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Information on Over-the-Horizon Radar
Part XVI - Ionospheric Disturbance and HF Radar

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Institute for Telecommunication Sciences and Aeronomy
U. S. Department of Commerce
Environmental Science Services Administration

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U.S. DEPARTMENT OF COMMERCE
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IONOSPHERIC DISTURBANCE AND HF RADAR

Vaughn Agy

U. S. Naval Research Laboratory Order No. N00173-68-0728

SPACE DISTURBANCE LABORATORY
ESSA TECHNICAL MEMORANDUM NO. 2

BOULDER, COLORADO
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FOREWORD

Most of the HF circuit performance predictions are based upon monthly averages of past measurements by hour of day plus a description of the daily distribution about the average. Some of the path loss data is available only in a coarse form.

This report shows an analytic excess loss approximation for auroral paths, and this method permits propagation geometry to be taken into account.

Since short term ionosphere behavior is important if HF radar operation is to be maintained continuously, it will be necessary to sense disturbances and then react both quickly and correctly. A part of this report introduces a study started of a particular disturbance, and it is intended to apply such studies to the problem of achieving continuous effective radar operation.

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Radar Techniques Branch
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Naval Research Laboratory

PROBLEM STATUS

This is an interim report on a phase of the problem.

AUTHORIZATION

USAF MIPR (30-602) 64-3412
to the Naval Research Laboratory
dated 26 March 1964
NRL Problem 53R02-42

IONOSPHERIC DISTURBANCE AND HF RADAR

Vaughn Agy

This is a continuation (and a correction) of work reported on in 1966.

It is shown that backscatter propagation differs from point-to-point propagation insofar as Doppler effects are concerned. Analogously, the dispersive nature of the ionosphere also shows itself differently in the two cases.

Certain F-layer disturbances are potentially troublesome to HF radar operations. One of these, which occurred during a 4-hour interval on February 11, 1958, is briefly discussed.

The effect of auroral absorption on HF radar is roughly approximated for different operating frequencies and station latitudes.

Key Words: Auroral absorption, backscatter, Doppler shifts, HF radar, ionospheric disturbance

1. INTRODUCTION

An earlier report (Agy, 1966) was an attempt to describe, on the basis of computation for simple models, the effects of a changing ionosphere on HF radar observations. The conclusions reached there apply, in fact, only to that part of backscatter return near the "leading edge". Correction is offered in Section 2 of this report.

Section 3 is a brief description of a type of ionospheric disturbance potentially troublesome to HF radar operation and a discussion of some of the details of one such disturbance for which a large amount of data is available for study.

Section 4 represents a first pass at a problem not heretofore considered: the effects of auroral-zone absorption on HF radar. The question has plagued HF communications for years and is still far from being answered satisfactorily. The approach used here is to assume median ionospheric conditions in the Arctic D region and the F layer and to compute absorption for rays taking off in a northerly direction at various angles of elevation from stations at different latitudes. The approximations are rough, but the results may be of interest. Suggestions for a closer approach to reality are made.

2. CHANGING IONOSPHERE

In ESSA Technical Memo #IERTM-ITSA-14 (Agy, 1966), it was suggested that the Doppler shifts (due to ionospheric change) experienced by backscattered radio waves may be greater (by an order of magnitude or more) than would be observed for the same frequency over a point-to-point circuit. Explicit in the derivation leading to this conclusion was the assumption of skip-distance focusing which would be effective only at (or near) the leading edge of the returned pulse. From the radar standpoint, the energy returned from well beyond the skip is far more important.

The usual technique for observing backscatter requires the use of a "gate" set for a fixed time-delay (group path). Where for point-to-point, the fixed ground range (transmitter-receiver separation) serves as a condition allowing computation of Doppler shifts produced by a changing ionosphere, the fixed group path serves for the backscatter case   Suppose the ionosphere to be represented by a set of parameters. [Three parameters are required if the ionosphere consists of a single parabolic (or quasi-parabolic) layer, e.g. critical frequency, minimum height, height of maximum ionization.] Let these parameters be $q_1, q_2, q_3, \ldots$.

If β = take-off angle, and
   f = operating frequency

then phase-path P, group path P', and ground range D may be represented respectively by:

$$
\begin{aligned}
P &= P(q_1, q_2, q_3, \ldots ; \beta ; f) \\
P' &= P'(q_1, q_2, q_3, \ldots ; \beta ; f) \\
D &= D(q_1, q_2, q_3, \ldots ; \beta ; f) \, .
\end{aligned}
\tag{1}
$$

The Doppler shift (in f) will be given by

$$\Delta f = -f/c \left(\frac{dP}{dt} \right) \tag{2}$$

where

$$\frac{dP}{dt} = \sum_i \left[\frac{\partial P}{\partial q_i} + \frac{\partial P}{\partial \beta} \cdot \frac{\partial \beta}{\partial q_i} \right] \frac{dq_i}{dt} \quad . \tag{3}$$

But evaluation of the bracketed expression on the right is possible only if $\frac{\partial \beta}{\partial q_i}$ can be found. [This amounts to saying that the take-off angle β must change in such a way that some defining condition -- e.g. D constant -- holds.]

For the point-to-point case since D is fixed, we have:

$$\frac{dD}{dt} = \sum_i \left[\frac{\partial D}{\partial q_i} + \frac{\partial D}{\partial \beta} \cdot \frac{\partial \beta}{\partial q_i} \right] \frac{dq_i}{dt} = 0 \tag{4}$$

and therefore

$$\frac{\partial D}{\partial q_i} + \frac{\partial D}{\partial \beta} \cdot \frac{\partial \beta}{\partial q_i} = 0 \tag{5}$$

or

$$\frac{\partial \beta}{\partial q_i} = - \frac{\frac{\partial D}{\partial q_i}}{\frac{\partial D}{\partial \beta}} \quad . \tag{6}$$

Formal substitution of P′ for D in (4)

$$\frac{\partial \beta}{\partial q_i} = - \frac{\frac{\partial P'}{\partial q_i}}{\frac{\partial P'}{\partial \beta}} \tag{7}$$

which holds for constant group path in the "open-end" case, i.e., half the round trip required for backscatter observations. Equation (7) is certainly different from (6); that the two equations do lead to different computed Doppler shifts is shown in Appendix 1 for the plane earth.

In the earlier report, since skip-distance focusing was assumed,

$$\frac{\partial D}{\partial \beta} = X = 0 \ . \tag{8}$$

If observations can be made on that part of the return for which (8) holds, the fact that X is constant with time (the value of the constant being zero in this case) can be used in the same fashion that the constancy of D (or of P′) was used above. We have, therefore,

$$\frac{dX}{dt} = \sum_i \left[\frac{dX}{\partial q_i} + \frac{\partial X}{\partial \beta} \cdot \frac{\partial \beta}{\partial q_i} \right] \frac{dq_i}{dt} = 0$$

or

$$\frac{\partial\beta}{\partial q_i} = - \frac{\frac{\partial X}{\partial q_i}}{\frac{\partial X}{\partial \beta}} \quad . \tag{9}$$

(It is necessary to keep in mind that $X = \frac{\partial D}{\partial \beta}$ is a function of q_i, β, and f and the condition $X = 0$ does not imply that $\frac{\partial X}{\partial \beta} = 0$. This is similar to noting that if $y = f(x)$ then dy/dx does not necessarily vanish at $y = 0$.)

