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RADIO TRANSMISSION HANDBOOK,
FREQUENCIES 1000 TO 30,000 KC

(Prepared by National Bureau of Standards under sponsorship of Communications Section, National Defense Research Committee)

Note.- This issue is preliminary, for comment. The data herein are for one season only, the present winter, and are not valid beyond the end of February. It is expected to issue supplements for other seasons. All users of this issue are requested to send any comments or suggestions on how the book may be made of more direct use, to Radio Section, National Bureau of Standards, Washington, D.C.

January 1, 1942.

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I. INTRODUCTION

The purpose of this Handbook is to show the conditions under which the different radio frequencies are usable in actual practice. The relations among frequency, distance, time, and location of transmission path, are complicated, but it has been possible to reduce the principal facts to a set of graphs presented in this Handbook. The data given herein are for winter-time only; it is expected to issue supplements giving the data for other seasons. The principal information is given by the graphs; a description of the graphs and how to use them is given in Secs. III and IV. The data are based on extensive measurements and communication experience.

II. FACTORS DETERMINING DISTANCE RANGE AND USABLE FREQUENCY.

The transmission of radio waves between the transmitting and receiving stations involves the passage of the "ground wave" along the ground and the "sky wave" reflected from conducting layers in the upper atmosphere. The sky wave generally predominates for all except short distances. The conducting layers from which sky waves are reflected consist of ionized air; they exist in the region called the ionosphere, 30 to 300 miles above the earth's surface. Knowledge of the ionosphere is necessary to understand radio wave transmission. An introduction to such understanding is given in this Section. The graphs in this Handbook, however, can be utilized without an understanding of the ionosphere or the processes of radio transmission; see explanation of graphs in Secs. III and IV.

<u>Noise Conditions at Receiving Station.</u>- Since radio waves decrease in intensity as they spread out from the transmitter, and since they lose energy by absorption in either the ground or the ionosphere, they finally become so weak that they can not be heard above the level of electrical noise at the receiving station. The electrical noise may be due to "static" or man-made electrical disturbance. The minimum radio field intensity needed to allow an intelligible signal to be heard above the noise at the receiving station is called the required field intensity, and the distance from the transmitter to any point beyond which the radio field intensity is less than the required field intensity is the distance range.

The required field intensity is subject to wide variation. It depends on the receiving antenna, the type and adjustments of receiving set, the local electrical noise, "static", and the type of modulation of the radio wave. It varies, with the noise, according to the time of day and season.

Other Factors Affecting Distance Range.- The distance range depends in addition on the transmitting station power and antenna and on the energy loss by absorption in the ground or ionosphere. The determination of distance ranges is a very complex problem, although effects of many of the factors, such as radiated power, antenna design, and absorption of the wave energy can be calculated with fair precision. No one graph or series of graphs can represent all possible variations of all the factors involved. For the distance range graphs, therefore, average receiving conditions were assumed, and calculations were made considering transmitter power, average ground absorption for land and for sea-water, ionosphere conditions and trends, and known variations of noise.

Fading.- In general, sky wave intensities undergo regular, well defined, and predictable long-time changes, due to diurnal, seasonal, and year-to-year variations in the ionosphere. They also undergo fast irregular changes, known as fading. Fading is due to three causes: interference of waves travelling over paths of slightly different lengths, changes of the state of polarization of the waves, and changes due to rapid variations in the amount of energy absorption which the wave undergoes while travelling through the ionosphere. In this Handbook fading is not considered, beyond the statement that any radio field intensities stated are a sort of average called the median field intensity, which is the value of field intensity that is exceeded half the time. That is, 50% of the time the instantaneous received field intensity is greater than the stated value of field intensity. Regarding the amount of time the instantaneous received field intensity is greater than values other than the median, the following approximate relation gives some information: $T = \epsilon^{-0.693\left(\frac{F}{F_0}\right)^2}$, where T is the fraction of the time the field intensity will exceed the value F, and F_0 is the median field intensity.

<u>The Ionosphere.</u>- As previously mentioned, the ionosphere is the region 30 to 300 miles above the earth's surface in which there are layers of ionized air which reflect radio waves. Detailed information about the ionosphere is given in the pamphlet (obtainable upon request from National Bureau of Standards, Washington, D.C.), "Radio transmission and the ionosphere", and in articles listed therein. A few main facts are given here.

There are two principal layers at night, and three in the daytime. One layer, called the E layer, is at a height of about 60 miles above the earth's surface. The F layer, at night, is at a little under 200 miles. The F_1 daytime layer is at about 140 miles, and the F_2 daytime layer at a height which varies between about 150 and 250 miles. Since the ionization in these layers is produced by sunlight, there are changes in both the ionization densities and the heights of the layers diurnally, seasonally, and from year to year.

The ionization density of a layer has an important bearing on the frequencies of radio waves which can be transmitted by reflection from it. The higher the frequency, the greater is the ionization density needed to reflect radio waves of that frequency. The maximum ionization density of a layer determines the maximum frequency which can be reflected from the layer. For waves transmitted vertically upward this maximum frequency is called the "critical frequency" of the layer. If the waves are sent obliquely, as in ordinary radio transmission, the maximum frequency is called the "maximum usable frequency" for the given distance. Waves of higher frequency than the critical or maximum usable frequencies penetrate through the layer and are not reflected back to earth from it.

<u>Maximum Usable Frequencies and Skip Distances.</u>- The maximum usable frequency for transmission over a given distance depends on two quantities, the critical frequency (which

depends upon the ionization density of the layer which reflects the waves) and the angle at which the waves meet the layer (which depends upon the height of the layer). A knowledge of the heights and critical frequencies of the ionosphere layers, therefore is sufficient to enable the maximum usable frequencies to be determined. The regular trends and variations of these ionosphere characteristics have been studied, and are now well enough understood that they, and therefore the maximum usable frequencies over any path in the world, can be predicted with reasonable accuracy. Such predictions are given each month in a report distributed to qualified agencies by the National Bureau of Standards.

The maximum usable frequency, in general, increases with transmission distance, at least out to about 2500 miles. Hence transmissions on the maximum usable frequency for any distance will be above the maximum usable frequency for shorter distances, and therefore can not be heard, by sky wave, closer to the transmitter than the given distance. In other words, instead of the higher-angle rays coming down to earth at shorter distances, they penetrate completely through the ionosphere and do not return to the earth. This causes a zone of silence between the limit of the ground-wave distance range and the distance for which the frequency being used is the maximum usable frequency. The outer edge of this zone of silence, or "skip zone", is called the skip distance. More generally, the skip distance is the distance to any point on one side of which a sky wave can be received, and on the other side it can not, because of penetration through the ionosphere.

Lowest Useful High Frequencies.- In travelling through the ionosphere, a radio wave sets the ions in motion. These ions collide with the molecules of the air, and lose some of their energy as heat in the collision. This energy is lost to the radio wave, and therefore the wave comes out of the ionosphere with less energy than it had when it entered. This energy is said to be lost by "absorption" in the ionosphere.

Absorption in the ionosphere is greater the lower the frequency of the wave, and the greater the number of collisions of ions with molecules of air in a given time (collisional frequency). Absorption can be measured at vertical incidence, just as the critical frequency can. The absorption undergone by a wave at oblique incidence (i.e., a wave travelling over a distance) can be calculated from the vertical-incidence absorption in much the same way that the maximum usable frequency can be calculated from the critical frequency.

In general, for a given path of transmission and time of day, waves of higher frequencies undergo less energy absorption than do waves of lower frequencies. Thus waves of lower frequencies arrive at the receiving point with less energy than waves of higher frequencies, if both types of waves start out with the same energy (i.e., if the radiated power of the transmitter is the same on high and low frequencies). Thus there is usually some frequency, for a given distance and radiated power of the transmitter, below which the field intensity of the waves at the receiver is too weak to use. This is called the lowest useful high frequency, for the given distance, radiated power, and state of the ionosphere. (It is not called the lowest useful frequency, because there is useful ground-wave transmission at very much lower frequencies).

In contrast to the maximum usable frequency, which does not depend on radiated power, the lowest useful high frequency depends on all the factors which were given above as affecting the distance range. The maximum usable frequency depends only on the state of the ionosphere; the lowest useful high frequency depends in addition on the equipment and on local receiving conditions, and is not nearly as well-defined or clear-cut as is the maximum usable frequency. Note that the lowest useful high frequency has the same relation to the distance range as has the maximum usable frequency to the skip distance. The distance range and the skip distance are the limits of the range of useful distances; the maximum usable frequency and the lowest useful high frequency are the limits of the band of useful frequencies.

It is possible to calculate with fair accuracy, from vertical-incidence measurements, the total median sky-wave field intensity as a function of distance for any radiated power and a given type of antenna. The field intensities required for reception depend on many factors, and much more detailed data would be needed before these requirements could be stated to an accuracy compatible with that of the field intensity. The maximum usable frequencies given in this Handbook can be considered as reasonably accurate average values, but the lowest useful high frequencies can be considered as only roughly approximate average values.

Departures from Average.- Distance-range data are usually given, for the sake of simplifying a comprehensive picture of them, as averages; they may be averages for quiet days, for a month or a season, or some other period of time. Quiet days are those when there is no ionosphere storm (see explanation below). Distance ranges, maximum usable frequencies, etc., are not exactly the same day after day, but are distributed about an average. The distribution of maximum usable frequencies about the average is fairly well established. As a rule, on quiet days, the maximum usable frequency is practically never less than 80% of the average and practically never greater than 120% of the average; only 13% of the time is it less than 90% of the average or greater than 110% of the average. No such general statements can be made about the lowest useful high frequency; local receiving conditions may vary widely from day to day, and the variation of energy absorption in the ionosphere has not been studied extensively.

Anomalies.- Besides the regular predictable sky-wave transmission that is characterized by the maximum usable frequencies shown in the graphs of this handbook, there occurs at irregular and unpredictable times very strong transmission, caused by reflection from E-layer heights, but at frequencies much greater than the normal maximum usable frequency. Such transmission is called sporadic-E transmission, and often results in excellent reception within the normal skip zone, and over long distances on frequencies which are considerably higher than any which normally are propagated by sky waves. This type of transmission is not usually widespread or of long duration. Sporadic E is patchy both in space and in time. It occurs rarely in the tropics, frequently during the summer in the temperate zones, especially at night, and quite frequently in polar regions.

Irregular and fluttery weak transmissions are often heard within the normal skip zone. These are caused by so-called scattered reflections. They follow complex paths involving reflection from irregularities in the ionosphere. They are stronger and more prevalent during ionosphere storms, but are receivable at other times within a thousand miles or so of the transmitter.

At irregular and unpredictable times all high-frequency transmissions on the daylight half of the world suddenly fade out. Such a fadeout is caused by a sudden very rapid increase in energy absorption below the E layer, which in turn is caused by a violent eruption on the sun which very suddenly pours out an enormous quantity of ultraviolet light. Recovery is gradual, lasting from a few minutes to several hours or more. The effects are greatest in the lower ranges of the high frequencies. Low frequencies (below 1500 kilocycles) are little affected. This effect is called a radio fadeout or "sudden ionosphere disturbance".

Another type of anomaly is the "ionosphere storm". It is a period of disturbance in the ionosphere causing abnormal radio conditions, such as decrease of maximum usable frequencies, increased skip distances, high layer heights, low received radio intensities, and usually also abnormal magnetic fluctuations. High-frequency transmission above 2000 kilocycles is of low intensity and subject to flutter fading caused by complex reflections from the unstable ionosphere. Night sky waves below 2000 kilocycles are greatly weakened, both during the storm and for several days after the effects on the higher frequencies have disappeared. All effects are greater in radio transmission paths passing through the polar regions. During the first few hours of severe ionosphere storms, and in high latitudes even for small storms, the ionosphere is very turbulent and radio transmission is weak and erratic. During the later stages of the storms the maximum usable frequencies are lowered and the lowest useful high frequencies are raised, so that the bands of useful frequencies are narrowed and sometimes completely disappear. Very low frequencies are little disturbed, and communication may be carried on at frequencies below 100 kilocycles when all high-frequency communication is impossible. Ionosphere storms are most severe in northern latitudes and decrease in intensity toward the equator.

An ionosphere storm usually develops during a period of a few minutes to an hour or more. The effects are noticed in the F or F_2 layer first and move progressively downward. Recovery to normal conditions usually takes several days, depending on the latitude and the severity of the storm. Ionosphere storms are probably caused by bursts of electrified particles from the sun. Their time of occurrence can not in general be predicted. They are most numerous in years when there are many sunspots, and at times they occur a day or two after one or more of the sudden radio fadeouts described above. There is some tendency for ionosphere storms to recur at intervals of about a little less than a month. This is about the period of one rotation of the sun, and may be caused by the reappearance of an active area on the part of the sun which faces the earth. This recurrence tendency may sometimes be used to predict the occurrence of mild or moderate ionosphere storminess; severe storms do not seem to recur.

III. DISTANCE-RANGE GRAPHS

The attached Figs. 1 through 32 show, for certain times of day at the receiving station, latitudes of the receiving station, and azimuths (bearings) of reception, the limits of distance over which practical radio communication is possible, for various values of radiated power. These graphs were calculated by the method outlined in the Appendix. The powers shown on the graphs are for radiotelephone communication; for a given distance range about 0.01 as much power would be required for radiotelegraph (CW) communication. Non-directive transmission is assumed. The graphs are based on the lowest field intensity which permits practical reception in the presence of ordinary background interference or noise. This does not mean satisfactory program reception for broadcasts, or extremely weak signals for CW reception which would require much repetition and great difficulty to receive. The graphs also assume the use of a reasonably good receiving set and an operator of reasonably good ability.

The distance-range graphs are only for frequencies greater than 1000 kilocycles (the behavior of frequencies lower than this is shown for a few cases in the graphs of the pamphlet, "Radio distance ranges", issued by the National Bureau of Standards). The solid-line curve in each graph represents the skip distance and also the maximum usable frequency. The maximum usable frequency for any distance is the frequency for which that distance is the skip distance. The dashed-line curves represent the upper limit of useful distance and also the lowest useful high frequency, for various powers of the transmitter.

The curves just mentioned represent sky-wave transmission. For frequencies above the maximum usable frequency, the relatively short ground-wave distance range is shown, for a power of 1 kilowatt, by the lines made up of long dashes. The two lines are labeled "land" and "ocean"; the distance range of the ground wave is much greater over the ocean than over the land because of the greater electrical conductivity of the ocean. For consistency, the 1-kilowatt line is everywhere shown with long dashes. On some of the graphs the 1-kilowatt curve is seen to have two branches at the lower frequencies (1 to 3 or 4 megacycles); this is because under some conditions at these frequencies the ocean ground wave is stronger than the sky wave, and determines the distance range over the sea.

The skip distance in general increases with frequency out to about 2500 miles. This is because the waves meet the ionosphere at angles which are flatter, the greater the distance of transmission. At distances greater than 2500 miles or so from the receiving point, however, the waves frequently encounter a degree of ionization considerably less than at or near the receiving point, and so the maximum usable frequency for transmission over these greater distances is often less than that for shorter distances; thus the skip distance curve often in such cases turns back toward lower frequencies at greater distances.

The skip distance is independent of transmitter power, since it is determined by complete penetration of the radio waves through the ionosphere, and no amount of power would be able to accomplish transmission under these conditions.

For distances at which transmission is possible, the power required for transmission increases as the distance increases. All the frequencies and distances which lie below the distance-range curves and to the left of the skip-distance curves are useful for transmission.

The scales of abscissas and ordinates on the distance-range graphs are cubical (i.e., numbers shown are proportional to cube of distance along scale, or, distance along scale is proportional to cube root of numbers). This scale was chosen because it spaces the data satisfactorily. A linear scale would crowd the low values too much, and a logarithmic scale would crowd the high values too much.

Use of the Graphs.- These distance-range graphs may be used in a number of ways. They are given for six times of day for a receiving station at latitude 40°N, and for two times of day for a receiving station at the equator (latitude 0°). For each latitude and time of day they are given for four azimuths of reception, i.e., for signals which arrive at the receiving station with bearings 0°, 90°, 180°, 270°, measured clockwise from the north. The graphs for a given azimuth apply with fair accuracy to paths which have bearings within about ±15° of that azimuth; they are roughly approximate for paths with bearings within ±45° of the given azimuth. The graphs for a given time of day apply with fair accuracy to any time within ± a half hour of the given time; they are roughly approximate for any time within ± two hours of the given time. Somewhat better accuracy for intermediate azimuths and times of day may be obtained by considering the distance ranges to vary smoothly in the intervals, and to interpolate for the desired time and azimuth between the graphs on either side. Note that the times of day given are local time at the receiving station.

Interpolation for other latitudes of receiving station is a more difficult procedure. The graphs for 40°N may be used for receiving locations between about latitudes 30°N and 50°N. The graphs for the equator are for receiving stations on or near land, where the static is great (tropical static). These may be used for receiving stations between 10°S and 10°N. For receiving on shipboard far away from land the static is considerably less, and the distance ranges are only slightly less (10% or 20% less) than for the same azimuth at 40°N. The skip distances are the same for receiving at sea as for receiving on or near land. For receiving at latitudes between 10°N and 30°N, distance ranges and skip distances should be determined by interpolation between the values for 40°N and the equator.

To summarize, the distance-range graphs of Figs. 1-32 may be used, with the necessary interpolation, to determine:

(a) For a given frequency and radiated power, the skip distance and distance range for any azimuth and time of day at receiving station.

(b) For a given distance and radiated power, the band of useful frequencies for any azimuth and time of day at receiving station.

(c) For a given distance and azimuth, the power required for communication at any frequency and time of day at receiving station.

(d) In general, any two of the following, given the other four:

Distance of transmission
Frequency
Azimuth of reception
Radiated power of transmitter
Time of day at receiving station
Latitude of receiving station.

Variations and Irregularities.- As mentioned above in "Departures from Average", the maximum usable frequencies are, except during ionosphere storms, practically never less than 80% of the average values given on the maps, and practically never greater than 120% of these values. The distance ranges and lowest useful high frequencies vary considerably more from day to day, but no definite statements can be made about such variations; many factors, such as varying local receiving conditions, in addition to varying ionospheric conditions, cause wide departures from the average values shown on the maps. The distance-range graphs of Figs. 1-32 are for average conditions on ionospherically quiet (not stormy) days. As described above in Sec. II, under "Anomalies", they may be subject to great variations on days of ionosphere storms, especially for paths which pass over or near polar regions. This is discussed further in Sec. V.

Under certain conditions it is possible to receive radio waves of frequencies greater than the regular maximum usable frequency (from transmitting stations within the skip zone), by means of sporadic-E transmission. This is also briefly discussed in the Section on "Anomalies" above. See also the graphs in the National Bureau of Standards pamphlet, "Radio Distance Ranges". This type of transmission is more common in temperate and polar latitudes than in tropical latitudes, and it is much more common, in the temperate latitudes, in summer than in winter, and is practically negligible in the spring and fall. The distance-range graphs are for transmission via the regular layers of the ionosphere, and exclude any sporadic or scattered transmission within the regular skip zone.

IV. USABLE-FREQUENCY "MAPS"

The attached Figs. 33 through 62 give the maximum usable frequencies, and the lowest useful high frequencies for 1 kilowatt radiated power, for reception, at the time and latitude stated on each Fig., from a transmitter located anywhere in the world. These Figs. are contour diagrams, with uniform latitude scales and longitude-difference scales. They are pseudo-maps, being like maps except that the horizontal scale is longitude difference instead of longitude. They are on a rectangular projection, which is similar to but not the same as the conventional Mercator projection of the world. A map of the world on this rectangular projection, showing the continents and land masses, is given in Fig. 75 for the purpose of facilitating determining relative locations of transmitting and receiving stations.

These diagrams will here be called maps. Their ordinates are degrees of latitude, north and south of the equator. The abscissas are degrees of longitude difference between the transmitting and the receiving locations. Thus if the transmitting location is 60° of longitude to the east of the receiving location it is located on the map 4 squares to the right of the vertical center line (line of 0° longitude difference). The receiving location is the intersection of the vertical center line and the line of latitude for which the map is prepared. The lines of longitude difference are spaced 15° because a longitude difference of 15° corresponds to one hour of time.

Use of the Maps.- Each curve on the maps passes through all the points in the world for which the maximum (or lowest) frequency in megacycles, for transmission from that point to the receiving station, is given by the number on the curve. In order to find the band of useful frequencies for transmission from any point in the world to the receiving station (for 1 kilowatt radiated power, phone, non-directive transmission), it is merely necessary to determine which of the maximum usable frequency curves, and which of the lowest useful high-frequency curves pass through the point in question. A frequency will be useful for transmission if it is below the maximum usable frequency, and above the lowest useful high frequency. If the lowest frequency thus determined is greater than the maximum usable frequency, transmission can not take place on any frequency in the range from 1 to 30 megacycles.

Procedure for Powers Other Than One Kilowatt.- The maximum usable frequency maps are independent of radiated power, as explained in Sec. III in the discussion of the skip-distance curves. The maps of lowest useful high frequency are given for a radiated power of 1 kilowatt, radio-telephone transmission. For other radiated powers, or for CW transmission, for which only 0.01 of the radiated power is required as for radio-telephone transmission of equal intelligibility, the following procedure may be used:

(a) Determine the lowest useful high frequency (for 1 kilowatt phone), from the maps.

(b) Select the distance-range graph (Figs. 1 through 32) nearest to the desired latitude, time of day, and azimuth.

(c) On this graph find the distance range corresponding to the frequency determined in (a), for 1 kilowatt phone.

(d) The lowest useful high frequency for any other power is the frequency corresponding to the same distance range and the other power.

Interpolation for Other Conditions.- Interpolation for times of day other than those given in these maps and for latitudes other than 40°N or 0° may be made and are subject to the same considerations as were discussed above regarding the distance-range charts. For long-distance transmission, the maps are in general somewhat easier to use than the distance-range charts, since no knowledge of distance or azimuth of reception is required; one need only know the locations of the transmitting and receiving stations.

Two sets of lowest-useful-high-frequency maps are given for the equator (latitude 0°). These correspond to receiving locations on or near land, where tropical static is severe, and far out at sea, where the static is little if any worse than at 40°N. The maximum-usable-frequency maps are, of course, the same for both types of receiver location.

Variations of Data with Time.- The same remarks on variations and irregularities that were given in Sec. III apply also to the usable-frequency maps (Figs. 33-62) described in this section. The distance-range graphs (Figs. 1-32) as well as the usable-frequency map (Figs. 33-62) are for conditions obtaining during the months of November 1941 through February 1942 (winter, 1941-42, in the northern hemisphere).

The distance ranges and lowest useful high frequencies will probably be but little different for next winter (the months of November 1942 through February 1943); the distance ranges may be slightly greater and the lowest useful high frequencies slightly less for this period. The maximum usable frequencies for November 1942 through February 1943 will be about 10% less than shown in this Handbook. If these variations are kept in mind, the graphs may also be used for November 1942 through February 1943. Equinoctial and summer conditions are quite different.

V. PATHS IN POLAR REGIONS

When a radio transmission path passes through latitudes higher than about 50° it may include regions where there is abnormally high absorption of the radio wave energy. Such paths are characterized by lower received intensity, and more fluctuation, than other paths.

Such poor reception is caused by conditions in the "auroral zones", the regions where visible aurora is most prevalent. In these zones there are nearly continuous magnetic and radio disturbances, and the disturbances are much more severe than in surrounding regions. These zones are roughly circular, centered at latitude 78°N, 65°W, and at 78°S, 111°E. The center line of each auroral zone is considered to have a radius of about 20°, and is considered to extend, for purposes of radio transmission calculations, about 10° on either side of the center line; see Figs. 76 and 77.

Since the absorption of the energy of radio waves is particularly severe in the auroral zones, and is thus not symmetrical about the geographic poles of the earth, the variation of absorption in polar regions is not directly a function of local time, as was assumed in making up the absorption map of Fig. 63. Thus an extra amount of absorption, in addition to that provided for in the charts, is undergone by radio waves traversing polar regions, and this absorption is a function of geographic longitude, and not of local time. The following considerations must therefore be allowed for, in determining radio transmission characteristics over any path which lies even partly in polar regions:

(1) Transmissions over paths which lie, even in part, in the auroral zones, are subject to a greater degree of irregularity and erratic performance than are transmissions over other paths.

(2) The absorption is very great, especially during daylight conditions in polar regions. As an example, stations operating at less than 6000 kilocycles can not be heard during daylight hours over any great distance in these regions.

(3) Severe and prolonged ionosphere storms occur frequently, often developing suddenly in the course of a few minutes. They are manifested by greatly increased absorption, which raises the lowest useful high frequency, and by a drop in the ionization of the higher layers of the ionosphere, which lowers the maximum usable frequency. The result is the narrowing or complete disappearance of the bands of useful frequencies. It is not unusual for long-distance transmission to be impossible on all high frequencies for a day or more at a time, and to be erratic and only partially recovered on a small portion of the frequency spectrum for as much as a week. There have been instances of ionospheric storminess lasting almost continuously for a month.

(4) Frequently also, in auroral zones during ionosphere storms, there appears strong, widespread, and continuous intense sporadic-E transmission lasting for many hours. This may considerably improve radio reception in certain directions and over some paths while it lasts, but there is no way of predicting it.

(5) During the polar winter night conditions (except during ionosphere storms) good radio transmission may be expected up to near the maximum usable frequency.

(6) Some paths which are similar except for direction seem to display different propagation characteristics. For example, from parts of Greenland, the European high-frequency stations on about 9 to 15 megacycles are heard much better than United States stations at similar distances and frequencies. Also, while transmission across the auroral zone between the United States and Greenland is unfavorable for the broadcast frequencies, 550 to 1500 kilocycles, United States stations on these frequencies are received extremely well in northern Canada and Greenland, during the winter night. Not enough is yet known about the auroral zone to explain such effects fully.

In view of the scarcity of quantitative data for the polar regions, the following procedure is suggested in order to aid in selecting frequencies for paths passing through polar regions:

(1) Determine the useful frequency band by the methods given in this Handbook.

(2) When any part of the transmission path enters one of the auroral zones, choose a frequency as high as possible in the band, say 80% of the maximum usable frequency. (To go higher would entail the danger of skipping, due to day-to-day variations).

(3) At times during severe ionosphere storms, there will be periods when no high frequency will be useful over a path in polar regions. At these times long-distance radio transmission is impossible except on a low frequency, 100 kilocycles or less.

APPENDIX.

CALCULATION OF DISTANCE RANGES FOR ANY PATH OR TIME OF DAY

The discussion here is of a more advanced nature than in other parts of the Handbook. As has been explained the graphs, Figs. 1 to 62, give directly, without calculations, the limits of distance and frequency between which radio communication is carried on. For distance, these limits are the skip distance and the distance range, and for frequency the limits are the maximum usable frequency and the lowest useful high frequency.

The graphs, Figs. 1 to 62, however, apply only to reception at two latitudes and at a few values of local time. This Appendix gives the means for calculating distance range or usable frequency for times of day or latitudes of receiving station which are not represented in the graphs, and to a greater degree of precision than can be obtained by interpolation between the values on the graphs.

Short-Path Calculations.- For radio transmission paths not over 2500 miles (4000 kilometers), the limits of usable frequency may be calculated with sufficient accuracy by the following procedure:

(1) To determine the maximum usable frequency for a path of length d, multiply the maximum usable frequency, given on the map of Fig. 63 at a point a distance $\frac{1}{2}$ d away from

the receiver in the direction of the transmitter, by the factor from the following table for the nearest value of d:

d in miles	factor	d in miles	factor
250	0.38	1500	0.85
500	0.44	1750	0.92
750	0.55	2000	0.98
1000	0.67	2250	1.01
1250	0.77	2500	1.03

(2) The lowest useful high frequency may be estimated by multiplying the maximum usable frequency calculated above by the following factors:

Time of day	Factor		
	Low power	Medium power	High power
Night (sunset to sunrise)	0.15	0.1	0.05
Sunrise to two hours after sunrise	0.6	0.5	0.4
Two hours before sunset to sunset	0.6	0.5	0.4
Around midday	0.7	0.6	0.5

For paths in excess of 4000 km (2500 mi), the following procedure may be used.

<u>Absorption Calculations for Long Paths.-</u> Fig. 64 is an energy-absorption map of the world for the months of November through February. The curves on this map are lines of equal wave absorption in the ionosphere. These lines are such that a wave crossing a given line undergoes at that point

the same absorption per unit distance along the path no matter where it crosses the line. The curves of equal absorption are centered on the sub-solar point, i.e., the place on the earth where the sun is directly overhead. In the main, they follow lines along which the sun is the same height above the horizon, since wave absorption is directly related to the altitude of the sun. They depart from this regularity, however, between latitudes 60° and 80°, north and south, because of extra absorption in the polar regions.

The numbers on the curves are values of the "absorption index" (k). This is the relative absorption that a radio wave undergoes referred to the absorption over the same length of path at the sub-solar point. At the sub-solar point the value of k is thus unity, and on the dark side of the world it is usually zero.

This map, as well as other maps used in this Handbook, is plotted on a rectangular diagram, with uniform scales of latitude and longitude difference. This is similar to but not the same as the conventional Mercator projection of the world. (An actual map of the world on this projection, showing the continents and land masses, is given in Fig. 75 for the purpose of facilitating the determination of the relative locations of transmitters and receivers). The ordinates of Figs. 63 and 64 are degrees of latitude, north and south of the equator. The abscissas are local times, rather than degrees of longitude, because ionosphere characteristics are functions chiefly of latitude and local time only. That is, the ionosphere "follows the sun", and ionosphere characteristics at a given latitude are approximately the same at the same local time, anywhere in the world. The local times stated are always <u>local times at the receiving location.</u>

Figs. 65 through 69 are maps on which are plotted great circles for various azimuths passing through receiving locations at various latitudes. They are on semi-transparent paper and are for use in conjunction with Figs. 63, 64, and 75. They are to aid in determining the regions of the world through which passes the transmission path to the receiving location from any place in the world. The receiving location is at the intersection of the line of latitude indicated in the title of the Figure, and the vertical center line of the map (longitude difference 0°). The abscissa scale in these maps is the difference in longitude between the transmitting and the receiving locations. The great-circle curves are for every 15° of azimuth measured clockwise from north. They converge on the receiving location and also at the antipodes (points at the opposite latitude and longitude at the edges of the map). The closed curves cross the great circles at distance intervals of 1000 kilometers and are used to obtain distances along great-circle paths. The great-circle map for a receiving station at a southern latitude is the same as that for the corresponding northern latitude turned upside down.

In this Appendix, distances are given in kilometers rather than miles, as published values of ionosphere characteristics are commonly in kilometers rather than miles. One mile = 1.6093 kilometers. There is another kind of mile called the "nautical mile", used by nautical men. One nautical mile = 1.1516 miles (sometimes called statute miles) = 1.8532 kilometers.

Suppose it is desired to transmit from any point A to a point B on a frequency f. Select the great-circle map for the latitude nearest the latitude of B. Align the great-circle map upon the absorption map (Fig. 64) in such a manner that the latitude scales coincide, and the zero longitude-difference line on the great-circle map lies on the local time on the absorption map which is the desired local time of reception at B.

Determine the distance from A to B by reference to the 1000-kilometer intervals on the great-circle map. Estimate the absorption index k at the middle of each 1000-kilometer interval between A and B and average them. Multiply the distance between transmitter and receiver (d) by the average absorption index k to obtain the "absorption factor" (kd) for the path. From the graph of "absorption constant" S_o given in Fig.70 as a function of frequency, determine the value of S_o for the desired frequency f. The "absorption constant" is the wave absorption in the ionosphere per unit length of path (1000 kilometers), for the wave at the sub-solar point, and is the logarithm of the ratio of the reflected to the incident field intensity, for a wave travelling 1000 kilometers at the sub-solar point.

From the graph of the logarithm of the unabsorbed field intensity (F_o) given in Fig. 71, determine F_o for the distance d from A to B. The "unabsorbed field intensity" is the field intensity that would be measured at a given distance for a radiated power of 1 kilowatt if there were no wave absorption in the ionosphere. For frequencies above about 3 Mc, this condition is approximately true at night, and so the unabsorbed field intensity is about the same as the actual night field intensity for the same distance. F_o is the logarithm of the microvolts per meter for 1 kilowatt radiated power.

The logarithm of the field intensity (F) actually present at B, in microvolts per meter for 1 kilowatt radiated at A, is $F = F_o - S_o(kd)$.

The logarithm of the field intensity for any value of radiated power is then obtained by adding to the value of F calculated above,the logarithm of the radiated power in kilowatts.

Having now determined the actual value of F, the logarithm of the field intensity at B, consult the graphs of logarithms of required field intensities given in Figs. 72, 73, and 74 for three different latitudes, for the months of November through February. Values for other latitudes may be estimated by interpolation. If F is equal to or greater than the value required for reception at B, transmission from A to B may be accomplished unless restricted by the maximum usable frequency. The values of required field intensity given here are for radio-telephone (phone) reception. For radio-telegraph (CW) reception the field intensities required are only one-tenth as great (logarithm values are 1 less than given by the curves).

The required field intensities for May through August, for any latitude, are the same as those for November through February for the same latitude on the other side of the equator.

Maximum Usable Frequency Calculations for Long Paths.- To determine whether the frequency f selected for transmission from A to B is less than the maximum usable frequency (and so will be usable), align the great-circle map used above upon the maximum usable frequency map of Fig. 63. This map, for the months of November 1941 through February 1942, is drawn so that the maximum usable frequency in megacycles for a wave crossing a line at the midpoint of a 3500-kilometer hop is the same, no matter where or in what direction it crosses the line. This map is laid off in local time, rather than in longitude.

Place the zero longitude-difference line of the great-circle map on the local time at point B on the maximum-usable-frequency map. Find the lowest maximum usable frequency which the path from A to B encounters. If this lowest value occurs at either end of the path the maximum usable frequency for transmission over the path is the value at a point 2000 kilometers from that end toward the middle of the path. If the lowest value occurs along the path somewhere, note the maximum usable frequencies 1000 kilometers on either side of the lowest point. The lower of these two values is the maximum usable frequency over the path from A to B.

The distance-range charts and usable-frequency maps of Figs. 1 through 62 were obtained by making these calculations for a great number of distances and frequencies. The calculations were plotted as field-intensity curves and from these the distance ranges were obtained.

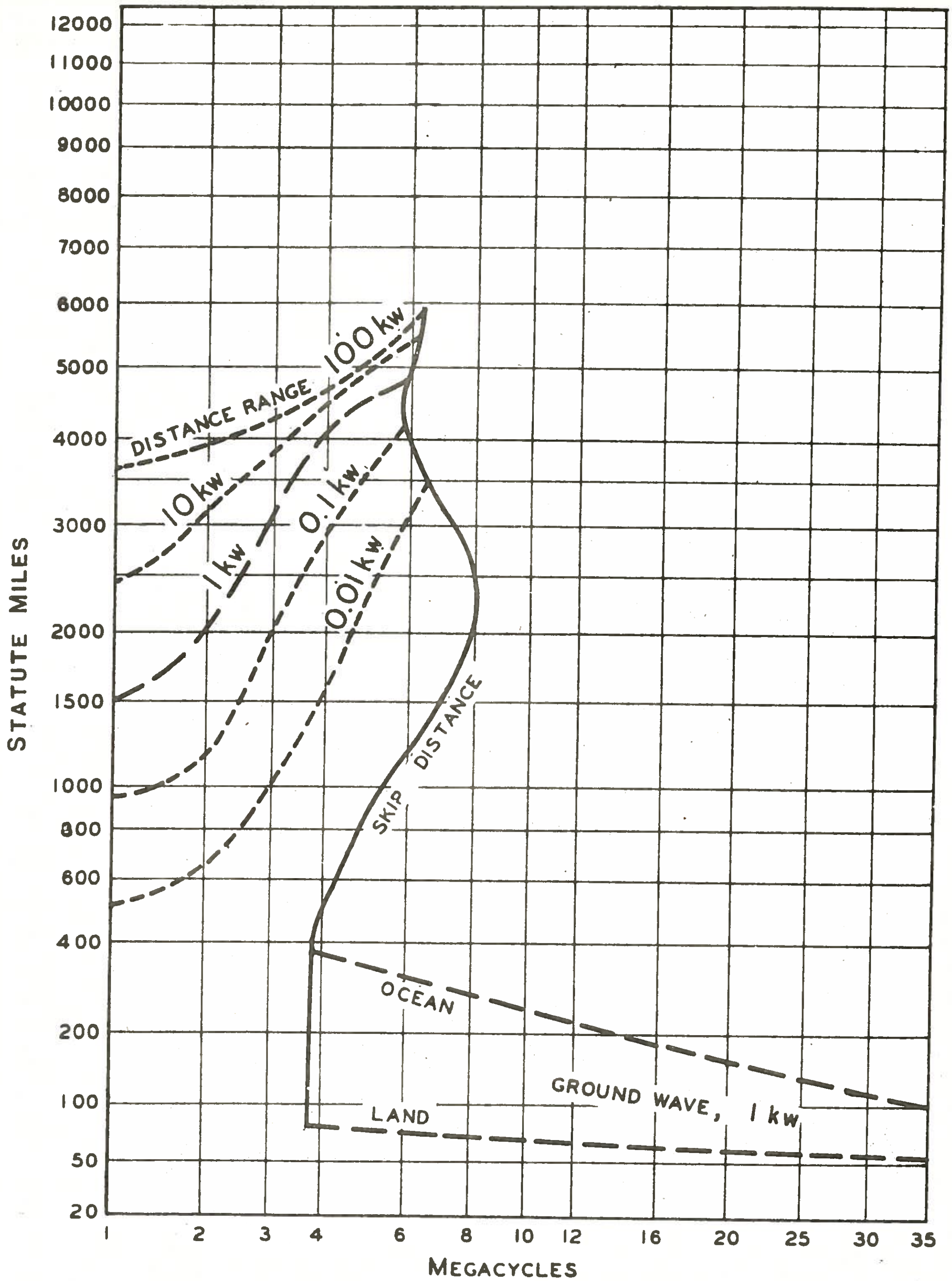

FIG. 1. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 0000 LOCAL TIME. AZIMUTH: 0°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

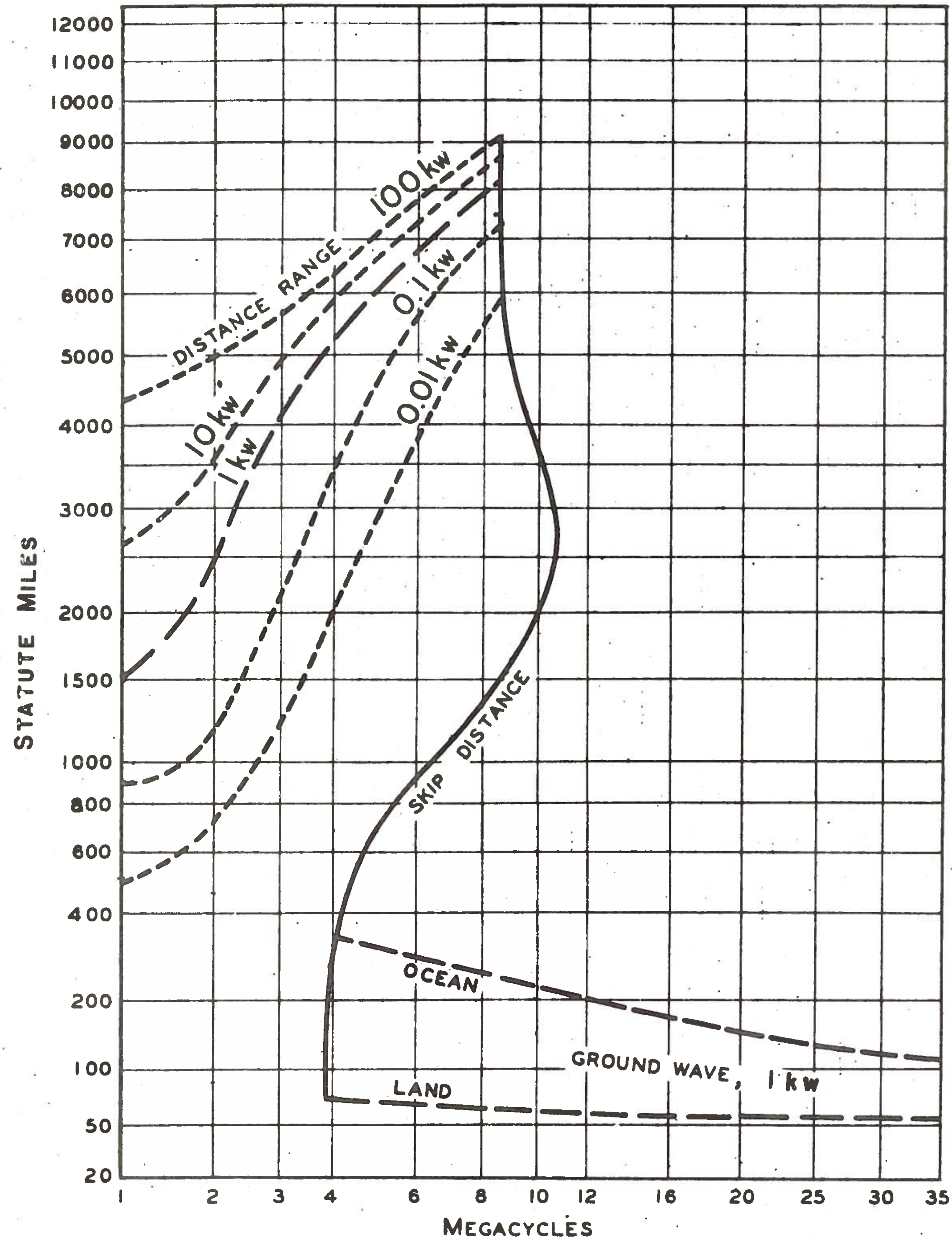

FIG. 2. RADIO DISTANCE RANGES.

