U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

WASHINGTON

JHD:ANK
I-6

Letter
Circular
LC615
(Supersedes
LC317)

DISTANCE RANGES OF RADIO WAVES

October 25, 1940.

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The distances over which practical radio transmission is possible are very different at different times of day, seasons, etc., and for different frequencies of the radio waves. This Letter Circular presents the results of experience in radio communication, by means of the four graph sheets attached.

Radio wave transmission takes place principally by the propagation of a "ground wave" along the ground and a "sky wave" reflected from the ionosphere. The ionosphere is the electrically conducting (ionized) region in the upper atmosphere, more than 30 miles above the earth's surface. As the radio waves travel out along the ground or in the atmosphere, their energy is reduced below what it would be if no causes of energy absorption existed. The absorption is due to the electrical resistance of materials in the earth and to ionized particles in the atmosphere. The amount of the absorption determines the maximum distances at which waves of various frequencies can be received, for given reception conditions at the receiver.

The distance range of the ground wave is in general great at low frequencies (below about 500 kilocycles per second), and decreases as the frequency is increased, because the ground-wave absorption increases with frequency. The distance range of the ground wave is different for earth of different conductivities and dielectric constants, but is fairly constant with time over a given transmission path at a given frequency.

The distance range of the sky wave is not constant with time, frequency, or path. As the graphs show, it is a minimum in approximately the broadcast band of frequencies (550 to 1600 kc), increasing with change of frequency in either direction. In the daytime the absorption of the sky wave is so great that there is almost no sky wave at frequencies from somewhat below to somewhat above the broadcast frequency band, particularly in the summer. Hence sky-wave propagation in the daytime (particularly in the summer), is only appreciable in the lower and higher frequency ranges. During the night, however, sky-wave propagation takes place throughout the entire range of frequencies.

(over)

The large variations of sky-wave propagation result from conditions and changes in the ionization of the ionosphere. Besides daily variation of daylight and darkness, factors such as latitude, season, magnetic storms, and solar disturbances, have been found to have effects upon this ionization. These changes in ionization result in variations in the distance range of radio waves from hour to hour, day to day, season to season, and year to year.

While the distance ranges of ground waves are calculable, there are no generally applicable formulas for sky waves. Thus we can not determine sky-wave distance ranges by any process of calculation but must use the accumulated results of experience. The attached graphs summarize experience and give average distance ranges as determined by numerous experimenters. There are considerable variations from the average for particular paths and times; the widths of the shaded boundaries on the graphs indicate roughly the variations found in common practice.

Detailed information about sky waves and the ionosphere is given in another Letter Circular of the Bureau, "Radio transmission and the ionosphere."

Above a certain frequency (which this year is about 4000 kc/s at night and higher in the daytime; see attached graphs), there is for each frequency a distance within which none of the regular sky wave is reflected back to the earth by the ionosphere. There is a zone, with an inner and outer boundary, in which there is no regular radio reception. This is called the skip zone and its outer boundary is called the skip distance.

Thus, in the right-hand portion of each of the attached graphs, for a specified frequency (e.g., 20 Mc/s, Fig. 3) the waves are receivable at distances from 0 up to the ground-wave range (different for land and ocean), are not receivable from there up to the distance given by the line marked "skip distance", and are receivable from there up to the "distance range" line.

In Figs. 1 and 2, part of the right-hand portion is cross-hatched and marked "Irregular Sporadic". This means that at the distances and frequencies indicated there is sporadic radio transmission at irregular times, even though in the skip zone. The times at which such transmission occurs are not predictable; it is most prevalent May to August, and occurs particularly in the late afternoon, the evening, and the forenoon, but may occur at any time of day or night. It is due to reflection from peculiarly ionized patches in the E layer of the ionosphere, and not the regular reflection (from the extended layers of the ionosphere) which accounts for the regular transmission. Scattered reflections from the ionosphere, which are fluttering and blurred and usually weak, are frequently receivable in the skip zone.

The scales of abscissas and ordinates on the attached 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 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.

The attached graphs show the limits of distance over which practical radio-telegraph communication is possible. They are based on the lowest field intensity which permits practical reception in the presence of average background interference or noise. For the broadcast frequencies this does not mean satisfactory program reception. The limiting field intensity is different at different frequencies and times. The following table gives limiting field intensity values typical of those used in determining the distance ranges, based on data in a number of papers listed in References at end hereof. This assumes the use of a good receiving set.