Equation (9) is different from either (6) or (7) -- giving much greater Doppler shifts than (6), for example.

Although there is no longer any concern that the backscatter return, under changing ionospheric conditions, will always suffer disastrous Doppler shifts, there may still be some interest in the computations indicated by (3) and (7) for simple models. Somewhat surprisingly the algebra is worse for this case than for either point-to-point (8) or skip-distance focusing (9) and has not been completed. Since programs are available making algebraic manipulation possible in the computer, relatively little time would be required for the computation. Few good comparative measurements have so far been made, but one set of backscatter records in the late summer of 1966 (by the HF radar group in the Ionospheric Telecommunications Laboratory of ESSA directed by L. Tveten) suggests greater complication than has ever been found on point-to-point records.

The earlier report also contained a section attempting to deal with moving irregularities in the ionosphere. A closer look at the algebra involved shows that, for the case of skip-distance focusing, the statements regarding the relatively small Doppler shifts to be expected are incorrect. The model -- a discontinuity in electron density across a vertical line -- actually allows considerably greater Doppler shifts than would be observed point-to-point. The small frequency changes observed during the passage of an irregularity along the propagation path is probably in fair agreement, however, with what would be calculated for observations using a fixed time-delay gate. These calculations have not been made.

Since the ionosphere is a dispersive medium, variations with respect to f must be considered. If f, rather than t, is treated as the independent variable, conclusions analogous to those above may be drawn. In effect, Appleton (1928), has pointed out that since

$$\mu' = \frac{d}{df}(\mu f) = \mu + f\frac{d}{df} \tag{10}$$

where μ = phase refractive index

f = operating frequency

μ' = group refractive index

then

$$P' = P + f\frac{dP}{df} \tag{11}$$

where P and P′ are phase path and group path respectively. Implicit in the derivation of (11), however, is the assumption of ground range (transmitter-receiver separation) independent of frequency. The way in which this bears on the problem is apparent from the following:

$$\frac{dP}{df} = \frac{\partial P}{\partial f} + \frac{\partial P}{\partial \beta}\cdot\frac{\partial \beta}{\partial f} \quad . \tag{3'}$$

If

$$\frac{dD}{df} = \frac{\partial D}{\partial f} + \frac{\partial D}{\partial \beta}\cdot\frac{\partial \beta}{\partial f} = 0 \quad , \tag{4'}$$

then

$$\frac{\partial \beta}{\partial f} = -\frac{\frac{\partial D}{\partial f}}{\frac{\partial D}{\partial \beta}} \quad . \tag{6'}$$

For group path independent of frequency (backscatter observations with a fixed time-delay gate):

$$\frac{\partial\beta}{\partial f} = -\frac{\frac{\partial P'}{\partial f}}{\frac{\partial P'}{\partial\beta}} \tag{7'}$$

and (6′) and (7′) differ in much the way that (6) and (7) do. (Appendix 1.)

For simplicity, if equations (1) represent the exact analytical expressions for P, P′, and D in terms of f_c, h_o, and h_{max} for a parabolic layer and plane earth (or quasi-parabolic layer and spherical earth) with no geomagnetic field, it is not difficult (although the algebra is messy) to show that (11) holds <u>if and only if</u> $\frac{dD}{df} = 0$. It is clear then that (11) is invalid for backscatter for this simple model -- and, by implication, for the physical situation as well. This result is of interest in view of a recent series of papers (Gething, 1965; Titheridge, 1965 and Gautier, 1966) which lead to the conclusion that (11) is valid for point-to-point -- regardless of the complexity of the model.

No attempt has been made to derive an equation analogous to (11) which may apply when P′ = constant. For the moment, the important fact is that (11) may <u>not</u> be used for the theoretical examination of backscatter measurements.

I should like to acknowledge the opportunity for discussion of the above points with personnel of the Ionospheric Telecommunications Laboratory, especially Dr. W. J. Surtees.

3. F-LAYER DISTURBANCE

High-frequency radar is remarkably stable in its operation. Use of the fixed time-delay gate (in practice, many may be used simultaneously) limits variation of ground range to the target area to a few percent if the antenna is moderately directional. For example, if the gate is fixed at a time delay corresponding to a one-way group path of 2,000 km, the ground range may vary from about 1,850 km for F-layer propagation to perhaps 1,980 km for propagation by Es, and two different F-layer configurations will normally give ground ranges in much closer agreement. For a changing F layer, then the Doppler shifts should be small (Section 2) and the "before and after" radar records will not greatly differ. It should be possible, therefore, to make continuous observations throughout the day and even during F-layer change associated with a storm.

As long as the observations are made on a frequency substantially below the MUF, the arguments for using the higher frequencies are sound: the absorption of the signal (Section 4) as well as ambiguity in both ground range and azimuth will be less. But if the MUF for a given gate is approached (or exceeded), the change can be serious: large Doppler shifts may occur (or transmission through the gate may fail entirely). It seems fitting, therefore, to study ionospheric storms in which there are large and rapid F-layer changes.

During the IGY, a period of high solar activity, a number of great magnetic storms occurred, some of which have been studied in moderate detail from several points of view. In most of these the greatest attention has been directed at the times when F-layer variations are obscured by spread-F or lower level phenomena, Es and/or D-region ionization, even at temperate latitudes. Although the inter-layer relationships are real and important, it is essentially impossible at these times to describe what happens in the F layer except in a gross statistical way.

Occasionally, however, large changes may be observed without the obscuring effects and such periods offer the best data for intensive study of the geographic and temporal variations in the F layer. One such period was in the earlier stages of the great magnetic storm of February 11, 1958.

After the sudden commencement (s.c.) at 0125 GMT there was an unusually large initial phase during which K_p (worldwide magnetic activity index) was 9o -- its highest possible value -- a level reached only one other time during the entire year. The F-layer effect of interest here started about an hour after the s.c., reached its maximum at about 0330 near the end of the initial phase and showed essentially complete recovery by 0530 GMT. Figure 1 is the Adak f-plot for February 10, 1958 (180° WMT). Note the "cut out" between about 1430 and 1730 (0230 - 0530 GMT) representing a drop in foF2 of 5 MHz followed by a rapid "recovery". An indication of the potential seriousness of such a disturbance is given by the change in 2,000 km-MUF: at 0200 GMT it was 26.8 MHz; at 0300, 15.8 MHz; and at 0400, 13.7 MHz. Very likely, for a distance of 2,000 km (1100 nmi) observation at 12 MHz or less would not have been much affected, but at 16 MHz, say, there would have been no return for well over an hour.

The fact that this kind of disturbance is rare could argue against a detailed analysis; but, it is rare principally in its short duration (a few hours) and in the evident lack of obscuring effects especially in the E or D regions. These characteristics facilitate study of the F-region disturbance since the normal diurnal changes are usually small in so short an interval and the "pure" F-region disturbance may be observed with less than usual guesswork or interpolation.

