

CRPL-D33

UNITED STATES DEPARTMENT OF COMMERCE

W. AVERELL HARRIMAN, Secretary

NATIONAL BUREAU OF STANDARDS

F. U. Condon, Director

National Bureau of Standards

AUG 21 1947

BASIC RADIO PROPAGATION PREDICTIONS
FOR AUGUST 1947
THREE MONTHS IN ADVANCE

ISSUED MAY 1947



[Published with approval of the Director of the Budget]

PREPARED BY CENTRAL RADIO PROPAGATION LABORATORY
National Bureau of Standards
Washington 25, D. C.

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.
Price 15 cents, \$1.50 per year on subscription

NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY

Basic Radio Propagation Predictions are prepared by the staff of the Central Radio Propagation Laboratory of the National Bureau of Standards under the direction of J. Howard Dellinger, Chief, and Newbern Smith, Assistant Chief.

The monthly reports of this CRPL-D series are distributed to the Army as the TB 11-499 series, by The Adjutant General; to the Navy as the DNC-13-1 series, by the Registered Publications Section, Division of Naval Communications; and to others by the CRPL.

The CRPL-D series is a monthly supplement to the IRPL Radio Propagation Handbook, Part 1, issued by the Army as TM 11-499 and by the Navy as DNC-13-1, and is required in order to make practical application of the basic Handbook.

Beginning with the July 1946 issue the CRPL-D series, "Basic Radio Propagation Predictions," is available on a purchase basis from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., on the following terms:

Single copy	15 cents
Annual subscription (12 issues)	\$1. 50

New subscribers and those desiring to continue to receive this publication should place their orders with the Superintendent of Documents.

The rules of the Superintendent of Documents require that remittances be made in advance, either by coupons sold in sets of 20 for \$1 and good until used, or by check or money order payable to the Superintendent of Documents. Currency, if used, is at sender's risk. Postage stamps, foreign money, and defaced or smooth coins are not acceptable. Postage is not required in the United States, to United States possessions, and to countries extending franking privileges. For mailing to other countries, an additional amount of about one-third of the purchase price is required. Remittances from foreign countries should be by international money order payable to the Superintendent of Documents or by draft on an American bank.

BASIC RADIO PROPAGATION PREDICTIONS FOR AUGUST 1947 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:

For the Army:

Office of the Chief Signal Officer, War Dept.
 Washington 25, D. C.
 Attention: SIGOL-2.

For the Navy:

Chief of Naval Operations,
 Navy Department,
 Washington 25, D. C.
 (CNC-20-Q).

For Others:

Central Radio Propagation Laboratory,
 National Bureau of Standards,
 Washington 25, D. C.

CONTENTS

I. Terminology.....	Page 2		
II. World-wide prediction charts and their uses..	Page 2	III. Determination, etc.—Continued.	
World map showing zones covered by		Nomogram for obtaining great-circle	
prediction charts, and auroral zones..	Fig. 1	distances, bearings, latitude and longi-	
<i>F</i> 2-zero-muf, in Mc, <i>W</i> zone, predicted	Fig. 5	tude of transmission control points.	
for August 1947.....	Fig. 5	Conversion scale for various distance	Fig. 4
<i>F</i> 2-4000-muf, in Mc, <i>W</i> zone, predicted	Fig. 6	units.....	
for August 1947.....	Fig. 6	IV. Calculation of maximum usable frequencies,	
<i>F</i> 2-zero-muf, in Mc, <i>I</i> zone, predicted for	Fig. 7	optimum working frequencies.....	Page 4
August 1947.....	Fig. 7	Nomograms for transforming <i>F</i> 2-zero-	
<i>F</i> 2-4000-muf, in Mc, <i>I</i> zone, predicted	Fig. 8	muf and <i>F</i> 2-4000-muf to equivalent	
for August 1947.....	Fig. 8	maximum usable frequencies at inter-	
<i>F</i> 2-zero-muf, in Mc, <i>E</i> zone, predicted	Fig. 9	mediate transmission distances; con-	
for August 1947.....	Fig. 9	version scale for obtaining optimum	
<i>F</i> 2-4000-muf, in Mc, <i>E</i> zone, predicted	Fig. 10	working frequencies.....	Fig. 13
for August 1947.....	Fig. 10	Nomogram for transforming <i>E</i> -layer	
<i>E</i> -layer 2000-muf, in Mc, predicted for	Fig. 11	2000-muf to equivalent maximum	
August 1947.....	Fig. 11	usable frequencies and optimum work-	
Median <i>f</i> <i>E</i> s, in Mc, predicted for August	Fig. 12	ing frequencies due to combined effect	
1947.....	Fig. 12	of <i>E</i> layer and <i>F</i> 1 layer at other trans-	
Percentage of time occurrence for <i>E</i> s-	Fig. 15	mission distances.....	Fig. 14
2000-muf in excess of 15 Mc, predicted	Fig. 15	V. Absorption, distance range, and lowest useful	
for August 1947.....	Fig. 15	high frequency.....	Page 6
III. Determination of great-circle distances, bear-	Page 2	VI. Sample muf and owf calculations.....	Page 6
ings, location of transmission control points..	Page 2	For short paths (under 4000 km), page	
Great-circle chart, centered on equator..	Fig. 2	6, table 1, and figure 16.	
Diagram of transmission path, auxiliary	Fig. 3	For long paths (over 4000 km), page 7,	
to explanation of use of distance-	Fig. 3	table 2, and figure 17.	
bearing nomogram, figure 4.....	Fig. 3		

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.

$F^{\circ}F2$ = 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 ($f^{\circ}F2$).

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 August 1947. 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 as discussed in the IRPL Radio Propagation Handbook, Part 1, War Dept. TM 11-499, Navy Dept. DNC-13-1, p. 52, 53, has been modified, substantially as indicated in reports IRPL-R11, 15, 16, and 19. The charts are constructed using data through February 1947 together with a predicted smoothed 12-month running-average Zurich sunspot number of 122, centered on August 1947.

Values of muf and owf based on the charts for the $F2$ -layer (figures 5 through 10) may be increased in accuracy by the use of the reports of the CRPL-Ja series, "Semimonthly Frequency Revision Factors," which are issued between 1 and 2 weeks in advance of the period for which predictions are made and are based on the latest available observations of radio, solar, and ionospheric conditions.

Although ionosphere characteristics are roughly similar for locations of equal latitude, there is also 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 Occurrence for 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 dis-

tances 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

n 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 *F2* 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 distances *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. The use of a work form similar to CRPL form AF is suggested (see table 1 and the blank form AF following figure 17). Note that form AF provides for the inclusion of sporadic E (E_s), which will be discussed under 3 below.

In following the instructions of this section (for propagation by the regular layers) form AF should be modified by omitting columns a , b , f , i and j . The item on procedure in column m should read: "Higher of g , h ," and in column n : "Higher of k , l ."

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 $F2$ -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 either 00 or 24 (not labeled) 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 $F2$ -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. Frequently it will be necessary to make the Greenwich meridian of the transparency coincide with an imagined 26, 28, etc., on the time scale. A convenient aid is to place marks at two-hour intervals on the equatorial line of the transparency.

(4) Repeat steps (1), (2), and (3) for the

$F2$ -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 $F2$ -zero-muf and $F2$ -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:

$F2$ -zero-muf=6.8 Mc. $F2$ -4000-muf=23.0 Mc.
For a distance of 2600 km the $F2$ muf is 19.1Mc.

(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 - $F1$ -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 $F2$ -owf from the $F2$ -muf determined under *c* above by multiplying each figure in column h by 0.85 or by using the conversion scale in figure 13. Enter in column l .

(2) Use for the E -owf the value of E - $F1$ -muf determined under *c* (6) above. This represents a change from the previous practice of taking 97 percent of the E - $F1$ -muf on the nomogram of figure 14. Enter in column k .

(3) Compare the $F2$ -owf and E -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. The use of a work form similar to CRPL form AH is suggested (see table 2 and the blank form AH following figure 17). Note that form AH provides for the inclusion of the effects of sporadic E (E_s), which will be discussed under 3 below.

In following the instructions of this section (for propagation by the regular layers) form AH should be modified by omitting columns a , b , e , g , h , and k . The item on procedure in column m should read: "Higher of c , d ;" in column n : "Higher of i , j ;" in column o : "Higher of d , f ;" and in column p : "Higher of j , l ."

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 either 00 or 24 (not labeled) 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. Frequently it will be necessary to make the Greenwich meridian of the transparency coincide with an imagined 26, 28, etc., on the time scale. A convenient aid is to place marks at two-hour intervals on the equatorial line of the transparency.

(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 g .

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 E_s

Sporadic- E (E_s) propagation may often allow regular transmission when regular E - or F_2 -layer propagation would not. E_s data are not yet sufficient to permit accurate calculations of such propagation, but the fE_s charts of figures 12 and 15 are given as a guide to E_s occurrence.

As the fE_s 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 fol-

lowing procedures should be used to include the effects of E_s 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 fE_s chart, figure 12, using the latitude scale for the zone containing the control point.

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

(3) Multiply fE_s by 5 in each case, obtaining the E_s -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 E_s -2000-muf. No other change is necessary.

(5) In the determination of owf subtract 4 Mc from the E_s -2000-muf to obtain the E_s -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 E_s -2000-owf. No other changes are necessary.

b. For paths under 4000 km long:

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

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

(3) Multiply fE_s by 5, obtaining the E_s -2000-muf. Enter in column b .

(4) In the determination of muf under IV, 1 c , find the E_s -muf for the path by use of the same nomogram, figure 14, as was used for the E - F_1 -muf, applying the E_s -2000-muf to 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 E_s -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 E_s -2000-muf found under (3) above to obtain the E_s -2000-owf, entering in column i . Now find the E_s -owf for the path, using the same nomogram, figure 14, as for the E -owf, applying the E_s -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 -owf, and the E_s -owf, columns l , k , j , is the owf for the path.

Because of the variable nature of E_s , and the relative uncertainty with which E_s is known, caution should be used in the application of E_s -owf, particularly for short paths. While transmission should take place most of the time on E_s -owf, fluctuations in E_s 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 E_s , although transmission may take place more than 80 percent of the time near the E_s -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 August 1947.

