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ANALYSIS OF IONOSPHERIC VERTICAL SOUNDINGS FOR ELECTRON DENSITY PROFILE DATA

I. FACILITIES FOR CONVENIENT MANUAL REDUCTION OF IONOGRAMS

BY J. W. WRIGHT AND R. B. NORTON

U. S. DEPARTMENT OF COMMERCE
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Abstract

Facilities for manual reduction of ionospheric vertical soundings to true heights are prepared using the "10 point" ratios of Ventrice and Schmerling. A study of the effects of the earth's magnetic field on true height calculations permits selection of five sets of these ratios assuring equal accuracy of application for any part of the world. The facilities available are in the form of transparent overlays and matching special graph paper.

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I. Introduction

Of the several methods available for the determination of electron density vs. height profiles from ionospheric vertical soundings, those which lend themselves best to large scale, frequent application invariably involve the use of electronic computers. A need exists, however, for a method of comparable accuracy which can be applied quickly and with a minimum of equipment. The method of Kelso,[1] (in which a true height is obtained as the simple average of the virtual heights at 5 or 10 frequencies selected according to a definite law) satisfies these requirements, but has the disadvantage that no account is taken of the influence of the earth's magnetic field.

Recently, by modifying the matrix method of Budden[2], Schmerling[3] has determined sampling ratios similar to Kelso's, but with the effect of the earth's magnetic field included. Ventrice and Schmerling[4] have presented tables of the sampling ratios with which ionograms obtained anywhere in the world may be analysed.

A method has been devised at the National Bureau of Standards for the determination of world zones of approximately equal magnetic field error. The Schmerling coefficients applying most closely to the characteristics of magnetic dip and gyrofrequency in each such zone have been selected. Overlays incorporating the selected coefficients have been devised; they may be used to analyze ionograms quickly and conveniently in the manner described below.

II. Description of Facilities

The "Ten Point" ratios for each zone are given in Table I. These are the ratios which the sampling frequencies bear to the frequency ("index frequency") at which the true height is desired. Since, within a zone, the sampling ratios vary only slightly with frequency, the same set of ratios may be used over a considerable portion of the frequency range. Only one set of ratios is necessary for the lowest dip/gyrofrequency zone, reflecting the fact that here the effect of the earth's magnetic field on the true height calculation is small. In the intermediate latitudes, two sets of ratios are needed, and at the higher latitudes three sets are necessary to preserve the same accuracy throughout the frequency range.

Scaling overlays and graph paper have been prepared specifically for the reduction of logarithmic ionograms obtained with NBS C-2, C-3, and C-4 ionosondes, but they may be applied to any virtual height curve traced or drawn onto the graph paper. The overlays may also be applied directly to the projected image of logarithmic ionograms, but it is essential that the frequency scale of the overlay and of the ionogram correspond exactly.

In the design of the overlays, advantage is taken of the logarithmic frequency scale of the ionogram. This is done by choosing a single index frequency of 25.0 Mc (indicated by "fN" on the overlays) for all zones and all frequency ranges to be covered. The 10 point ratios have then been located on the logarithmic frequency scale as fractions of this index frequency. Because of the logarithmic scale, the same overlay can be used at any point on the ionogram for which the 10 point ratios are appropriate. Where two or three sets of ratios are necessary within a zone to treat adequately the entire frequency scale, they all appear together on the same overlay, and use the same index.

An example of one of the overlays available, and of the graph paper, are shown in reduced size in Figs. 1 and 2. A transparent overlay for any zone and a supply of graph paper can be provided to bona fide workers upon request to World Data Center A, National Bureau of Standards, Boulder, Colorado, USA.

III. Specification of World Zones

The world has been divided into five zones such that the variation of the magnetic field effect is satisfactorily small within each zone. The division is carried out in terms of the magnetic parameters that affect true height calculations--dip and field strength.

