Transatlantic Long-Wave Radio Telephone Transmission and Related Phenomena from 1923 to 1933

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It is shown that transatlantic long-wave radio field strength is related to the 11-year cycles of terrestrial magnetic activity, sunspots, solar limb-prominences, and ultra-violet radiation. The directness of correlation between long-wave radio and these other phenomena is apparently only approximate. Very good seasonal and monthly correlation is obtained between magnetic activity and daylight radio transmission. Magnetic storms are shown to have prolonged and delayed effects on day and night radio transmission, obscuring tendencies for 27-day recurrences on long waves. No reference is made to the probable mechanism of long-wave radio transmission because a paper, now in preparation, will be concerned primarily with this subject.

Introduction

THIS paper summarizes a study of the transatlantic long-wave radio transmission data (near 60 kilocycles) collected by the American Telephone and Telegraph Company and the General Post Office of Great Britain during the period from 1923 to 1933, including the development tests from 1923 to 1926 and the period of operation of the commercial radio telephone circuits from January 1927 to December 1933.

A correlation is presented between terrestrial magnetic activity, sunspot-numbers, solar limb-prominences, ultra-violet radiation, and transatlantic long-wave radio telephone field strength observations during one 11-year sunspot cycle. By expressing the variables with different scales better correlations have been obtained. These are given on averages of years, months, seasons, and days. Examples of delayed night and day field strength changes accompanying long magnetic storms are included in this presentation.

It is generally believed that solar radiation influences the transmission [1*] of radio signals but the detailed mechanism by which the influence is exerted [2] is not entirely clear. The number and relative effects of other factors that may influence radio transmission are also uncertain. Solar phenomena, magnetic activity, and radio transmission appear to have some time-phase relations but these relations have not been clearly established. Some of the results of the studies reported herein contribute to the evaluation of these effects while other results give new or corroborative information on the qualitative relations between the solar, magnetic, and radio phenomena.

* Numbers refer to the references in the bibliography.

In any particular study, the field strengths of the radio transmitters were corrected to a constant antenna current and expressed in decibels above one microvolt per meter. Where a study involved a comparison between data observed at different locations, or on different frequencies, corrections were applied to reduce the data to a common basis by the application of the Bell System Long-Wave Radio Transmission Formula.[3]

The transmitters and transmission paths involved are indicated in Table I.

TABLE I

Years	Transmitter		Rocky Point, N. Y., to
	West–East		
1923–1924	57 Kc.	2XS	New Southgate, England
1925	57 Kc.	2XS	Chedzoy, England
1926 (to Sept.)	57 Kc.	2XS	Wroughton, England
1926 (Oct.) to 1928	60 Kc.	WNL	Wroughton, England
1927 (Mar.) to 1933	60 Kc.	WNL	Cupar, Scotland
	East–West		
			Rugby, England, to
1927–1930, part of 1931	60 Kc.	GBT	Houlton, Maine
Remainder of 1931	68 Kc.	GKA	Houlton, Maine
1932–1933	68 Kc.	GBY	Houlton, Maine

Statistical Frequency Distributions

In making a correlation study the best results are obtained when observations of the variables involved have the same type of statistical "frequency distribution." As illustrated in Fig. 1, the cumulative frequency distribution curves of long-wave field strength observations, when plotted (in decibels) on "arithmetic probability" paper, tend to be straight lines and thus of the Normal Law type. The best correlation will therefore be obtained when the other variables involved have approximately straight-line distributions on the same type (arithmetic probability) of coordinates.

Accordingly, cumulative distribution curves were so made for all the variables used in this study. It was found that good approximations to the Normal Law distribution were obtained with logarithmic scales for radio field strength (db above 1 $\mu v/m$), monthly averages of solar limb-prominences, sunspot-numbers, and u_1 measure * of magnetic activity. However, for the "C" measure of magnetic character of days and monthly averages of ultra-violet radiation, linear scales were found to be better than logarithmic scales.