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 F_2 -layer muf and owf, and also E_s -muf and 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 for the path obtained by the

procedure of section IV, 1 for the regular layers only are given in columns k and l of table 1. The higher of these two values for each even hour is underscored and plotted in figure 16. The resulting graph of owf , for the regular layers only, is shown as a solid-line curve. It will be noted from table 1 that E - owf is the controlling frequency for the regular layers between the hours of 1400 and 2000.

Values of E_s - owf are controlling for hours for which the value in column j exceeds the corresponding underlined value in columns k or l . For the month of August, E_s - owf is not the controlling frequency over this path at any time. Accordingly, no values of E_s - owf are plotted in figure 16.

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

10.5 Mc will not skip, on the average, at any time of day, but its use is not advisable because of the day-to-day variability, causing some probability of skip during the night hours. Furthermore, because of ionospheric absorption during the daytime, which is more pronounced at low frequencies, it is advisable to use frequencies as little below the owf as possible.

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 9.1 Mc, to be used from 0020 to 1230 GCT, and a day frequency of 13.5 Mc, to be used from 1230 to 0020 GCT, would be satisfactory. The periods of usefulness of these frequencies are shown by the heavy dashed line on figure 16.

2. FOR LONG PATHS

Required: The muf and owf for transmission between Washington, D. C. (39.0° N, 77.5° W) and Trieste (45.7° N, 13.8° E) for average conditions during the month of August 1947.

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 F_2 -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 E_s 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 E_s . 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 14.0 Mc is used, although higher frequencies

may be used during much of the twenty-four hours.

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 11.3 Mc may be used from 0320 to 0950 GCT, a frequency of 19.0 Mc may be used from 1140 to 0050 GCT, and a transition frequency of 14.5 Mc may be used from 0050 to 0320 GCT, and from 0950 to 1140 GCT.

By inspection of the absorption chart and the noise map (figs. 87 and 119, 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.

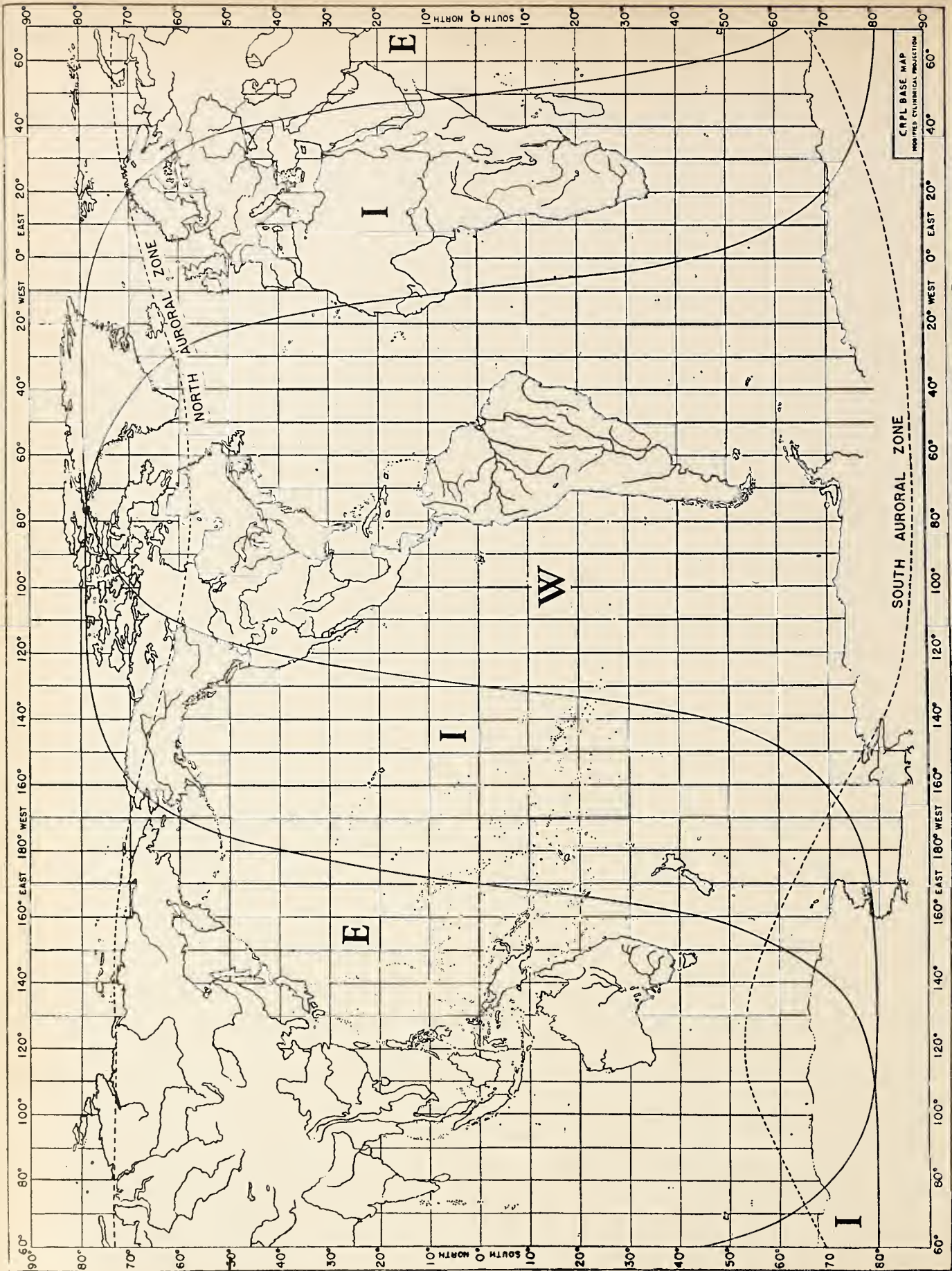


Fig. 1. WORLD MAP SHOWING ZONES COVERED BY PREDICTED CHARTS, AND AURORAL ZONES.

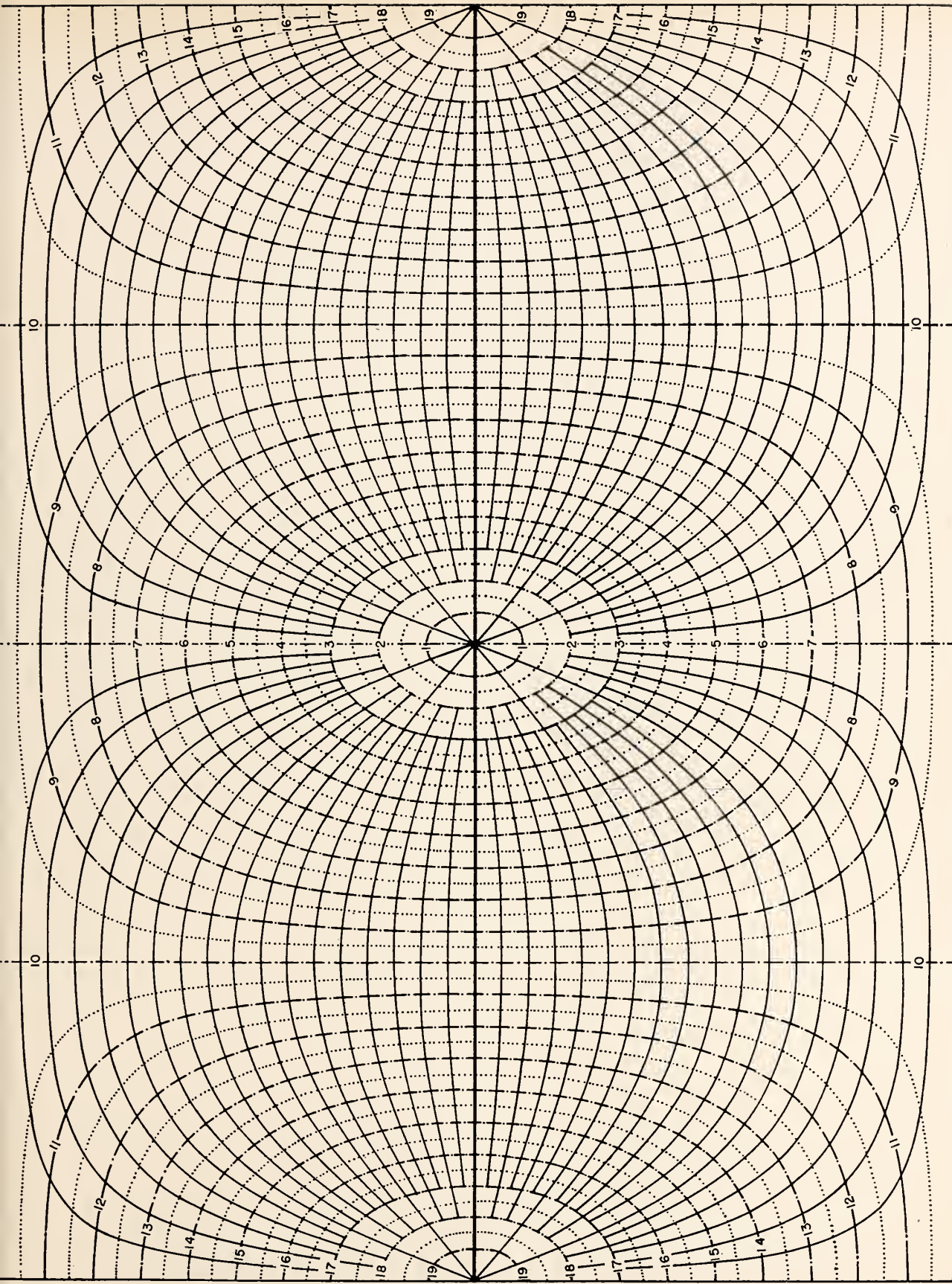


Fig. 2. GREAT CIRCLE CHART CENTERED ON EQUATOR. SOLID LINES REPRESENT GREAT CIRCLES. NUMBERED DOT-DASH LINES INDICATE DISTANCES IN THOUSANDS OF KILOMETERS.