F-layer changes of this magnitude will normally occur during the main phase of the geomagnetic storm when at high temperate latitudes (e.g. Washington or Adak) there may be "auroral zone" absorption to render the F layer unobservable part of the time and the analysis therefore questionable. From a radar viewpoint the D-region ionization will restrict use of the lower frequencies at much the same time that the F-layer "depletion" removes the higher ones. In HF communications terminology, the MUF-LUF separation decreases (or disappears). During this particular brief disturbance the F-layer variations seem to be similar to those reported for ionospheric storms and may be so treated.

The disturbance has been found in the ionospheric data from stations ranging around the world and in both northern and southern latitudes. For stations within about 5° of the geomagnetic equator in the sunlit hemisphere, the change in foF2 is positive rather than negative (as is reported for the usual storm). Temperate zone stations in the Southern Hemisphere, since the summer daytime values of foF2 are less, and of foF1 greater, show "G condition" in this period, i.e., foF2 less than foF1.

After the recovery (by 0530) mentioned above, the Adak foF2 by about 0600 (1800 Adak time) has begun its evening decline somewhat earlier and more precipitously than usual and by 0800 is so obscured (by spread echo, blanketing by Es, and absorption) as to be unscalable until 1800 (0600 Adak time February 11) so that detailed F-layer variations during the main phase of the magnetic storm were unobserved. At the Japanese stations, except for stratification not usually seen at these hours, the F-layer variations are quite easily described for 02-05 GMT. They become masked by spread echo, blanketing, "absorption near the critical frequency", or by interference (depending, in part, on the station) around 10 GMT so that there is little useful F-layer information until 21 GMT. Thus even near 25° geomagnetic latitude, during most of the main phase of the magnetic storm, F-layer details are lacking; for the major storms this is the rule rather than the exception. The opportunity offered here for a large scale (worldwide) analysis of an ionospheric disturbance showing large rapid F-layer changes is unusual, but clearly worthwhile.

A beginning, but only a beginning, has been made on the analysis. Very little has heretofore been done on the variations of the height distribution of electron density during a storm. (Top-side observations are now available to help in such studies for more recent periods.) In this case it is found that at Adak the maximum electron density fell (in $1\frac{1}{2}$ hours) by almost 70% while the height of maximum density went from about 350 km at 0200 GMT to 420 km at 0300 to 330 km at 0330. In the ensuing half hour the maximum electron density increased by almost 50% and its height increased to 570 km. Then as the height decreased, the maximum electron density increased to a point within 6% of its original value $3\frac{1}{2}$ hours earlier. It is clear from the order and magnitude of these changes that the storm effect is not merely a redistribution in height of existing ionization.

Continuation of the study would be desirable for its "practical" results, as they apply to HF radar (and communications), but also for the more "basic" value it may have in aiding our understanding of ionospheric storm phenomena. Several approaches should be followed: a search should be made to learn the frequency of occurrence of such "short duration storms"; ionograms from other stations for this event should be analyzed to learn how the electron-density height distributions vary with latitude and longitude; geomagnetic variations should be analyzed and these results related to those of the ionospheric data analysis. If more recent events are found, the top-side data (if available) should be included in the overall analysis.

Ionosphere storms have been studied for over 30 years and there are strangely conflicting statements in the literature. The detailed study of even one (quasi-) storm should give solid support (or clear-cut denial) to some of these with the result that the morphology at least may become clearer.

4. AURORAL ZONE ABSORPTION

At auroral latitudes the ionosphere presents problems more rarely encountered nearer the equator -- problems involving every ionospheric region. The F layer, normally responsible for the propagation of HF over distances required for OHD, suffers more frequently from rapid change in electron content and distribution and the higher frequencies may therefore be less reliable. (Section 2)

This F-region variability may be offset to some extent by the frequent occurrence of intense Es which allows a strong, reasonably steady, return from the target area, although optimum use of Es will require a choice from a wide range of operating frequencies and a higher degree of predictability than is presently available.

Additional ionization is often produced in the D region resulting in "abnormal" absorption of HF radio waves. Occasionally the absorption amounts to total "blackout" during which even a tremendous increase in power will not give signals strong enough for use. Two types of high latitude absorption may occur -- Polar Cap Absorption and Auroral Zone Absorption. For the present only the second of these will be considered.

The problem has not been solved for HF communications in spite of considerable effort over many years, so it is hardly expected that this report will be anything more than a somewhat tentative indication of a potentially useful approach.

If it were possible to predict electron density at all heights and geographic locations for a given instant, ray-tracing programs are available which would allow computation of target locations and transmission losses. For the moment, since no such detail is possible, we will confine our efforts to the "median situation" using estimates (based on past data) of the diurnally varying F layer and D region.

For the Arctic D region, the most amenable information comes from riometer measurements made in Canada (Hartz et al., 1963) as treated by Hargreaves (1966). The distribution of median absorption of galactic radio noise on 30 MHz may be derived and is here restated analytically as a function of time and latitude. The distribution found by Hartz et al. is thereby modified in this first pass at the problem, to one of greater symmetry. Figure 2 reproduces Hartz's distribution and figure 3 represents the one used here. Following Hargreaves we assume the latitude variation to be Gaussian. The secondary maximum near midnight (remarked on by Hartz et al.) is thought to be related to Es occurrence and is eliminated here. We do not differentiate between geographic (local mean) time and geomagnetic time. The F layer is described as "quasi-parabolic" (Agy, 1966) with a time-varying critical frequency and minimum height and fixed semi-thickness over a spherical earth. The absorption suffered by the radar ray as it passes through the D region (at 90 km height) is assumed to vary inversely with the square of the frequency and directly with the secant of the angle between the ray and the earth radius. If the target is below 90 km, there will be two D-region penetration points, and the "round trip" requires doubling the "one-way attenuation". The detailed formulation of the problem is given in Appendix 2,

$$A_f = 2 \cdot \left(\frac{30}{f}\right)^2 \cdot (A_1 + A_2) \cdot \sec \phi_{90} \tag{12}$$

where A_f = absorption (in dB) of radar ray

f = operating frequency

A_1, A_2 = riometer absorption at 30 MHz and vertical incidence at each D-region penetration point .

It must be kept in mind that the absorption experienced does not depend simply on the D-region pattern since the point at which the

D region is penetrated depends to some extent on the propagating layer. The F-layer parameters, foF2 and minimum height, are given in figure 4.

A fixed "semi-thickness" -- height difference between the bottom of the layer and the level of maximum ionization density -- of 100 km was used. All of these parameters may be changed to agree better with observed or expected conditions. The present program is based on the assumption of a quasi-parabolic layer, but this is arbitrary as is the assumption of no E-region ionization.

In figure 5 the diurnal variation of ground range to the target area is shown for three different frequencies in terms of take-off angle, β, as the parameter. There will be no return, of course for $\beta < 0^{\circ}$. As β increases, if the operating frequency is high enough, a point is reached at which the ray penetrates the F layer and again there will be no return. This condition is indicated by the cross-hatched areas.

Although latitudes are given in figure 5, no latitudinal variation of the F layer is considered, and these labels become significant only when the D-region absorption pattern (fig. 3) is included in the computations. When this is done, figure 5a results where, now, auroral absorption contours have been added to the purely geometric information given in figure 5. The "excess" absorption indicated includes neither the normal nondeviative absorption (experienced at all latitudes) nor the antenna gain which, of course, varies with take-off angle. For figure 5 and figure 5a, the target is on the ground.

