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BASIC RADIO PROPAGATION PREDICTIONS FOR DECEMBER 1946 THREE MONTHS IN ADVANCE

ISSUED SEPTEMBER 1946

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CENTRAL* RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS
WASHINGTON 25, D. C.

Issued
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BASIC RADIO PROPAGATION PREDICTIONS FOR DECEMBER 1946 THREE MONTHS IN ADVANCE

Comments are invited from users of this report as to the accuracy of predictions when applied to the solution of specific radio propagation problems. Such comments or queries concerning radio propagation should be addressed as follows:

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For Others:
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*On July 1, 1946, the Interservice Radio Propagation Laboratory ceased to exist as such.
At that time, the duties and functions of the IRPL were absorbed by the Central Radio Propagation Laboratory, established at the National Bureau of Standards on May 1, 1946, to act as an organization for centralizing and coordinating basic research and prediction service in the field of radio wave propagation.

I. TERMINOLOGY

The following symbols are used, as recommended by the International Radio Propagation Conference held in Washington, D. C., 17 April to 5 May 1944.

$f^{\circ}F2$ = ordinary-wave critical frequency for the $F2$ layer.

$f^{x}F2$ = extraordinary-wave critical frequency for the $F2$ layer.

Es = sporadic, or abnormal, E.

fEs = highest frequency of Es reflections.

muf or MUF = maximum usable frequency.

owf or OWF = optimum working frequency.

4000-muf chart = contour chart of muf for 4000-kilometer paths.

2000-muf chart = contour chart of muf for 2000-kilometer paths.

Zero-muf chart = contour chart of vertical-incidence critical frequency, extraordinary wave ($f^{x}F2$).

II. WORLD-WIDE PREDICTION CHARTS AND THEIR USES

The charts, figures 5 to 11, present world-wide predictions of monthly average maximum usable frequencies for December 1946. Conditions may be markedly different on disturbed days, especially in or near the auroral zones, shown on the map of figure 1. The method of prediction is discussed in the IRPL Radio Propagation Handbook, Part 1, War Dept. TM 11–499, Navy Dept. DNC–13–1, p. 52, 53.

Although ionosphere characteristics are roughly similar for locations of equal latitude, there is also a considerable variation with longitude, especially in the case of the $F2$ layer. This "longitude effect" seems to be related to geomagnetic latitude. Attention was first called to this effect in the report "Radio Propagation Conditions" issued 10 Sept. 1943; it was brought into general operational use in the next issue (14 Oct. 1943).

The longitude effect in the $F2$ layer is taken care of by providing world charts for three zones, in each of which the ionosphere characteristics are considered independent of longitude, for practical purposes. These zones are indicated on the world map, figure 1.

Two $F2$ charts are provided for each zone, one of which, the "zero-muf chart," shows the vertical-incidence muf, or the critical frequency for the extraordinary wave, and the other, the "4000-muf chart," shows the muf for a transmission distance of 4000 km. Do not confuse the zero-muf charts with the $f^{\circ}F2$ charts appearing in the previous IRPL reports "Radio Propagation Conditions." (Values of $F2$-zero-muf exceed those of $f^{\circ}F2$ for the same location and local time by an amount approximately equal to half the gyro-frequency for the location. See IRPL Radio Propagation Handbook, Part 1 (War Dept. TM 11–499 and Navy Dept. DNC–13–1), p. 18, 19, 28, and fig. 9).

The longitude variation is operationally negligible in the case of the normal E layer and therefore only one E-layer chart is provided.

The variation of fEs with geomagnetic latitude seems to be well marked and important. Consequently, the fEs charts are constructed on the basis of geomagnetic latitude.

Since there are, as yet insufficient correlated data, the fEs charts are much less precise than the other charts. Instructions for use of these charts appear in section IV, 3.

Attention is called to the fact that the 50-percent contour in figure 15, "Percentage of Time of Occurrence of Es-2000-muf in Excess of 15 Mc," does not necessarily coincide with the 3-Mc contour in figure 12, "Median fEs, in Mc," because the two charts are prepared independently.

III. DETERMINATION OF GREAT-CIRCLE DISTANCES, BEARINGS, AND LOCATION OF TRANSMISSION CONTROL POINTS

1. BY USE OF THE WORLD MAP AND GREAT-CIRCLE CHART

Figure 1 is a map of the world. Figure 2 is a chart to the same scale as figure 1, on which the solid-line curves crossing the equator at a single point represent great circles. The numbered dot-dash lines crossing the great circles indicate distances along them in thousands of kilometers. In using figures 1 and 2, proceed as follows:

a. Place a piece of transparent paper over the map, figure 1, and draw the equatorial line (zero degrees). Place dots over the locations of the transmitting and receiving stations. Also mark the meridian whose local times are to be used as the times for calculation. Usually the Greenwich meridian is used.

b. Place this transparency over the chart, figure 2, and, keeping the equatorial line of the transparency always on the equatorial line of figure 2, slide the transparency horizontally until the terminal points marked on it fall either on the same great circle or the same proportional distance between adjacent great-circle curves. Draw in the path.

c. For paths shorter than 4000 km, locate the midpoint of the path, keeping the transparency in position on figure 2 and using as a distance scale the points at which the numbered lines in figure 2 cross the path as drawn on the transparency.

d. For paths longer than 4000 km, designating the ends as the *A*-end and *B*-end, respectively, locate on the path and mark with a dot the following "control points," scaling the distances as in *c* above:

For *F*2 layer, points *A* and *B*, 2000 km from each end.

For *E* layer, points *A′* and *B′*, 1000 km from each end.

2. BY USE OF THE NOMOGRAM OF FIGURE 4

Note.—Values near the ends of the nomogram scales of figure 4 are subject to error because the scales are compressed. If exact values are required in those regions, they should be calculated by means of the usual trigonometric formulas.

In figure 3, *Z* and *S* are the locations of the transmitting and receiving stations, where *Z* is the west and *S* the east end of the path. *If a point lies in the Southern Hemisphere, its angle of latitude is always taken as negative. Northern-Hemisphere latitudes are taken as positive.*

a. To obtain the great-circle distance ZS (short route):

(1) Draw a slant line from (lat. $Z-$lat. S) measured up from the bottom on the left-hand scale to (lat. $Z+$lat. S) measured down from the top of the right-hand scale. If (lat. $Z-$lat. S) or (lat. $Z+$lat. S) is negative, regard it as positive.

(2) Determine the separation in longitude of the stations. Regard as positive. If the angle so obtained is greater than 180°, then subtract from 360°. Measure this angle along the bottom scale, and erect a vertical line to the slant line obtained in (1).

(3) From the intersection of the lines draw a horizontal line to the left-hand scale. This gives *ZS* in degrees.

(4) Convert the distance *ZS* to kilometers, miles or nautical miles, by using the scale at the bottom of figure 4.

Note.—The *long great-circle route* in degrees is simply $360°-ZS$. The value will always be greater than 180°. Therefore in order to obtain the distance in miles from the conversion scale, the value for the degrees in excess of 180° is added to the value for 180°.

b. To obtain the bearing angle PZS (short route):

(1) Subtract the short-route distance *ZS* in degrees obtained in *a* from 90° to get *h*. The value of *h* may be negative, and should be substituted in (2) below without change of sign.

(2) Draw a slant line from (lat. $Z-h$) measured up from the bottom on the left-hand scale to (lat. $Z+h$) measured down from the top on the right-hand scale. If (lat. $Z-h$) or (lat. $Z+h$) is negative, regard it as positive.

(3) From (90°$-$lat. *S*) measured up from the bottom on the left-hand scale, draw a horizontal line until it intersects the previous slant line.

(4) From the point of intersection draw a vertical line to the bottom scale. This gives the bearing angle *PZS*. The angle may be either east or west of north, and must be determined by inspection of a map.

c. To obtain the bearing angle PSZ:

(1) Repeat steps (1), (2), (3), and (4) in *b*, interchanging *Z* and *S* in all computations. The result obtained is the interior angle *PSZ*, in degrees.

(2) The bearing angle *PSZ* is 360° minus the result obtained in (1) (as bearings are customarily given clockwise from due north).

Note.—The long-route bearing angle is simply obtained by adding 180° to the short-route value as determined in *b* or *c* above.

d. To obtain the latitude of Q (mid- or other point of path):

(This calculation is in principle the converse of *b*.)

(1) Obtain *ZQ* in degrees. If *Q* is the midpoint of the path, *ZQ* will be equal to one-half *ZS*. If *Q* is one of the 2000-km "control points," *ZQ* will be approximately 18°, or $ZS-18°$.

(2) Subtract *ZQ* from 90° to get *h′*. The value of *h′* may be negative, and should be substituted in (3) below without change of sign.

(3) Draw a slant line from (lat. $Z-h'$) measured up from the bottom on the left-hand scale, to (lat. $Z+h'$) measured down from the top on the right-hand scale. If (lat. $Z-h'$) or (lat. $Z+h'$) is negative, regard it as positive.

(4) From the bearing angle *PZS* (taken always as less than 180°) measured to the right on the bottom scale, draw a vertical line to meet the above slant line.

(5) From this intersection draw a horizontal line to the left-hand scale.

(6) Subtract the reading given from 90° to give the latitude of *Q*. (If the answer is negative, then *Q* is in the Southern Hemisphere.)

e. To obtain the longitude difference t′ between Z and Q:

(This calculation is in principle the converse of *a*.)

(1) Draw a straight line from (lat. $Z-$lat. Q) measured up from the bottom on the left-hand scale to (lat. $Z+$lat. Q) measured down from the top on the right-hand scale. If (lat. $Z-$lat. Q) or (lat. $Z+$lat. Q) is negative, regard it as positive.

(2) From the left-hand side, at *ZQ*, in degrees, draw a horizontal line to the above slant line.

(3) At the intersection drop a vertical line to the bottom scale, which gives *t′* in degrees.

IV. CALCULATION OF MAXIMUM USABLE FREQUENCIES, OPTIMUM WORKING FREQUENCIES

1. PROCEDURE FOR DETERMINATION OF MUF AND OWF FOR TRANSMISSION DISTANCES UNDER 4000 KM (PROPAGATION BY THE REGULAR LAYERS)

a. Prepare or obtain work forms similar to CRPL form AF (see table 1). Note that form AF provides for the inclusion of sporadic *E* (*Es*), which will be discussed under (3) below.

b. Locate the midpoint of the transmission path, using the methods of section III above and by laying the great-circle path transparency back on the world map of figure 1, with the ends of the path in their proper location, determine in which geographical zone, *E*, *I*, or *W*, the midpoint falls.

c. To determine the maximum usable frequency (muf):

(1) Place the great-circle transparency over the *F*2-zero-muf chart for the proper zone of the midpoint of the path, and, keeping the equatorial line of the transparency over the equatorial line of the chart, slide the transparency horizontally until the Greenwich meridian coincides with 00 on the time scale. Note that all points on the great-circle path are in their proper local time relationship to Greenwich because 24 hours on the time scale of a muf chart is drawn to the same scale as 360° of longitude on the world map.

(2) Read the value of *F*2-zero-muf for the midpoint of the path and enter in column *d* of form AF.

(3) Repeat for 02, 04, etc. on the time scale.

(4) Repeat steps (1), (2), and (3) for the *F*2-4000-muf chart for the proper zone and again for the *E*-layer 2000-muf chart, figure 11, entering values in columns *e* and *c*, respectively.

(5) For each hour place a straightedge between the values of *F*2-zero-muf and *F*2-4000-muf at the left- and right-hand sides, respectively, of the grid nomogram, figure 13, and read the value of the muf for the actual path length at the intersection point of the straightedge with the appropriate vertical distance line. Enter in column *h*. *Example*:

*F*2-zero-muf=6.8 Mc. *F*2-4000-muf=23.0 Mc. For a distance of 2600-km the *F*2 muf is 19.1 Mc.

(6) For each hour place a straightedge between the value of the *E*-layer 2000-muf on the left-hand scale of the nomogram, figure 14, and the value of the path length on the right-hand scale, and read the *E*-*F*1-muf for that path length, off the central scale. (Example on nomogram.) Enter in column *g*.

