National Bureau of Standards

SEP 22 1947

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Instructions for the use of Basic Radio Propagation Predictions

U. S. Department of Commerce
National Bureau of Standards

The Central Radio Propagation Laboratory

The propagation of radio waves over long distances depends on their reflection from the ionosphere, the electrically conducting layers in the earth's upper atmosphere. The characteristics of these layers are continuously changing. For regular and reliable communication, it is therefore necessary to collect and analyze ionospheric data from stations all over the world in order that predictions of usable frequencies between any two places at any hour can be made. During the war, the United States Joint Communications Board set up the Interservice Radio Propagation Laboratory at the National Bureau of Standards to centralize ionospheric work and predictions for the armed forces of the United States.

On May 1, 1946, this activity returned to peacetime status as the Central Radio Propagation Laboratory of the National Bureau of Standards. Designed to act as a permanent centralizing agency for propagation predictions and studies, analogous in the field of radio to the reports of the Weather Bureau in the field of meteorology, the Central Radio Propagation Laboratory was established in cooperation with the many Government agencies vitally concerned with communication and radar propagation problems. These agencies are represented on the advisory Executive Council of the laboratory, including representatives of the War Department, Navy Department, Civil Aeronautics Authority, Federal Communications Commission, State Department, Coast Guard, Coast and Geodetic Survey, and the Weather Bureau. In addition, industry is represented by the Radio Technical Planning Board, while the Carnegie Institution of Washington serves in an advisory capacity.

The Central Radio Propagation Laboratory receives and analyzes data from approximately 60 stations located throughout the world, including 13 domestic and 8 overseas stations which are operated either directly or under contract by the National Bureau of Standards. Ionospheric data and predictions are disseminated to the armed forces, commercial users, scientists, and laboratories. The basic ionospheric research of the laboratory includes theoretical and experimental studies of maximum usable frequencies, ionospheric absorption, long-time variations of radio propagation characteristics, the effects of the sun on radio propagation, and the relation between radio disturbance and geomagnetic variation. In the microwave field, the laboratory is investigating the relation between radio propagation and weather phenomena as well as methods by which predictions can be made and radio communications improved in this portion of the radio-frequency spectrum. Another phase of the laboratory's work is the development and maintenance of standards and methods of measurement of many basic electrical quantities throughout the entire frequency spectrum.

Basic Radio Propagation Predictions

These predictions are published each month, 3 months in advance of the month to which the predictions apply, for those concerned with radio communication. The Basic Radio Propagation Predictions (CRPL Series D) permit the determination of the best sky-wave frequencies over any path at any time of day for average conditions for the month of prediction. Charts of extraordinary-wave critical frequency for the F2 layer, of maximum usable frequency for a transmission distance of 4,000 km, and of percentage of time occurrence for transmission by sporadic E in excess of 15 Mc, for a distance of 2,000 km, are included.

Annual subscription for the Basic Radio Propagation Predictions: United States, Canada, Cuba, Mexico, Newfoundland, and the Republic of Panama, $1.50; other countries, $2. Orders, with remittances, should be sent to the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

U. S. DEPARTMENT OF COMMERCE
W. Averell Harriman, Secretary
NATIONAL BUREAU OF STANDARDS
E. U. Condon, Director

Instructions for the use of Basic Radio Propagation Predictions

National Bureau of Standards Circular 465
Issued August 27, 1947

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. - Price 25 cents

Preface

This manual was prepared by the staff of the Central Radio Propagation Laboratory, National Bureau of Standards, under the direction of J. Howard Dellinger, Chief, and Newbern Smith, Assistant Chief. Its purpose is to explain how calculations of maximum usable frequencies and optimum working frequencies may be made for sky-wave transmission over any path for any time of day during the month in question by use of the contour charts of frequency issued monthly in the Basic Radio Propagation Predictions (CRPL Series D).

The methods involved, although detailed, are relatively simple. An approximate great-circle path is drawn by tracing, and "control points" are found whose locations are dependent upon the length of the path. Values of critical frequencies and maximum usable frequencies (for distances of 2,000 km and 4,000 km) are scaled at these control points, and, in the case of paths less than 4,000 km in length, are converted by nomograms to obtain values for the actual length of the path. Comparisons are made between frequencies as reflected from the various layers and from patches of sporadic *E*, as well as between reflections at different control points. The most important case of all, namely transmission by the *F*2-layer over a transmission path more than 4,000 km in length, is worked out simply by scaling the *F*2-layer maximum usable frequencies for a distance of 4,000 km, at each of two control points, and then choosing the lower of the two values thus found.

It is believed that these technics for the calculation of optimum working frequencies will be of material assistance in the design of communication equipment and in assigning and using radio frequencies for most efficient radio sky-wave transmission.

E. U. Condon, *Director.*

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1. 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 4,000-kilometer paths.

2000–muf chart = contour chart of muf for 2,000-kilometer paths.

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

2. Aids To Be Used With CRPL–D Series

This manual, prepared for use with the CRPL–D series, "Basic Radio Propagation Predictions," contains essentially the material hitherto repeated in each issue of that series, together with prediction charts and sample problems for the months of June and March 1947. Beginning with CRPL–D37, issued September 1947, the CRPL–D series will consist of:

(a) the contour charts of $F2$–zero–muf and $F2$–4000–muf for each of the three zones, W, I, and E into which the world is divided for the purpose of taking into consideration the variation of the characteristics of the $F2$ layer with longitude;

(b) the world-wide contour chart of E-layer 2000–muf;

(c) the contour chart of median fEs, and

(d) the chart showing percentage of time occurrence for Es-2000-muf in excess of 15 Mc.

These nine charts, corresponding to figures 3 to 10 and 13 of this manual, will be issued as usual 3 months in advance of the month for which the predictions are made.

The subscription price of the CRPL–D series, new form, is $1.50 per year.

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.

As aids to the preparation of tables and graphs of maximum usable and optimum working frequencies, the following material is duplicated at the end of this manual:

CRPL Base Map (fig. 1).

Great Circle Chart Centered on Equator (fig. 2).

Nomogram for Transforming F2-Zero-Muf and F2-4000-Muf to Equivalent Maximum Usable Frequencies at Intermediate Transmission Distances (fig. 11).

Nomogram for Transforming E-layer 2000-Muf to Equivalent Maximum Usable Frequencies and Optimum Working Frequencies (fig. 12).

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

3. World-Wide Prediction Charts and Their Uses

The charts, figures 3 to 9, give world-wide predictions of monthly average maximum usable frequencies for June 1947. In addition, figures 16 to 20 give predictions for March 1947. Conditions may be markedly different on disturbed days, especially in or near the auroral zones, shown on the map of figure 1.

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. 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 4,000 km. 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 gyrofrequency for the location.

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 5.3.

Attention is called to the fact that the 50-percent contour in figure 13, "Percentage of Time Occurrence for *Es*-2000-muf in Excess of 15 Mc," does not necessarily coincide with the 3-Mc contour in figure 10, "Median *fEs*, in Mc," because the two charts are prepared independently.

4. Determination of Great-Circle Distances and Location of Transmission Control Points

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 two points 180° apart 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. Often 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 great-circle path which passes through the terminal points. The paths between Washington, D. C., and Miami, Fla., and Washington and Trieste, are shown in their correct positions on figure 2.

(c) For paths shorter than 4,000 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. The midpoint of the Washington-Miami path is at M on figure 2.

(d) For paths longer than 4,000 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, 2,000 km from each end.

For E layer, points A' and B', 1,000 km from each end.

These points for the Washington-Trieste path are shown on figure 2.

5. Calculation of Maximum Usable Frequencies and Optimum Working Frequencies

5.1. Determination of MUF and OWF for Distances Less Than or Equal to 4,000 km (Propagation by E and F Layers)

(a) The use of a work form similar to CRPL form AF is suggested (see table 1 and the blank form AF, following fig. 23). Note that form AF provides for the inclusion of sporadic E (*Es*), which is discussed in section 5.3.

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 by using the methods of section 4 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 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 *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. 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 2-hour intervals on the equatorial line of the transparency.

(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 9, 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 11, 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, interpolating between the oblique lines. Enter in column h.

Example:

*F*2-zero-muf=6.8 Mc. *F*2-4000-muf=23.0 Mc. For a distance of 3,000 km the *F*2 muf is 20.8 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 12, 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 each figure in column h by 0.85 or by using the conversion scale in figure 11. Enter in column l.

(2) Use for the *E*-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 12. Enter in column k.

(3) Compare the *F*2-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.

5.2. Determination of MUF and OWF for Distances Greater Than 4,000 km (Propagation by E and F 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 4, (d).)

(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 fig. 23.) Note that form AH provides for the inclusion of the effects of sporadic *E* (*Es*), which are discussed in section 5.3.

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 4. 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 5.1, (b), 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 2-hour intervals on the equatorial line of the transparency.

(4) Repeat steps (1), (2), and (3) on the *E*-layer 2000-muf chart, figure 9, 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 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 9, 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 11, 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 11, 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.

5.3. 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 10 and 13 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 10 and 13, 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 4,000 km or less; determination of muf:

(1) Follow the instructions of section 5.1, filling in columns c, d, e, g, h, of CRPL form AF (table 3).

(2) Place the great-circle path transparency prepared in section 4, over the median *fEs* chart, figure 10, making sure to use the latitude scale for the zone containing the control point.

(3) Scale *fEs* at the midpoint of the path, in a manner similar to that outlined in section 5.1 (c), (1), (2), and (3). Enter in column a of form AF (table 3).

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

(5) Find the *Es*-muf for the path by use of the nomogram, figure 12, applying the values of *Es*-2000-muf (found in the preceding step and entered in column b) to the left-hand scale and reading the answer on the middle scale. Enter in column f.

(6) Compare the values of muf in columns f, g, h. The highest of the three values, the *Es*-muf, the *E*-*F*1-muf, and the *F*2-muf, is the muf for the path. Enter in column m.

(b) For paths 4,000 km or less; determination of owf:

(1) In addition to the columns previously filled in under (a) above, fill in columns k and l of table 3.

(2) Subtract 4 Mc from the value of *Es*-2000-muf previously entered in column b of table 3, thus obtaining the *Es*-2000-owf. Enter in column i.

(3) Find the *Es*-owf for the path by use of the nomogram, figure 12, applying the *Es*-2000-owf (found in the preceding step and entered in column i) to the left-hand scale and reading the answer on the middle scale. Enter in column j.

(4) Compare the values of owf in columns j, k, l. The highest of the three values, the *Es*-owf, the

E-owf, and the *F*2-owf, is the owf for the path. Enter in column n.

(c) For paths over 4,000 km in length; determination of muf:

(1) Follow the instructions of section 5.2, filling in columns c, d, i, j, of CRPL form AH (table 4).

(2) Repeat step (2) of (a) above.

(3) Scale *fFs* at control points *A′* and *B′*, in a manner similar to that outlined in section 5.2 (d), (1), (2), and (3). Enter in columns a and g, respectively, on form AH (table 4).

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

(5) Compare the values of muf in columns b, c, d. The highest of each set of three values is the muf for the *A*-end. Enter in column m.

(6) Compare the values of muf in columns h, i, j. The highest of each set of three values is the muf for the *B*-end. Enter in column n.

(7) Compare the values of muf in columns m and n. The lower of the two values, the muf for the *A*-end and the muf for the *B*-end, is the muf for the path. Enter in column q.

(d) For paths over 4,000 km in length; determination of owf:

(1) In addition to the columns previously filled in under (c) above, fill in columns f and l of table 4.

(2) Subtract 4 Mc from the values of *Es*-2000-muf previously entered in columns b and h of table 4, thus obtaining the *Es*-2000-owf for the *A*-end and the *B*-end of the path. Enter in columns e and k, respectively.

(3) Compare the values of owf in columns d, e, f (column d represents both muf and owf). The highest of each set of three values is the owf for the *A*-end. Enter in column o.

(4) Compare the values of owf in columns j, k, l (column j represents both muf and owf). The highest of each set of three values is the owf for the *B*-end. Enter in column p.

(5) Compare the values of owf in columns o and p. The lower of the two values, the owf for the *A*-end and the owf for the *B*-end, is the owf for the path. Enter in column r.

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. Even when 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.

6. Choice of Operating Frequencies

The charts of the CRPL–D series give information only on the upper limits of operating frequencies for sky-wave propagation. The lower limits of frequency are determined by ionospheric absorption, transmitter power, and signal-noise relationships at the receiving location; the calculation of these factors is outside the scope of this manual.

The knowledge of the upper frequency limits is generally adequate for most high-frequency propagation problems normally encountered in the field. If communication is possible at all, it will be best on frequencies near the upper limit; thus, in any given case, if operating frequencies are chosen near the calculated owf prediction, the best practicable communications operation should be obtained.

The use of frequencies too far below the owf will result in weak reception owing to increasing ionospheric absorption as the frequency decreases. If frequencies above the owf are used, there is increasing liability to propagation failure due to skipping, or penetration through the ionosphere; and communication may be difficult or slow because of increased fading due to multipath propagation.

A practical factor which needs to be considered is the number of frequencies available and the undesirability of changing frequency too often. Also, at times, interference in crowded portions of the frequency spectrum may necessitate use of a frequency that would not otherwise be best. Thus, considerable use may be made of *Es* propagation at the higher frequencies, bearing in mind the necessity of changing to a lower frequency at times when *fEs* is too low.

It will generally be found that on paths 4,000 km or less, for a given season and phase of the sunspot cycle, two frequencies are adequate—a day frequency and a night frequency. Very few paths, even of great lengths, require more than three frequencies for a given season and phase of the sunspot cycle. If a number of frequencies are available, good operating practice is to schedule their use so as to be as close as practicable to, but not above, the owf. If failure occurs on a frequency so chosen, the following procedures are recommended:

1. If a night frequency fails, in the neighborhood of sunrise, change to a higher frequency (the day or transition frequency).

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2. If a day frequency fails, in the neighborhood of sunset, change to a lower frequency (the night or transition frequency).

3. If the day frequency fails during full daylight hours over the path, try first the next higher frequency, and, if that does not work, the next lower frequency.

4. If the night frequency fails during the hours of darkness over the path, change to the next lower frequency.

5. Abrupt cessation of signals during the day probably signifies a solar flare disturbance, with greatly increased absorption; if higher frequencies do not work, nothing will, except frequencies below 100 kc or so.

6. Abrupt cessation of signals at sunset or at night indicates skipping; a lower frequency should be used.

7. Gradual cessation of signals usually indicates increasing ionospheric absorption; a higher frequency should be used. However, during ionosphere storms of the type associated with magnetic disturbances, with the greatest effects apparent in high latitudes, a frequency lower than usual should be used. Such storms, not to be confused with the sudden ionosphere disturbances of 5 above, are usually characterized by flutter fading, especially marked at night, as well as increased absorption. At times it will be necessary to relay through points within 35° of the equator.

Finally, it should be noted that transmission paths crossing or passing near the auroral zone (see fig. 1) are especially liable to ionospheric and magnetic disturbance; propagation over such paths may be relatively poor, even at best, and subject to protracted periods of complete blackout. The calculation of owf over such paths is unreliable; extreme variation in $f°F2$, together with frequent occurrence of *Es* may make operation nearly as reliable at frequencies much higher than the calculated owf as at the owf itself.

7. Sample MUF and OWF Calculations

7.1. Problem 1 (Short Path)

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 June 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 1,500 km, all in W zone.

The values of *E*- and *F*2-layer muf and owf for even hours, GCT, as determined by using the procedure given in section 5.1, are given in table 1. Values of *Es*-muf and owf, determined in accordance with the instructions of section 5.3, (a), (b), are given in table 3. The final values are presented graphically in figure 14, no separation of muf according to layers being shown, but with the owf for the regular layers and the owf, including *Es*, being shown separately.

Inspection of columns g and h of table 1 shows that *F*2-muf is the controlling frequency for the regular layers during 7 of the 12 hours listed. Comparison of columns k and l of table 1 shows that *F*2-owf is the controlling frequency for the regular layers during exactly half of the hours listed. Note that, while *F*2-muf controls at 2200, *E*-owf controls at this hour.

A comparison of columns m and n of table 1 with the corresponding columns of table 3 discloses that sporadic-*E* plays an important part, *Es*-muf being the controlling frequency throughout the entire 24 hours, while *Es*-owf controlled except at 0200, 1800 and 2000. At 0200, *F2*-owf controlled, while at the two latter hours *E*-owf was the controlling frequency. Thus the results of tables 1 and 3 illustrate all possible types of control of transmission by the *E* and *F*2 layers and by *Es*, except for cases in which *F*2-muf or *E*-muf is higher than *Es*-muf. It is not unusual for *E*-muf to be the highest of the three over a short path, although this does not occur in this particular problem.

Figure 14 shows that skip will occur, on the average, during the night hours, if a frequency as high as 15.0 Mc is used. A frequency as high as 13.5 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 14 shows that a night frequency of 10.2 Mc, to be used from 0015 to 1205 GCT, and a day frequency of 14.5 Mc, to be used from 1205 to 0015 GCT, would be satisfactory. The periods of usefulness of these frequencies are shown by the heavy dashed line on figure 14.

These values of frequency were obtained by including *Es*-owf in the calculations, and consequently, for the reason indicated in the last paragraph of section 5, some interruptions in servic may be expected on the night frequency, since the night frequency, as shown in figure 14, was chosen above the owf for the regular layers between 0730 and 1050. Better service may possibly be obtained by choosing a lower night frequency, closer to the regular-layer owf.

7.2. Problem 2 (Long Path)

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 June 1947.