Correlation by Years

In spite of the irregularities in the long-wave field strength curves in Fig. 2, it is evident that during the sunspot maximum period the radio

* See Appendix I.

field strength tended to be higher than during the years of sunspot minimum. The same applies to solar limb-prominences, magnetic activity, and ultra-violet radiation.† The irregularities in the radio telephone field strength curves are more nearly duplicated in the curves

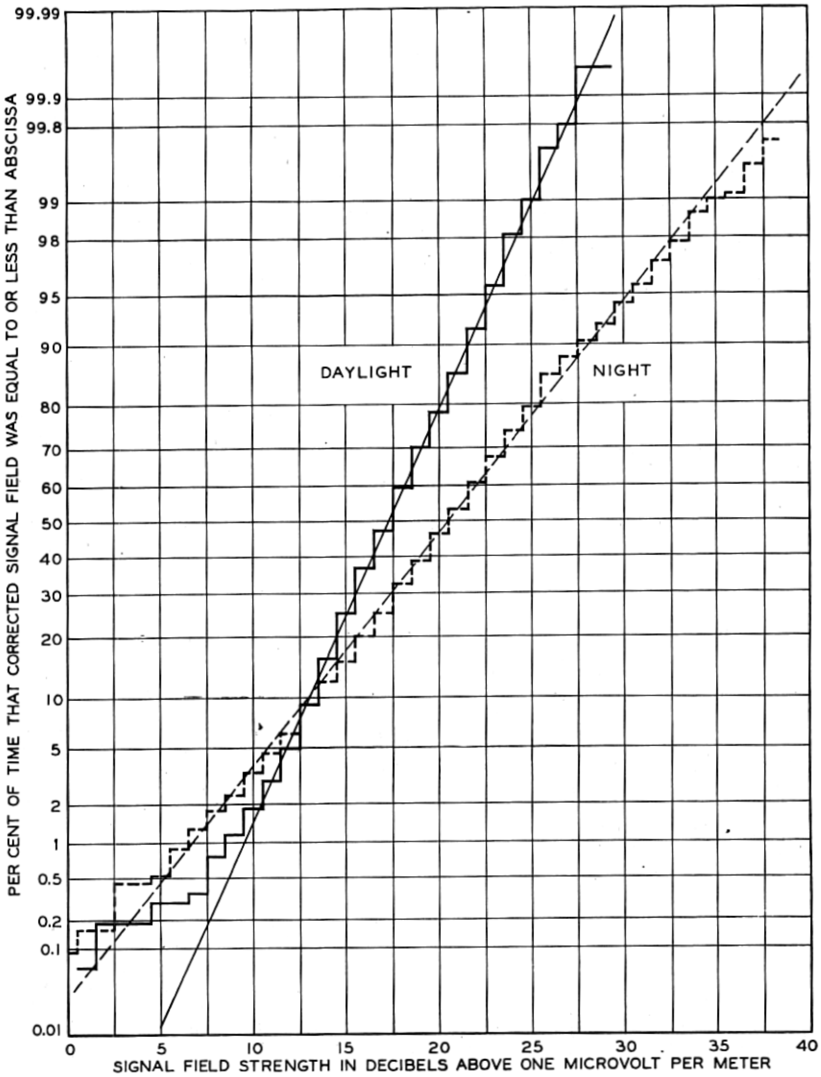

Fig. 1—Cumulative distribution of hourly observations of the field strength of WNL—60 kc. at Cupar, Scotland, in 1933, corrected to 375 amperes. (1699 observations for all-daylight path, 1146 observations for all-night-time path.)

† The measure of ultra-violet radiation is the ratio of intensity of ultra-violet ($\lambda = 0.32\mu$) to green ($\lambda = 0.50\mu$). Ratio for June 1924 = 1.