(7) Compare the values of muf obtained by operations (1) to (6). The higher of the two values (columns *g* and *h* of form AF) thus determined is the muf for the path. Enter in column *m*.

d. To determine the optimum working frequency (owf):

(1) Calculate the *F*2-owf from the *F*2-muf determined under *c* above by multiplying by 0.85 or using the conversion scale in figure 13. Enter in column *l*.

(2) Use for the *E*-*F*1-owf the value of *E*-*F*1-muf determined under *c*, (6) above. This represents a change from the previous practice of taking 97 percent of the *E*-*F*1-muf on the nomogram of figure 14. Enter in column *k*.

(3) Compare the *F*2-owf and *E*-*F*1-owf. The higher of the two values (columns *k* and *l* of form AF) is that of the path owf. Enter in column *n*.

2. PROCEDURE FOR DETERMINATION OF MUF AND OWF FOR TRANSMISSION DISTANCES GREATER THAN 4000 KM (PROPAGATION BY THE REGULAR LAYERS)

a. General considerations:

The procedure outlined below is based on the following assumptions:

(1) That there are *F*2-layer control points *A* and *B* and *E*-layer control points *A′* and *B′* (See section III, 1 *d* above).

(2) That the highest frequency that will "take off" along the path at the *A*-end is the *highest* frequency that can be propagated at *A* and *A′* considered together.

(3) That the highest frequency that will come in along the path at the *B*-end is the *highest* frequency that can be propagated at *B* and *B′* considered together.

(4) That the highest frequency that can be propagated from the *A*-end to the *B*-end is the *lower* of the two frequencies of (2) and (3) above.

(5) That the frequency obtained in (4) is the same for propagation from the *B*-end to the *A*-end.

b. Prepare or obtain work forms similar to CRPL form AH (see table 2). Note that form AH provides for the inclusion of the effects of sporadic *E* (*Es*), which will be discussed under 3 below.

c. Locate the control points *A* and *A′* at one end of the path and *B* and *B′* at the other end of the path as explained under section III, 1 *d* above. For very long paths the "short route" (minor arc of the great-circle path) and the "long route" (major arc) need be considered. Placing the transparency back on the world map, determine as in section IV, 1, *b* above in which geographical zone, *E*, *I*, or *W*, each of the control points *A* and *B* falls.

d. To determine the muf:

(1) Place the great-circle transparency over the *F*2-4000-muf chart for the zone of control point *A* and, keeping the equatorial line of the transparency over the equatorial line of the chart, slide the transparency horizontally until the Greenwich meridian coincides with 00 on the time scale.

(2) Read the value of *F*2-4000-muf for control point *A*. Enter in column *c* of form AH.

(3) Repeat for 02, 04, etc. on the time scale.

(4) Repeat steps (1), (2), and (3) on the *E*-layer 2000-muf chart, figure 11, using control point *A′*. Enter values in column *d*.

(5) Determine the muf for the *A*-end as the higher of the *F*2-4000-muf, column *c*, and the *E*-layer 2000-muf, column *d*. Enter in column *m*.

(6) Read the value of *F*2-4000-muf for control point *B*, using the *F*2-4000-muf chart for the proper zone. Enter values in column *i*.

(7) Repeat for 02, 04, etc. on the time scale.

(8) Read the values of *E*-layer 2000-muf on the *E*-layer 2000-muf chart, figure 11, using control point *B′*. Enter values in column *j*.

(9) Determine the muf for the *B*-end as the higher of the *F*2-4000-muf, column *i*, and the *E*-layer 2000-muf, column *j*. Enter in column *n*.

(10) Compare the two muf values of columns *m* and *n*. The lower of the two is the muf for the transmission path under consideration. Enter in column *q*.

e. To determine the owf:

(1) Use the scaled data of the previous procedure.

(2) Multiply the *F*2-4000-muf for the *A*-end, column *c*, by 0.85, or use the conversion scale in figure 13, to obtain the *F*2-4000-owf for the *A*-end, column *f*.

(3) Multiply the *F*2-4000-muf for the *B*-end, column *i*, by 0.85, or use the conversion scale in figure 13, to obtain the *F*2-4000-owf for the *B*-end, column *l*.

(4) Compare the *F*2-4000-owf for the *A*-end, column *f*, with the *E*-layer 2000-muf for the *A*-end, column *d*. The higher of the two is the owf for the *A*-end. Enter in column *o*.

(5) Compare the *F*2-4000-owf for the *B*-end, column *l*, with the *E*-layer 2000-muf for the *B*-end, column *j*. The higher of the two is the owf for the *B*-end. Enter in column *p*.

(6) Compare the two owf values of columns *o* and *p*. The lower of the two is the owf for the transmission path under consideration. Enter in column *r*.

3. PROCEDURES FOR INCLUSION OF THE EFFECTS OF *Es*

Sporadic-*E* (*Es*) propagation may often allow regular transmission when regular *E*- or *F*2-layer propagation would not. *Es* data are not yet sufficient to permit accurate calculations of such propagation, but the *fEs* charts of figures 12 and 15 are given as a guide to *Es* occurrence.

As the *fEs* charts are constructed from considerations of geomagnetic latitude, three latitude scales are provided at the right of the charts of figures 12 and 15, one for each of the three zones of figure 1 (*E*, *I*, and *W*).

Until further improvements are made, the following procedures should be used to include the effects of *Es* in the calculations of muf and owf.

a. For paths over 4000 km long:

(1) Place the great-circle path transparency prepared in section III, 1, over the median *fEs* chart, figure 12, using the latitude scale for the zone containing the control point.

(2) Scale *fEs* at control points *A′* and *B′*. Enter in columns *a* and *g*, respectively, on form AH.

(3) Multiply *fEs* by 5 in each case, obtaining the *Es*-2000-muf. Enter in columns *b* and *h*, respectively.

(4) In the determination of muf modify the procedure (steps (5) and (9)) of section IV, 2, *d* above to obtain the muf for the *A*- and *B*-ends, respectively, as the highest of the *three* items, the *F*2-4000-muf, the *E*-layer 2000-muf, and the *Es*-2000-muf. No other change is necessary.

(5) In the determination of owf subtract 4 Mc from the *Es*-2000-muf to obtain the *Es*-2000-owf for the *A*-end and *B*-end, respectively, entering the results in columns *e* and *k*. Then modify the procedure (steps (4) and (5)) of section IV, 2, *e* to obtain the owf for the *A*- and *B*-ends, respectively, as the highest of the *three* items, the *F*2-4000-owf, the *E*-layer 2000-muf, and the *Es*-2000-owf. No other changes are necessary.

b. For paths under 4000 km long:

(1) Repeat step (1) of *a* above.

(2) Scale *fEs* at the midpoint of the path. Enter in column *a* of form AF.

(3) Multiply *fEs* by 5, obtaining the *Es*-2000-muf. Enter in column *b*.

(4) In the determination of muf under IV, 1, *c*, find the *Es*-muf for the path by use of the same nomogram, figure 14, as was used for the *E*-*F*1-muf, applying the *Es*-2000-muf on the left-hand scale and reading the answer on the middle scale. Enter in column *f*. Then modify the procedure in IV, 1, *c*, (7) so that the highest of the *three* values, the *F*2-muf, the *E*-*F*1-muf, and the *Es*-muf, columns *h*, *g*, *f*, is the muf for the path.

(5) In the determination of owf under IV, 1, *d*, subtract 4 Mc from the *Es*-2000-muf found under (3) above to obtain the *Es*-2000-owf, entering in column *i*. Now find the *Es*-owf for the path, using the same nomogram, figure 14, as for the *E*-*F*1-owf, applying the *Es*-2000-owf to the left-hand

scale and reading the answer on the middle scale. Enter in column *j*. Then modify the procedure in section IV, 1, *d* (3) so that the highest of the *three* values, the *F*2-owf, the *E*-*F*1-owf, and the *Es*-owf, columns *l*, *k*, *j*, is the owf for the path.

Because of the variable nature of *Es*, and the relative uncertainty with which *Es* is known, caution should be used in the application of *Es*-owf, particularly for short paths. While transmission should take place most of the time on *Es*-owf, fluctuations in *Es* may at times interrupt service. It is thus often desirable to operate near the owf for the regular layers (*E*, *F*1, *F*2) only, without the inclusion of *Es*, although transmission may take place more than 80 percent of the time near the *Es*-owf.

V. ABSORPTION, DISTANCE RANGE, AND LOWEST USEFUL HIGH FREQUENCY

The procedures outlined in the text of this report will give an adequate solution to most of the high-frequency propagation problems that will normally be encountered in the field. If operating frequencies are chosen near the calculated owf prediction in any given case, best possible results should be had, at least in communications work.

The use of frequencies too far below the owf will result in weak reception because of increasing ionospheric absorption as the frequency decreases. The factor that limits the usefulness of low field intensities is usually atmospheric noise at the receiving location.

The determination of lowest useful high frequencies is more difficult than the determination of muf and the techniques for their prediction are less far advanced.

The subject of absorption, distance range, and lowest useful high frequency is discussed at length in IRPL Radio Propagation Handbook, Part 1, p. 69–97 (War Dept. TM 11–499, Navy Dept. DNC–13–1), and formulas, graphs, and nomograms for calculation are given there.

Simpler and more accurate techniques are being developed and will be released as soon as the work is completed.

VI. SAMPLE MUF AND OWF CALCULATIONS

1. FOR SHORT PATHS

Required: The muf and owf for transmission between Washington, D. C. (39.0° N, 77.5° W) and Miami, Fla. (25.7° N, 80.5° W) for average conditions during the month of December 1946.

Solution:

Let the local time used for this problem be GCT (*Z* time or that of 0° longitude).

The midpoint of the path is at approximately 32.5° N, 79.0° W, and the transmission path length is approximately 1500 km, all in *W* zone.

The values of *E*- and *F2*-layer muf and owf, and also *Es*-owf for even hours, GCT, as determined by using the procedure given in section IV, are given in table 1. The final values are presented graphically in figure 16.

Values of owf obtained by the procedure of section IV, 1, *c* for the regular layers only are underscored in columns *k* and *l* of table 1, and are plotted in figure 16. Controlling values of *Es*-owf in column *j* are shown as a dotted line in figure 16, and the solid-line curve of owf is for the regular layers only.

Figure 16 shows that skip will occur, on the average, during the night hours, if a frequency as high as 11.5 Mc is used. A frequency as high as 9.0 Mc will not skip, on the average, at any time of day, but its use is not advisable because of (a) the day-to-day variability, causing some probability of skip during the night hours, and (b) ionospheric absorption during the daytime, which is more pronounced at low frequencies.

A satisfactory plan to insure continuous transmission at all times, over a path like this, involves the use of two frequencies, one for night and one for day. Figure 16 shows that a night frequency of 7.4 Mc, to be used from 2310 to 1245 GCT, and a day frequency of 12.5 Mc, to be used from 1245 to 2310 GCT, would be satisfactory. The periods of usefulness of these frequencies are shown by the heavy dashed line on figure 16.

These values of frequency were obtained by including *Es*-owf in the calculations, and consequently, for the reason indicated in the last paragraph of IV, above, some interruptions in service may be expected on the night frequency, since the night frequency, as shown in figure 16, was chosen above the owf for the regular layers. Better service may possibly be obtained by choosing a lower night frequency, closer to the regular-layer owf.

2. FOR LONG PATHS

Required: The muf and owf for transmission between Washington, D. C. (39.0° N, 77.5° W) and Trieste, Italy (45.7° N, 13.8° E) for average conditions during the month of December 1946.

Solution:

Let the local time for this problem be GCT (*Z* time or that of 0° longitude).

The path length is approximately 7100 km, and the two $F2$-layer control points, A and B, respectively, are at approximately 49° N, 56.5° W, and 52° N, 12.5° W. These are, respectively, in the W zone and the I zone, as shown on the map, figure 1. The two E-layer and Es control points, A' and B', respectively, are located at approximately 44° N, 68.5° W, and 49.5° N, 1.5° E. These are in the W and I zones, respectively.

The values of muf and owf over this transmission path, as determined by the procedure in section IV, are given in table 2 for even hours, GCT. Provision has been made in the computation of this table for the inclusion of the effects of Es. The final figures are shown graphically in figure 17.