NOV 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 0000 LOCAL TIME. AZIMUTH: 90°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

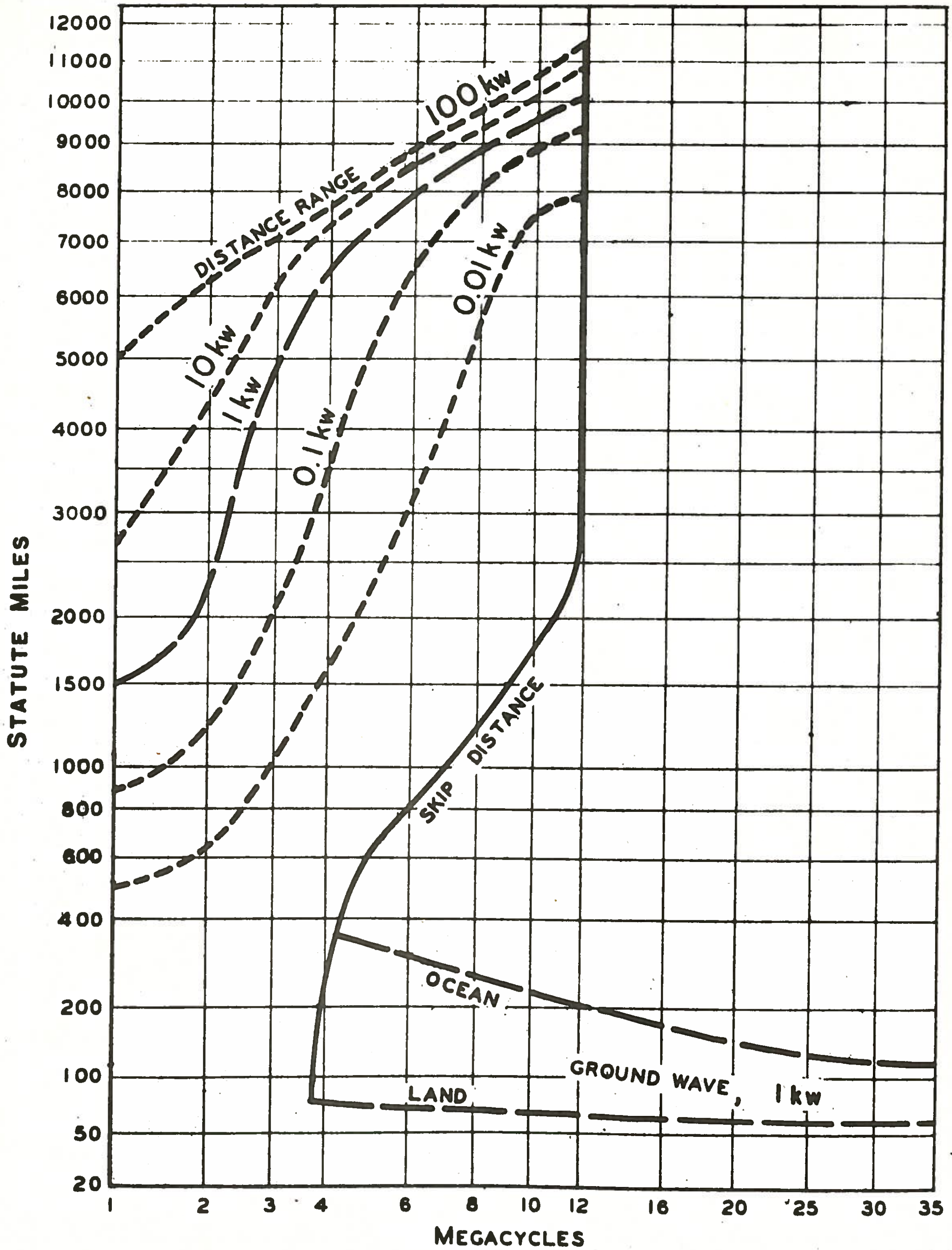

FIG. 3. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 0000 LOCAL TIME. AZIMUTH: 180°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

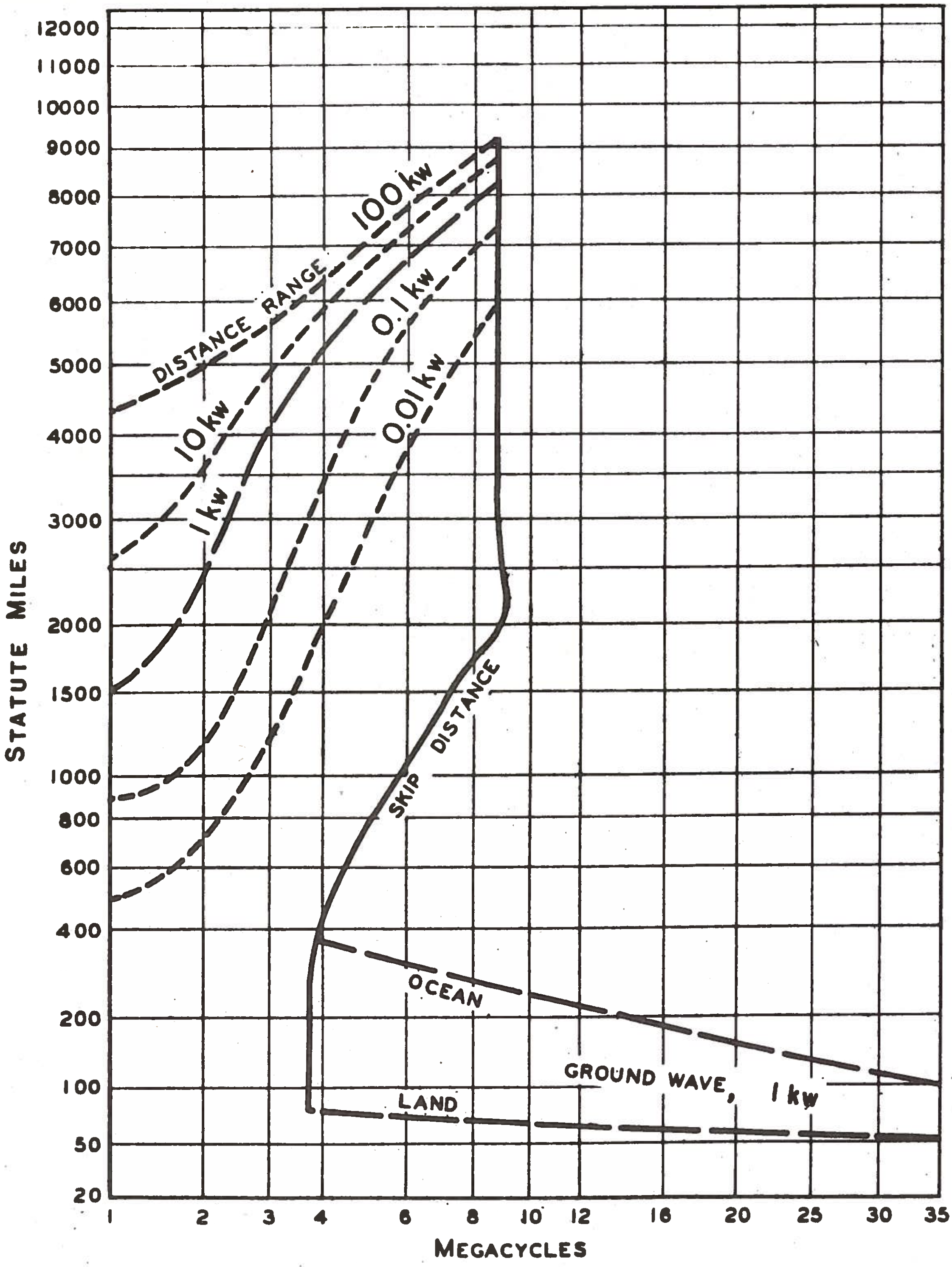

FIG. 4. RADIO DISTANCE RANGES.
NOV. 1941 THROUGH FEB. 1942.
LATITUDE: 40° N. 0000 LOCAL TIME. AZIMUTH: 270°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

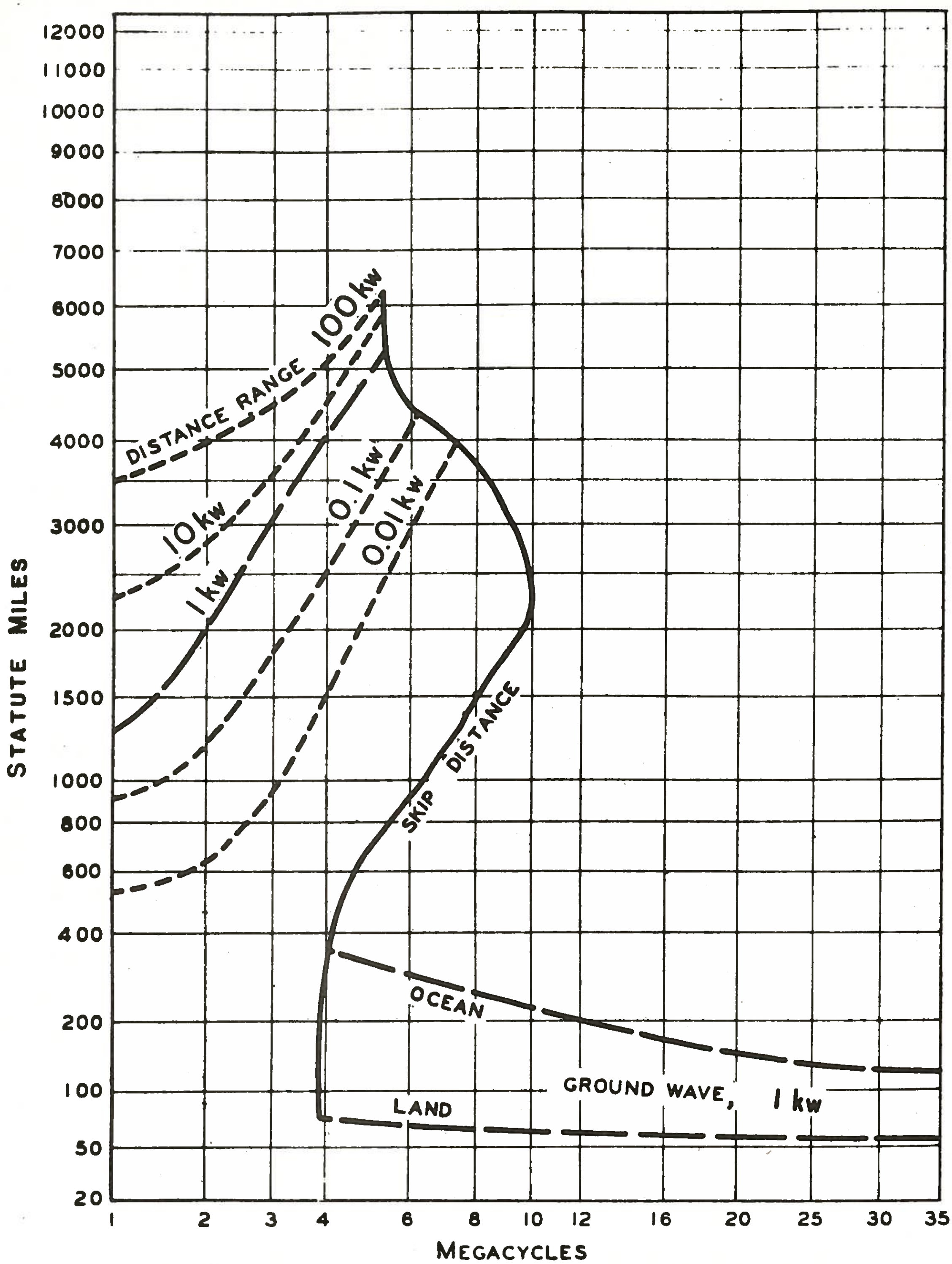

FIG. 5. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 0400 LOCAL TIME. AZIMUTH: 0°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

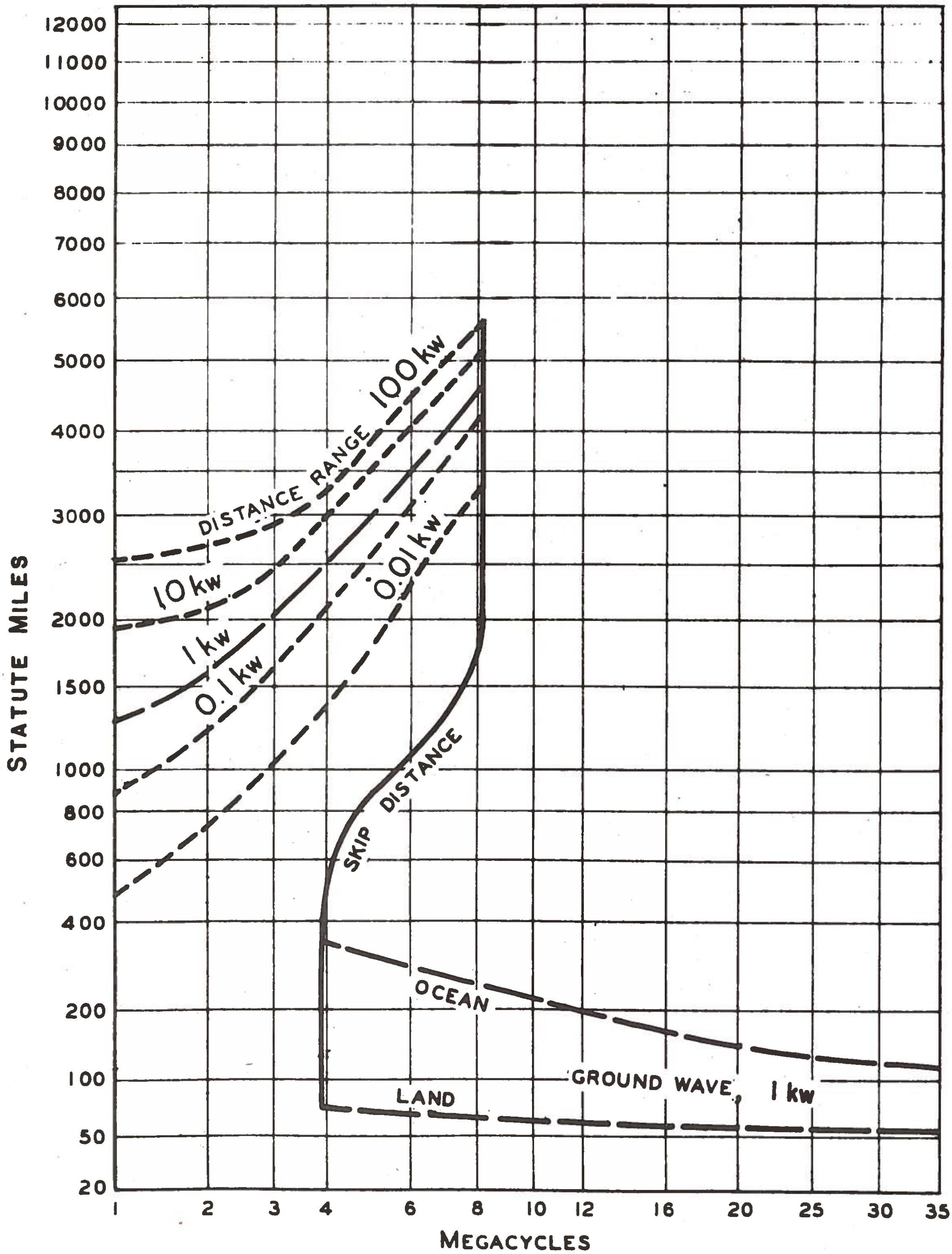

FIG. 6. RADIO DISTANCE RANGES.
NOV. 1941 THROUGH FEB. 1942.
LATITUDE: 40° N. 0400 LOCAL TIME. AZIMUTH: 90°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

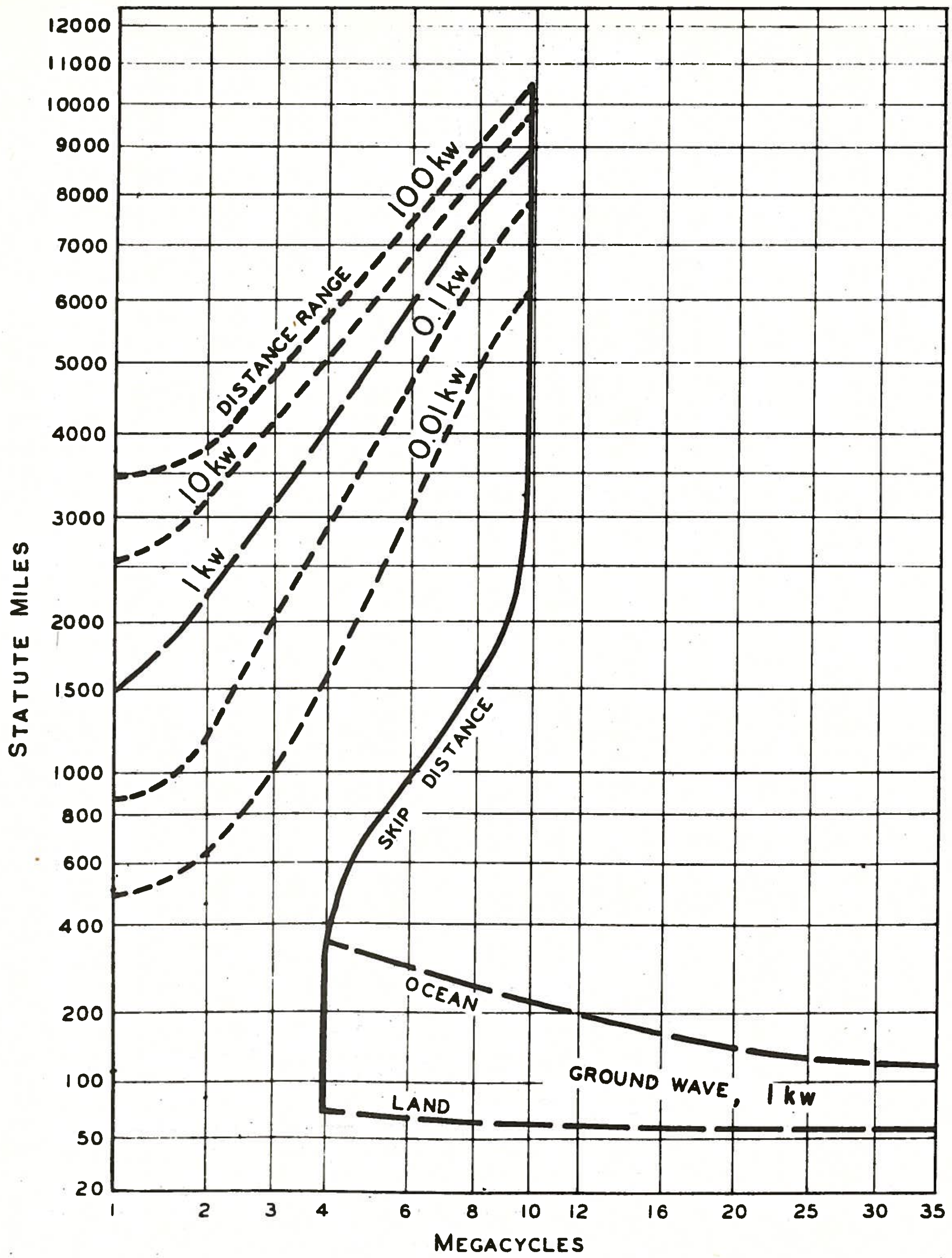

FIG. 7. RADIO DISTANCE RANGES.
NOV. 1941 THROUGH FEB. 1942.
LATITUDE: 40° N. 0400 LOCAL TIME. AZIMUTH: 180°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

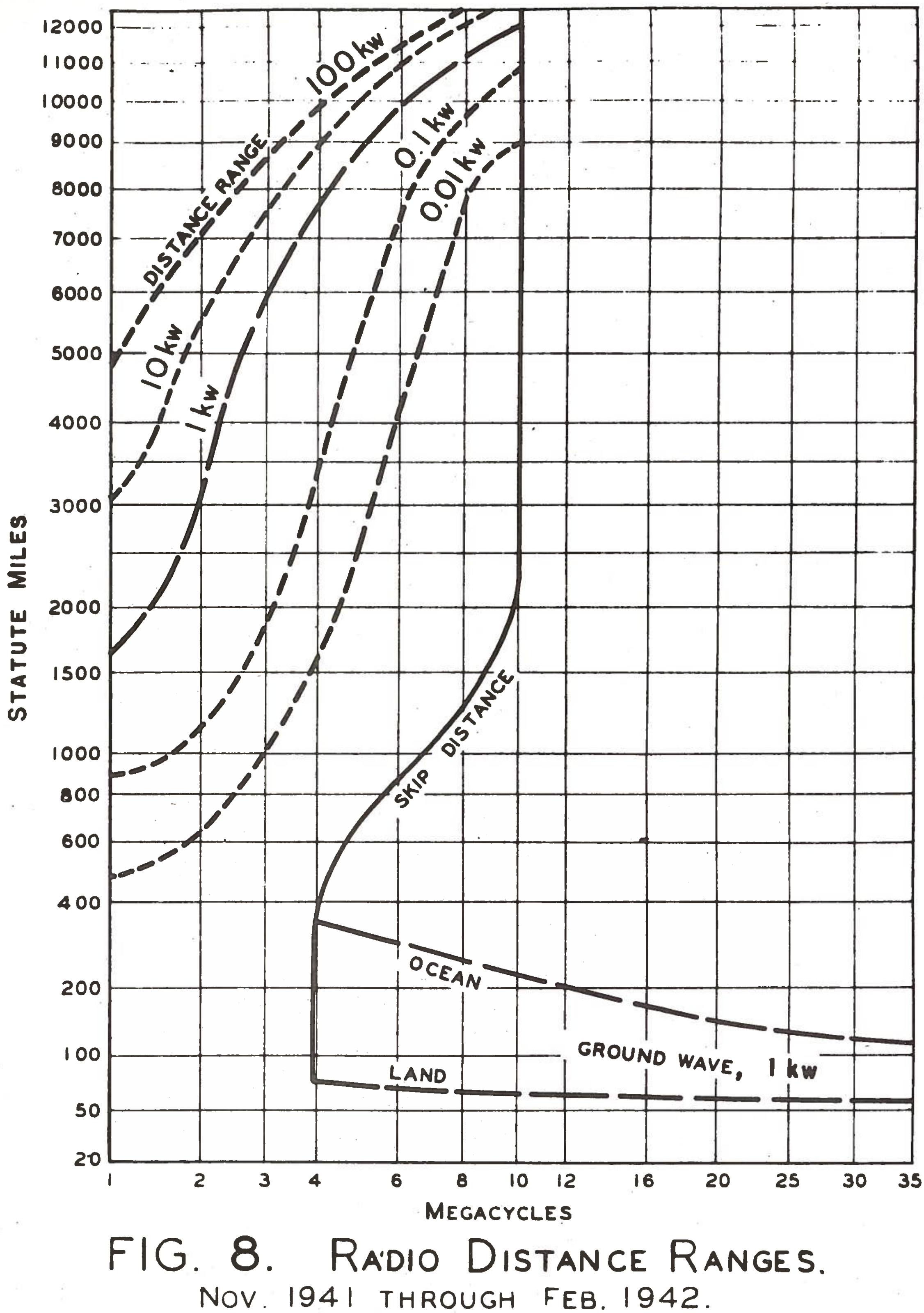

FIG. 8. RADIO DISTANCE RANGES.
NOV. 1941 THROUGH FEB. 1942.
LATITUDE: 40° N. 0400 LOCAL TIME. AZIMUTH: 270°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

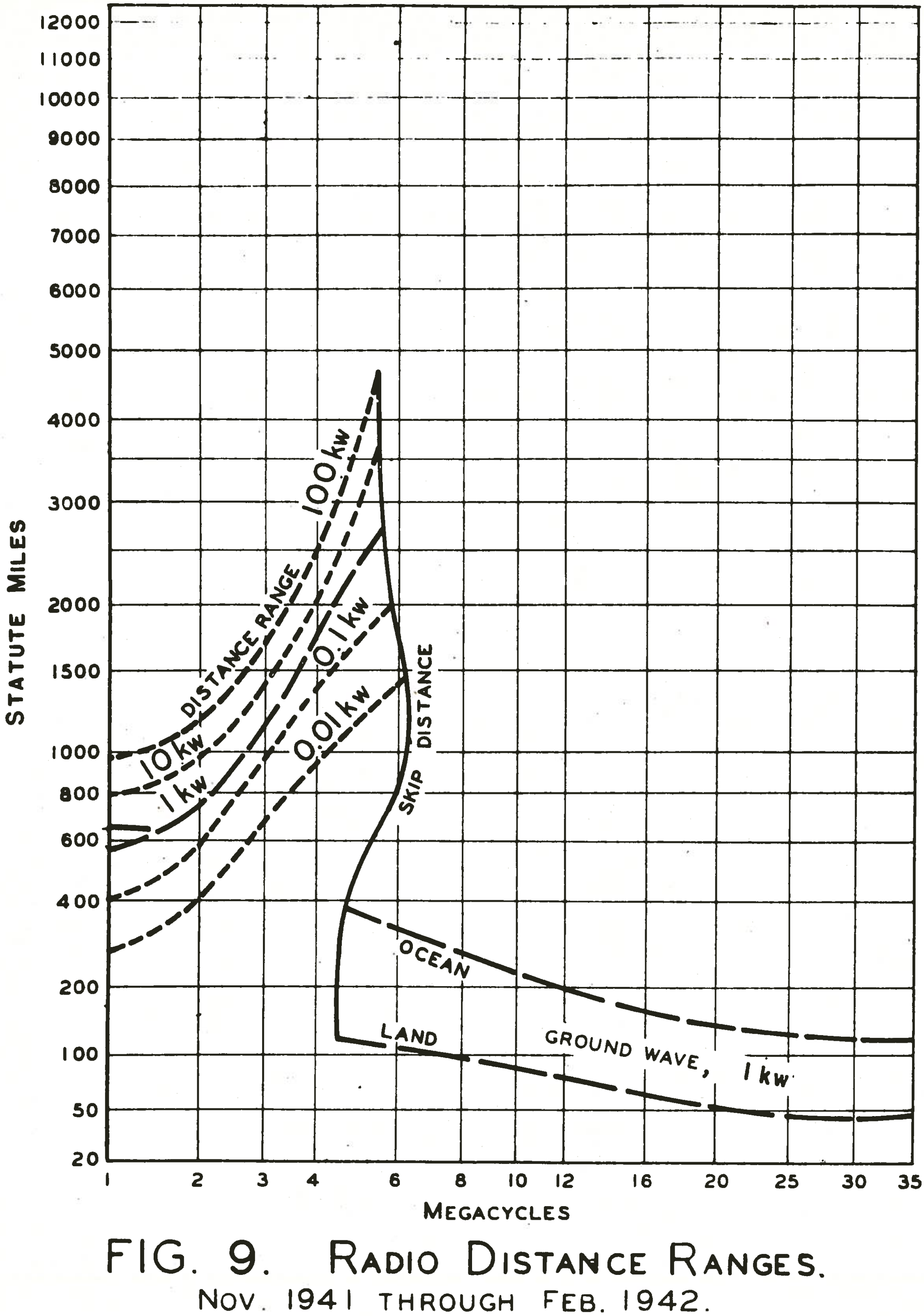

FIG. 9. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 0800 LOCAL TIME. AZIMUTH: 0°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

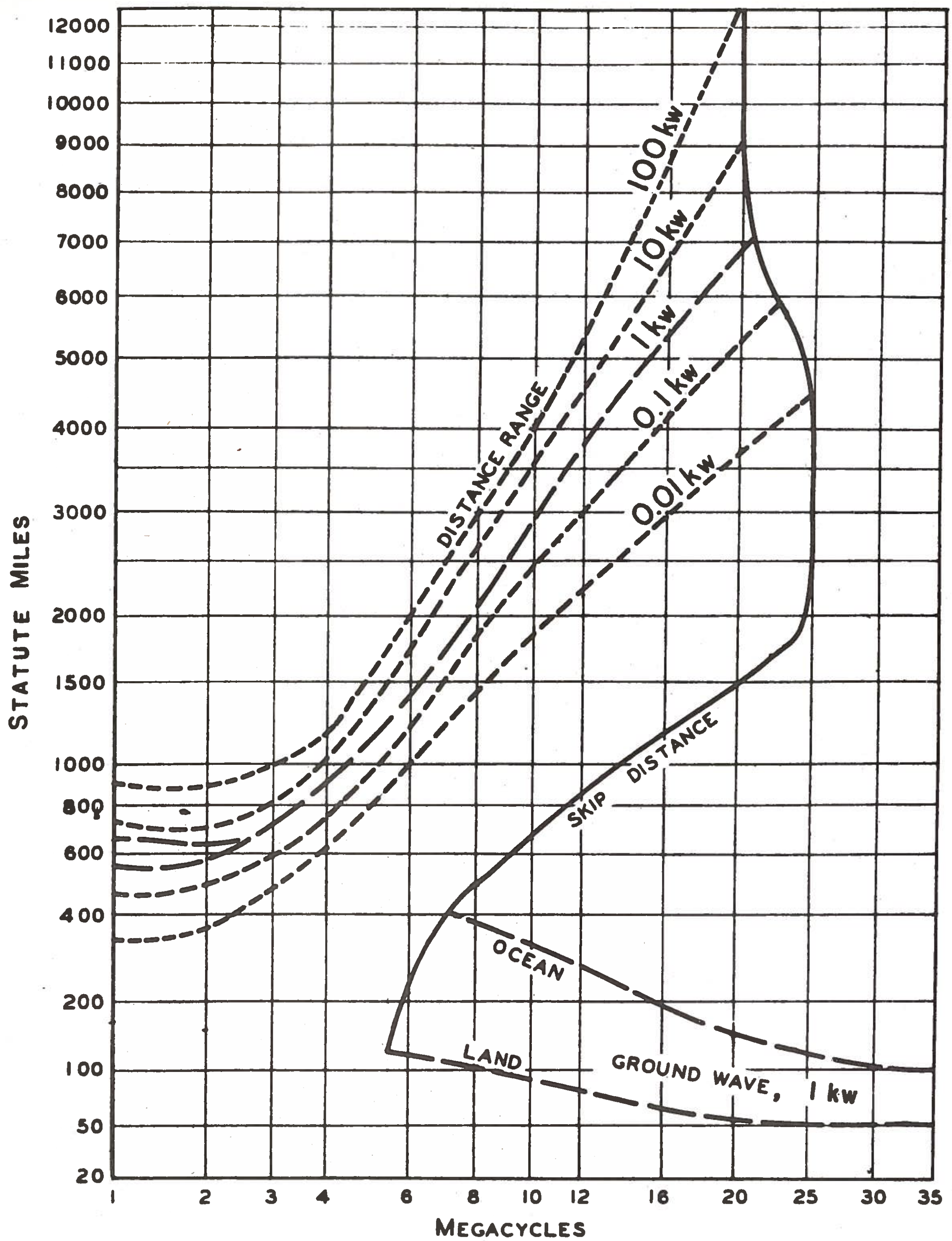

FIG. 10. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 0800 LOCAL TIME. AZIMUTH: 90°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

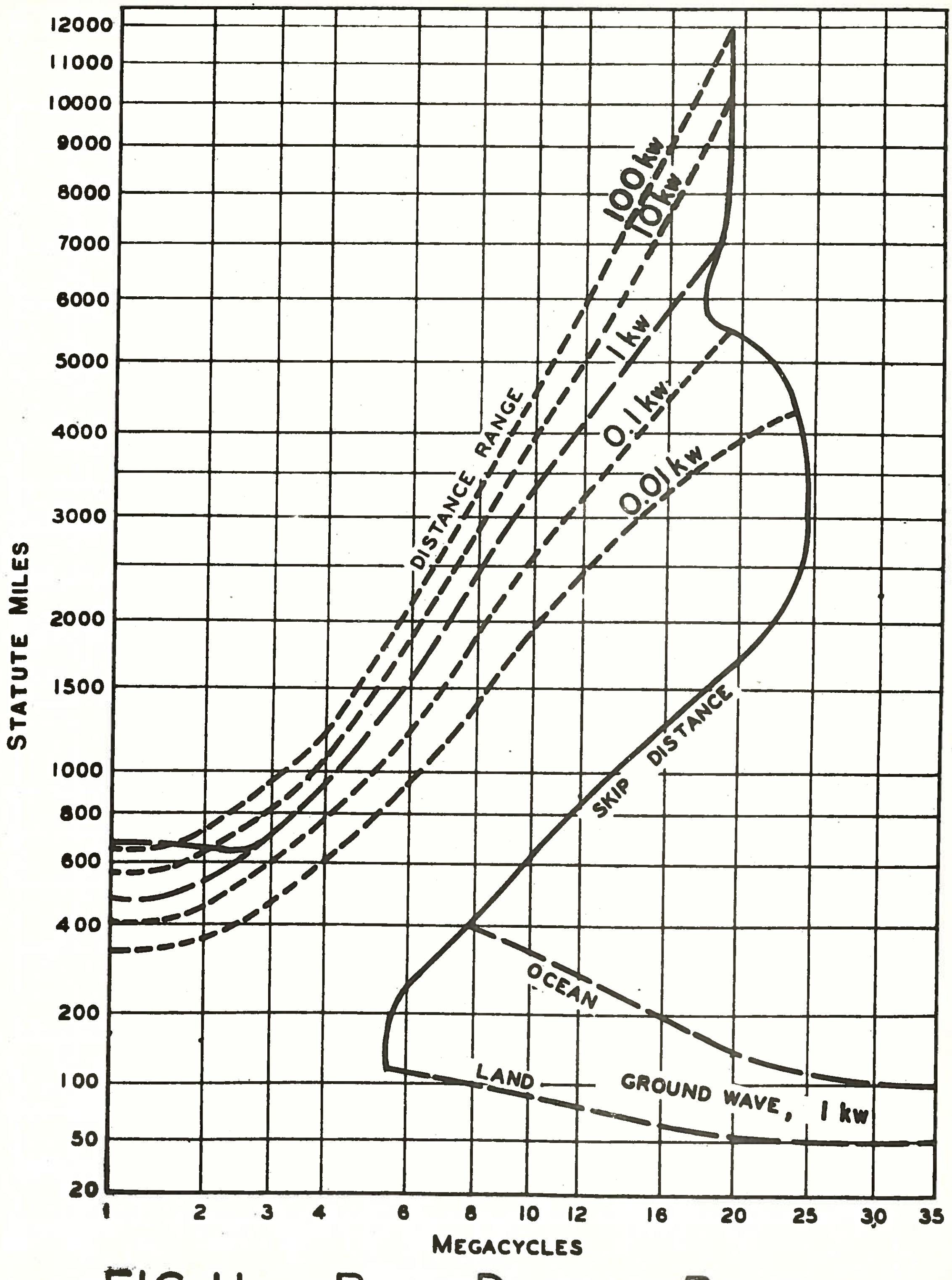

FIG. 11. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 0800 LOCAL TIME. AZIMUTH: 180°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

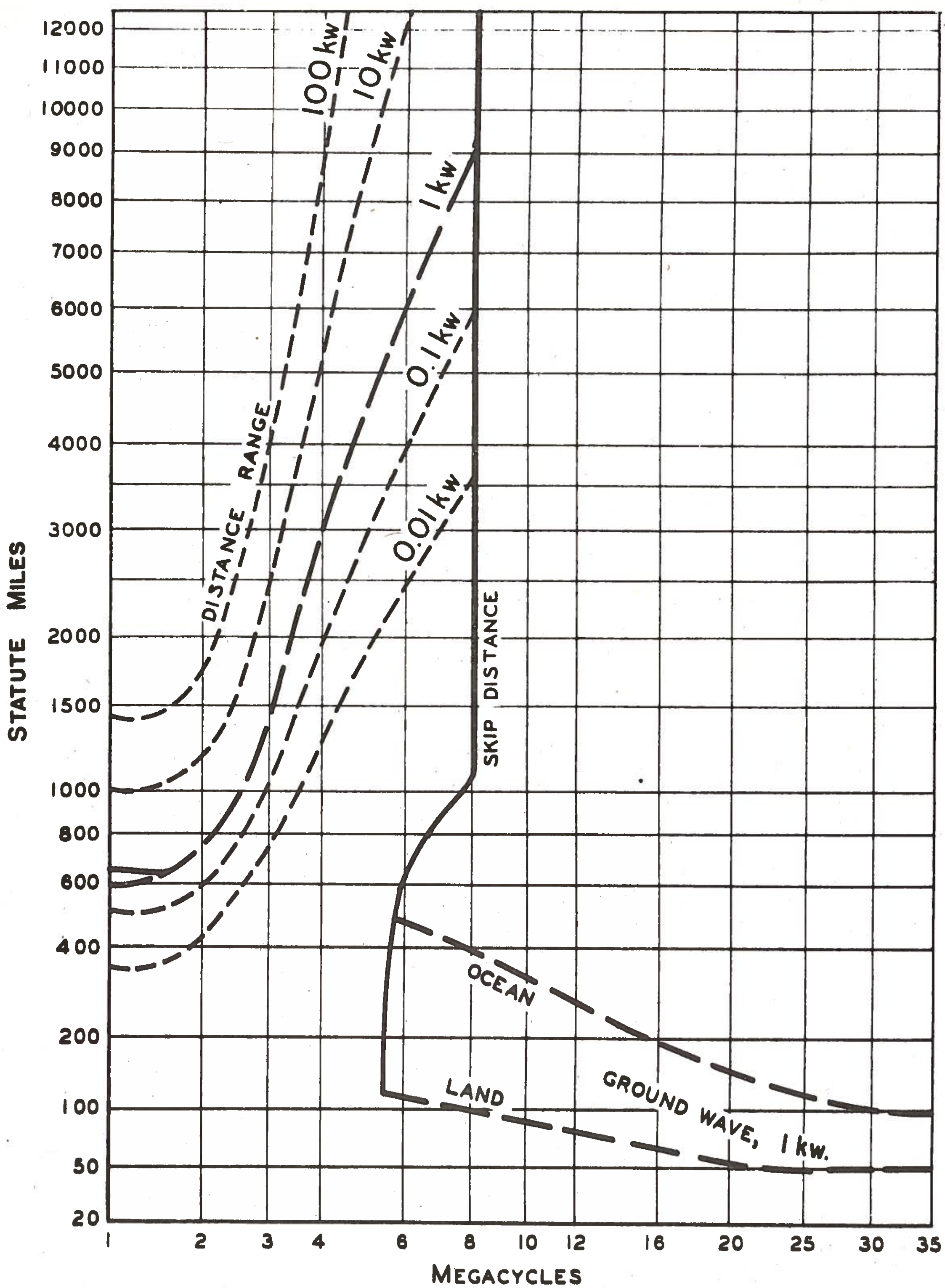

FIG. 12. Radio Distance Ranges.

Nov. 1941 through Feb. 1942.

Latitude: 40° N. 0800 Local Time. Azimuth: 270°

(Powers shown on curves are for phone transmission.
Powers for CW transmission are 0.01 as great.)