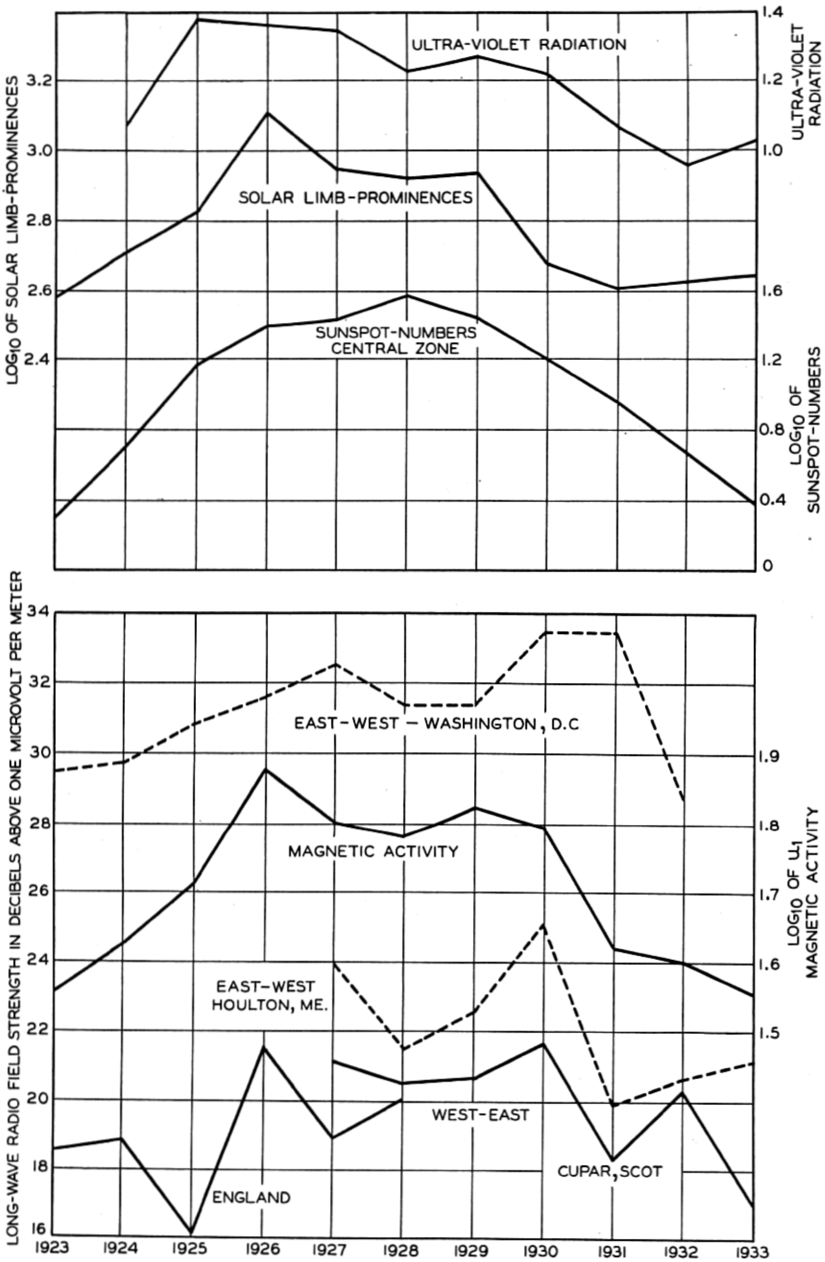

Fig. 2—Annual averages of solar phenomena, terrestrial magnetic activity, and long-wave radio transmission during one 11-year sunspot cycle.