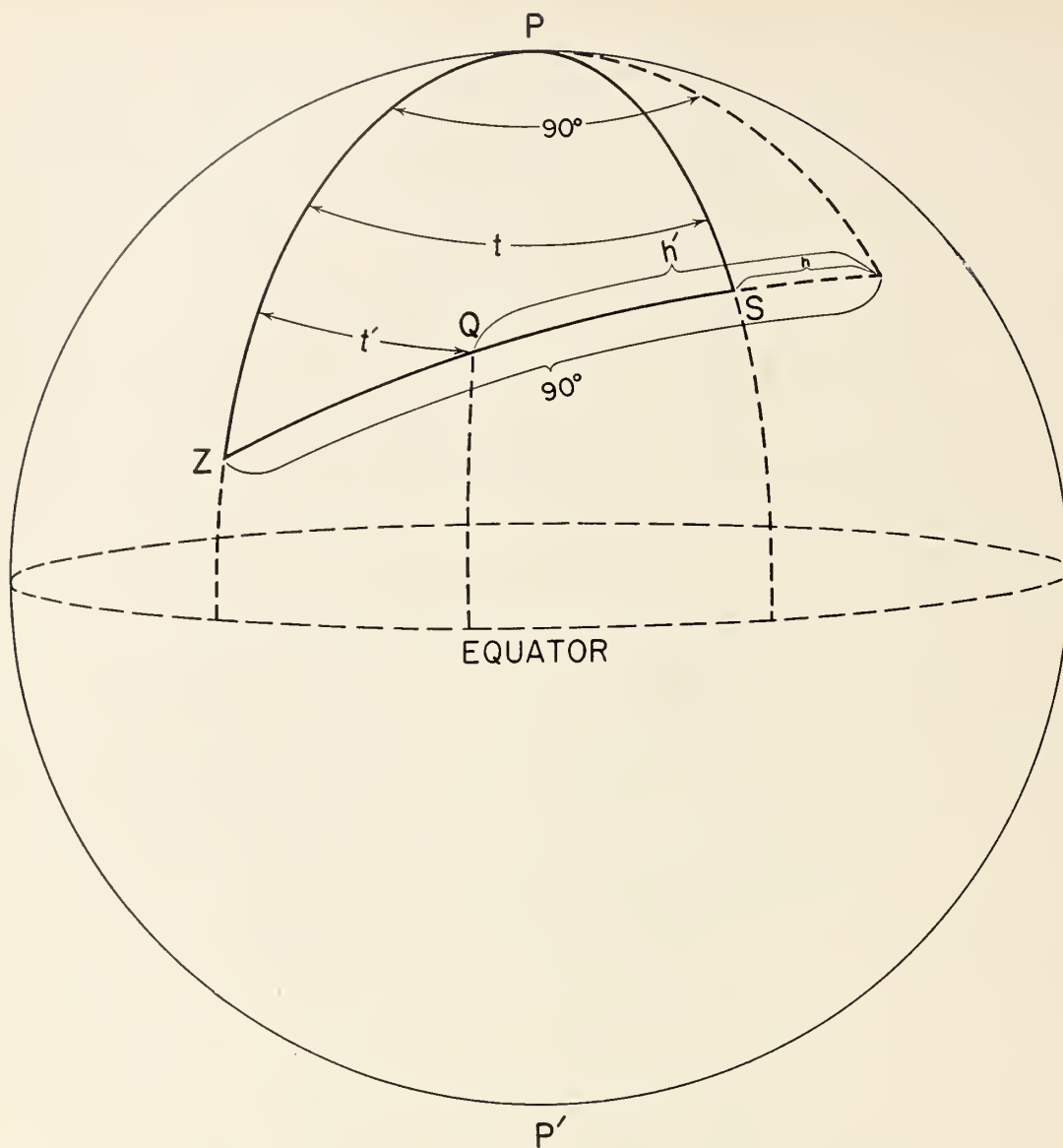


Fig. 3. DIAGRAM OF TRANSMISSION PATH AUXILIARY TO EXPLANATION OF USE OF DISTANCE — BEARING NOMOGRAM, FIG. 4.

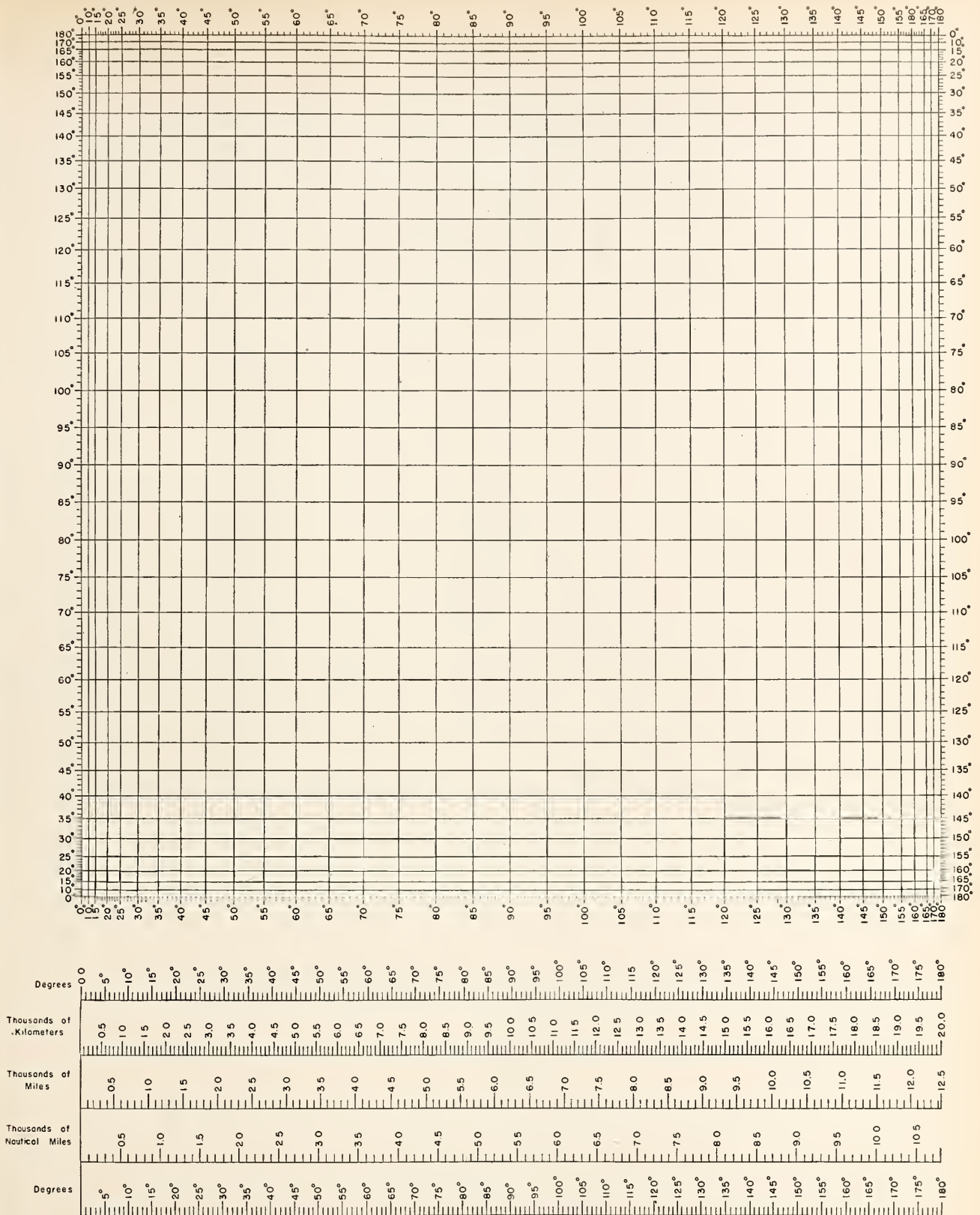


Fig. 4. NOMOGRAM (AFTER D'OCAGNE) FOR OBTAINING GREAT-CIRCLE DISTANCES, BEARINGS, LATITUDE AND LONGITUDE OF TRANSMISSION CONTROL POINTS, SOLAR ZENITH ANGLES.
CONVERSION SCALE FOR VARIOUS DISTANCE UNITS.