A graph of the boundaries within which fall all values of the earth's magnetic dip and field strength (represented by gyrofrequency) is shown in Fig. 3. Five zones of equal magnetic field error are also shown. To determine the zone appropriate for an ionospheric observatory (and hence the group of 10 point coefficients to be used there) it is necessary to know only the magnetic dip and the gyrofrequency at 200 km (=2.552F, where F is the total field strength at ground in cgs units).

The study of errors due to the magnetic field, and the resulting delimitation of world zones, have been accomplished by computing the errors produced by using inappropriate magnetic field parameters in the calculation of the true height curves from a single virtual height curve. In the present case, the errors have been characterized by their magnitudes at 95.5 per cent of the penetration frequency of the parabolic layer best fitting the computed true height curves. Since the errors generally increase nearer the penetration frequency, our estimates should provide a reliable guide to the magnitude and world-wide variations of these errors.

When the proper set of coefficients for any zone and frequency range are used, the largest errors at 95.5 per cent of the penetration frequency, incurred within the zone, will be 0.025 of the semi-thickness of the best fitting parabolic layer. The errors will be larger nearer the penetration frequency. Also, at the highest dip angles (near 90°) the above factor may approach 0.07. In a typical case of a parabolic layer with a 10 Mc penetration frequency and of 200 km half thickness, the magnetic error at 9.55 Mc will be 5 km or less within the zone.

IV. Method of Analysis

It is recommended that the ordinary virtual height curve be first obtained on the graph paper to assure correspondence of the frequency scales and to permit easy measurement of heights at the sampling frequencies. This may be done in two ways:

A. The ionogram image may be projected from film onto the graph paper supplied. The h' (f) curve for the ordinary ray is traced onto the paper; any corrections necessary to assure proper correspondence of the height and frequency markers with the corresponding scales of the paper should be made continuously along the curve.

B. Alternatively, virtual heights may be plotted onto the graph paper, either directly from the "B-Scan" presentation of the ionosonde (especially valuable for rapid or "real time" analyses), or from ionograms obtained on non-logarithmic equipment. Enough heights must be plotted to permit the h' (f) curve to be drawn fairly accurately.

The tracing or graph of virtual height must now be "completed." Several steps are necessary:

(1) An extrapolation of the virtual height graph to low frequencies is usually necessary, since often the lower sampling points fall well below the 1.0 Mc lower limit of the ionogram. In general, little harm results from assuming that the height of reflection below 1.0 Mc is constant, except perhaps at sunrise and sunset, and in cases of night E.

(2) Large gaps in the virtual height curve due to deviative absorption (near penetration frequencies) or to equipment insensitivity, should be filled in by careful estimates of the most reasonable curve.

(3) Parts of the virtual height curve obscured by blanketing sporadic E should be filled in with a reasonable curve.

More detailed consideration of the treatment of difficult cases is given to guide the systematic scaling of virtual height data for analysis by the Budden matrix method, in informal memoranda from the National Bureau of Standards.

The overlay permits the determination of the true height of reflection at any frequency chosen on the ordinary virtual height curve. The number of heights to determine, and their distribution in frequency are matters of individual choice, and will depend on the purpose for which the work is to be done. To define adequately the true height profile, five to ten individual determinations will usually suffice, unless great detail near penetration frequencies is desired. Often a useful first value to get is the true height of the F2 layer maximum, corresponding to foF2.

In any case, the analysis using these overlays proceeds as follows:

The overlay is placed on the ionogram tracing so that its height lines are parallel to those on the tracing, and so that the line indicated by fN (the index frequency) falls on the frequency at which the true height is desired. (To find h max F2, the line fN should be aligned with foF2.) At the intersections of the h' (f) curve with each of the sampling points indicated on the overlay, the virtual heights are scaled and added together. Any of the points that fall below 1.0 Mc must be represented in the sum by making an appropriate assumption about the virtual heights at low frequencies. The overlay should not be moved until all ten values have been obtained. One tenth of the sum is then the true height of reflection at the chosen frequency. It should be remembered that for certain of the world zones, the sampling points depend upon the frequency at which the true height is to be derived. The overlays for these zones have the two or three sets of sampling ratios plotted on the same overlay. The user must select the set appropriate to the point of the frequency scale (value of fN) under analysis.