If the target is at a height greater than the 90 km assumed for the absorbing layer, there will be only one D-region penetration point and the absorption suffered by the radar ray will consequently be less. Figures 6 and 6a represent this case, where figure 6 gives the geometric results and figure 6a includes auroral absorption. (The comments concerning the latitude labels in figure 5 apply here also.)

The computer output for the program leading to figures 5 and 6 also includes target location and group path to the target ($=\frac{1}{2}c\Delta t$ where c is the velocity of light and Δt is the time delay, i.e., the travel time for the transmitted pulse.) Figures 5 and 6 are for 0° azimuth (north) -- other azimuths may also be considered but, for now, with no corresponding change in the F-layer parameters.

Modifications aimed at improvement are possible. For example, latitudinal variation of the F layer can be approximated. By making longitude and local time equivalent, further variation with longitude can be built in. We may distinguish between geographic latitude (and time) and geomagnetic latitude (and time). The analytical expression for the D-region pattern can be modified to bring about better agreement with the observed pattern -- or the observed pattern itself may be used.

The effect of geomagnetic activity requires further study. It may be approximated by application of Hargreaves' results to the analytic formulation used here. With disturbance, the latitude of the maximum decreases, and the absorption at all latitudes increases. But there may also be some change in the shape or orientation of the pattern and the details are not well known.

If it is understood that the results given here are only roughly approximate, they may still be useful in aiding decisions on station location and frequency for optimum coverage.

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Appendix 1

For a plane earth

$$P' = D \sec \beta \tag{13}$$

and

$$\begin{aligned} \frac{\partial P'}{\partial q_i} &= \frac{\partial D}{\partial q_i} \sec \beta \\ \frac{\partial P'}{\partial \beta} &= \frac{\partial D}{\partial \beta} \sec \beta + D \sec \beta \tan \beta \quad . \end{aligned} \tag{14}$$

Then (7) gives

$$\frac{\partial \beta}{\partial q_i} = - \frac{\dfrac{\partial P'}{\partial q_i}}{\dfrac{\partial P'}{\partial \beta}} = - \frac{\dfrac{\partial D}{\partial q_i} \sec \beta}{\dfrac{\partial D}{\partial \beta} \sec \beta + D \sec \beta \tan \beta}$$

or

$$\frac{\dfrac{\partial P'}{\partial q_i}}{\dfrac{\partial P'}{\partial \beta}} = \frac{\dfrac{\partial D}{\partial q_i}}{\dfrac{\partial D}{\partial \beta} + D \tan \beta} \; . \tag{15}$$

From (15) it is seen that (6) and (7) can be identical only if $D \tan \beta = 0$.

For a parabolic layer for which f_c = critical frequency, y = semi-thickness, h_o = height of bottom of layer, we have

$$D = \frac{f y}{f_c} \cos \beta \, \ell n \, \frac{f_c + f \sin \beta}{f_c - f \sin \beta} + 2h_o \cot \beta$$

or

$$D \tan \beta = \frac{f y}{f_c} \sin \beta \, \ell n \, \frac{f_c + f \sin \beta}{f_c - f \sin \beta} + 2h_o$$

so that D tan β cannot vanish even for β=0 or 90°. It is therefore concluded that the Doppler shifts in the two cases are not identical (allowing for the backscatter factor of 2). Since $\frac{\partial D}{\partial \beta}$ for the low-angle ray is negative and D tan β always positive, the differences can, in fact, be quite large.

If q_i be replaced by f in (15), the difference between (6′) and (7′) becomes clear.

Appendix 2

From Hargreaves we have:

$$Q = Q_o \exp -\left[\frac{(\lambda-\lambda_o)^2}{2\sigma_1^2}\right] \qquad (16)$$

where Q is the mean diurnal percent frequency of occurrence of riometer-measured absorption greater than 1 dB at (geomagnetic) latitude λ and where:

$$Q_o = \text{maximum } Q = 5.5$$

$$\lambda_o = 62^o$$

$$\sigma_1 = 4.5 \quad .$$

In order to introduce time variations -- to approximate figure 2 -- we take the local (geomagnetic) time of the maximum, t_o, to be 0800. Examination of figure 2 suggests that at least two time-dependent quantities should be considered:

1. The maximum in the latitude variation
2. The width (σ) of the latitude variation

(3. The time variation in the latitude of the maximum appears to be relatively small.)

These considerations lead to

$$Q = Q_1 \exp -\left[\frac{(\lambda-\lambda_o)^2}{2\sigma^2}\right] \qquad (17)$$

where

$$Q_1 = Q_o[\ 1.227 + 0.955 \cos(\omega t - \omega t_o)\ ] \qquad (18)$$

$$\sigma = \sigma_1[\ 0.976 - 0.104 \cos(\omega t - \omega t_o)\ ] \qquad (19)$$

and where

$$t = \text{local (geomagnetic) time and}$$
$$\omega = 15^\circ/\text{hour} .$$

Figure 3 is a contour plot of (17).

Finally, it is assumed that the pattern of figure 2 (or figure 3) may be treated as an instantaneous pattern -- i.e., that local (geomagnetic) time and longitude are exactly equivalent. For a given local time at the station, the location within the pattern of the D-region penetration points can be computed for the F layer obtaining at that time. At each penetration point then

$$Q_1 = Q_o[1.227 + 0.955 \cos (\phi + \omega t_s - \omega t_o)] \qquad (18')$$

$$\sigma = \sigma_1[0.976 - 0.104 \cos (\phi + \omega t_s - \omega t_o)] \qquad (19')$$

where

t_s = local time at the station

ϕ = longitude of the penetration point relative to that of the station.

Hargreaves shows that median absorption A_m is given by

$$A_m = \left(\frac{Q}{K}\right)^{\frac{1}{n}} \qquad (20)$$

where for the data available

$$K = 22.0$$
$$n = 3.5$$

A_m is found, then, by using equation (18′), (19′), (17), and (20) for each penetration point and using this value as A_1 (or A_2) in (12).