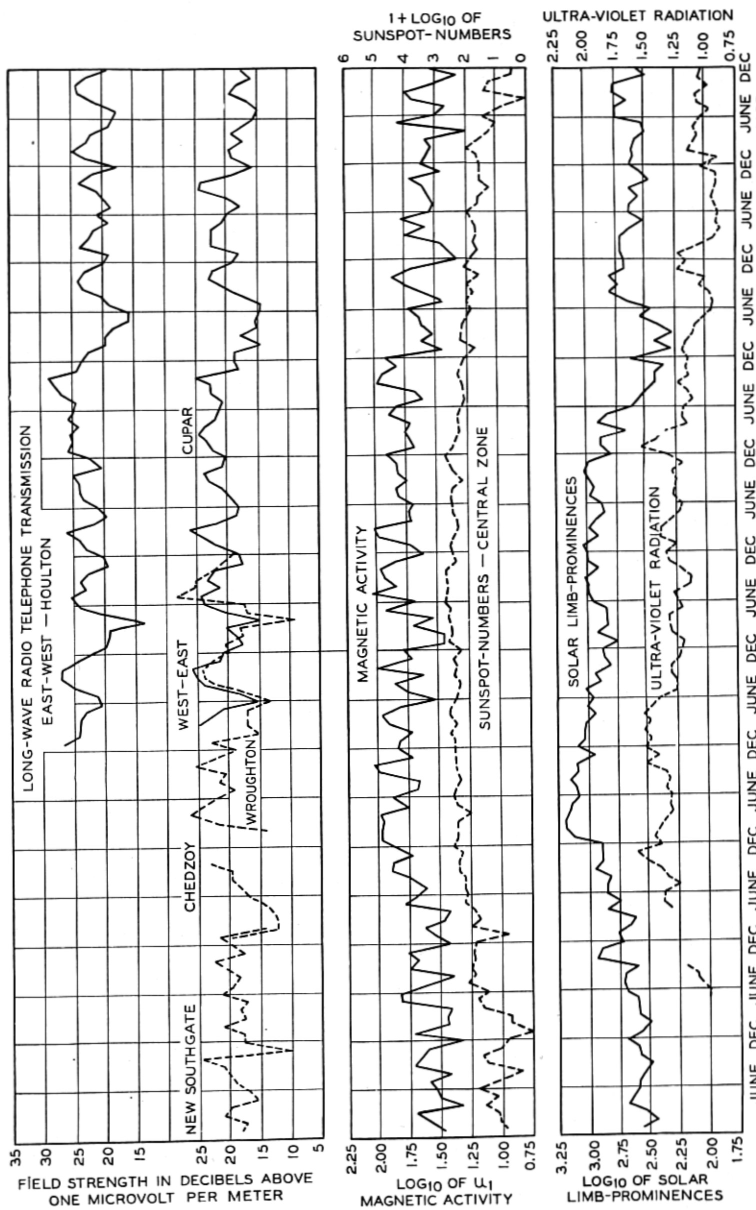

Fig. 3—Monthly averages of solar phenomena, terrestrial magnetic activity, and long-wave radio transmission during one 11-year sunspot cycle.

of magnetic activity and solar limb-prominences than in the sunspot and ultra-violet curves. The curve of reception at Washington, D. C., of signals from several European telegraph stations on longer wave-lengths (15 to 30 kc.) followed the Houlton and Cupar curves fairly well except in 1931.

The decrease in long-wave field strength apparently lagged a year or two behind the decrease in sunspot-numbers. This may perhaps be explained by the lower heliographic latitude of the sunspots near the minimum of the solar cycle, offsetting the decrease in number of spots.

Correlation by Months

Monthly averages of the same phenomena as shown in Fig. 2 are plotted in Fig. 3, omitting the curve of radio telegraph reception at Washington. There seems to be little or no obvious correlation between the field strength curves and the other curves except for the one of magnetic activity. Sunspots in the central portion of the solar disc are believed to have the major influence on terrestrial phenomena,[4, 5, 6, 7] and therefore the sunspot-numbers employed in this analysis are those for the central zone * of the sun. Solar limb-prominences would hardly be expected to have considerable influence † on the terrestrial phenomena, although some relation is suggested by Fig. 2. Monthly averages of ultra-violet radiation also offer little explanation of the variations of long-wave fields.

Magnetic activity easily gives the best correlation with long-wave fields on a month-to-month basis. A scatter diagram was constructed in which the West–East and East–West monthly averages of daylight long-wave radio transmission were correlated with terrestrial magnetic activity for the years 1927–1932. For WNL the coefficient of correlation [8] is 0.526 ± 0.059; for GBT and GBY, 0.747 ± 0.067, indicating a high degree of correlation. Such correlation means either that magnetic activity affects radio transmission or that both are affected similarly by a common cause of disturbance.[9]

The coefficient of correlation of magnetic activity with the monthly averages of WNL and 2XS at New Southgate in 1923 and 1924, at Chedzoy in 1925, and at Wroughton in 1926, 1927, and 1928 is 0.38 ± 0.10.

* From 1917 to 1928, inclusive, the "central zone" of the sun was defined as that part of the sun's surface included between two meridians situated 30° on either side of the central meridian. (The central meridian is that meridian of the sun which bisects the sun's disc.) Beginning in the year 1929 the central zone is defined as the area on the sun's disc enclosed by a central circle having a diameter half that of the disc.

