respectively (marked in Figure 2) and that remained relatively stationary until 03:30 UT when an auroral substorm was in evidence with rapid movements of auroral forms. The measuring aircraft encountered this auroral E-layer as an overhead layer between 03:10 and 03:20 UT. The aircraft's position is indicated in Figure 2 near the bottom scale. From 67.2° CGL to the northern-most latitude reached by the aircraft (75° CGL) the ionograms show E_s consistently, vary-ing in height, mostly strong with FE_s up to 12 MHz. South of 67.2° CGL down to 66° CGL there was no trace of E_s. From 66° to 60° CGL the exis-tence of E_s is unknown due to lack of reliable data. The contour lines for the F-layer in that latitude range are inferred from St. John's data and from arctic ionospheric models being developed at AFCRL.
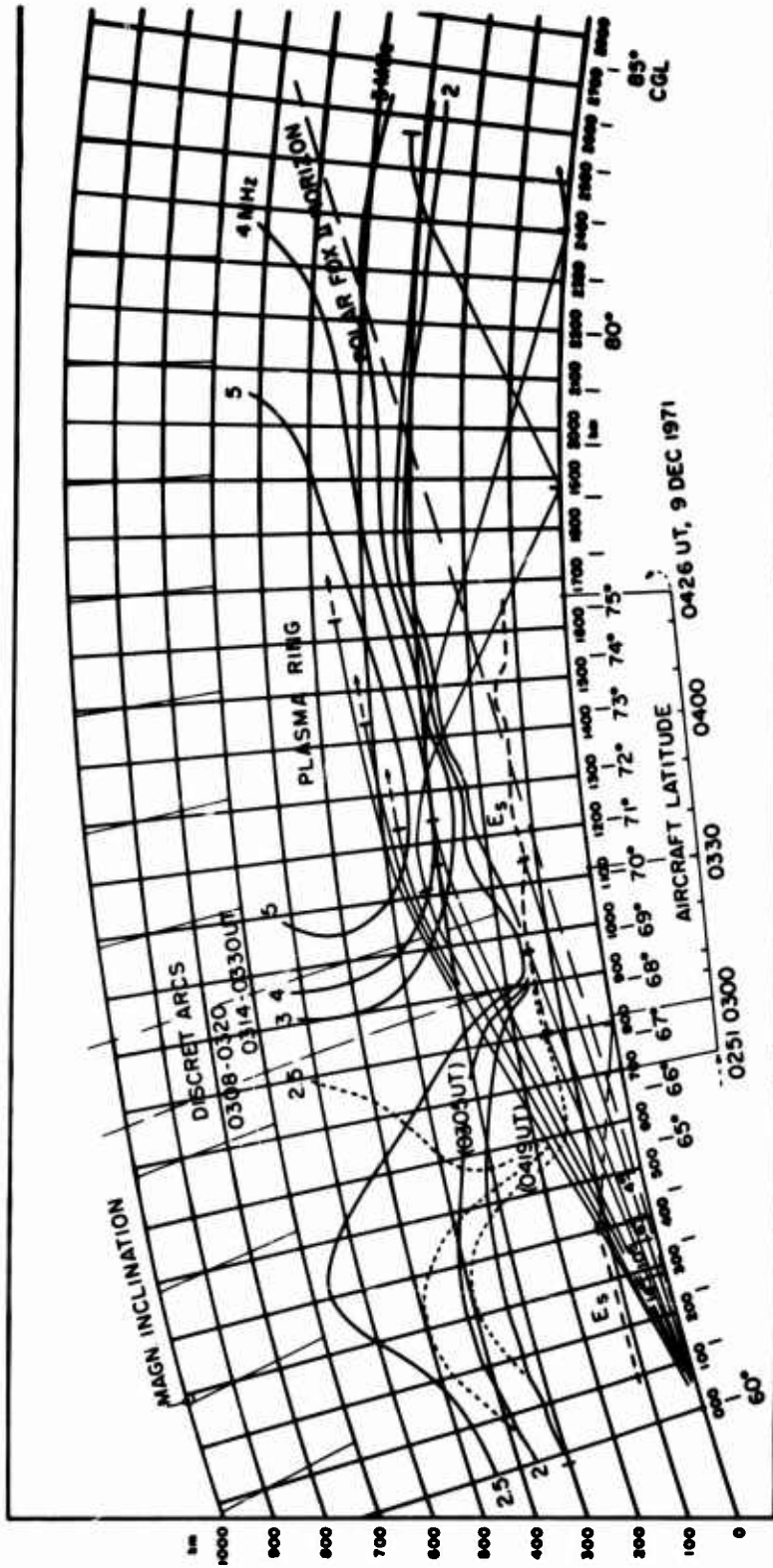
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FIGURE 2 IONIZATION CROSS-SECTION AND RAY-PATH GEOMETRY FOR 8 MHz ALONG GEOMAGNETIC MERIDIAN THROUGH THE POLAR FOX II SITE (at 60° CGL) ON 9 DECEMBER 1971 FROM 03:05 TO 04:30 UT. The contour lines are in terms of plasma frequency.

