Developments in Radio Sky-Wave Propagation Research and Applications During the War*

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Summary—**This paper discusses the work done by the Interservice Radio Propagation Laboratory during World War II. The circumstances leading to the establishment of IRPL are described and the problems which are faced are stated. The measures taken in the solutions of these problems are outlined, and some of the results are presented. Specific services performed by IRPL during the war for the armed forces and commercial companies are recounted.**

THE INFLUENCE of the ionized layers of the earth's upper atmosphere, the ionosphere, on radio wave propagation has been recognized ever since the experiments of Breit and Tuve and of Appleton proved its existence. Because of the scarcity of adequate ionospheric data, however, and because relatively few radio men realized its importance, the use of ionospheric data in radio communications before the war was relatively small.

The important part played by radio during the war brought to light the necessity for having adequate radio propagation information. No matter how good the equipment was at the transmitting and receiving ends, satisfactory communication could not be had unless the waves were propagated with sufficient strength to be receivable. Variations in propagation conditions proved to be several orders of magnitude greater than variations in transmitter power or receiver sensitivity. Furthermore, the extreme crowding of the radio-frequency spectrum made necessary full utilization of all available frequencies, and an appropriate selection of frequencies could be made only with the help of radio propagation data. Also, security considerations dictated that the frequencies used should be the best for use and the least likely to be intercepted by the enemy. The design of equipment, especially of antenna systems, was found to depend critically upon a knowledge of radio propagation conditions. In addition, other applications of radio, such as radar and direction finding, involved considerations of propagation regarding range, accuracy, and receivable intensities.

With the widespread use of radio communication by the armed forces, especially in parts of the world where but little experience had been had, the need for improved radio propagation information became apparent early in the war. An aircraft disaster in the European Theater led to the establishment of the British Inter-Services Ionosphere Bureau (ISIB) in 1941, and the exigencies of air force operation in the Southwest Pacific resulted in the formation of the Australian Radio Propagation Committee (ARPC), both instituted to furnish radio propagation data and predictions to their respective armies, navies, and air forces. Correspondingly, in 1942, the Interservice Radio Propagation Laboratory (IRPL) was established in the National Bureau of Standards by order of the U. S Joint Chiefs of Staff, acting through the Wave Propagation Committee of the U. S. Joint Communications Board, with the functions of (1) centralizing data on radio propagation and related effects, from all available sources, (2) keeping continuous world-wide records of ionosphere characteristics and related solar, geophysical and cosmic data, and (3) preparing the resulting information and furnishing it to the armed forces. This involved maintaining ionospheric observatories, centralizing data from these and other ionospheric observatories operated by other agencies and other countries, performing experimental and research work as necessary to supplement existing sources of data, preparing predictions and forecasts of radio propagation conditions for all parts of the world, issuing charts, tables, handbooks, and bulletins for immediate dissemination to the armed forces, maintaining a "special problem" consulting service to give immediate answers to urgent military problems, and co-operating in this work with other agencies of the United Nations.

The groundwork for the prediction of radio propagation conditions and ranges of useful frequencies had been laid by the previous ionosphere researches of the National Bureau of Standards, some of the results of which were published in the PROCEEDINGS OF THE I.R.E. from 1937 to 1940, under the title, "Characteristics of the Ionosphere at Washington, D. C." During 1941 to 1943, at the request of the National Defense Research Committee, the National Bureau of Standards made a study of the correlation of direction-finder errors with ionospheric conditions, and prepared a "radio transmission handbook" to permit usable frequency calculations.

In meeting the requirement of predicting useful frequencies over any paths anywhere in the world, the IRPL was confronted by five major problems: (1) the obtaining of adequate ionospheric data on a world-wide basis, (2) the development of methods for calculating maximum usable frequency over long paths, (3) the development of methods for calculating sky-wave field intensities, (4) the determination of minimum required field intensities, and (5) the development of methods for forecasting ionosphere storms.