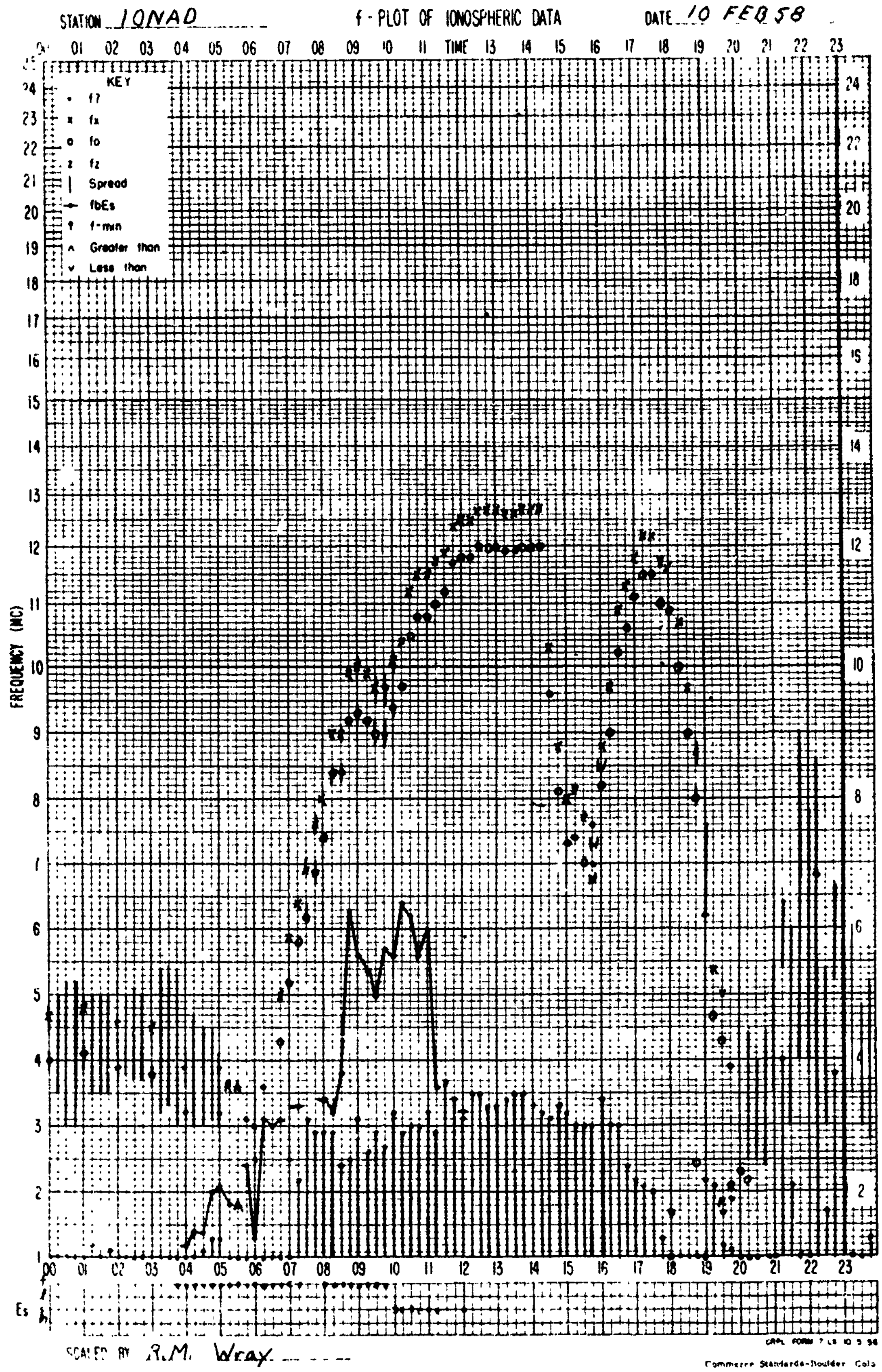

Fig. 1 Adak f-plot Feb. 10, 1958.

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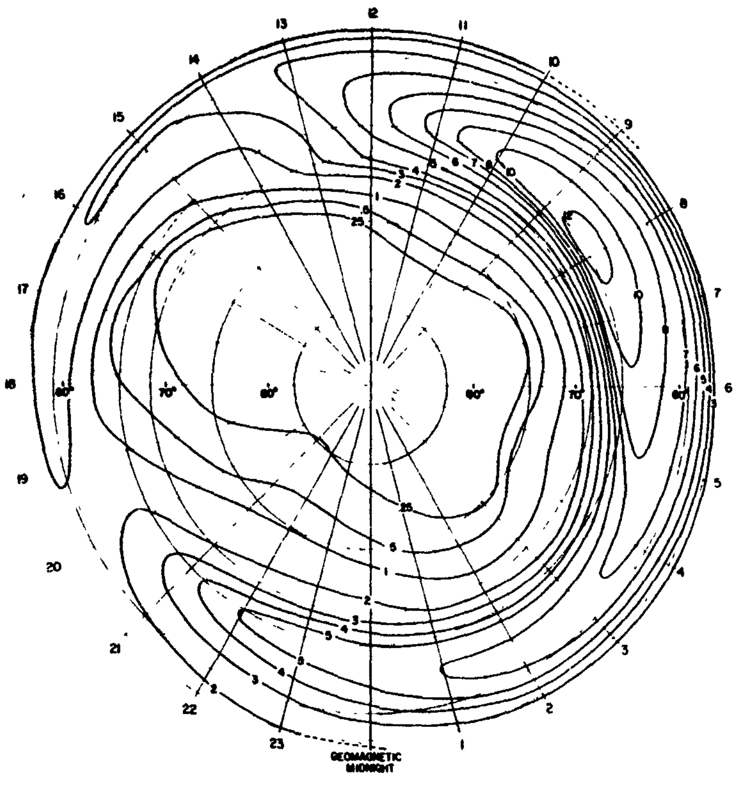

Fig. 2 Contour diagram showing the time percentage occurrence of auroral absorption of 1.0 dB or more as a function of geomagnetic latitude and mean geomagnetic time. (Hartz, Montbriand, and Vogan, 1963)