V. Example of Application

To illustrate the results obtained by application of an overlay to a typical ionogram, the 10 point ratios of Zone III were used to analyse a few points on the virtual height curve shown in Fig. 4. This curve, obtained at the U.S. Army Signal Corps White Sands (New Mexico) station, is typical of nighttime conditions; with such ionograms true height determinations may be made quite accurately. The magnetic dip (60.4°) and gyrofrequency (1.343 Mc at 200 km) at White Sands place this station near the northern boundary of Zone III.

The true heights calculated at 0.2 Mc intervals using the Budden matrix method may be compared on the figure with four heights determined using the 10 point ratios of Zone III. The numerical values obtained by both methods agree within 2 km.

References

1. Kelso, J. M. Journal of Geophysical Research, 57, 357 (1952).

2. Budden, K. G. "A Method for Determining the Variation of Electron Density with Height (N(Z) curves) from Curves of Equivalent Height Against Frequency ((h'f) curves)" Report of the Physical Society Conference on the Physics of the Ionosphere, Cavendish Laboratory, Cambridge, 1955. Page 332.

3. Schmerling, E. R. Journal of Atmospheric and Terrestrial Physics, 12, 8, (1958).

4. Ventrice, C. A. and Schmerling, E. R., Scientific Report No. 106 Ionosphere Research Laboratory, Pennsylvania State University.

Table I

Zone I	Zone II		Zone III			Zone IV			Zone V		
(All Freq.)	f<6.5	f>6.5	f<4.5	4.5<f<8.0	f>8.0	f<4.5	4.5<f<8.0	f>8.0	f<4.5	4.5<f<8.0	f>8.0
.996	.993	.994	.989	.991	.992	.986	.989	.990	.983	.986	.988
.968	.960	.962	.948	.952	.955	.941	.946	.949	.932	.937	.941
.915	.901	.907	.882	.888	.897	.870	.879	.890	.856	.866	.878
.839	.823	.834	.796	.810	.823	.782	.800	.815	.765	.784	.802
.745	.730	.743	.699	.718	.733	.683	.708	.726	.666	.692	.712
.635	.622	.635	.590	.612	.626	.576	.603	.620	.559	.587	.607
.510	.500	.512	.473	.493	.505	.461	.485	.500	.445	.471	.489
.373	.366	.375	.348	.362	.371	.338	.355	.367	.326	.344	.359
.229	.225	.228	.215	.221	.227	.208	.216	.224	.201	.210	.219
.078	.077	.077	.074	.075	.076	.071	.073	.074	.069	.071	.073