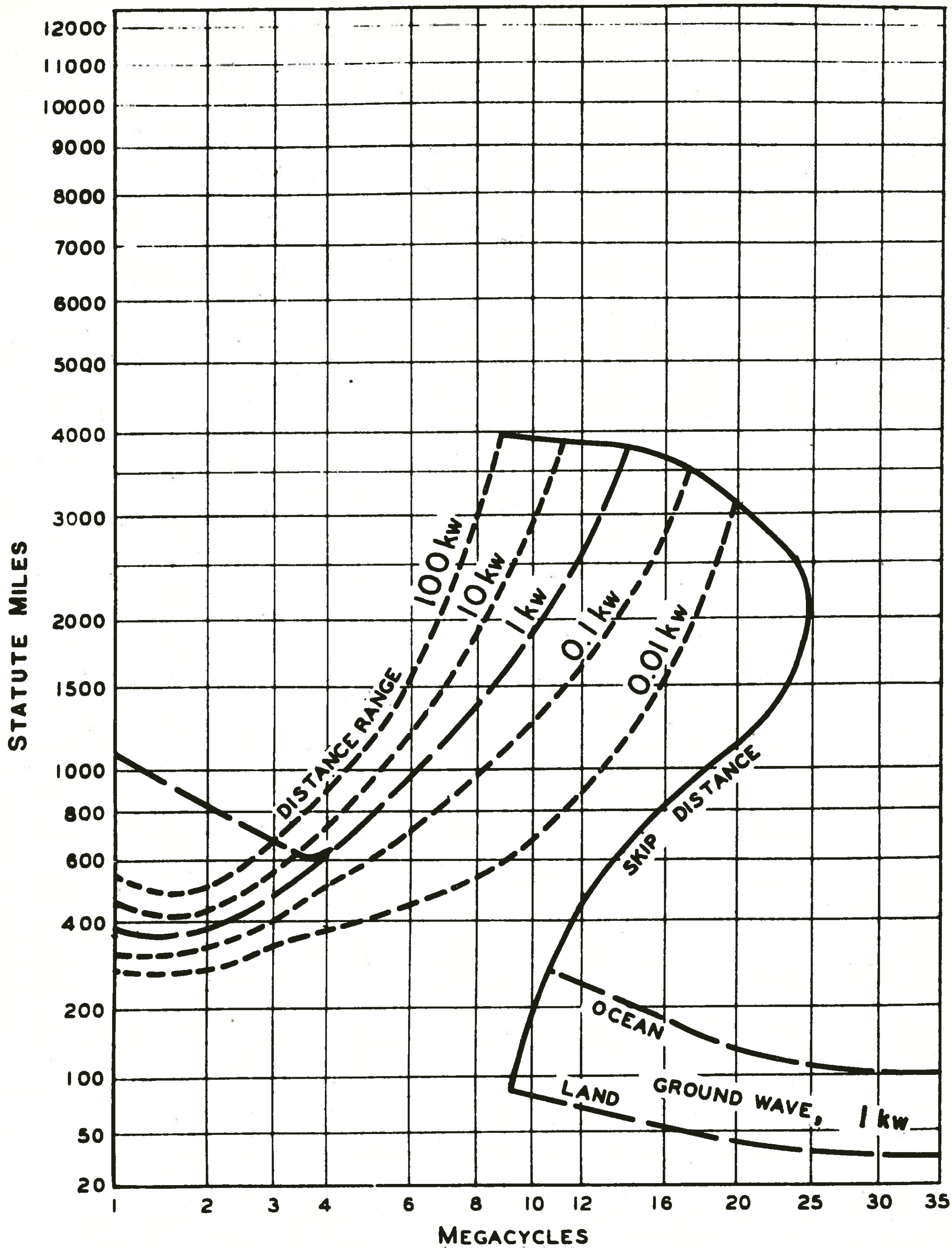

FIG. 13. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 1200 LOCAL TIME. AZIMUTH: 0°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

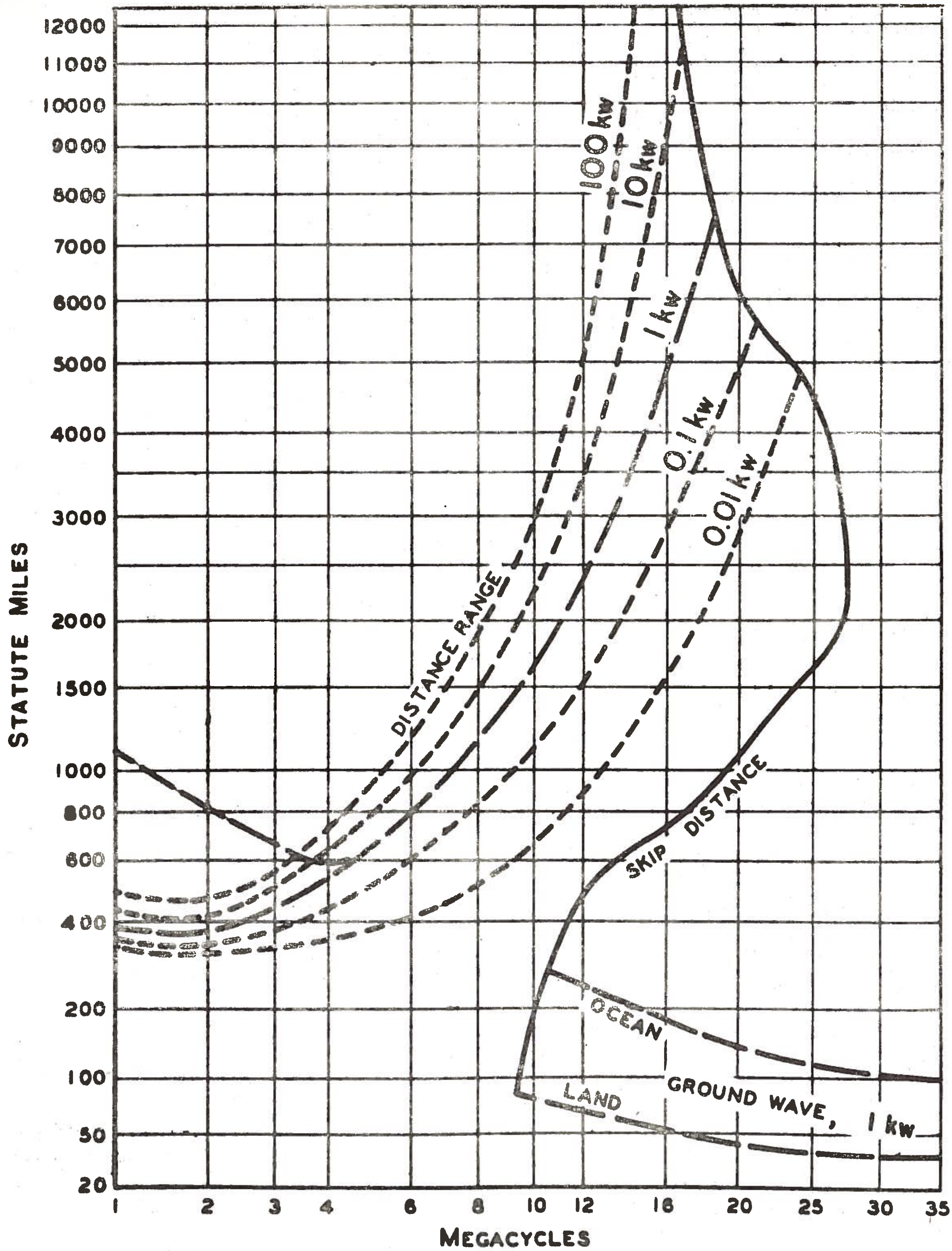

FIG. 14. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 1200 LOCAL TIME. AZIMUTH: 90°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

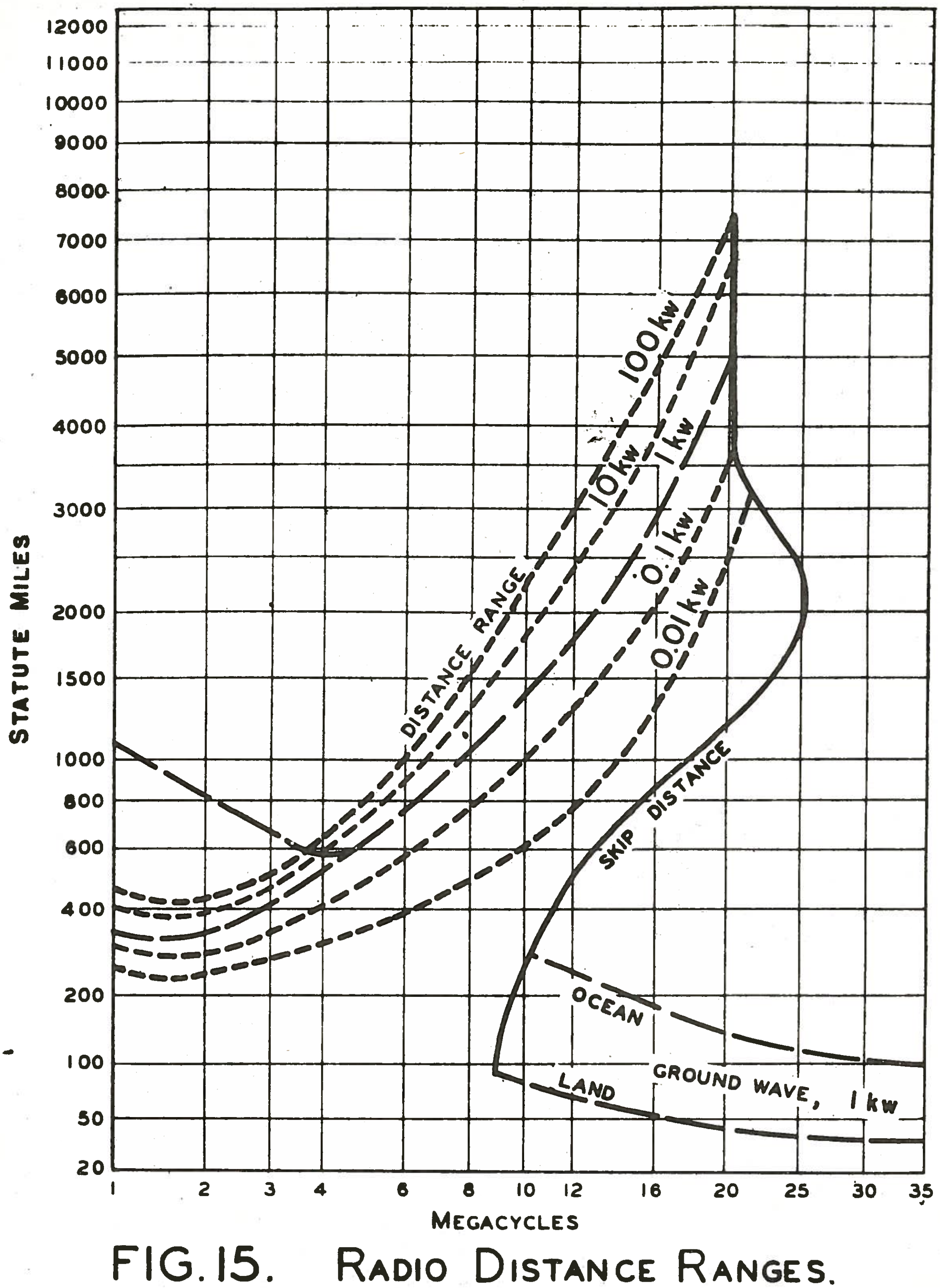

FIG. 15. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 1200 LOCAL TIME. AZIMUTH: 180°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

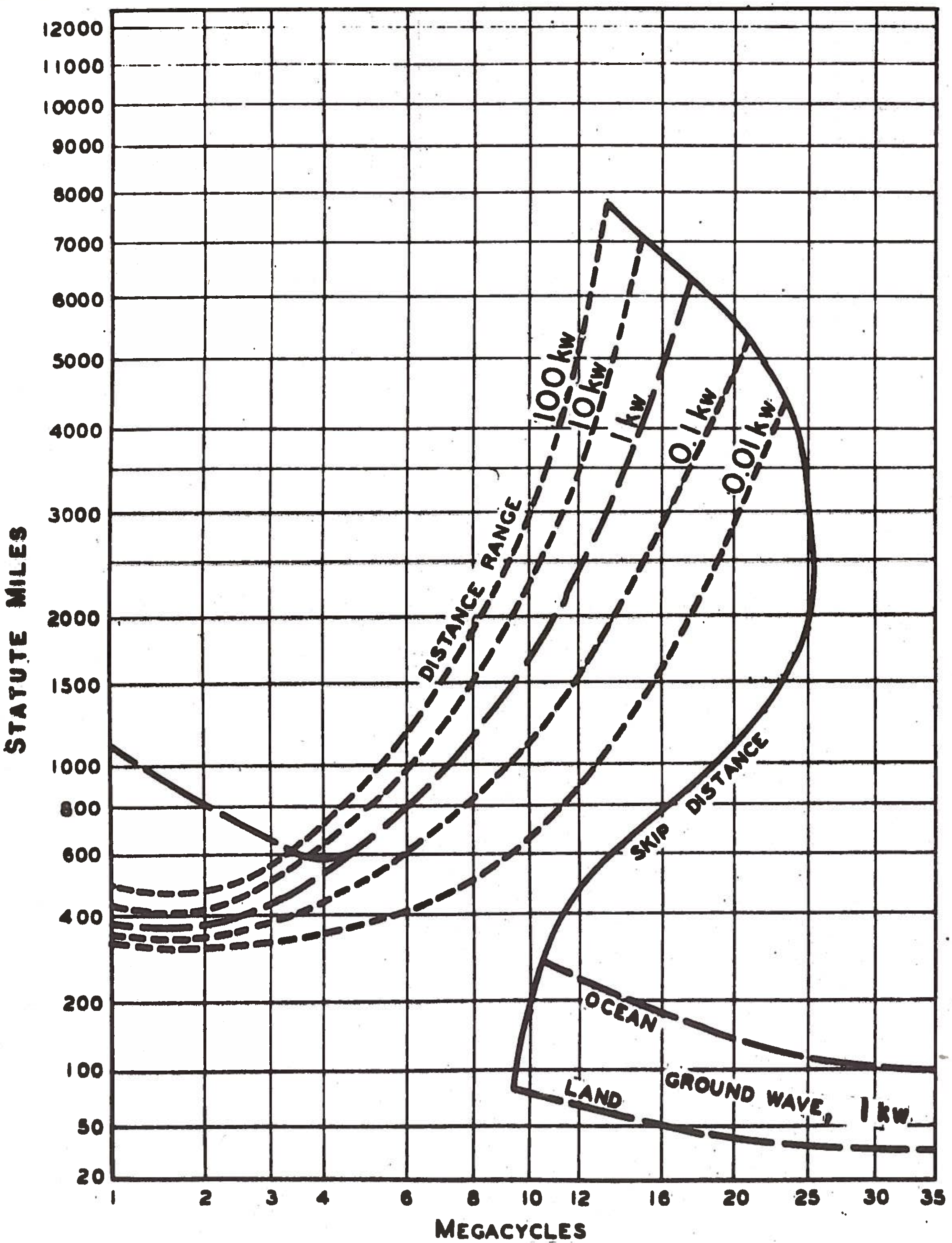

FIG. 16. RADIO DISTANCE RANGES.

NOV 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 1200 LOCAL TIME. AZIMUTH: 270°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

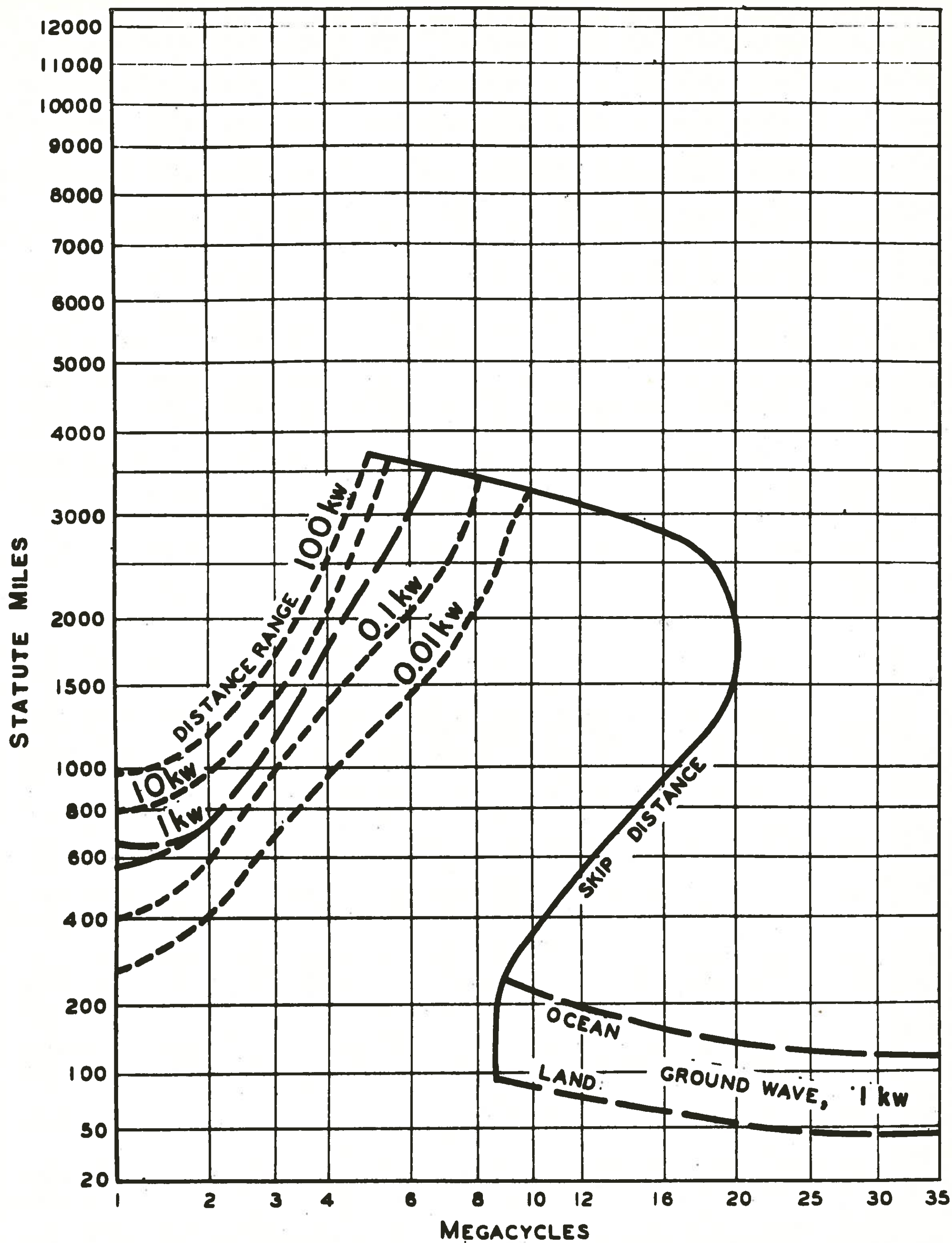

FIG. 17. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 1600 LOCAL TIME. AZIMUTH: 0°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

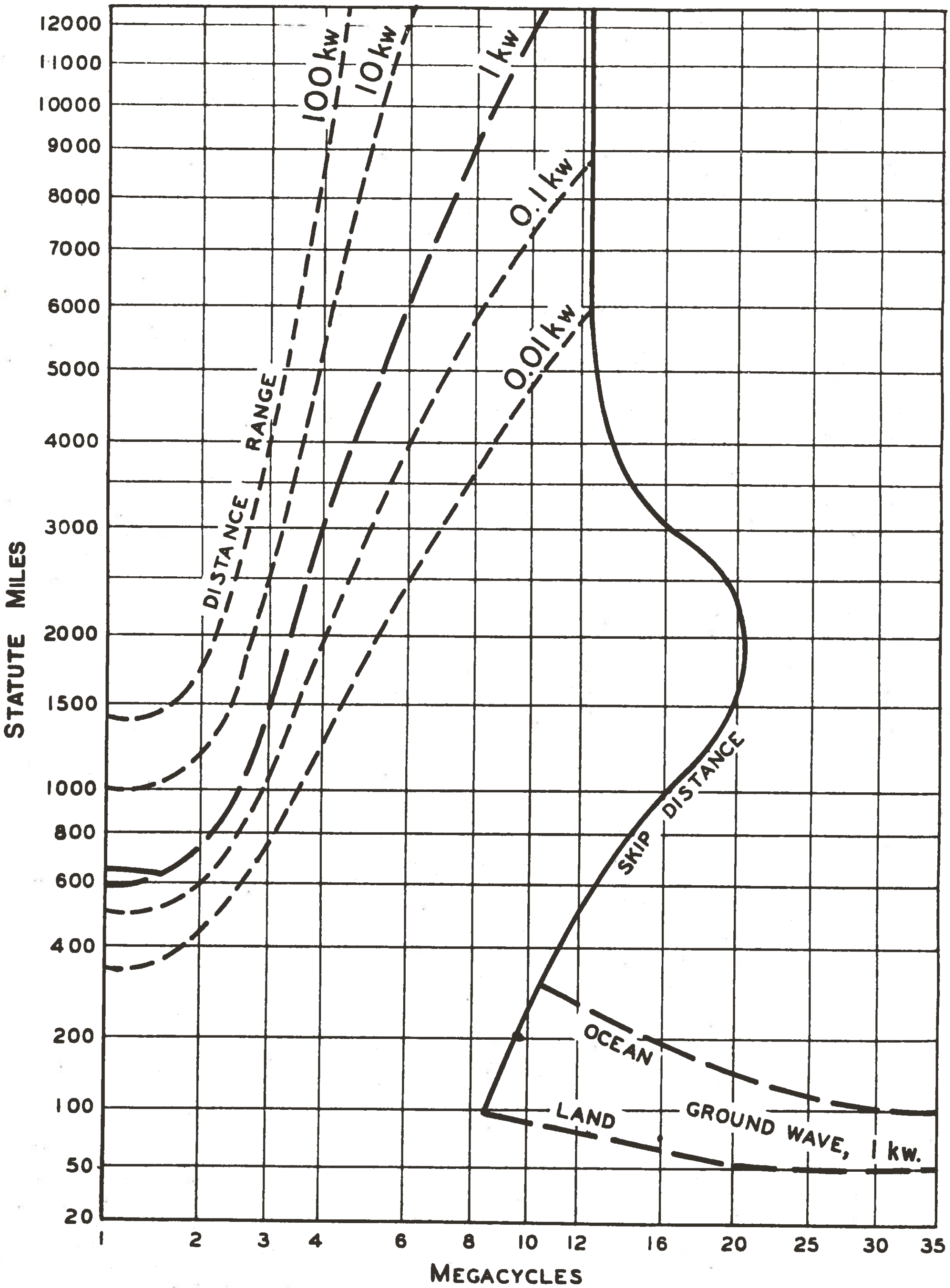

FIG. 18. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 1600 LOCAL TIME. AZIMUTH: 90°

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

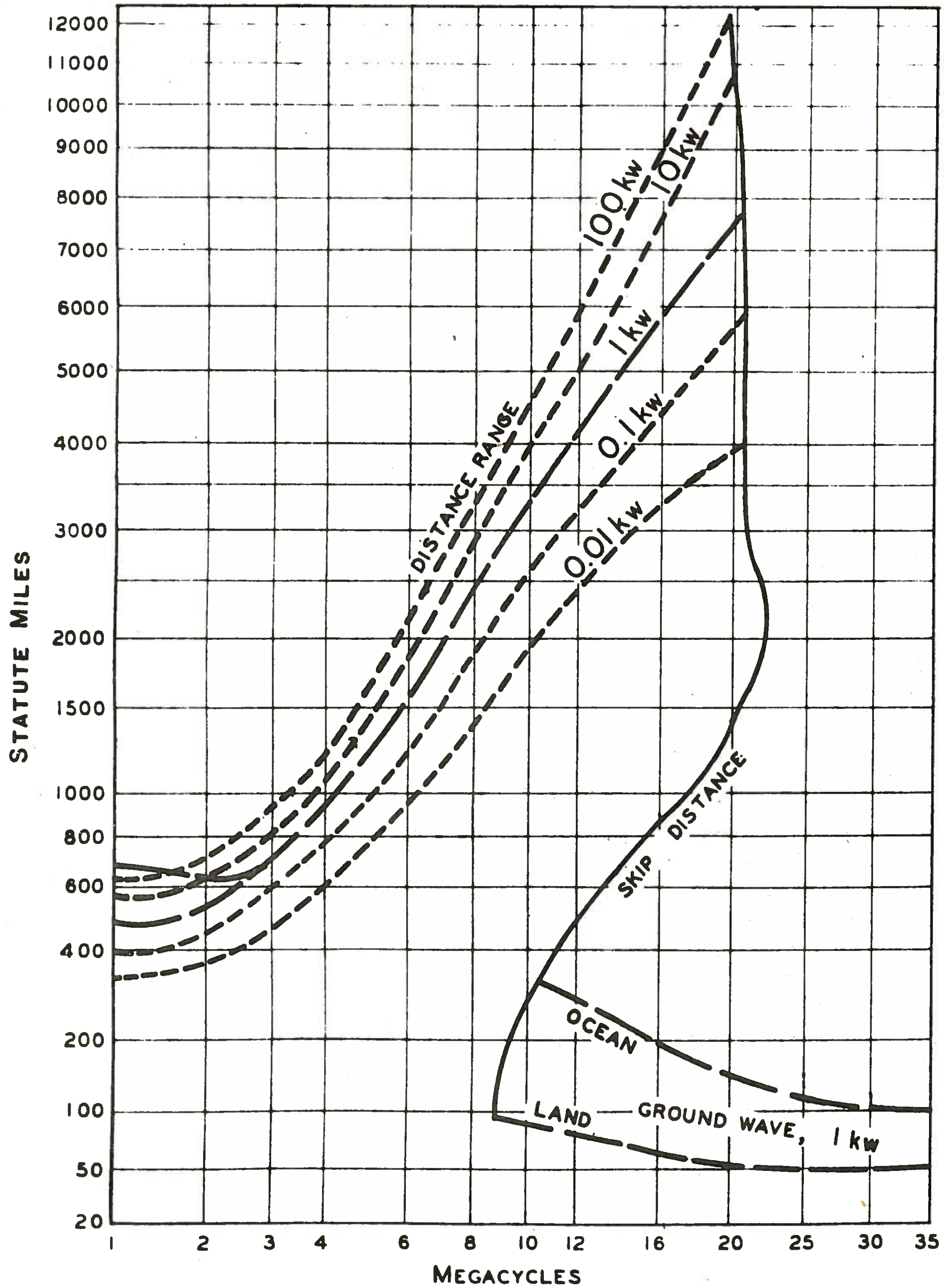

FIG. 19. Radio Distance Ranges.

Nov 1941 through Feb. 1942.

Latitude: 40° N. 1600 Local Time. Azimuth: 180°.

(Powers shown on curves are for phone transmission. Powers for CW transmission are 0.01 as great.)

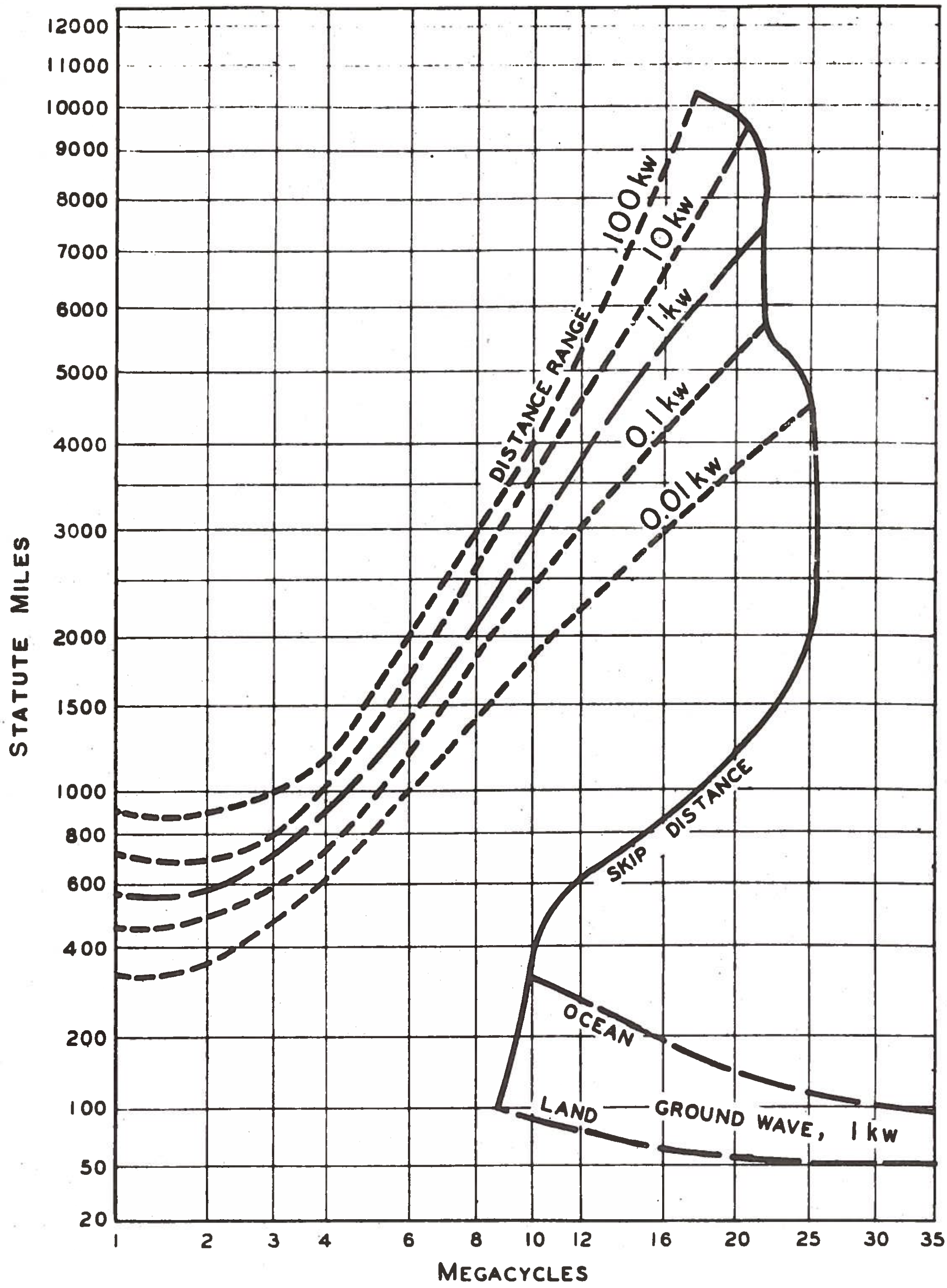

FIG. 20. Radio Distance Ranges.

Nov. 1941 through Feb. 1942.

Latitude: 40° N. 1600 local time. Azimuth: 270°.

(Powers shown on curves are for phone transmission.
Powers for CW transmission are 0.01 as great.)

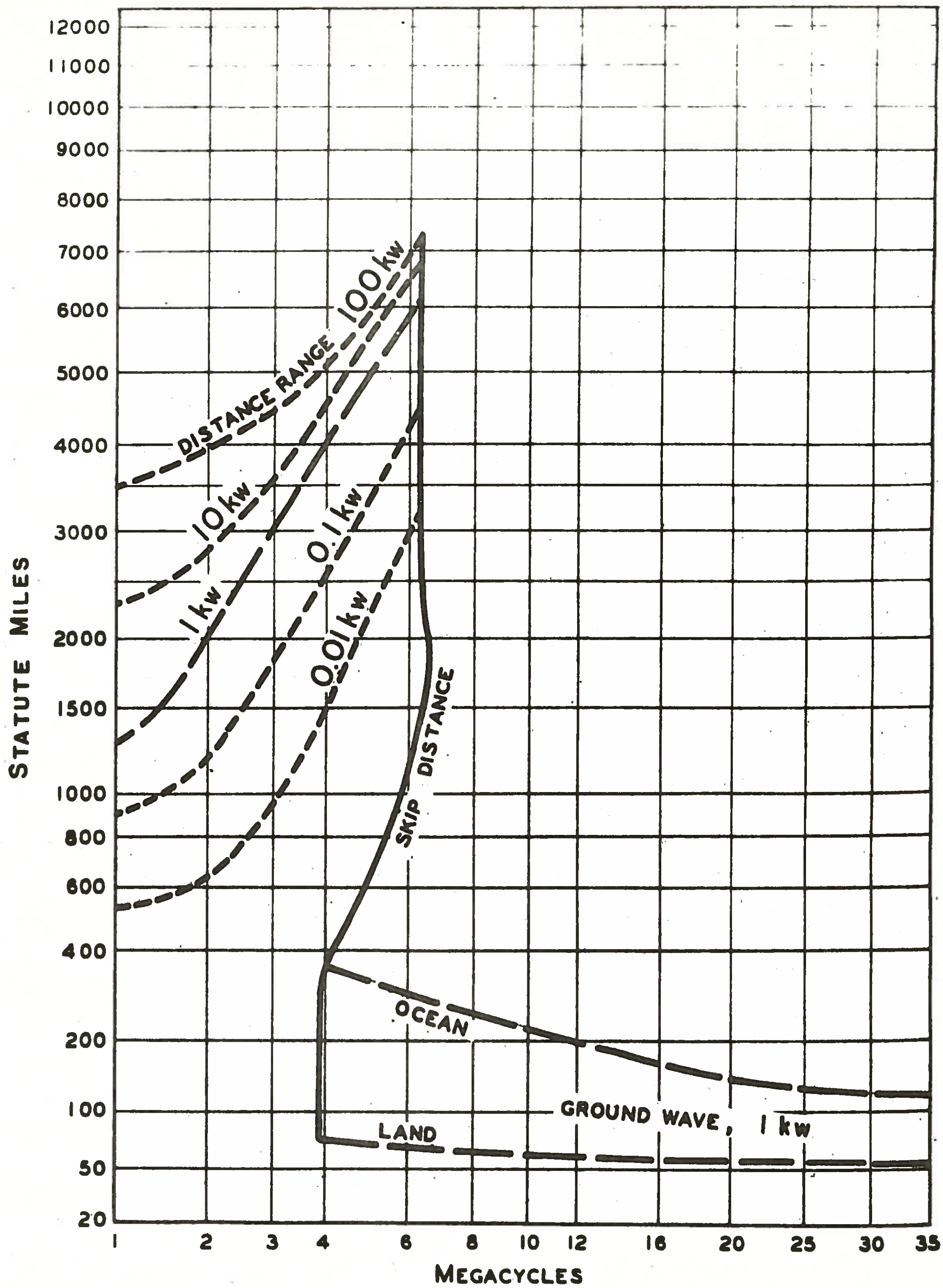

FIG. 21. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 2000 LOCAL TIME. AZIMUTH: 0°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

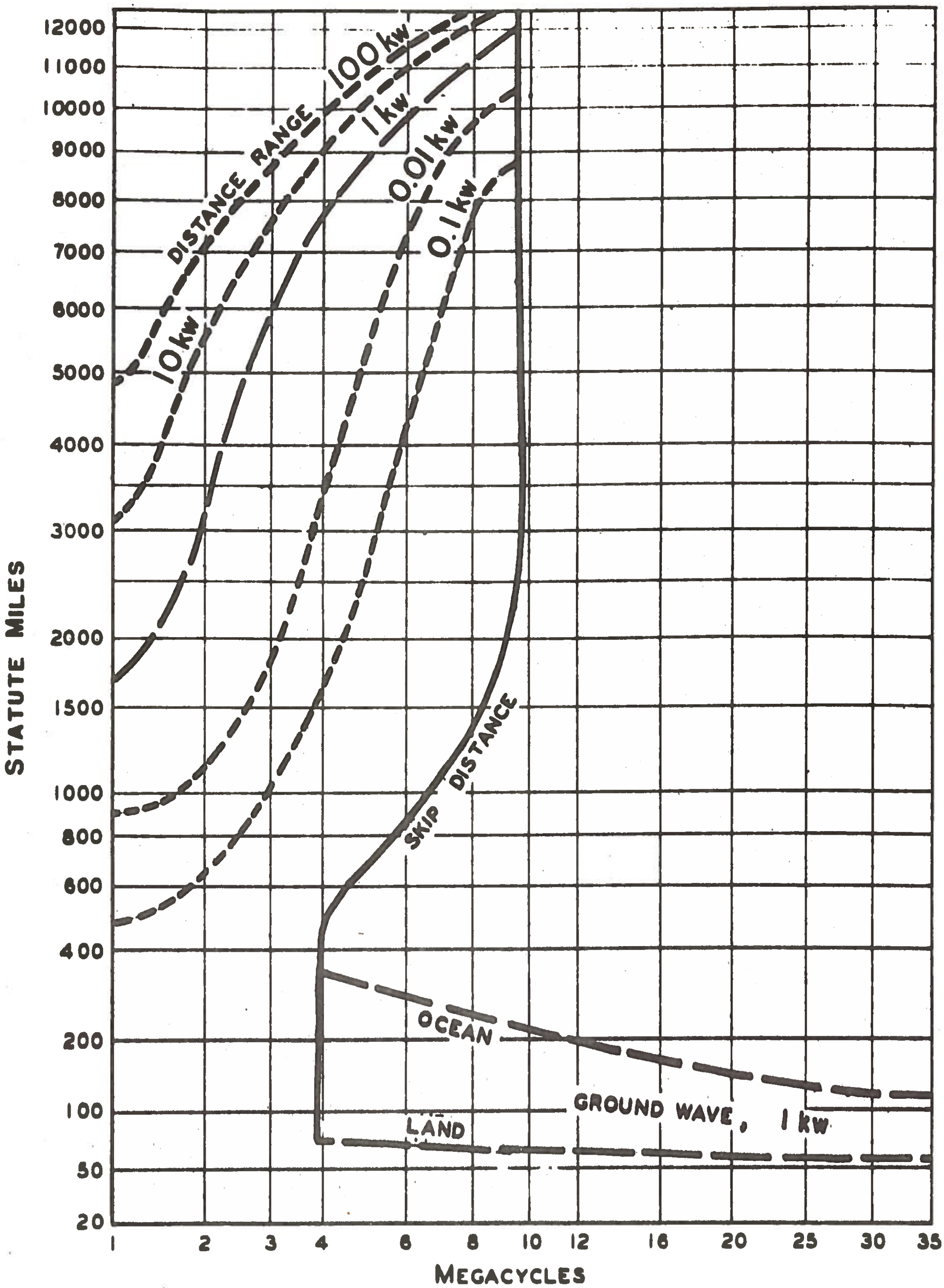

FIG. 22. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 2000 LOCAL TIME. AZIMUTH: 90°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

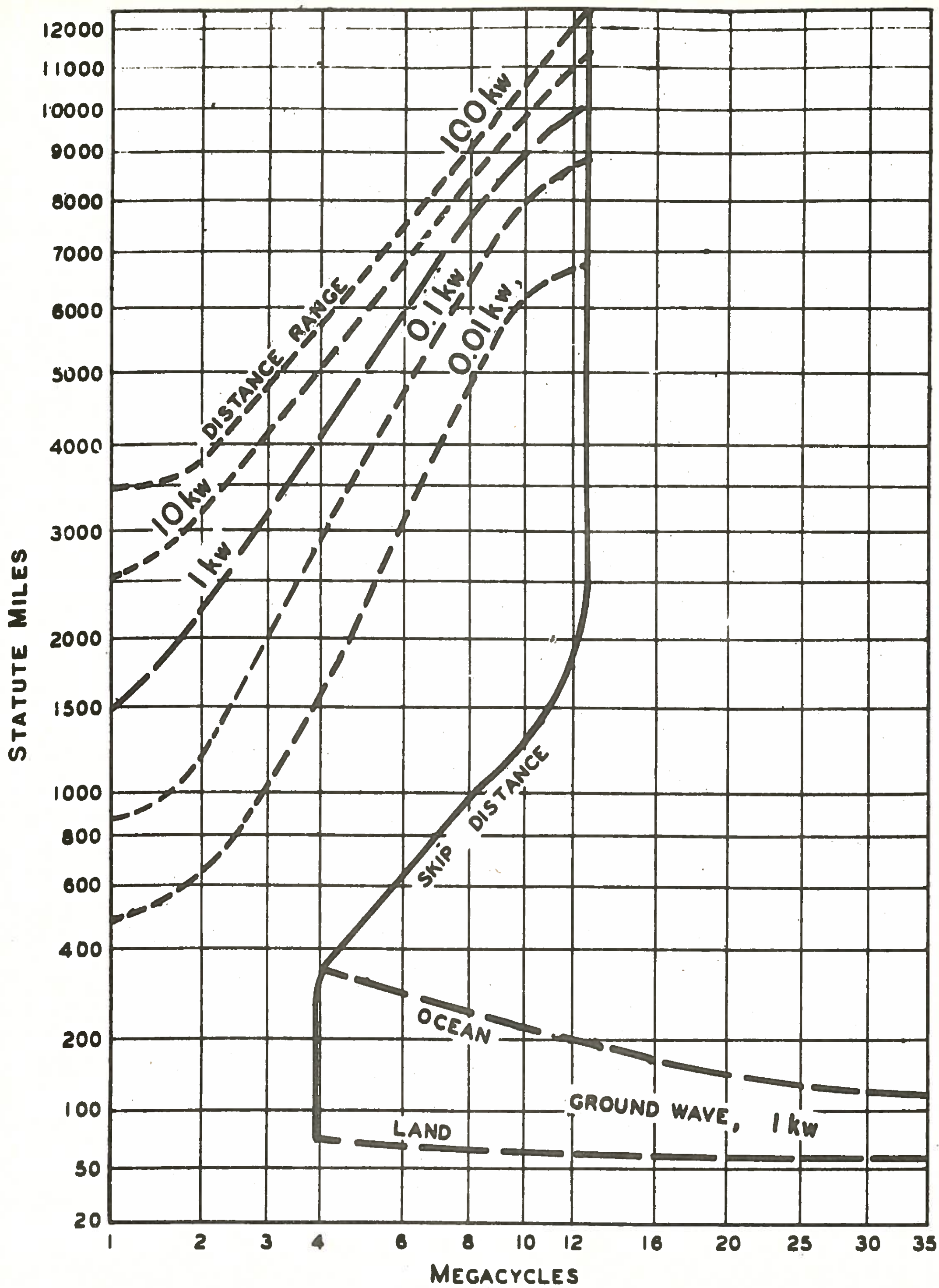

FIG. 23. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 2000 LOCAL TIME. AZIMUTH: 180°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