Solution:

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

The path length is approximately 7,100 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 *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 5.2, for the regular layers only, are given in table 2 for even hours, GCT. In table 4, as well as in the graph of figure 15, provision has been made for the inclusion of the effects of *Es*. A comparison of columns q and r of table 2 with the corresponding columns of table 4 shows that computation of *Es*-muf and owf might just as well have been omitted, except for the 1400 and 1600-hour values of muf and the 1400-hour value of owf. Only rarely will *Es* be the determining factor, either for the muf or owf, over a path more than 4,000 km in length. It is even less likely that the *E*-layer muf will control transmission over such a path, although instances have been recorded, particularly during periods of relatively low solar activity. Note that *E*-owf controls at 1600 in tables 2 and 4.

Figure 15 shows that skip will occur, on the average, during the night hours if a frequency as high as 16.0 Mc is used, although higher frequencies may be used during much of the 24 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 12.8 Mc may be used from 0425 to 0950 GCT, a frequency of 18.5 Mc may be used from 1340 to 0115 GCT, and a transition frequency of 15.5 Mc may be used from 0115 to 0425 GCT, and from 0950 to 1340 GCT.

By inspection of the absorption chart and the noise map (figs. 85 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.

7.3. Problem 3 (Short Path)

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 March 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 1,500 km, all in W zone.

The values of *E*- and *F*2-layer muf and owf, and also *Es*-muf and owf for even hours, GCT, as determined by the procedure given in section 5, are given in table 5. The final values are presented graphically in figure 22.

Values of owf for the path obtained by the procedure of section 5.1 for the regular layers only are given in columns k and l of table 5. The higher of these two values for each even hour is underscored and plotted in figure 22. The resulting graph of owf, for the regular layers only, is shown as a solid-line curve.

Values of *Es*-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 March, *Es*-owf is not the controlling frequency over this path at any time. Accordingly, no values of *Es*-owf are plotted in figure 22.

Figure 22 shows that skip will occur, on the average, during the night hours, if a frequency as high as 12.0 Mc is used. A frequency as high as 9.5 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 22 shows that a night frequency of 8.2 Mc, to be used from 0105 to 1200 GCT, and a day frequency of 13.3 Mc, to be used from 1200 to 0105 GCT, would be satisfactory. The periods of usefulness of these frequencies are shown by the heavy dashed line on figure 22.

This problem is given for additional practice, and so that results may be compared with those of problem 1. In problem 1, *Es*-muf controlled throughout, and *Es*-owf during most of the 24 hours. Considering propagation by the regular layers only, control was divided approximately evenly between the *E* and *F*2 layers. In problem 3, the *F*2 layer controls throughout.

7.4. Problem 4 (Long Path)

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 March 1947.

Solution:

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

The path length is approximately 7,100 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 *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 5, are given in table 6 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 23.

Figure 23 shows that skip will occur, on the average, during the night hours if a frequency as high as 13.0 Mc is used, although higher frequencies may be used during much of the 24 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 9.9 Mc may be used from 2235 to 1010 GCT, a frequency of 24.0 Mc may be used from 1200 to 2035 GCT, and a transition frequency of 16.5 Mc may be used from 1010 to 1200 GCT, and from 2035 to 2235 GCT.

By inspection of the absorption chart and the noise map (figs. 82 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.

This problem is given for additional practice, and so that the results may be compared with those of problem 2. For the Washington-Trieste path for March 1947, the *F*2-layer controls throughout. Familiarity with the procedure will enable the user of the prediction contours to determine by inspection whether it is necessary to consider propagation by the *E* layer or by *Es*. In many cases the work can be greatly shortened by omitting filling out many of the columns of forms AF and AH.

8. Seasonal and Cyclic Effects

By comparing figure 14 with figure 22 and figure 15 with figure 23, an idea may be gained of the variation of recommended frequency usage over these paths from the spring equinox to midsummer. However, these examples have been given all for a period of rising and relatively intense sunspot activity. As an illustration of the range of variation to be expected, the suggested frequency usage for January 1945 for the Washington-Miami path involved 4.5 Mc and 10.5 Mc, compared to 10.2 Mc and 14.5 Mc for June 1947, while for the Washington-Trieste path the suggested frequencies were 5.0 Mc, 7.5 Mc, and 12.0 Mc, for January 1945, compared to 9.9 Mc, 16.5 Mc, and 24.0 Mc for March 1947. The predicted smoothed 12-month running-average Zurich sunspot numbers centered on March 1947 and June 1947 were 105 and 112, respectively, whereas the actual number centered on January 1945 was 22. Within the past hundred years, the 12-month running-average relative sunspot numbers reached a high of 140 in 1870, and a low of 1.4 in 1913.

CRPL-FORM AF
(modified)

TABLE I.—Solution of short-path transmission problem.
Propagation by the regular layers only.

DATE 30 January 1947

MUF-OWF WORK SHEET FOR PATHS 4000 KM OR LESS

From Washington, D.C. To Miami, Fla. Distance, 1500 km Zone W Predicted for June 1947

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	5Xa	Scale	Scale	Scale				b-4.0		Same as g	.85h	HIGHER OF G,H	HIGHER OF K,L
00			9.6	8.3	23.8		8.9	14.7			8.9	12.5	14.7	12.5
01														
02				7.8	22.0			13.4				11.4	13.4	11.4
03														
04				7.5	20.8			12.8				10.9	12.8	10.9
05														
06				7.2	19.5			12.1				10.3	12.1	10.3
07														
08				6.7	18.5			11.4				9.7	11.4	9.7
09														
10			6.7	6.1	17.3		6.2	10.5			6.2	8.9	10.5	8.9
11														
12			14.2	7.1	21.0		13.1	12.7			13.1	10.8	13.1	13.1
13														
14			17.7	8.4	24.4		16.4	14.8			16.4	12.6	16.4	16.4
15														
16			19.4	8.8	25.2		18.0	15.4			18.0	13.1	18.0	18.0
17														
18			19.9	8.9	25.8		18.4	15.7			18.4	13.3	18.4	18.4
19														
20			18.4	9.0	27.2		17.0	16.3			17.0	13.8	17.0	17.0
21														
22			15.5	8.9	26.4		14.3	15.8			14.3	13.4	15.8	14.3
23														
Done by														
Checked														

CRPL-FORM AH
(modified)

TABLE 2.—Solution of long-path transmission problem.
Propagation by the regular layers only.

DATE 30 January 1947

MUF-OWF WORK SHEET FOR PATHS OVER 4000 KM

From Washington, D.C. To Trieste Distance, 7100 km Predicted for June 1947

Note: All frequencies are in megacycles.

	A-end						B-end											
	Pt. A in W Zone			Pt. A' in W Zone			Pt. B in I Zone			Pt. B' in I Zone								
GCT	f_{E_s}	E_s 2000-muf	F_2 4000-muf	E-layer 2000-muf	E_s 2000-owf	F_2 4000-owf	f_{E_s}	E_s 2000-muf	F_2 4000-muf	E-layer 2000-muf	E_s 2000-owf	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	HIGHER OF C,D	HIGHER OF I,J	HIGHER OF D,F	HIGHER OF J,L	Lower of m,n	Lower of o,p
00			26.2	8.8		22.3			23.4			19.9	26.2	23.4	22.3	19.9	23.4	19.9
01																		
02			23.6			20.1			20.6			17.5	23.6	20.6	20.1	17.5	20.6	17.5
03																		
04			19.0			16.2			19.0	8.0		16.2	19.0	19.0	16.2	16.2	19.0	16.2
05																		
06			15.6			13.3			21.4	13.3		18.2	15.6	21.4	13.3	18.2	15.6	13.3
07																		
08			15.6			13.3			23.6	16.7		20.1	15.6	23.6	13.3	20.1	15.6	13.3
09																		
10			18.6	11.5		15.8			24.2	18.1		20.6	18.6	24.2	15.8	20.6	18.6	15.8
11																		
12			20.0	15.8		17.0			24.2	18.9		20.6	20.0	24.2	17.0	20.6	20.0	17.0
13																		
14			21.5	17.9		18.3			23.0	18.0		19.6	21.5	23.0	18.3	19.6	21.5	18.3
15																		
16			22.3	19.2		19.0			25.0	16.4		21.2	22.3	25.0	19.2	21.2	22.3	19.2
17																		
18			24.0	18.6		20.4			26.3	13.1		22.4	24.0	26.3	20.4	22.4	24.0	20.4
19																		
20			25.2	17.3		21.4			26.7	7.3		22.7	25.2	26.7	21.4	22.7	25.2	21.4
21																		
22			27.2	14.3		23.1			25.2			21.4	27.2	25.2	23.1	21.4	25.2	21.4
23																		
Done by																		
Checked																		

CRPL-FORM AF

TABLE 3.—Solution of short—path transmission problem. DATE 30 January 1947

MUF-OWF WORK SHEET FOR PATHS 4000 KM OR LESS

From Washington, D.C. To Miami, Fla. Distance, 1500 km Zone W Predicted for June 1947

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	4.0	20.0	9.6	8.3	23.8	18.4	8.9	14.7	16.0	14.7	8.9	12.5	18.4	14.7
01														
02	3.2	16.0		7.8	22.0	14.7		13.4	12.0	11.1		11.4	14.7	11.4
03														
04	3.2	16.0		7.5	20.8	14.7		12.8	12.0	11.1		10.9	14.7	11.1
05														
06	3.2	16.0		7.2	19.5	14.7		12.1	12.0	11.1		10.3	14.7	11.1
07														
08	3.1	15.5		6.7	18.5	14.3		11.4	11.5	10.7		9.7	14.3	10.7
09														
10	3.1	15.5	6.7	6.1	17.3	14.3	6.2	10.5	11.5	10.7	6.2	8.9	14.3	10.7
11														
12	3.9	19.5	14.2	7.1	21.0	18.1	13.1	12.7	15.5	14.4	13.1	10.8	18.1	14.4
13														
14	5.4	27.0	17.7	8.4	24.4	25.1	16.4	14.8	23.0	21.2	16.4	12.6	25.1	21.2
15														
16	5.4	27.0	19.4	8.8	25.2	25.1	18.0	15.4	23.0	21.2	18.0	13.1	25.1	21.2
17														
18	4.7	23.5	19.9	8.9	25.8	21.8	18.4	15.7	19.5	18.0	18.4	13.3	21.8	18.4
19														
20	4.3	21.5	18.4	9.0	27.2	19.8	17.0	16.3	17.5	16.1	17.0	13.8	19.8	17.0
21														
22	4.2	21.0	15.5	8.9	26.4	19.3	14.3	15.8	17.0	15.8	14.3	13.4	19.3	15.8
23														
Done by														
Checked														

CRPL-FORM AH

TABLE 4.—Solution of long-path transmission problem. DATE 30 January 1947

MUF-OWF WORK SHEET FOR PATHS OVER 4000 KM.

From Washington, D. C. To Trieste Distance, 7100 km Predicted for June 1947

Note: All frequencies are in megacycles.

	A-end						B-end											
	Pt. A in W Zone			Pt. A' in W Zone			Pt. B in I Zone			Pt. B' in I Zone			MUF	MUF	OWF	OWF	MUF for PATH	OWF for PATH
GCT	f_{E_s}	E_s 2000-muf	F_2 4000-muf	E-layer 2000-muf	E_s 2000-owf	F_2 4000-owf	f_{E_s}	E_s 2000-muf	F_2 4000-muf	E-layer 2000-muf	E_s 2000-owf	F_2 4000-owf	A-end	B-end	A-end	B-end		
	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	2.3	11.5	26.2	8.8	7.5	22.3	3.0	15.0	23.4		11.0	19.9	26.2	23.4	22.3	19.9	23.4	19.9
01																		
02	2.0	10.0	23.6		6.0	20.1	3.0	15.0	20.6		11.0	17.5	23.6	20.6	20.1	17.5	20.6	17.5
03																		
04			19.0			16.2	3.0	15.0	19.0	8.0	11.0	16.2	19.0	19.0	16.2	16.2	19.0	16.2
05																		
06			15.6			13.3	4.0	20.0	21.4	13.3	16.0	18.2	15.6	21.4	13.3	18.2	15.6	13.3
07																		
08			15.6			13.3	5.0	25.0	23.6	16.7	21.0	20.1	15.6	25.0	13.3	21.0	15.6	13.3
09																		
10			18.6	11.5		15.8	5.0	25.0	24.2	18.1	21.0	20.6	18.6	25.0	15.8	21.0	18.6	15.8
11																		
12	2.9	14.5	20.0	15.8	10.5	17.0	4.9	24.5	24.2	18.9	20.5	20.6	20.0	24.5	17.0	20.6	20.0	17.0
13																		
14	4.6	23.0	21.5	17.9	19.0	18.3	4.2	21.0	23.0	18.0	17.0	19.6	23.0	23.0	19.0	19.6	23.0	19.0
15																		
16	4.6	23.0	22.3	19.2	19.0	19.0	3.9	19.5	25.0	16.4	15.5	21.2	23.0	25.0	19.2	21.2	23.0	19.2
17																		
18	4.0	20.0	24.0	18.6	16.0	20.4	3.5	17.5	26.3	13.1	13.5	22.4	24.0	26.3	20.4	22.4	24.0	20.4
19																		
20	3.7	18.5	25.2	17.3	14.5	21.4	3.1	15.5	26.7	7.3	11.5	22.7	25.2	26.7	21.4	22.7	25.2	21.4
21																		
22	3.1	15.5	27.2	14.3	11.5	23.1	3.0	15.0	25.2		11.0	21.4	27.2	25.2	23.1	21.4	25.2	21.4
23																		
Done by																		
Checked																		

CRPL—FORM AF

TABLE 5.— Solution of short-path transmission problem. DATE 31 October 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 Mar. 1947

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	2.0	10.0		10.4	30.2	9.4		18.3	6.0	5.6		15.6	18.3	15.6
01														
02				7.7	23.0			13.8				11.7	13.8	11.7
03														
04				6.9	20.0			12.1				10.3	12.1	10.3
05														
06				6.5	19.0			11.5				9.8	11.5	9.8
07														
08				6.1	17.5			10.6				9.0	10.6	9.0
09														
10				5.6	15.8			9.7				8.2	9.7	8.2
11														
12			11.2	8.1	27.0		10.3	15.6			10.3	13.3	15.6	13.3
13														
14	3.0	15.0	16.2	11.0	35.0	13.8	15.0	20.5	11.0	10.1	15.0	17.4	20.5	17.4
15														
16	3.4	17.0	18.3	12.0	37.2	15.7	17.0	22.1	13.0	12.0	17.0	18.8	22.1	18.8
17														
18	3.5	17.5	18.7	11.5	35.6	16.1	17.2	21.2	13.5	12.4	17.2	18.0	21.2	18.0
19														
20	3.2	16.0	17.5	12.0	37.5	14.7	16.1	22.2	12.0	11.0	16.1	18.9	22.2	18.9
21														
22	2.6	13.0	13.8	11.4	36.5	12.0	12.7	21.5	9.0	8.3	12.7	18.3	21.5	18.3
23														
Done by														
Checked														

757088—47——3

CRPL–FORM AH

TABLE 4.—Solution of long—path transmission problem. DATE 30 January 1947

MUF–OWF WORK SHEET FOR PATHS OVER 4000 KM.

From Washington, D. C. To Trieste Distance, 7100 km Predicted for June 1947

Note: All frequencies are in megacycles.

	A-end						B-end											
	Pt. A in W Zone			Pt. A' in W Zone			Pt. B in I Zone			Pt. B' in I Zone			MUF	MUF	OWF	OWF	MUF for PATH	OWF for PATH
GCT	f_{E_s}	E_s 2000-muf	F_2 4000-muf	E-layer 2000-muf	E_s 2000-owf	F_2 4000-owf	f_{E_s}	E_s 2000-muf	F_2 4000-muf	E-layer 2000-muf	E_s 2000-owf	F_2 4000-owf	A-end	B-end	A-end	B-end		
	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	2.3	11.5	26.2	8.8	7.5	22.3	3.0	15.0	23.4		11.0	19.9	26.2	23.4	22.3	19.9	23.4	19.9
01																		
02	2.0	10.0	23.6		6.0	20.1	3.0	15.0	20.6		11.0	17.5	23.6	20.6	20.1	17.5	20.6	17.5
03																		
04			19.0			16.2	3.0	15.0	19.0	8.0	11.0	16.2	19.0	19.0	16.2	16.2	19.0	16.2
05																		
06			15.6			13.3	4.0	20.0	21.4	13.3	16.0	18.2	15.6	21.4	13.3	18.2	15.6	13.3
07																		
08			15.6			13.3	5.0	25.0	23.6	16.7	21.0	20.1	15.6	25.0	13.3	21.0	15.6	13.3
09																		
10			18.6	11.5		15.8	5.0	25.0	24.2	18.1	21.0	20.6	18.6	25.0	15.8	21.0	18.6	15.8
11																		
12	2.9	14.5	20.0	15.8	10.5	17.0	4.9	24.5	24.2	18.9	20.5	20.6	20.0	24.5	17.0	20.6	20.0	17.0
13																		
14	4.6	23.0	21.5	17.9	19.0	18.3	4.2	21.0	23.0	18.0	17.0	19.6	23.0	23.0	19.0	19.6	23.0	19.0
15																		
16	4.6	23.0	22.3	19.2	19.0	19.0	3.9	19.5	25.0	16.4	15.5	21.2	23.0	25.0	19.2	21.2	23.0	19.2
17																		
18	4.0	20.0	24.0	18.6	16.0	20.4	3.5	17.5	26.3	13.1	13.5	22.4	24.0	26.3	20.4	22.4	24.0	20.4
19																		
20	3.7	18.5	25.2	17.3	14.5	21.4	3.1	15.5	26.7	7.3	11.5	22.7	25.2	26.7	21.4	22.7	25.2	21.4
21																		
22	3.1	15.5	27.2	14.3	11.5	23.1	3.0	15.0	25.2		11.0	21.4	27.2	25.2	23.1	21.4	25.2	21.4
23																		
Done by																		
Checked																		

CRPL—FORM AF

TABLE 5.— Solution of short-path transmission problem.