	0.1 Mc	1.0 Mc	5.0 Mc	10.0 Mc
Summer day	60 µv/m	10 µv/m	10 µv/m	3 µv/m
Summer night	100	50	15	1
Winter day	25	1	2	1
Winter night	35	5	1	1

When atmospherics ("static") or other sources of interference are great, e.g., in the tropics, larger received field intensities are required and the distance ranges are less. The graphs assume the use of one kilowatt radiated power, and non-directional antennas. For greater power the distance ranges will be somewhat greater. For transmission over a given path, received intensity is proportional to the square root of radiated power, but there is no simple relation between distance range and either radiated power or received field intensity.

The day graphs are based on noon conditions and the night graphs are based on midnight conditions. In a general way, there is progressive change from one to the other, but with some tendency for day conditions to persist through dusk, and night conditions to persist through dawn. The conditions of spring and autumn are intermediate between those of summer and winter, autumn resembling winter somewhat more than summer. Information is given for each month and for all times of day in the summaries regularly published by the Bureau in the Proceedings of the Institute of Radio Engineers and QST.

The attached graphs are based principally upon data for the latitude of Washington, but serve as a guide for transmission anywhere in the temperate zones. They are not as accurate for polar or equatorial latitudes.

In general, the distance ranges for paths which lie partly in day and partly in night portions of the globe are intermediate between those shown in the day and night graphs, for the range of frequencies which can be used both day and night. For paths which cross the sunset line in summer, the usable frequencies will be about the same as the usable summer day frequencies. For paths across the sunset line in winter, the usable frequencies will be a little higher than the night frequencies shown in graphs. For transmissions across the sunrise line, both summer and winter the usable frequencies will be a little lower than the night frequencies shown in graphs. Frequently the conditions of the ionosphere on the light and dark sides of sunrise are widely different. Under such conditions it is often so difficult to transmit across the sunrise line that it is almost a barrier to high-frequency radio communication.

The attached graphs give distance ranges for the current year only. They change from year to year because of changes of ionization in the ionosphere. These changes are caused by the changing ultraviolet radiation from the sun in an approximate eleven-year cycle. The graphs will therefore be revised each year.

The distance ranges given in the graphs are the distances for good intelligible reception; they are not the limits of distance at which interference can be caused. A field intensity sufficient to cause troublesome interference may be produced at a much greater distance than the maximum distance of reliable reception.

References

A few selected references, for further information, are given here. See also the Bureau's Letter Circular, referred to above, "Radio transmission and the ionosphere."

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Attached:
Fig. 1. Summer 1941, Day, (1 kw).
Fig. 2. " " Night (1 kw).
Fig. 3. Winter 1940-41, Day, (1 kw).
Fig. 4. " " " Night, (1 kw).