B-71710

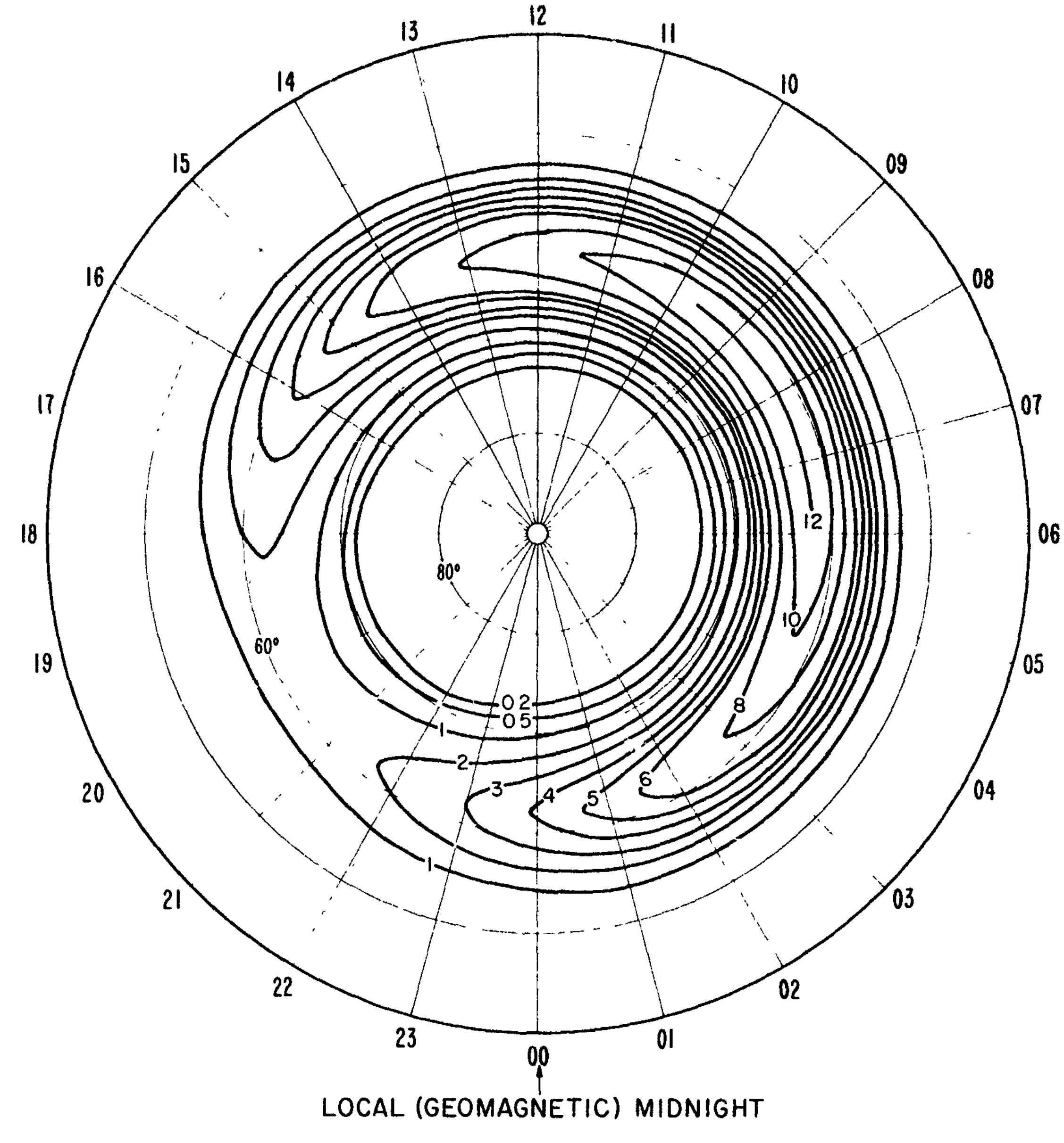

Fig. 3 Analytic approximation to Fig. 2.