DATE 31 October 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 Mar. 1947

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	2.0	10.0		10.4	30.2	9.4		18.3	6.0	5.6		15.6	18.3	15.6
01														
02				7.7	23.0			13.8				11.7	13.8	11.7
03														
04				6.9	20.0			12.1				10.3	12.1	10.3
05														
06				6.5	19.0			11.5				9.8	11.5	9.8
07														
08				6.1	17.5			10.6				9.0	10.6	9.0
09														
10				5.6	15.8			9.7				8.2	9.7	8.2
11														
12			11.2	8.1	27.0		10.3	15.6			10.3	13.3	15.6	13.3
13														
14	3.0	15.0	16.2	11.0	35.0	13.8	15.0	20.5	11.0	10.1	15.0	17.4	20.5	17.4
15														
16	3.4	17.0	18.3	12.0	37.2	15.7	17.0	22.1	13.0	12.0	17.0	18.8	22.1	18.8
17														
18	3.5	17.5	18.7	11.5	35.6	16.1	17.2	21.2	13.5	12.4	17.2	18.0	21.2	18.0
19														
20	3.2	16.0	17.5	12.0	37.5	14.7	16.1	22.2	12.0	11.0	16.1	18.9	22.2	18.9
21														
22	2.6	13.0	13.8	11.4	36.5	12.0	12.7	21.5	9.0	8.3	12.7	18.3	21.5	18.3
23														
Done by														
Checked														

757088—47——3

CRPL- FORM AH

TABLE 6.— Solution of long-path transmission problem.

DATE 31 October 1946

MUF-OWF WORK SHEET FOR PATHS OVER 4000 KM.

From Washington, D. C. To Trieste, Italy Distance, 7100 km Predicted for March 1947

Note: All frequencies are in megacycles.

	A-end						B-end											
	Pt. A in W Zone			Pt. A' in W Zone			Pt. B in I Zone			Pt. B' in I Zone								
GCT	f_{E_S}	E_S 2000-muf	F_2 4000-muf	E-layer 2000-muf	E_S 2000-owf	F_2 4000-owf	f_{E_S}	E_S 2000-muf	F_2 4000-muf	E-layer 2000-muf	E_S 2000-owf	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			26.5			22.5			16.0			13.6	26.5	16.0	22.5	13.6	16.0	13.6
01																		
02			21.9			18.6			13.6			11.6	21.9	13.6	18.6	11.6	13.6	11.6
03																		
04			18.3			15.6	2.0	10.0	12.1		6.0	10.3	18.3	12.1	15.6	10.3	12.1	10.3
05																		
06			16.6			14.1	2.2	11.0	11.8	6.7	7.0	10.0	16.6	11.8	14.1	10.0	11.8	10.0
07																		
08			14.7			12.5	3.1	15.5	23.2	13.3	11.5	19.7	14.7	23.2	12.5	19.7	14.7	12.5
09																		
10			19.0			16.2	3.2	16.0	30.8	15.8	12.0	26.2	19.0	30.8	16.2	26.2	19.0	16.2
11																		
12	2.4	12.0	28.2	12.4	8.0	24.0	3.3	16.5	35.6	16.6	12.5	30.3	28.2	35.6	24.0	30.3	28.2	24.0
13																		
14	3.1	15.5	34.2	15.7	11.5	29.1	3.3	16.5	36.8	16.0	12.5	31.3	34.2	36.8	29.1	31.3	34.2	29.1
15																		
16	3.2	16.0	37.0	17.2	12.0	31.4	2.8	14.0	36.6	13.6	10.0	31.1	37.0	36.6	31.4	31.1	36.6	31.1
17																		
18	3.2	16.0	38.7	17.0	12.0	32.9	2.0	10.0	34.7	7.2	6.0	29.5	38.7	34.7	32.9	29.5	34.7	29.5
19																		
20	3.0	15.0	38.8	15.2	11.0	33.0	2.0	10.0	30.1		6.0	25.6	38.8	30.1	33.0	25.6	30.1	25.6
21																		
22	2.0	10.0	37.4	10.8	6.0	31.8	2.0	10.0	21.7		6.0	18.4	37.4	21.7	31.8	18.4	21.7	18.4
23																		
Done by																		
Checked																		

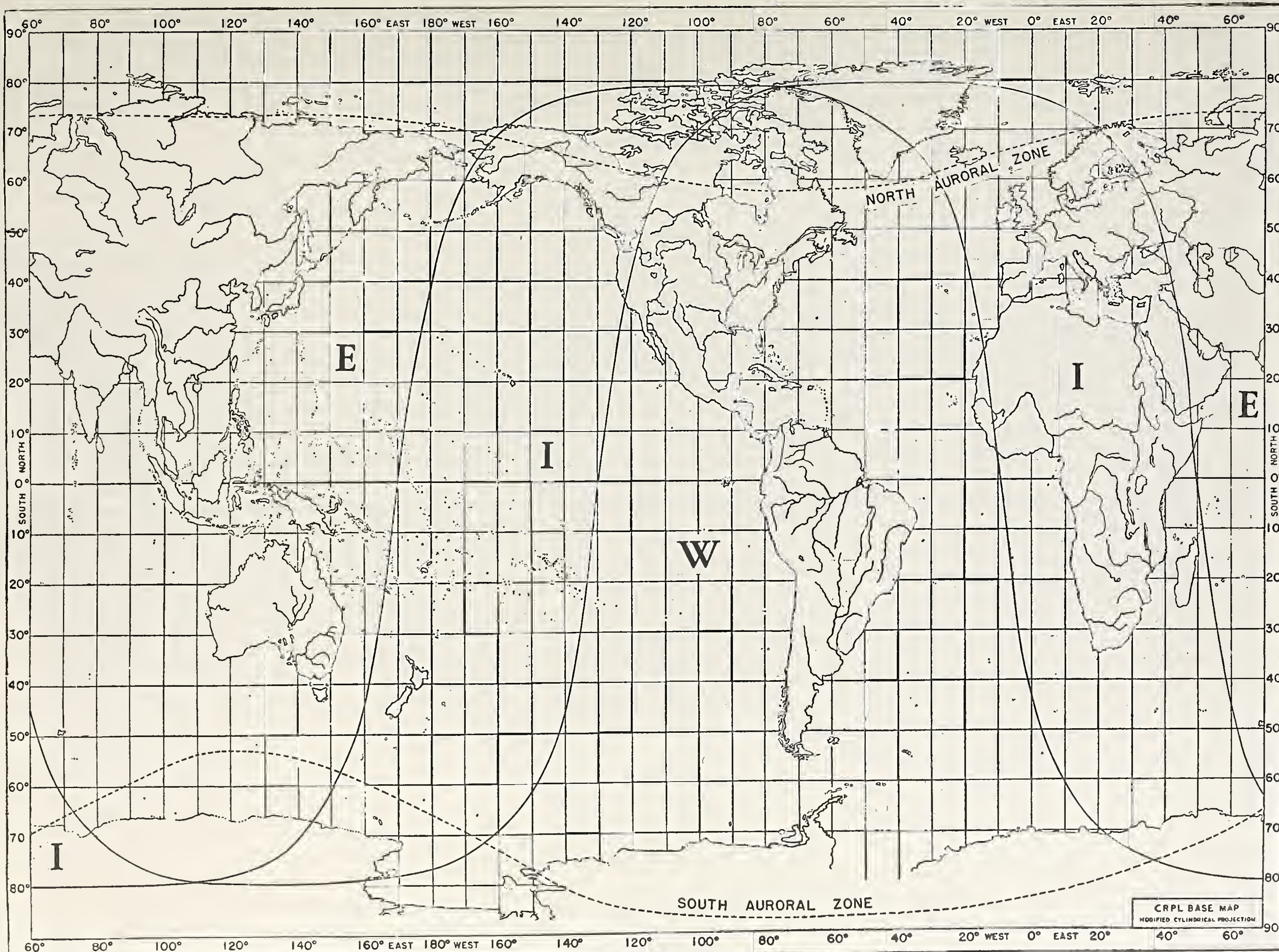

Fig. I. WORLD MAP SHOWING ZONES COVERED BY PREDICTED CHARTS, AND AURORAL ZONES.

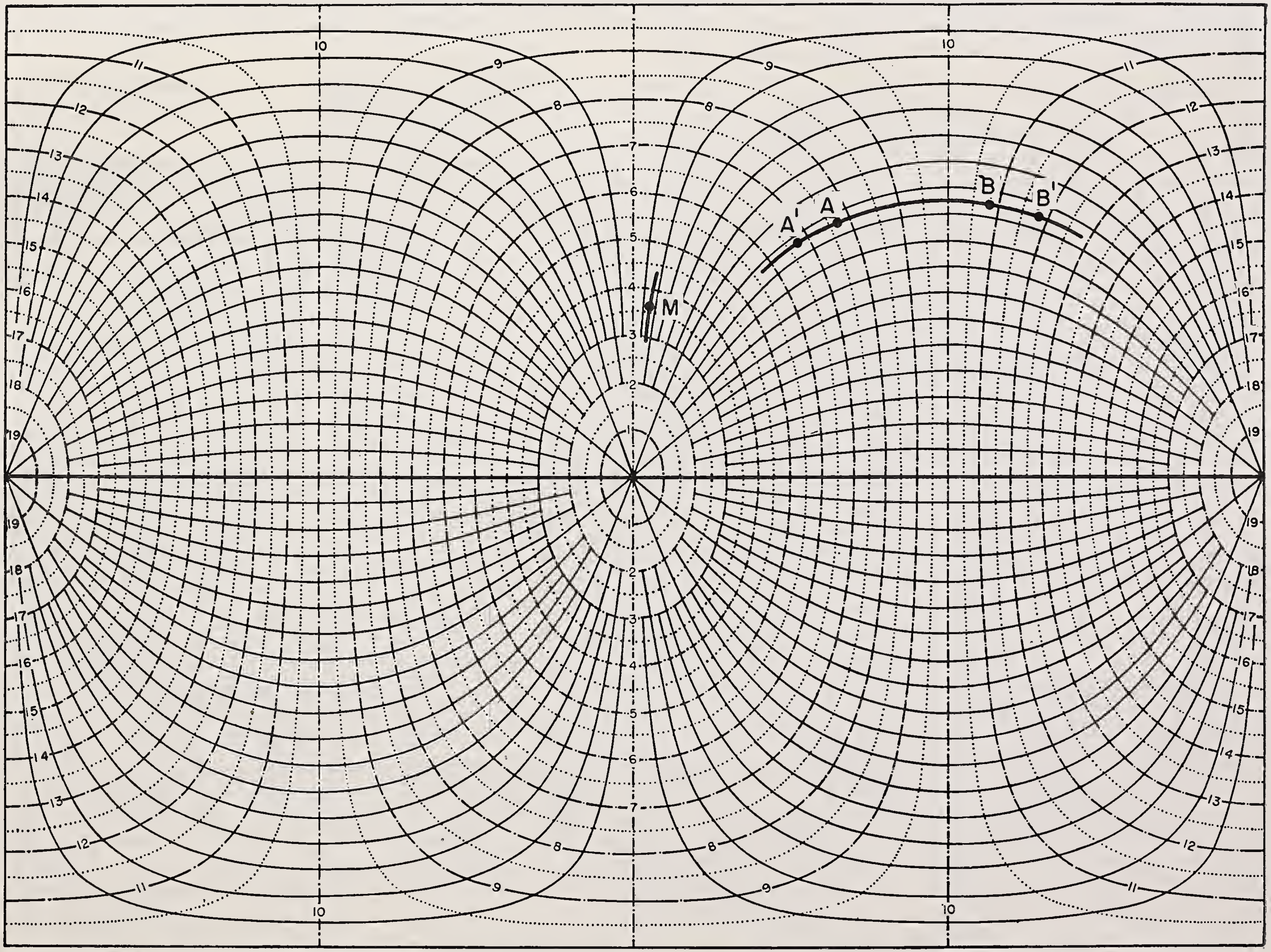

Fig. 2. GREAT CIRCLE CHART CENTERED ON EQUATOR. SOLID LINES REPRESENT GREAT CIRCLES. NUMBERED DOT–DASH LINES INDICATE DISTANCES IN THOUSANDS OF KILOMETERS.