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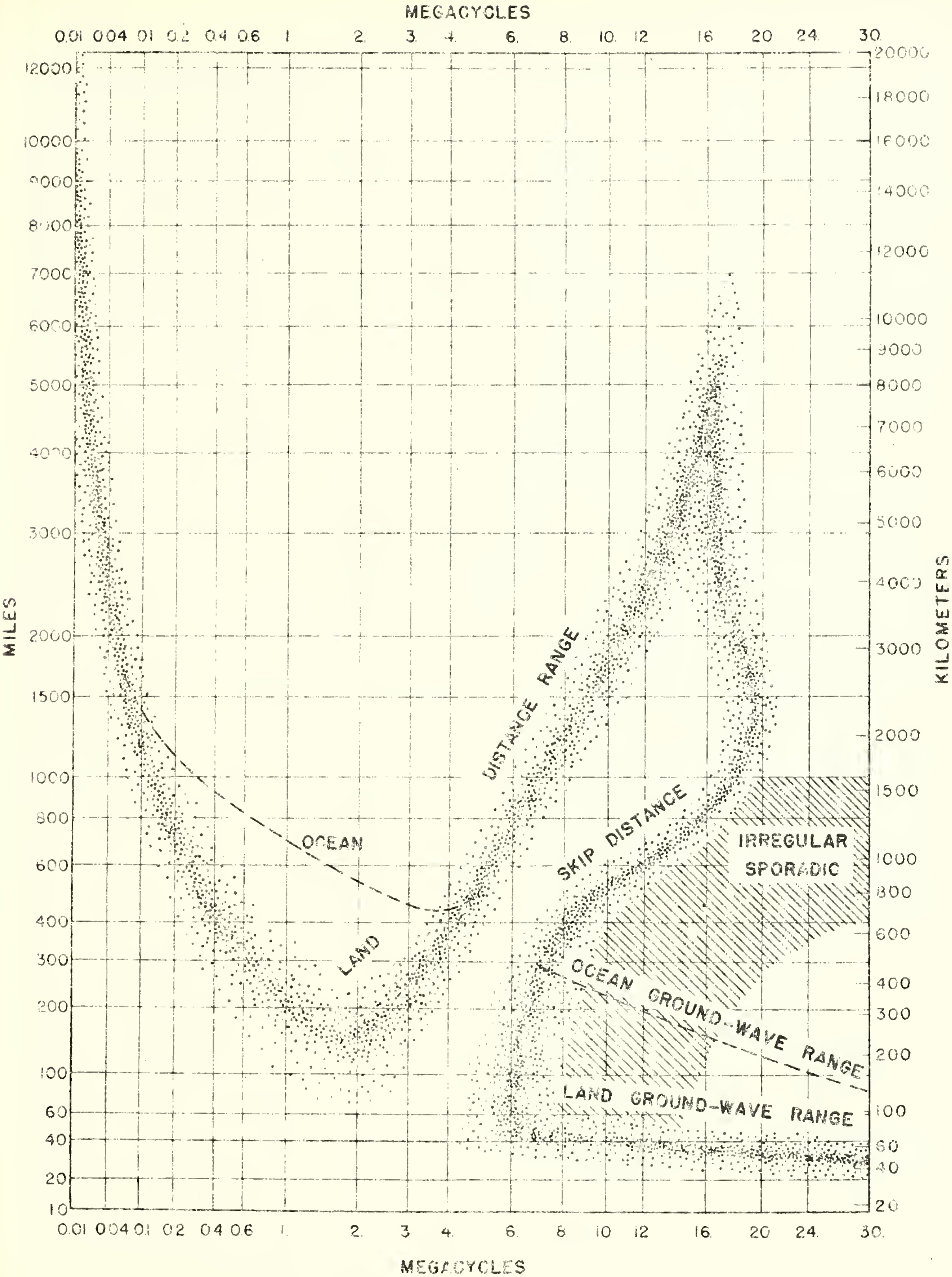
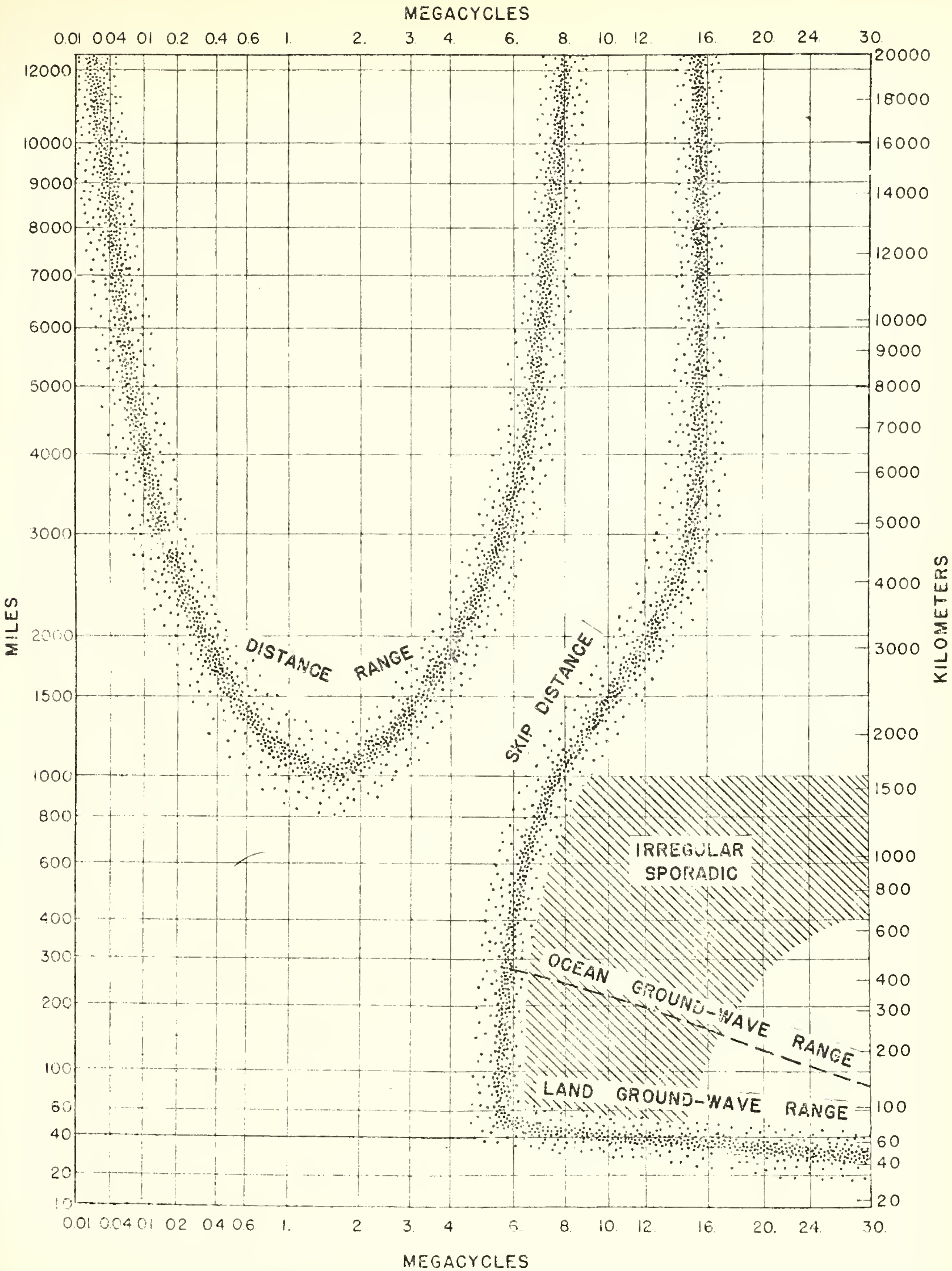