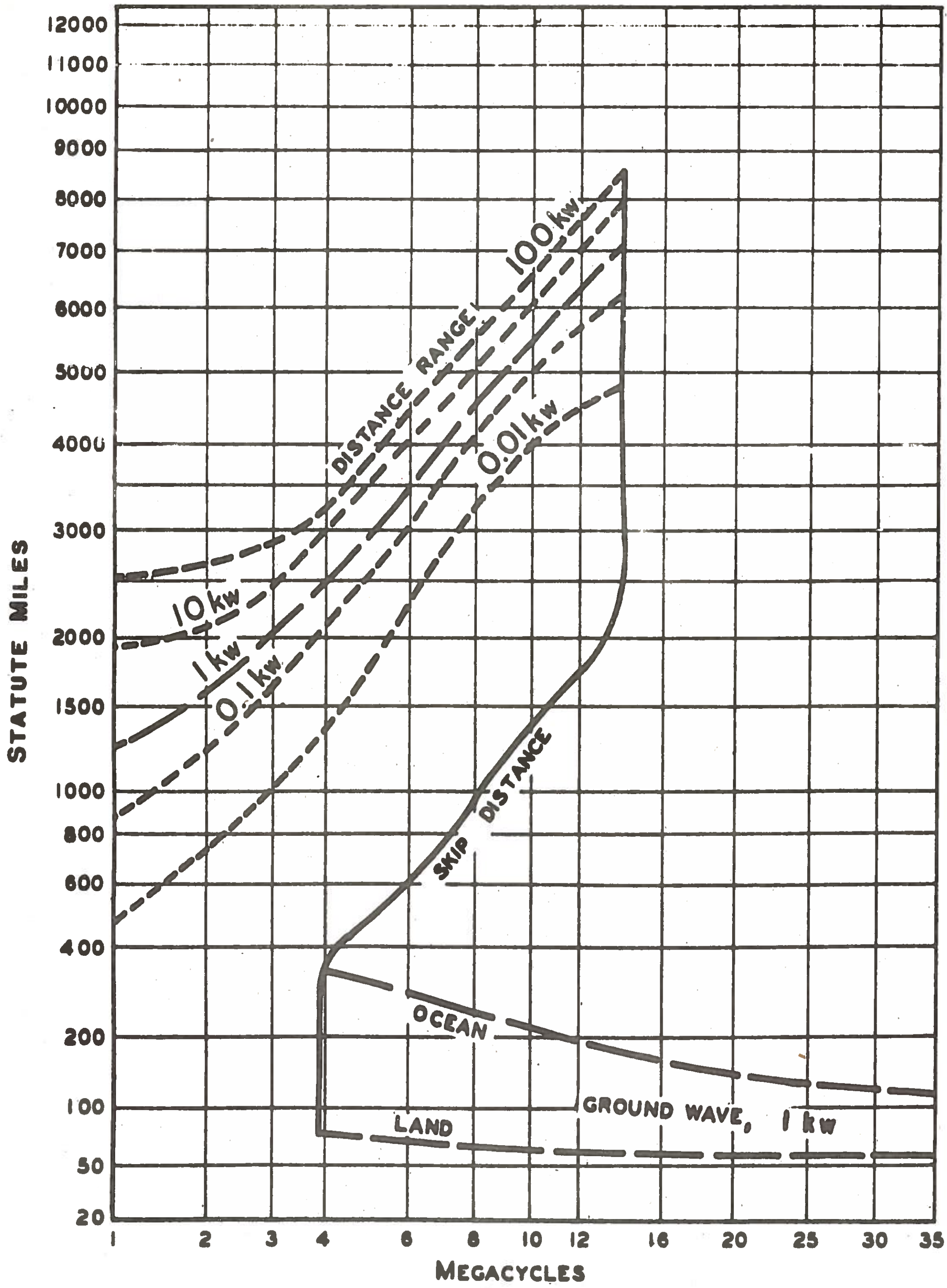

FIG. 24. RADIO DISTANCE RANGES.
NOV. 1941 THROUGH FEB. 1942.
LATITUDE: 40° N. 2000 LOCAL TIME. AZIMUTH: 270°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

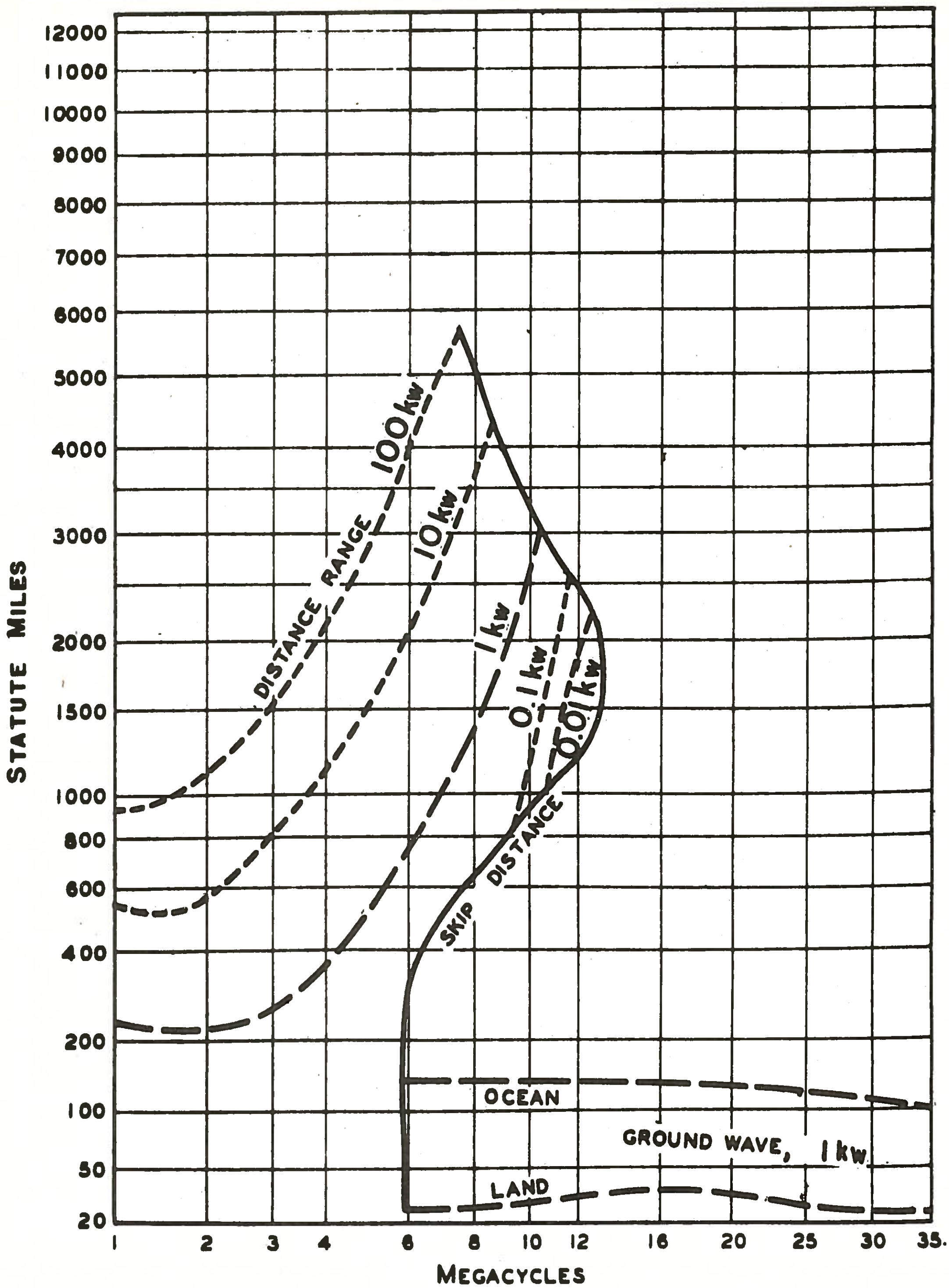

FIG. 25. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 0°. 0000 LOCAL TIME. AZIMUTH: 0°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

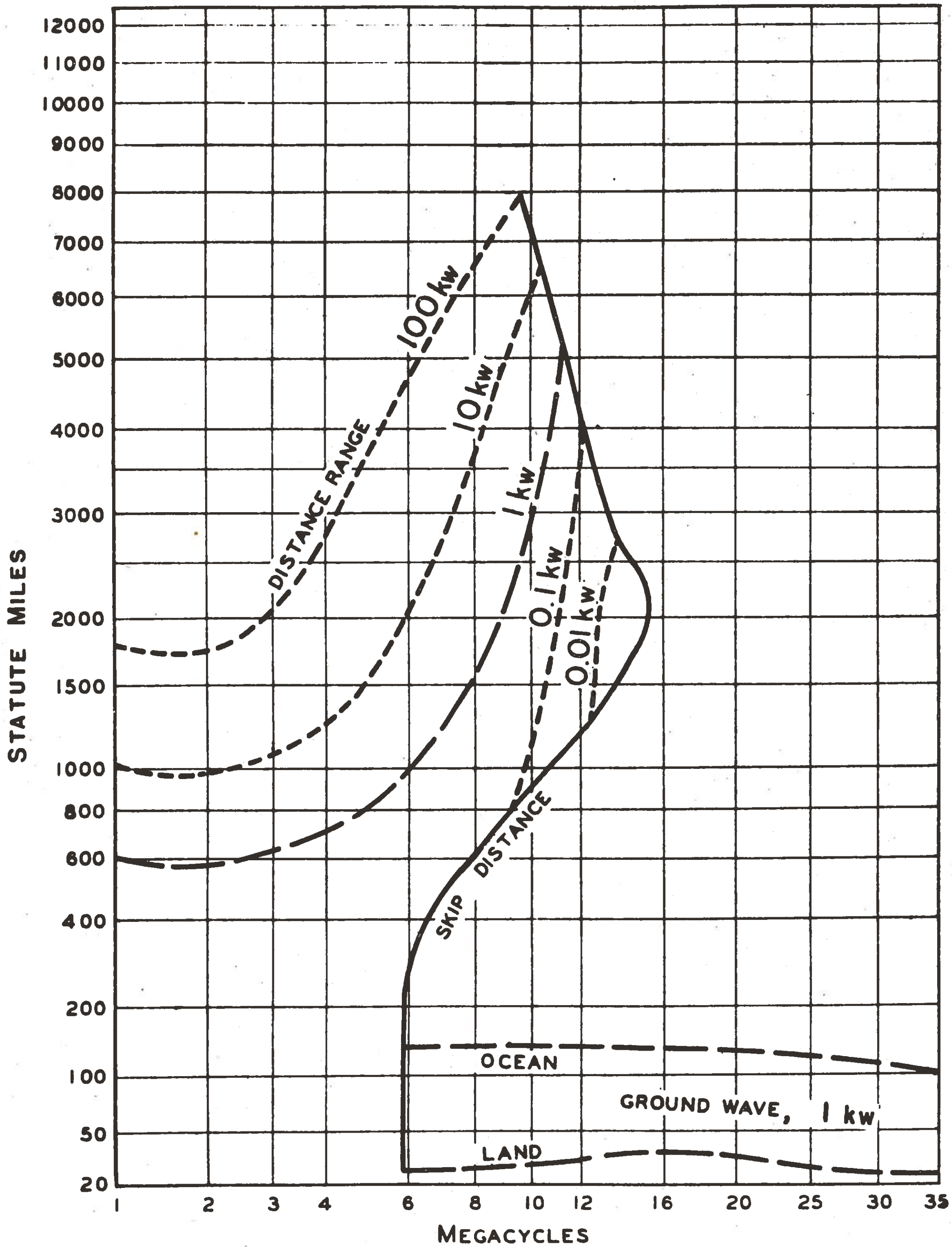

FIG. 26. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 0°. 0000 LOCAL TIME. AZIMUTH: 90°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

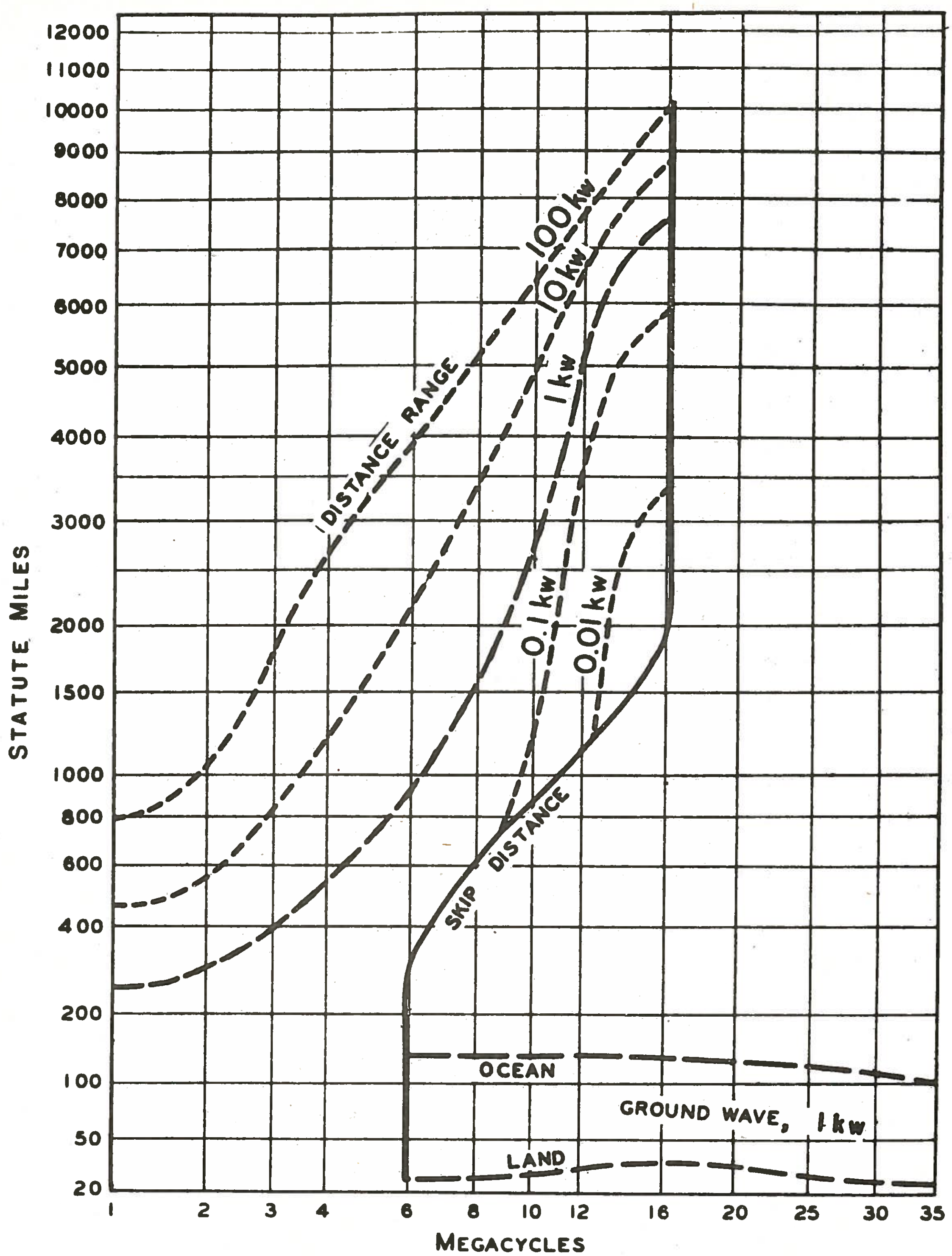

FIG. 27. Radio Distance Ranges.

Nov. 1941 through Feb. 1942.

Latitude: 0°. 0000 Local Time. Azimuth: 180°.

(Powers shown on curves are for phone transmission. Powers for CW transmission are 0.01 as great.)

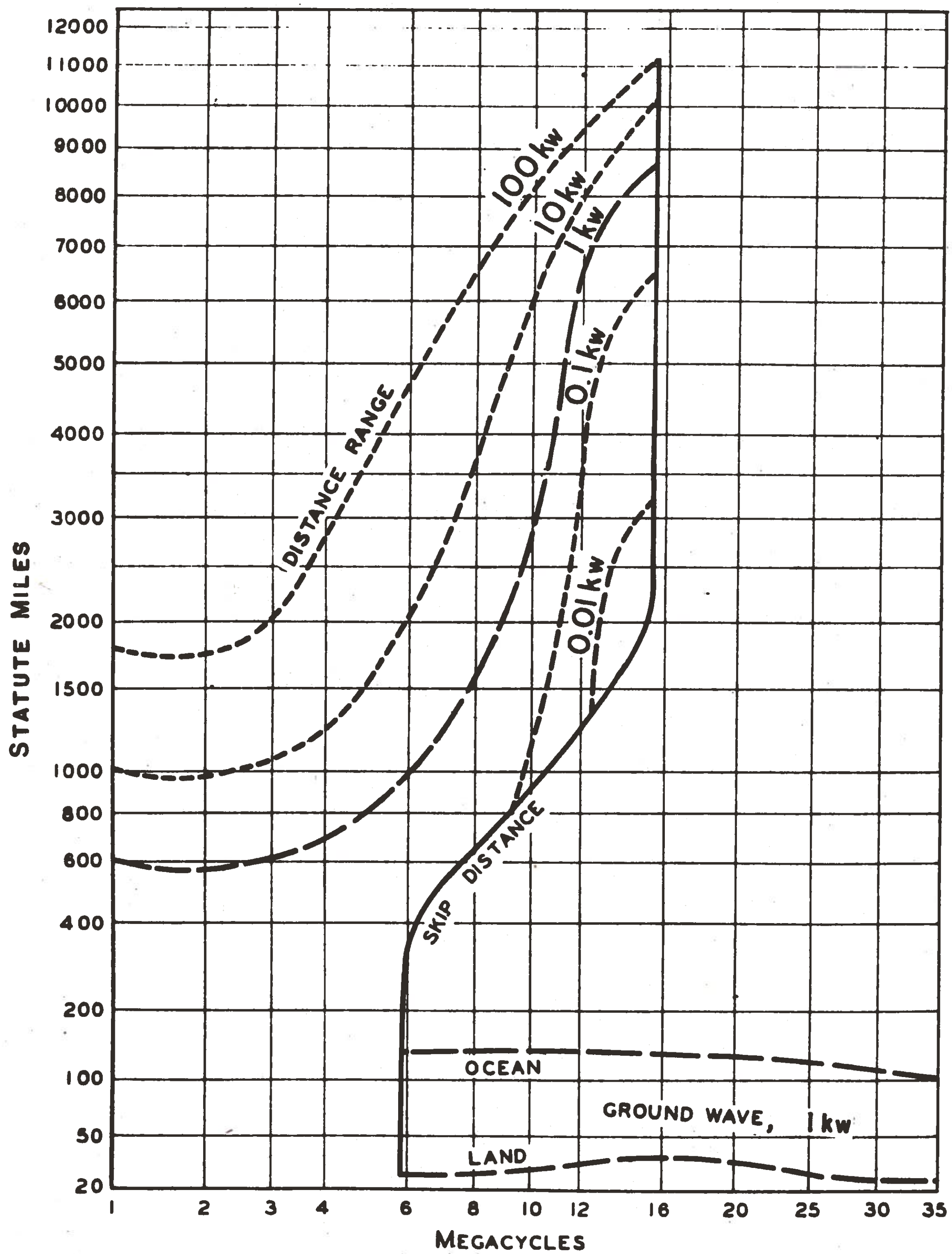

FIG. 28. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 0°. 0000 LOCAL TIME. AZIMUTH: 270°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

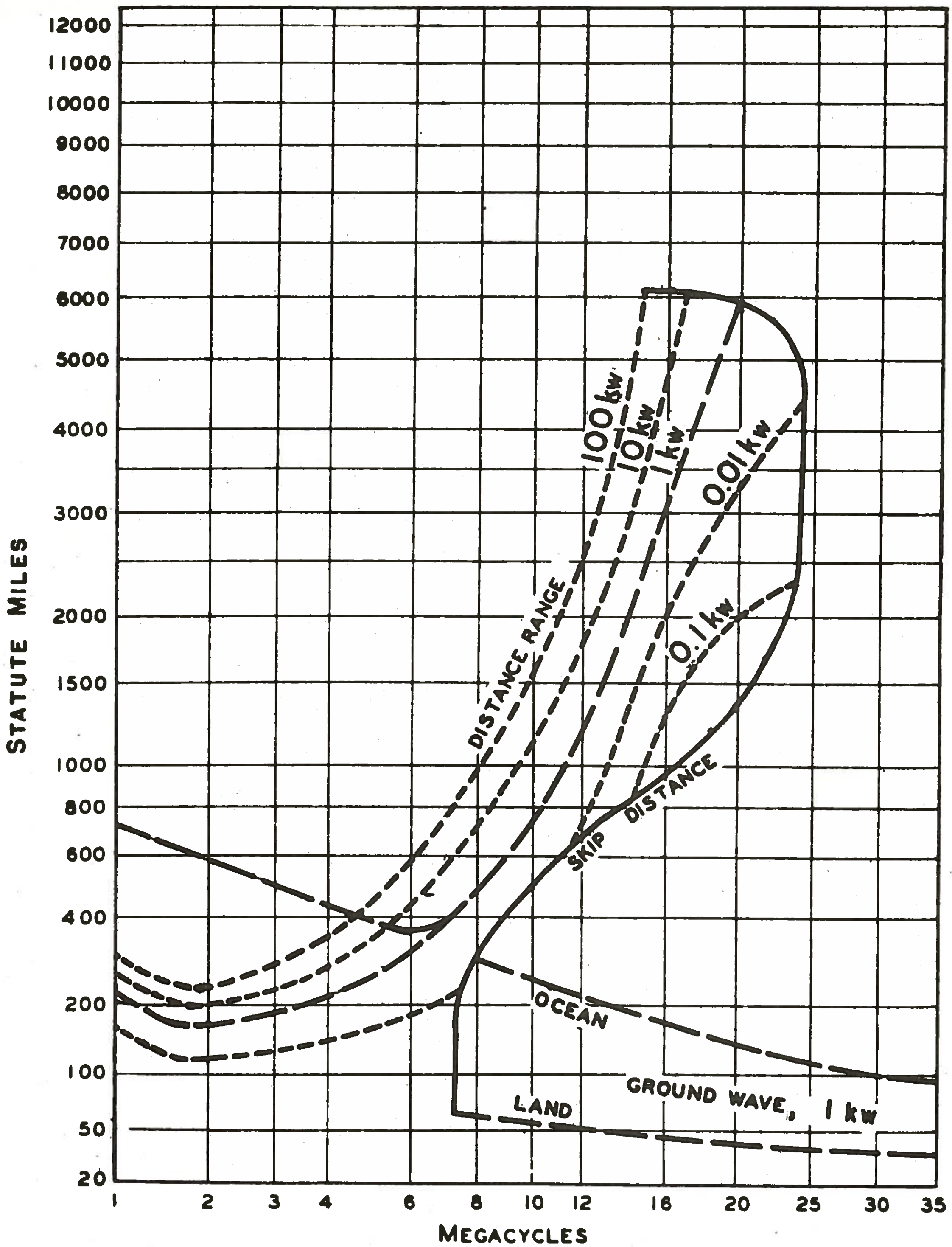

FIG. 29. RADIO DISTANCE RANGES.
NOV. 1941 THROUGH FEB. 1942.
LATITUDE: 0°. 1200 LOCAL TIME. AZIMUTH: 0°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

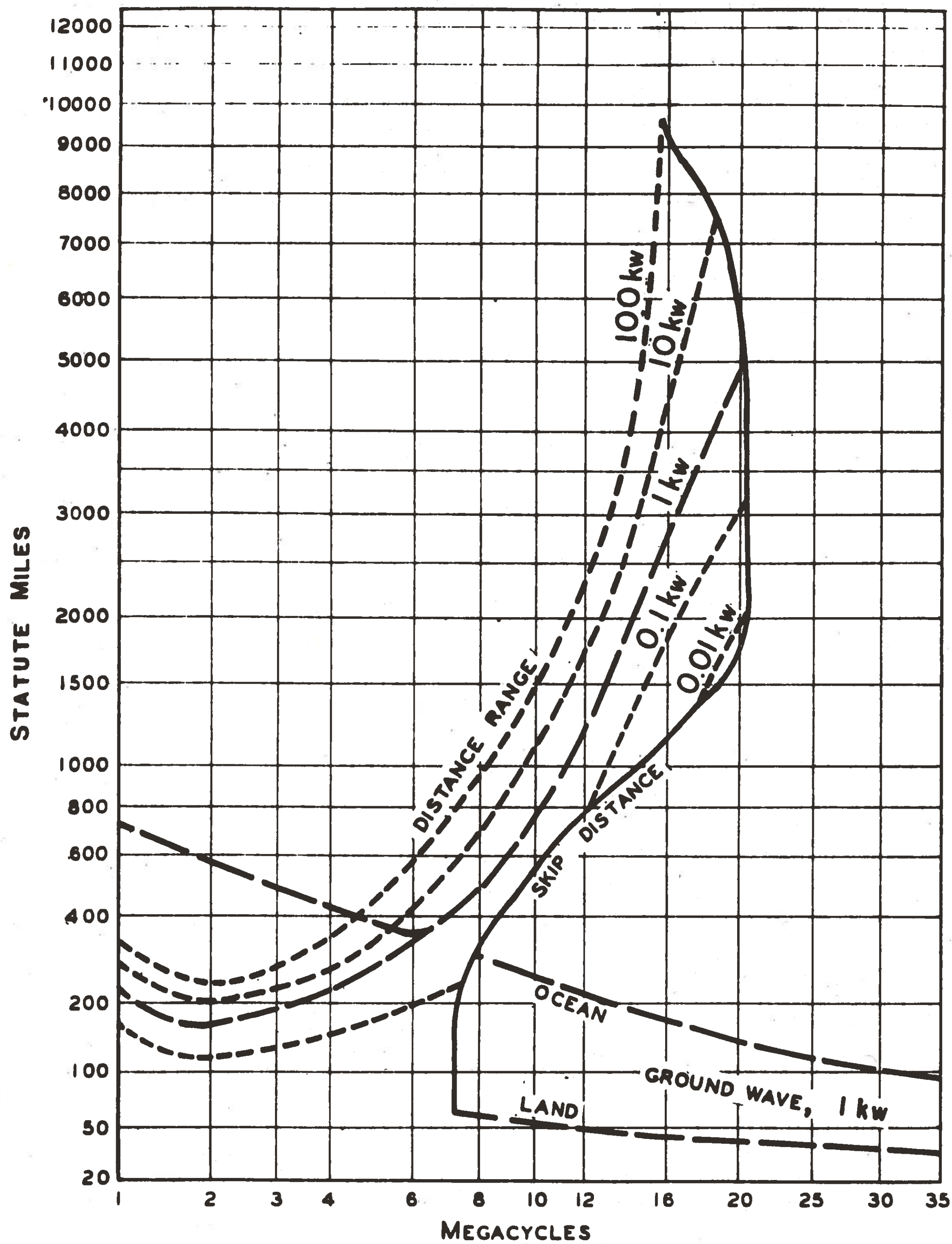

FIG. 30. RADIO DISTANCE RANGES.
NOV. 1941 THROUGH FEB. 1942.
LATITUDE: 0°. 1200 LOCAL TIME. AZIMUTH: 90°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

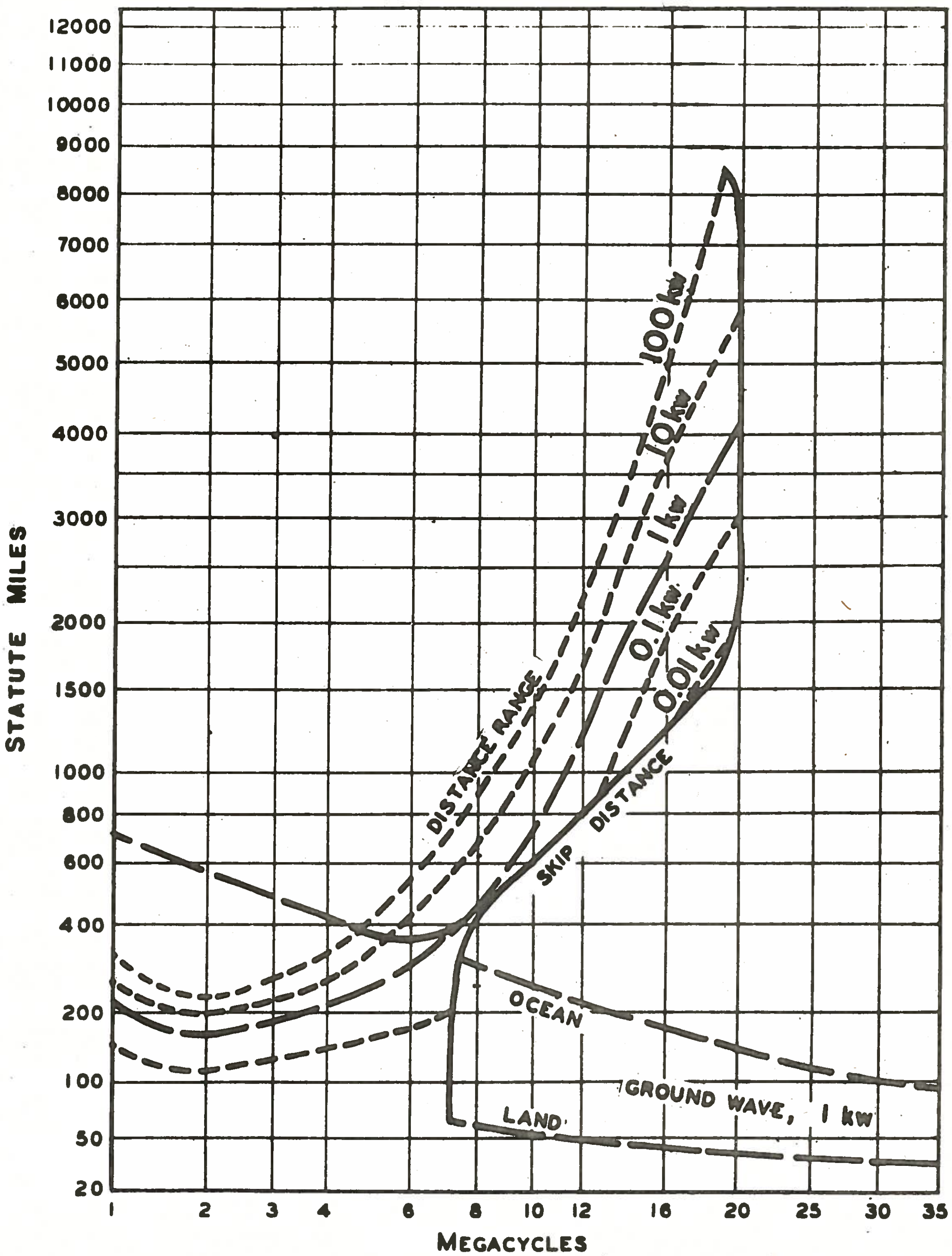

FIG. 31. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 0°. 1200 LOCAL TIME. AZIMUTH: 180°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION. POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

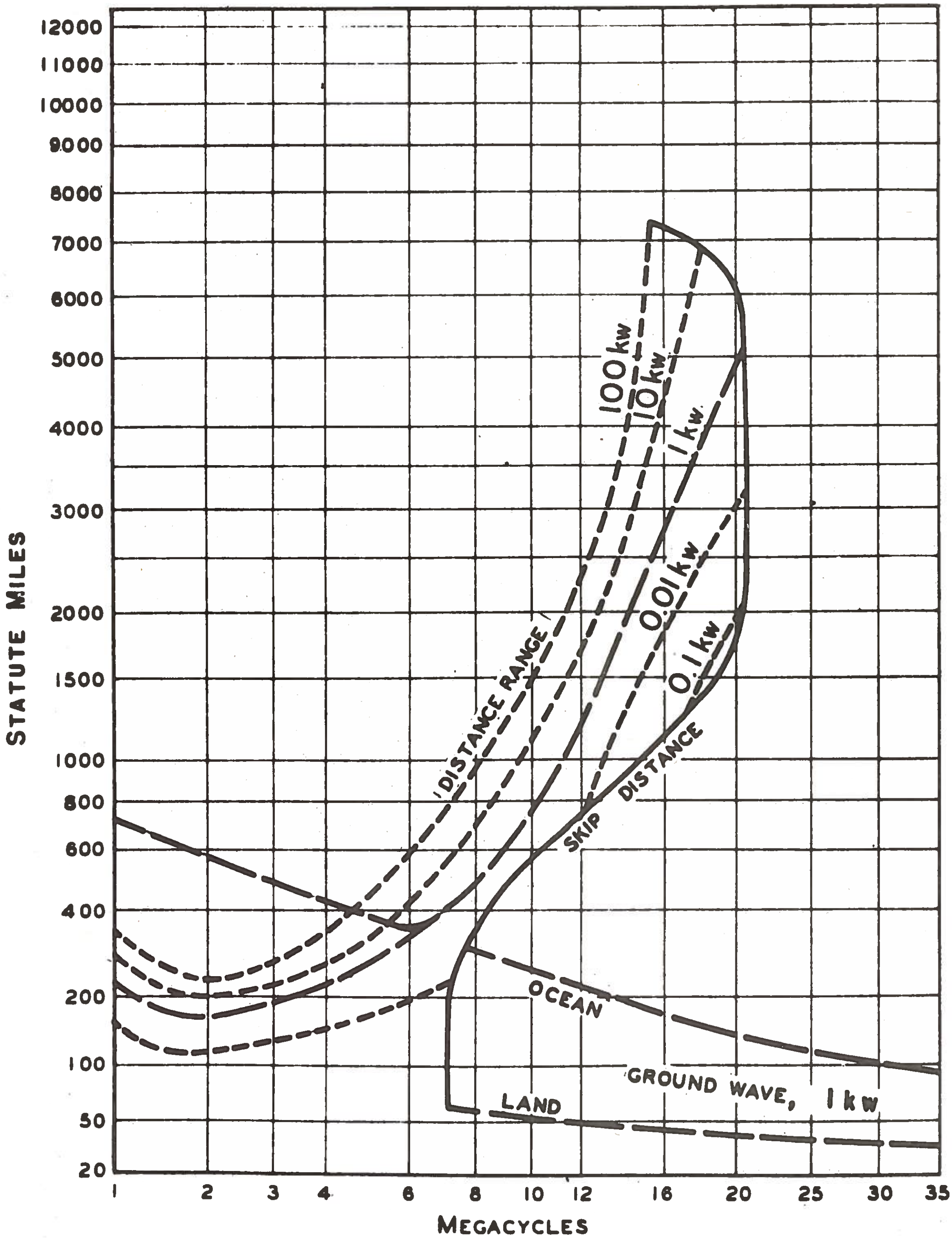

FIG. 32. RADIO DISTANCE RANGES.

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 0°. 1200 LOCAL TIME. AZIMUTH: 270°.

(POWERS SHOWN ON CURVES ARE FOR PHONE TRANSMISSION.
POWERS FOR CW TRANSMISSION ARE 0.01 AS GREAT.)

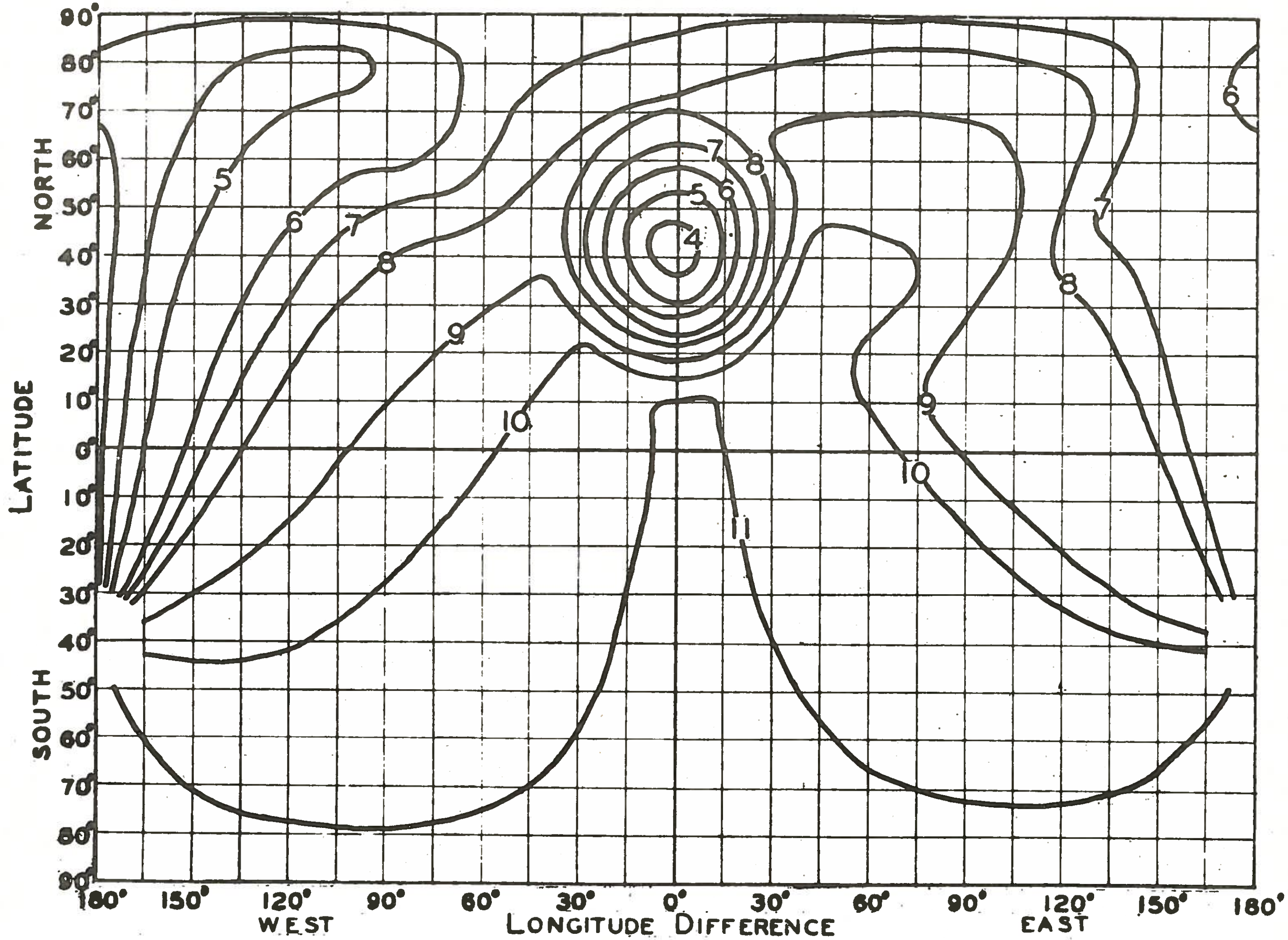

FIG. 33. MAXIMUM USABLE FREQUENCY
NOV. 1941 THROUGH FEB. 1942.
LATITUDE: 40° N. 0000 LOCAL TIME.
(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES):

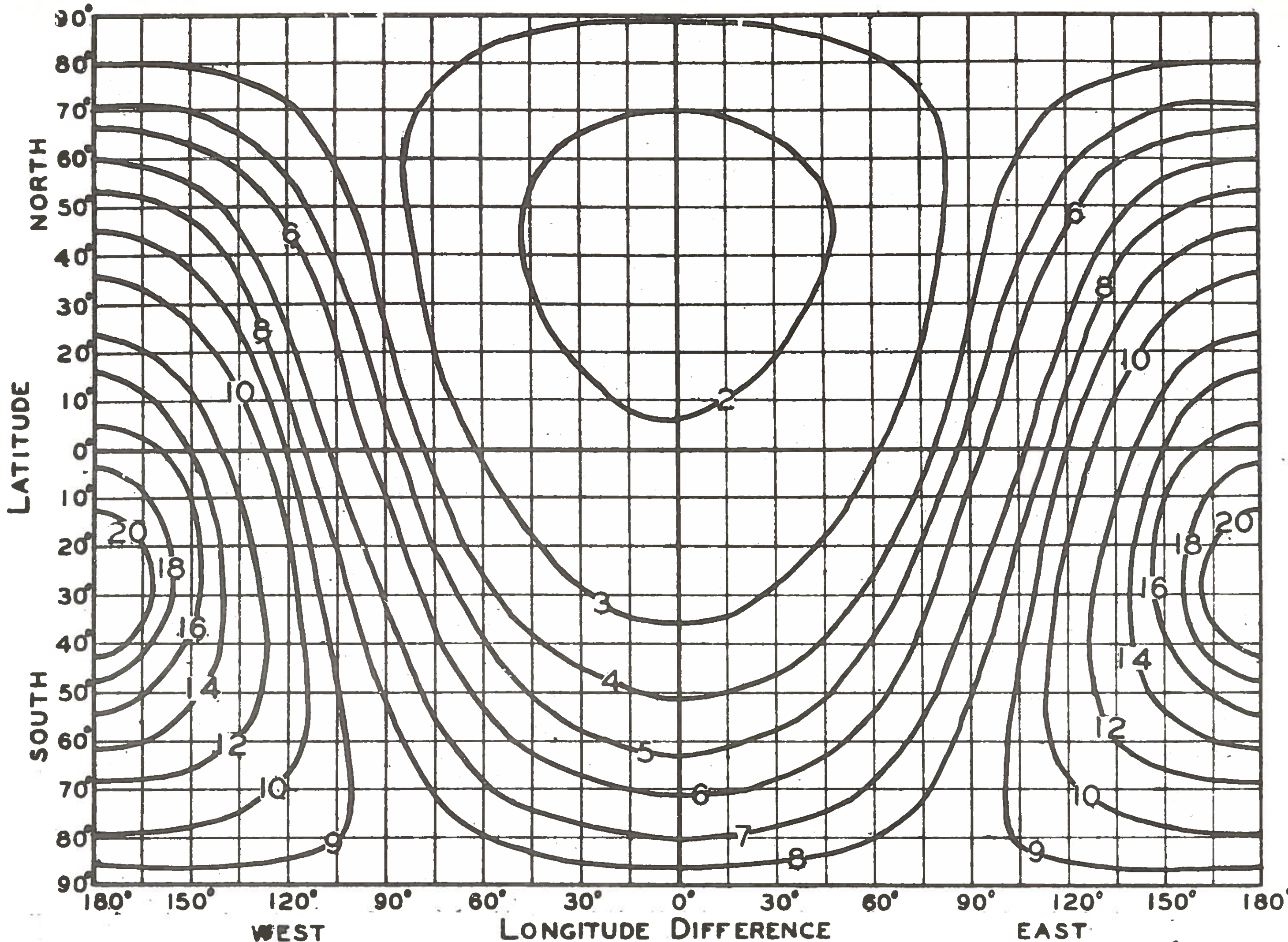

FIG. 34. LOWEST USEFUL HIGH FREQUENCY (1 KW).