TEN-POINT COEFFICIENTS APPLICABLE TO VARIOUS RANGES OF INDEX FREQUENCY
IN FIVE ZONES OF EQUAL MAGNETIC ERROR

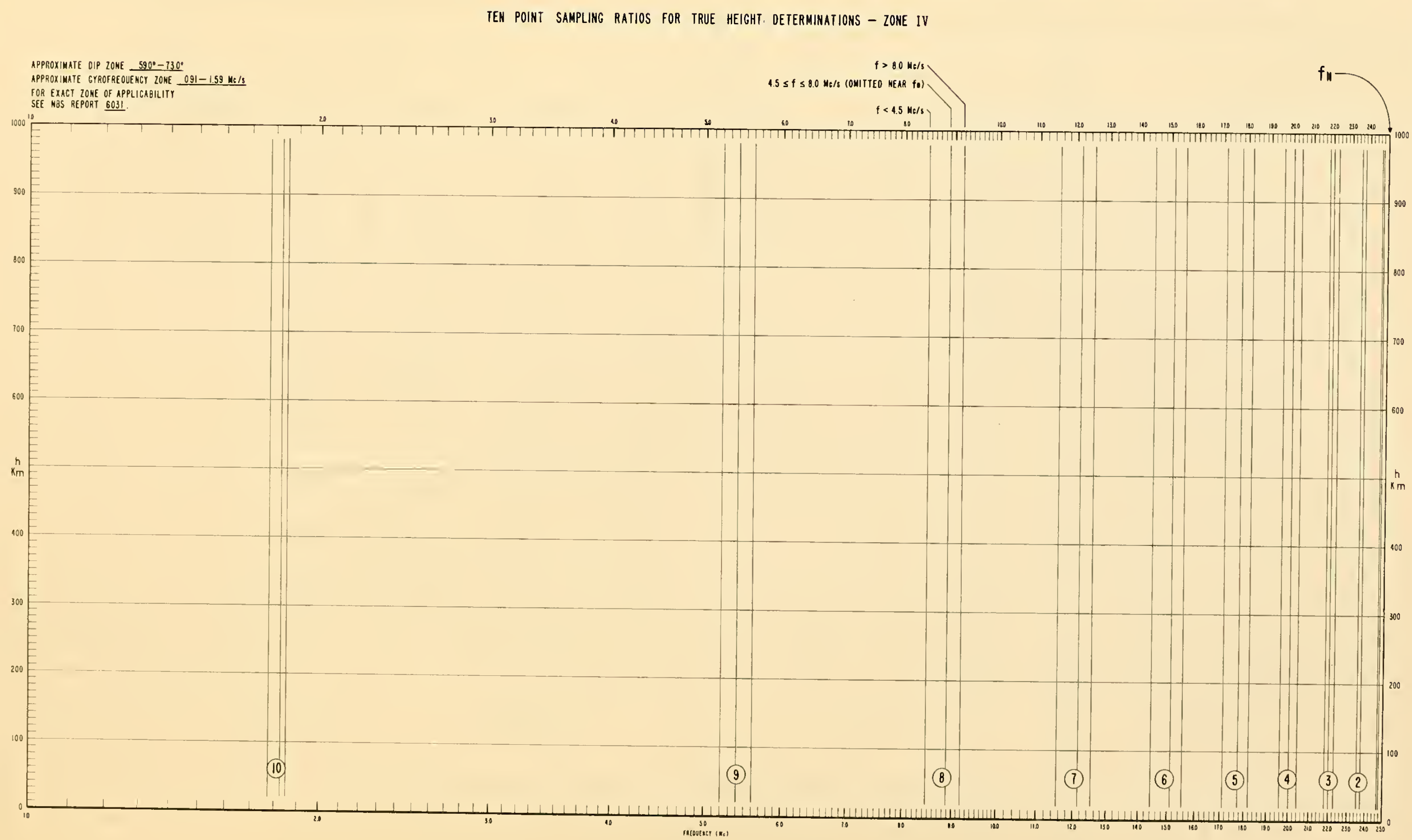


FIGURE I EXAMPLE OF OVERLAY (ZONE IV); ACTUAL SIZE OF TRANSPARENCY APPROXIMATELY 32.7cm X 16.2cm.