The dotted southward extension of the auroral E-layer contour lines occurring at 04:19 UT is mainly inferred from ISIS II observations. The soft-particle spectrometer in that satellite measured at that time and latitude a smooth isotropic number flux of about 10^9 cm^{-2} s^{-1} $ster^{-1}$ of electrons in the 9-eV-to-12-keV spectral range (preliminary evaluation, courtesy of Dr. Winningham).[3] In particular, about 0.1 erg/cm^2 s of 1-keV-to-3-keV electrons were deposited, from which a solid auroral E layer can be inferred.

The region of the auroral E layer (formerly called night E), which generally is characterized on the ionograms by intense spread of the trace in frequency, was all the time associated with E_s-traces of a coarse structure, indicating strong scattering regions tens of km apart in horizontal distance. The F region, indicated in Figure 2 as "Plasma Ring," also gave rise to intense spread echoes. These observations are in accordance with many more on other days and hours and represent characteristic features of the ionosphere associated with the auroral oval.

III   INTERPRETATION OF POLAR FOX II BACKSCATTER DATA

From the POLAR FOX II data obtained during the joint measuring period (courtesy J. H. Chisholm and B. J. Burdick)[3] we selected the portions that looked northward, with a constant operational frequency, for the times that were sufficiently simultaneous with our derived ionization profile. The Figures 3 through 6 show echo power in a relative dB scale versus radar range, and also the echo spectrum. The latter represents an average over about 20 s and has an inherent ambiguity of 30 Hz. Two consecutive records two minutes apart for azimuths of $-12°$ and $+6°$ from true north respectively are reproduced side by side.

The data of Figure 3 were taken near 02:28 UT at a time when the ionization profile must have appeared as in Figure 2 except for the sharp auroral-E-layer bump between 68° and 69° CGL. We interpret the echoes from 1000 to 1200 km as direct backscatter from field-aligned irregularities in E-layer heights. The echo from the range <1000 km could be the ground via sporadic E (the existence of which is unconfirmed). But more likely it too is direct E-layer backscatter. The only convincing piece of ground return is the echo near 2000 km. The corresponding ray paths for this and the echoes discussed below are indicated in Figure 2. The returns from ranges near 1500 km and from >2300 km both appear to originate from field-aligned irregularities in the F layer. One is a direct F echo, and the other is propagated via a regular F layer and ground reflection. The range of 1900 km is approximately the skip distance for 8 MHz. No ground echo is seen at a closer distance (except for the doubtful E_s-supported echo).