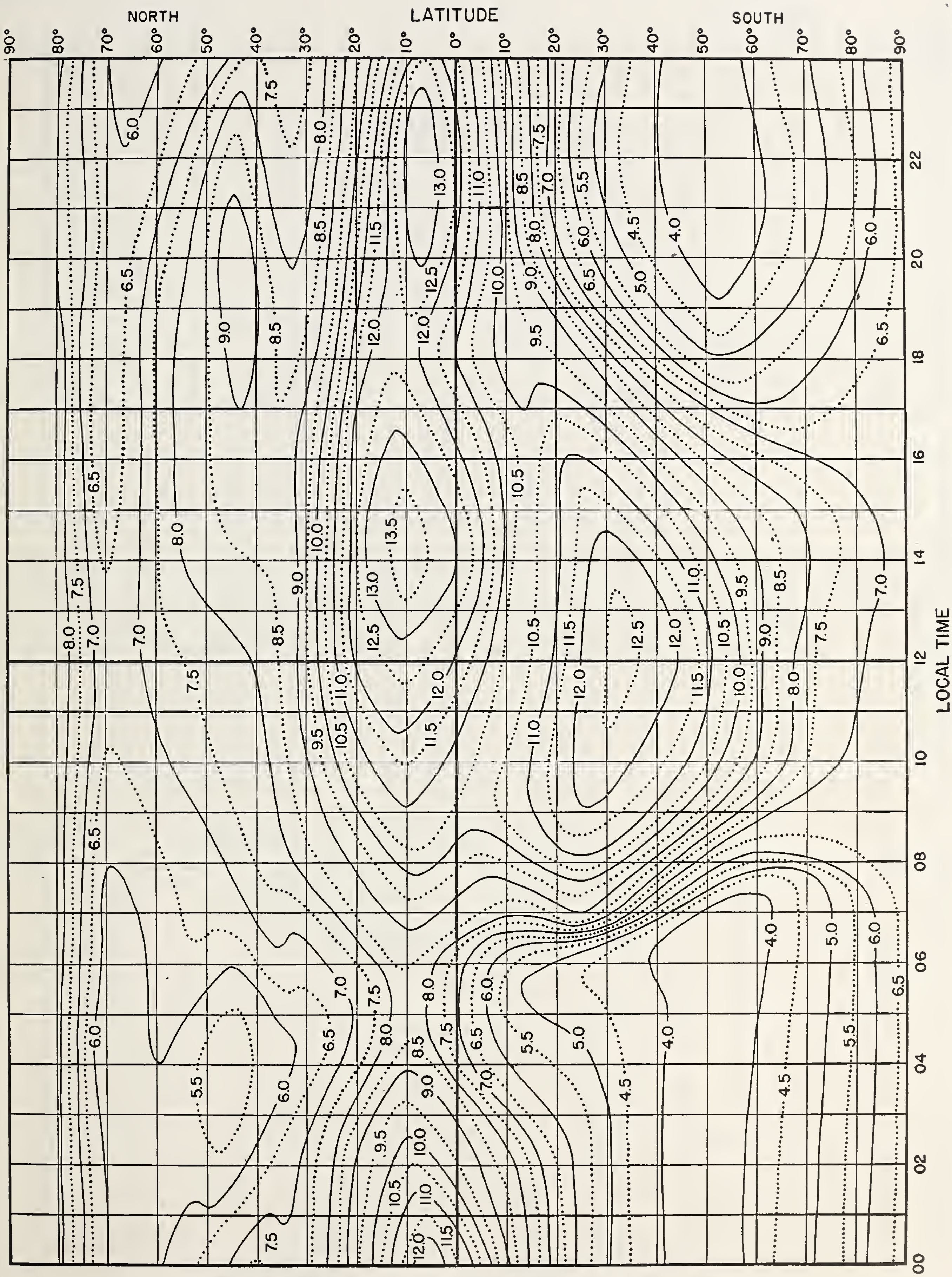

Fig. 3 F_2 ZERO—MUF, IN Mc, W ZONE, PREDICTED FOR JUNE 1947

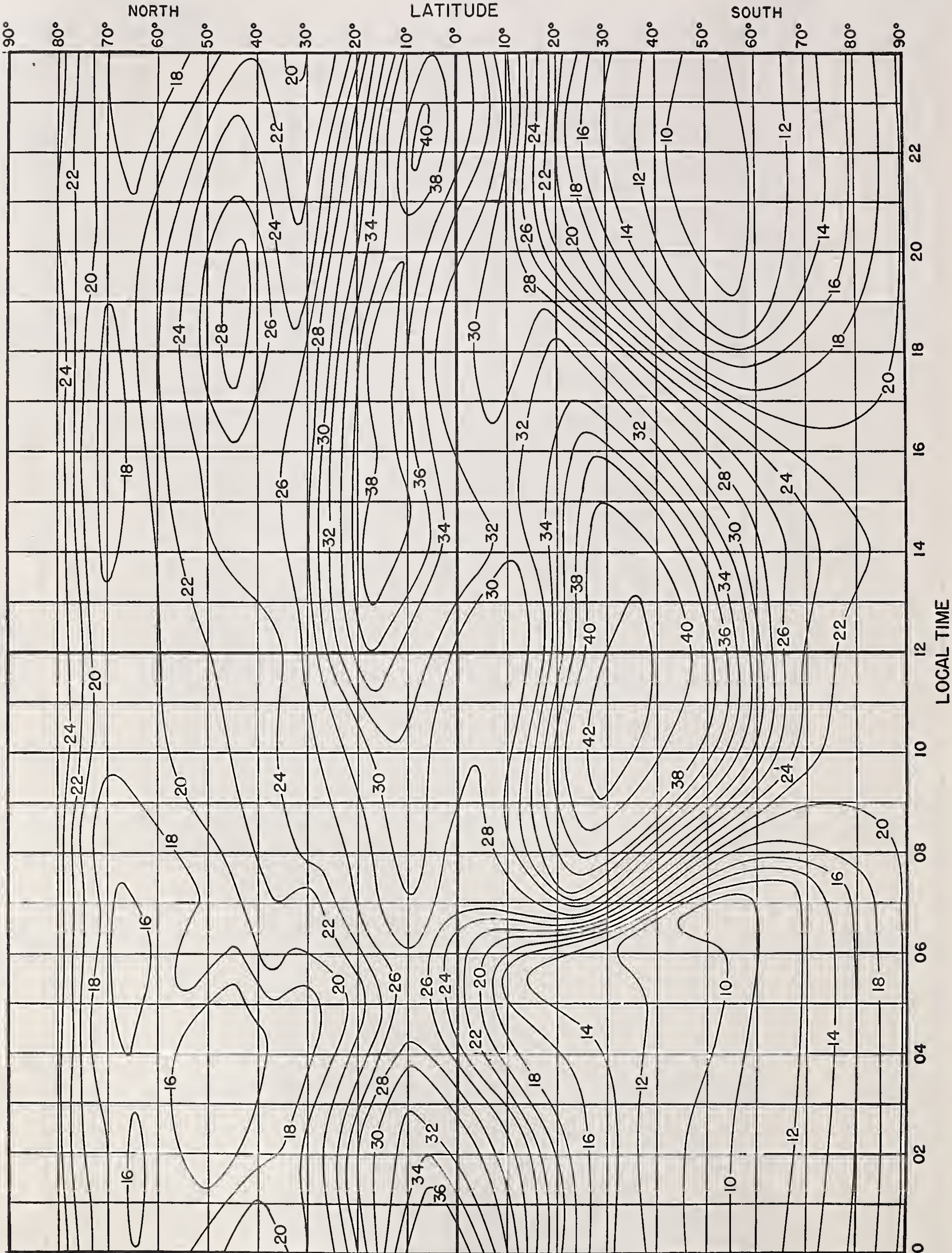

Fig. 4 F_2 4000—MUF, IN Mc, W ZONE, PREDICTED FOR JUNE 1947

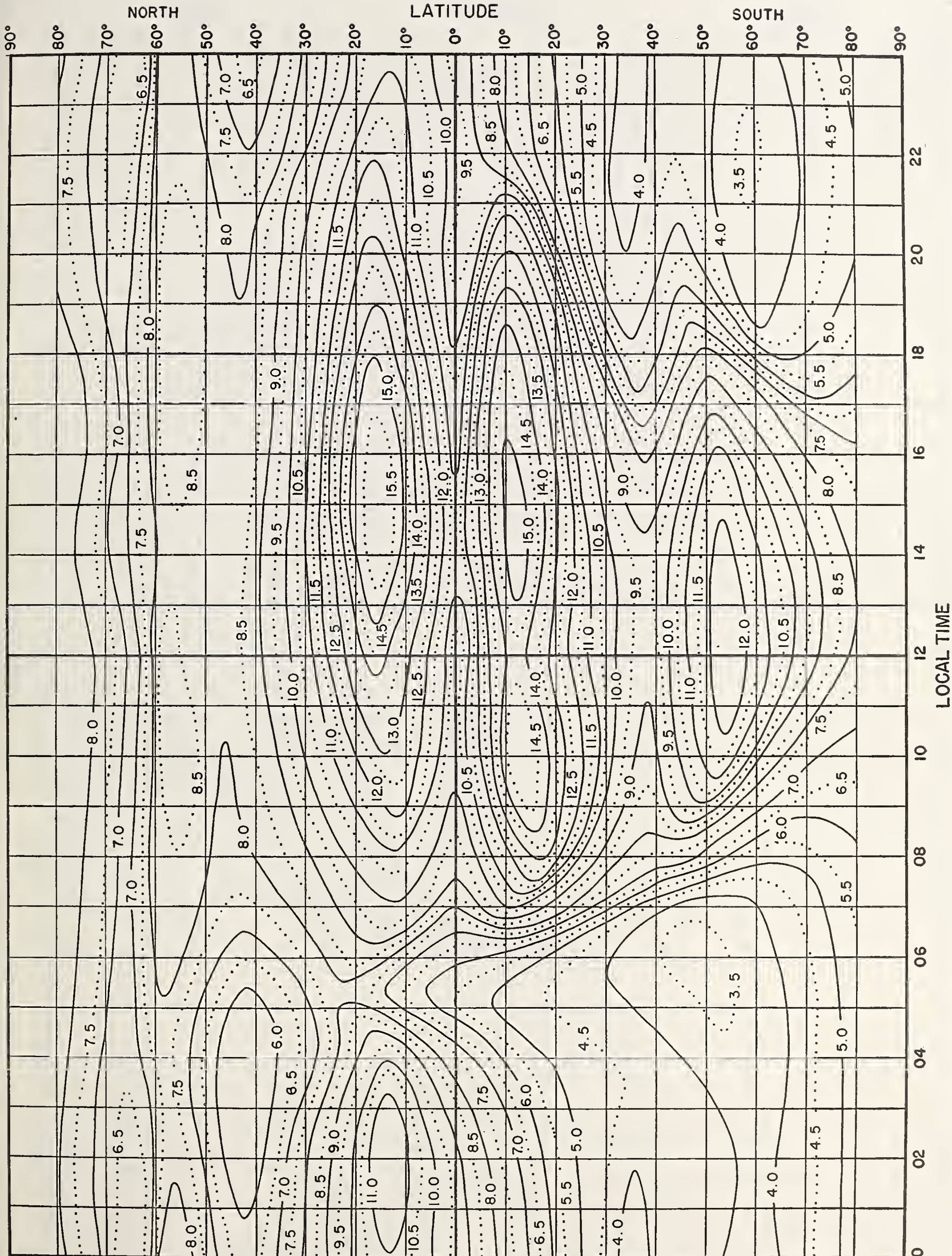

Fig. 5 F_2 ZERO—MUF, IN Mc, I ZONE, PREDICTED FOR JUNE 1947

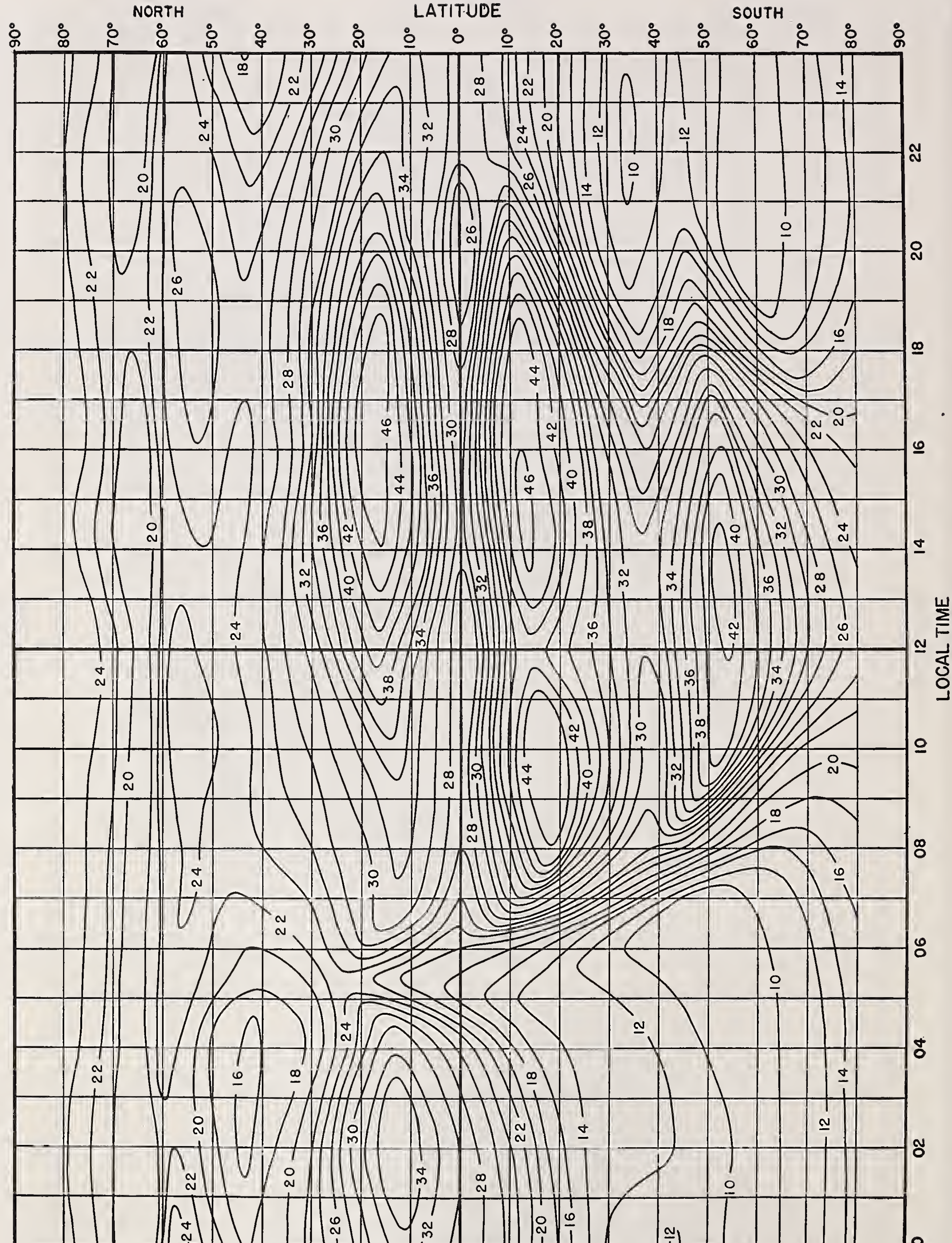

Fig. 6 F$_2$ 4000—MUF, IN Mc, I ZONE, PREDICTED FOR JUNE 1947

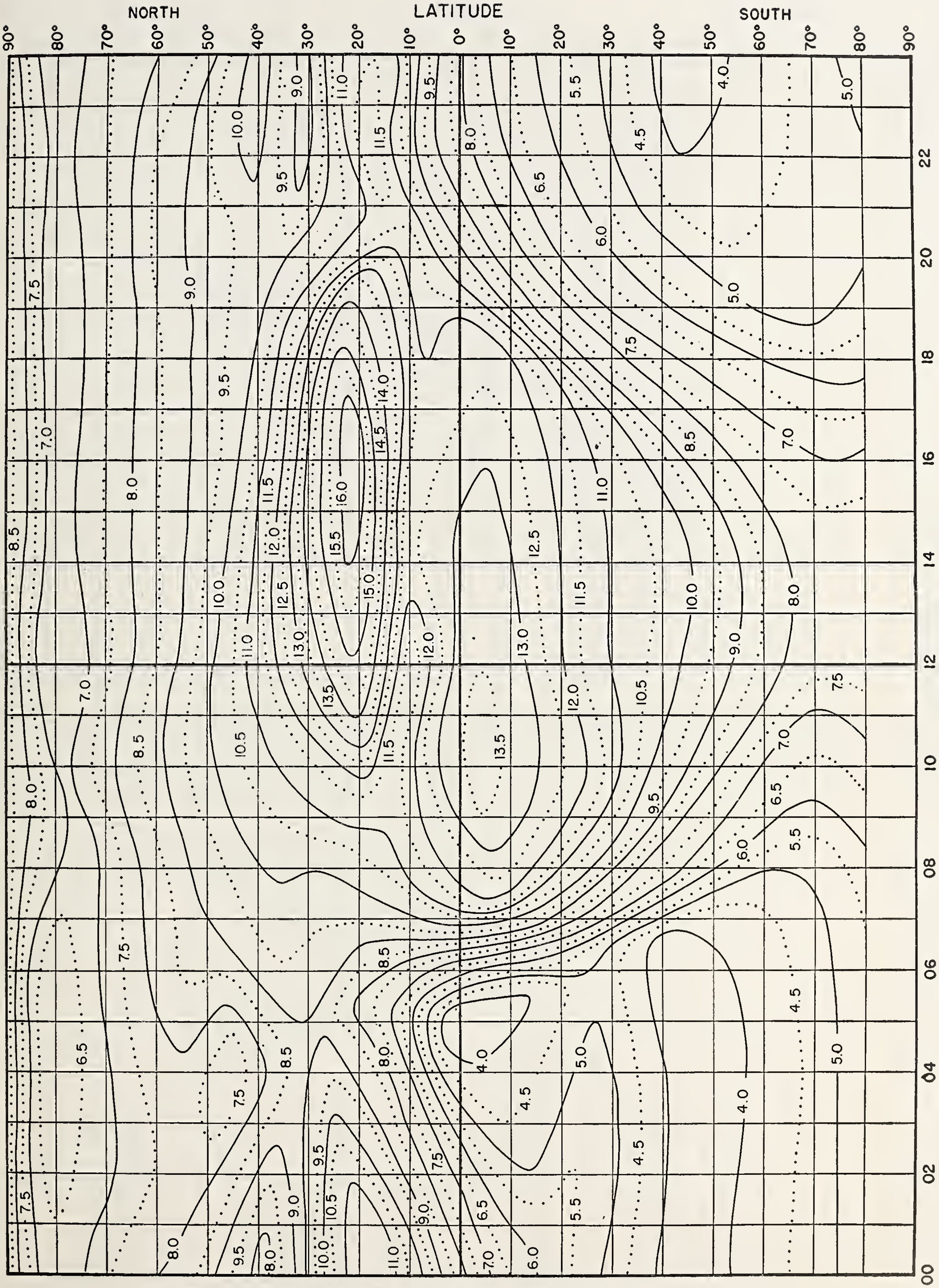

Fig. 7 F_2 ZERO—MUF, IN Mc, E ZONE, PREDICTED FOR JUNE 1947

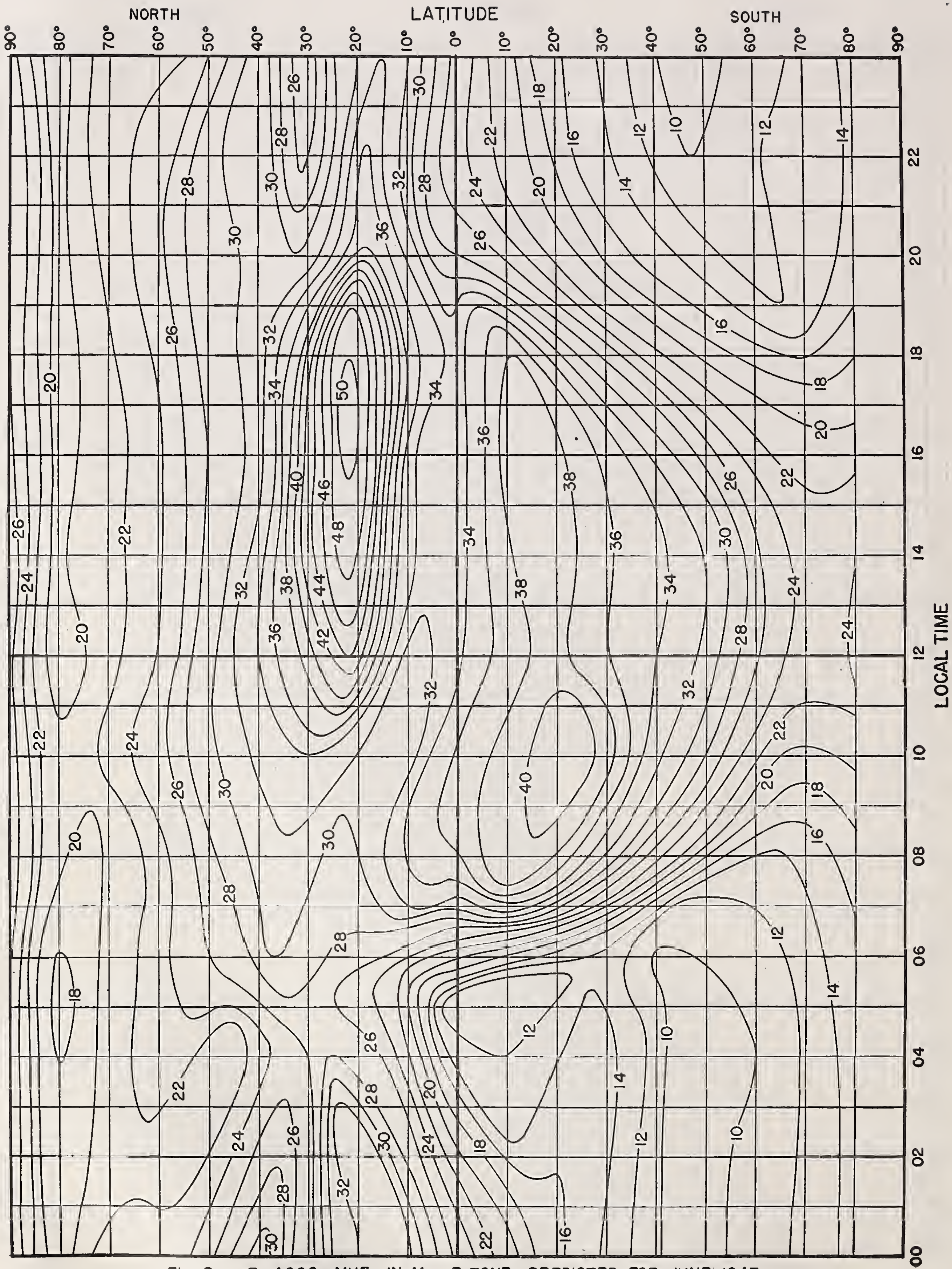

Fig. 8 F_2 4000—MUF, IN Mc, E ZONE, PREDICTED FOR JUNE 1947

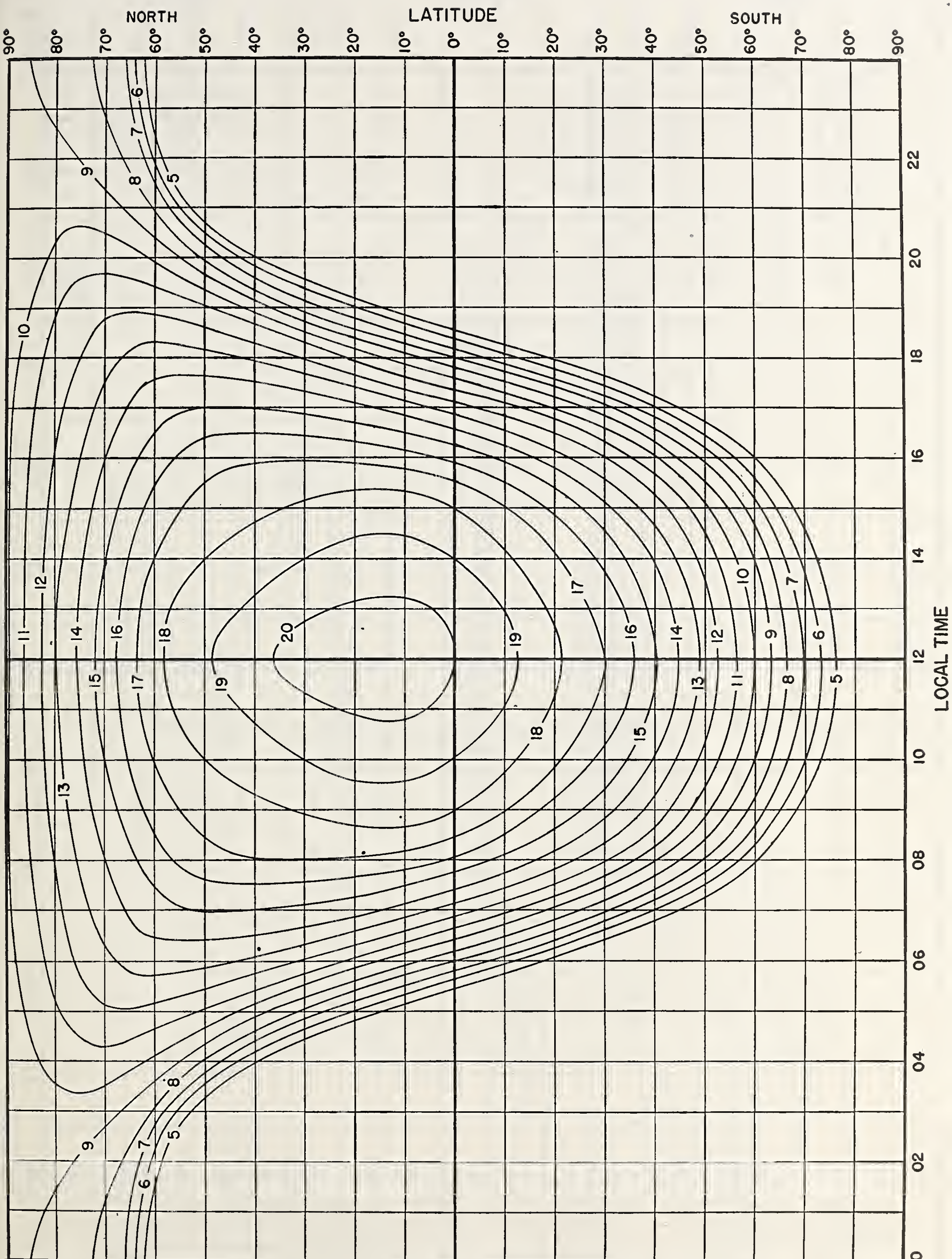