NOV. 1941 THROUGH FEB 1942

LATITUDE: 40° N. 0000 LOCAL TIME

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

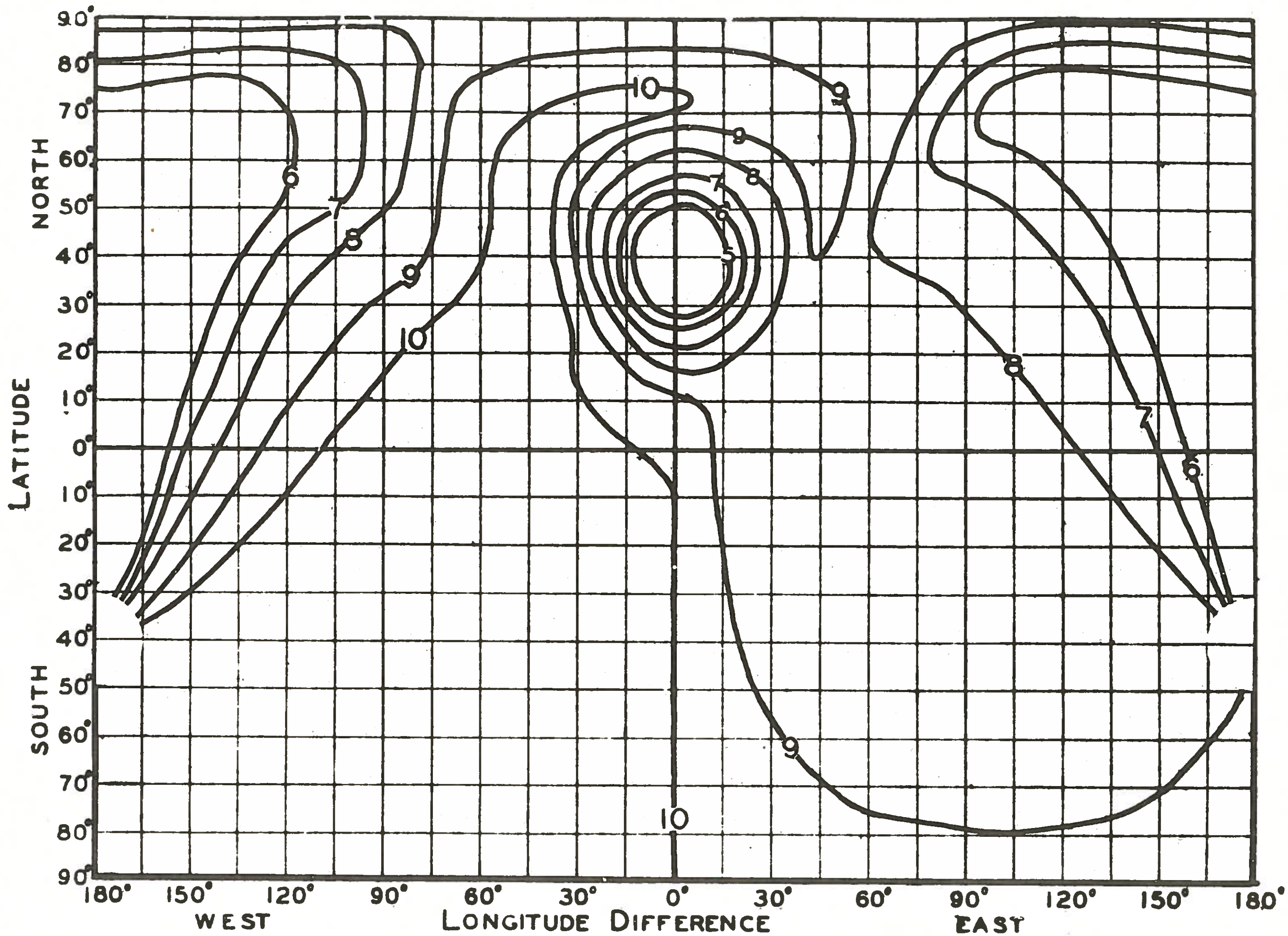

FIG. 35. MAXIMUM USABLE FREQUENCY

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 0400 LOCAL TIME.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

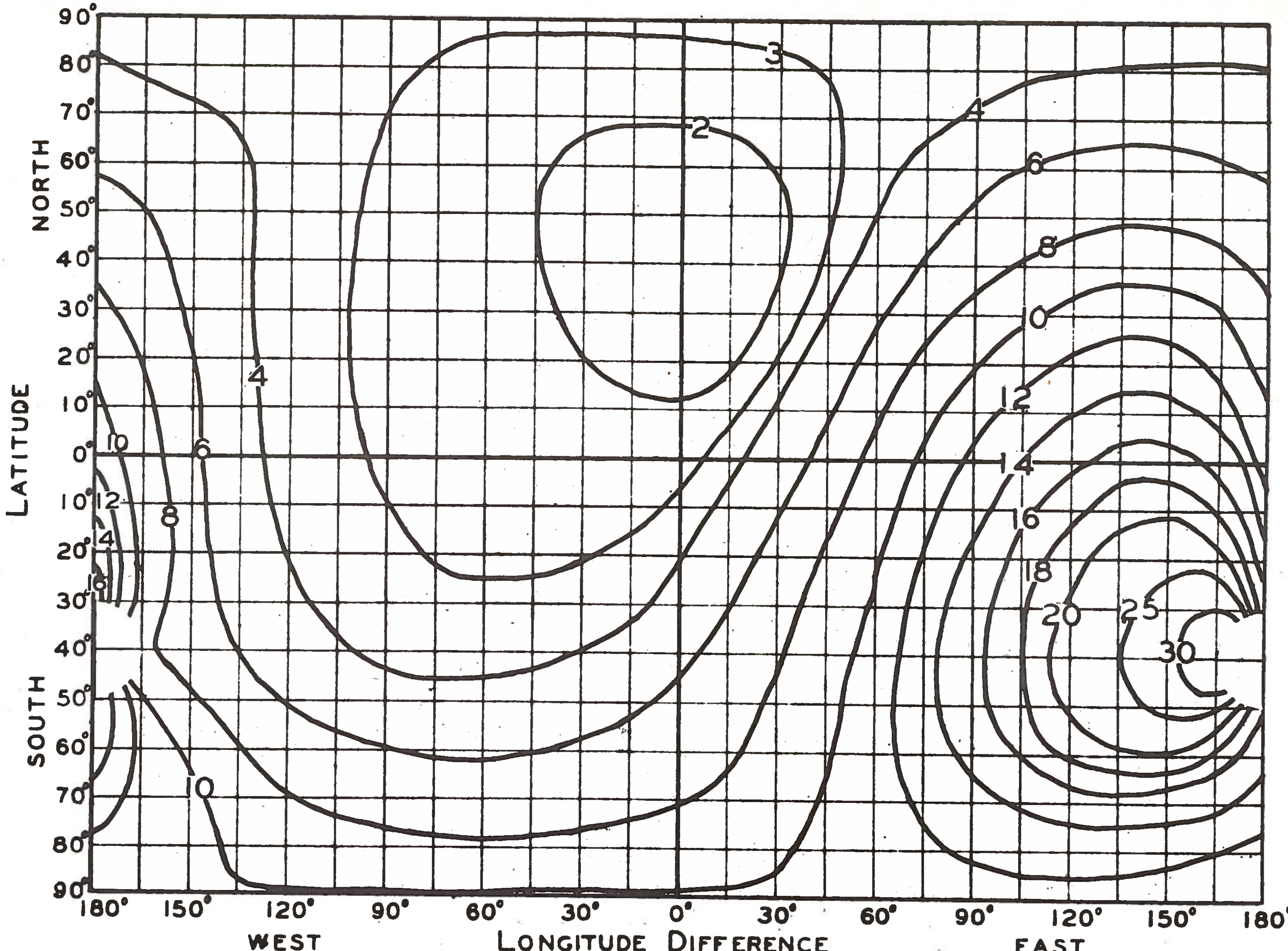

FIG. 36. LOWEST USEFUL HIGH FREQUENCY (1 KW).

NOV 1941 THROUGH FEB 1942.

LATITUDE: 40° N. 0400 LOCAL TIME

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

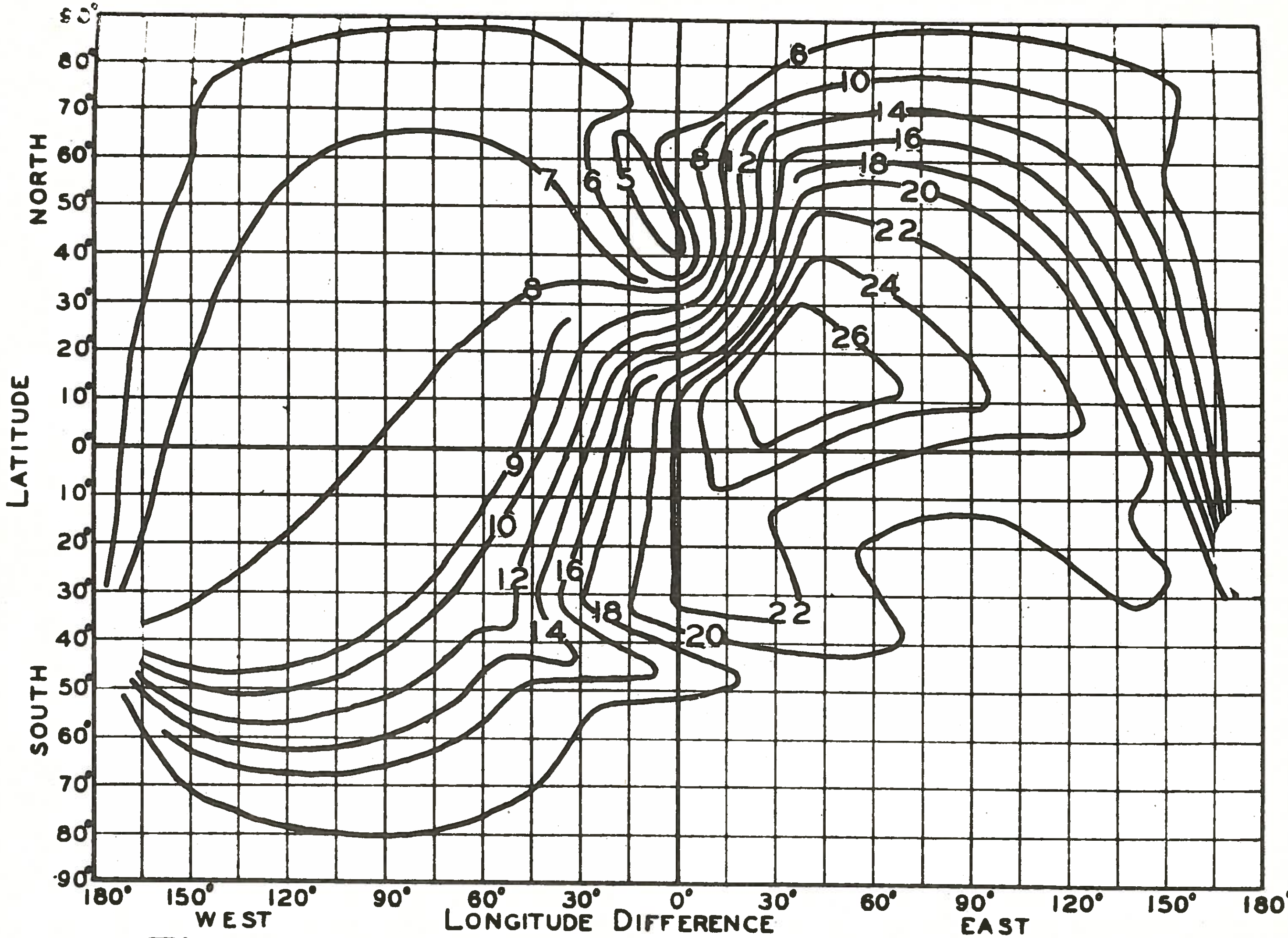

FIG. 37. MAXIMUM USABLE FREQUENCY

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 0800 LOCAL TIME.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

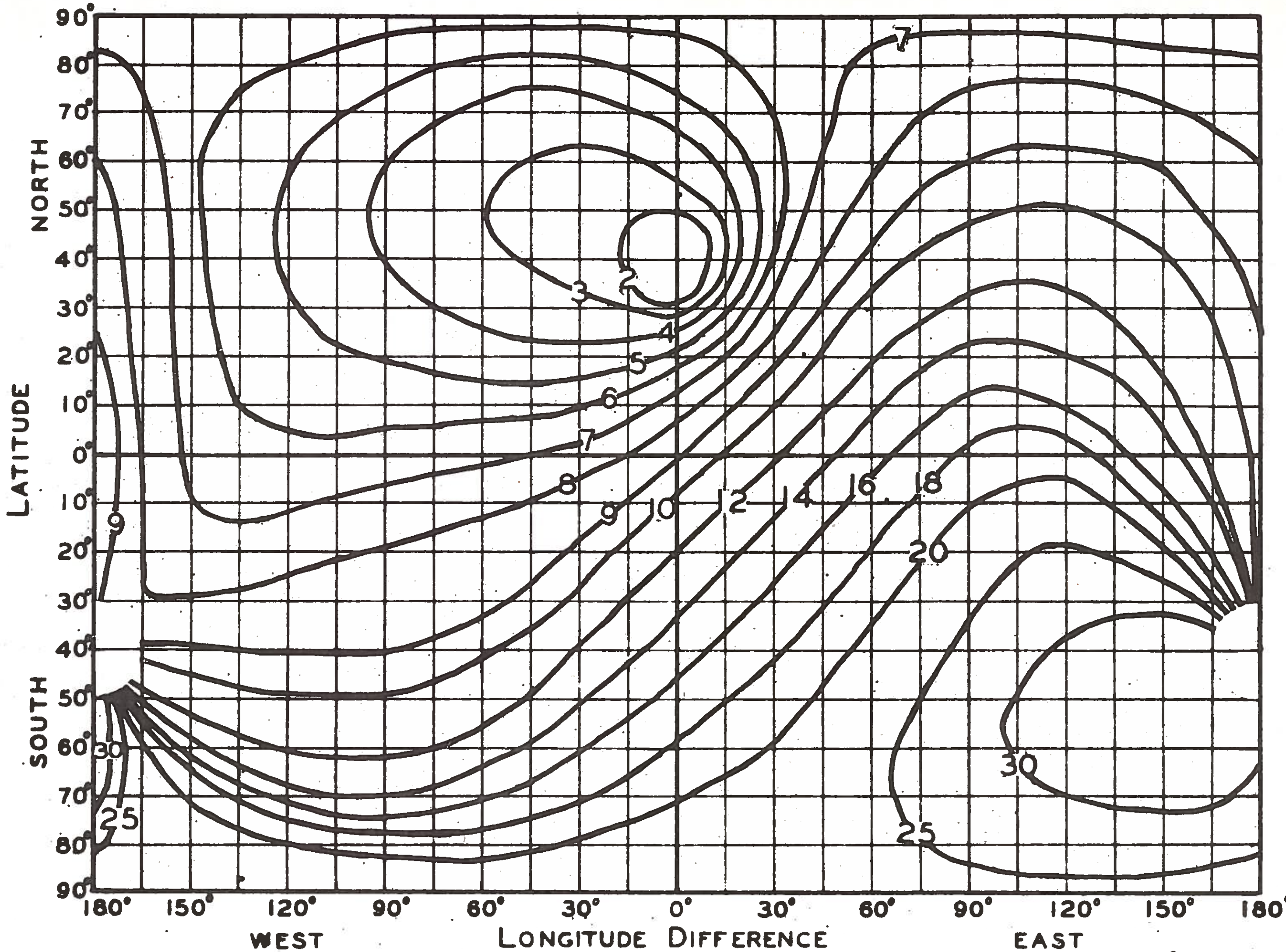

FIG. 38. LOWEST USEFUL HIGH FREQUENCY (1 KW).

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 0800 LOCAL TIME.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

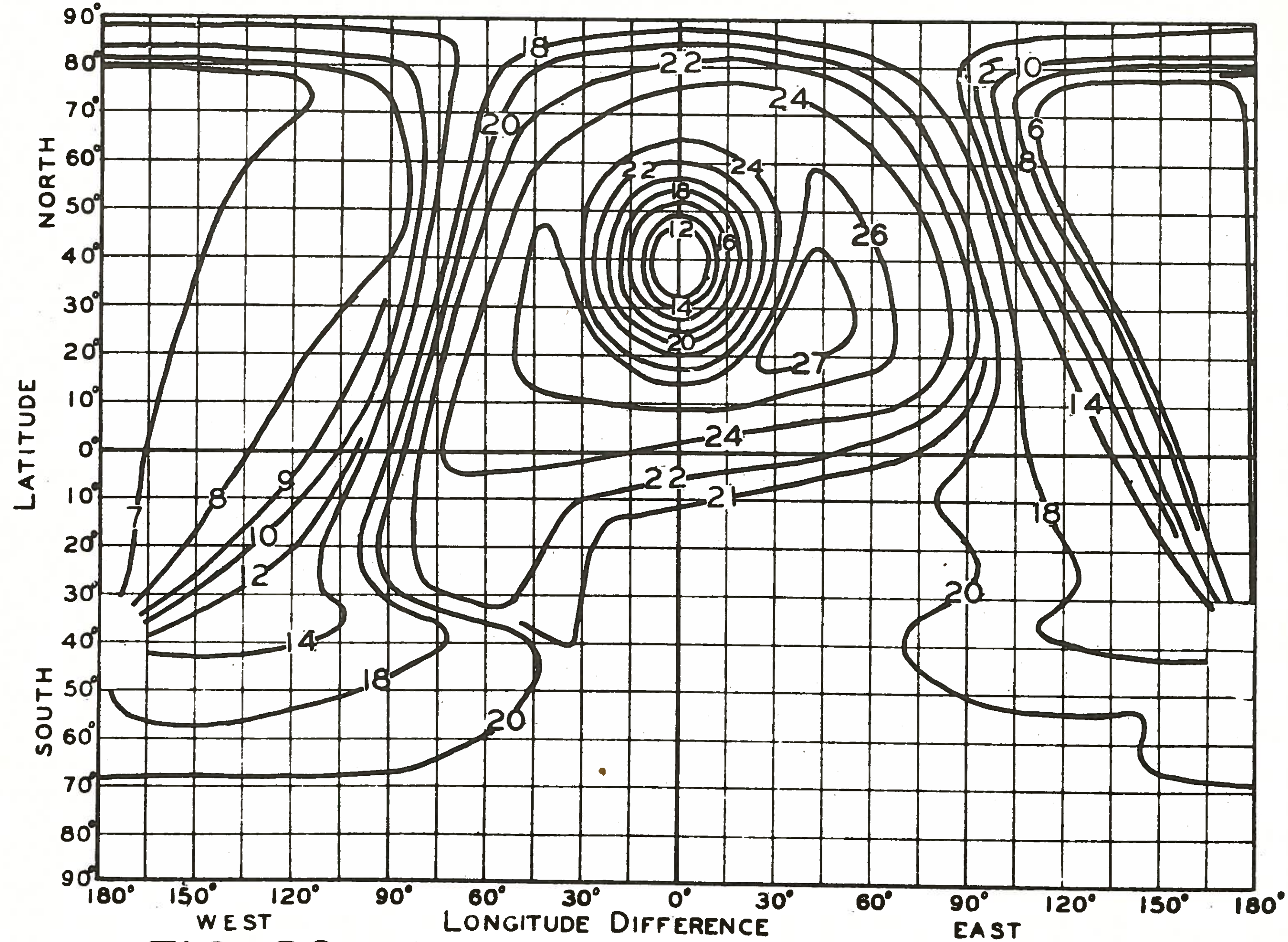

FIG. 39. MAXIMUM USABLE FREQUENCY
NOV. 1941 THROUGH FEB. 1942.
LATITUDE: 40° N. 1200 LOCAL TIME.
(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

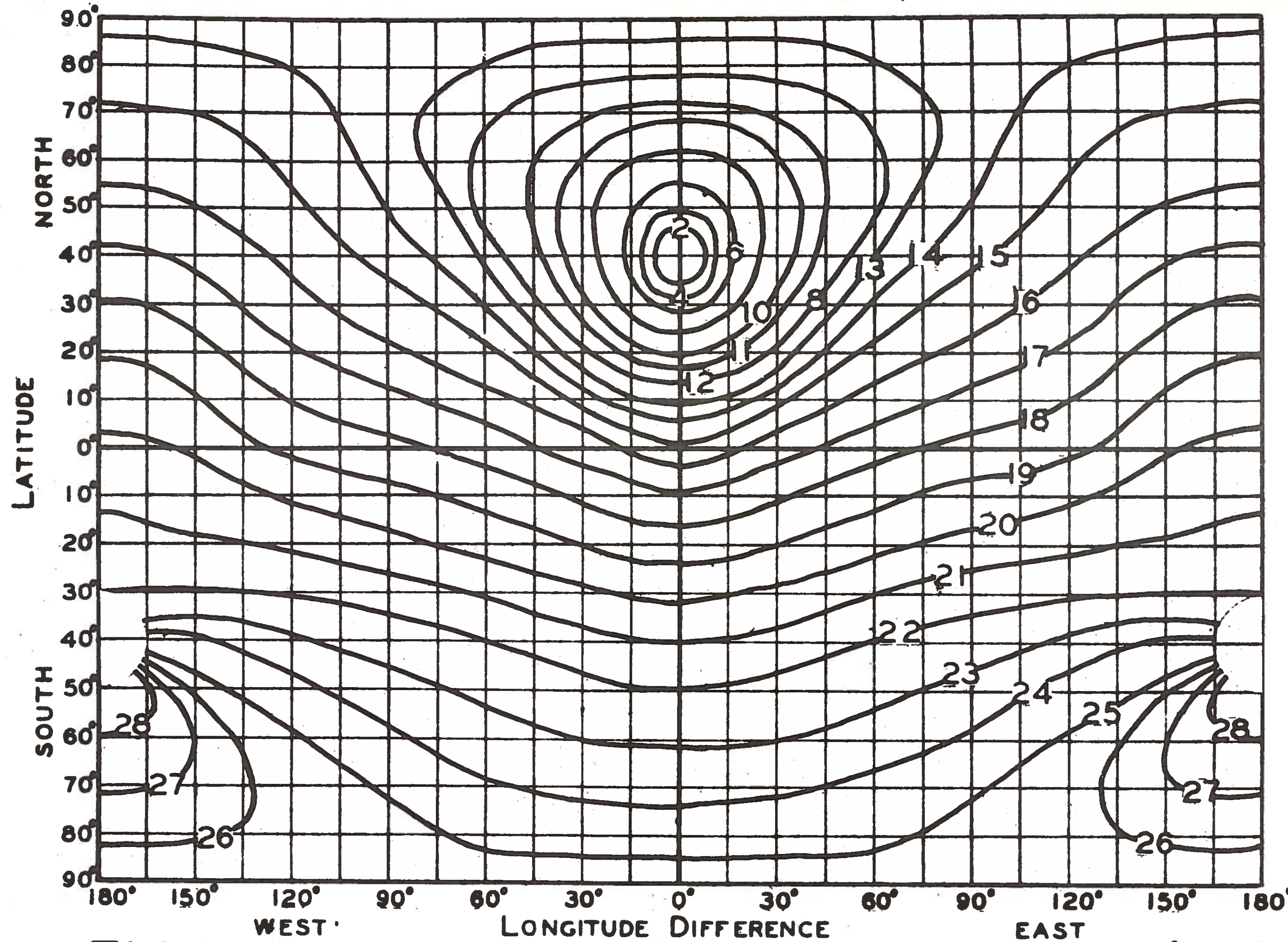

FIG. 40. LOWEST USEFUL HIGH FREQUENCY (1 KW).

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 1200 LOCAL TIME.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

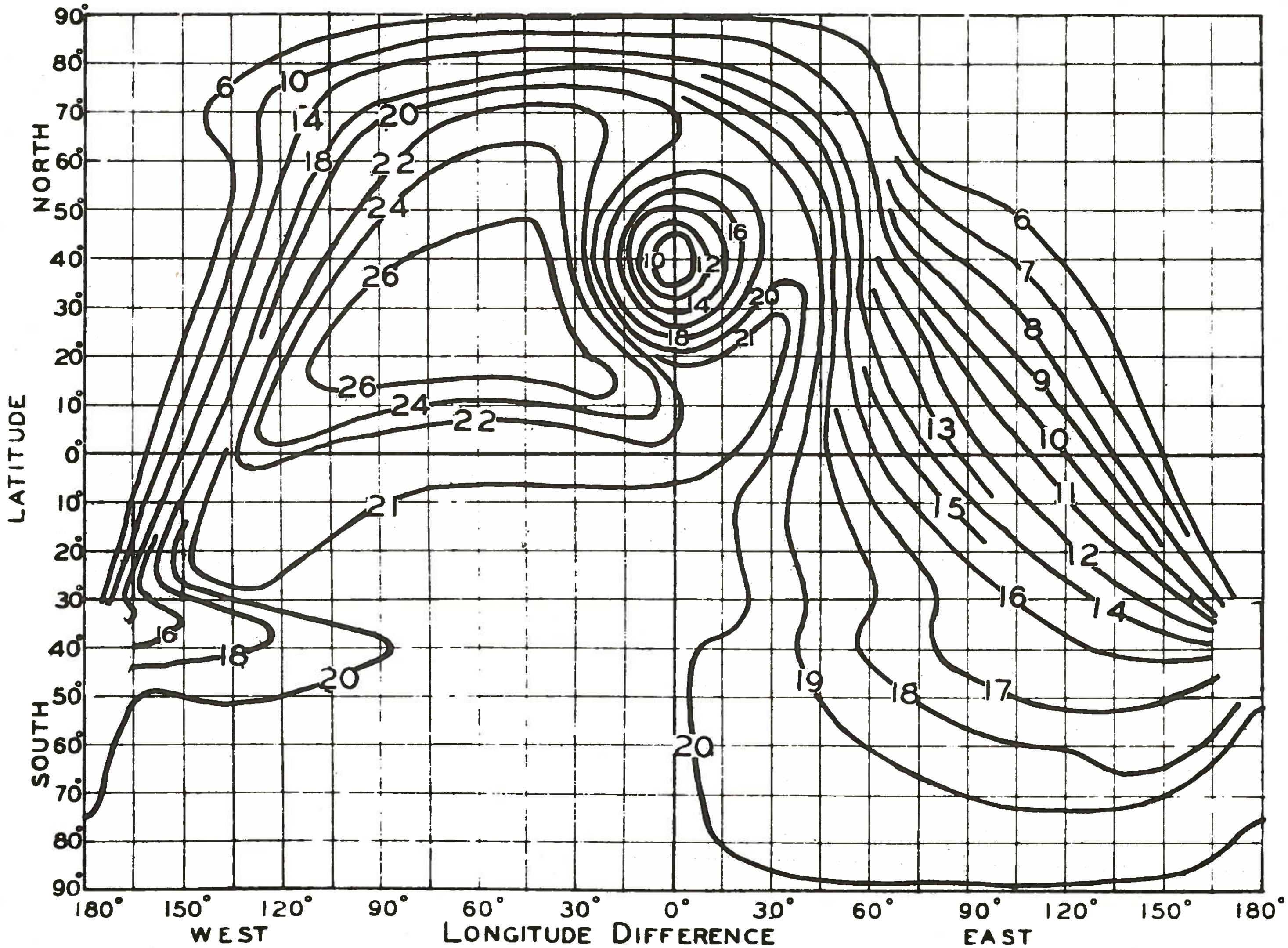

FIG. 41. MAXIMUM USABLE FREQUENCY
NOV. 1941 THROUGH FEB. 1942.
LATITUDE: 40° N. 1600 LOCAL TIME.
(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

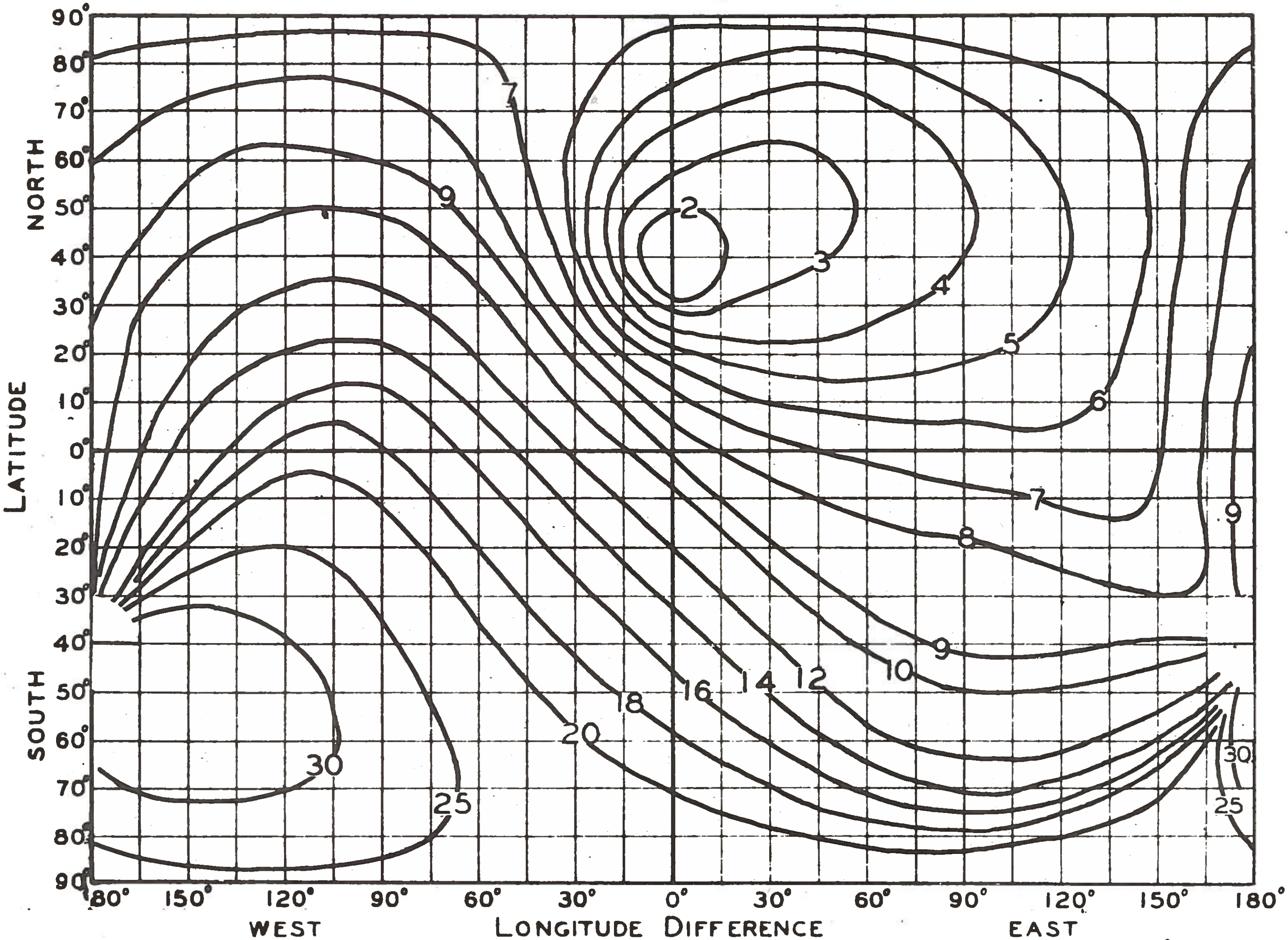

FIG. 42. LOWEST USEFUL HIGH FREQUENCY (1 KW).

NOV 1941 THROUGH FEB. 1942

LATITUDE: 40° N. 1600 LOCAL TIME.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

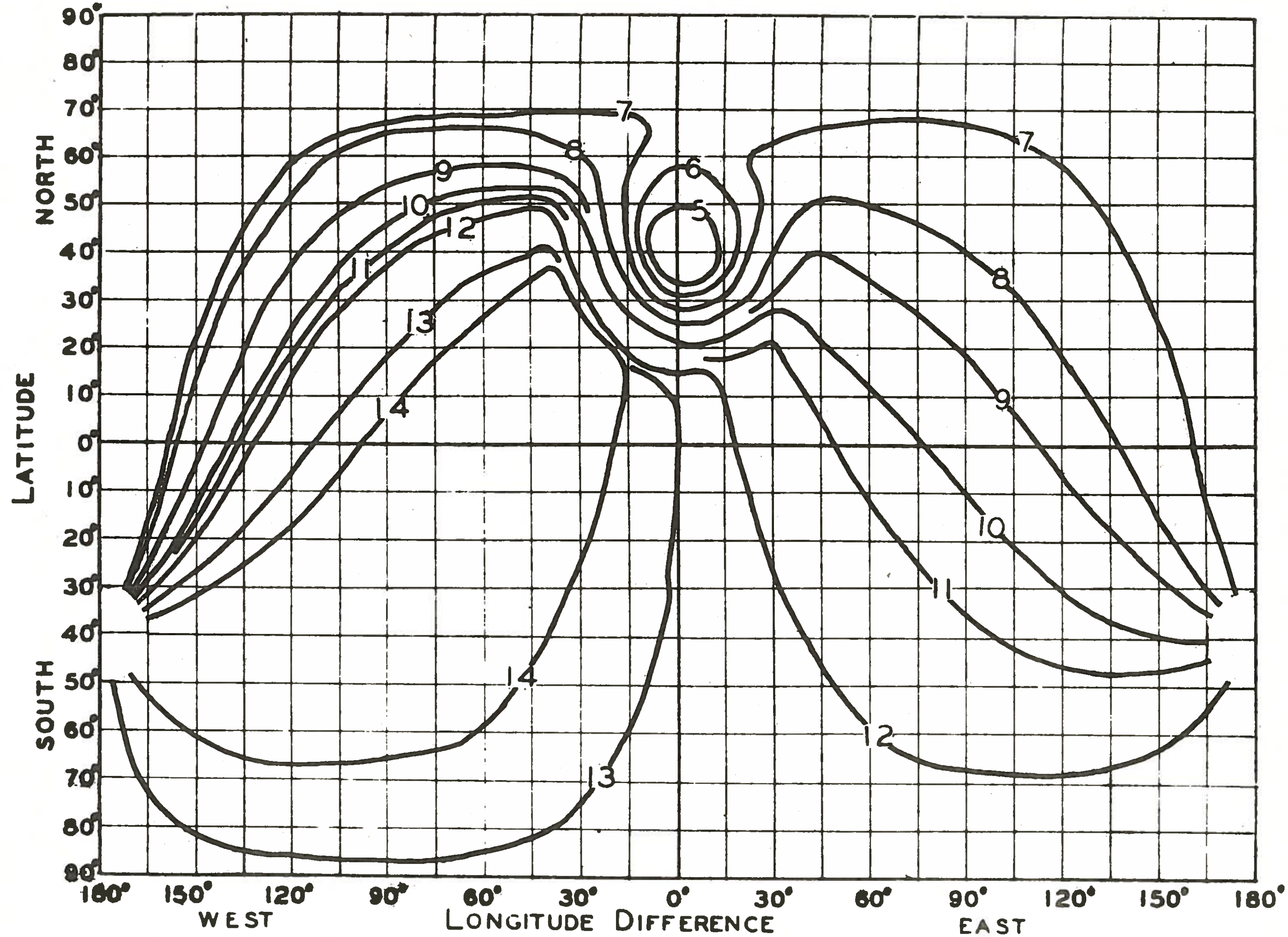

FIG. 43. MAXIMUM USABLE FREQUENCY

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 40° N. 2000 LOCAL TIME.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

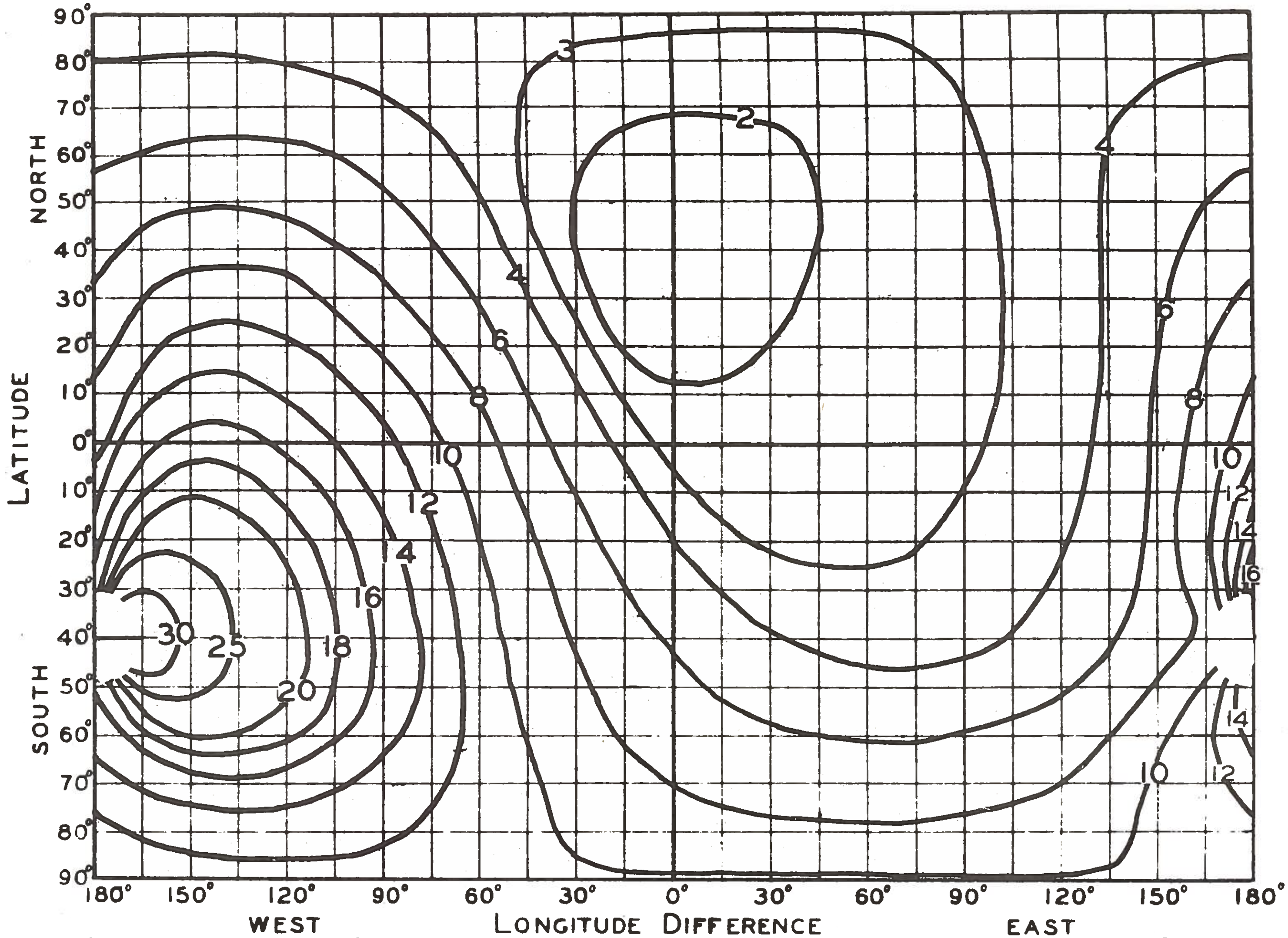

FIG. 44. LOWEST USEFUL HIGH FREQUENCY (1 KW).

NOV. 1941 THROUGH FEB 1942.