The data of Figure 4 were taken near 03:17 UT. At that time two discrete auroral arcs at a radar range of about 1000 km had existed for about 10 min and evidence of a developing auroral substorm became apparent from the airborne all-sky photographs. The POLAR FOX II data show only intense direct returns from the ionosphere, while no ground backscatter is observed. The closest echo may be taken as from 800 km (closer echoes due to range-sidelobe contamination[3]) and coincides well with the southernmost edge of E_s occurrence seen by the airborne equipment 17 min earlier. As seen from Figure 2 the perpendicularity condition for reflection from field-aligned irregularities at 130 km height is fulfilled to within ±3° for all ranges from 800 to 1200 km. The echoes near 1200 km in Figure 4, however, are probably a mixture of direct E and direct F returns since in heights above about 300 km the perpendicularity condition is also fulfilled for ranges >1100 km. According to the ray-path geometry of Figure 2, all echo returns are contained within the
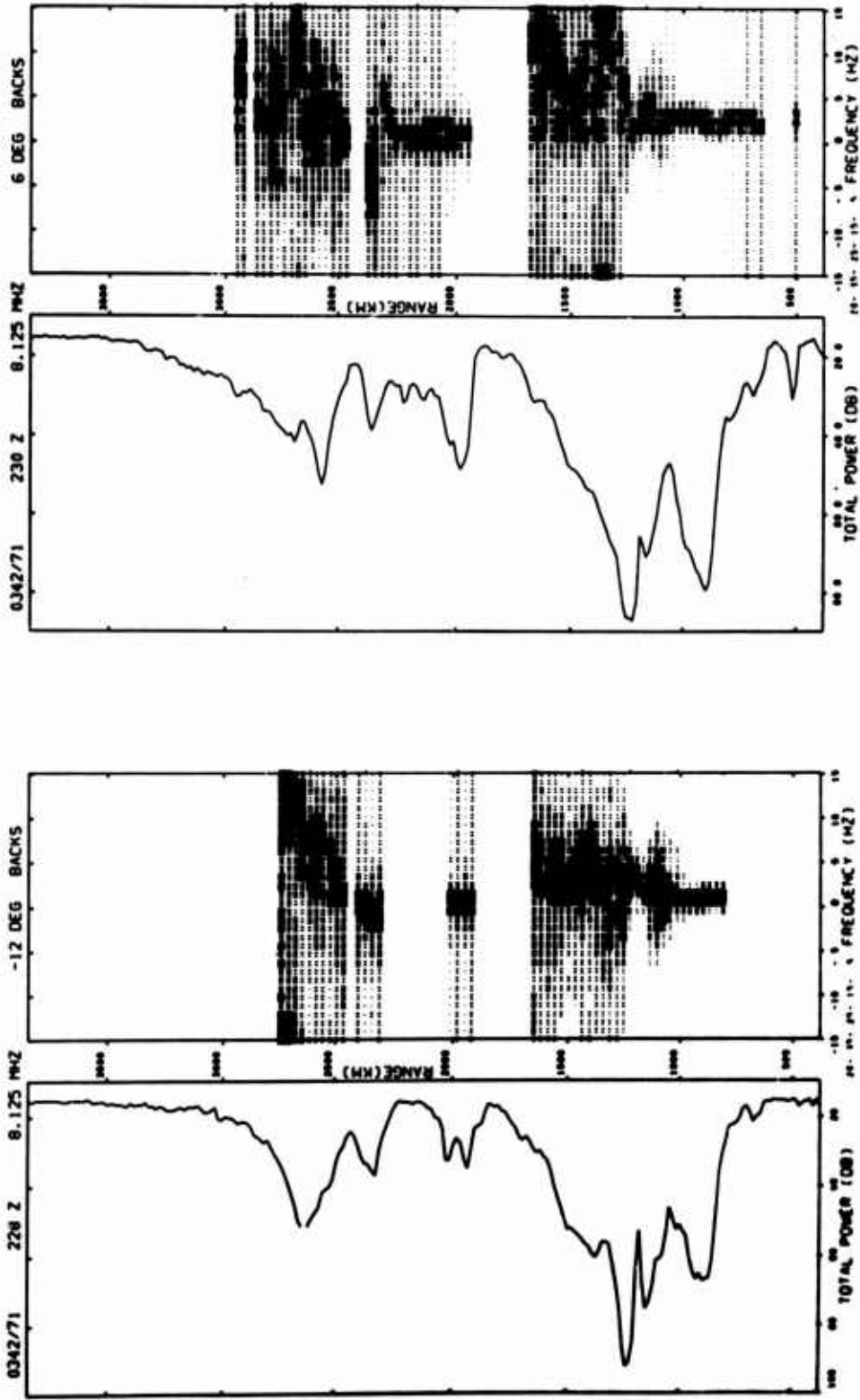
FIGURE 3   POLAR FOX II BACKSCATTER RECORD OF ECHO POWER (in relative dB) AND SPECTRUM vs. RADAR RANGE ON 9 DECEMBER 1971. The UT time is indicated (for example, 228 Z = 02:28 UT). Also indicated are the operational frequency and the azimuth in degree from true north.
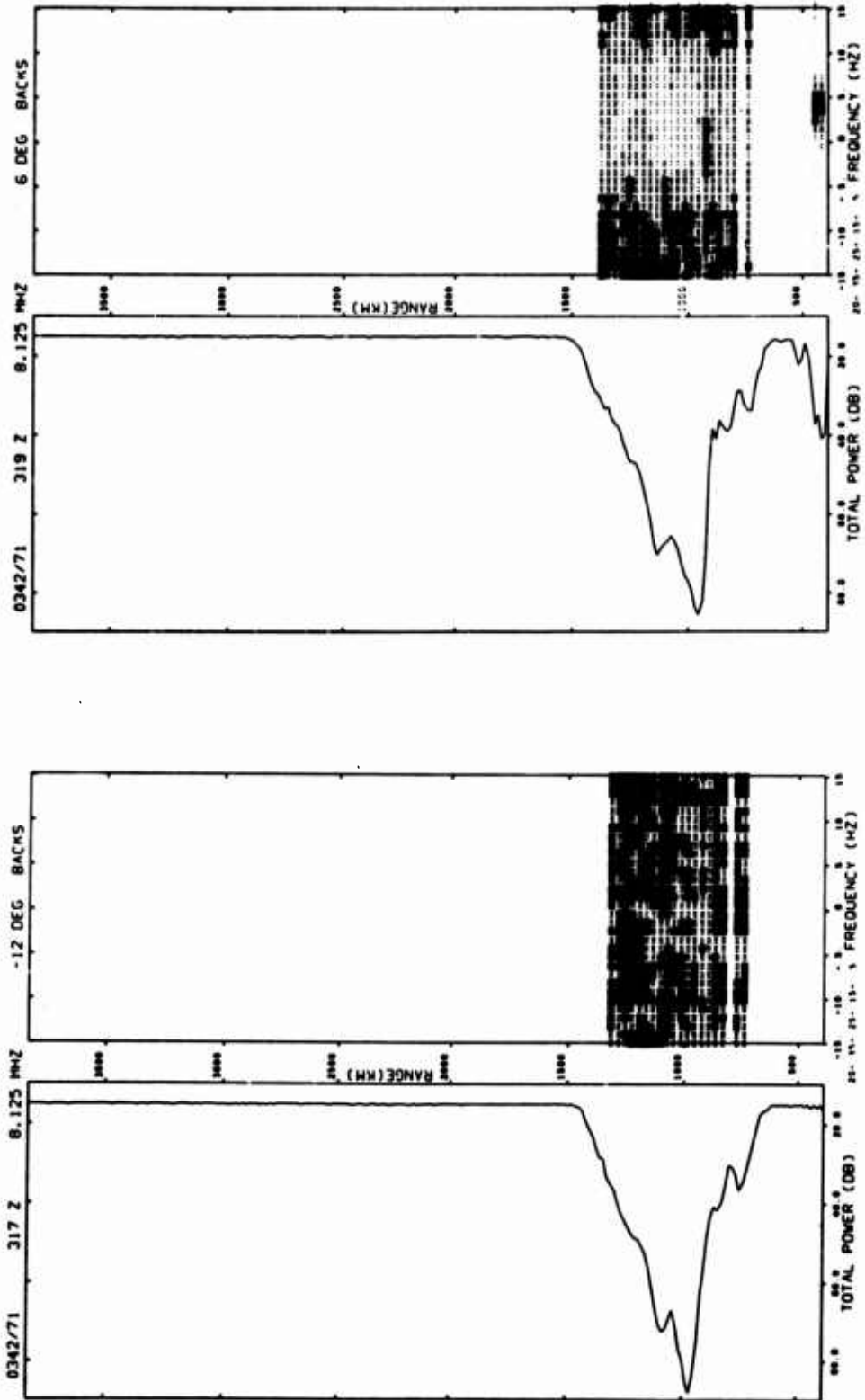
FIGURE 4   POLAR FOX II DATA ON 9 DECEMBER 1971 FOR 03:17 AND 03:19 UT