Fig. 9 E–LAYER 2000–MUF, IN Mc, PREDICTED FOR JUNE 1947

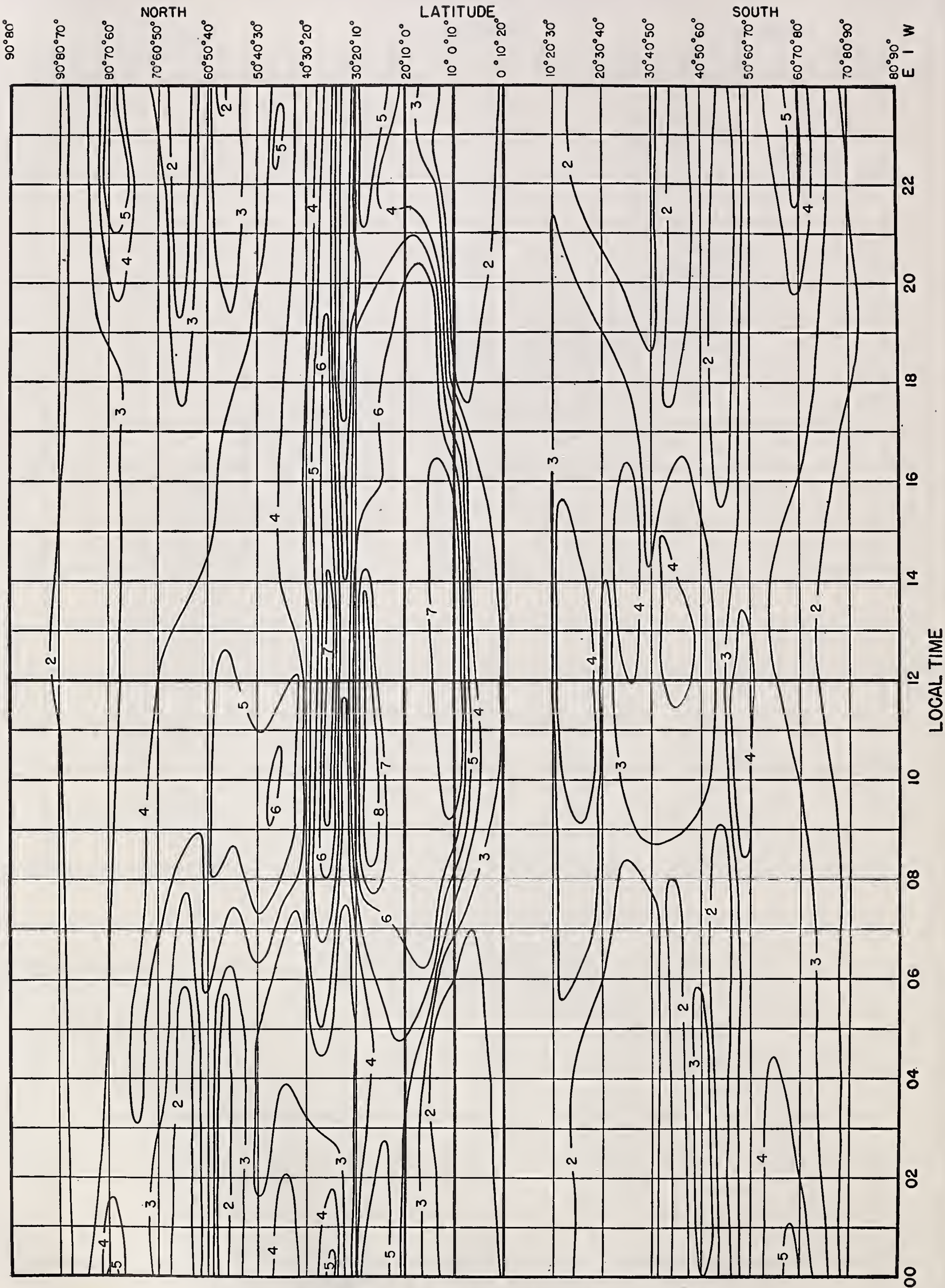

Fig. 10 MEDIAN f_{E_S}, IN Mc, PREDICTED FOR JUNE 1947

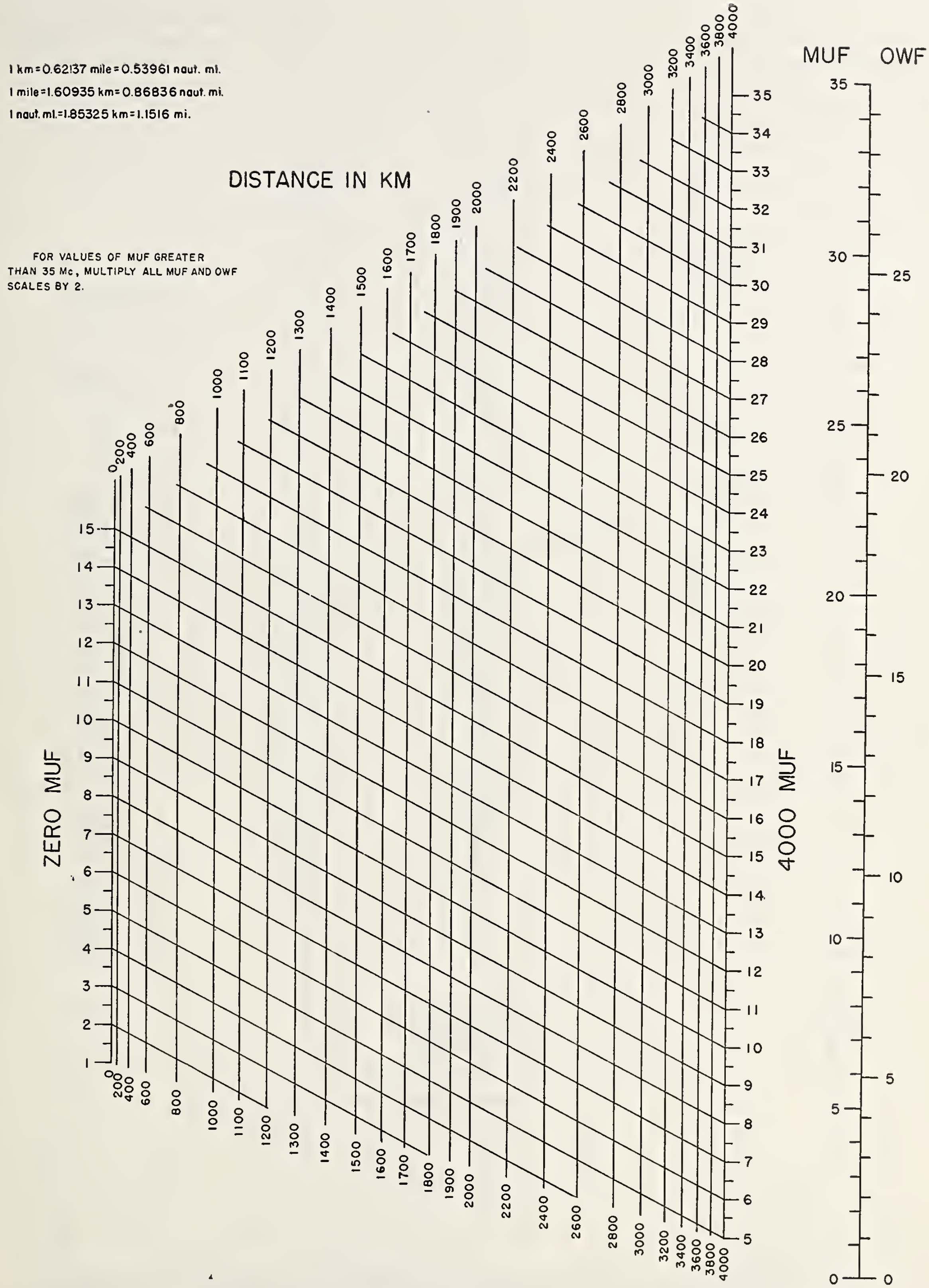

FIG. 11 NOMOGRAM FOR TRANSFORMING F_2—ZERO—MUF AND F_2—4000—MUF TO EQUIVALENT MAXIMUM USABLE FREQUENCIES AT INTERMEDIATE TRANSMISSION DISTANCES; CONVERSION SCALE FOR OBTAINING OPTIMUM WORKING FREQUENCIES.

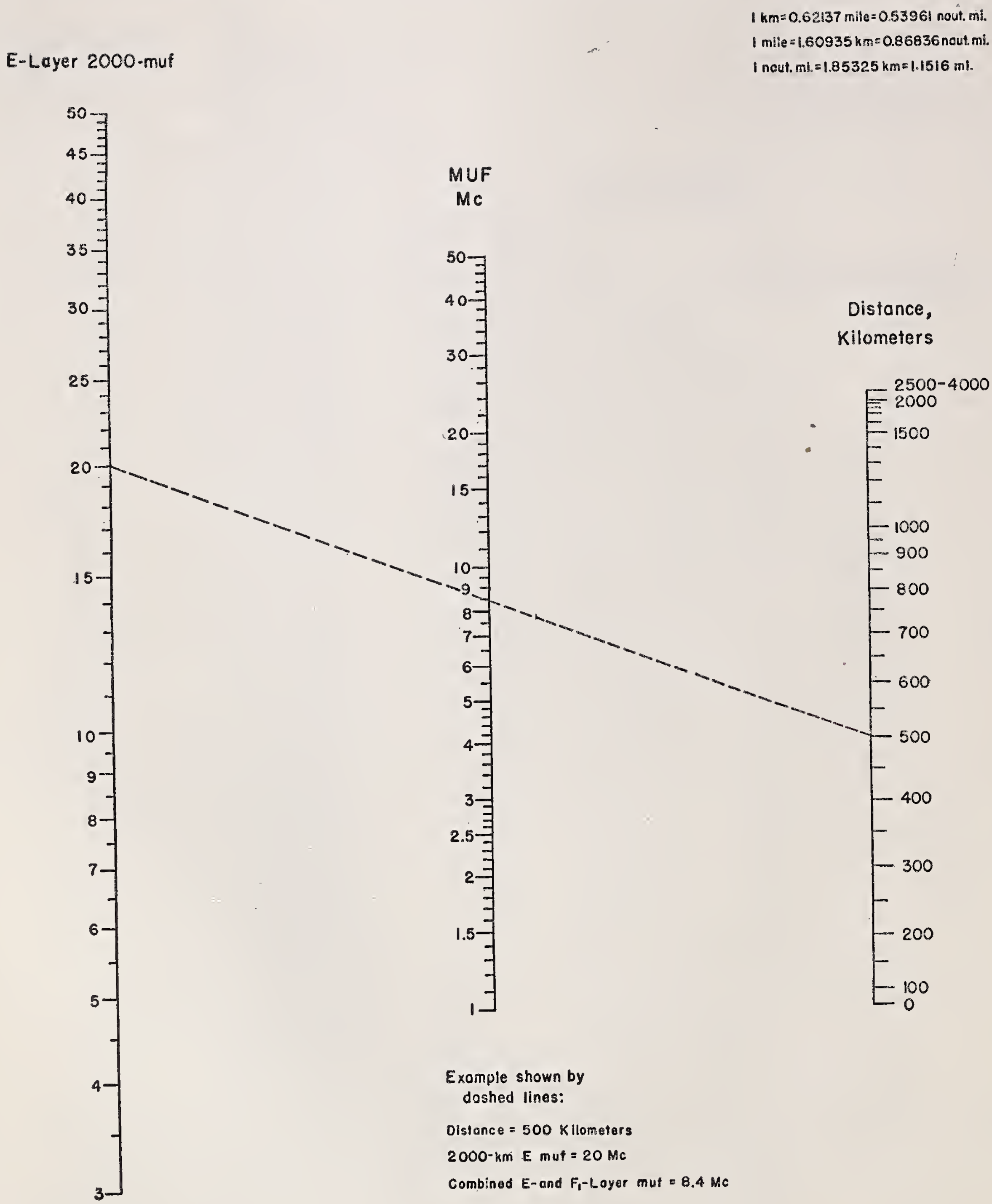

FIG. 12 NOMOGRAM FOR TRANSFORMING E—LAYER 2000—MUF TO EQUIVALENT MAXIMUM USABLE FREQUENCIES AND OPTIMUM WORKING FREQUENCIES DUE TO COMBINED EFFECT OF E LAYER AND F_1 LAYER AT OTHER TRANSMISSION DISTANCES.