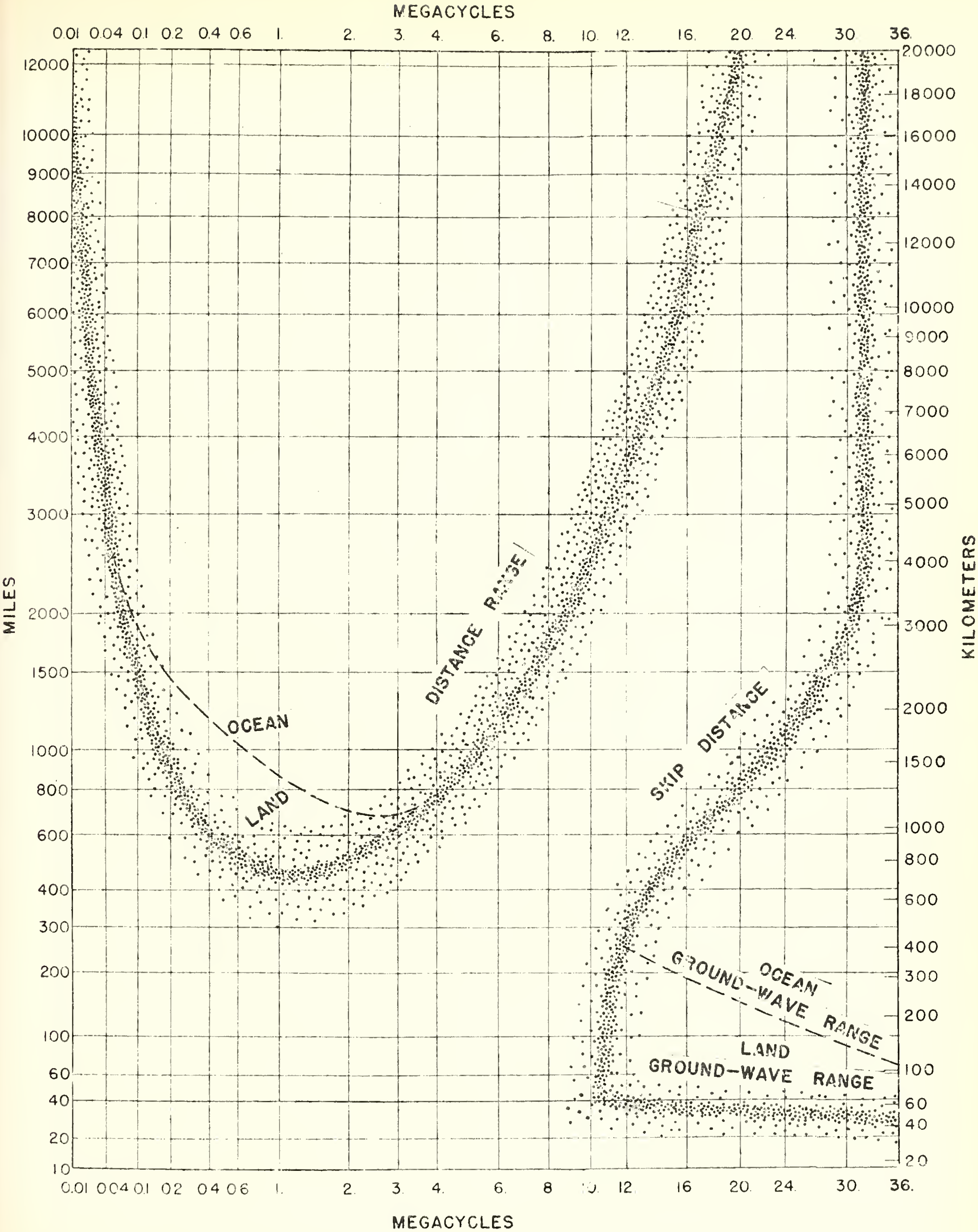
SUMMER 1941 DAY

Fig 1



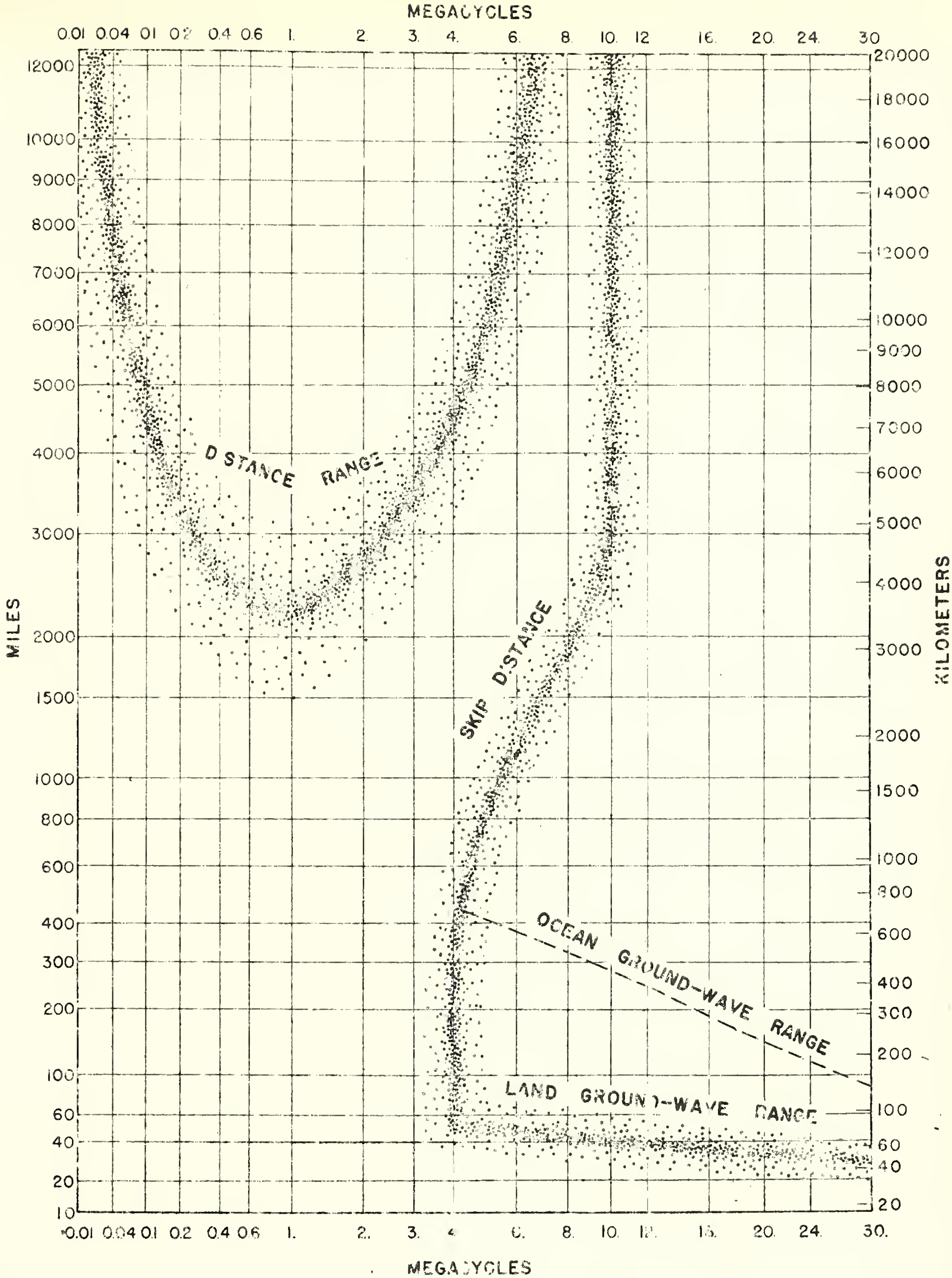
SUMMER 1941 NIGHT

Fig. 2



WINTER 1940-41 DAY

Fig. 3



WINTER 1940-41 NIGHT

Fig 4