radar's elevation angles from 0° to 14°. A remarkable feature of this backscatter record is that no energy returns from >1400 km. This means that at that particular time the rays with elevation angles between 10° and 13°, which, theoretically, according to Figure 2, could carry a ground return, are highly attenuated probably due to strong backscatter in F-layer heights.

The data of Figure 5 are taken about one hour after those of Figure 4. At this time (04:19 UT) the contour lines of Figure 2 are still valid for the F layer from 68° to 75° CGL. From the evidence of satellite data, however, the contour lines of the E layer had expanded southward to the configuration indicated by dotted lines. For ray paths reaching the F layer as indicated, this causes very little additional refraction at 8 MHz and therefore would make little difference. However this E layer is associated with irregularities, and those cause direct backscatter echoes at ranges as close as about 600 km (see Figure 5, considering range sidelobe contamination as being 23 dB down from peak[3]). Although the aspect of the ray paths at that range (600 km) and height (120 to 140 km) is, by more than 4°, off perpendicularity with the magnetic field vector, the scatter process appears to be strong enough and causes sufficient attenuation of those rays that penetrate to render them useless for carrying a strong enough F-layer-supported ground return. If this interpretation is accepted, the returns from near 1200 km must come from the E layer via an elevation angle close to 0°. The Doppler shift of about +12 Hz is constant over the entire range and suggests a movement with a velocity component toward the station of about 225 m/s.