† Solar limb-prominences may have a more direct relation to sunspots without having any significant relation to terrestrial phenomena.

Very striking and significant results were obtained when seasonal averages of magnetic activity and radio field strength were plotted in Fig. 4 to indicate seasonal trends. Except for the magnetic sub-maximum in May the curves of field strength and magnetic activity

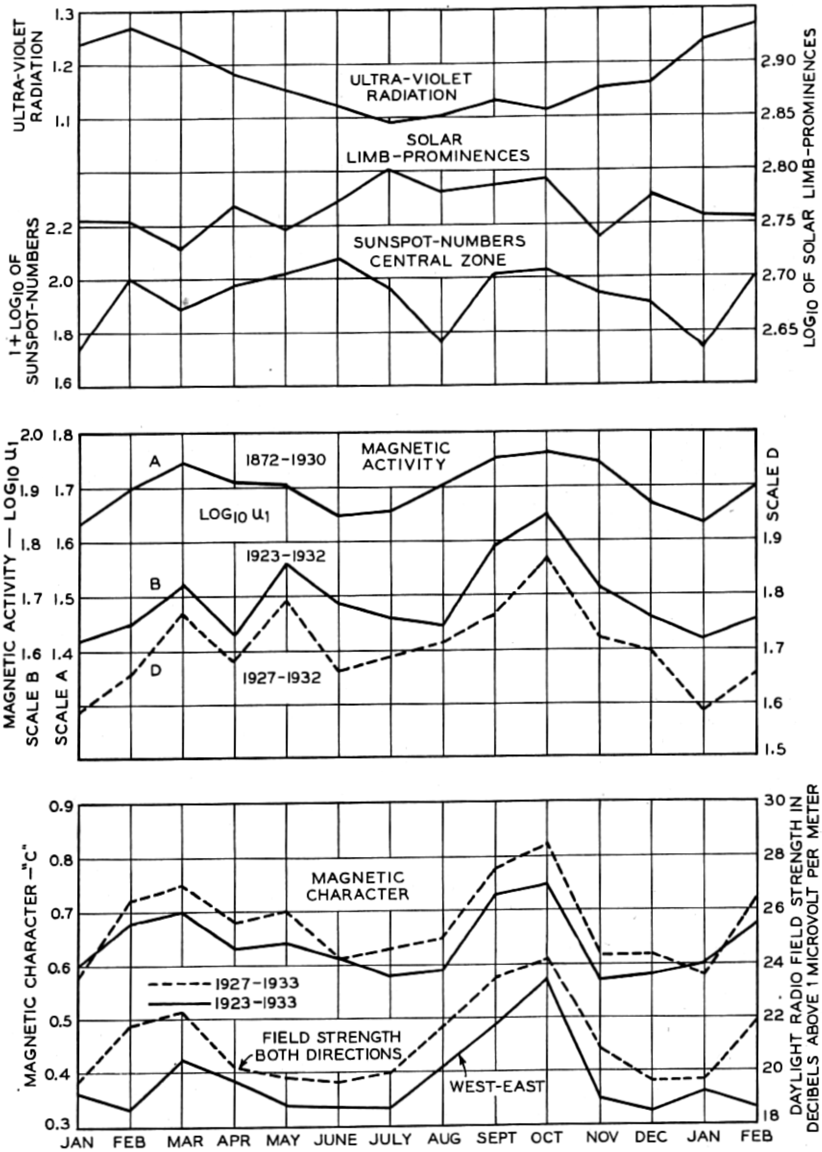

Fig. 4—Seasonal averages of long-wave radio field strength compared with solar phenomena and terrestrial magnetic activity.

are closely in phase. While the two curves of average magnetic characterization ("C") are considered not so reliable * for this analysis as the u_1 curves, the same equinoctial maxima appear in all magnetic curves. However, seasonal averages of solar limb-prominences, sunspot-numbers, and ultra-violet radiation apparently have no significance in relation to radio field strength. Bartels [10] found that there is no real seasonal cycle of sunspot-numbers. Cupar and Houlton observations were combined † for the years 1927 to 1933 to make the dashed curve.