Figure 17 shows that skip will occur, on the average, during the night hours if a frequency as high as 12.0 Mc is used, although higher frequencies may be used during a limited portion of the day.

A good, practical arrangement to insure continuous transmission at all times is to select three frequencies, in a manner similar to that suggested in the preceding problem. A frequency of 9.6 Mc may be used from 1835 to 1105 GCT, a frequency of 19.5 Mc may be used from 1140 to 1715 GCT, and a transition frequency of 13.5 Mc may be used from 1105 to 1140, and from 1715 to 1835 GCT.

By inspection of the absorption chart and the noise map (figs. 91 and 120 of the IRPL Radio Propagation Handbook, Part 1, War Dept. TM 11–499, Navy Dept. DNC–13–1), it may be seen that considerations of the lowest useful high frequency over this path may be of considerable importance in selecting frequencies for use. Consequently, in cases of transmission failure on the frequencies here recommended, particularly in the case of the transition frequency, changing the frequency to a value slightly under the muf for the path may be advisable.

The bearing of Trieste from Washington is approximately 51°, and that of Washington from Trieste is approximately 299°, both determined by the nomogram of figure 4.

CRPL — FORM AF

TABLE 1.— Solution of short-path transmission problem.

DATE 31 July 1946

MUF-OWF WORK SHEET FOR PATHS 4000 KM OR LESS

From Washington, D.C. To Miami, Fla. Distance, 1500 km Zone W Predicted for Dec. 1946

Note: All frequencies are in megacycles.

GCT	f_{E_s}	E_s 2000-muf	E-layer 2000-muf	F_2 zero-muf	F_2 4000-muf	E_s-muf for Path	E-F_1-muf for Path	F_2-muf for Path	E_s 2000-owf	E_s-owf for Path	E-owf for Path	F_2-owf for Path	MUF for Path	OWF for Path
	a	b	c	d	e	f	g	h	i	j	k	l	m	n
Procedure	Scale	5 X a	Scale	Scale	Scale				b–4.0		Same as g	.85 h	Highest of f, g, h	Highest of j, k, l
00	2.7	13.5		5.7	17.6	12.4		9.4	9.5	8.8		8.0	12.4	8.8
01														
02	2.5	12.5		4.6	13.5	11.5		8.1	8.5	7.8		6.9	11.5	7.8
03														
04	2.5	12.5		4.7	13.1	11.5		8.1	8.5	7.8		6.9	11.5	7.8
05														
06	2.5	12.5		4.8	13.8	11.5		8.4	8.5	7.8		7.1	11.5	7.8
07														
08	2.6	13.0		4.8	14.0	12.0		8.5	9.0	8.3		7.2	12.0	8.3
09														
10	2.5	12.5		4.4	12.3	11.5		7.4	8.5	7.8		6.3	11.5	7.8
11														
12	2.8	14.0	7.0	5.5	19.0	12.9	6.4	10.8	10.0	9.2	6.4	9.2	12.9	9.2
13														
14	2.9	14.5	13.4	9.6	32.2	13.3	12.3	18.6	10.5	9.7	12.3	15.8	18.6	15.8
15														
16	2.9	14.5	16.0	10.4	33.5	13.3	14.7	19.6	10.5	9.7	14.7	16.7	19.6	16.7
17														
18	2.9	14.5	16.2	10.7	34.8	13.3	14.9	20.3	10.5	9.7	14.9	17.2	20.3	17.2
19														
20	2.8	14.0	14.1	10.9	37.2	12.9	13.1	21.4	10.0	9.2	13.1	18.2	21.4	18.2
21														
22	2.8	14.0	8.8	10.1	34.3	12.9	8.2	19.7	10.0	9.2	8.2	16.7	19.7	16.7
23														
Done by														
Checked														

CRPL — FORM AH

TABLE 2.—Solution of long-path transmission problem.
MUF-OWF WORK SHEET FOR PATHS OVER 4000 KM.

DATE 31 July 1946

From Washington, D.C. To Trieste, Italy Distance, 7100 km Predicted for Dec. 1946

Note. All frequencies are in megacycles

GCT	A-end: Pt. A in W Zone f_{E_s}	A-end: Pt. A in W Zone E_s 2000-muf	A-end: Pt. A in W Zone F_2 4000-muf	A-end: Pt. A' in W Zone E-layer 2000-muf	A-end: Pt. A' in W Zone E_s 2000-owf	A-end: Pt. A' in W Zone F_2 4000-owf	B-end: Pt B in I Zone f_{E_s}	B-end: Pt B in I Zone E_s 2000-muf	B-end: Pt B in I Zone F_2 4000-muf	B-end: Pt B' in I Zone E-layer 2000-muf	B-end: Pt B' in I Zone E_s 2000-owf	B-end: Pt B' in I Zone F_2 4000-owf	MUF A-end	MUF B-end	OWF A-end	OWF B-end	MUF for PATH	OWF for PATH
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r
Procedure	Scale pt A'	5 x a	Scale pt A	Scale pt A'	b - 4 0	85 c	Scale pt B'	5 x g	Scale pt B	Scale pt B'	h - 4 0	85 i	Highest of b,c,d	Highest of h,i,j	Highest of d,e,f	Highest of j,k,l	Lower of m,n	Lower of o,p
00			16.4			14.0	3.1	15.5	9.4		11.5	8.0	16.4	15.5	14.0	11.5	15.5	11.5
01																		
02			11.4			9.7	3.1	15.5	10.5		11.5	8.9	11.4	15.5	9.7	11.5	11.4	9.7
03																		
04			11.4			9.7	3.1	15.5	11.0		11.5	9.4	11.4	15.5	9.7	11.5	11.4	9.7
05																		
06			11.7			9.9	3.1	15.5	9.5		11.5	8.1	11.7	15.5	9.9	11.5	11.7	9.9
07																		
08			12.0			10.2	3.1	15.5	10.6	8.8	11.5	9.0	12.0	15.5	10.2	11.5	12.0	10.2
09																		
10			11.8			10.0	3.2	16.0	28.6	12.7	12.0	24.3	11.8	28.6	10.0	24.3	11.8	10.0
11																		
12			26.0	7.7		22.1	3.8	19.0	33.5	13.6	15.0	28.5	26.0	33.5	22.1	28.5	26.0	22.1
13																		
14	3.6	18.0	35.6	12.7	14.0	30.3	3.4	17.0	35.2	12.3	13.0	29.9	35.6	35.2	30.3	29.9	35.2	29.9
15																		
16	4.5	22.5	41.0	14.5	18.5	34.8	3.1	15.5	32.5	7.5	11.5	27.6	41.0	32.5	34.8	27.6	32.5	27.6
17																		
18	3.9	19.5	39.4	13.8	15.5	33.5	3.1	15.5	19.6		11.5	16.7	39.4	19.6	33.5	16.7	19.6	16.7
19																		
20			33.7	10.7		28.6	3.1	15.5	11.8		11.5	10.0	33.7	15.5	28.6	11.5	15.5	11.5
21																		
22			22.3			18.9	3.1	15.5	9.2		11.5	7.8	22.3	15.5	18.9	11.5	15.5	11.5
23																		
Done by																		
Checked																		

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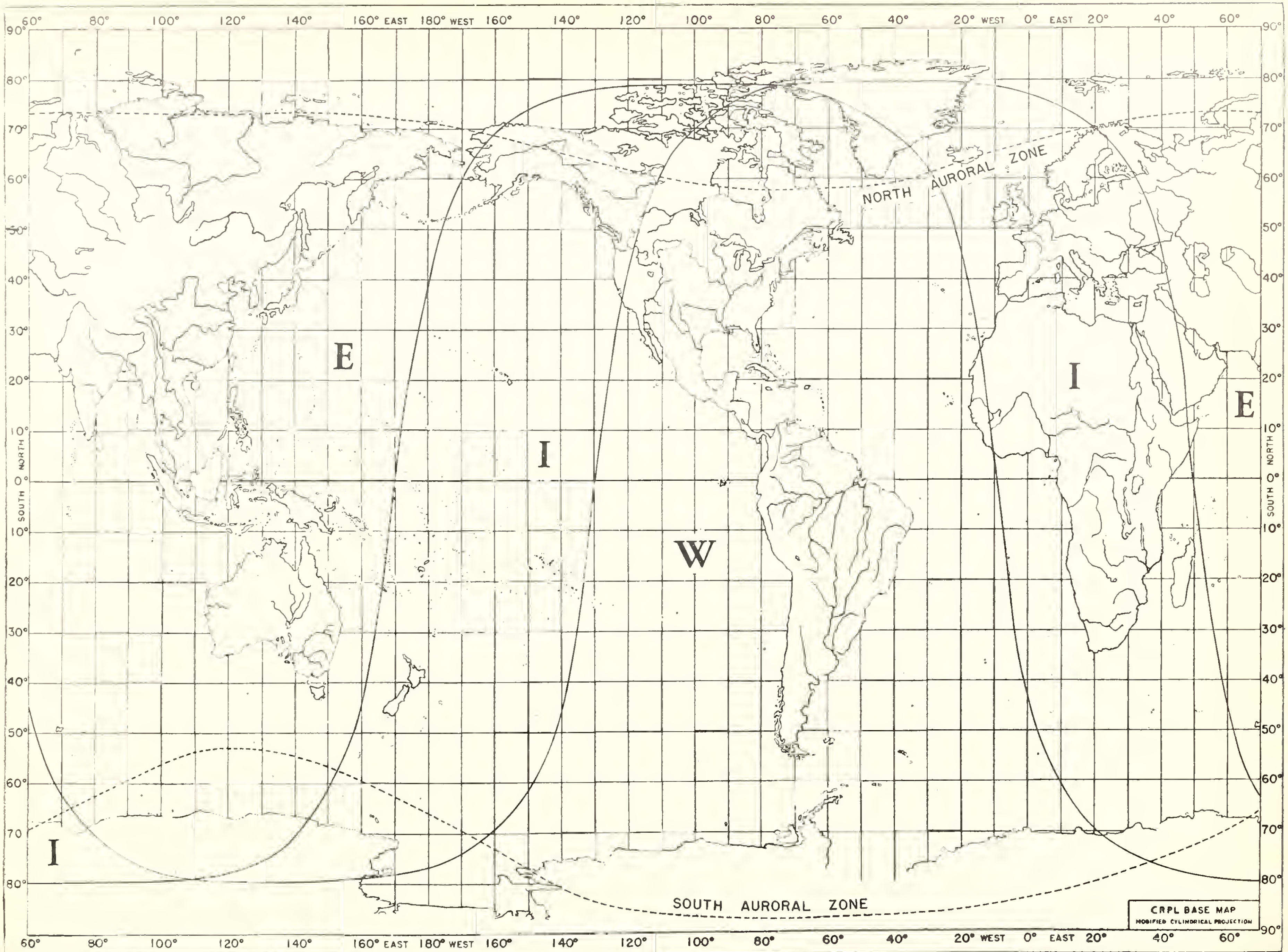