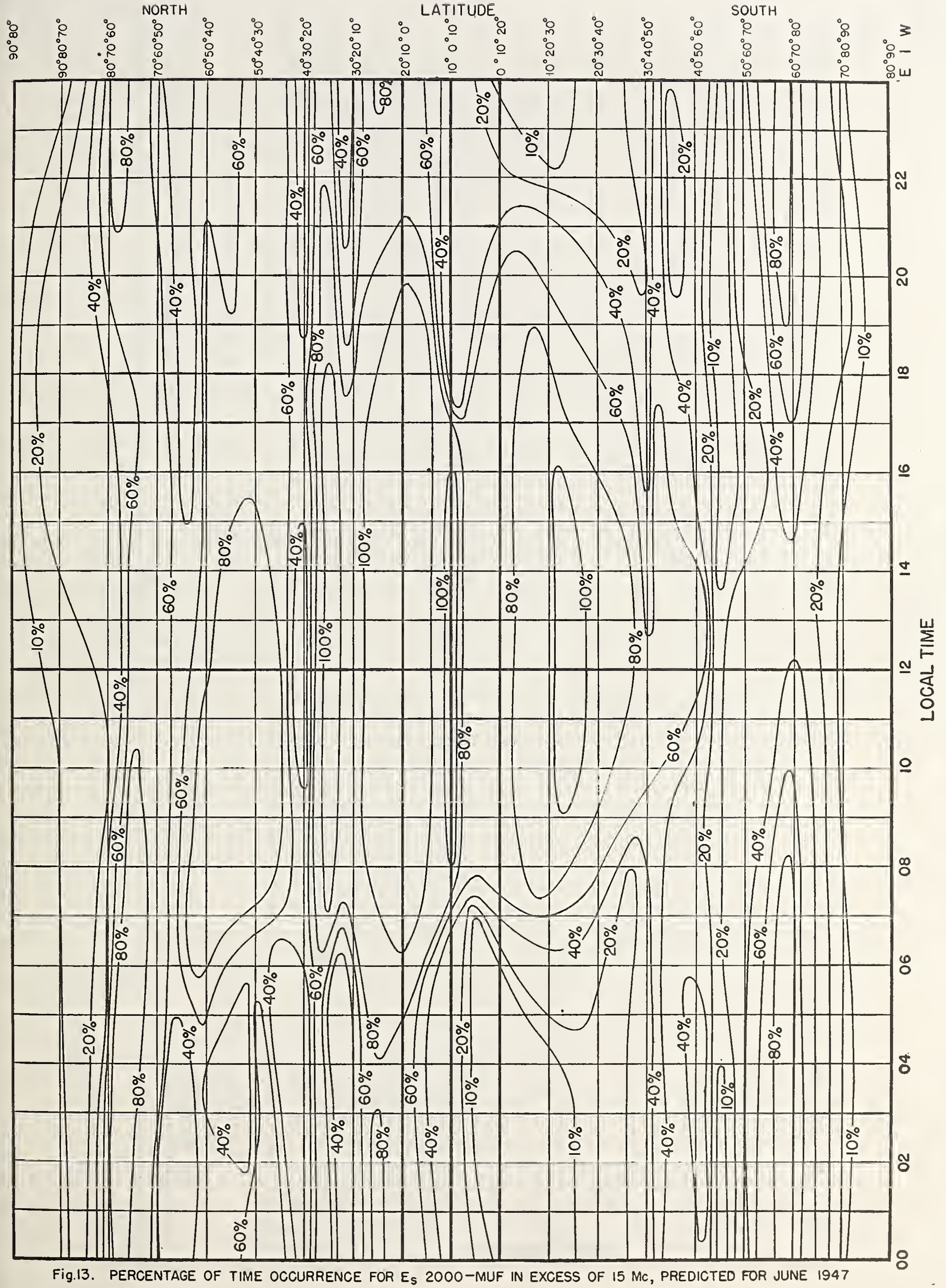

Fig.13. PERCENTAGE OF TIME OCCURRENCE FOR E_s 2000—MUF IN EXCESS OF 15 Mc, PREDICTED FOR JUNE 1947

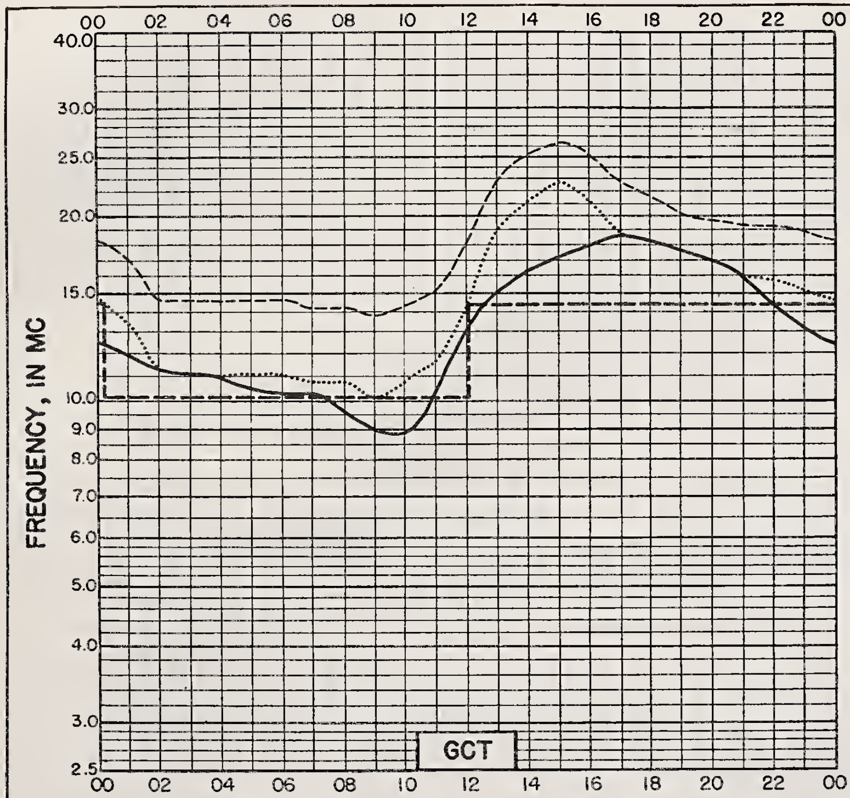

Fig. 14. SAMPLE SOLUTION OF TRANSMISSION PROBLEM FOR SHORT PATH, JUNE 1947

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

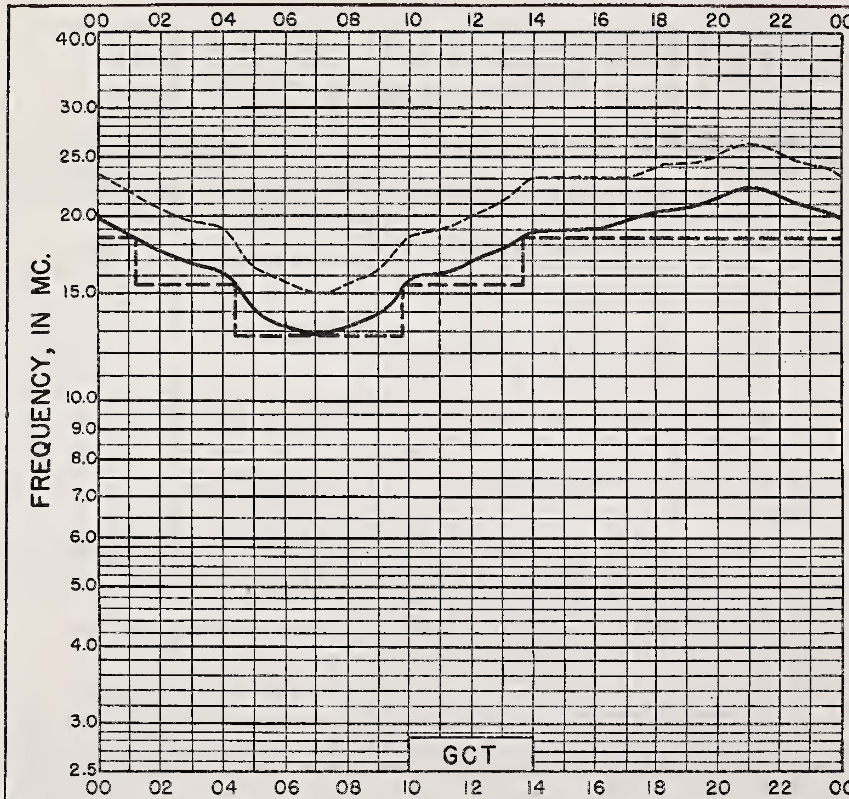

Fig. 15. SAMPLE SOLUTION OF TRANSMISSION PROBLEM FOR LONG PATH, JUNE 1947

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

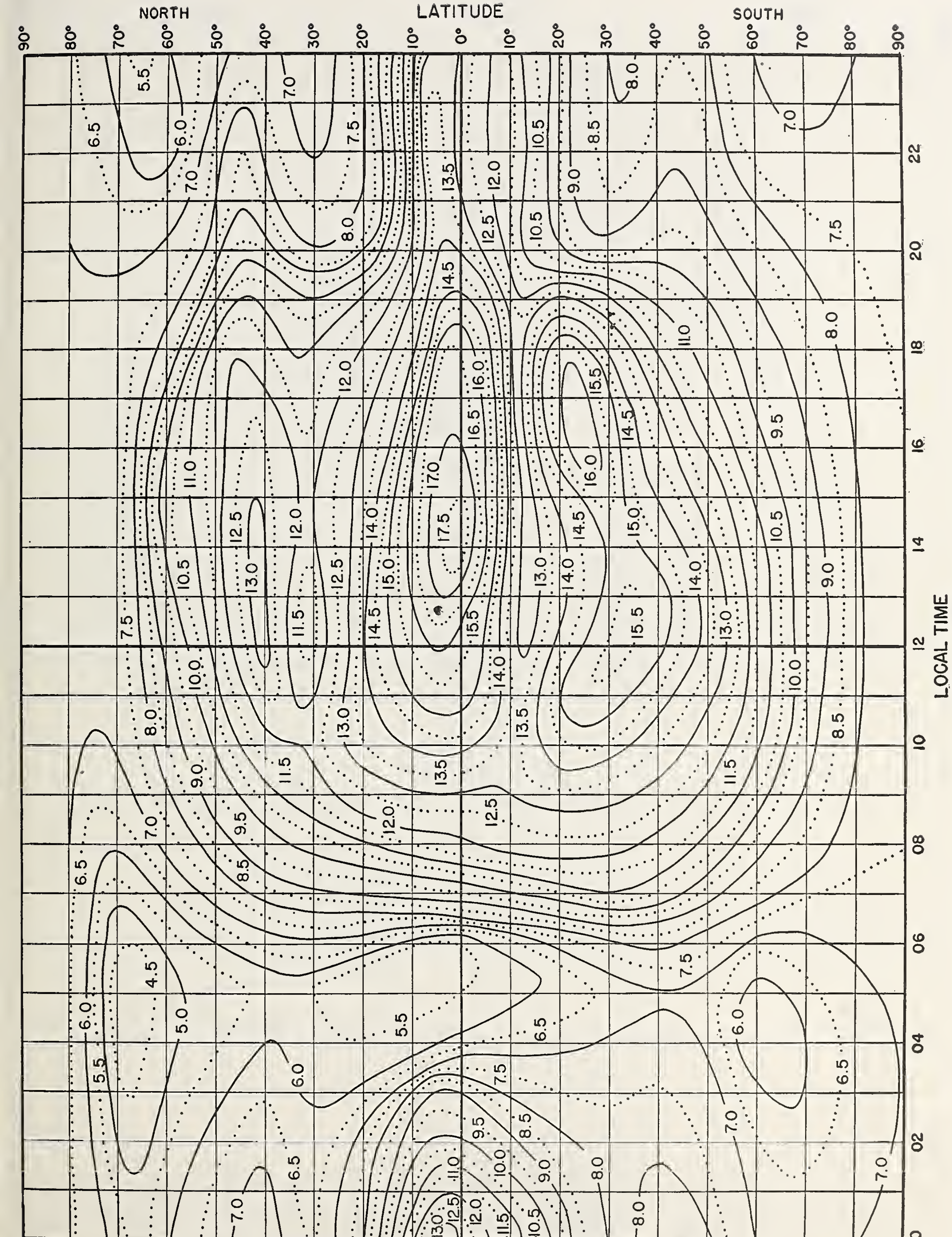

Fig. 16. F_2 ZERO—MUF, IN Mc, W ZONE, PREDICTED FOR MARCH 1947

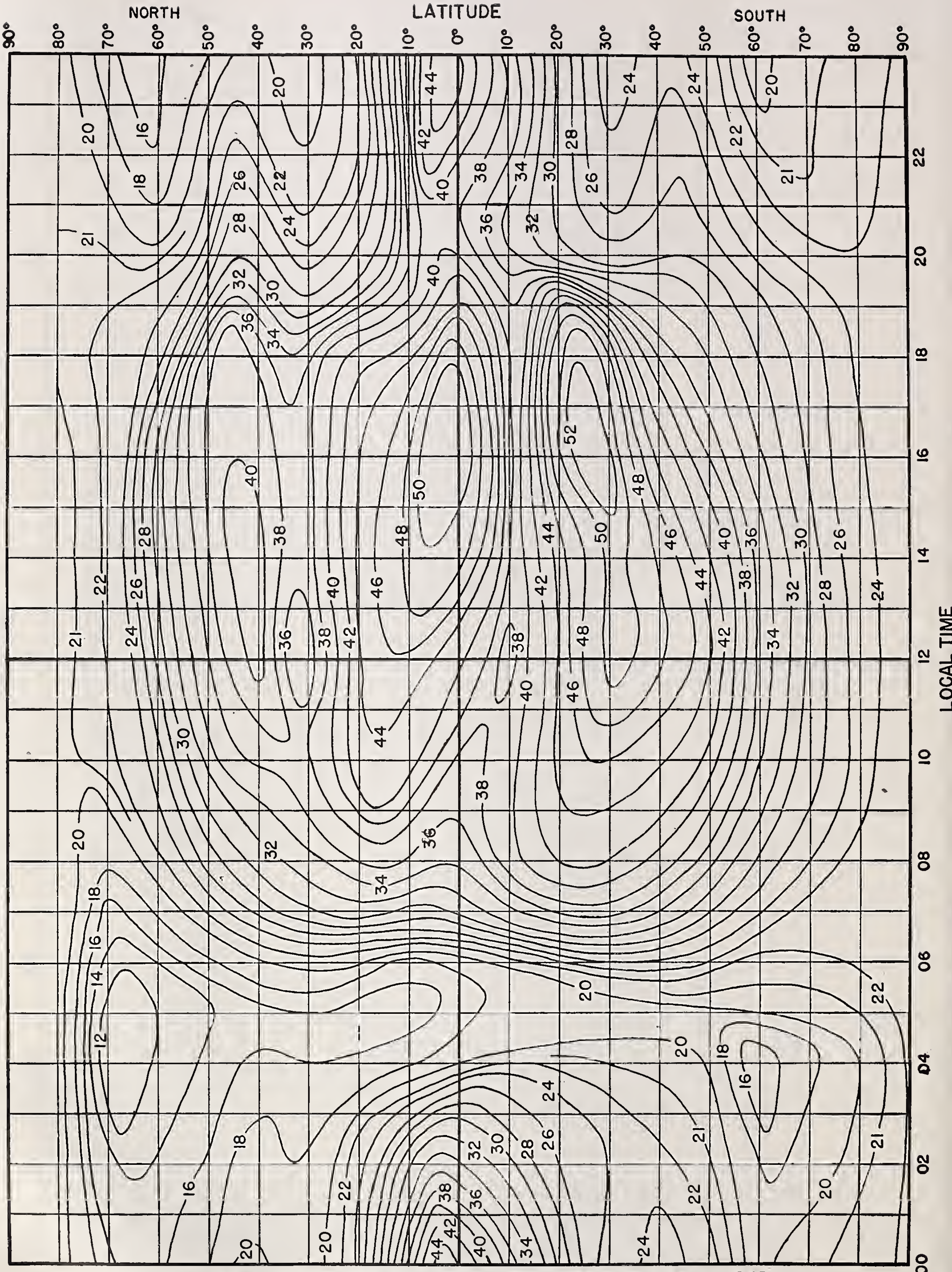

Fig.17. F_2 4000—MUF, IN Mc, W ZONE, PREDICTED FOR MARCH 1947

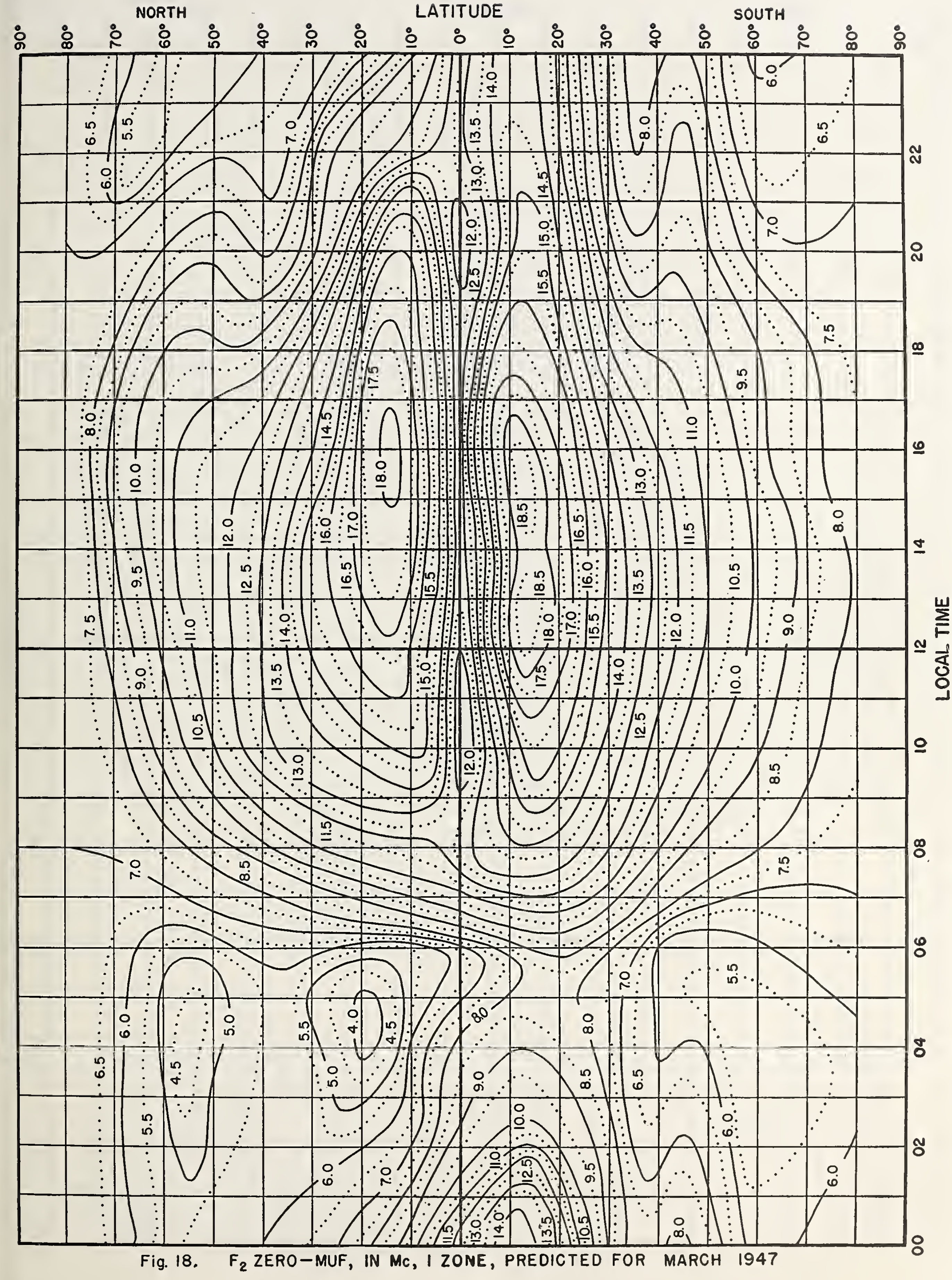

Fig. 18. F_2 ZERO—MUF, IN Mc, I ZONE, PREDICTED FOR MARCH 1947

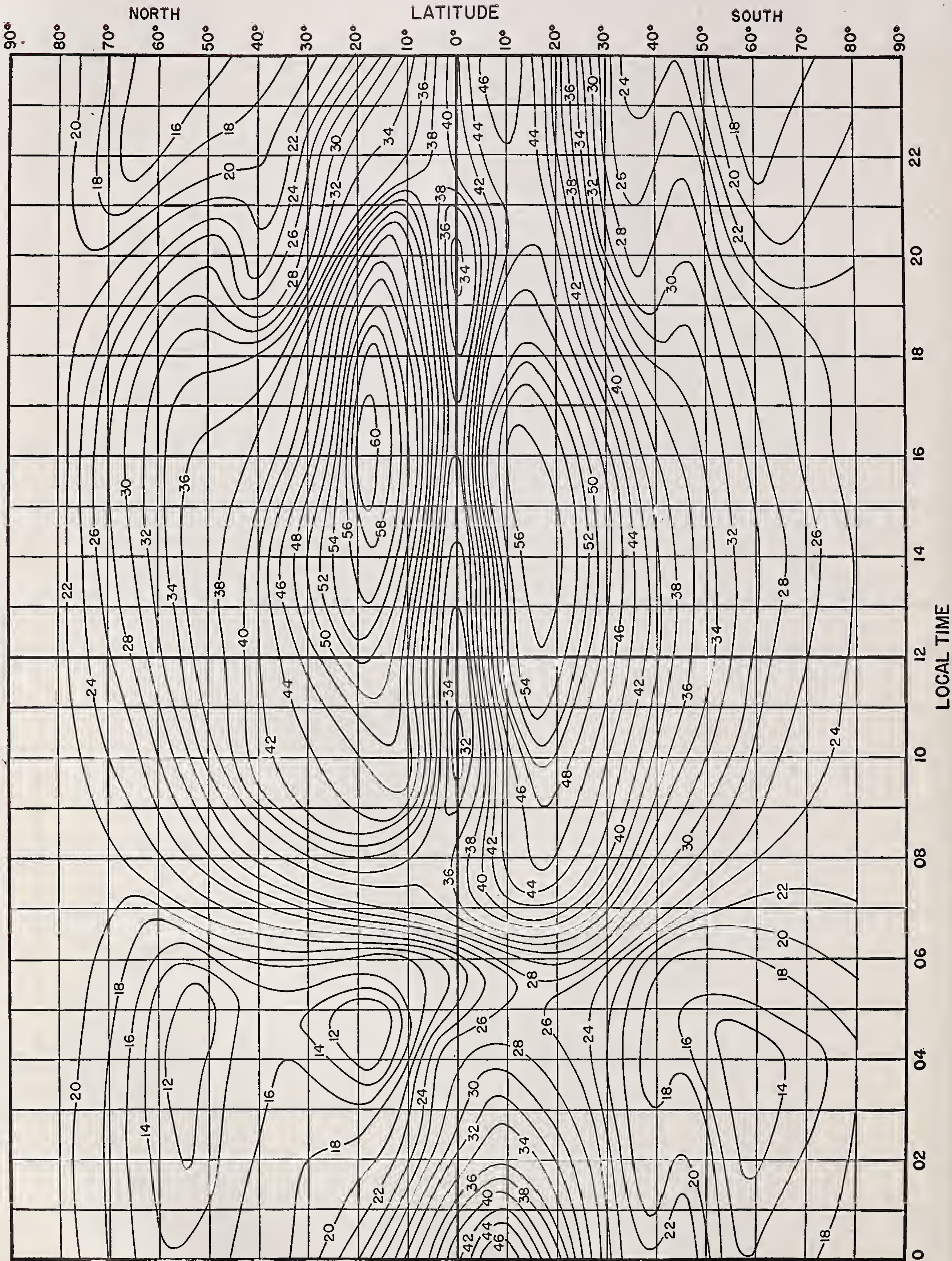

Fig. 19. F_2 4000—MUF, IN Mc, I ZONE, PREDICTED FOR MARCH 1947

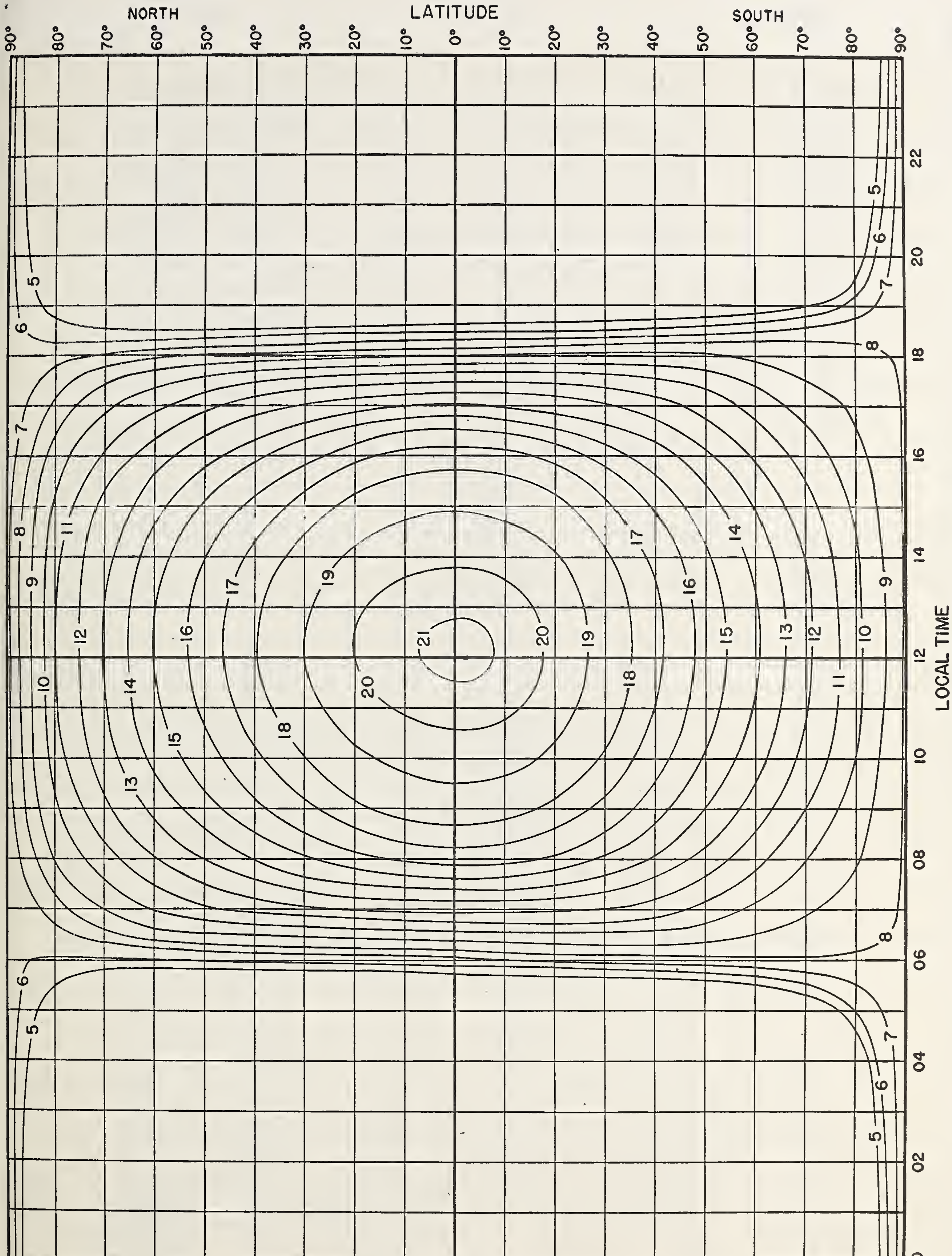