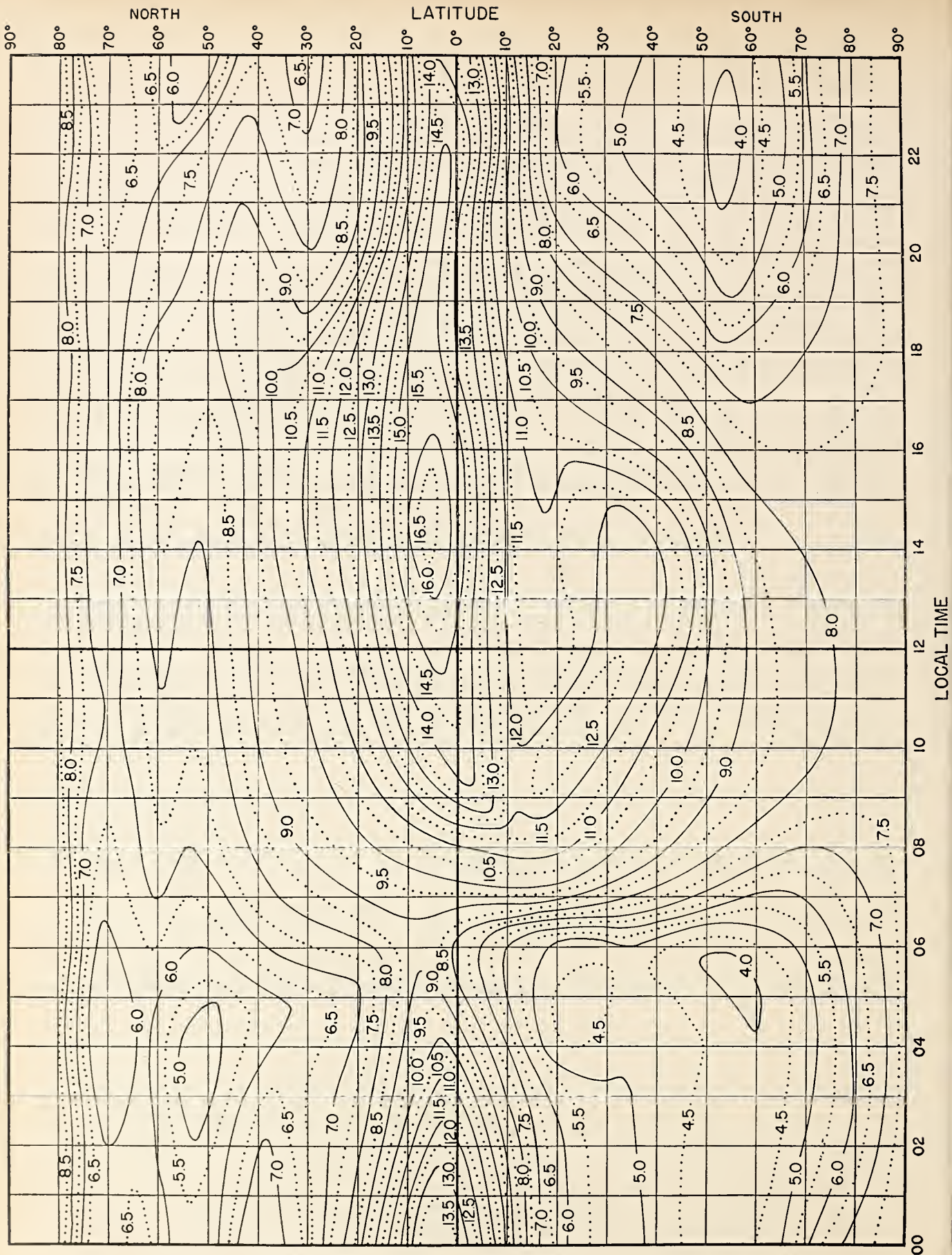


Fig. 5. F_2 ZERO-MUF, IN Mc, W ZONE, PREDICTED FOR AUGUST 1947

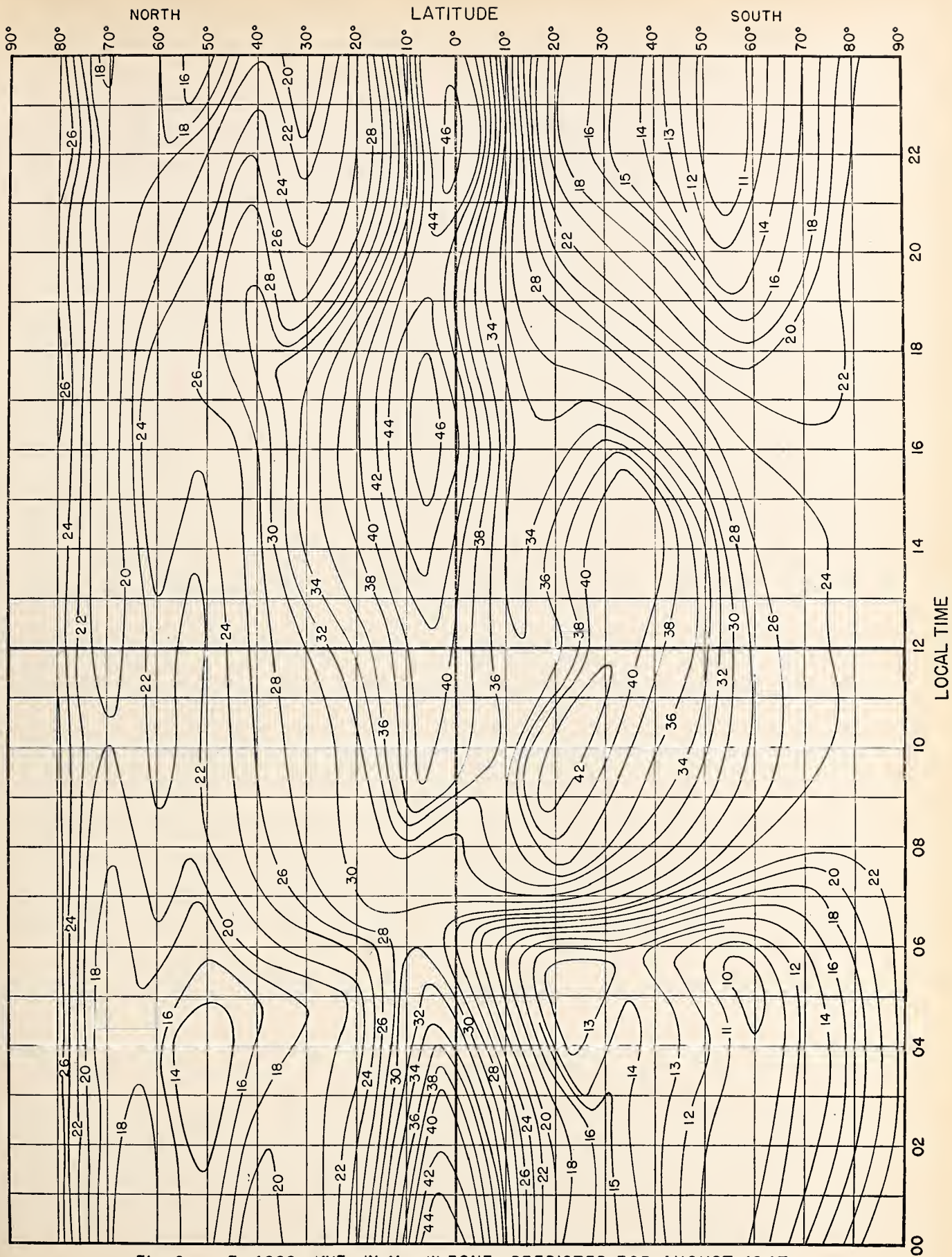


Fig 6 F₂ 4000-MUF, IN Mc, W ZONE, PREDICTED FOR AUGUST 1947

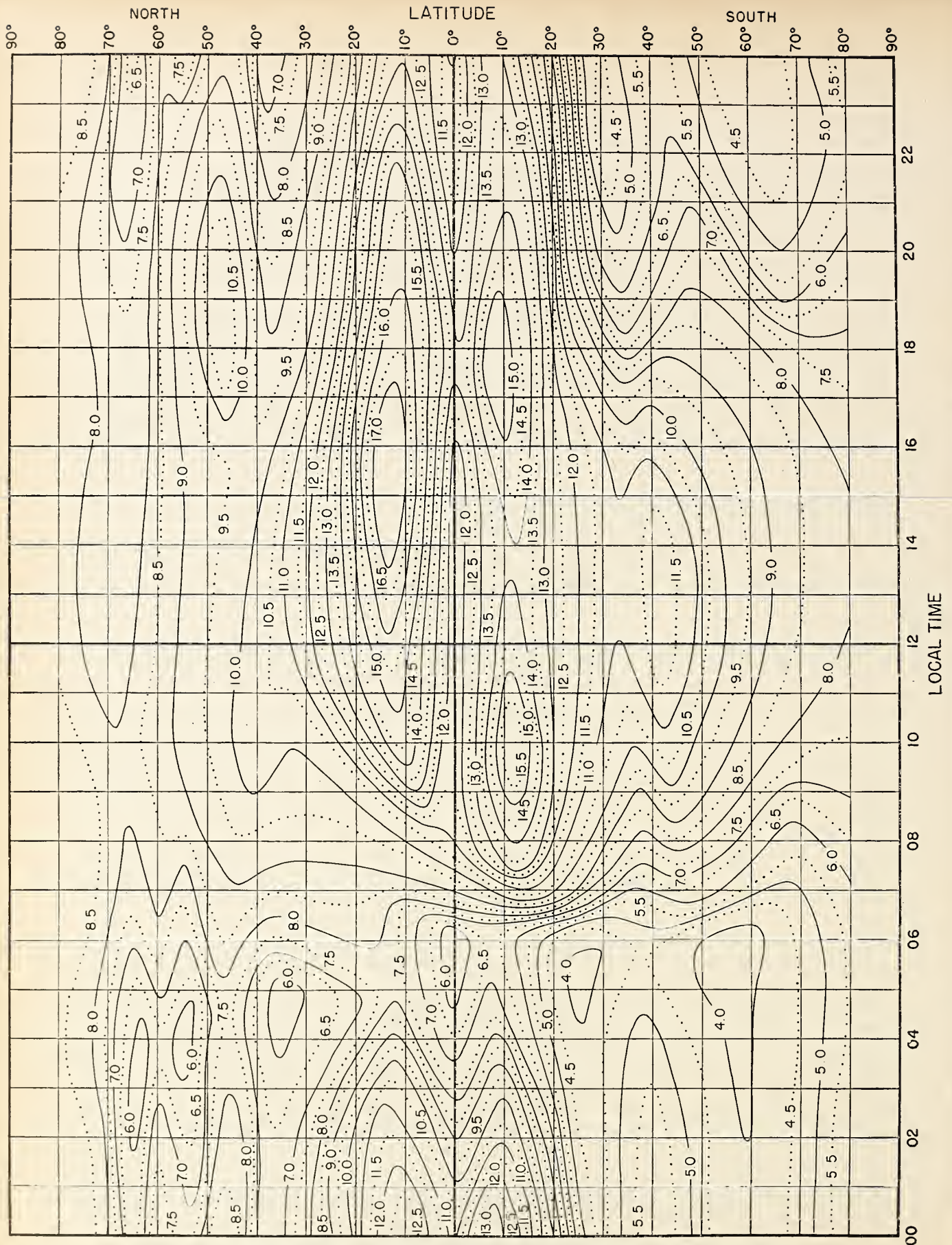


Fig. 7. F_2 ZERO - MUF, IN Mc, I ZONE, PREDICTED FOR AUGUST 1947

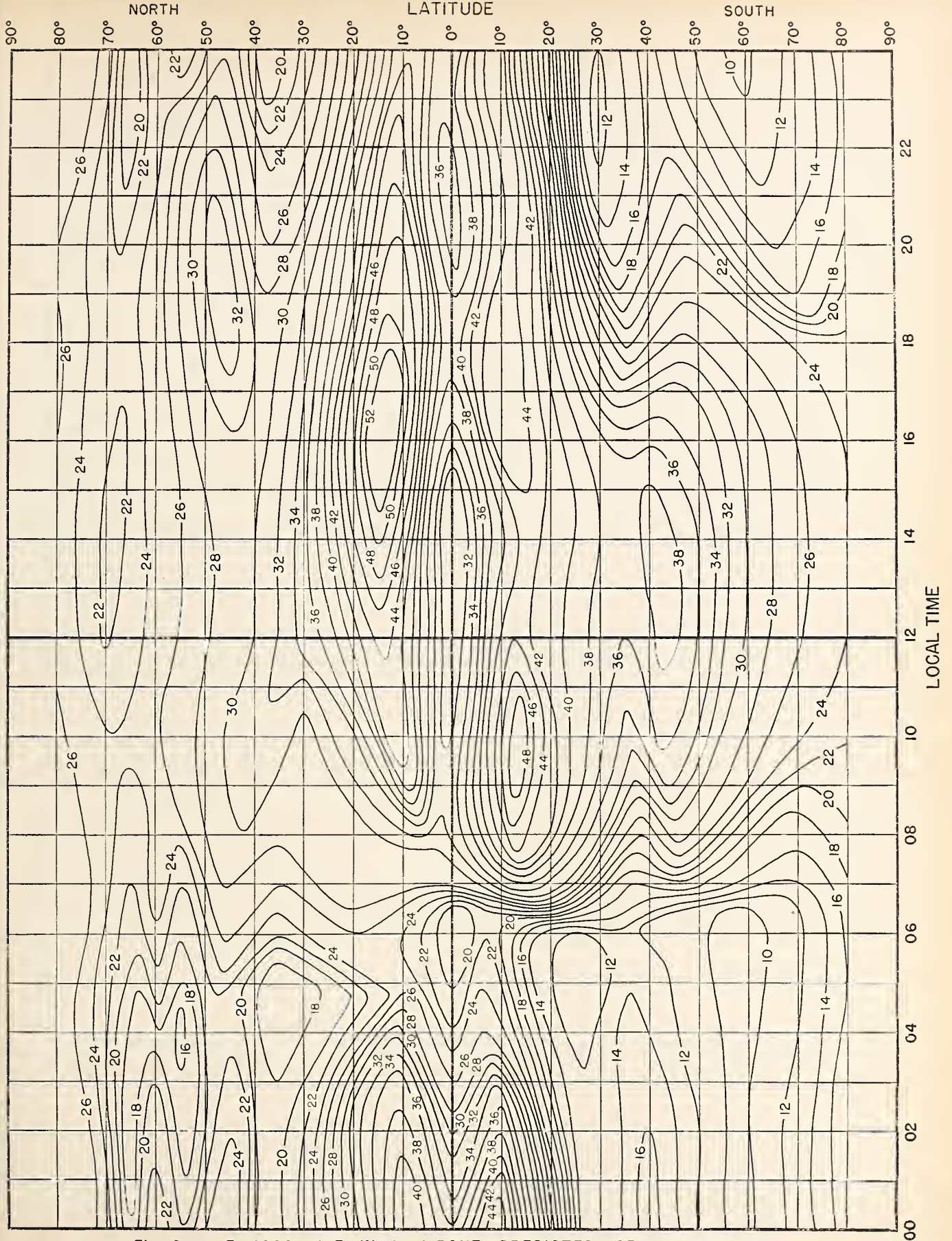


Fig. 8. F_2 4000-MUF, IN Mc, I ZONE, PREDICTED FOR AUGUST 1947