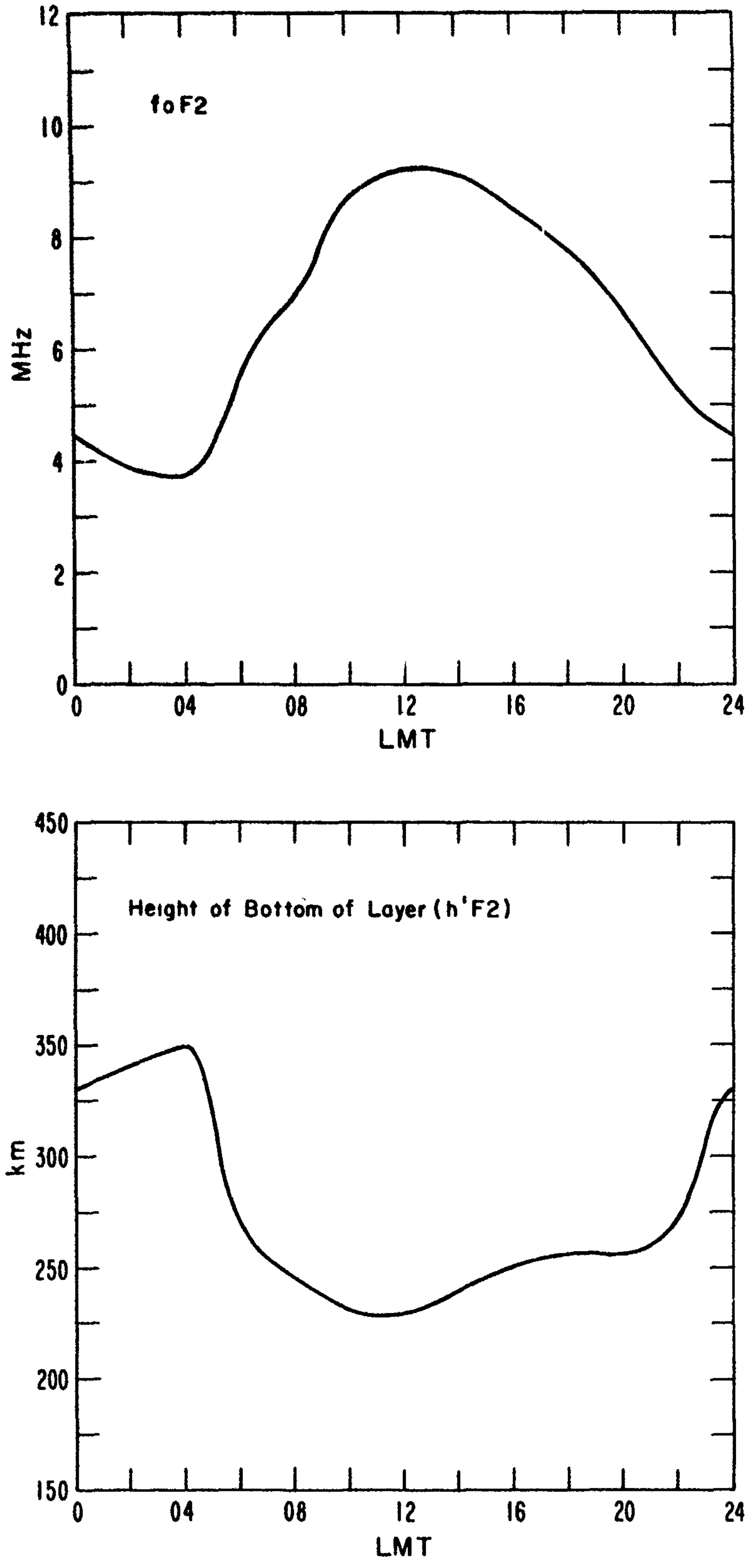

Fig. 4 MEDIAN DIURNAL VARIATION
OF PROPAGATING LAYER

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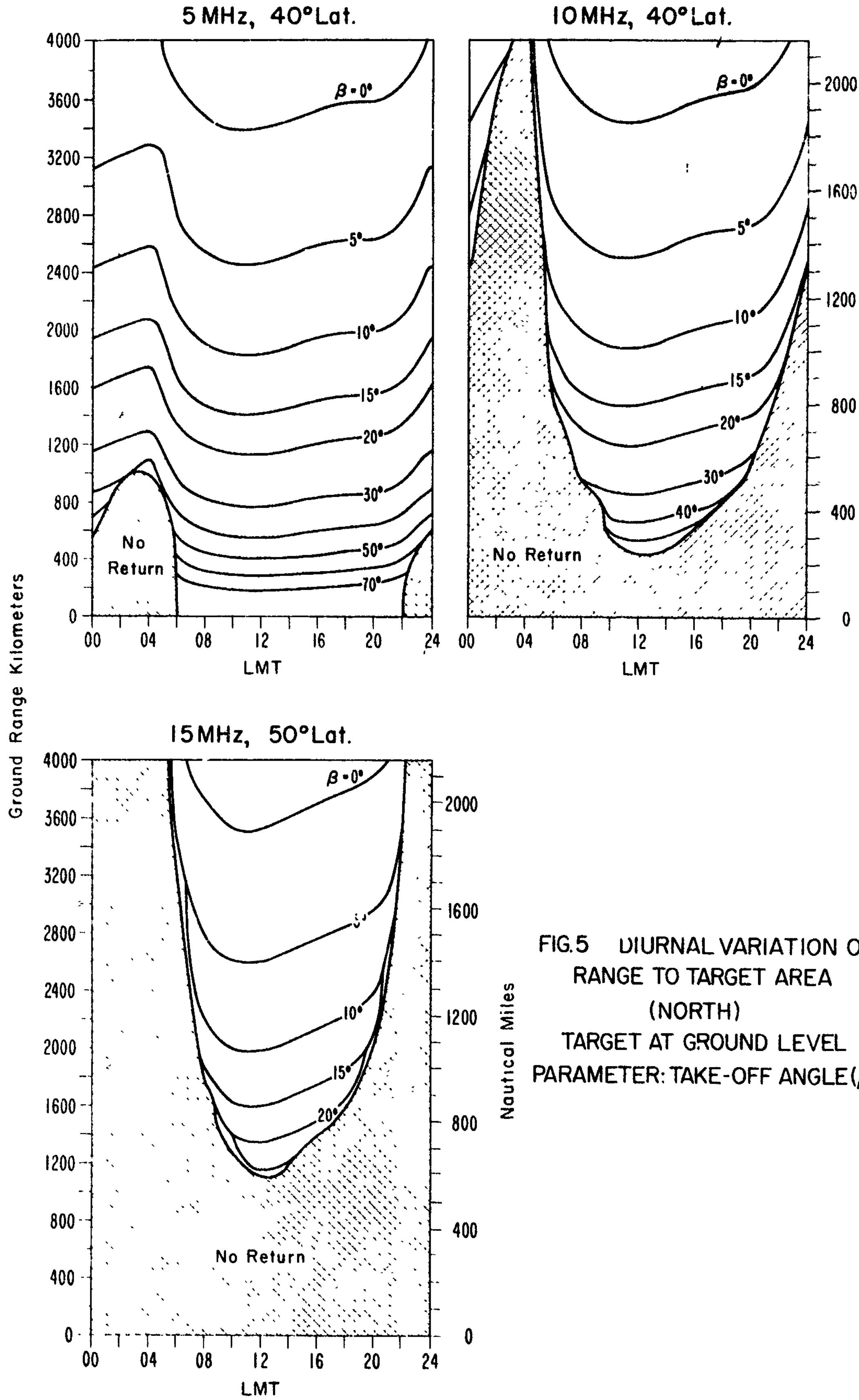

FIG.5 DIURNAL VARIATION OF RANGE TO TARGET AREA (NORTH)
TARGET AT GROUND LEVEL
PARAMETER: TAKE-OFF ANGLE (β)

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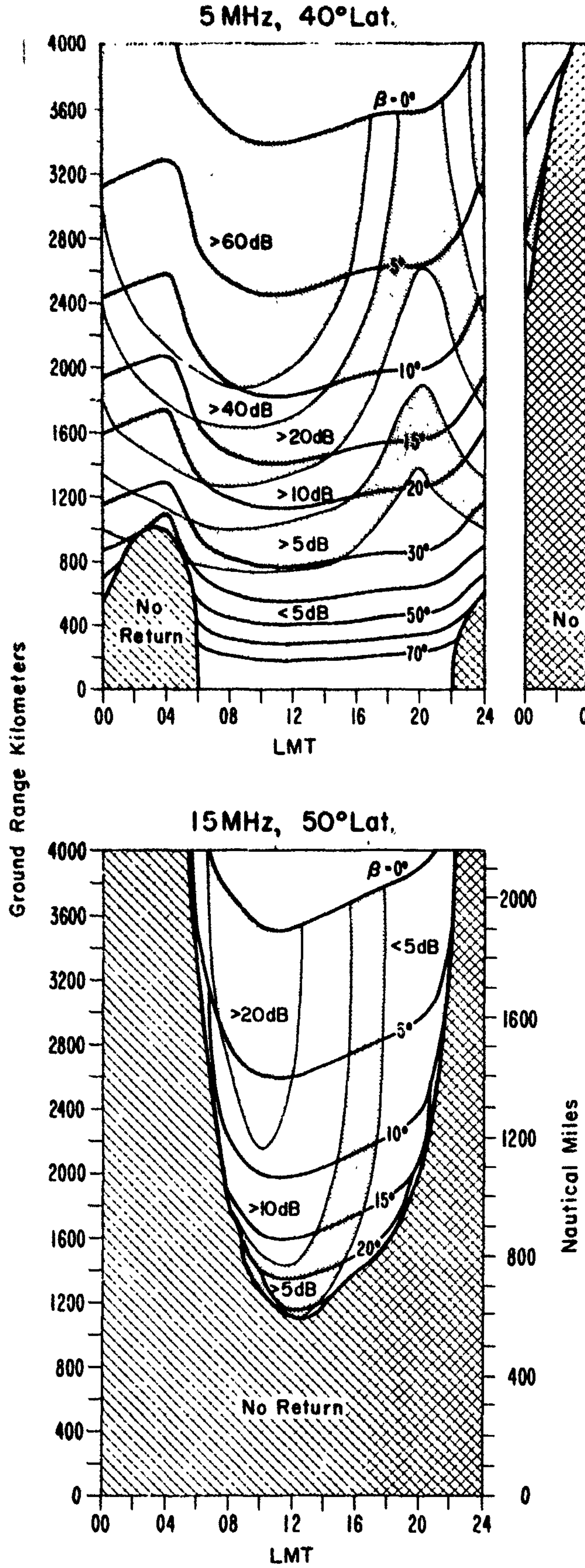

FIG. 5a DIURNAL VARIATION OF RANGE TO TARGET AREA (NORTH)
TARGET AT GROUND LEVEL
PARAMETER: TAKE-OFF ANGLE (β)
AURORAL ZONE ABSORPTION