Fig. 1. WORLD MAP SHOWING ZONES COVERED BY PREDICTED CHARTS, AND AURORAL ZONES

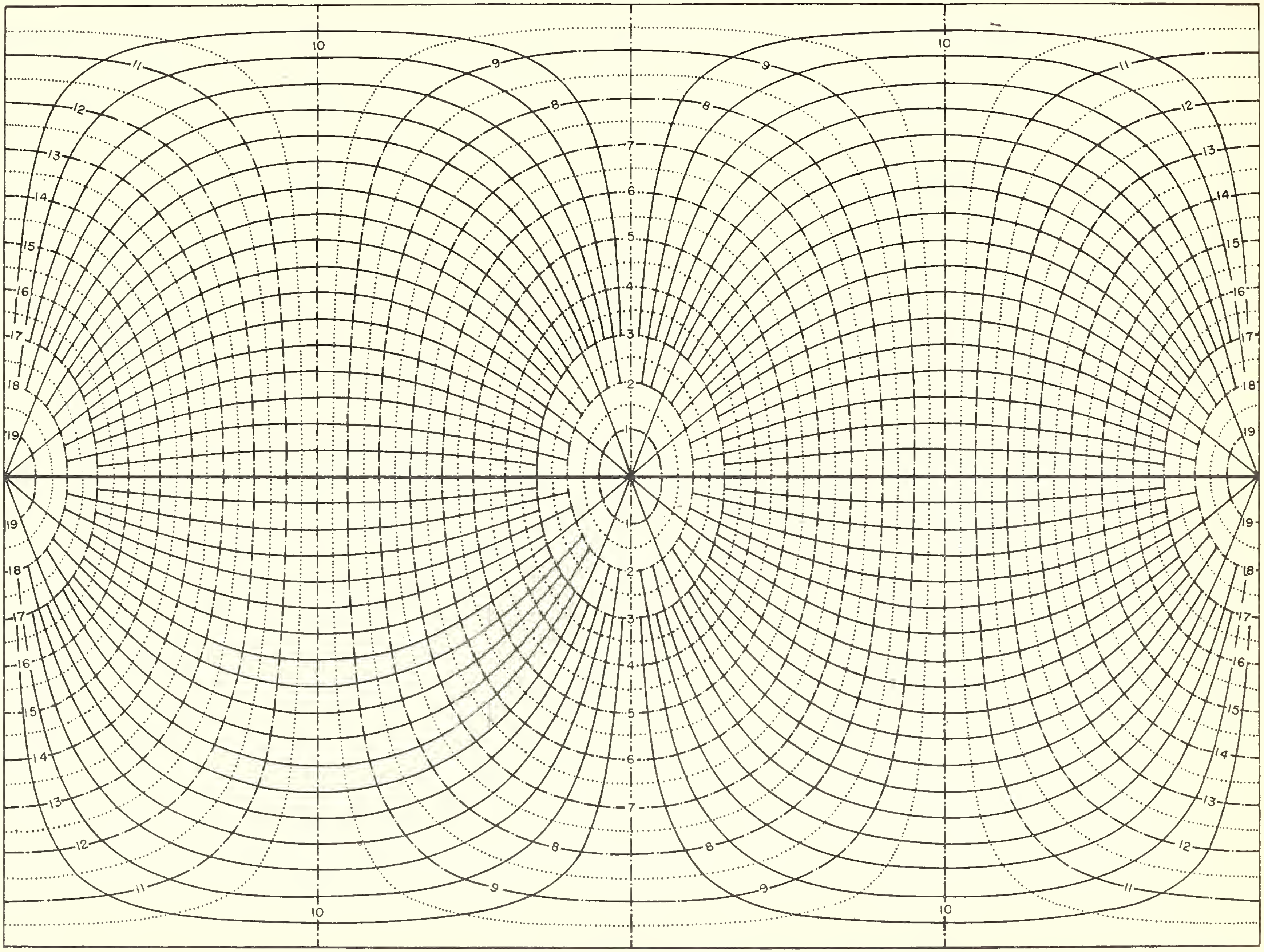

Fig. 2. GREAT CIRCLE CHART CENTERED ON EQUATOR. SOLID LINES REPRESENT GREAT CIRCLES. NUMBERED DOT-DASH LINES INDICATE DISTANCES IN THOUSANDS OF KILOMETERS.

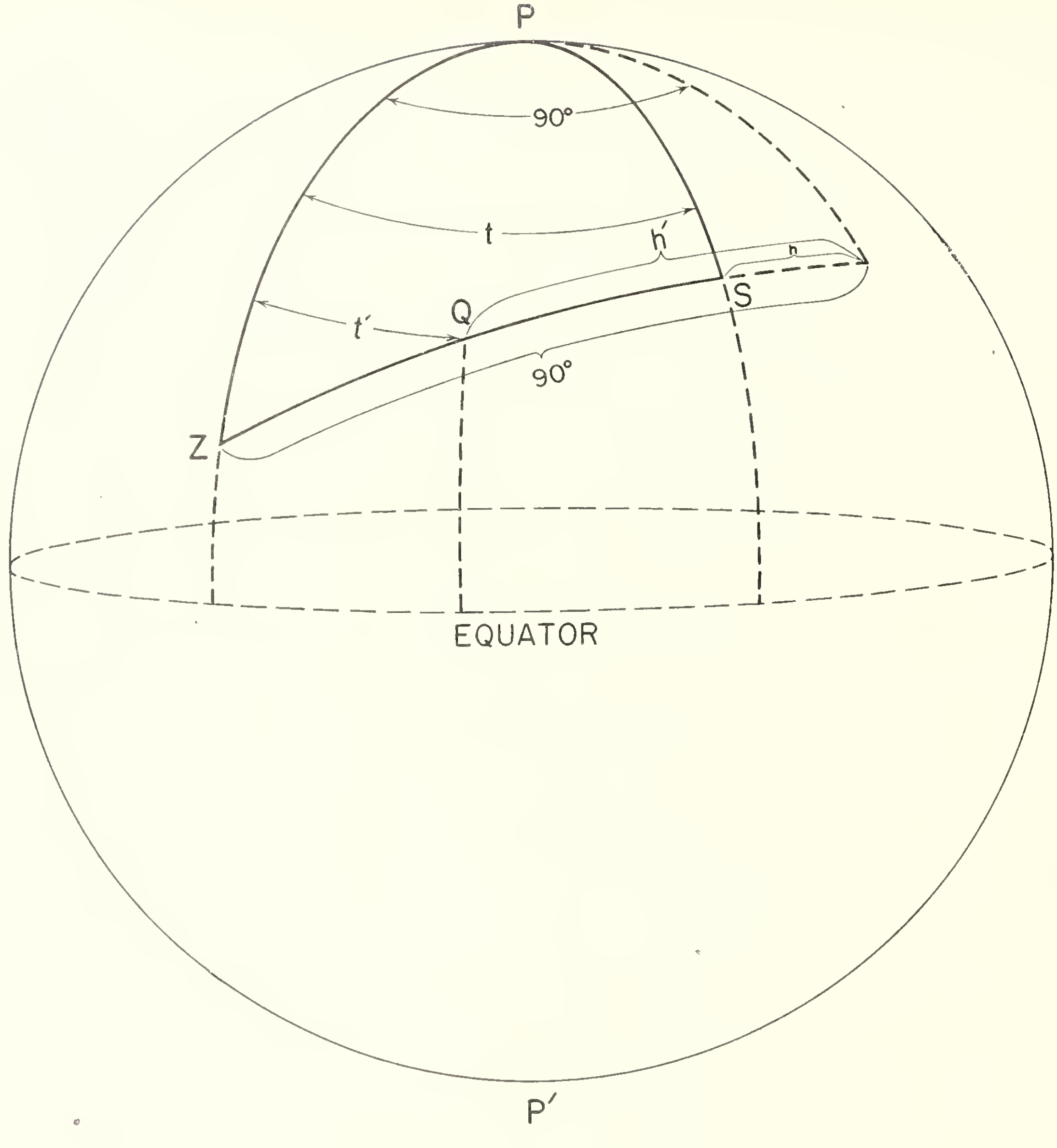

Fig. 3. DIAGRAM OF TRANSMISSION PATH AUXILIARY TO EXPLANATION OF USE OF DISTANCE – BEARING NOMOGRAM, FIG. 4.

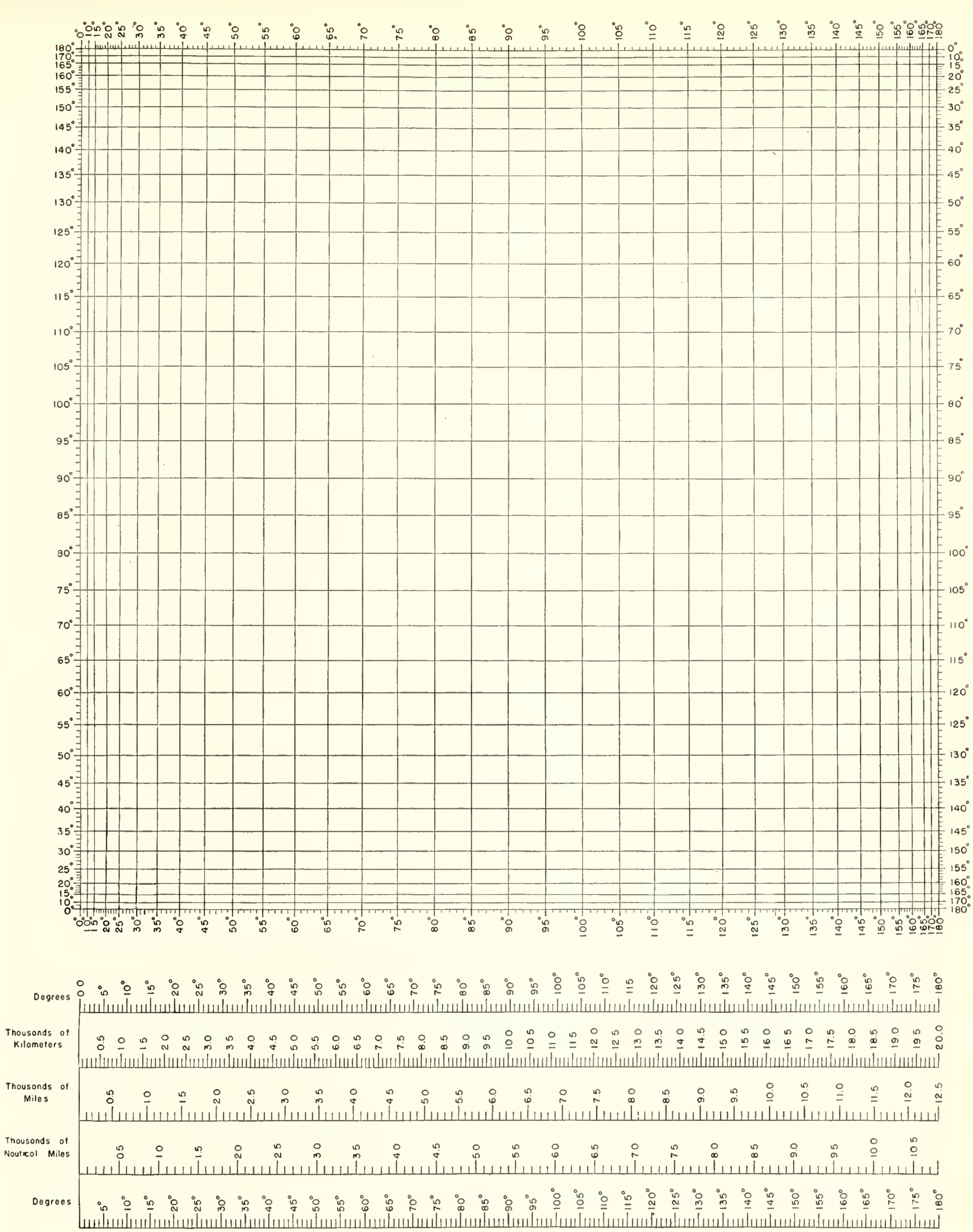

Fig. 4. NOMOGRAM (AFTER D'OCAGNE) FOR OBTAINING GREAT-CIRCLE DISTANCES, BEARINGS, LATITUDE AND LONGITUDE OF TRANSMISSION CONTROL POINTS, SOLAR ZENITH ANGLES.

CONVERSION SCALE FOR VARIOUS DISTANCE UNITS.