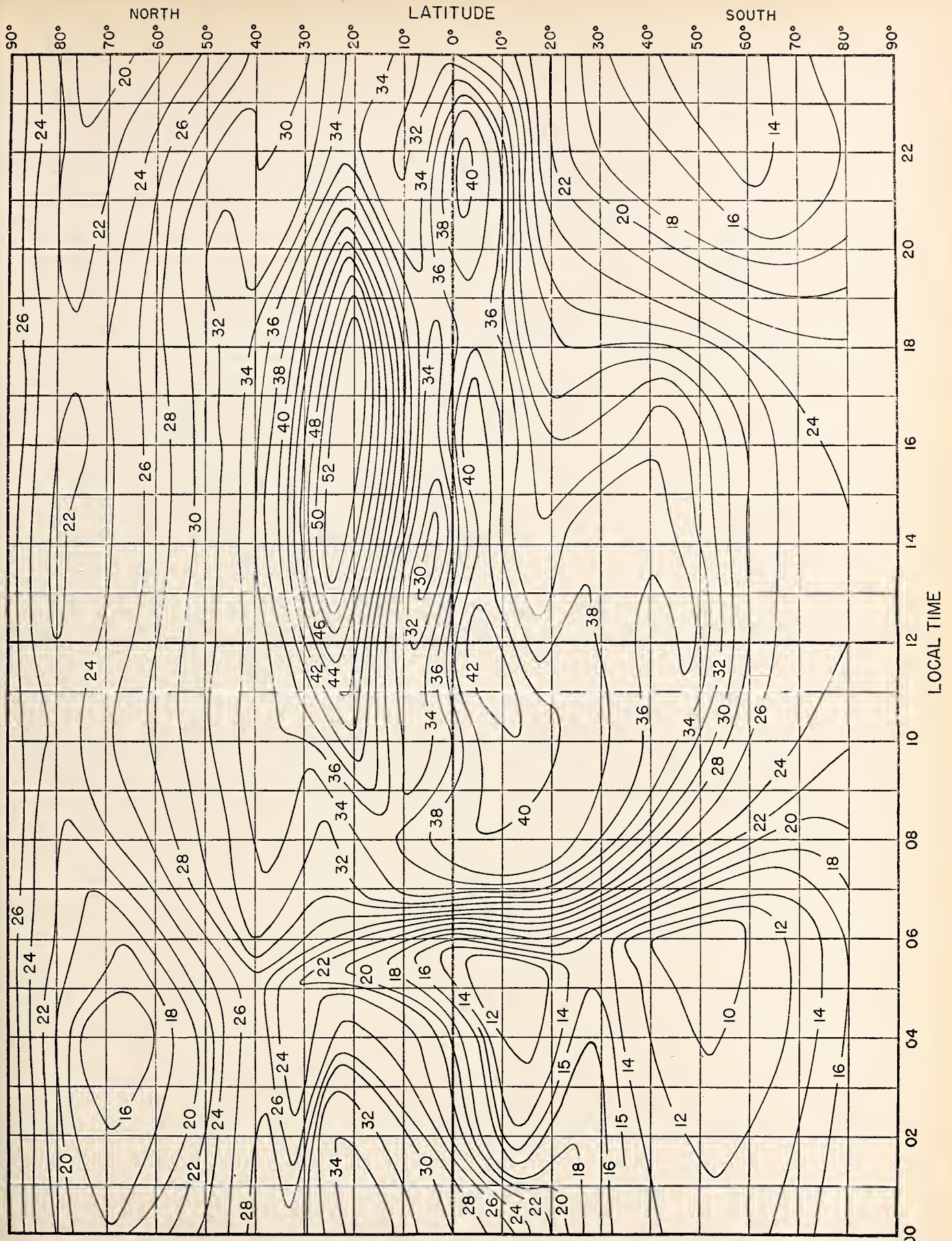


Fig. 10. F₂ 4000-MUF, IN Mc, E ZONE, PREDICTED FOR AUGUST 1947

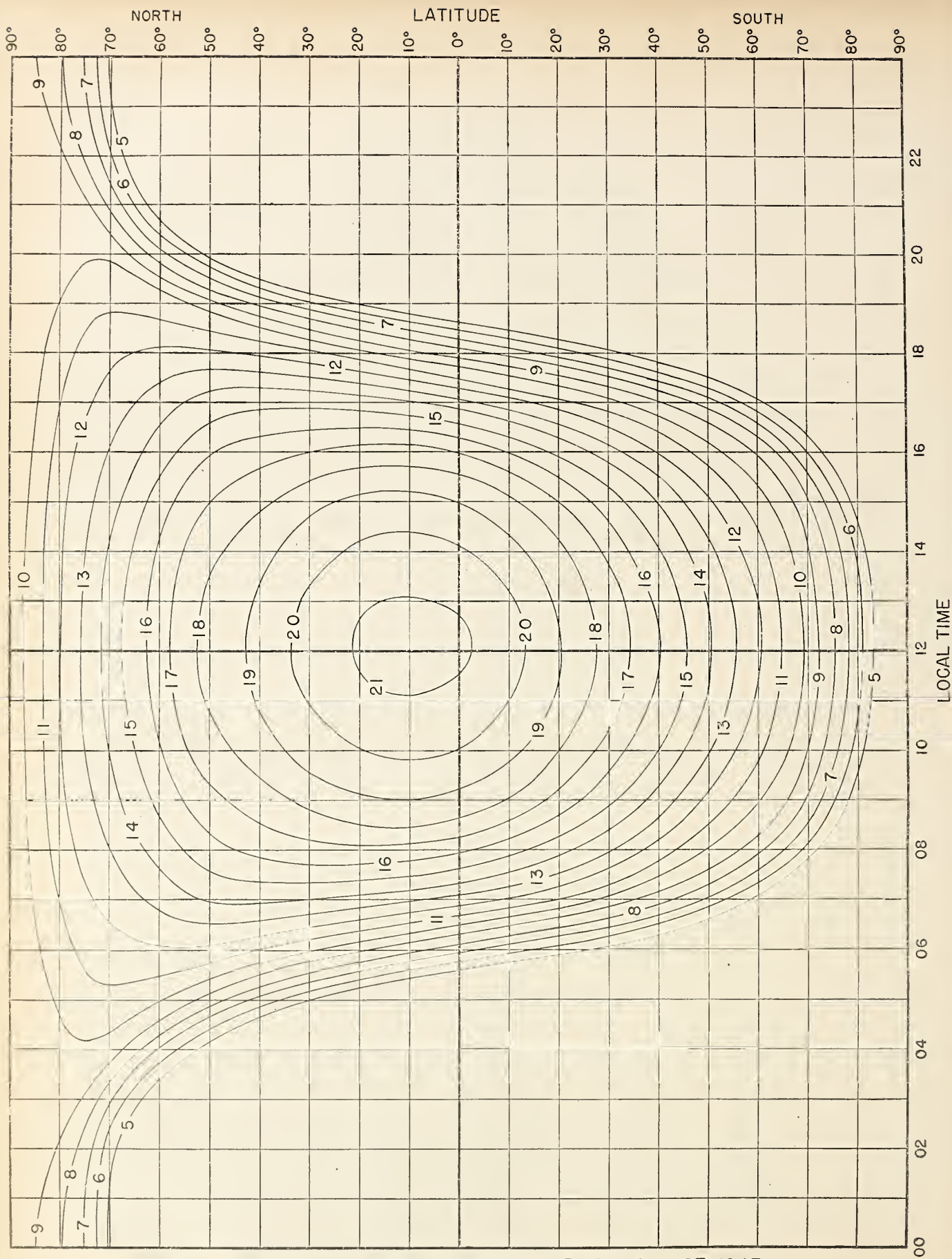


Fig. II. E-LAYER 2000-MUF, IN Mc, PREDICTED FOR AUGUST 1947

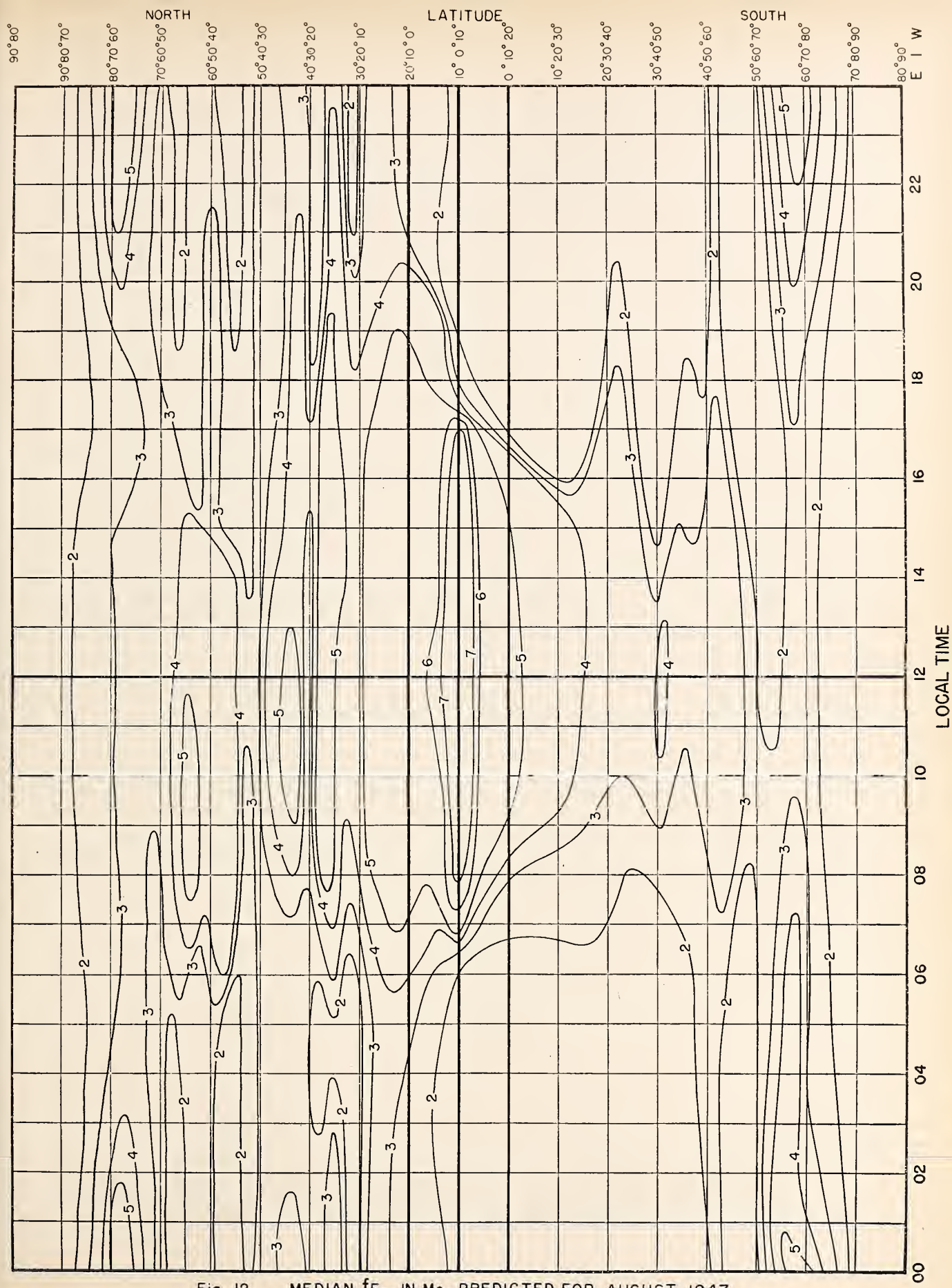


Fig. 12. MEDIAN fE_s , IN Mc, PREDICTED FOR AUGUST 1947

1 km = 0.62137 mile = 0.53961 naut. mi.
 1 mile = 1.60935 km = 0.86836 naut. mi.