* Decimal classification: R112.41×R113.65. Original manuscript received by the Institute, January 15, 1947; revised manuscript received, May 2, 1947. Presented, 1946 Winter Technical Meeting, New York, N. Y., January 26, 1946.
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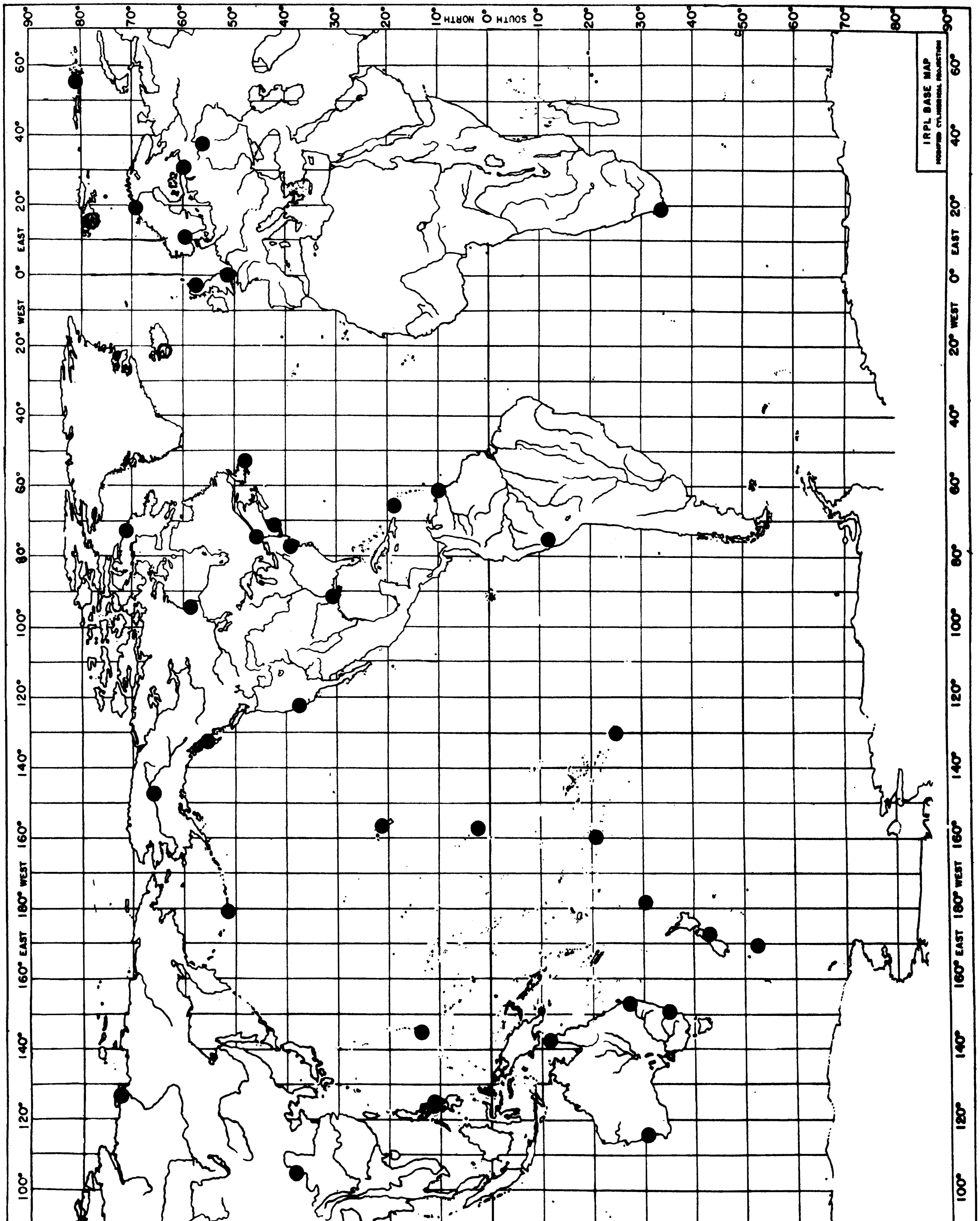

Fig. 1—Active ionospheric stations reporting data to IRPL in 1945.