710359—46——3

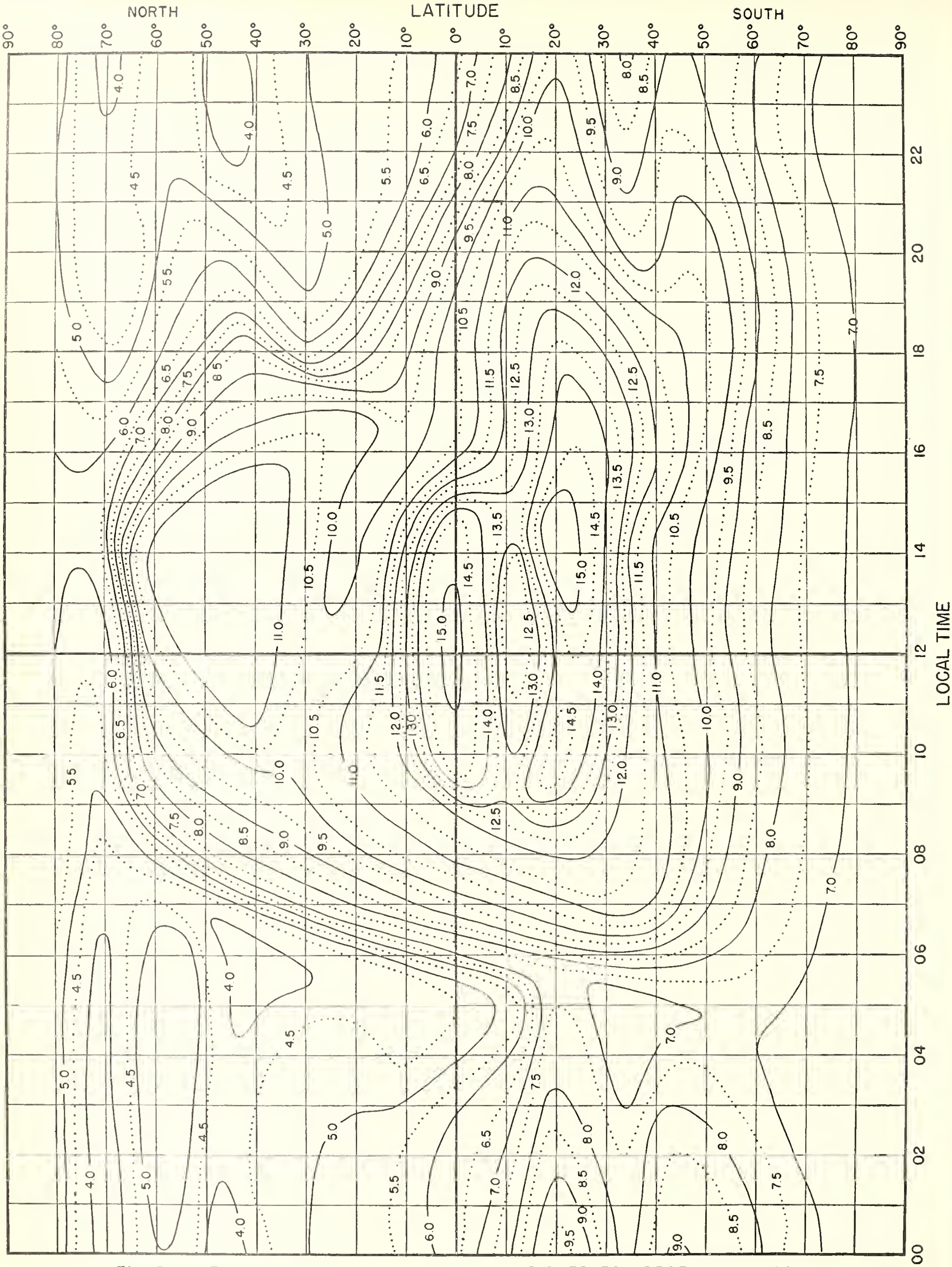

Fig. 5. F_2 ZERO—MUF, IN Mc, W ZONE, PREDICTED FOR DECEMBER, 1946

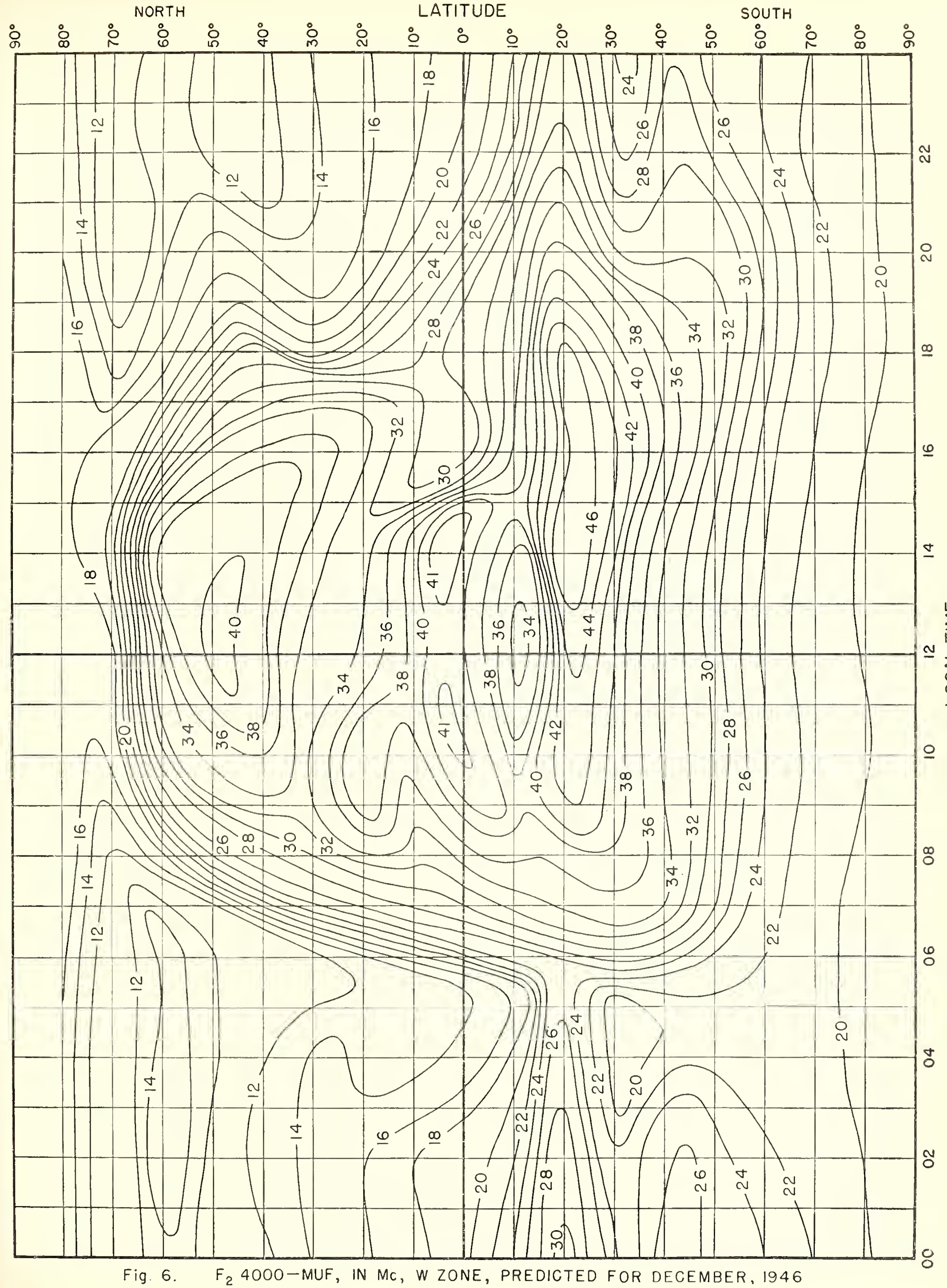

Fig. 6. F_2 4000—MUF, IN Mc, W ZONE, PREDICTED FOR DECEMBER, 1946

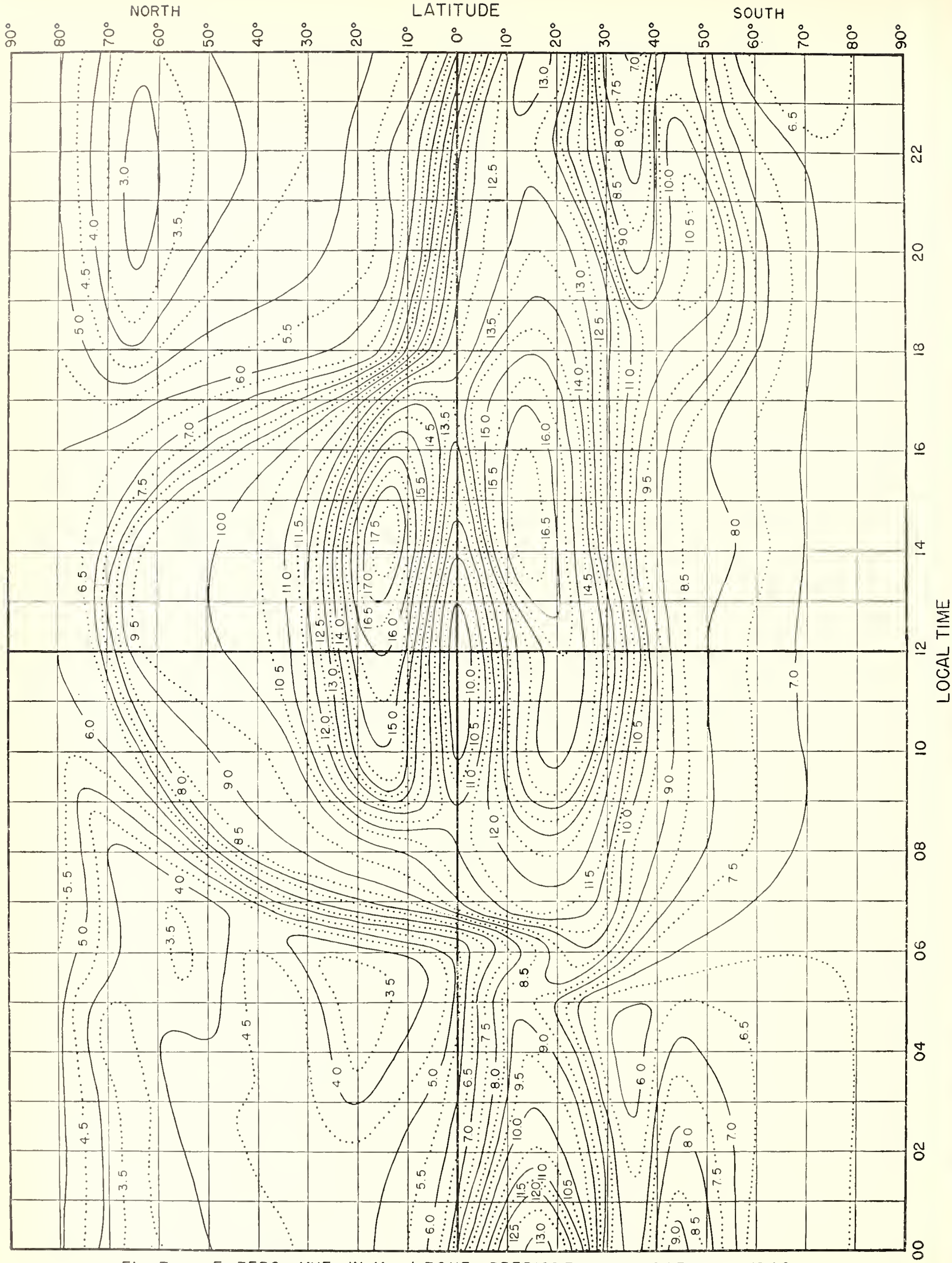

Fig. 7. F_2 ZERO—MUF, IN Mc, I ZONE, PREDICTED FOR DECEMBER, 1946