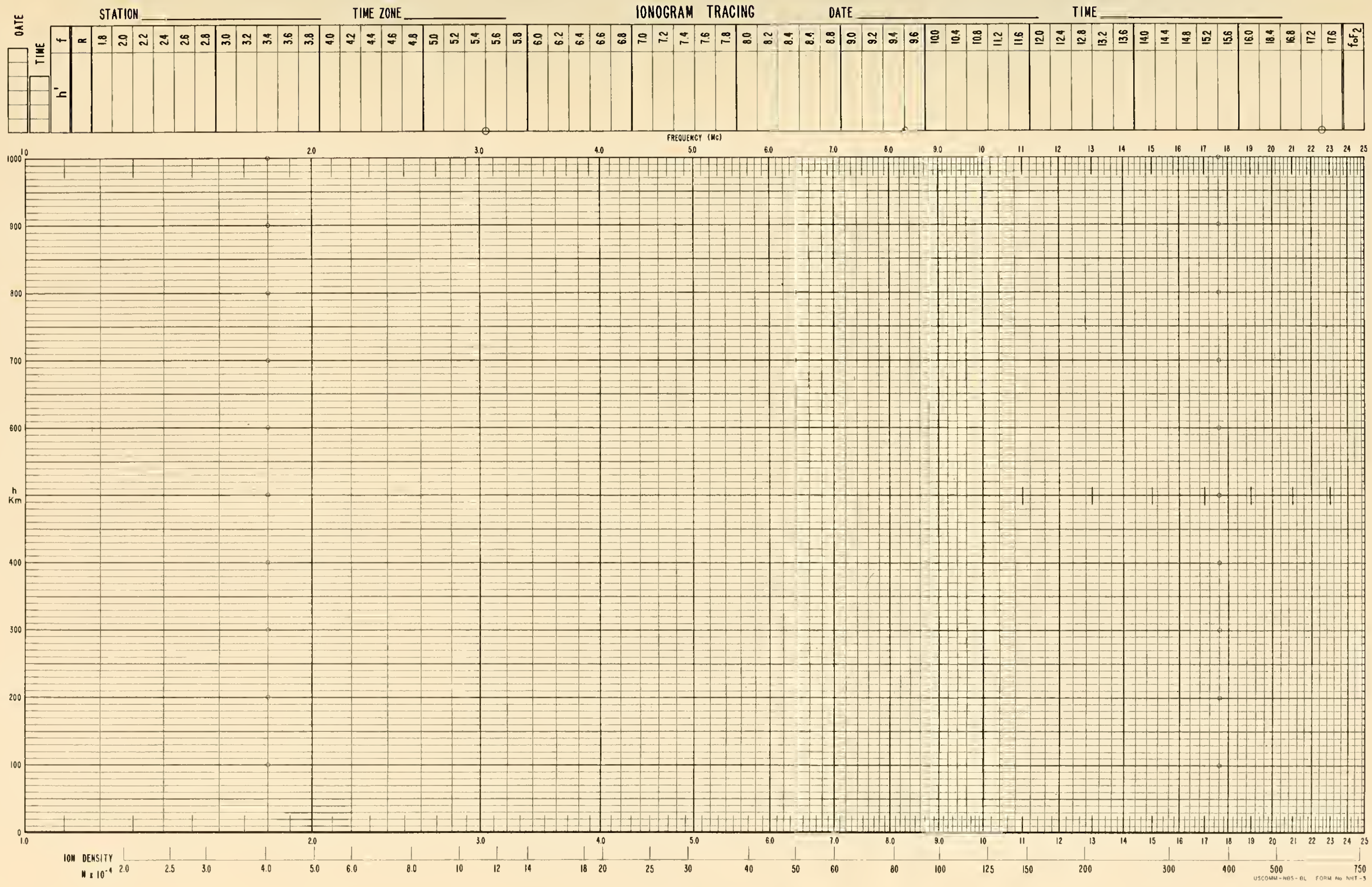


FIGURE 2 EXAMPLE OF MULTIPURPOSE GRAPH PAPER.