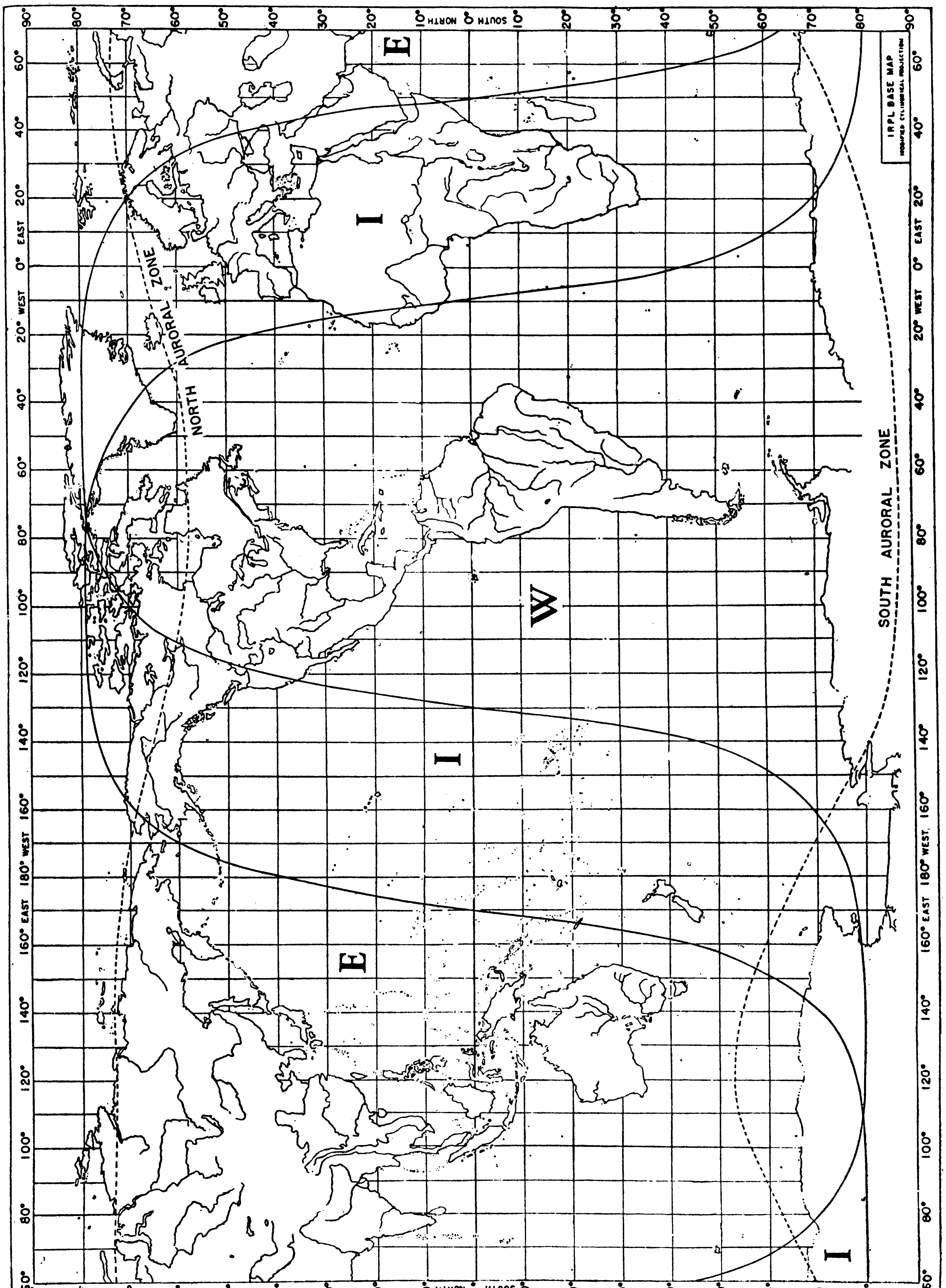

Fig. 2—World map showing zones covered by predicted charts.

At the outset, the IRPL was faced with the necessity of obtaining sufficient ionospheric data to permit predictions to be made anywhere in the world. At that time ionospheric observations were being made only at six locations in the world: Washington, D. C.; Slough, England; Huancayo, Peru; Watheroo and Sydney, Australia; and Christchurch, New Zealand. Regular data were available to the IRPL only from the first, third, and fourth of these. Immediate steps were taken to expand the world-wide coverage, with the cooperation of the Carnegie Institution of Washington; the United States Army and Navy; the Canadian Navy and Air Force; the British Admiralty, ISIB, the National Physical Laboratory and the British Broadcasting Corporation; the Australian organization, the ARPC; and the U.S.S.R., with the result that by the end of the war 44 stations were regularly reporting ionospheric observations, as shown in Fig. 1. This network of stations, together with analysis of radio traffic data from a number of communications networks, permitted the continual improvement of world charts of predicted ionosphere characteristics, from the small beginnings in 1941, based on only three stations, to the comprehensive charts now published monthly in the IRPL-D series reports. The knowledge gained from the greatly expanded world-wide ionospheric coverage permitted a much improved delineation of the regular variations of the ionosphere with latitude and local time, so that, for example, the hitherto seemingly anomalous behavior of northern and southern hemisphere stations fell into a consistent world picture.

In the course of their work it became necessary to place radio propagation predictions on a regular, world-wide basis, such that the great mass of data could be handled expeditiously and practical predictions issued regularly.

In order to use the data which were being received from all over the world for prediction purposes, it was necessary not only to understand their geographic, diurnal, and seasonal variations, but also to determine their relationship to relative sunspot numbers. A simple correlation of values of ionosphere characteristics with relative sunspot numbers had been previously found, but during the war trends of the variation of these characteristics with sunspot number were determined for the locations on earth of many of the ionosphere stations. A technique of prediction of ionosphere characteristics at any location, using standard statistical methods, was evolved, involving an estimate of the relative sunspot number for the month of prediction. A nomographic method for doing this type of prediction rapidly was later developed.

As another consequence of the improved world-wide coverage, the so-called "longitude effect" was discovered and put into operational use in 1943. This was the discovery that ionosphere characteristics were not, as previously supposed, the same, at the same local time, for stations at about the same latitude but different longitudes. Instead, they depended to a great extent on the geomagnetic latitudes of the station. Thus the station at Delhi, India, showed quite different characteristics from those observed at Baton Rouge, La.