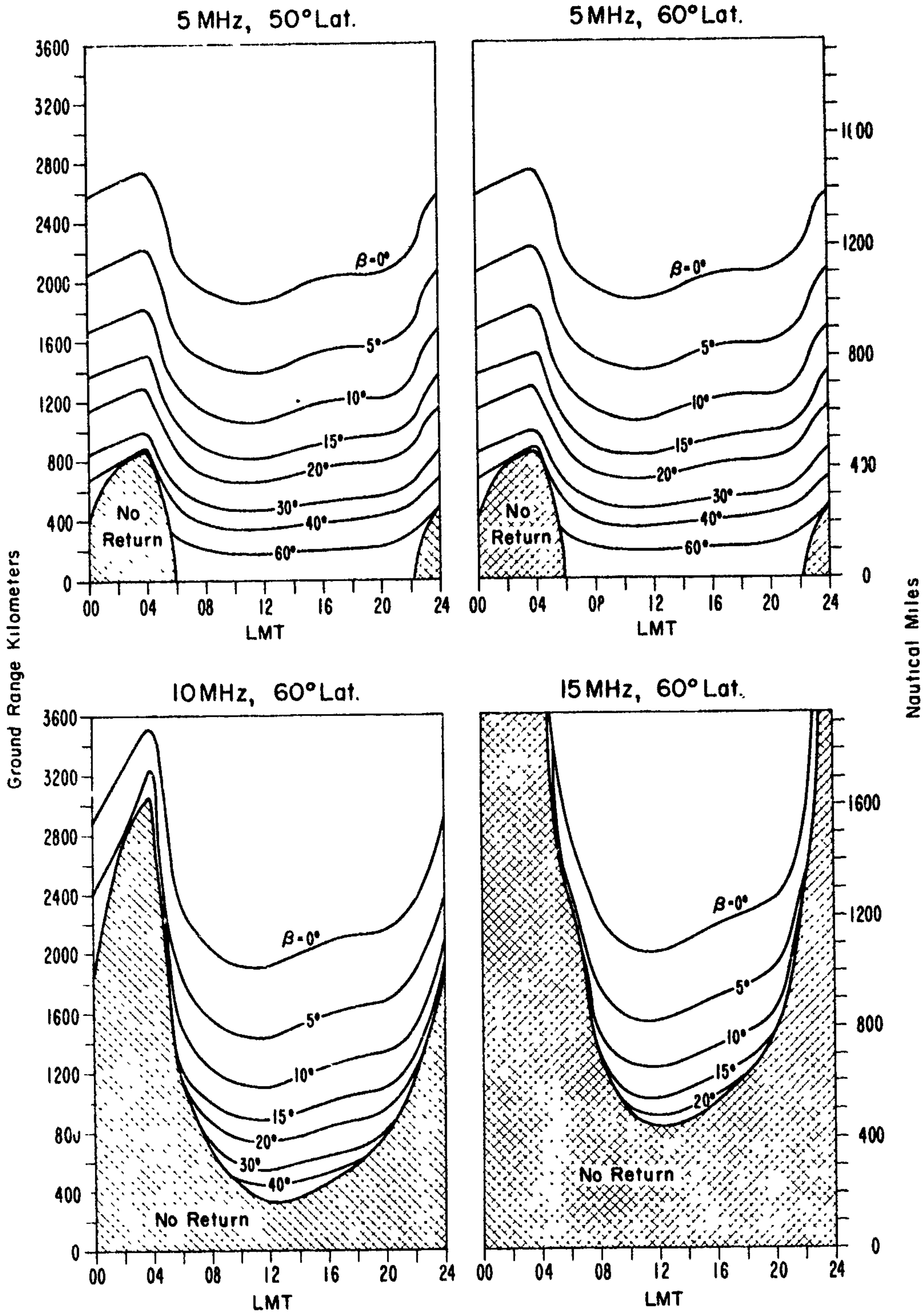

FIG.6 DIURNAL VARIATION OF RANGE TO TARGET AREA (NORTH)

TARGET AT 185 km LEVEL

PARAMETER: TAKE-OFF ANGLE (β)

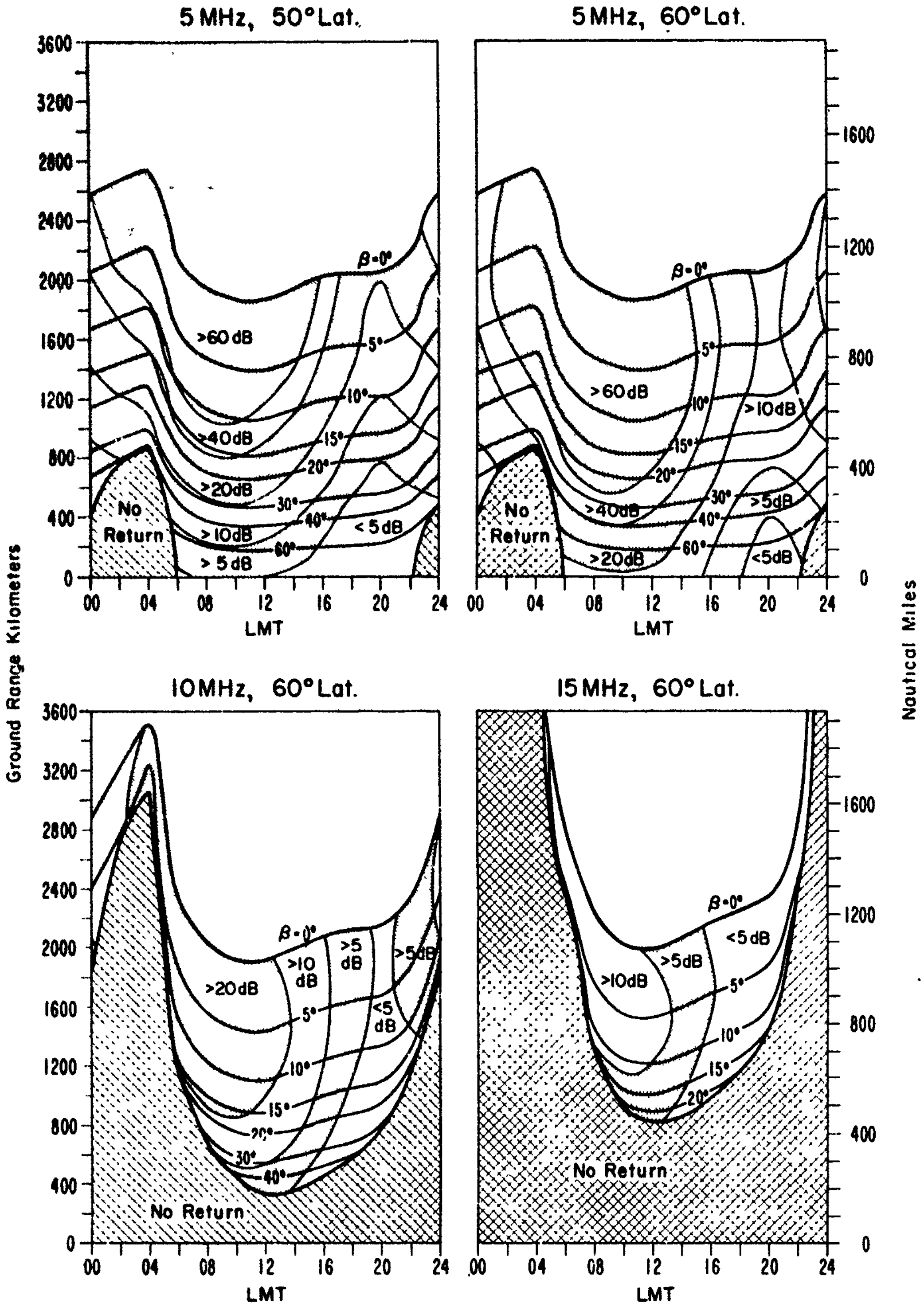

FIG 6a DIURNAL VARIATION OF RANGE TO TARGET AREA (NORTH)
TARGET AT 185 km LEVEL
PARAMETER: TAKE-OFF ANGLE (β)
AURORAL ZONE ABSORPTION

71712

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13. ABSTRACT

This is a continuation (and a correction) ~~of work reported on in 1966.~~

It is shown that backscatter propagation differs from point-to-point propagation insofar as Doppler effects are concerned. Analogously, the dispersive nature of the ionosphere also shows itself differently in the two cases.

Certain F-layer disturbances are potentially troublesome to HF radar operations. One of these, which occurred during a 4-hour interval on February 11, 1958, is briefly discussed.

The effect of auroral absorption on HF radar is roughly approximated for different operating frequencies and station latitudes.

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20 February 1997

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