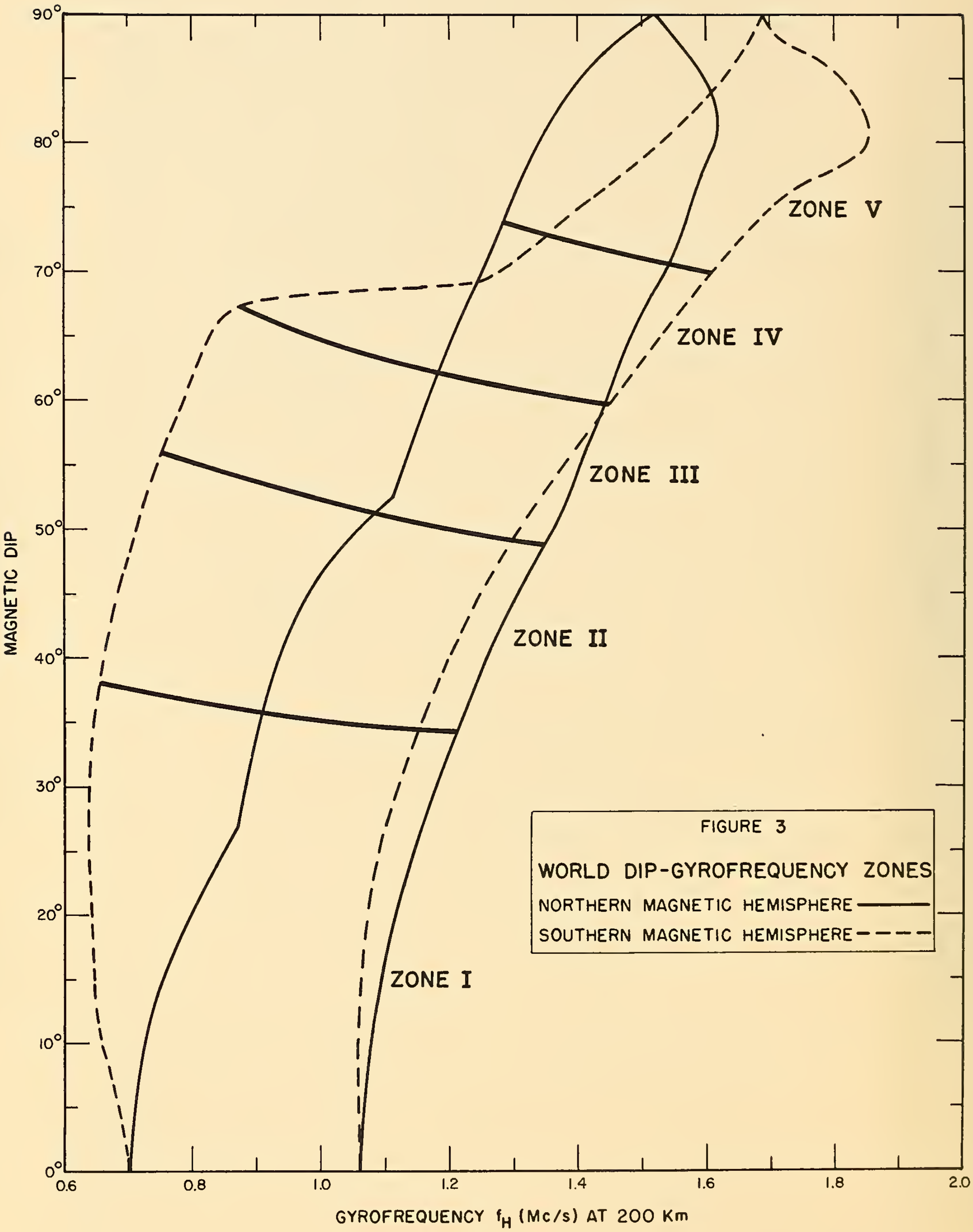


FIGURE 3

WORLD DIP-GYROFREQUENCY ZONES

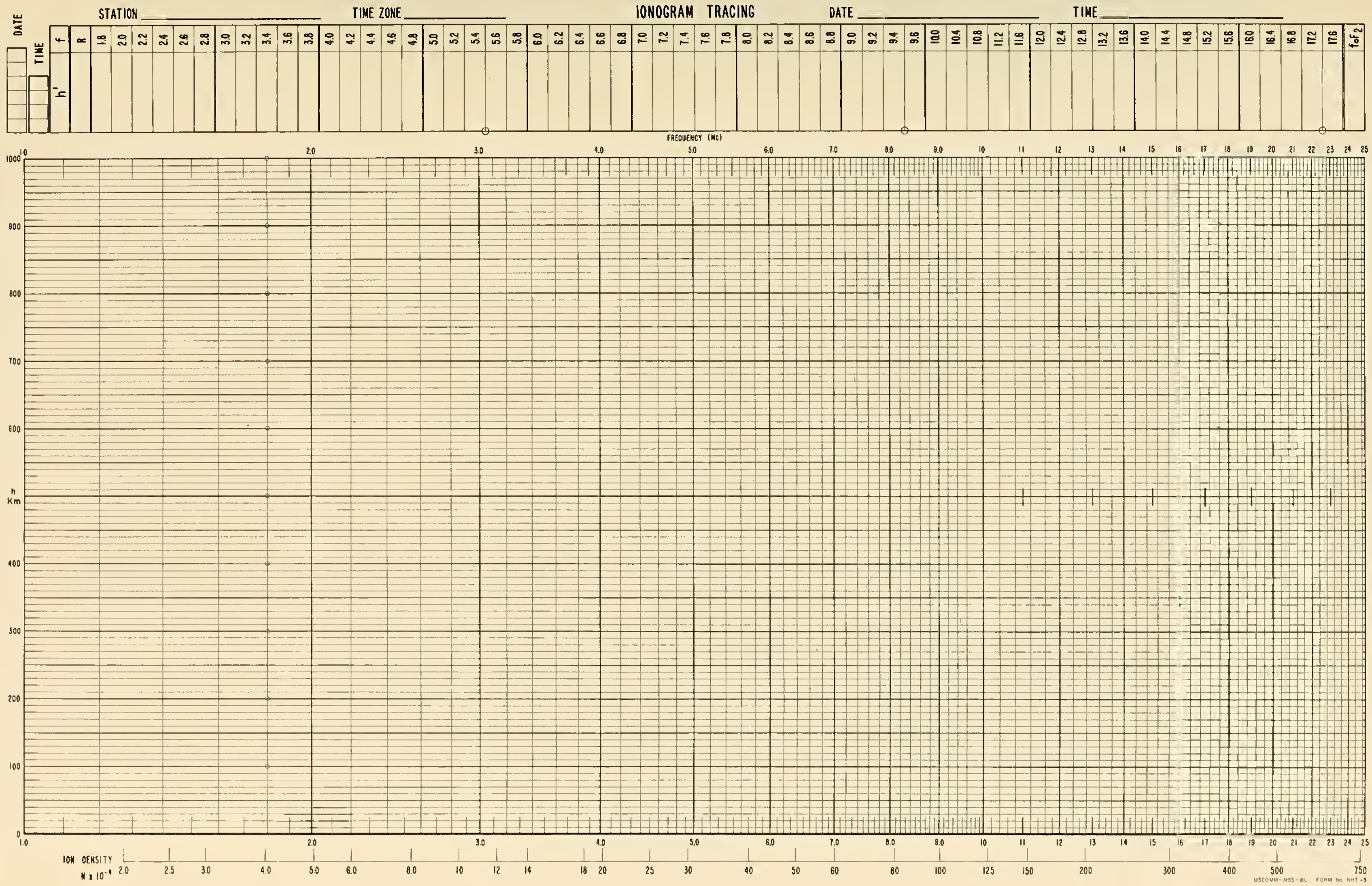
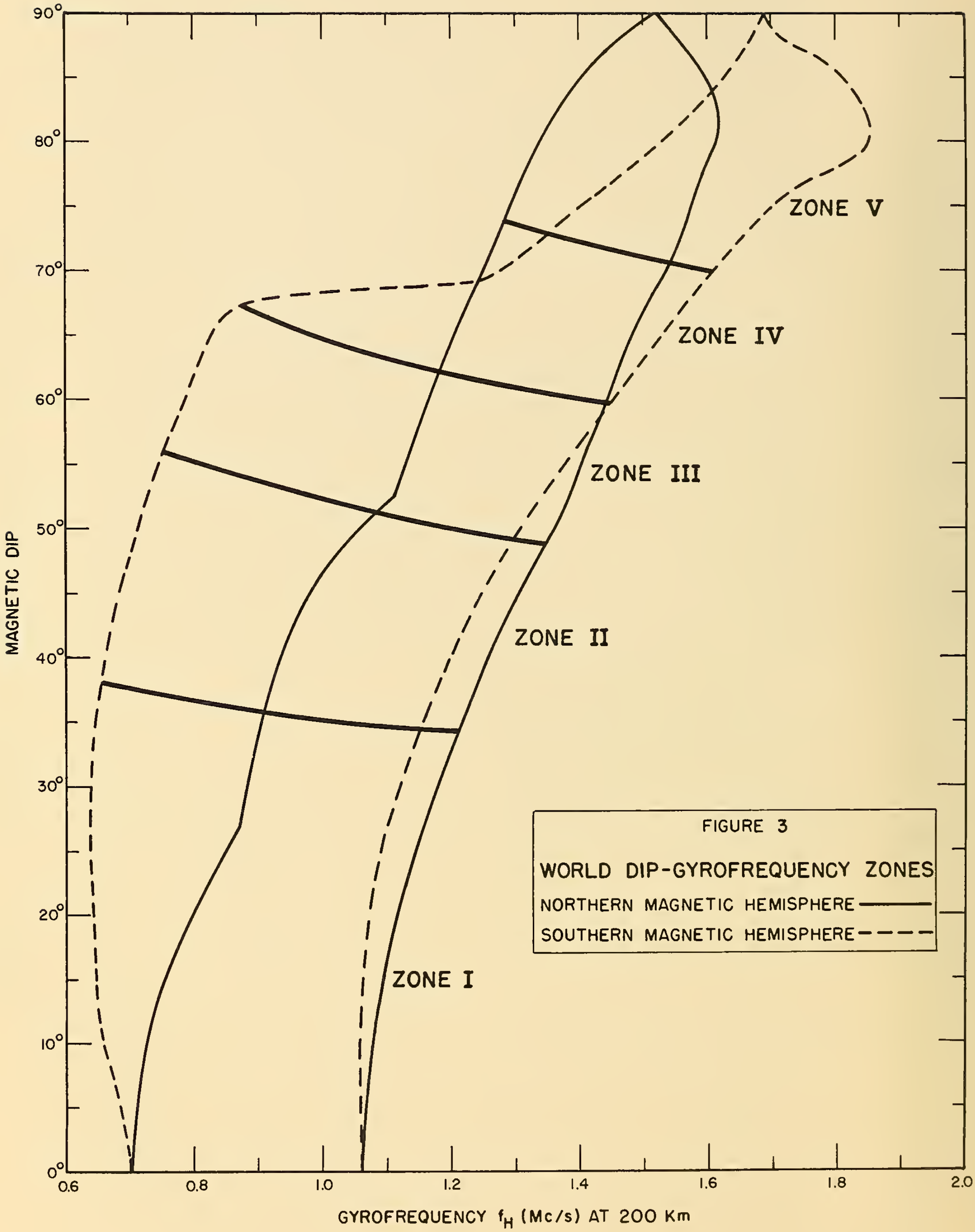


FIGURE 2 EXAMPLE OF MULTIPURPOSE GRAPH PAPER.


ZONE V
ZONE IV
ZONE III
ZONE II
ZONE I
FIGURE 3
WORLD DIP-GYROFREQUENCY ZONES
NORTHERN MAGNETIC HEMISPHERE
SOUTHERN MAGNETIC HEMISPHERE
MAGNETIC DIP
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
GYROFREQUENCY f_H (Mc/s) AT 200 Km

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