West–East average transmission for eleven years is shown by the solid curve at the bottom of Fig. 4. The February dip was recorded at Cupar, Scotland, in 1931 only but was previously observed at the receiving locations in England (also during four of the seven years at Houlton). The $\log_{10} u_1$ curve for 1872–1930 was derived from data published by J. Bartels [10] in a comprehensive analysis of magnetic data, which he critically examined for the reality of seasonal variability. The other $\log_{10} u_1$ magnetic activity curves ‡ cover the first ten of the eleven years for which the radio data are available in one direction, and the first six of the seven years for which radio data are available in both directions, East–West and West–East.

Correlation with Magnetic Storms

The average daylight radio field strength of long-wave signals does not reach a maximum until five to eight days § after the peak of a long magnetic storm, nor does the average night-time field reach a minimum until about the same time. This is shown (Fig. 5) by a study of 25 storms of four or five days duration in the four years from 1930 to 1933, inclusive. The incidence of succeeding storms did not permit the study to include a longer time after the storms had subsided, so that less than one complete cycle of field variation is all that can be shown with any confidence. Data for WNL, GBT, and GBY were combined to obtain the trend curves for the radio field strength. A study of 16 periods (in the years 1927–1933) of one and two months' duration, including one to three significant magnetic storms, showed that the difficulty involved in extending this kind of study to individual storms lies primarily in the lack of highly accurate radio data.

* See Appendix I.

† See Appendix II.

‡ These curves were drawn before the data for magnetic activity (u_1) for 1933 were available. The 1933 data became available shortly before the paper was released for publication but do not materially change the overall picture.

§ C. N. Anderson [11] showed a similar delay in the maximum increase of daylight field following severe magnetic storms in 1927 and 1928. I. J. Wymore [12] found a delay of about two days for signals of somewhat longer wave-length.

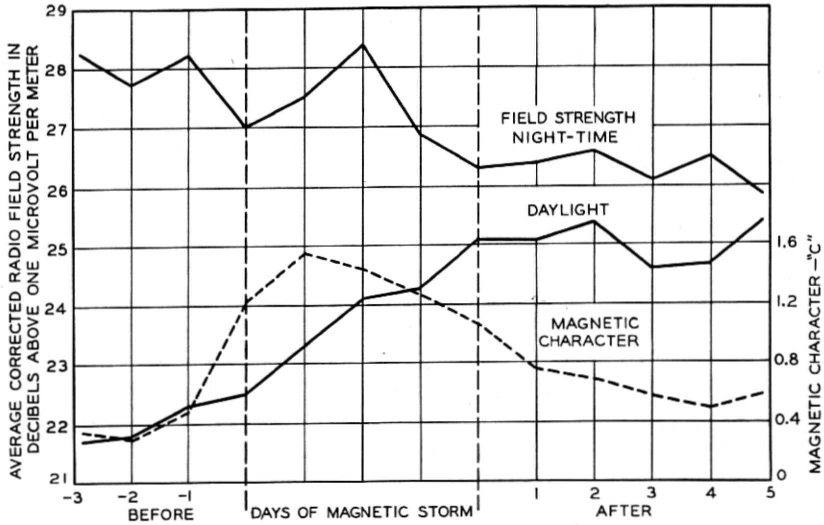

Fig. 5—Average daylight and night-time long-wave radio field strength before and after 25 long magnetic storms.

27-Day Intervals

Sunspot-numbers and terrestrial magnetic disturbances tend to be repeated at 27-day intervals.[10] A recurrence correlation for "radio character" and magnetic character has been published by A. M. Skellett,[13] who based the radio data upon the relative intensity from day to day of the disturbances of the short-wave telephone circuits between New York and London. A recurrence chart for long-wave radio is shown in Fig. 6, based upon the deviation from the 50-day moving average of the average daylight radio field strength of WNL (60 kc.) at Cupar for seven years beginning with March 1927. A measure of the international magnetic character figure ("*C*") for each day in the same period is likewise shown in this figure.

It is evident that the 27-day recurrence phenomenon is obscured on long waves, probably because magnetic storms are followed by prolonged effects on the long-wave fields, as was pointed out in connection with Fig. 5.