Following this discovery, the world was divided, for practical operational purposes, into the three zones shown in the map of Fig. 2. In each zone the characteristics are independent of longitude, to a good enough practical approximation.

The second problem faced by the IRPL was the development of a simple rapid method of obtaining the maximum usable frequency (m.u.f.) over any paths in any part of the world. The groundwork for this was laid in 1936 when the "transmission curve" method of scaling ionospheric records was devised, leading to factors which could be applied to critical-frequency data to obtain m.u.f. values. These factors were satisfactory for distances up to 2500 miles, but for greater distances the method of multiple hops proved clumsy and, indeed, quite inadequate in the light of observed radio propagation data.

Consequently, the empirical "two-control point" method was devised (independently at the IRPL and ISIB) for paths longer than 2500 miles, whereby the m.u.f. over such a path is limited by the lower of the 2500-mile m.u.f. at two control points, 1250 miles from each station along the great-circle path connecting the two stations. This procedure gave much better results. As the volume of data increased, it became more and more apparent that normal F_2- or E-layer propagation was completely inadequate to account for a considerable part of the observed transmissions, particularly at times when E_s (sporadic E) was present. Consequently an extended analysis of E_s occurrence was made, and sufficient regularity was found to make E_s predictions possible, subject to the much wider day-to-day variability than in the case of the normal layers. Considerable further improvement in m.u.f. calculations was then made by including the effects of "sporadic-E" (E_s) propagation, also on a two-control-point basis.

World charts were prepared giving predictions of maximum usable frequencies, three months in advance. These, are continued in the monthly publication now issued through the Government Printing Office.

The urgent need for knowing distance ranges and lowest useful high frequency (l.u.h.f.) led to the next major problem undertaken by the IRPL—the calculation of sky-wave field intensities. To meet this, the field-intensity-recording program, begun by the National Bureau of Standards early in the last decade, was greatly expanded by installation of recorders at the new United States ionospheric stations. Fig. 3 shows a sample automatic field-intensity record. At the same time, theoretical studies of ionospheric absorption at oblique and vertical incidence were undertaken, in an attempt to obtain a simplified solution to the problem as rapid in operation as the method of calculating m.u.f.

An "equivalence theorem," similar to that used in

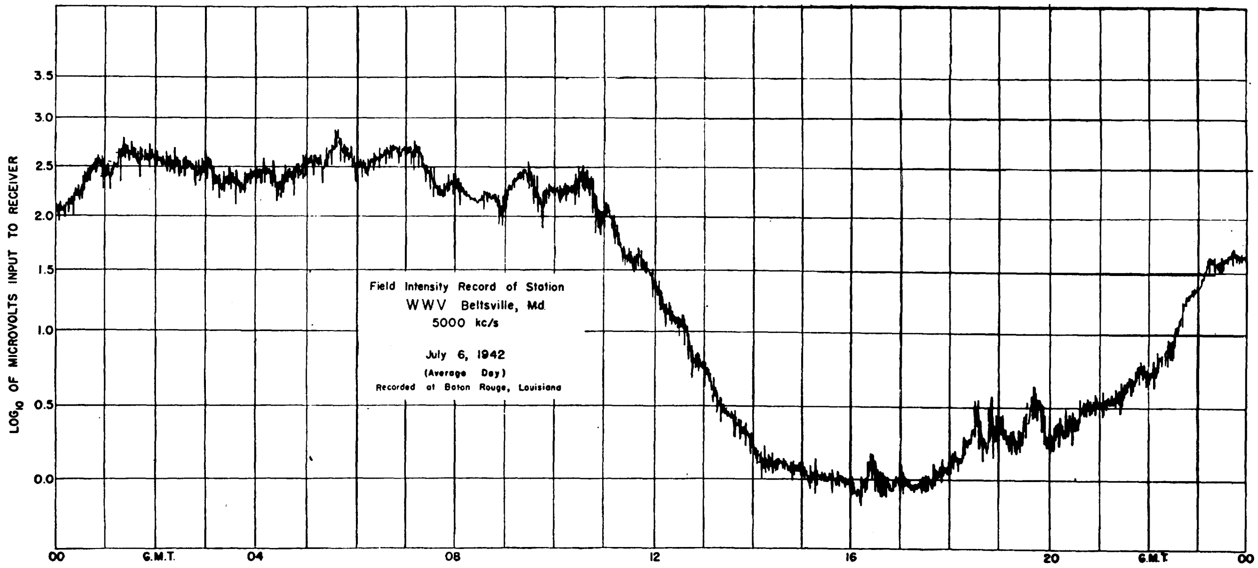

Fig. 3—Continuous automatic record of received radio field intensities.

calculating m.u.f., was used, employing the observed field-intensity data to supply numerical values to the many uncertain factors in the equation. It was found that the diurnal variation of ionospheric absorption varied to a good approximation, on the average, linearly with the cosine of the zenith angle of the sun, a fact which simplified greatly the integration of ionospheric absorption over a given transmission path; the absorption could then be determined as a function of frequency, distance, and average solar zenith angle over the path.