 1 naut. mi. = 1.85325 km = 1.1516 mi.

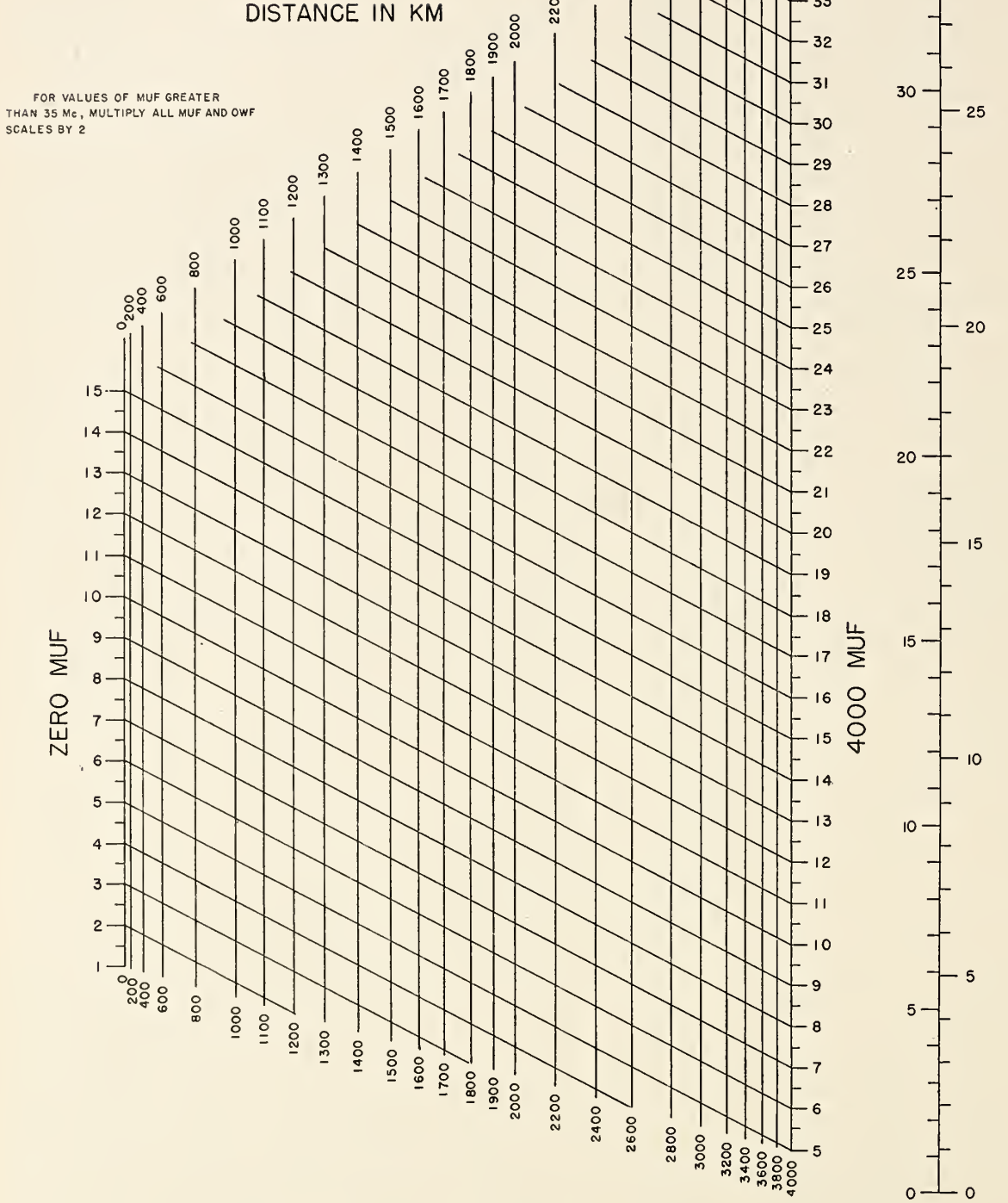


FIG.13. NOMOGRAM FOR TRANSFORMING F_2 -ZERO-MUF AND F_2 -4000-MUF TO EQUIVALENT MAXIMUM USABLE FREQUENCIES AT INTERMEDIATE TRANSMISSION DISTANCES; CONVERSION SCALE FOR OBTAINING OPTIMUM WORKING FREQUENCIES.

1 km = 0.62137 mile = 0.53961 naut. mi.
 1 mile = 1.60935 km = 0.86836 naut. mi.
 1 naut. mi. = 1.85325 km = 1.1516 ml.