LATITUDE: 40° N. 2000 LOCAL TIME.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

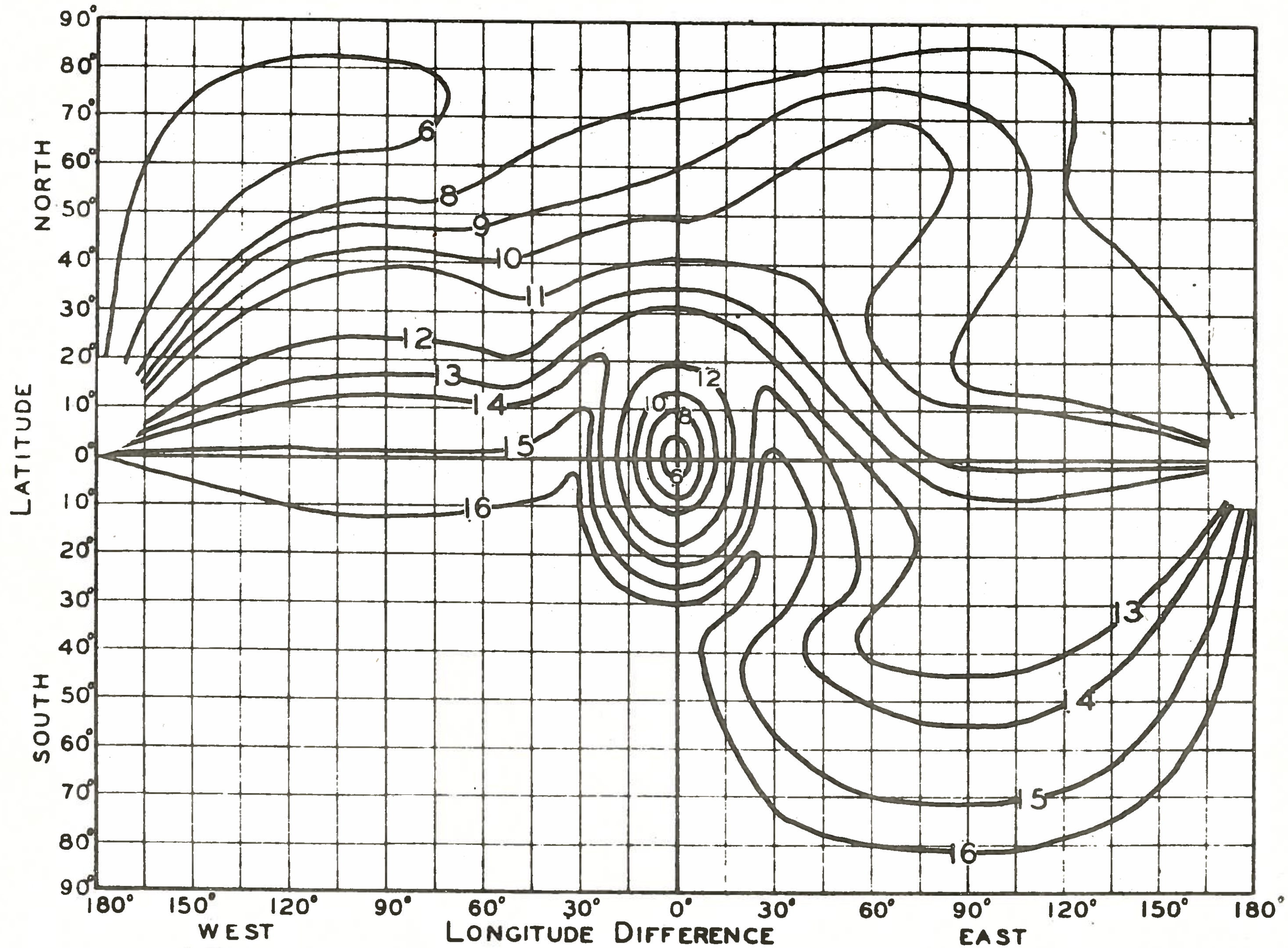

FIG. 45 MAXIMUM USABLE FREQUENCY

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 0°. 0000 LOCAL TIME.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

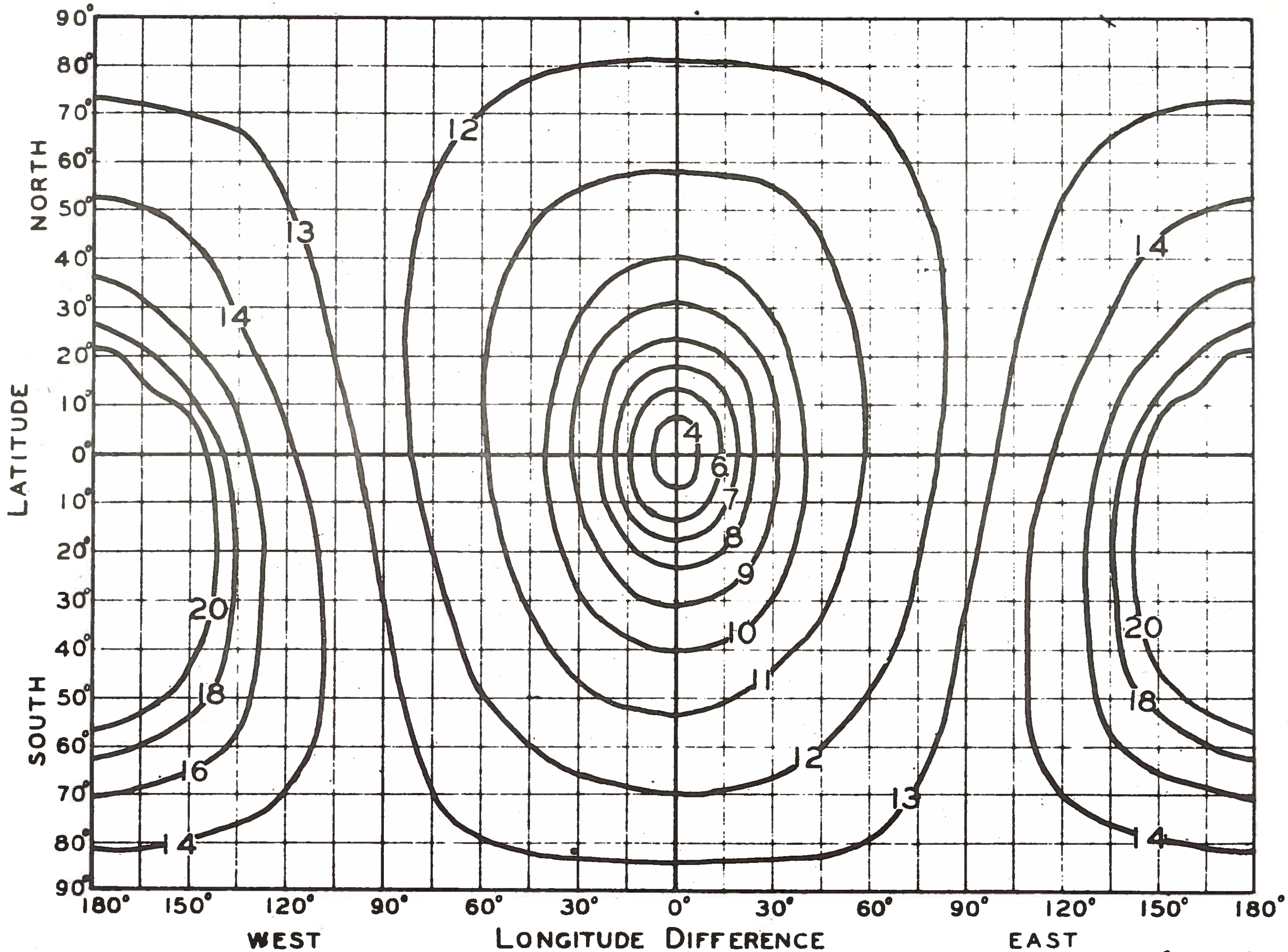

FIG. 46. LOWEST USEFUL HIGH FREQUENCY (1 KW).

NOV. 1941 THROUGH FEB. 1942.

LATITUDE 0°. 0000 LOCAL TIME. OVER OR NEAR LAND.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

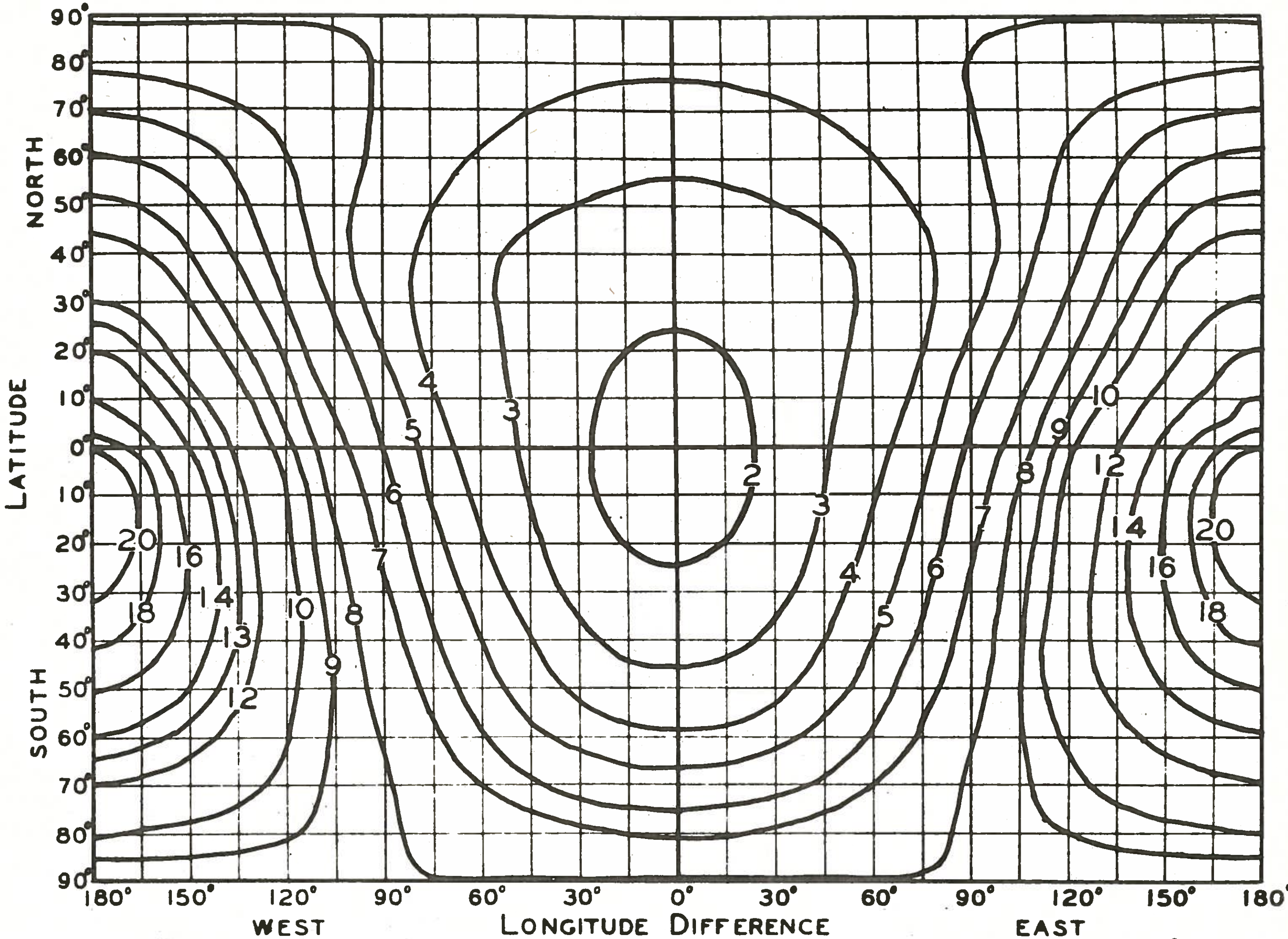

FIG. 47. LOWEST USEFUL HIGH FREQUENCY (1 KW).

NOV 1941 THROUGH FEB. 1942.

LATITUDE 0°. 0000 LOCAL TIME. OVER OPEN OCEAN

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

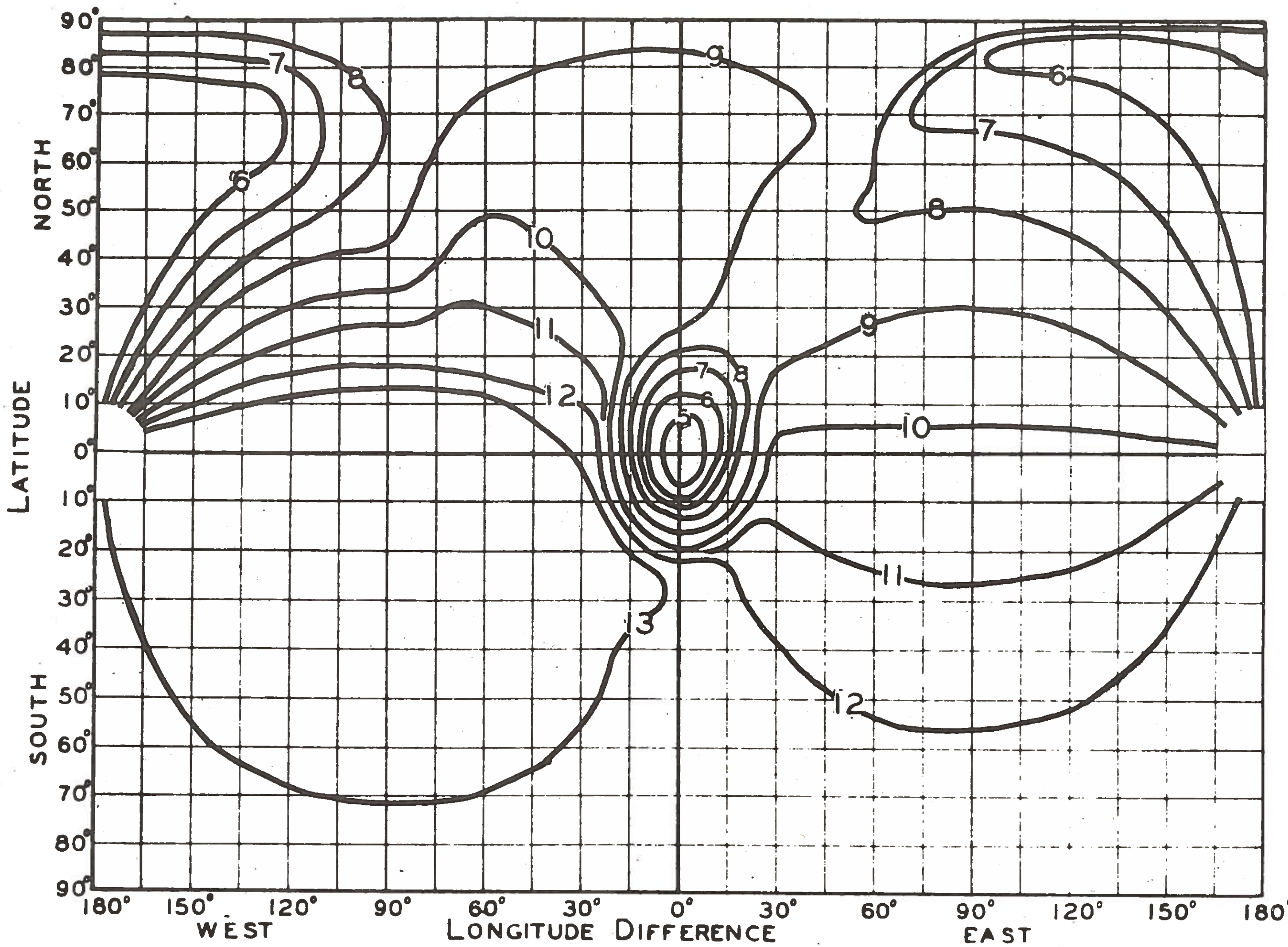

FIG. 48. MAXIMUM USABLE FREQUENCY

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 0°. 0400 LOCAL TIME.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

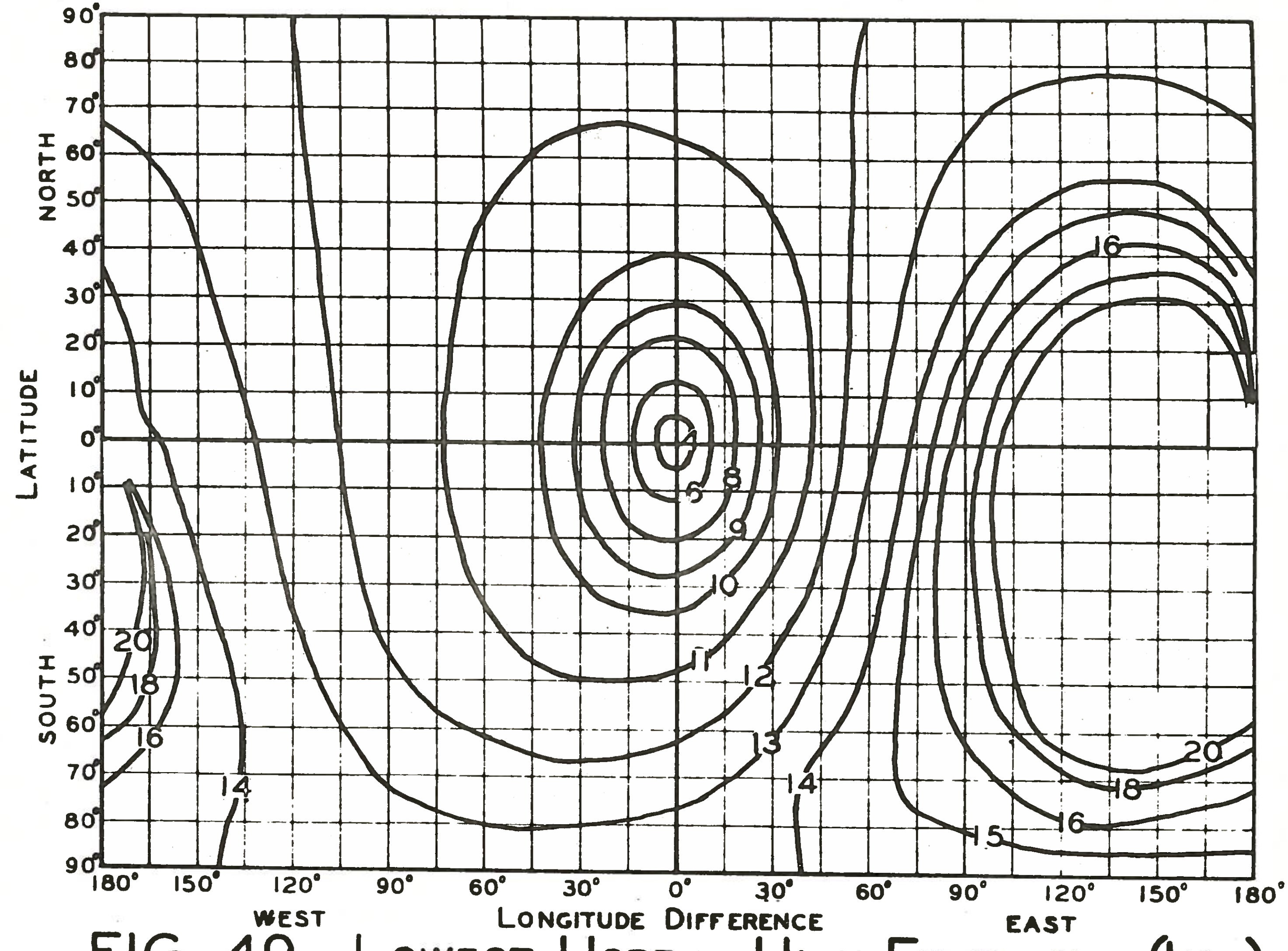

FIG. 49. LOWEST USEFUL HIGH FREQUENCY (1 KW).
NOV. 1941 THROUGH FEB. 1942.
LATITUDE 0°. 0400 LOCAL TIME. OVER OR NEAR LAND.
(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

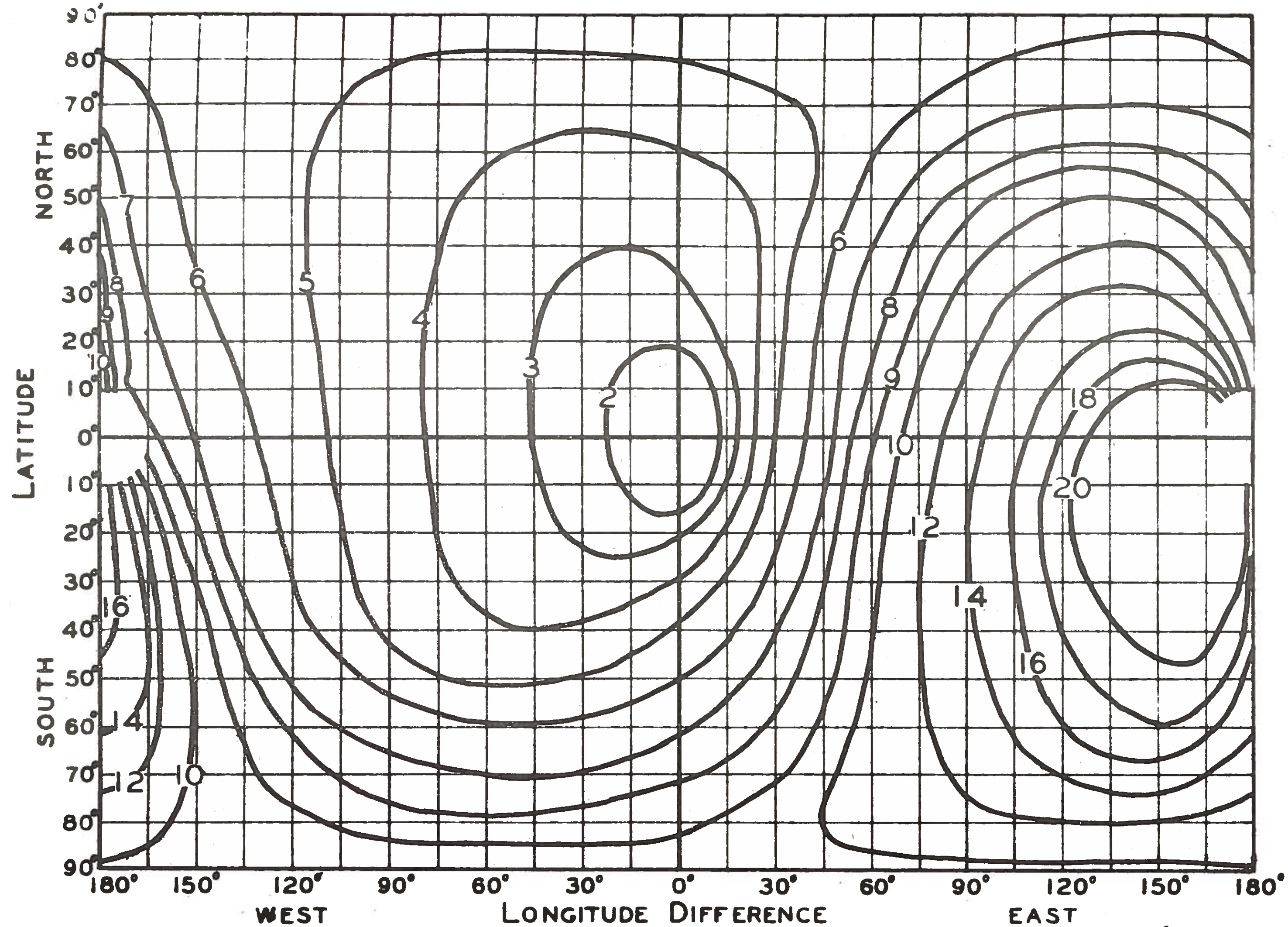

FIG. 50. LOWEST USEFUL HIGH FREQUENCY (1 KW).

NOV. 1941 THROUGH FEB. 1942.

LATITUDE 0°. 0400 LOCAL TIME. OVER OPEN OCEAN.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

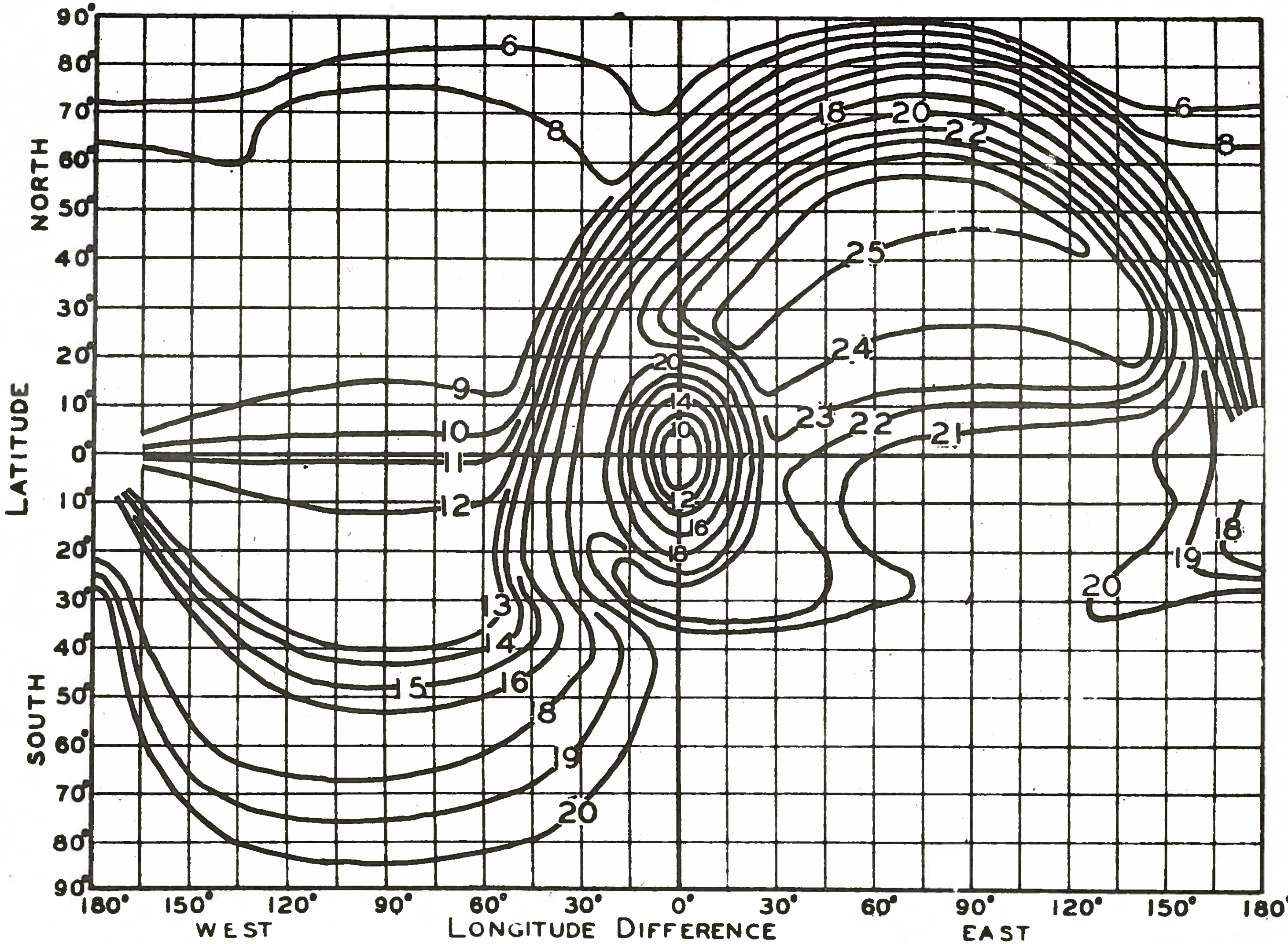

FIG. 51. MAXIMUM USABLE FREQUENCY

NOV. 1941 THROUGH FEB. 1942.

LATITUDE. 0°. 0800 LOCAL TIME.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

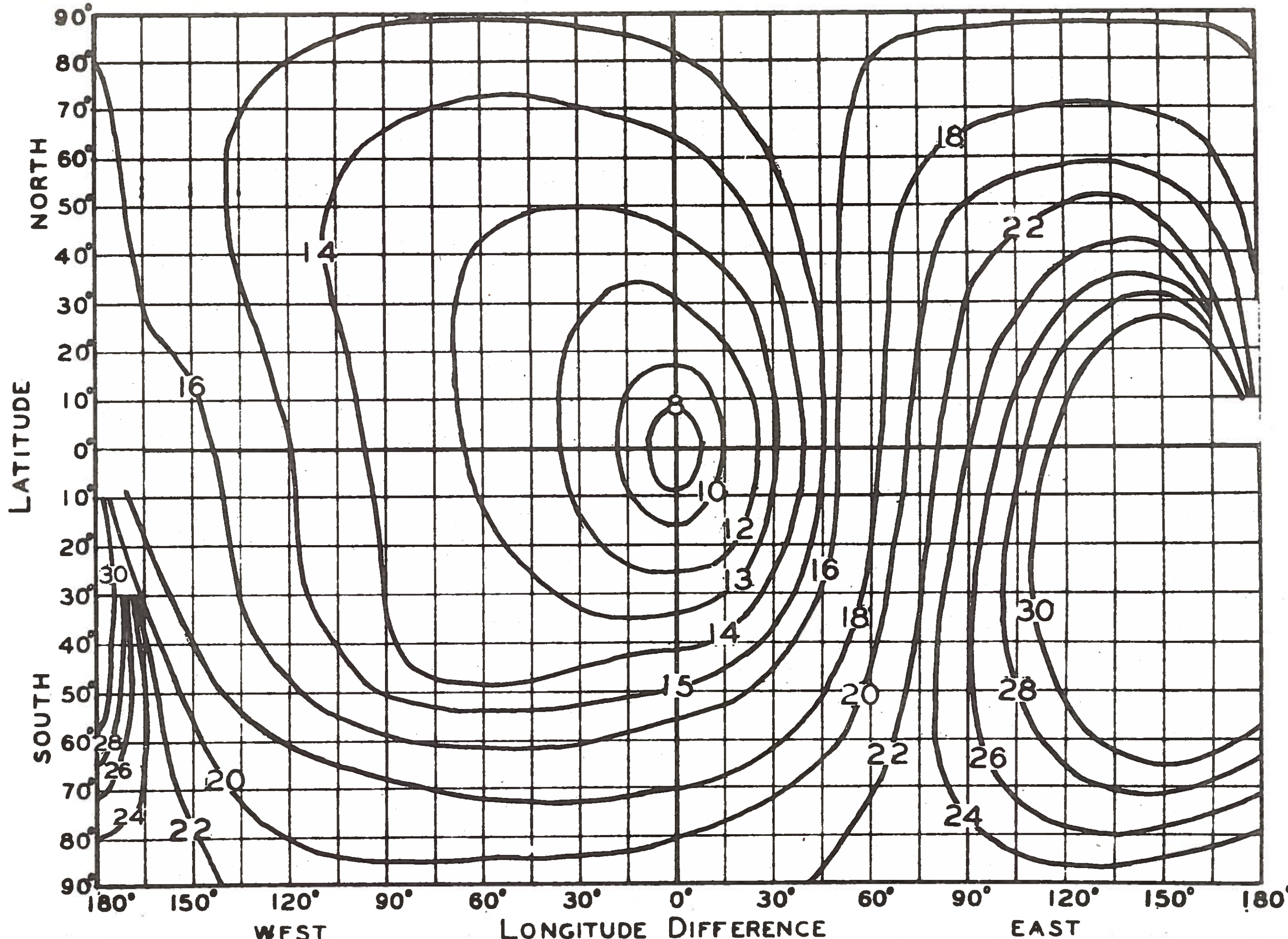

FIG. 52. LOWEST USEFUL HIGH FREQUENCY (1KW).

NOV. 1941 THROUGH FEB. 1942.

LATITUDE 0°. 0800 LOCAL TIME. OVER OR NEAR LAND

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

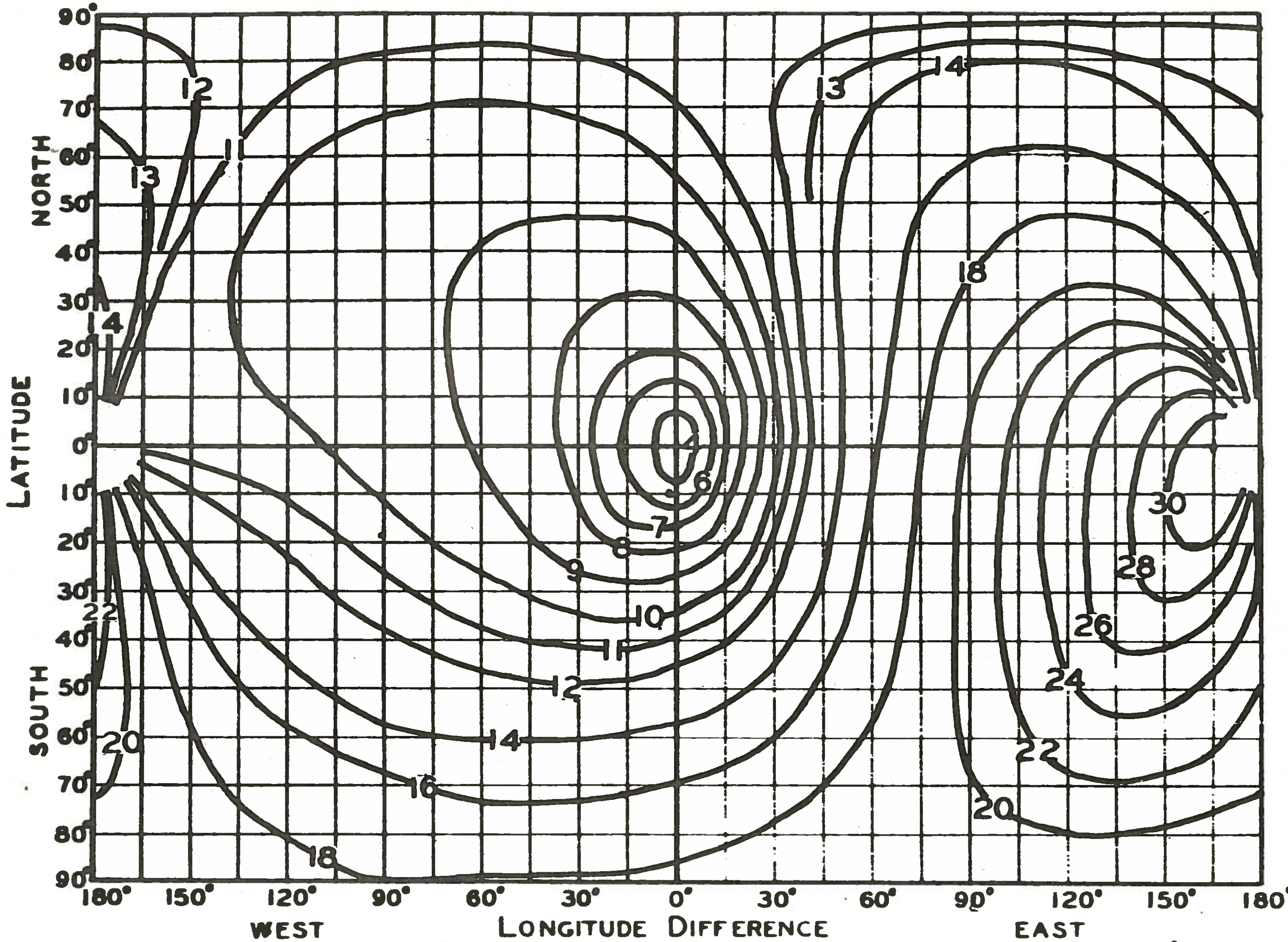

FIG. 53. LOWEST USEFUL HIGH FREQUENCY (1KW).

NOV. 1941 THROUGH FEB 1942.

LATITUDE 0°. 0800 LOCAL TIME. OVER OPEN OCEAN.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

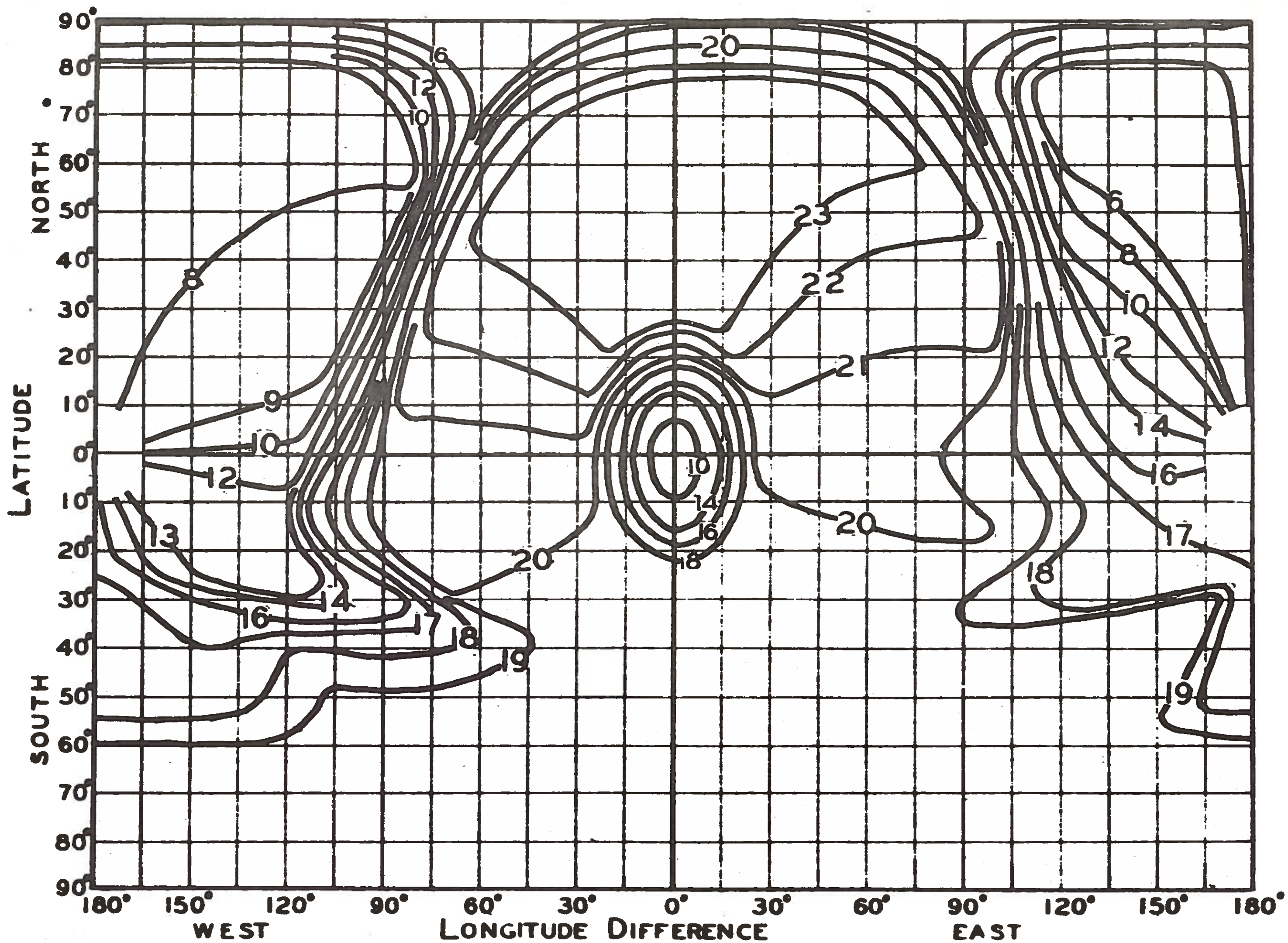

FIG. 54. MAXIMUM USABLE FREQUENCY

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 0°. 1200 LOCAL TIME.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

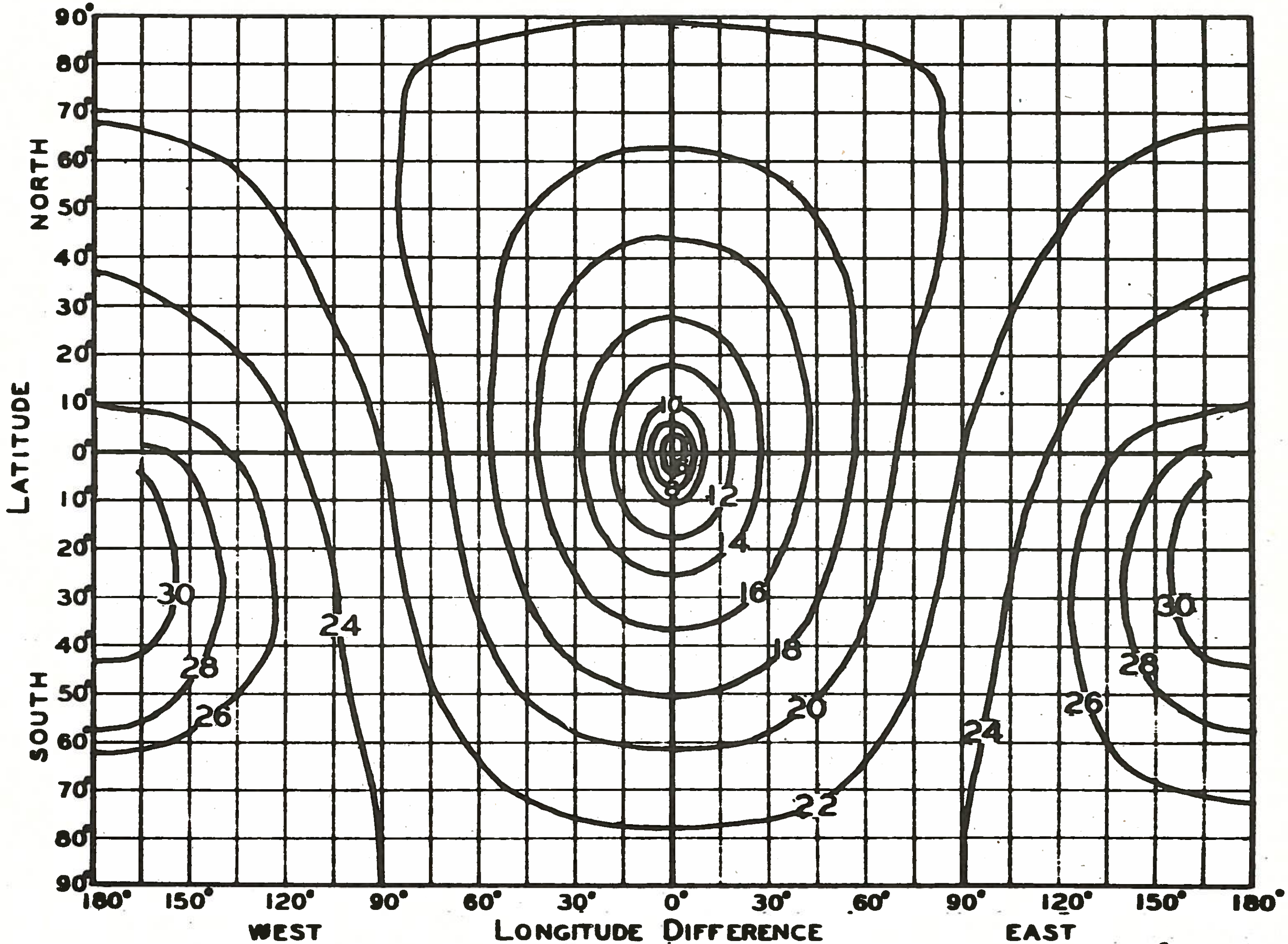

FIG. 55. LOWEST USEFUL HIGH FREQUENCY (1KW).

NOV. 1941 THROUGH FEB. 1942.