The determination of sky-wave field intensity did not of itself give the whole story, however, unless information also could be available as to the minimum fields required for radio communication. Thus, the fourth major problem confronting the IRPL was the determination of minimum field intensities necessary to overcome atmospheric radio noise, which was the principal type of noise encountered at sky-wave frequencies. This is still the subject about which least is known in the field of sky-wave communication. Some fragmentary measurements were available, and a beginning on the problem had been made at the ISIB in England. All available data on atmospheric radio noise and required fields were collected, as well as data on thunderstorms, which are the source of atmospheric noise. The result of the analysis was to divide the world into zones corresponding to different grades of noise intensity, taking into account both the generation and the propagation of the noise. Fig. 4 shows one such chart, for November through March. The principal noise-generating centers are in the East Indies, Central and South America, and Africa, with secondary centers in the tropical oceans—the "doldrum belts." For each noise grade, a set of curves of required intensities was constructed, similar to the one shown in Fig. 5. These were for good 95 per cent intelligible radiotelephone communications, and empirical factors were deduced for other types of service; for example, manual c.w. telegraphy required only 1/7 as great intensities, while four-tone single-side-band six-channel radio teletype might required only 1/14 as great intensities. Much of this work was done with the close collaboration and assistance of the Radio Propagation Unit of the Office of the Chief Signal Officer of the U. S. Army.

For convenience in use, the required field graphs were plotted on nomograms involving frequency and absorption index, so that the l.u.h.f. could be read off directly.

The fifth major problem of the IRPL was the forecasting of ionosphere storms—those abnormalities often associated with geomagnetic storms—which disrupt radio communications, especially in the Arctic. The military importance of the North Atlantic, which reaches into the auroral zone, or zone of maximum disturbance, made it indeed urgent to know when communications were likely to be interrupted. The urgency is apparent when it is realized that aircraft depended largely on radio aids for navigation over the North Atlantic.

Therefore a program was undertaken, in collaboration with the Department of Terrestrial Magnetism, Carnegie Institution of Washington, to study the relations between ionosphere storms and the sun, whose radiations produce the storms. Improved observational techniques, like the Harvard University coronagraph, a device for photographing the extremely active solar corona, contributed to the study. As a result of the analysis, a weekly forecast was issued, which proved to be of some value to the armed services. The world was divided into zones of varying ionospheric disturbance, as shown in Fig. 6, and forecasts were made for each zone.