The shadowing effect of the scatter by E-layer irregularities at magnetic latitudes >65 CGL is also seen in Figure 6. Within ten minutes of the data in Figure 5 the direct E scatter has then moved slightly closer to the station and the Doppler shift has decreased. Near 1500 km,
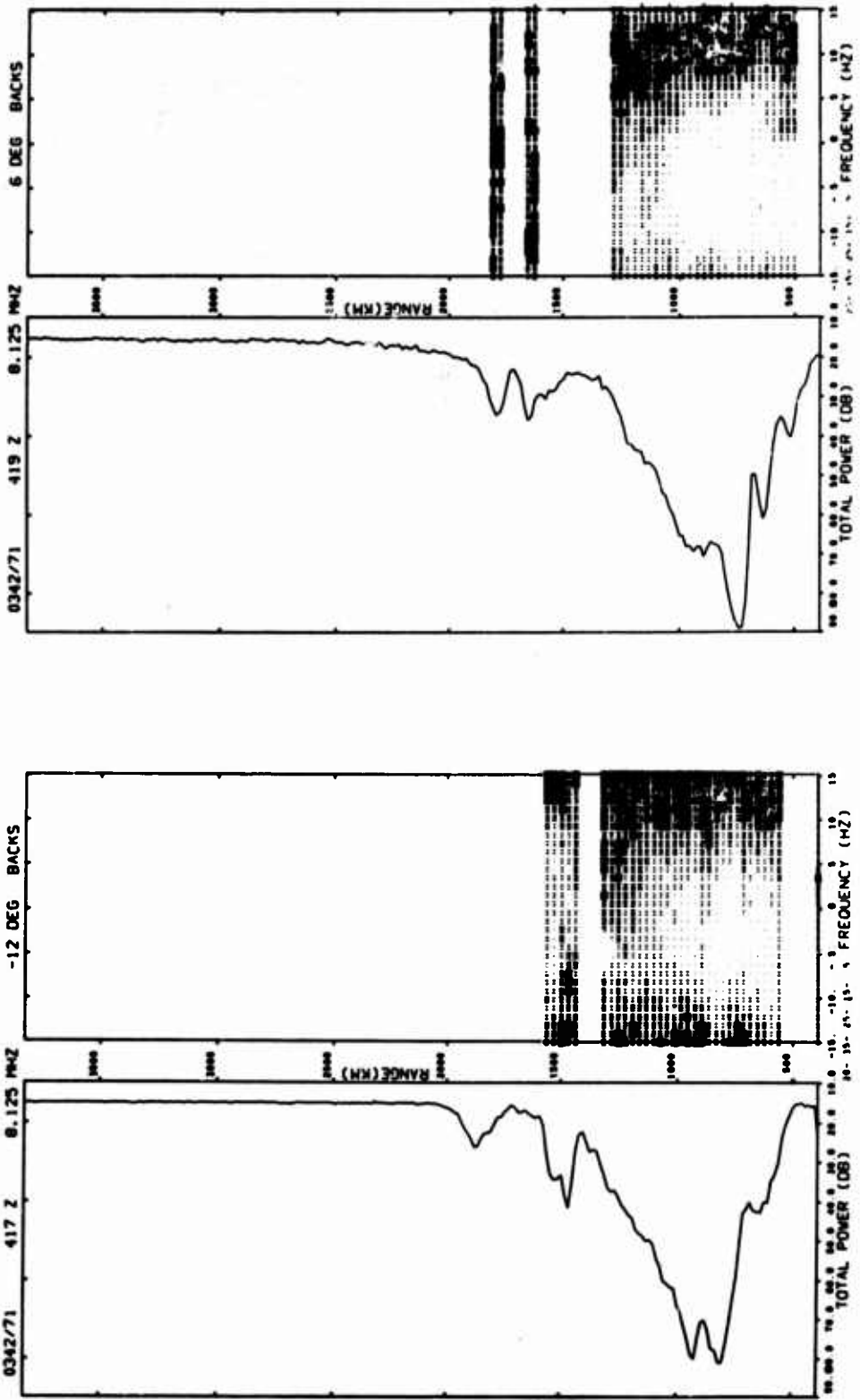
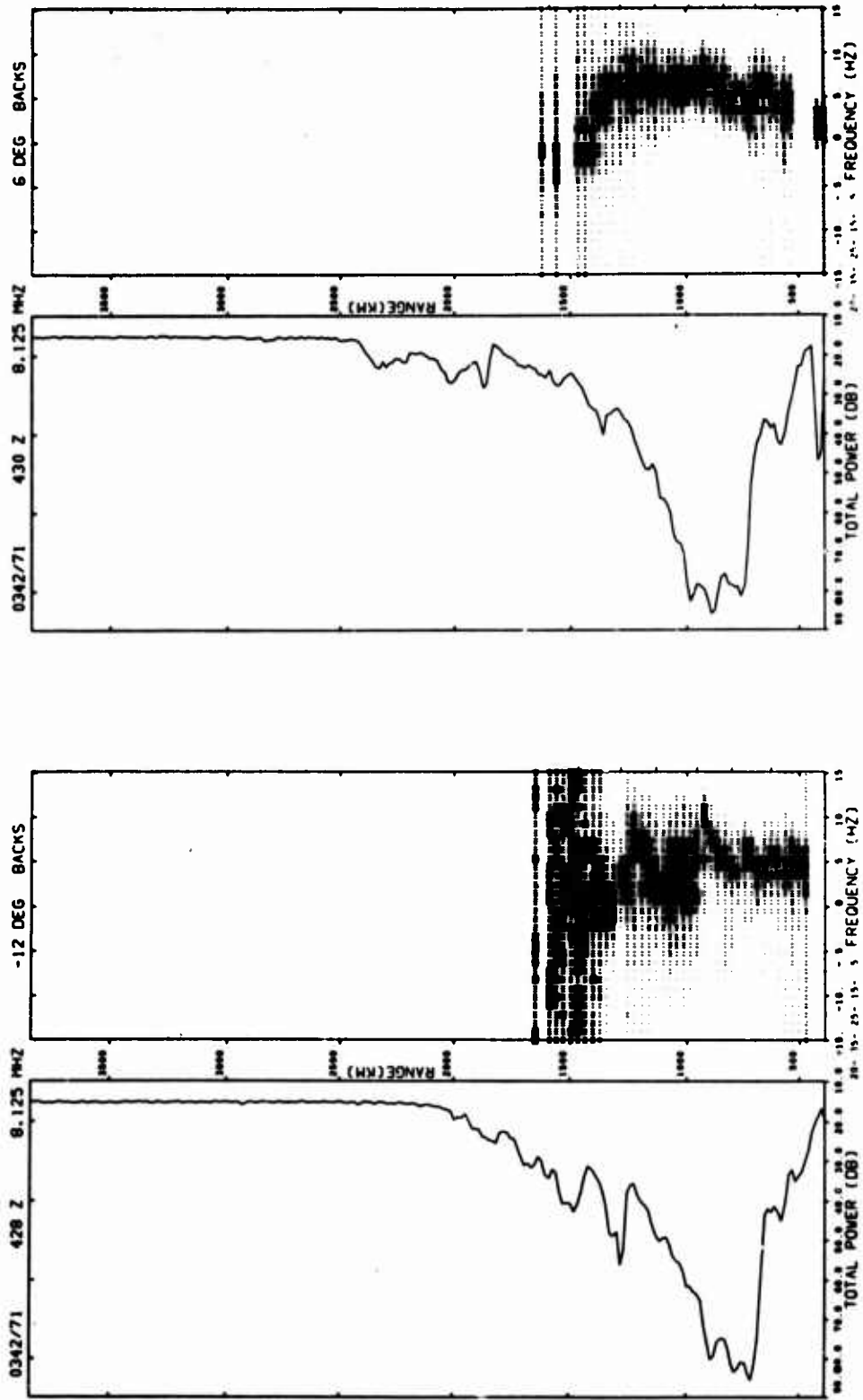FIGURE 5   POLAR FOX II DATA ON 9 DECEMBER 1971 FOR 04:17 AND 04:19 UT