LATITUDE 0°. 1200 LOCAL TIME. OVER OR NEAR LAND

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

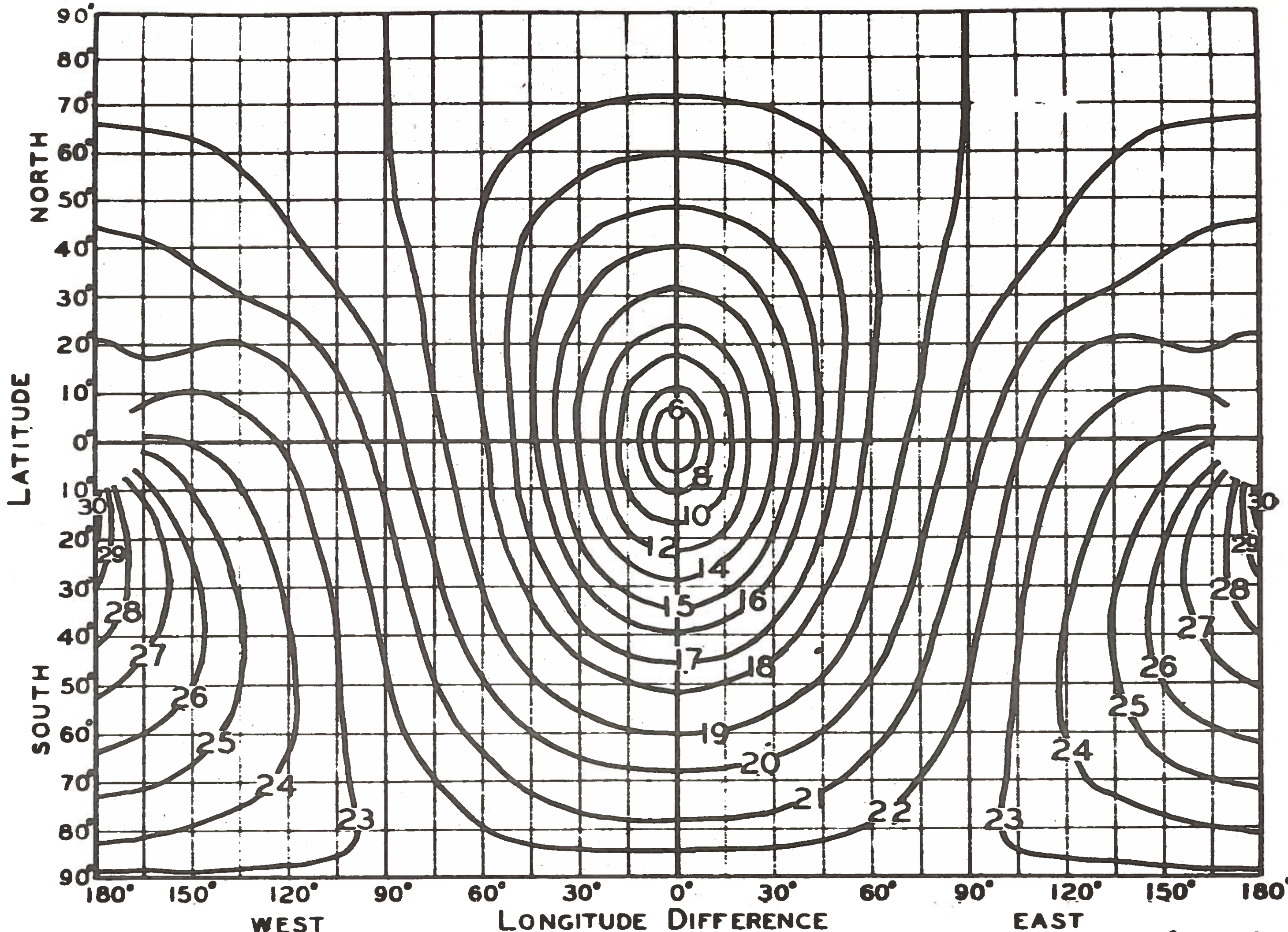

FIG. 56. LOWEST USEFUL HIGH FREQUENCY (1 KW).

NOV. 1941 THROUGH FEB. 1942.

LATITUDE 0°. 1200 LOCAL TIME. OVER OPEN OCEAN.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

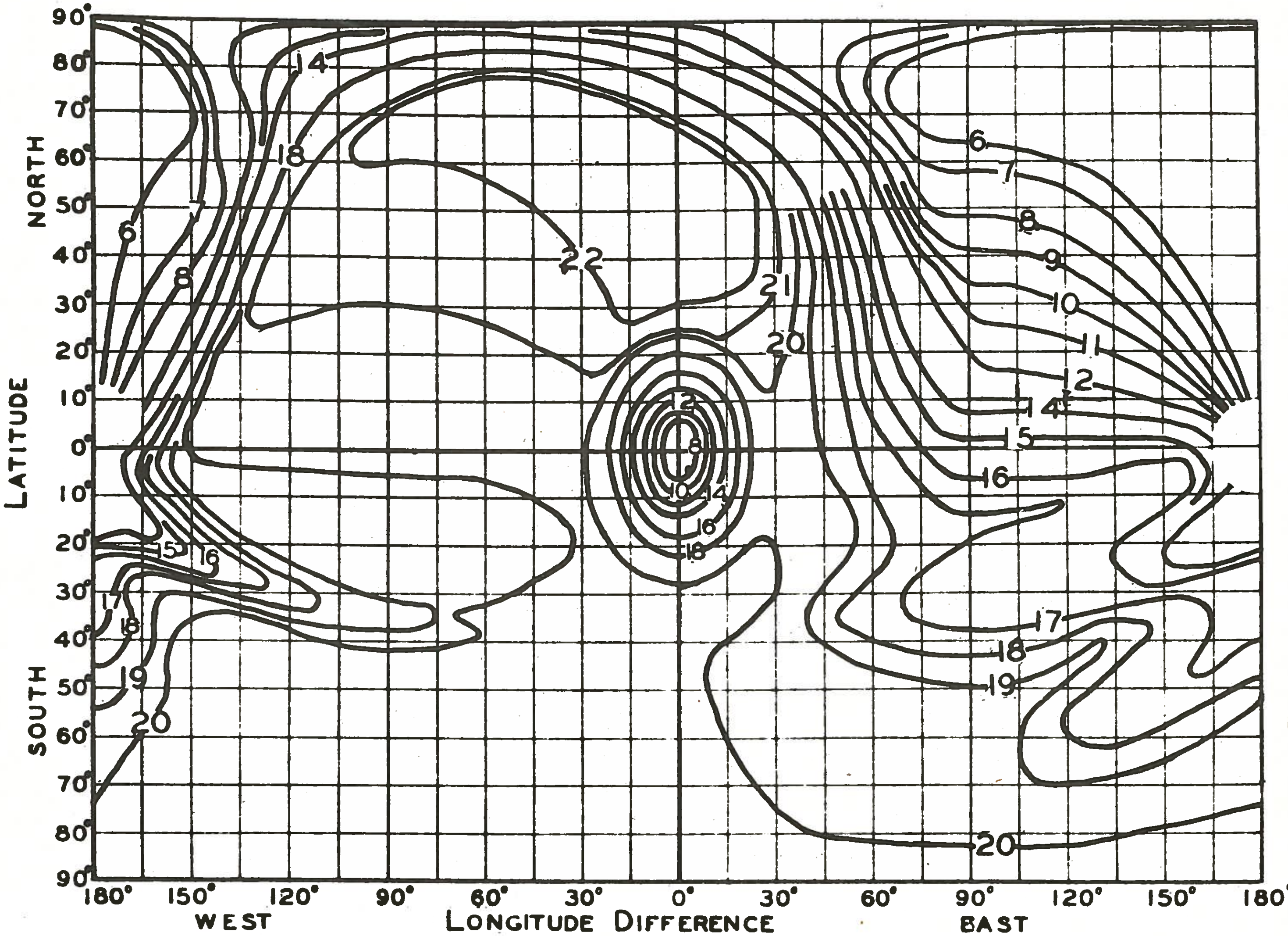

FIG. 57. MAXIMUM USABLE FREQUENCY

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 0°. 1600 LOCAL TIME.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

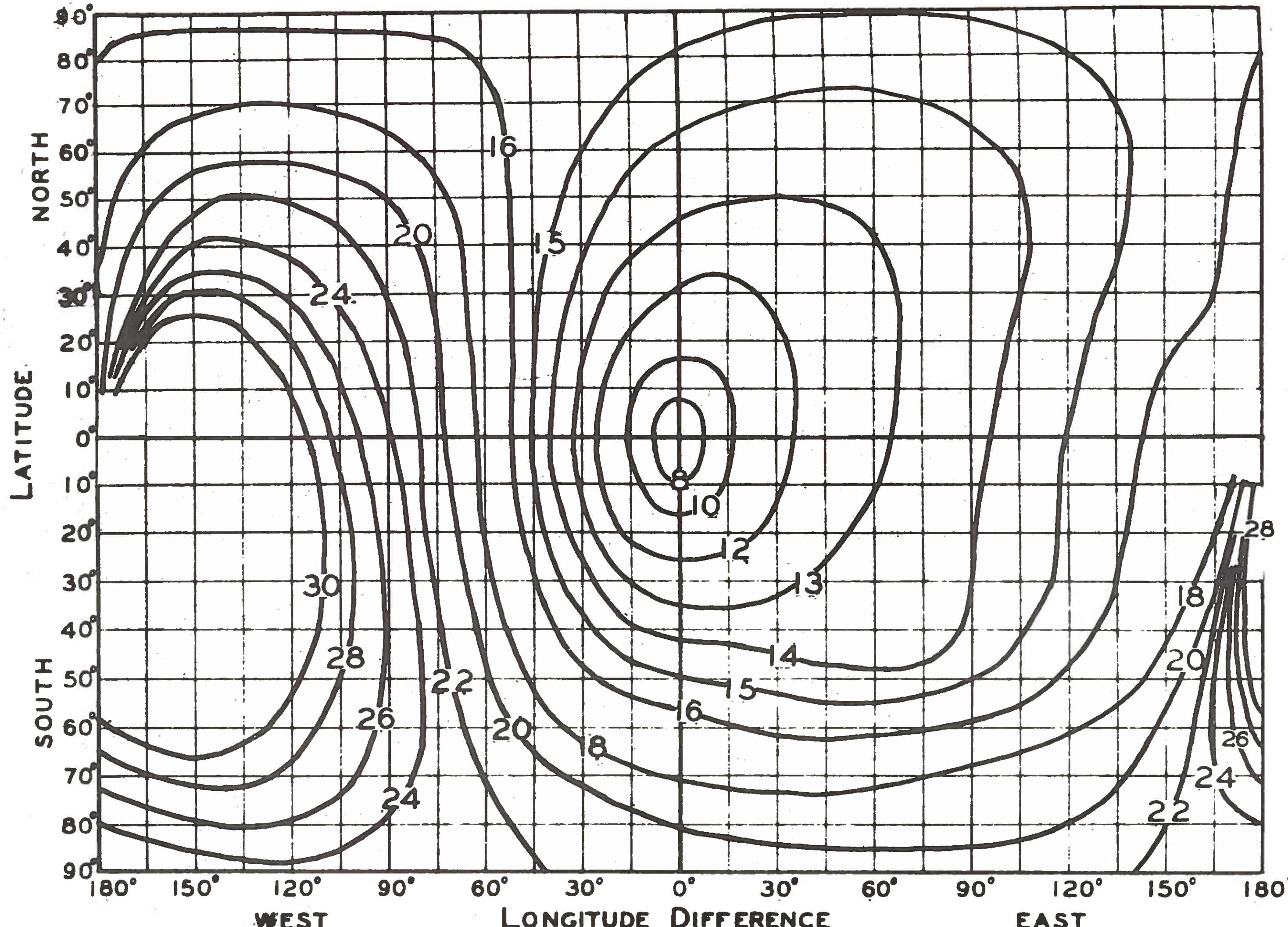

FIG. 58. LOWEST USEFUL HIGH FREQUENCY (1 KW).

NOV. 1941 THROUGH FEB. 1942.

LATITUDE 0°. 1600 LOCAL TIME. OVER OR NEAR LAND.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

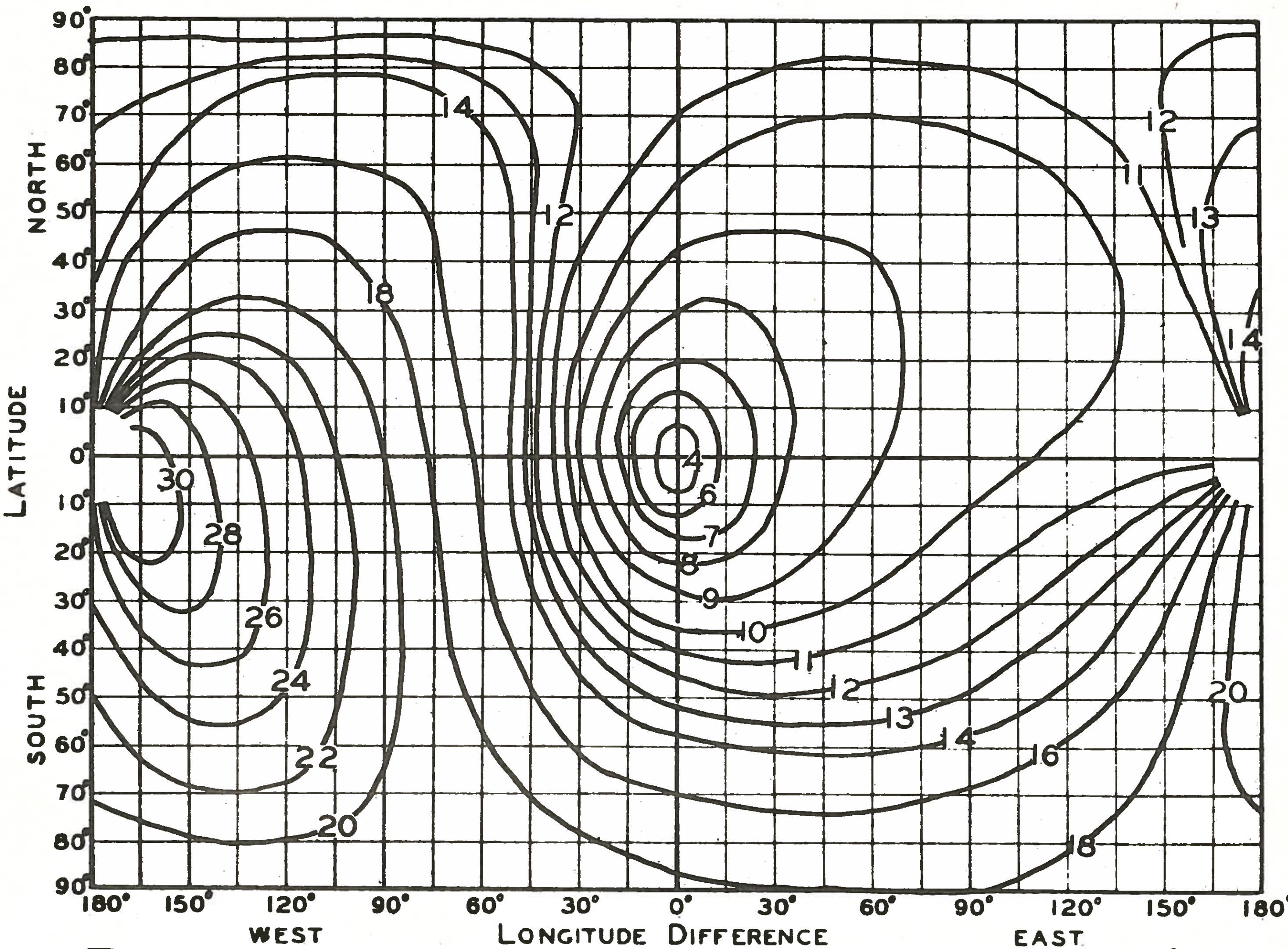

FIG. 59. LOWEST USEFUL HIGH FREQUENCY (1 KW).

NOV. 1941 THROUGH FEB. 1942.

LATITUDE 0°. 1600 LOCAL TIME. OVER OPEN OCEAN.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

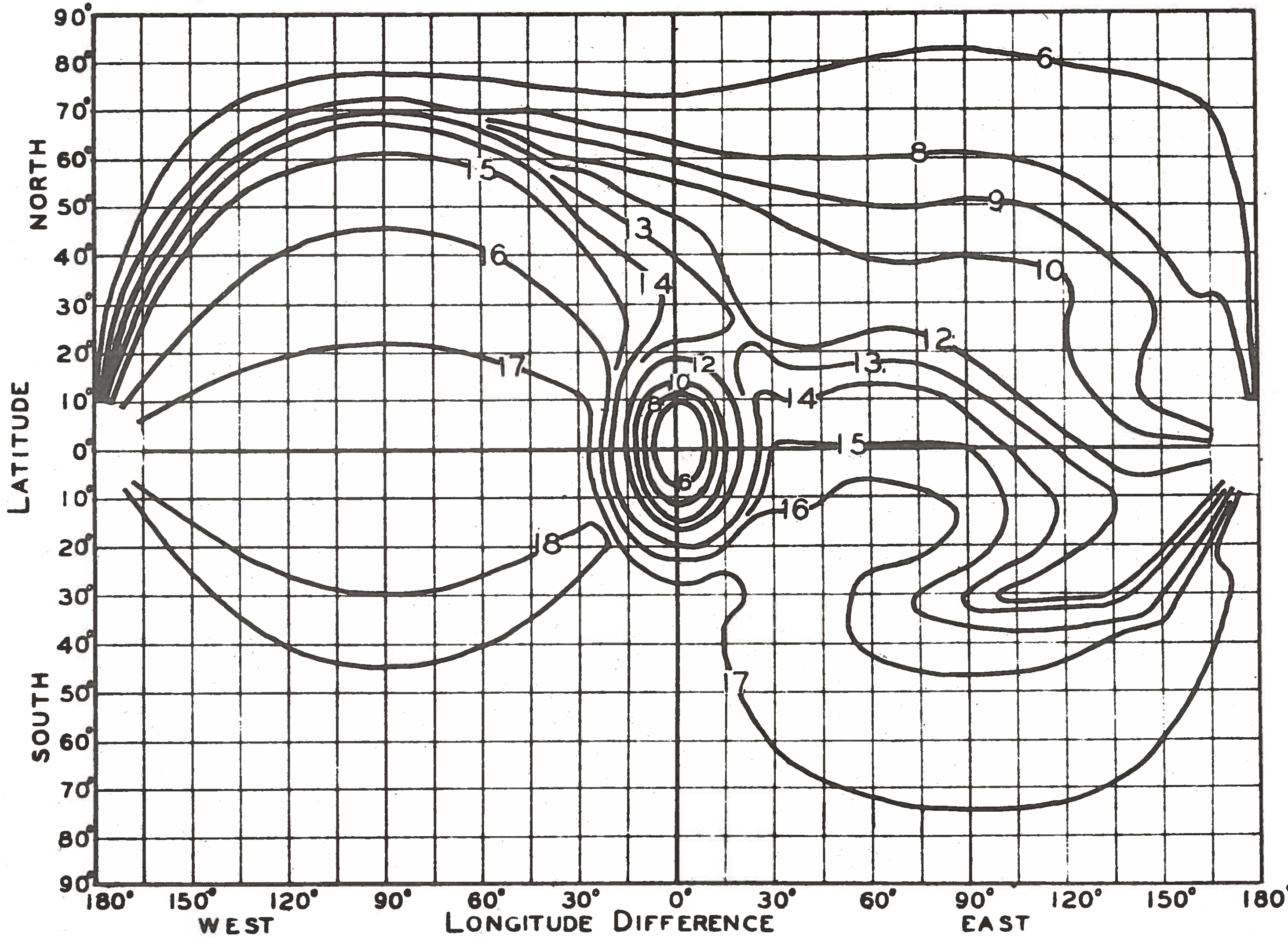

FIG. 60. MAXIMUM USABLE FREQUENCY

NOV. 1941 THROUGH FEB. 1942.

LATITUDE: 0°. 2000 LOCAL TIME.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

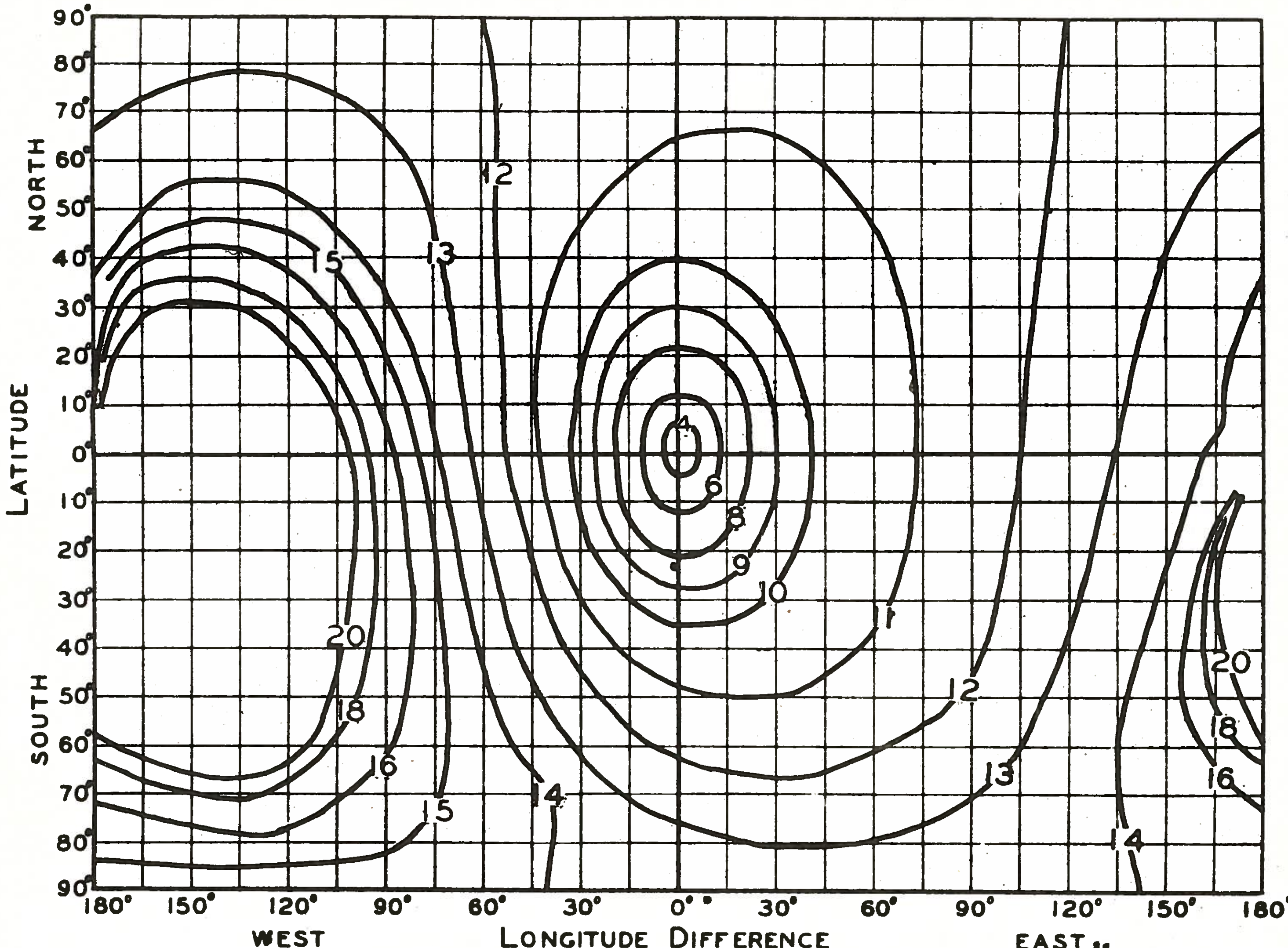

FIG. 61. LOWEST USEFUL HIGH FREQUENCY (1 KW).
NOV. 1941 THROUGH FEB. 1942.
LATITUDE 0°. 2000 LOCAL TIME. OVER OR NEAR LAND.
(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

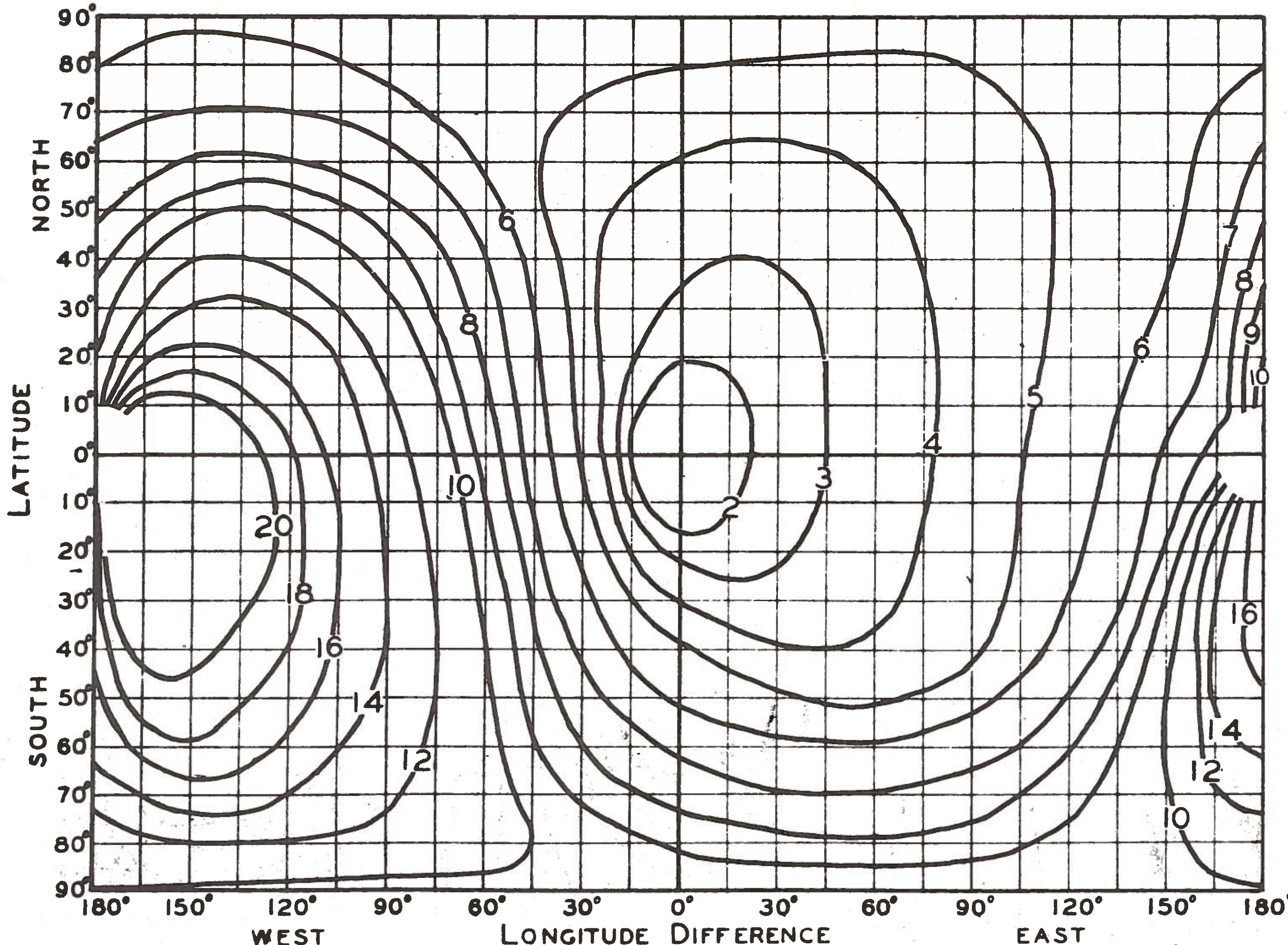

FIG. 62. LOWEST USEFUL HIGH FREQUENCY (1 KW).

NOV. 1941 THROUGH FEB 1942.

LATITUDE 0°. 2000 LOCAL TIME. OVER OPEN OCEAN.

(NUMBERS ON CURVES ARE FREQUENCIES IN MEGACYCLES).

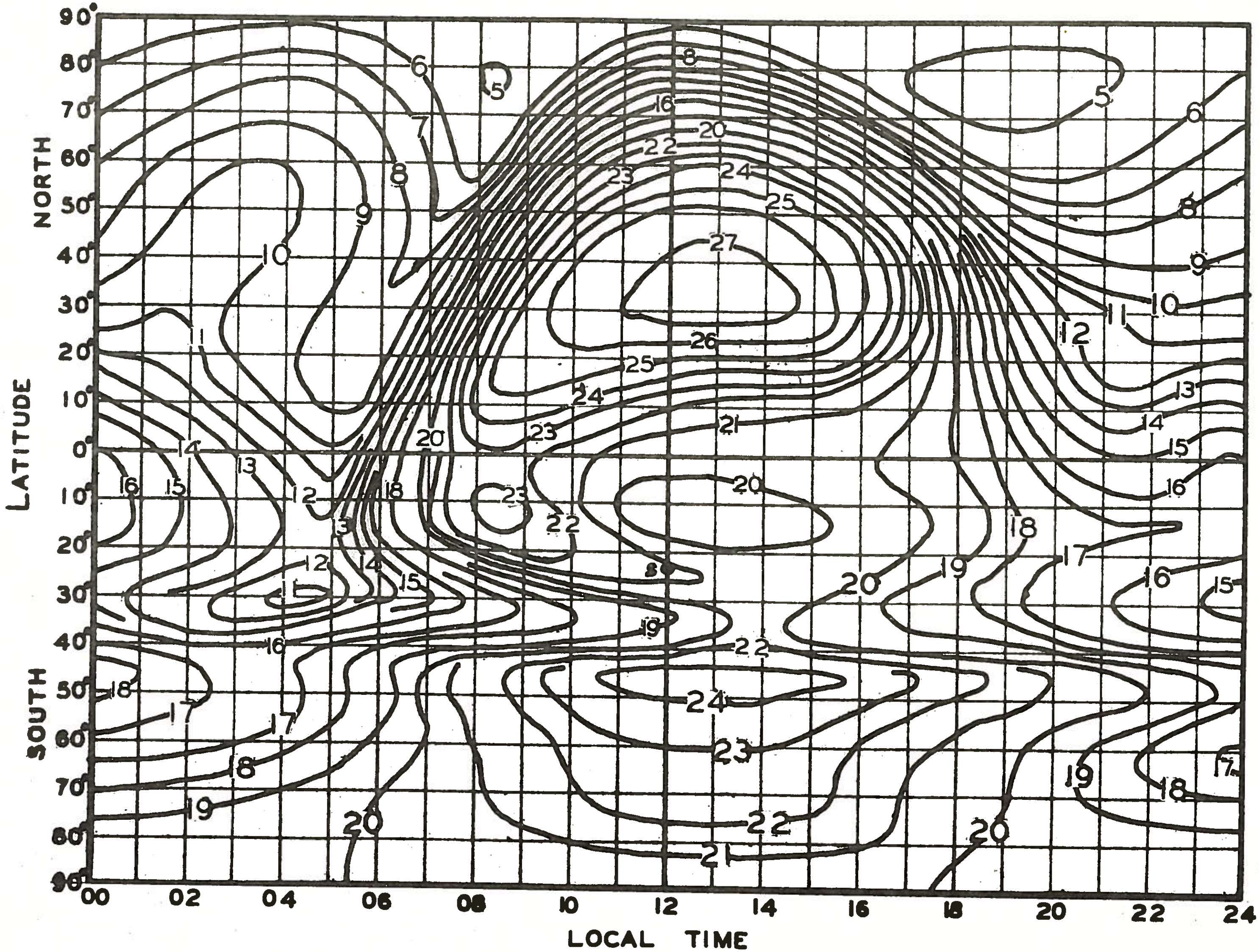

Fig. 63. Maximum-usable-frequency map of the world, November 1941 through February 1942. S is the sub-solar point. Numbers on curves are maximum usable frequencies in megacycles, for waves traversing 3500-kilometer hops.

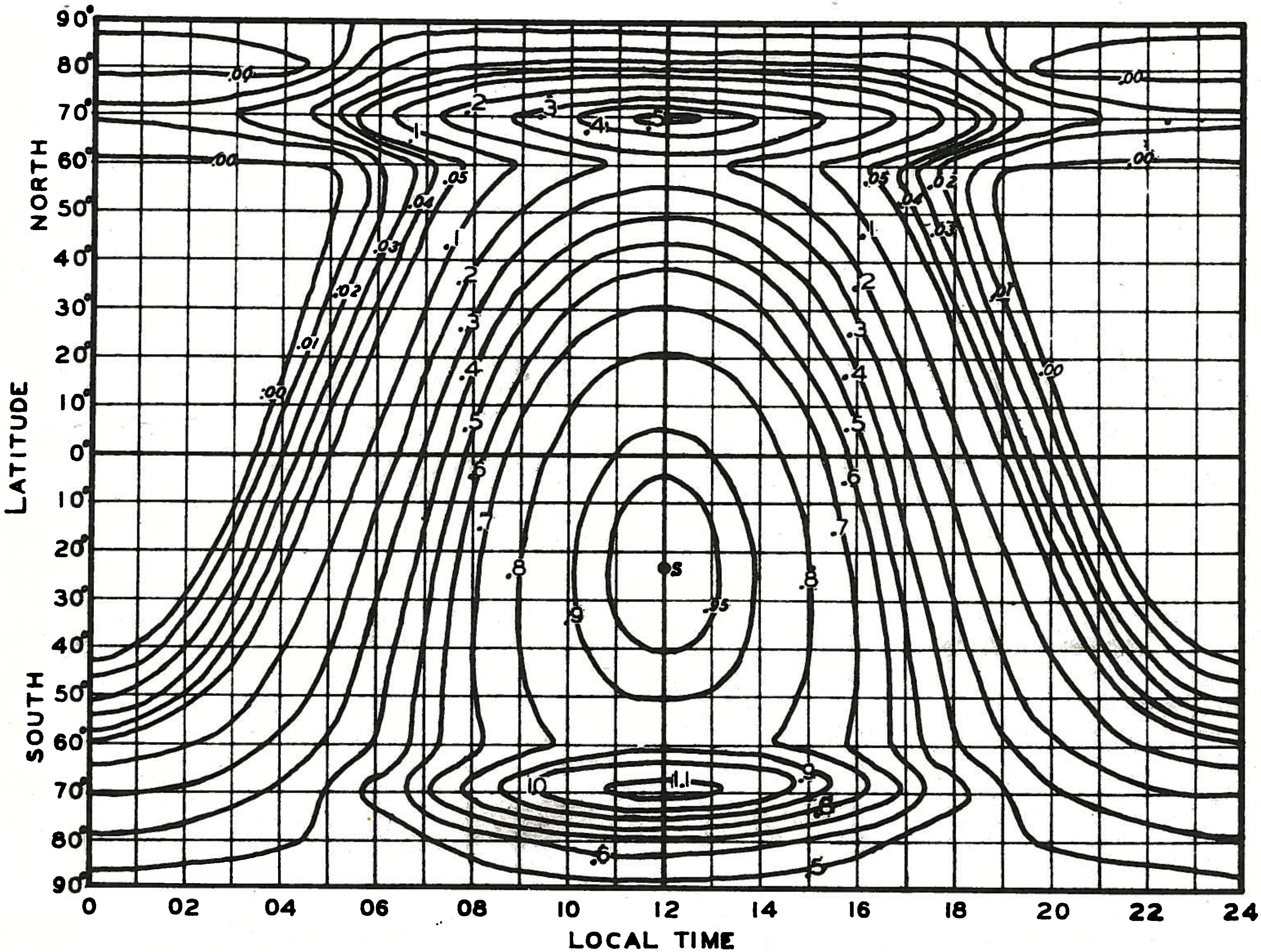

Fig. 64. Absorption map of the world, November through February. S is the sub-solar point. Numbers on curves are values of absorption index, K (ratio of actual absorption to absorption at sub-solar point, for a given frequency and length of path).

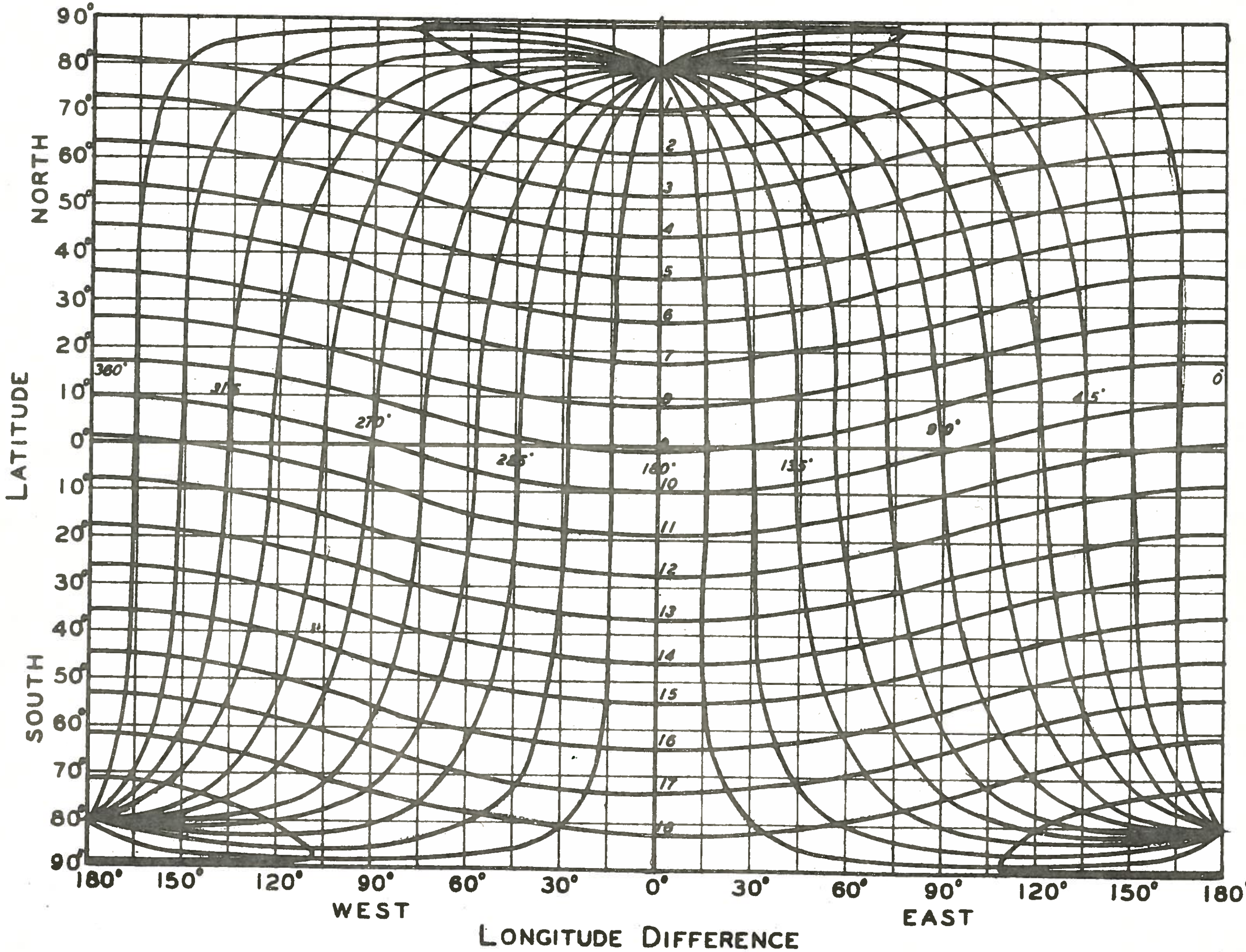

Fig. 65. Great-circle map of the world, based on reception at 80° north latitude. Numbers on great-circle curves are azimuths in degrees measured clockwise from north. Numbers on other curves are great-circle distances in thousands of kilometers.

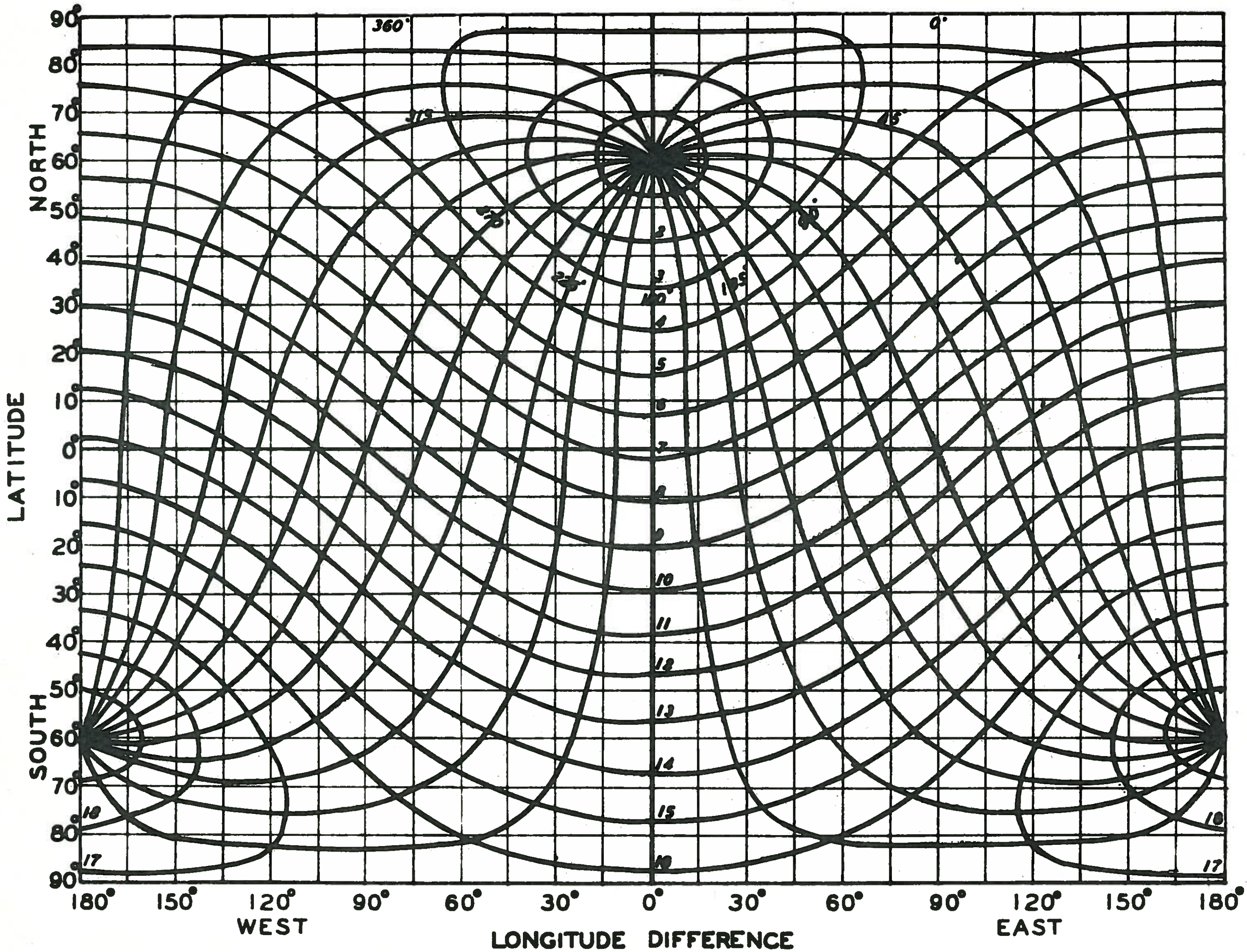

Fig. 66. Great-circle map of the world, based on reception at 60° north latitude. Numbers on great-circle curves are azimuths in degrees measured clockwise from north. Numbers on other curves are great-circle distances in thousands of kilometers.