Fig. 20. E–LAYER 2000–MUF, IN Mc, PREDICTED FOR MARCH 1947

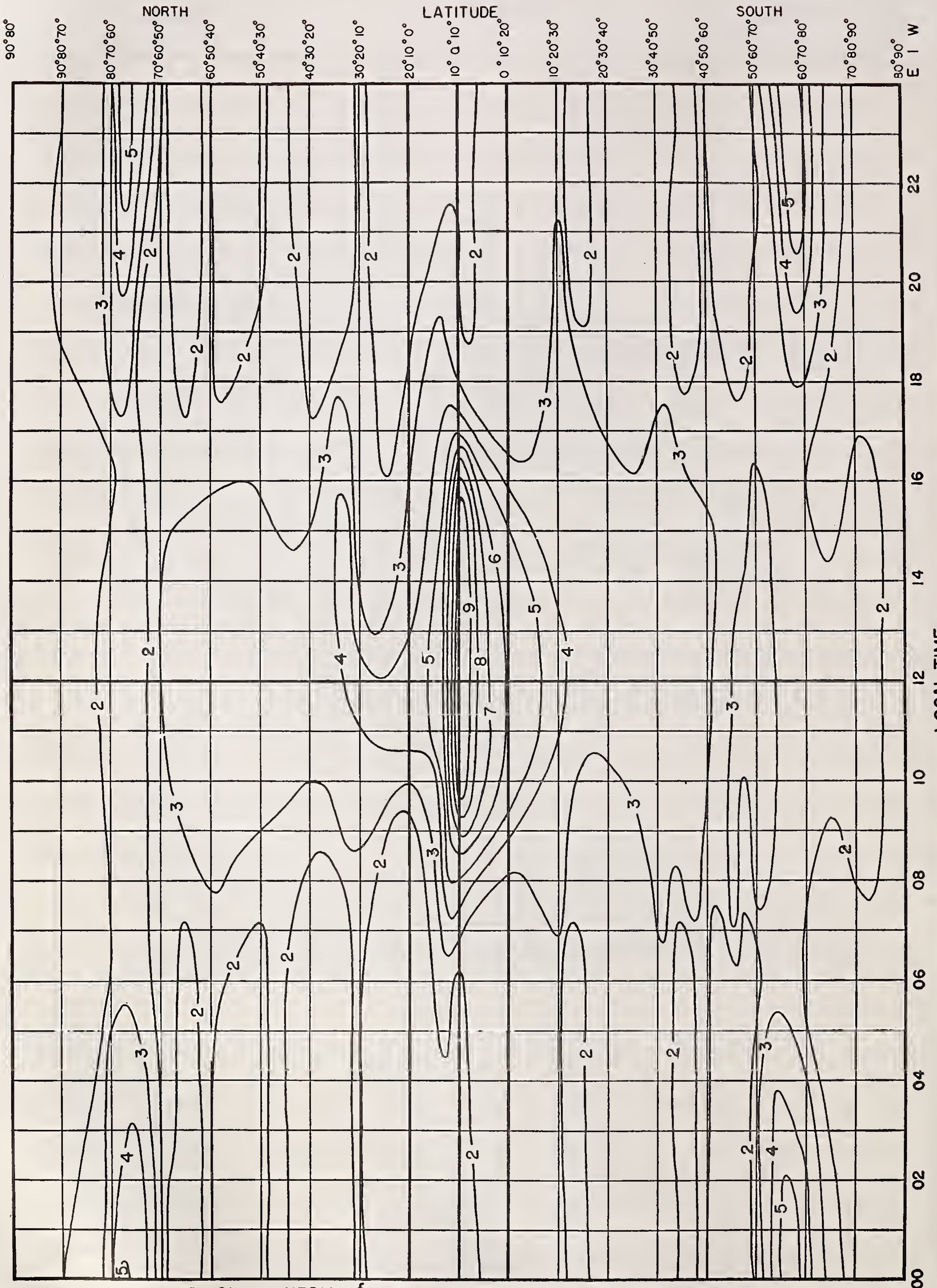

Fig. 21. MEDIAN f_{E_s}, IN Mc, PREDICTED FOR MARCH 1947

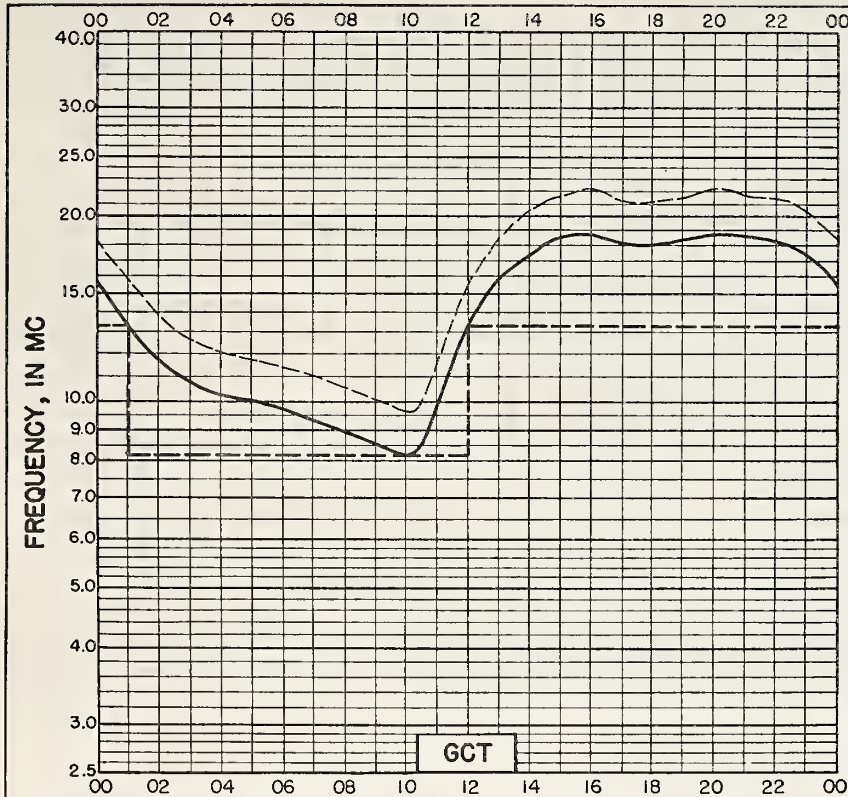

Fig. 22. SAMPLE SOLUTION OF TRANSMISSION PROBLEM FOR SHORT PATH, MARCH 1947

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

---- MUF —— OWF ---- SUGGESTED FREQUENCY USAGE

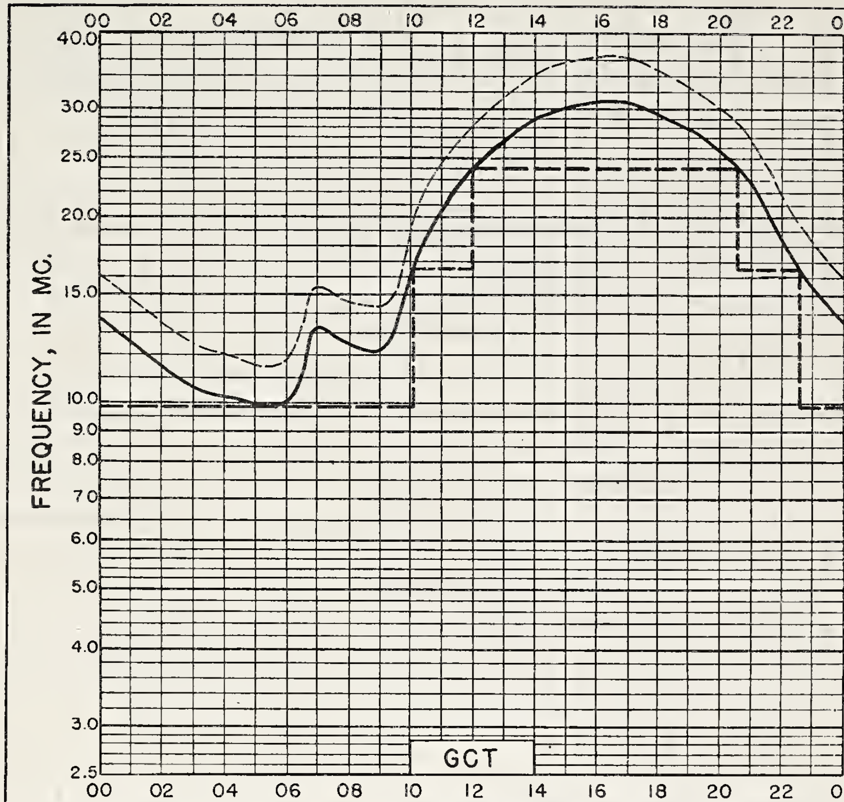

Fig. 23. SAMPLE SOLUTION OF TRANSMISSION PROBLEM FOR LONG PATH, MARCH 1947

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

---- MUF —— OWF ---- SUGGESTED FREQUENCY USAGE

FORM AF

CRPL

Date ________

MUF-OWF WORK SHEET FOR PATHS 4000 KM OR LESS

From ____________ To ____________ Distance, ________ km Zone____ Predicted for ____ 194__

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														
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														

FORM AH

CRPL

Date____________

MUF-OWF WORK SHEET FOR PATHS OVER 4000 KM.