E-Layer 2000-muf

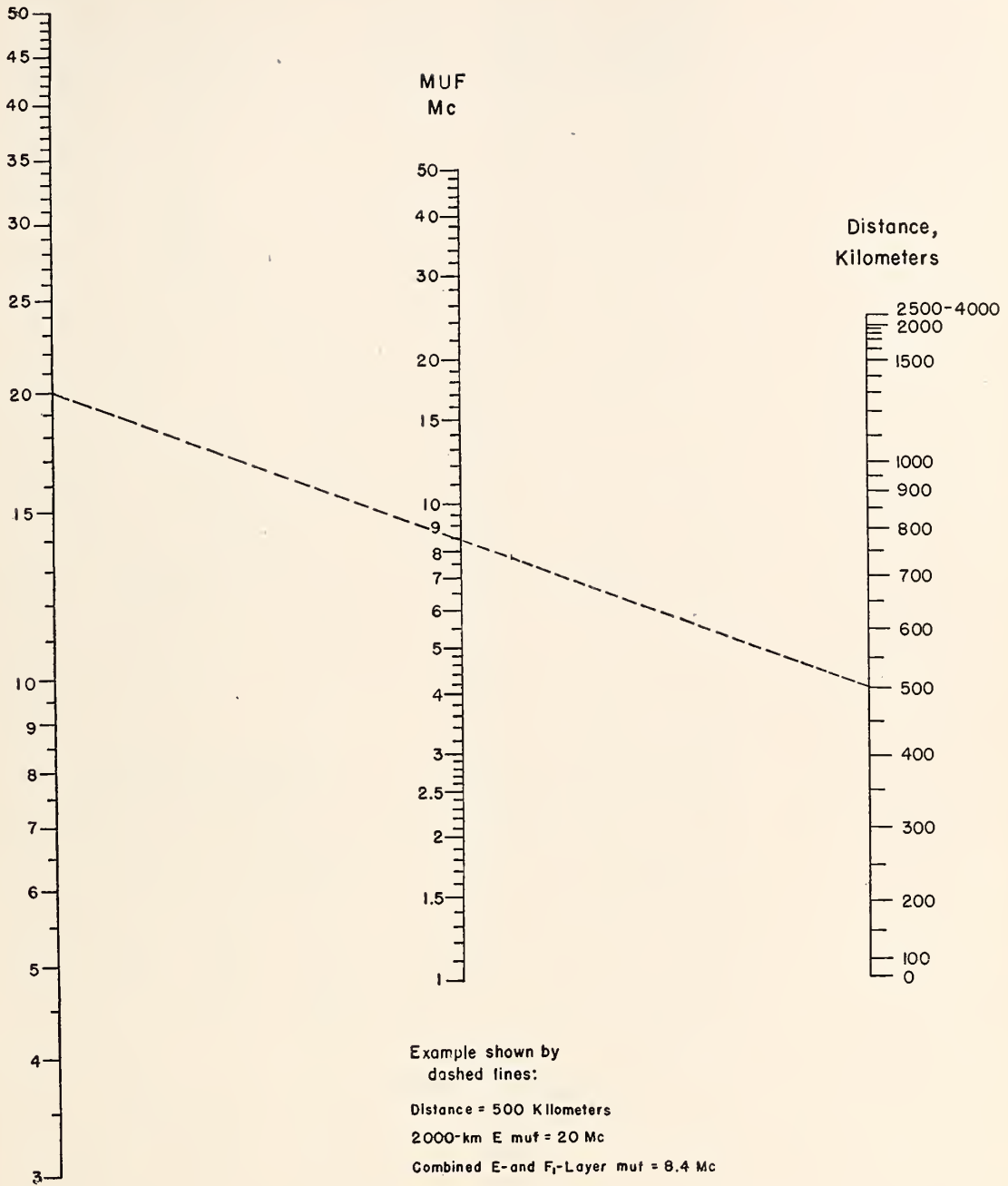


FIG. 14 NOMOGRAM FOR TRANSFORMING E-LAYER 2000-MUF TO EQUIVALENT MAXIMUM USABLE FREQUENCIES AND OPTIMUM WORKING FREQUENCIES DUE TO COMBINED EFFECT OF E LAYER AND F₁ LAYER AT OTHER TRANSMISSION DISTANCES.

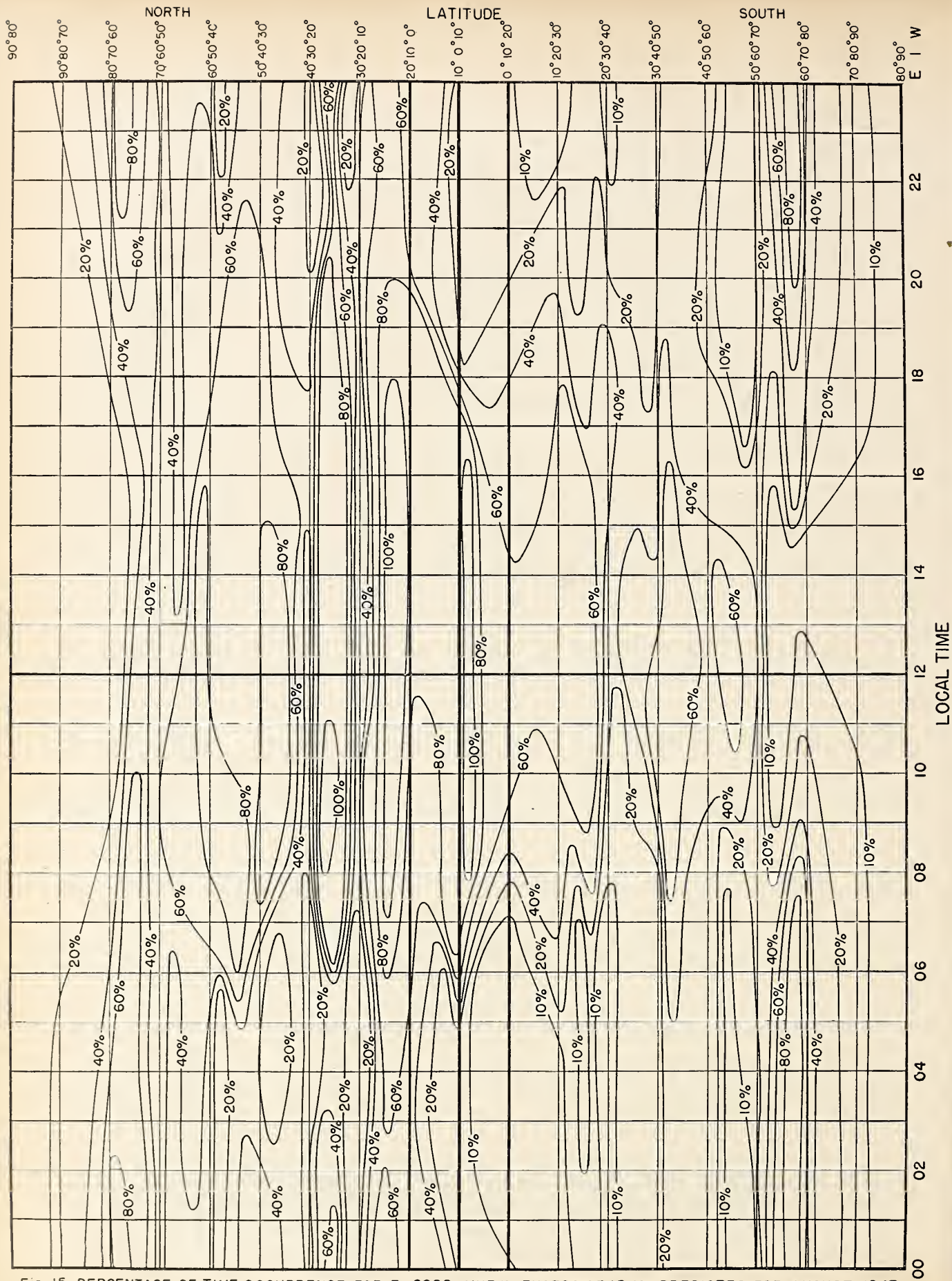
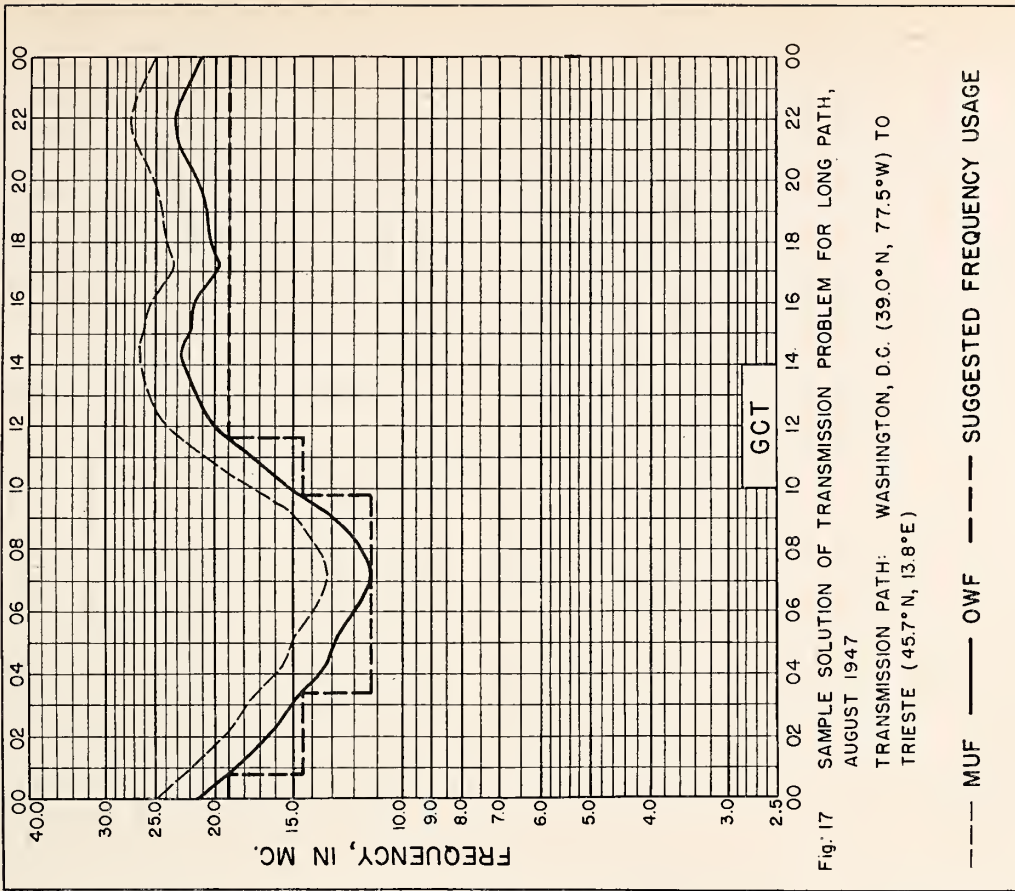
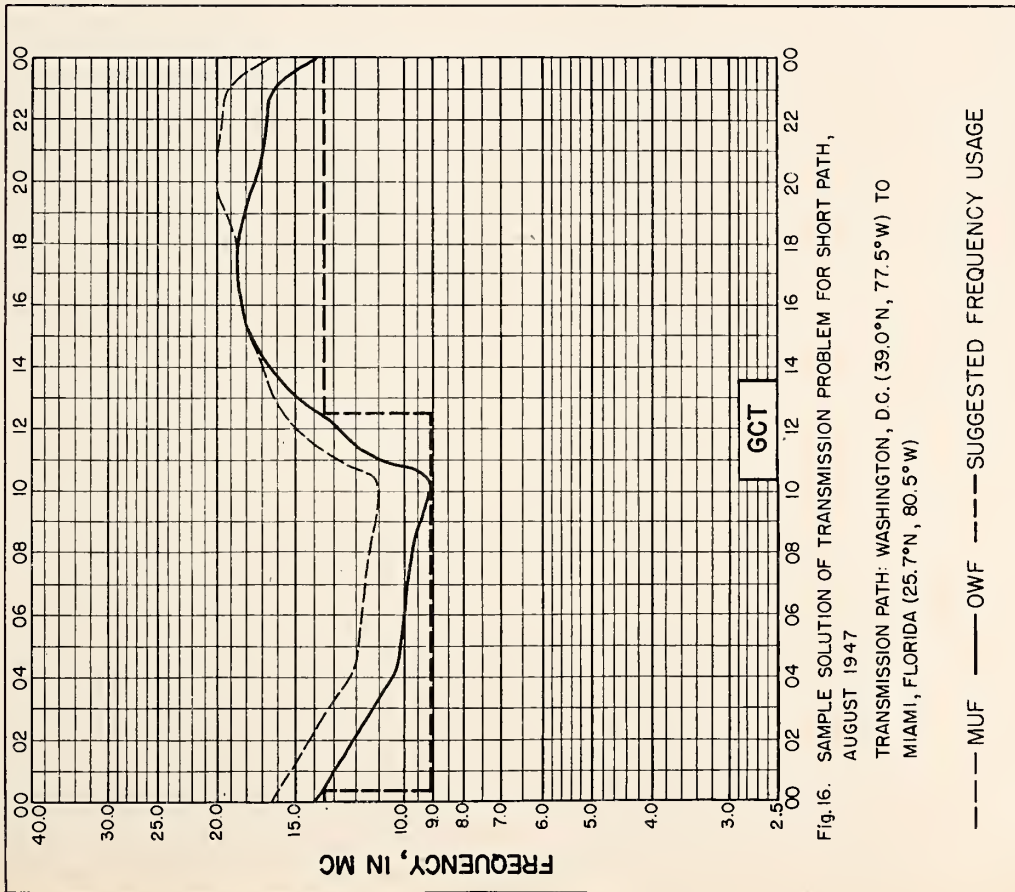