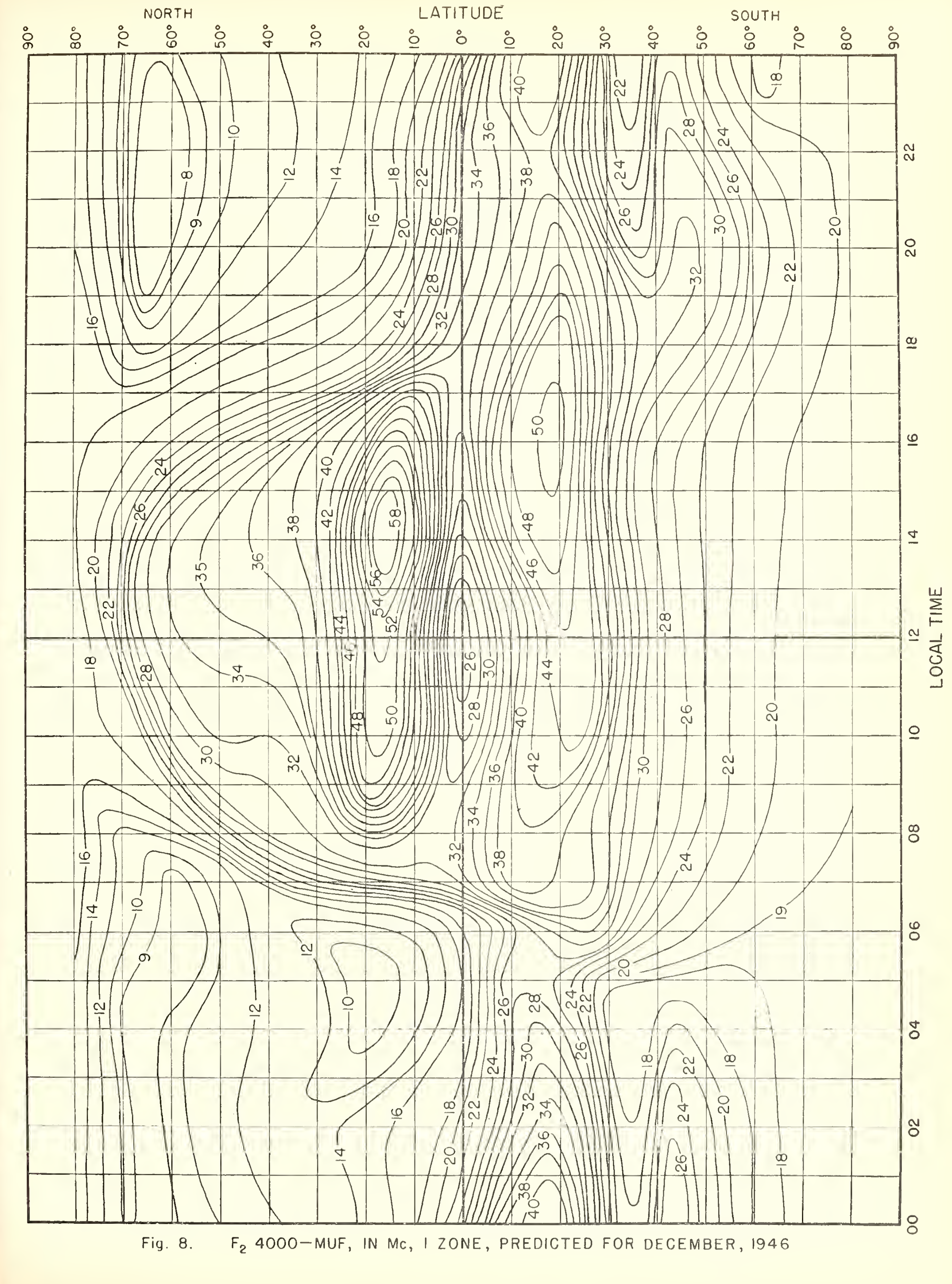

Fig. 8. F_2 4000—MUF, IN Mc, I ZONE, PREDICTED FOR DECEMBER, 1946

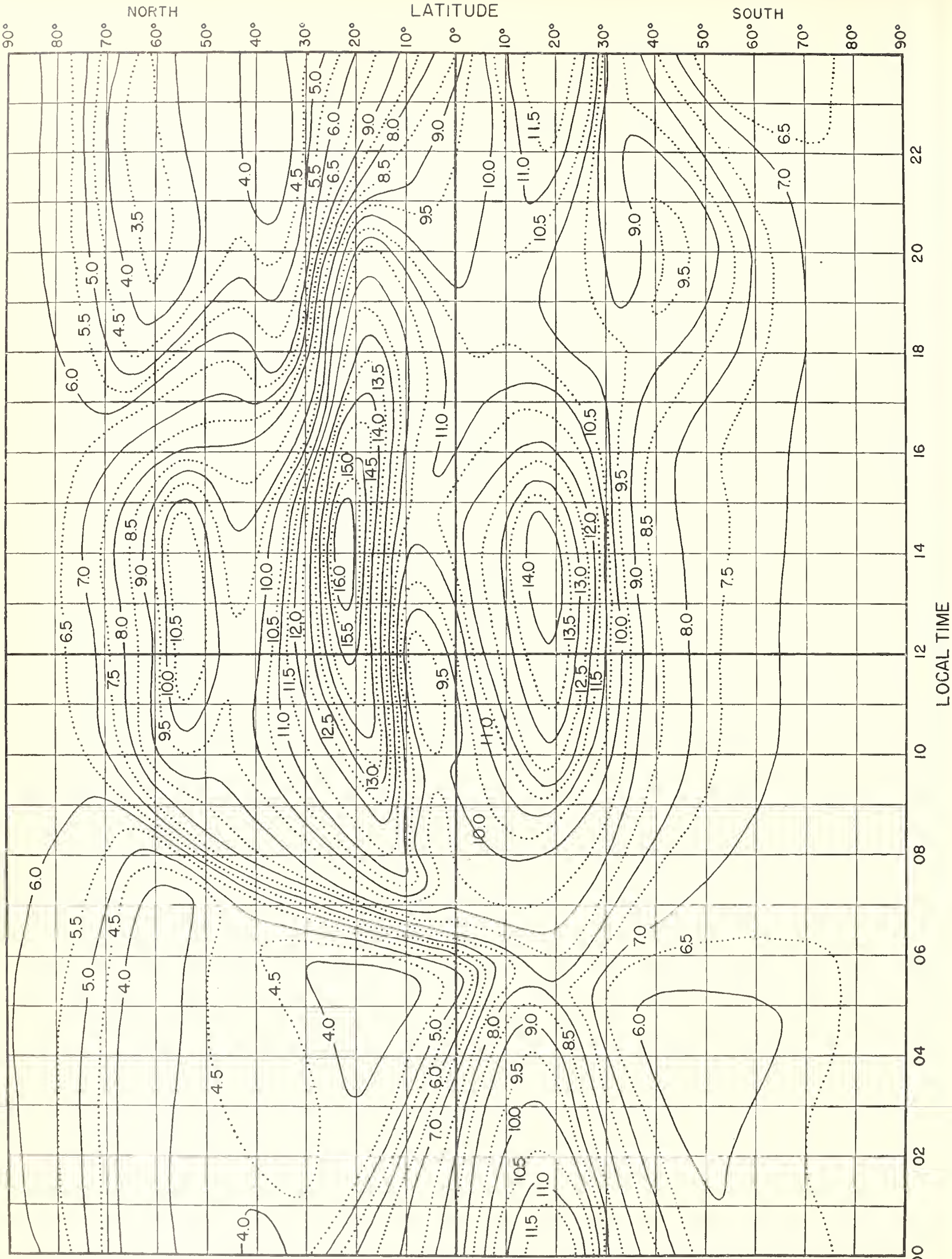

Fig. 9. F_2 ZERO-MUF, IN Mc, E ZONE, PREDICTED FOR DECEMBER, 1946.

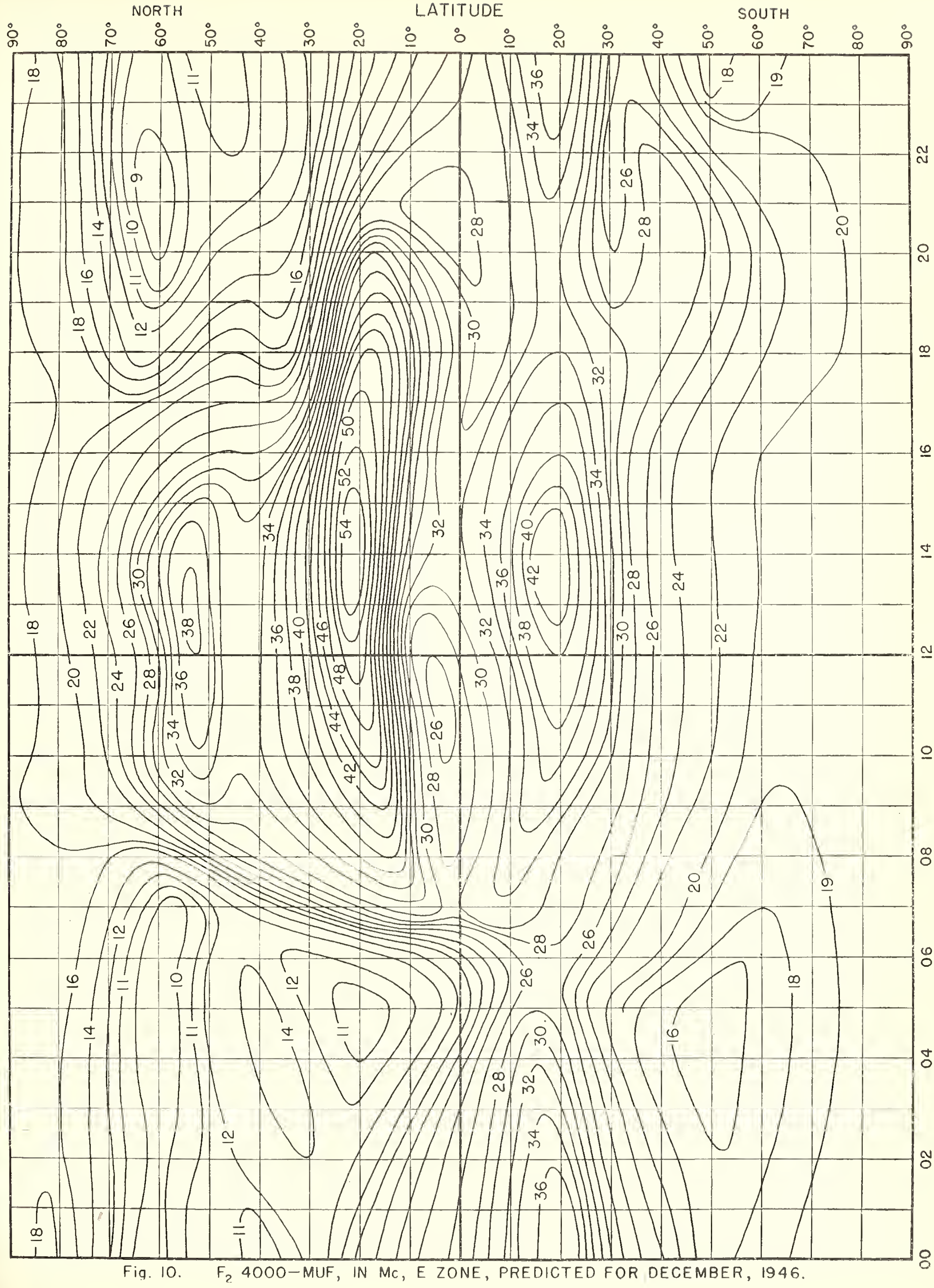

Fig. 10. F_2 4000–MUF, IN Mc, E ZONE, PREDICTED FOR DECEMBER, 1946.