A different approach, however, led to a considerably

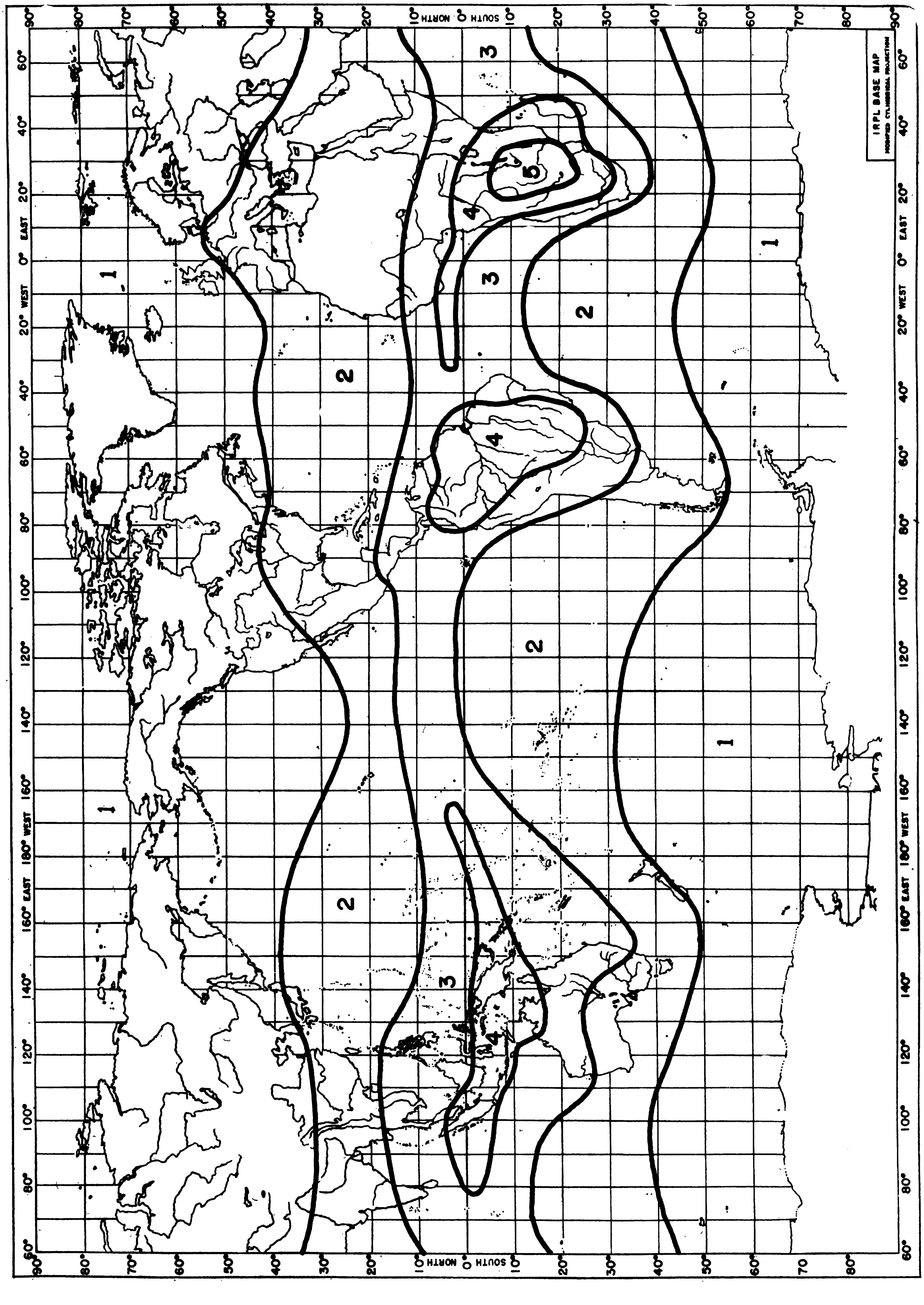

Fig. 4—Map showing atmospheric radio noise zones (November through March).

more accurate service of forecasting disturbances a shorter time in advance. In this, studies of the behavior of radio-d.f. bearings over the North Atlantic path showed that it was possible to issue warnings of radio disturbance a few hours to a half day or more in advance. Consequently a short-time warning service was

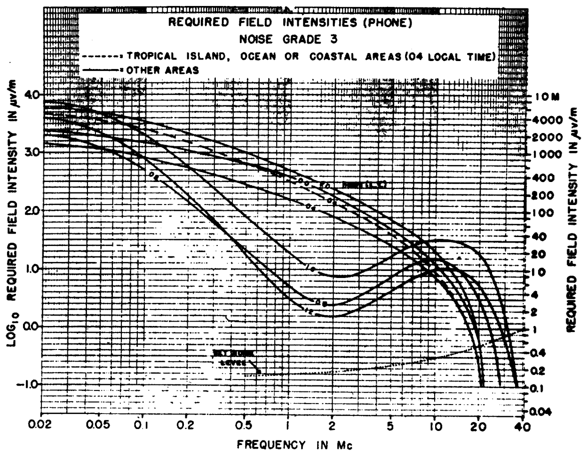

Fig. 5—Minimum field intensities required for satisfactory radiotelephone communications in the presence of atmospheric radio noise (noise grade 3).

inaugurated whereby such warnings were telephoned and telegraphed daily to interested agencies. With the lifting of wartime restrictions, this warning service is now being broadcast regularly over WWV, the National Bureau of Standards station at Beltsville, Md., at 20 and 50 minutes past each hour. A group of N's or W's is transmitted, the former meaning "no warning" (quiet conditions expected) and the latter "warning" (disturbed conditions over the North Atlantic expected or in progress).

During the war the IRPL performed many specific services for the armed forces and commercial companies doing war work, involving consultation and advice, on their special problems involving radio wave propagation. Types of problems included the determination of best usable frequencies for specified services, such as point-to-point, short-distance tactical operations, plane-to-ground, high-frequency broadcast, the prediction of ground-wave and sky-wave distance ranges under different conditions, advice as to types of antennas and lowest required radiated power for specified purposes, and frequency allocation. As the techniques promulgated by IRPL became more widely disseminated, many types of problems, especially those in frequency allocation, were eventually solved by the Army and Navy groups in which they originated.

In January, 1944, a two-weeks training course in radio wave propagation was given by IRPL. It was for officers who were to be taught the principles of radio wave propagation and methods of problem solution and then assigned to overseas communication groups, where they could put on a scientific basis the assignment of radio operating frequencies in the field. Others were then to be sent to training units within the United States to organize courses in which additional officers could be instructed in this work. The student body consisted of two groups, the first group consisting of eleven Army Air Forces officers, four officers from the Signal Corps, and three Navy officers, and the second group consisting of fifteen enlisted men and one officer from the Signal Corps, who formed the nucleus of the Radio Propagation Unit of the Signal Corps. The course comprised twenty-five lectures by scientists and others working directly in radio wave propagation, interspersed with problem sessions in which the students were coached in the solution of practical radio wave propagation problems.