FIGURE 6   POLAR FOX II DATA ON 9 DECEMBER 1971 FOR 04:28 AND 04:30 UT

direct returns from the F layer reappear, again suggesting that the rays with elevation angles 12° to 14° are no longer entirely blocked by the E-layer scatterers at 600 km range. The F-layer scatterers, however, cause high attenuation of the propagating ray. This prevents observation of ground returns, which, according to Figure 2, are theoretically possible within the limited range of elevation angles from 10° to 13° approximately.

The period covered by the data of Figures 3 through 6 includes an auroral substorm. The airborne data taken during the hours after this period show that another substorm follows with a peak near 05:00 UT. The planetary magnetic index Kp was 3^+. The period of this analysis, therefore, happens to cover a moderate-to-disturbed magnetic period during the night in December and represents unfavorable conditions for ionospheric propagation.

Radar data taken at azimuths greatly deviating from magnetic north were also taken during this period but were not analyzed in detail. For this, the ray paths are not contained in one vertical plane and a three-dimensional ray tracing would be necessary. This may be seen from Figure 2 by realizing that the contour lines shown are actually surfaces extending approximately east-west along constant magnetic latitudes. The POLAR FOX II data for azimuths $>\pm20^\circ$ off north show fairly often echo Doppler shifts, the amounts of which change with azimuth and/or with range. This fact is difficult to explain if one assumes that ion-acoustic waves associated with two-stream instabilities are the cause. The observed Doppler shifts, therefore, are probably not directly associated with the auroral electrojet but are due to moving irregularities of other origin, such as the E X B instability.

IV CONCLUSIONS

Under unfavorable conditions, which in arctic regions north of
60° geomagnetic latitude occur fairly often, a backscatter radar may see
the ground only in very limited range sections. A major reason for this
is that the radiated energy is attenuated by scattering on field-aligned
irregularities. The bulk of those appear to be embedded in or extend
beyond the auroral E layer (also called night E) and the auroral F layer
(also called plasma ring), and the effective strength of the scatterers
varies with auroral activity. The said regions are part of the arctic
ionosphere which, although related to visible aurora, covers a wide lati-
tudinal range north and south of it.

Another reason for not seeing the ground at some range sections
is contamination by clutter. The latter originates from the field-aligned
irregularities. Those move at various speeds and directions and appear
sometimes uniform and at other times turbulent within a radar resolution
cell. A more sophisticated analysis of the spectrum in its correlation
to azimuth might provide an improvement of this situation. Such an analy-
sis--namely AFCRL's Doppler and angle-of-arrival spectrum-measurements
(DASSM) program, is currently under way.

The ionization profile of Figure 2 is one example of many others
observed. It should be obvious that the reflection surfaces provided by
the arctic F layer are far from horizontally stratified. As a conse-
quence, beacons may at times appear far removed from both the predicted
azimuth and the predicted range. As a further consequence for a back-
scatter radar this means either a requirement for a large number of
beacons or the necessity for computing the radar field. The latter re-
quires the specification of the ionosphere in real time and a versatile
three-dimension ray-tracing capability.

ACKNOWLEDGMENTS

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1. Canadian Ionospheric Data, Dec. 1971, Department of Communications, Director Telecommunications Regulation Branch, Berger Building, Ottawa 4, Canada, UNCLASSIFIED.

2. J. D. Winningham, University of Texas, private communication.

3. J. H. Chisholm and B. J. Burdick, "POLAR FOX II Radar Observations at Auroral Latitudes Coincident with AFCRL Airborne Ionospheric Measurements (U)," these Proceedings.