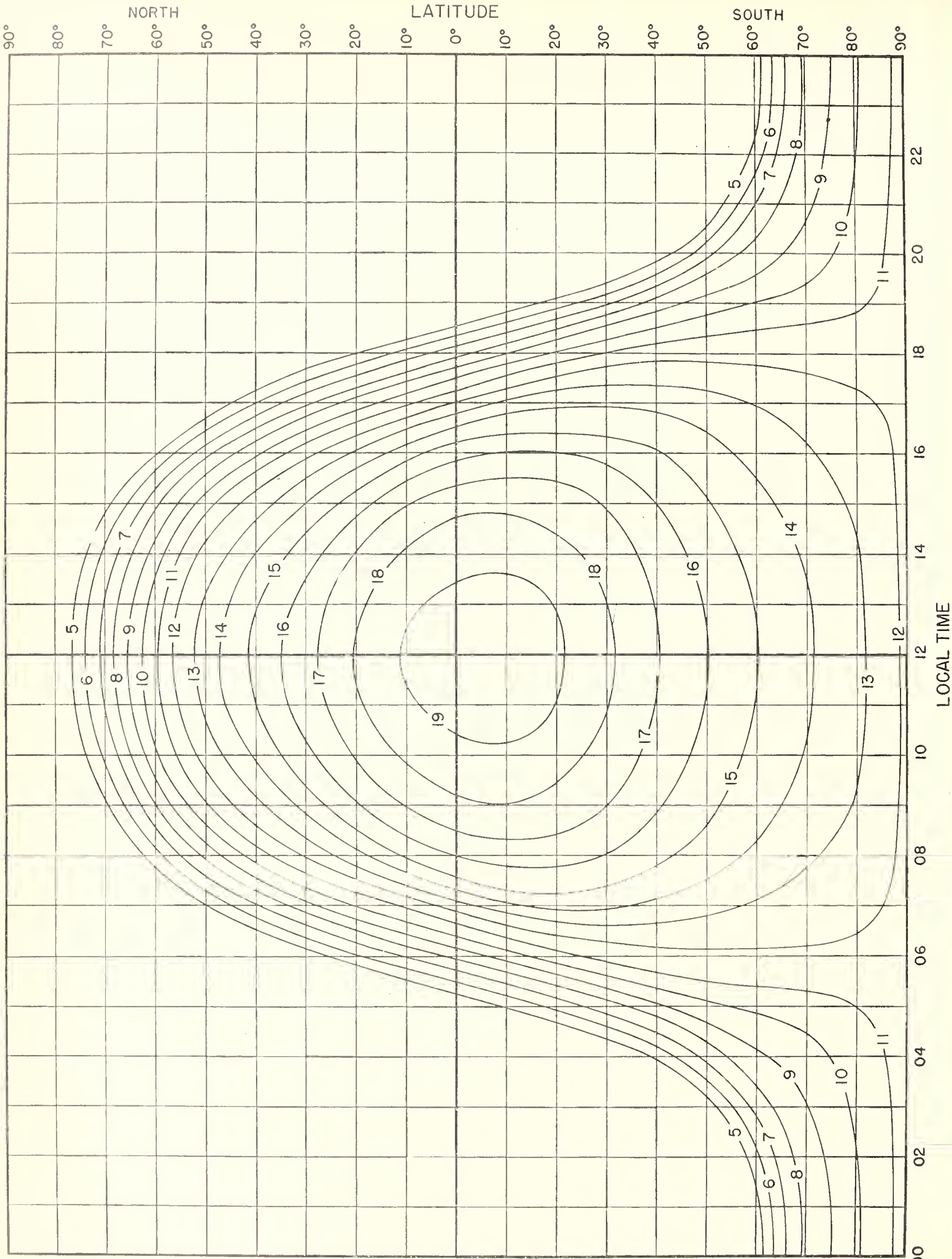

Fig. 11 E–LAYER 2000–MUF, IN Mc, PREDICTED FOR DECEMBER, 1946.

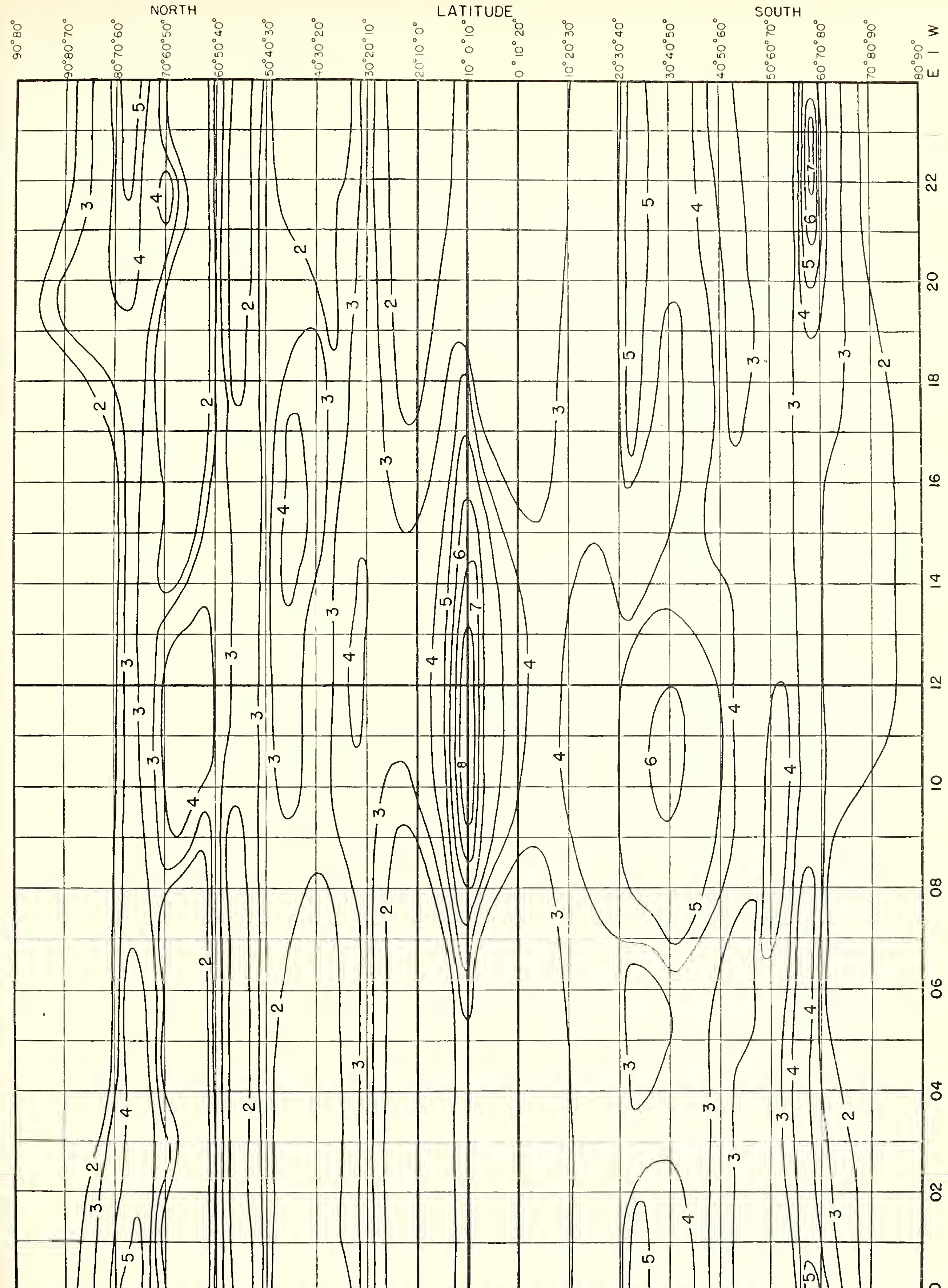

Fig. 12 MEDIAN $f E_s$, IN Mc, PREDICTED FOR DECEMBER, 1946.

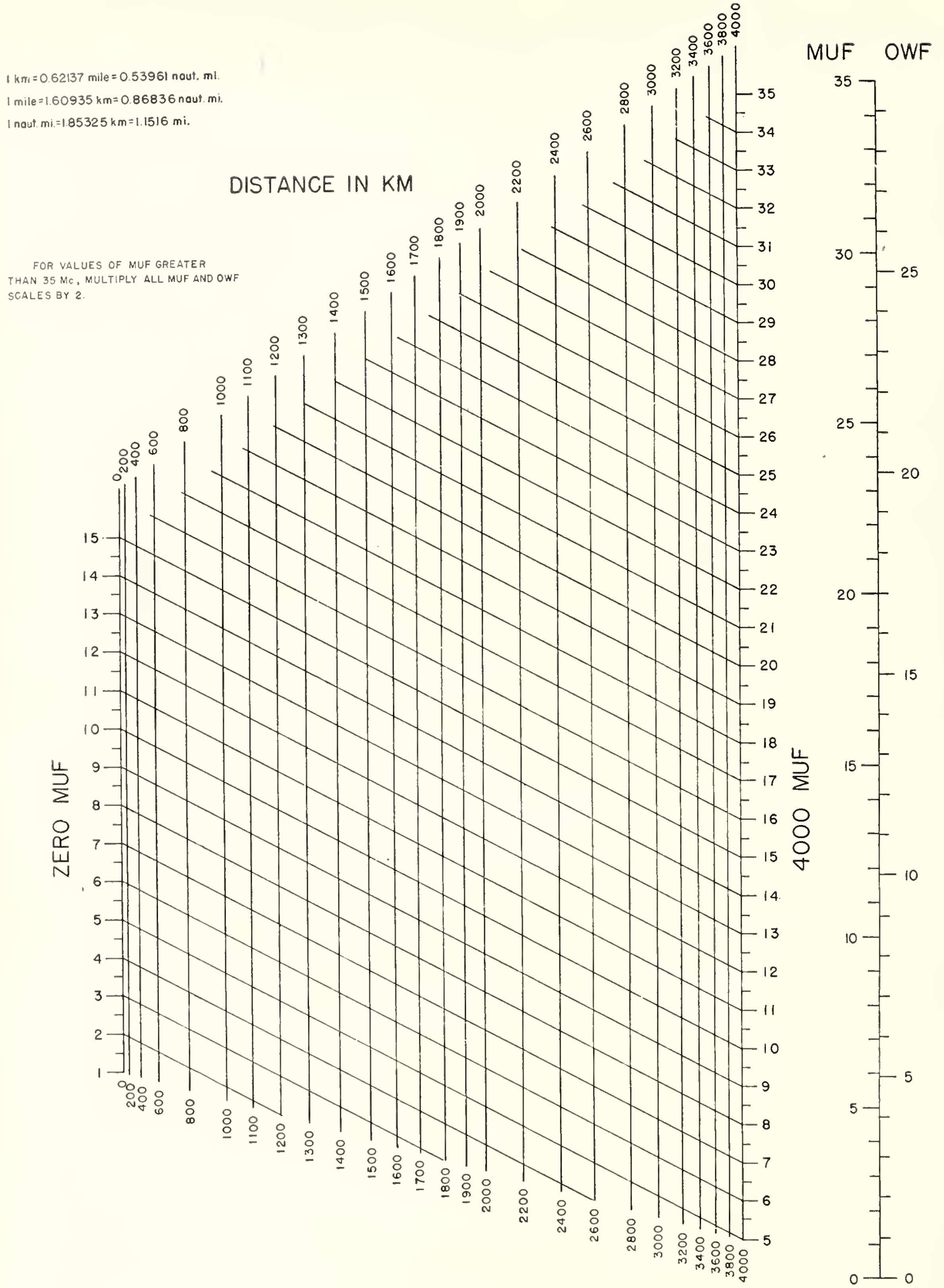

FIG. 13. NOMOGRAM FOR TRANSFORMING F_2–ZERO–MUF AND F_2–4000–MUF TO EQUIVALENT MAXIMUM USABLE FREQUENCIES AT INTERMEDIATE TRANSMISSION DISTANCES; CONVERSION SCALE FOR OBTAINING OPTIMUM WORKING FREQUENCIES.