As a further aid in determining the proper usage of radio frequencies, three handbooks were issued. The first handbook, "Radio Transmission Handbook—Frequencies 1000 to 30,000 kc.," was issued in January, 1942, giving the basic principles of radio sky-wave propagation, and such computational procedures as were extant at that time, together with preliminary versions of prediction charts and predictions for the winter. A supplement to this handbook was issued June 1, 1942, which gave summer predictions.

On November 15, 1943, the "IRPL Radio Propagation Handbook, Part 1" was issued. This handbook, issued as an IRPL publication, and also as an Army training manual (TM 11-499) and a Navy publication (DNC-13), gave a descriptive discussion of the behavior of the ionosphere and of the theory behind maximum usable frequencies and lowest useful high frequencies. Prediction charts of maximum usable frequencies and absorption constants were given. Techniques for the determination of m.u.f. and l.u.h.f. over any path at any time were given to the extent that they had been developed at the time. It is impossible to express fully the valuable aid and support received by the IRPL from other agencies. Close and continuous liaison was maintained with the Department of Naval Communications (CNO) and the Radio Propagation Unit of the Army Signal Corps (SPSOL); valuable assistance and suggestions were interchanged with personnel in those departments working with IRPL in the solution of basic problems and applications. Close co-operation was maintained with other branches of the Army and Navy having need of radio propagation data, including the Army Security Agency, the Army Air Forces, other branches of the Signal Corps, the Navy Bureau of Ships, Bureau of Aeronautics, Coast Guard, and other branches of Naval Operations.

Acknowledgment is made to the Department of Terrestrial Magnetism, Carnegie Institution of Washington, for its extremely valuable assistance in operating ionosphere stations and collecting much of the geophysical and solar data upon which the services of the IRPL were based, and to the untiring work of its staff in co-operating in the entire radio propagation program. Acknowledgment is also wholeheartedly given to the full co-operation, from the very beginning, of the radio prop-