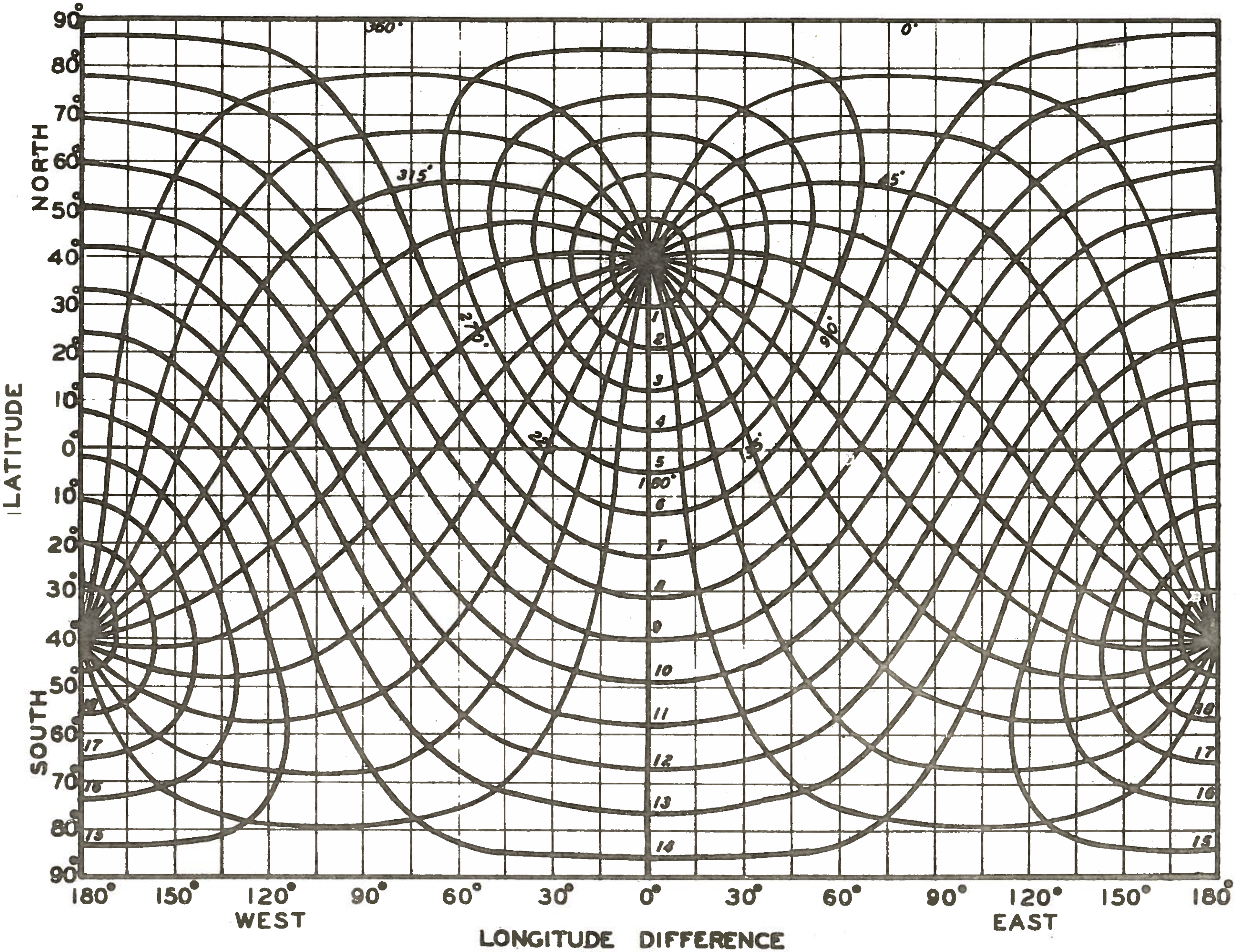

Fig. 67. Great-circle map of the world, based on reception at 40° north latitude.
Numbers on great-circle curves are azimuths in degrees measured clockwise from north.
Numbers on other curves are great-circle distances in thousands of kilometers.

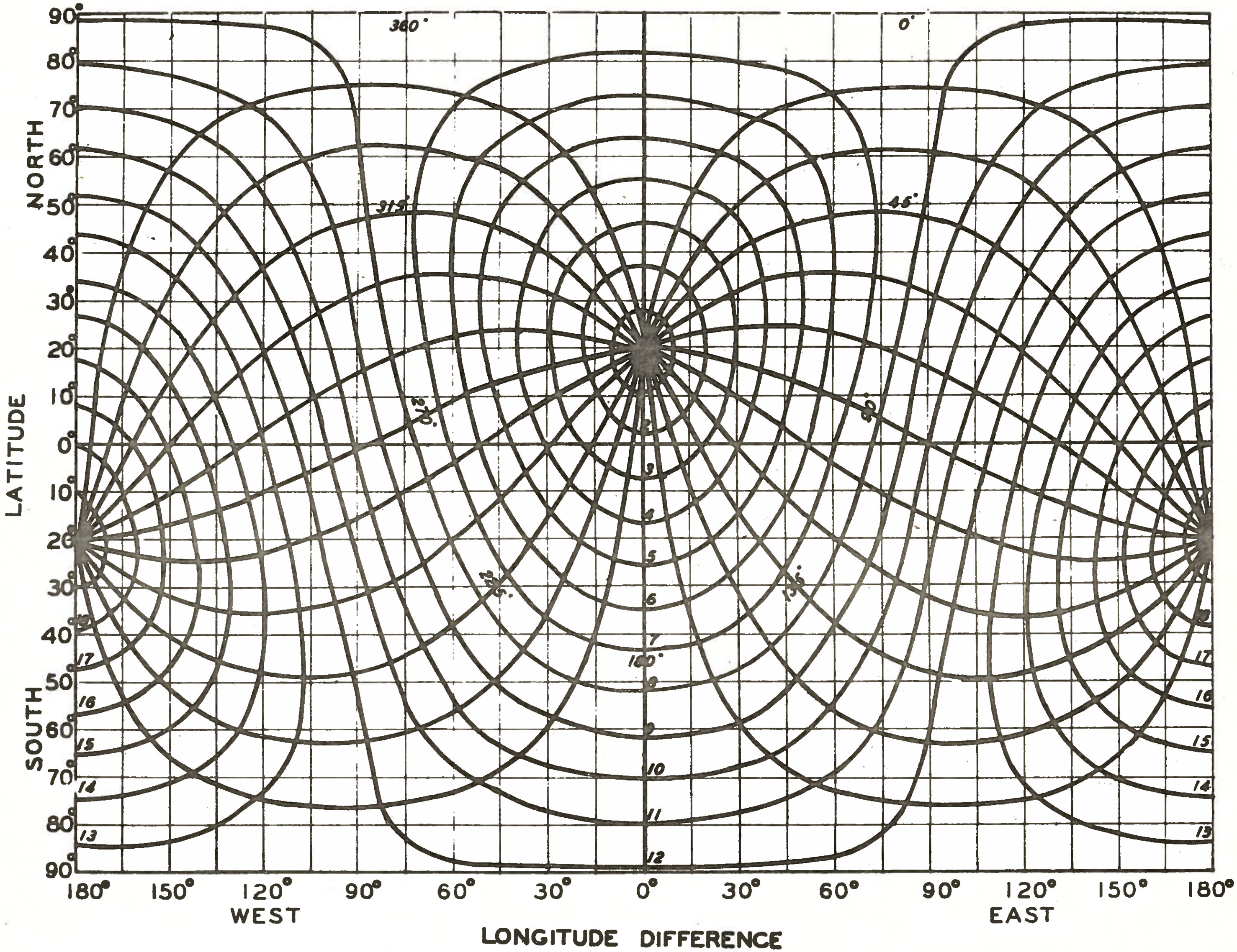

Fig. 68. Great-circle map of the world, based on reception at 20° north latitude.

Numbers on great-circle curves are azimuths in degrees measured clockwise from north.

Numbers on other curves are great-circle distances in thousands of kilometers.

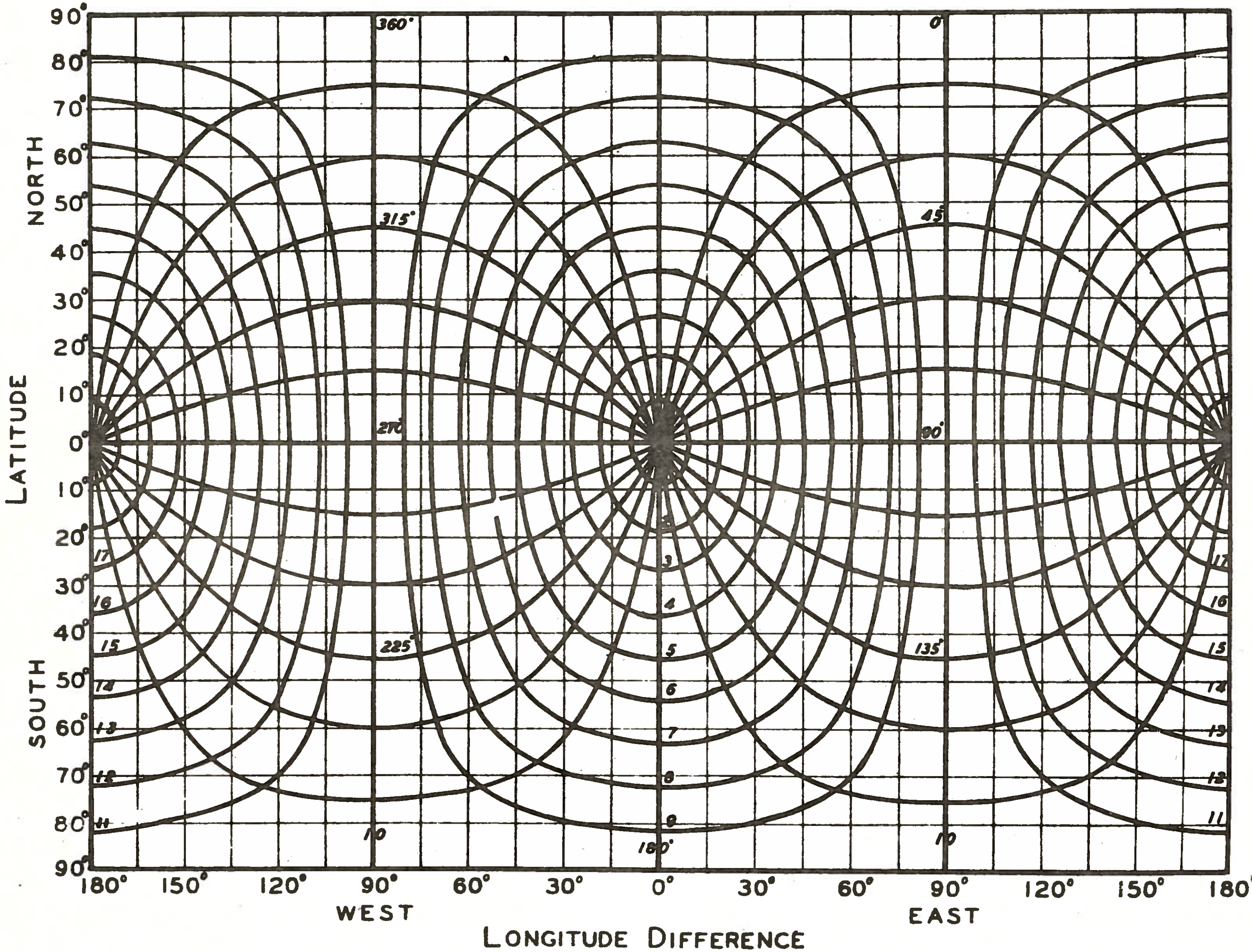

Fig. 69. Great-circle map of the world, based on reception at equator. Numbers on great-circle curves are azimuths in degrees measured clockwise from north. Numbers on other curves are great-circle distances in thousands of kilometers.

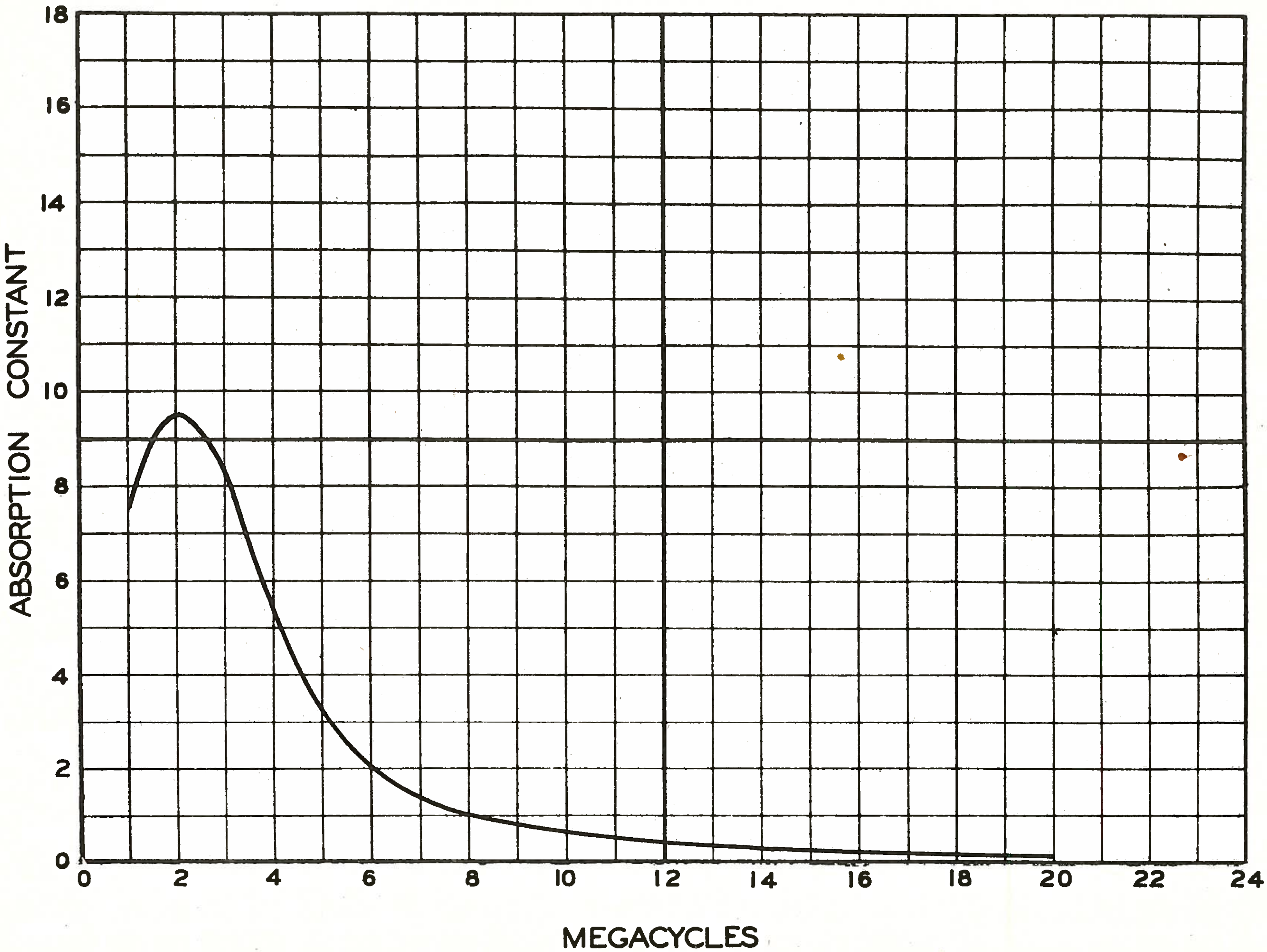

Fig. 70. Absorption constant (S_0) as a function of frequency.

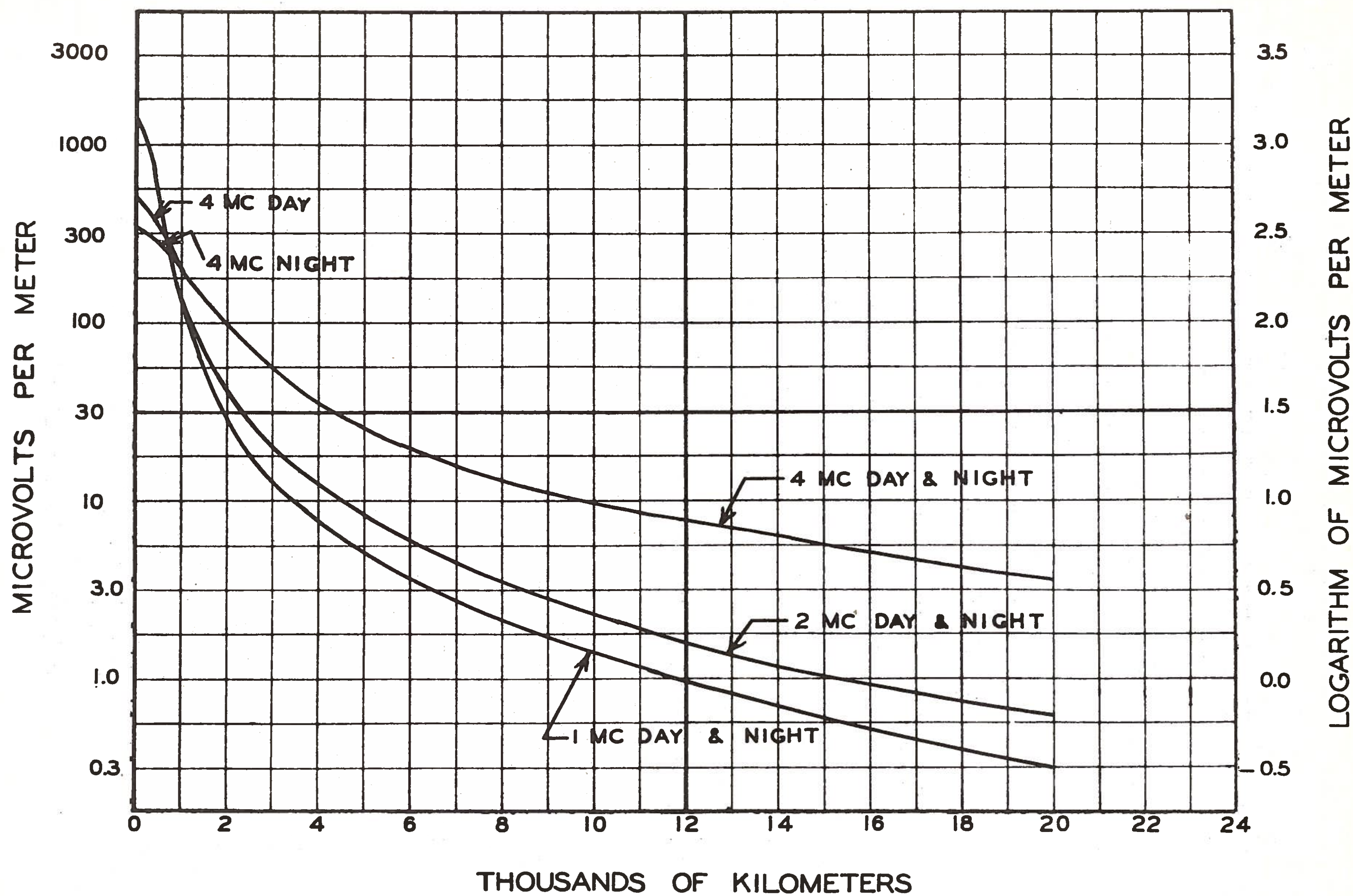

Fig. 71. Logarithm of unabsorbed field intensity (F_o), for 1 kilowatt radiated power, as a function of distance.

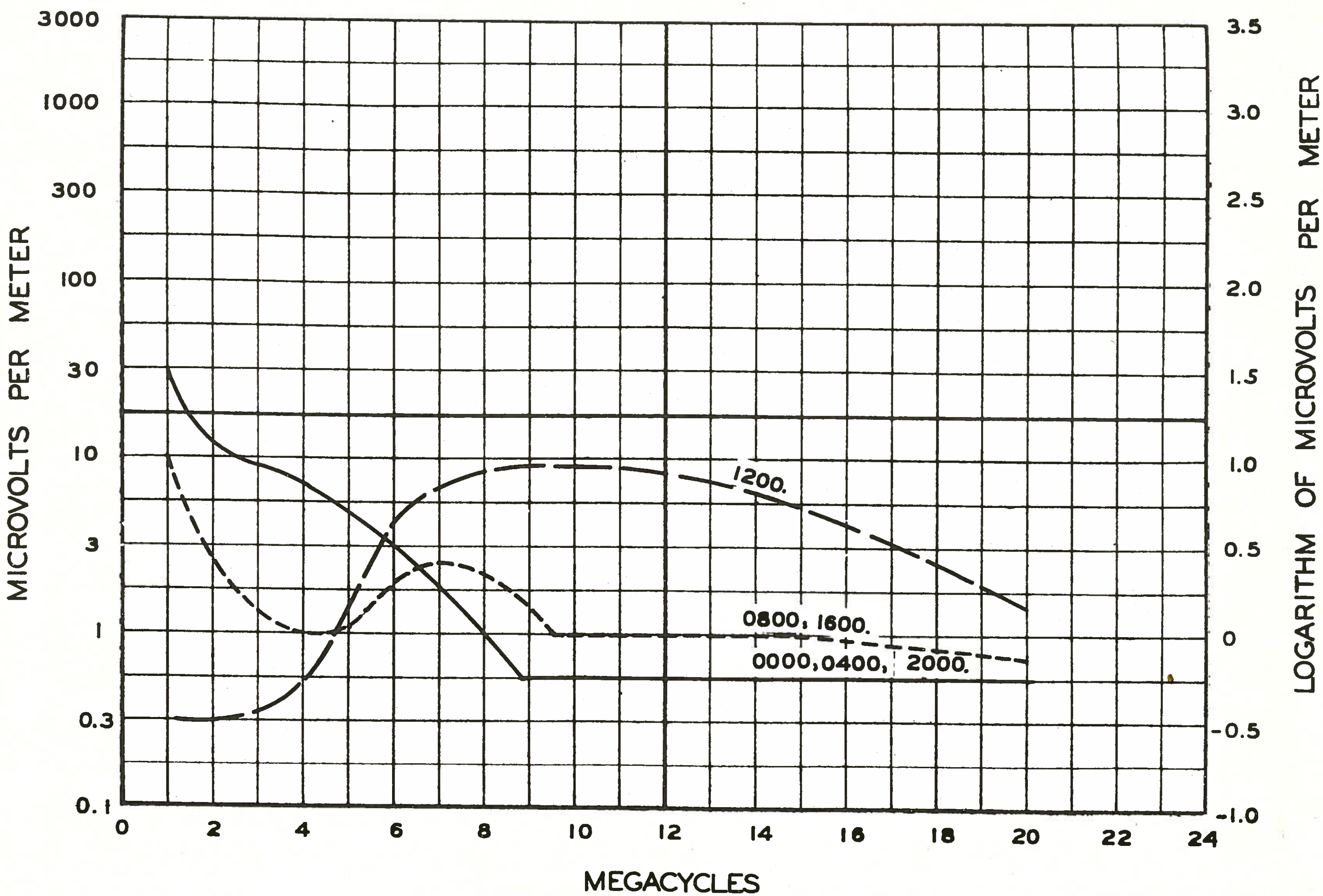

Fig. 72. Logarithms of required field intensities for radio-telephone reception, November through February. Latitude of receiver 40°N. For radio-telegraph reception field intensities required are 0.1 as great (decrease logarithm by 1). Numbers on curves are local times at receiving point.

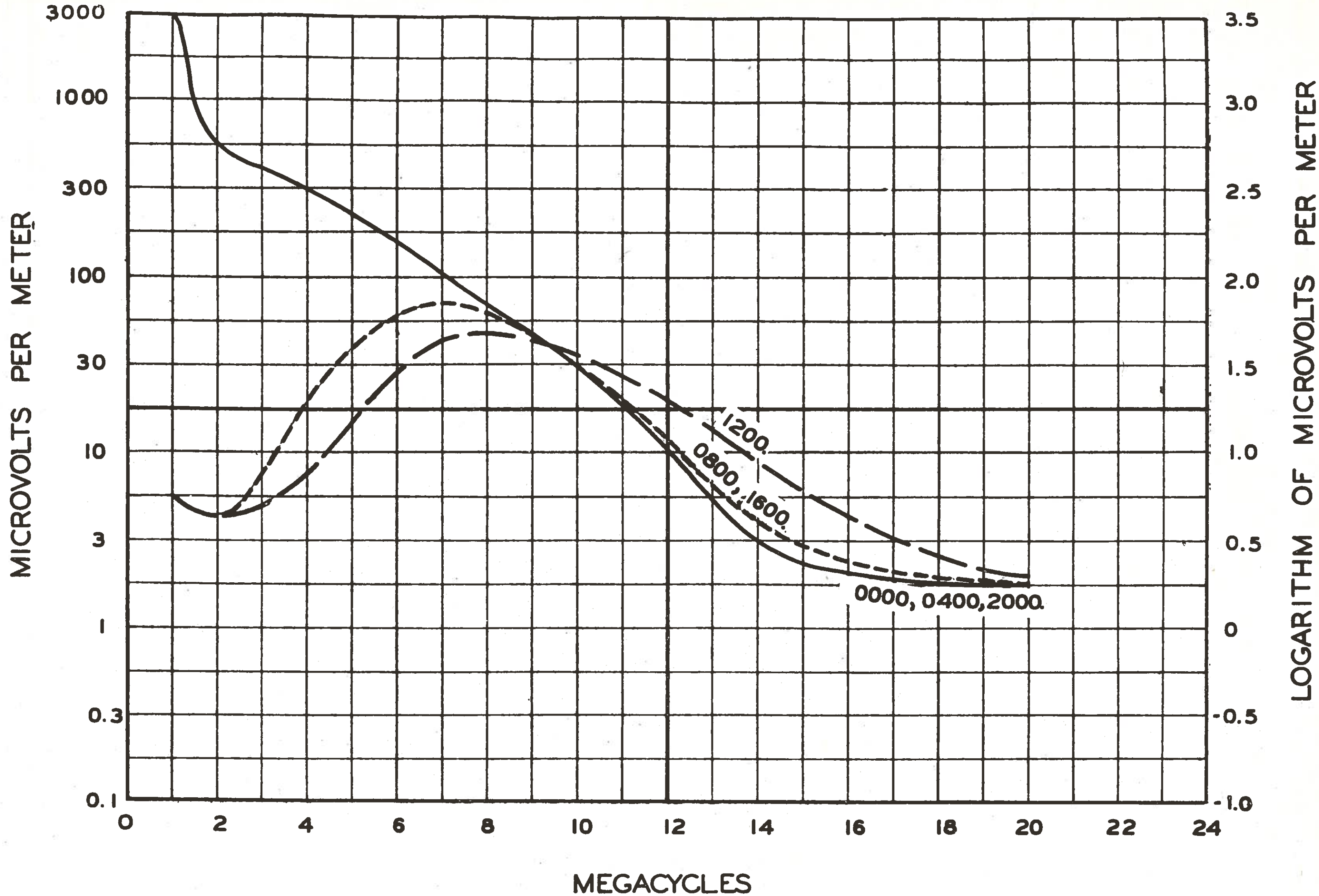

Fig. 73. Logarithms of required field intensities for radio-telephone reception, November through February. Latitude of receiver 0°. For radio-telegraph reception field intensities required are 0.1 as great (decrease logarithm by 1). Numbers on curves are local times at receiving point.

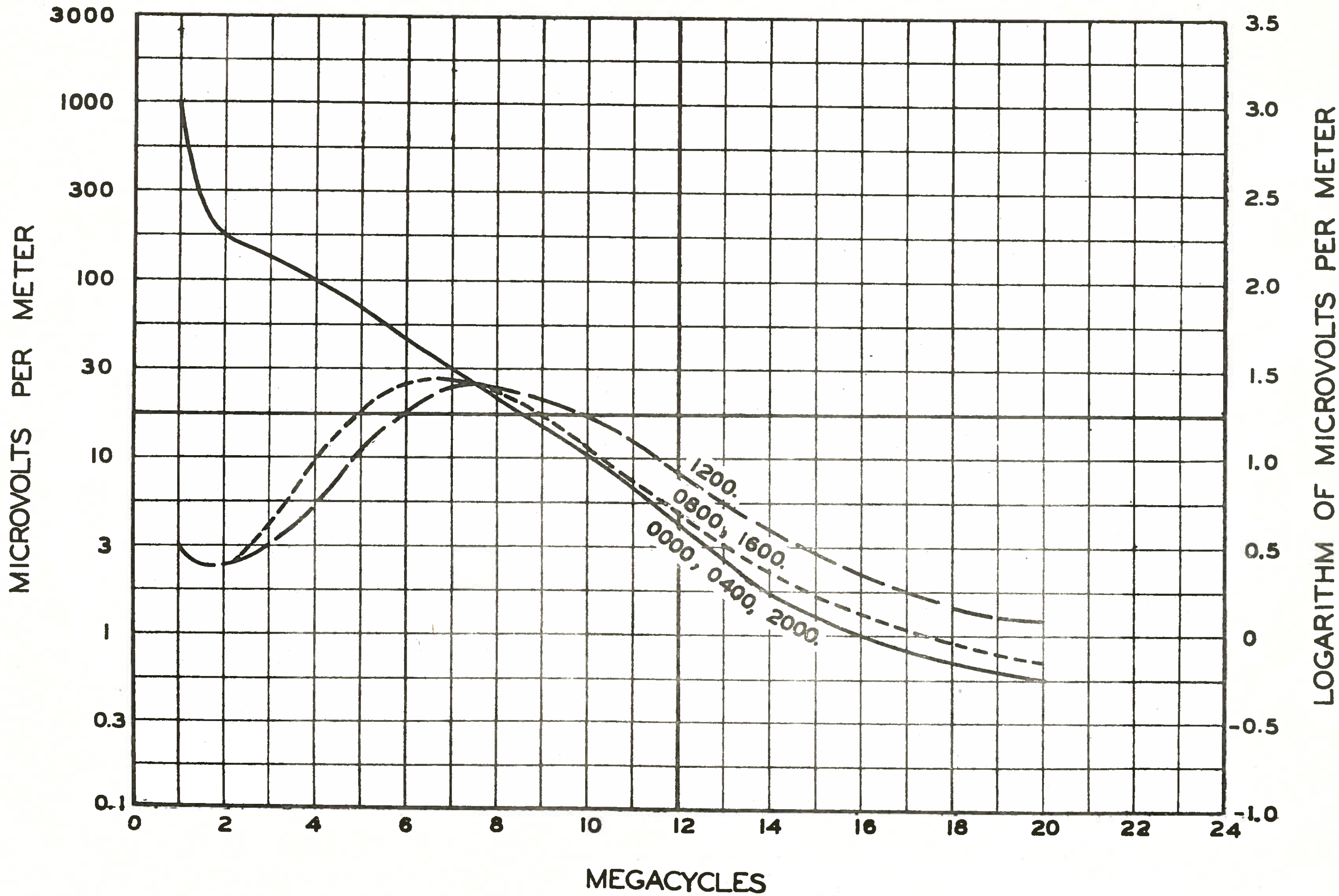

Fig. 74. Logarithms of required field intensities for radio-telephone reception, November through February. Latitude of receiver 40°3. For radio-telegraph reception field intensities required are 0.1 as great (decrease logarithm by 1). Numbers on curves are local times at receiving point.

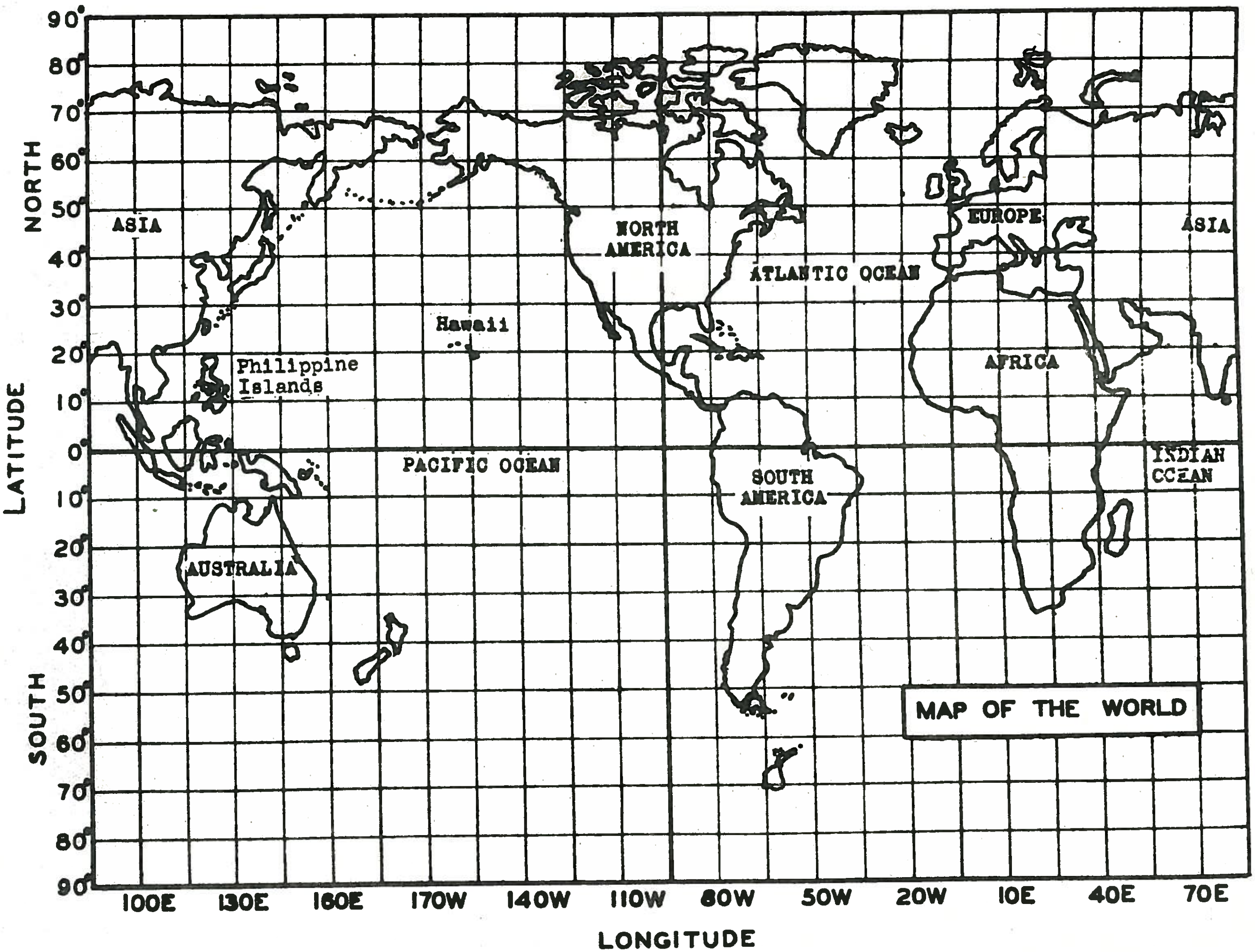

Fig. 75. Actual map of the world on rectangular projection.

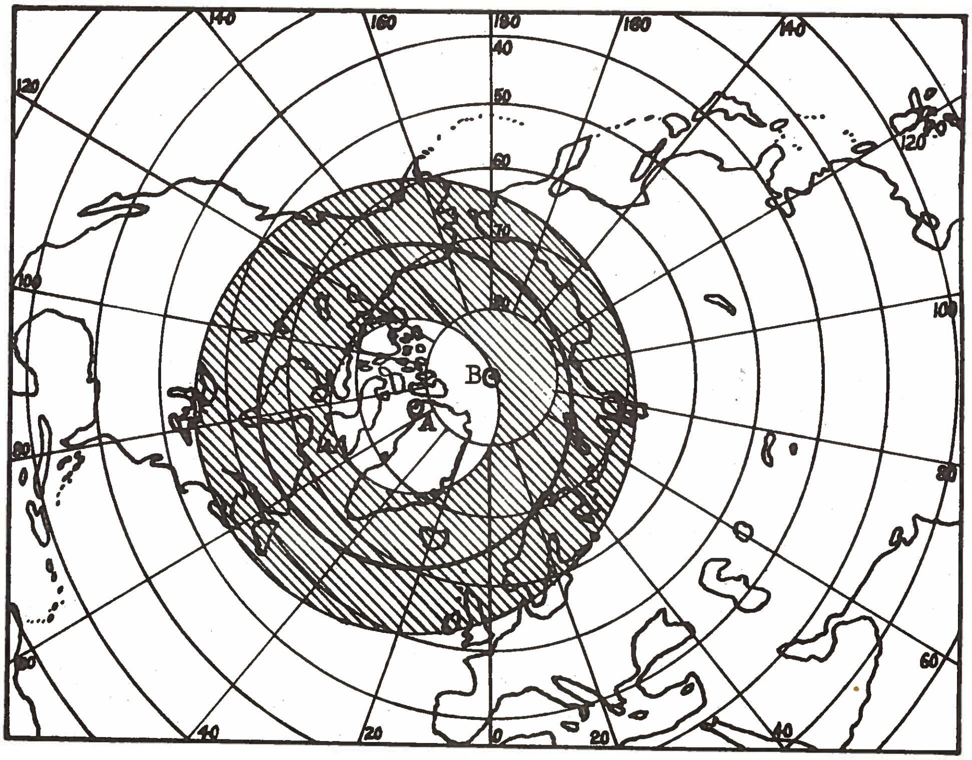

Fig. 76. Northern auroral zone. A is the north magnetic axis pole; B is the north geographic pole.

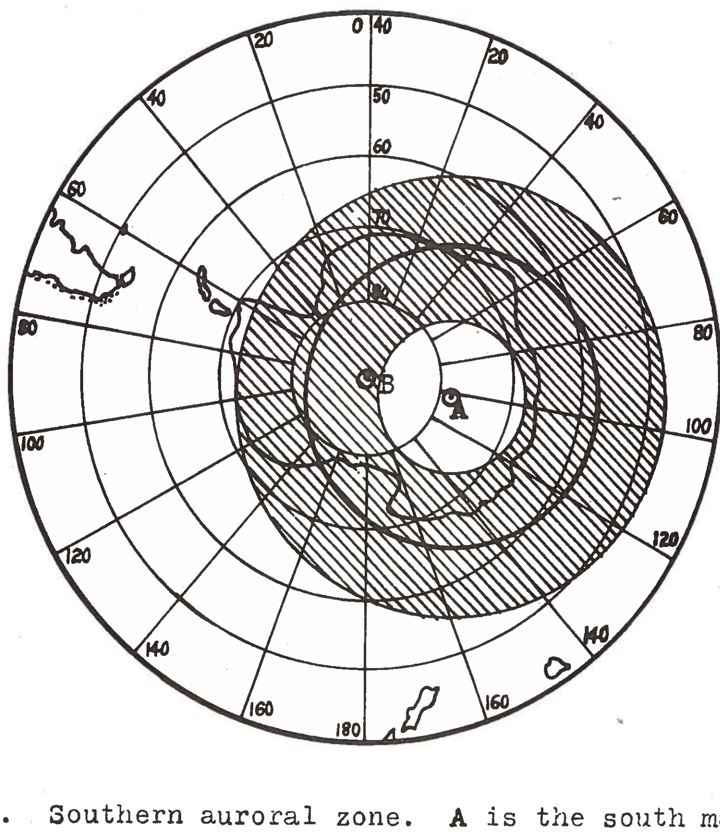

Fig. 77. Southern auroral zone. A is the south magnetic axis pole; B is the south geographic pole.

MAPS FOR USE IN CALCULATING DISTANCE RANGES IN ACCORDANCE WITH PROCEDURES IN APPENDIX.

Fig. 63. Maximum-usable-frequency map.

Fig. 64. Absorption-index map.

Fig. 65. Great-circle map for 80°N.

Fig. 66, Great-circle map for 60°N.

Fig. 67. Great-circle map for 40°N.

Fig. 68. Great-circle map for 20°N.

Fig. 69. Great-circle map for equator.

Fig. 75. Actual map of the world on rectangular projection.

These maps are printed on semi-transparent paper so that they can be seen through when placed over each other. See instructions in Appendix.