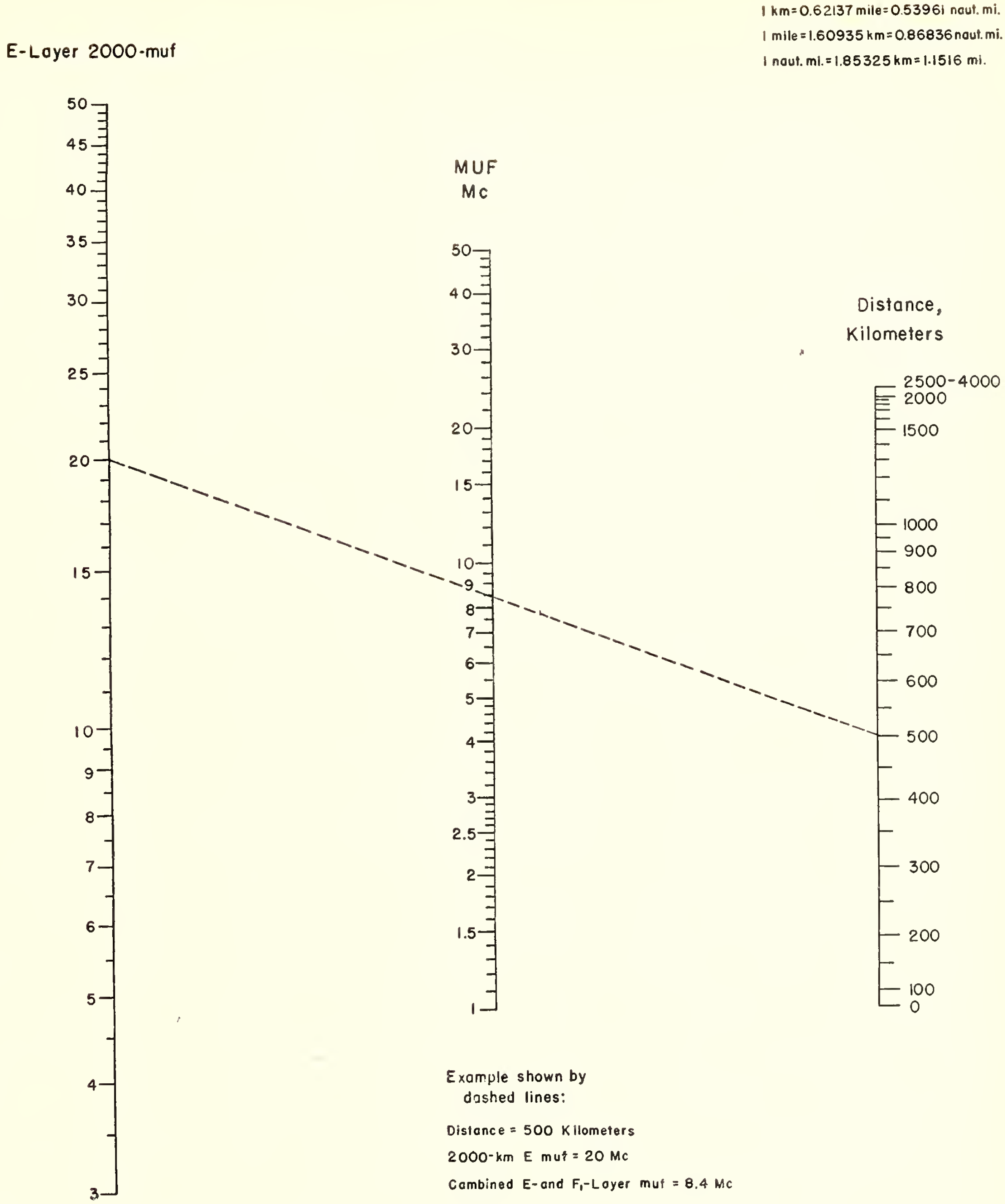

FIG. 14 NOMOGRAM FOR TRANSFORMING E—LAYER 2000—MUF TO EQUIVALENT MAXIMUM USABLE FREQUENCIES AND OPTIMUM WORKING FREQUENCIES DUE TO COMBINED EFFECT OF E LAYER AND F_1 LAYER AT OTHER TRANSMISSION DISTANCES.

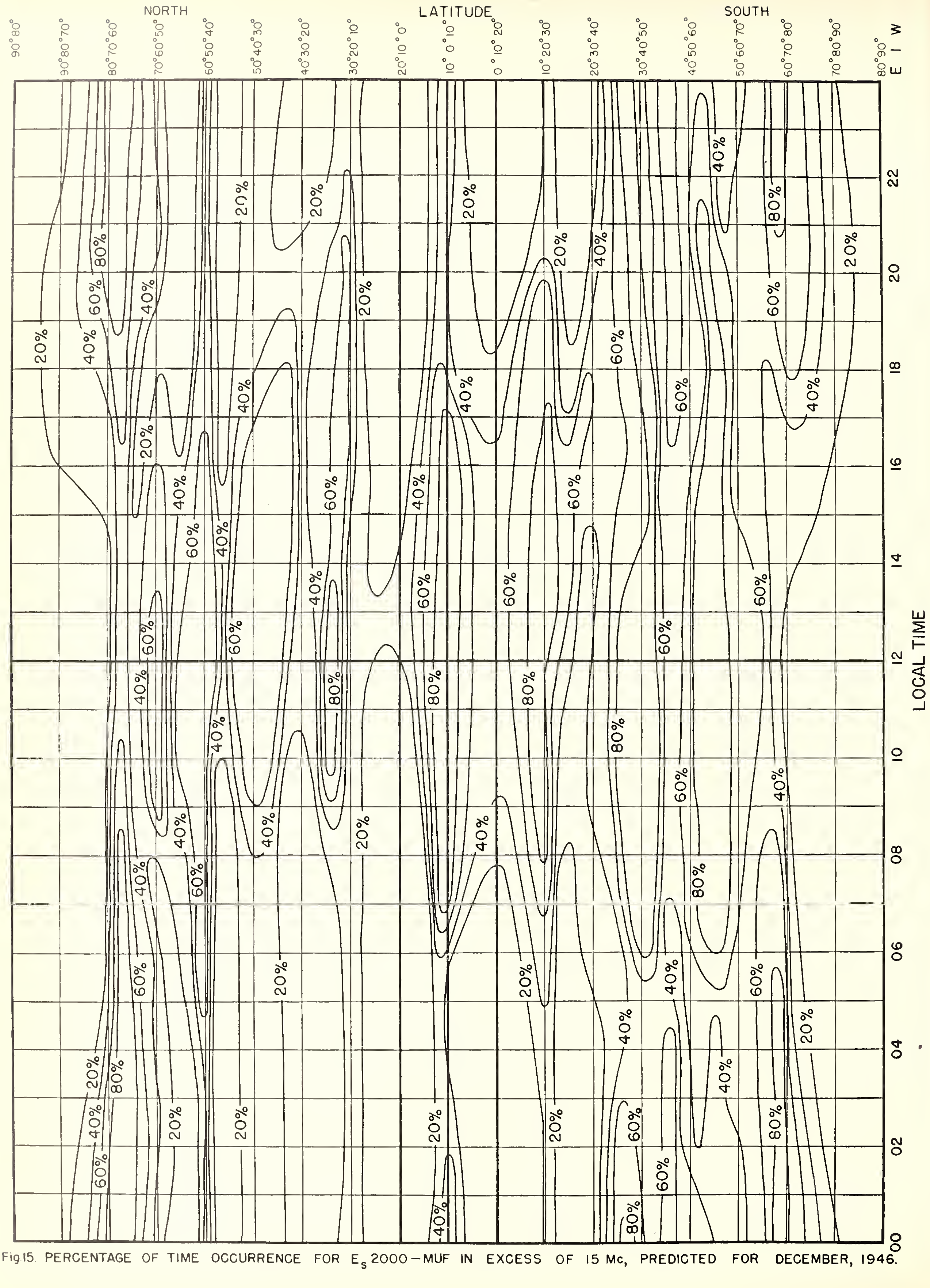

Fig.15. PERCENTAGE OF TIME OCCURRENCE FOR E_s 2000—MUF IN EXCESS OF 15 Mc, PREDICTED FOR DECEMBER, 1946.

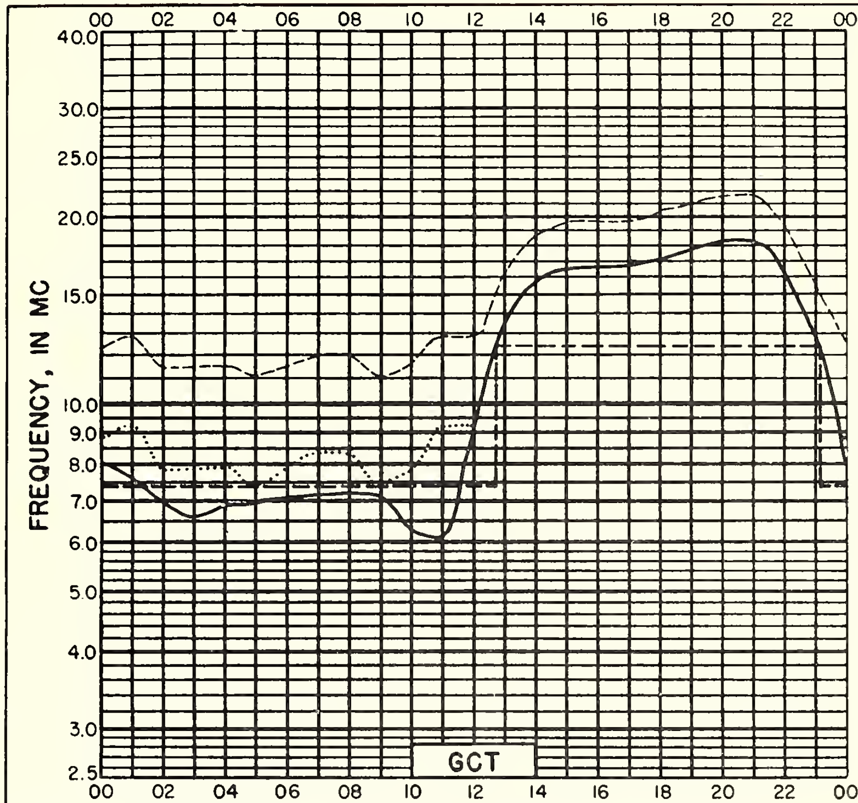

Fig. 16. SAMPLE SOLUTION OF TRANSMISSION PROBLEM FOR SHORT PATH, DECEMBER, 1946

TRANSMISSION PATH: WASHINGTON, D.C. (39.0°N, 77.5°W) TO MIAMI, FLORIDA (25.7°N, 80.5°W)

MUF INCLUDING Es
SUGGESTED FREQUENCY USAGE
OWF FOR REGULAR LAYERS ONLY
OWF INCLUDING Es

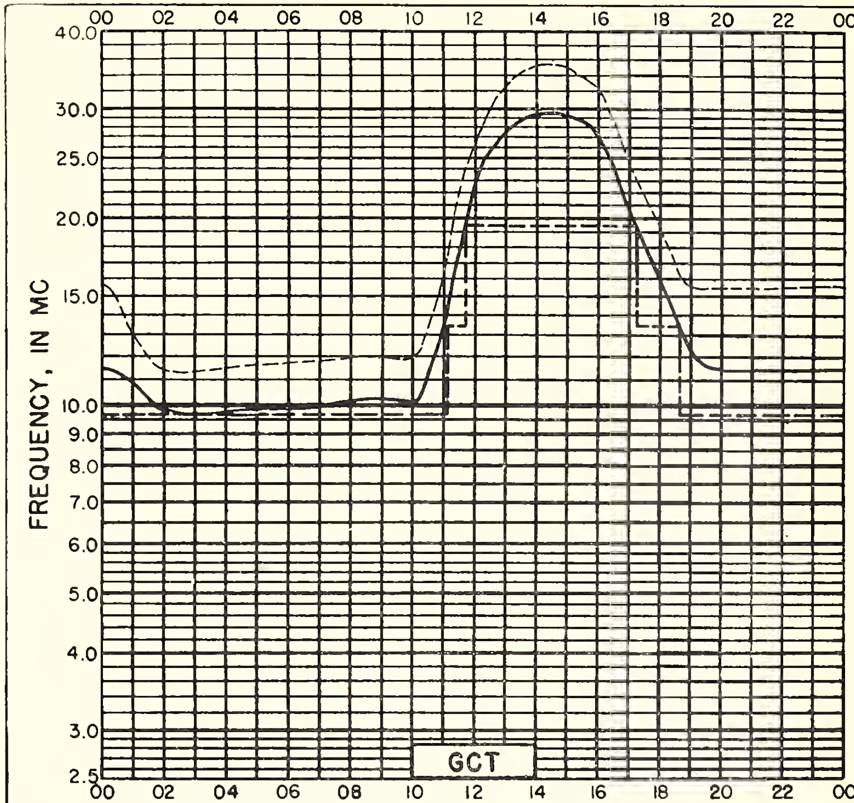

Fig. 17. SAMPLE SOLUTION OF TRANSMISSION PROBLEM FOR LONG PATH, DECEMBER, 1946

TRANSMISSION PATH: WASHINGTON, D.C. (39.0°N, 77.5°W) TO TRIESTE, ITALY (45.7°N, 13.8°E)

MUF OWF SUGGESTED FREQUENCY USAGE

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