Fig. 15 PERCENTAGE OF TIME OCCURRENCE FOR E_s 2000-MUF IN EXCESS OF 15 Mc PREDICTED FOR AUGUST 1947



MUF-OWF WORK SHEET FOR PATHS 4000 KM OR LESS

Date _____

From _____ To _____ Distance, _____ km Zone _____ Predicted for _____ 194_____

Note: All frequencies are in megacycles.

GCT	fE _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	.85h	Highest of f,g,h	Highest of j,k,l
00														
01														
02														
03														
04														
05														
06														
07														
08														
09														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21														
22														
23														
Done by														
Checked														

MUF-OWF WORK SHEET FOR PATHS OVER 4000 KM.

From _____ To _____ Distance, _____ km Predicted for _____

Note: All frequencies are in megacycles.

	A-end					B-end					MUF	MUF	OWF	OWF	MUF	MUF	OWF	OWF	
	Pt. A in Zone	F ₂ 4000- muf	E-layer 2000- muf	E _s 2000- owf	F ₂ 4000- owf	fE _s	E _s 2000- muf	F ₂ 4000- muf	E-layer 2000- muf	E _s 2000- owf									F ₂ 4000- owf
	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'	l-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																			
01																			
02																			
03																			
04																			
05																			
06																			
07																			
08																			
09																			
10																			
11																			
12																			
13																			
14																			
15																			
16																			
17																			
18																			
19																			
20																			
21																			
22																			
23																			
Done by																			
Checked																			



CRPL and IRPL REPORTS

Daily:

Radio disturbance warnings, every half hour from broadcast station WWV of the National Bureau of Standards. Telephoned and telegraphed reports of ionospheric, solar, geomagnetic, and radio propagation data.

Weekly:

CRPL-J. Radio Propagation Forecast (of days most likely to be disturbed during following month).

Semimonthly:

CRPL-Ja. Semimonthly Frequency Revision Factors for CRPL Basic Radio Propagation Prediction Reports.

Monthly:

CRPL-D. Basic Radio Propagation Predictions—Three months in advance. (War Dept. TB 11-499, monthly supplements to TM 11-499; Navy Dept. DNC-13-1 (), monthly supplements to DNC-13-1.)

CRPL-F. Ionospheric Data.

Quarterly:

*IRPL-A. Recommended Frequency Bands for Ships and Aircraft in the Atlantic and Pacific.

*IRPL-H. Frequency Guide for Operating Personnel.

Reports on high-frequency standards.

Reports on microwave standards.

Reports issued in past:

IRPL Radio Propagation Handbook, Part 1. (War Dept. TM 11-499; Navy Dept. DNC-13-1.)

IRPL-C61. Report of the International Radio Propagation Conference, 17 April to 5 May 1944.

IRPL-G1 through G12. Correlation of D. F. Errors With Ionospheric Conditions.

IRPL-R. Unscheduled reports:

R4. Methods Used by IRPL for the Prediction of Ionospheric Characteristics and Maximum Usable Frequencies.

R5. Criteria for Ionospheric Storminess.

R6. Experimental Studies of Ionospheric Propagation as Applied to the Loran System.

R7. Second Report on Experimental Studies of Ionospheric Propagation as Applied to the Loran System.

R9. An Automatic Instantaneous Indicator of Skip Distance and MUF.

R10. A Proposal for the Use of Rockets for the Study of the Ionosphere.

R11. A Nomographic Method for Both Prediction and Observation Correlation of Ionosphere Characteristics.

R12. Short Time Variations in Ionospheric Characteristics.

R14. A Graphical Method for Calculating Ground Reflection Coefficients.

R15. Predicted Limits for F_2 -layer Radio Transmission Throughout the Solar Cycle.

R16. Predicted F_2 -layer Frequencies Throughout the Solar Cycle, for Summer, Winter, and Equinox Season.

R17. Japanese Ionospheric Data—1943.

R18. Comparison of Geomagnetic Records and North Atlantic Radio Propagation Quality Figures—October 1943 Through May 1945.

R19. Nomographic Predictions of F_2 -layer Frequencies Throughout the Solar Cycle, for June.

R20. Nomographic Predictions of F_2 -layer Frequencies Throughout the Solar Cycle, for September.

R21. Notes on the Preparation of Skip-Distance and MUF Charts for Use by Direction-Finder Stations. (For distances out to 4000 km.)

R22. Nomographic Predictions of F_2 -layer Frequencies Throughout the Solar Cycle, for December.

R23. Solar-Cycle Data for Correlation With Radio Propagation Phenomena.

R24. Relations Between Band Width, Pulse Shape and Usefulness of Pulses in the Loran System.

R25. The Prediction of Solar Activity as a Basis for Predictions of Radio Propagation Phenomena.

R26. The Ionosphere as a Measure of Solar Activity.

R27. Relationships Between Radio Propagation Disturbance and Central Meridian Passage of Sunspots Grouped by Distance From Center of Disc.

R28. Nomographic Predictions of F_2 -layer Frequencies Throughout the Solar Cycle, for January.

R29 and 29-A. Revised Classification of Radio Subjects Used in National Bureau of Standards and First Supplement (N. B. S. Letter Circular LC-814 and Supplement, superseding Circular C385).

R30. Disturbance Rating in Values of IRPL Quality—Figure Scale From A. T. & T. Co. Transmission Disturbance Reports to Replace T. D. Figures as Reported.

R31. North Atlantic Radio Propagation Disturbances, October 1943 Through October 1945.

R32. Nomographic Predictions of F_2 -layer Frequencies Throughout the Solar Cycle, for February.

R33. Ionospheric Data on File at IRPL.

R34. The Interpretation of Recorded Values of fEs .

R35. Comparison of Percentage of Total Time of Second-Multiple Es Reflections and That of fEs in Excess of 3 Mc.

IRPL-T. Reports on Tropospheric Propagation.

T1. Radar operation and weather. (Superseded by JANP 101.)

T2. Radar coverage and weather. (Superseded by JANP 102.)

CRPL-T3. Tropospheric Propagation and Radio-Meteorology. (Reissue of Columbia Wave Propagation Group WPG-5.)

*Items bearing this symbol are distributed only by U. S. Navy in NONREGISTERED PUBLICATIONS MEMORANDA (NRPM). IRPL-A and -H issued under one cover with NRPM identifying numbers.