From ____________________ To ____________________ Distance, __________ km Predicted for ____________________ 194__

Note: All frequencies are in megacycles.

	A-end						B-end											
	Pt. A in ____ Zone			Pt. A' in ____ Zone			Pt. B in ____ Zone			Pt. B' in ____ Zone			MUF	MUF	OWF	OWF	MUF for	OWF for
GCT	f_{E_s}	E_s 2000-muf	F_2 4000-muf	E-layer 2000-muf	E_s 2000-owf	F_2 4000-owf	f_{E_s}	E_s 2000-muf	F_2 4000-muf	E-layer 2000-muf	E_s 2000-owf	F_2 4000-owf	A-end	B-end	A-end	B-end	PATH	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																		
01																		
02																		
03																		
04																		
05																		
06																		
07																		
08																		
09																		
10																		
11																		
12																		
13																		
14																		
15																		
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23																		
Done by																		
Checked																		

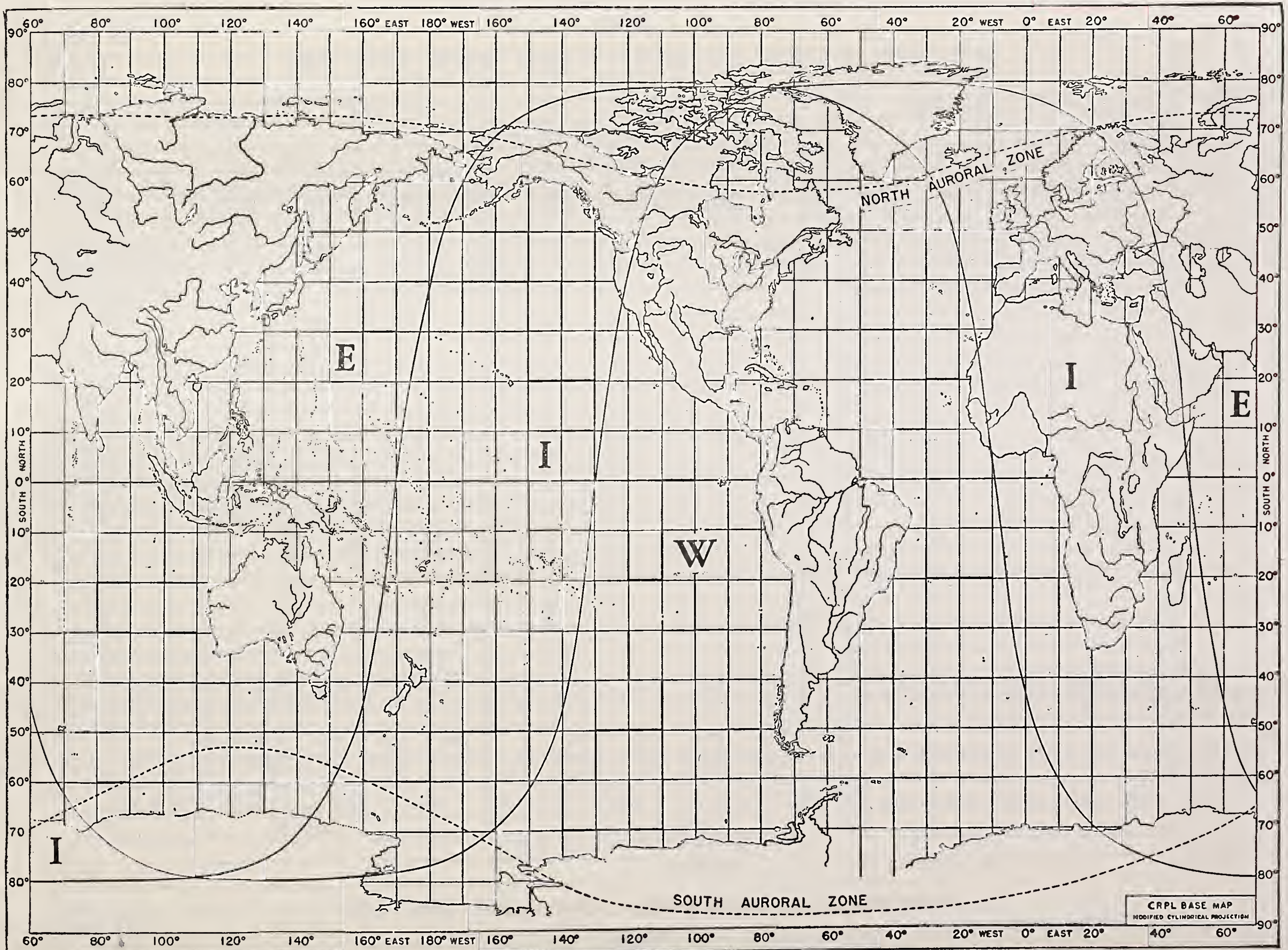

Fig. 1. WORLD MAP SHOWING ZONES COVERED BY PREDICTED CHARTS, AND AURORAL ZONES.

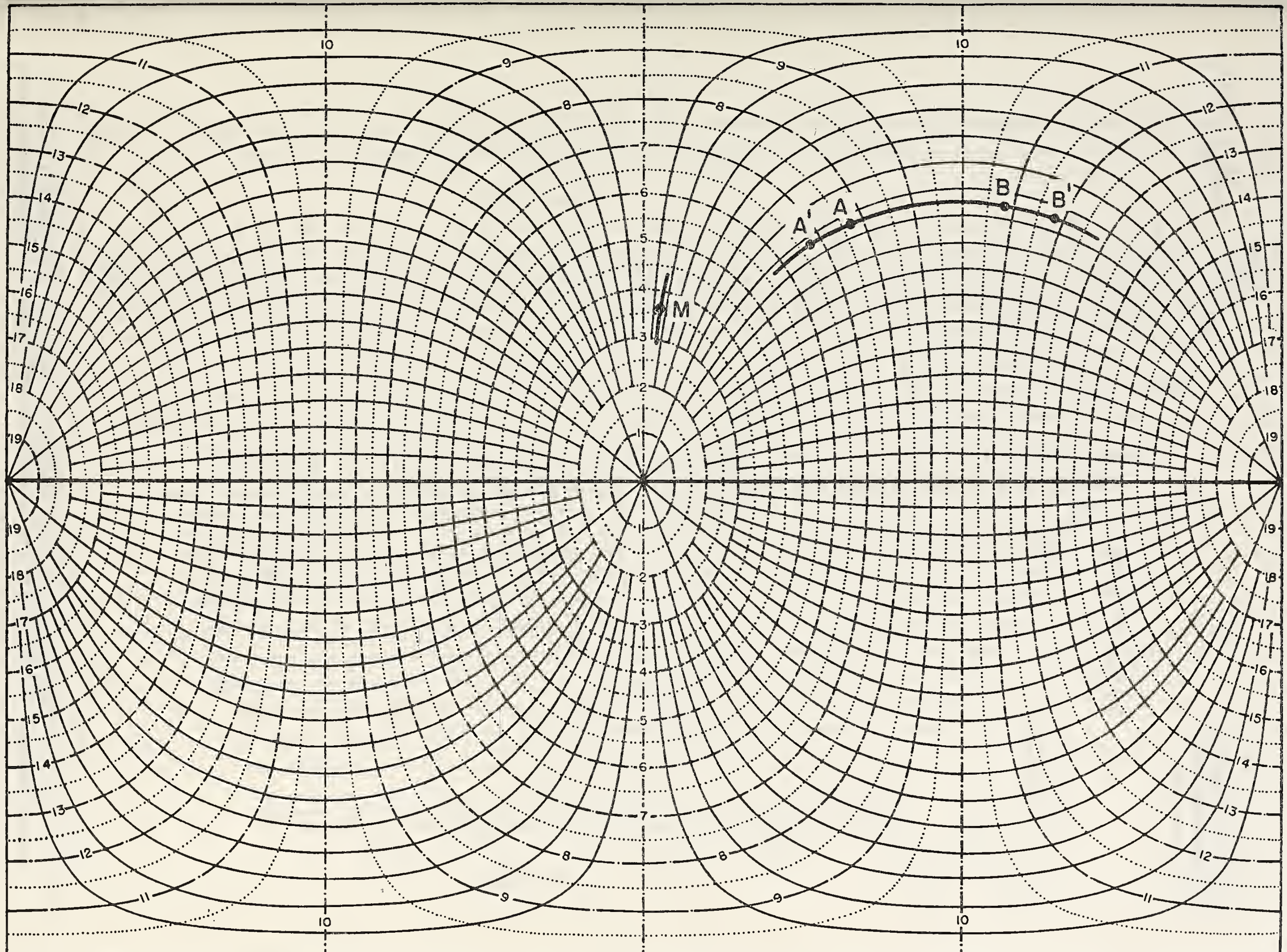

Fig. 2. GREAT CIRCLE CHART CENTERED ON EQUATOR. SOLID LINES REPRESENT GREAT CIRCLES. NUMBERED DOT-DASH LINES INDICATE DISTANCES IN THOUSANDS OF KILOMETERS.

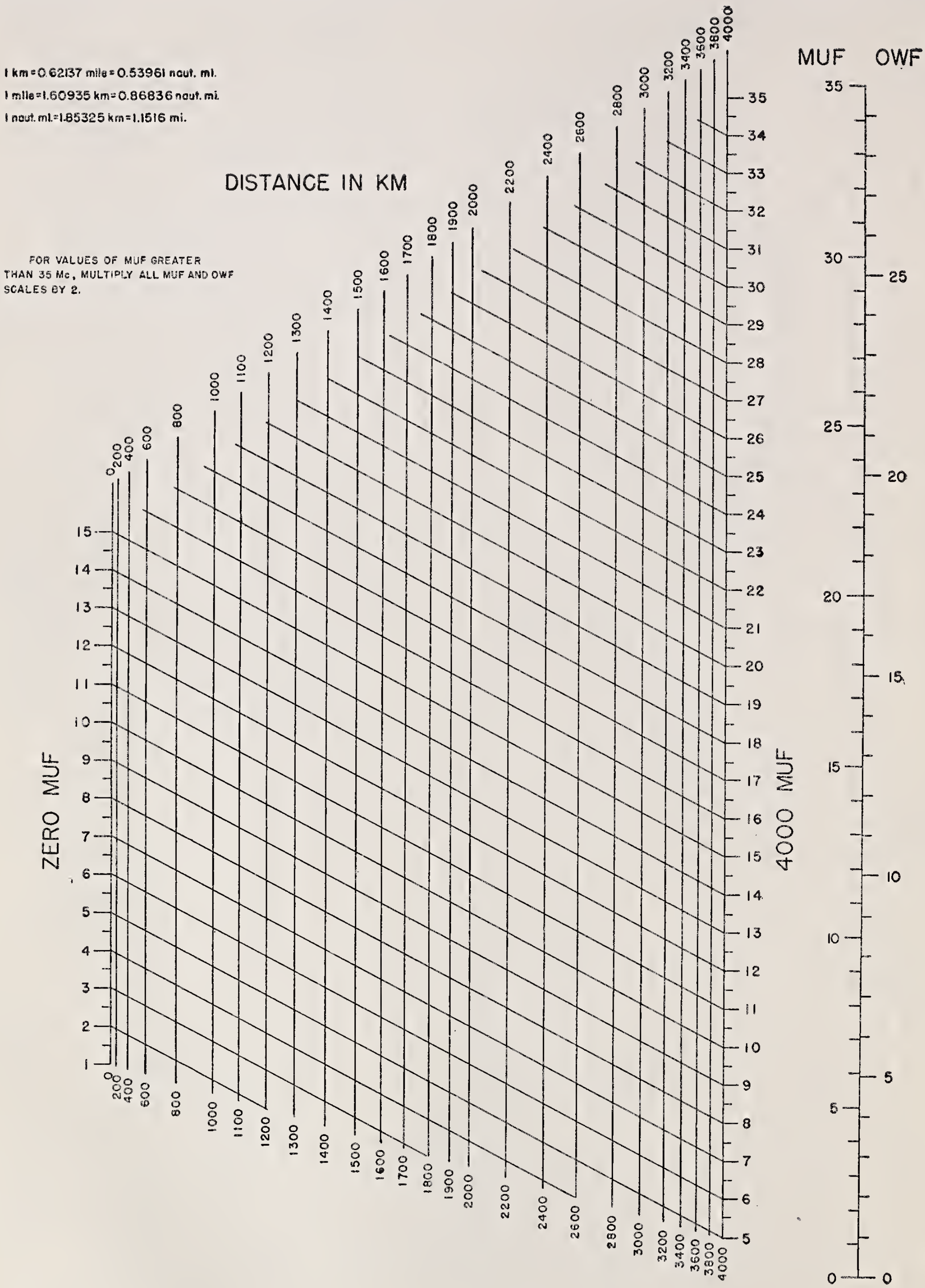

FIG. 11 NOMOGRAM FOR TRANSFORMING F_2—ZERO—MUF AND F_2—4000—MUF TO EQUIVALENT MAXIMUM USABLE FREQUENCIES AT INTERMEDIATE TRANSMISSION DISTANCES; CONVERSION SCALE FOR OBTAINING OPTIMUM WORKING FREQUENCIES.

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 mi.

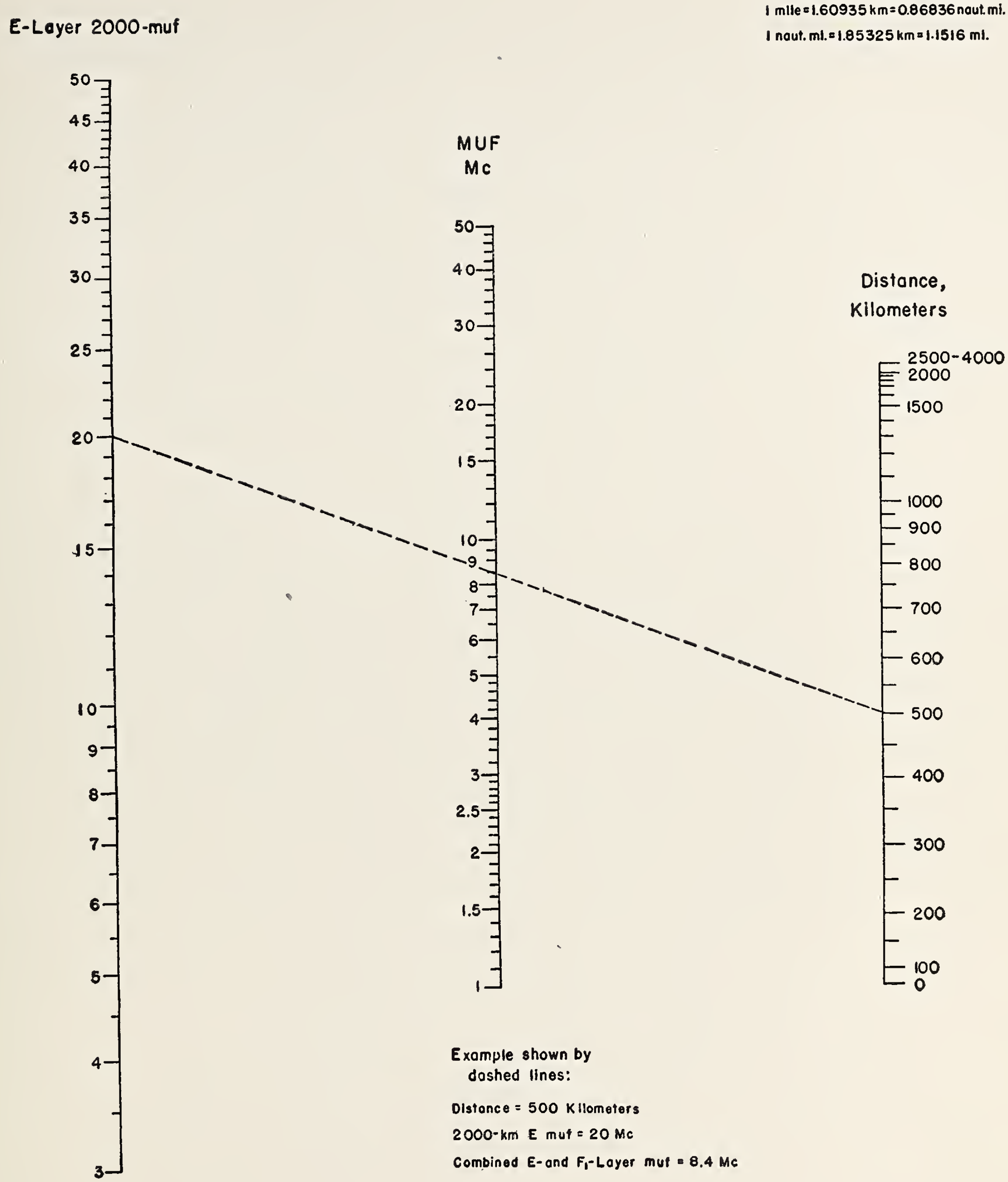

FIG. 12 NOMOGRAM FOR TRANSFORMING E—LAYER 2000—MUF TO EQUIVALENT MAXIMUM USABLE FREQUENCIES AND OPTIMUM WORKING FREQUENCIES DUE TO COMBINED EFFECT OF E LAYER AND F_1 LAYER AT OTHER TRANSMISSION DISTANCES.

U. S. GOVERNMENT PRINTING OFFICE: 1947