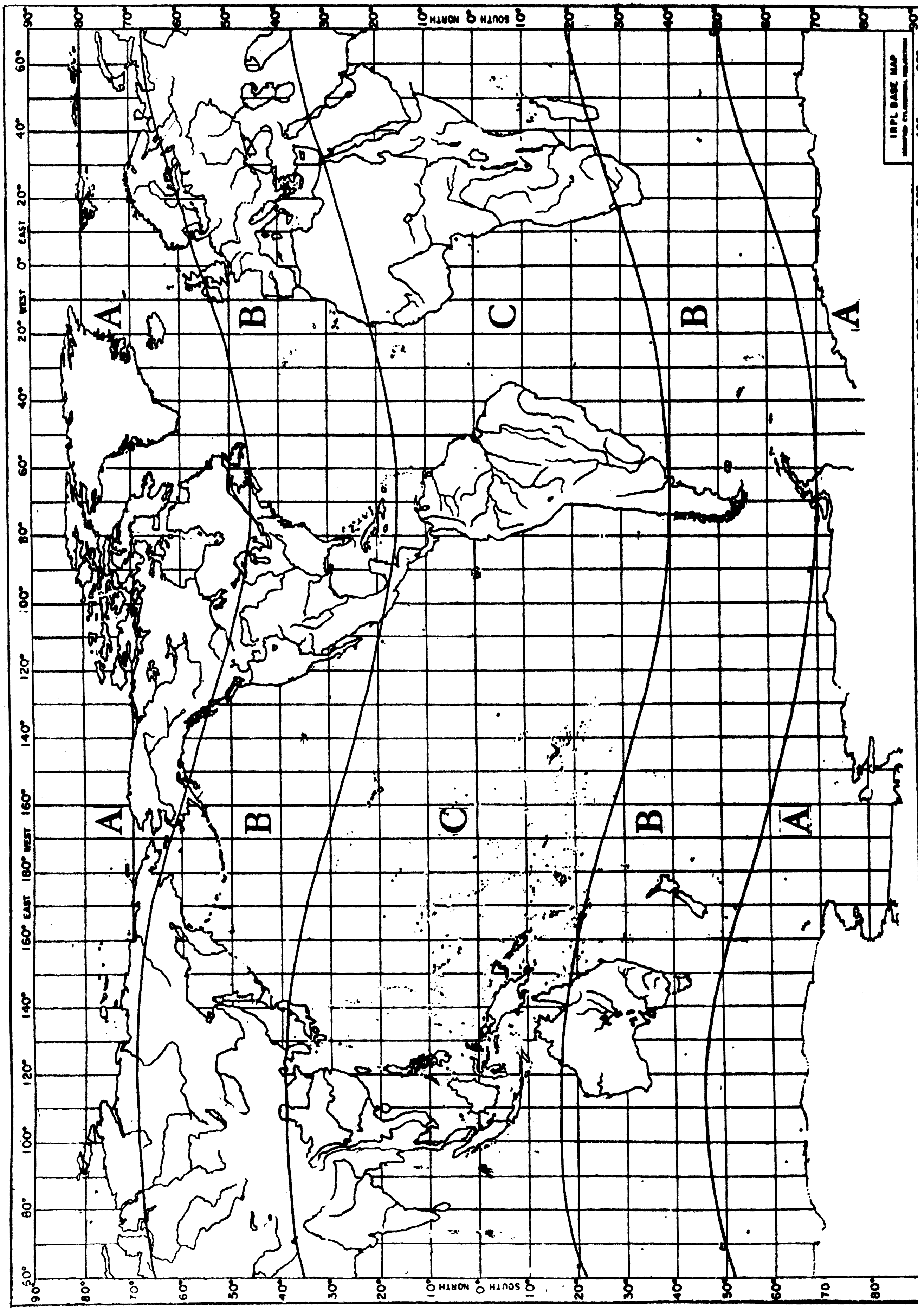

Fig. 6—World map showing zones of different degrees of ionospheric disturbance.

agation organizations of other countries—Canada, Great Britain, Australia, and New Zealand—without which no world-wide radio propagation program would have been possible.

Many commercial organizations and other agencies gave valuable assistance to the work of the IRPL. An analysis of radio traffic data was regularly provided by United States communication companies, such as RCA Communications, Mackay, Press Wireless, and A. T. & T., from Army and Navy networks, and from other Government agencies such as the C.A.A. and the F.C.C.; this analysis assisted greatly in predicting and checking predictions of usable frequencies, and in correcting and corroborating theoretical processes of analysis.

With the conversion to the postwar era, the work of the IRPL is carried on and extended by the Central Radio Propagation Laboratory of the National Bureau of Standards. Particular emphasis is laid on research in radio propagation at all frequencies.

Alternating-Current Measurements of Magnetic Properties*

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Summary—**Herein is presented a critical analysis of various procedures for determining the permeability and core loss of ferromagnetic materials, together with a discussion of the limitations under which such observations are made and the interpretations which should be applied to the data obtained.**

Introduction

IT IS THE purpose of this paper to discuss various methods for the a.c. measurement of the magnetic properties of a specimen of ferromagnetic material and, it is hoped, to clarify certain phases of these techniques about which some misunderstanding has existed. The system of magnetic nomenclature and definitions recently adopted by the American Society for Testing Materials[1] will be used.

Magnetic Condition of the Specimen

It is a well-known, but sometimes ignored, fact that all ferromagnetic materials exhibit the phenomenon of hysteresis and have, in effect, a "memory," so that any present (instantaneous) condition is more or less influenced by past events. To obtain significant and reproducible data it is first essential to erase all memory of previous conditions. This preliminary demagnetization may be accomplished by subjecting the specimen to a substantial a.c. magnetization which is then gradually reduced to zero. Thereafter, any applied a.c. magnetization must be removed by a gradual reduction to zero, rather than by interrupting the circuit at some arbitrary time in the cycle.

If any subsequent magnetization is then due to a symmetrically alternating current (having no d.c. component), the specimen will be in a symmetrically cyclically magnetized (SCM) condition, wherein the mean values of both induction and magnetizing force are zero. For either polarity of magnetization, the *peak* values of each of these parameters will be equal, and are designated as their *normal* values.

In addition to hysteresis, it is less generally known that some materials exhibit a definite *magnetization lag*. If, having acquired in them a stabilized variation in B and H, a change is made in the amplitude of the cyclic variation of H, some time (representing a considerable number of cycles) may elapse before a completely stabilized variation and a new maximum value of induction is attained. This magnetization lag appears to be more pronounced for a given increase than for a corresponding decrease in magnetizing force, doubtless due to the effect of retentivity.

When measuring a specimen at different values of cyclic H, it would thus appear desirable to start with the maximum contemplated value and successively reduce this parameter. For incremental measurements, however, the biasing component of H must be increased progressively from an initially demagnetized condition to avoid any retentivity in the biasing H.

It should be remembered that the magnetic properties of some materials may, to a certain degree, be modified by mechanical strains in punching operations on flat laminations, or in the rolling of flat stock into toroidal cores. Subsequent metallurgical treatment may then be necessary to restore the natural magnetic condition of the material. The author is of the opinion, however, that a limited amount of easy and careful shearing may not disturb the specimen as much as is sometimes anticipated (see Appendix E).

* Decimal classification: R282.3. Original manuscript received by the Institute, March 11, 1947; revised manuscript received, July 10, 1947. Presented, Rochester Fall Meeting, November 11, 1946, Rochester, N. Y.

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[1] A.S.T.M. Specification A127-44T, 1944 Book for Metals, pp. 1437–1443.