Correlation by Days

The average daylight field strength on long waves is improved on days of magnetic disturbance,[14] as compared with calm days.[15] Cumulative distribution curves of daily averages of daylight field strength of WNL (Rocky Point to Cupar, Scotland) for 1930 and 1933 are shown in Fig. 7, for calm and disturbed days.* Similar data for east-to-west

* A magnetically calm day is defined for the purposes of this paper as a day for which the international magnetic character figure "*C*" is from 0.0 to 0.3. A magnetically disturbed day is here characterized by a figure from 1.2 to 2.0.

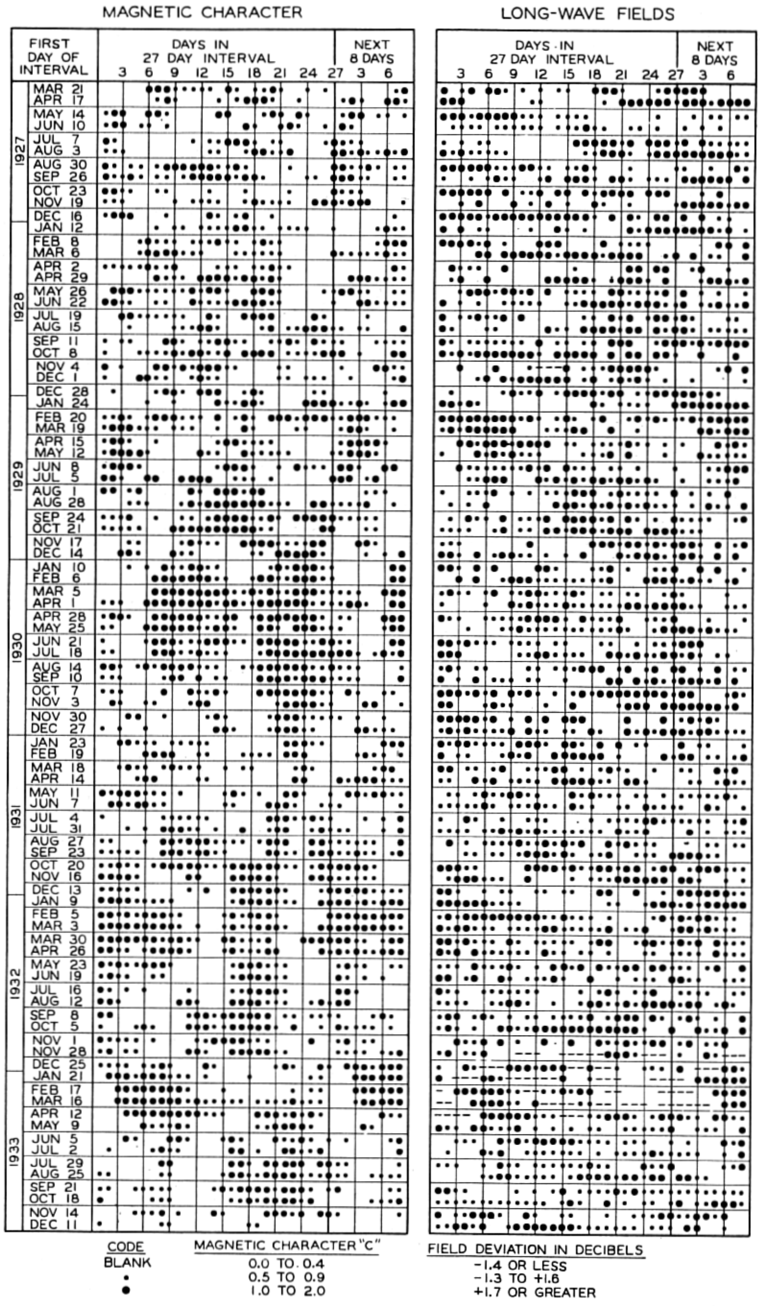

Fig. 6—Twenty-seven-day recurrence diagram of magnetic character and deviation of average daylight field of WNL from 50-day moving average.

transmission from Rugby to Houlton were obtained but are not reproduced. (It will be observed that the antenna current to which the data are corrected is different for different years. This basis results in a convenient spacing of the distribution curves to prevent

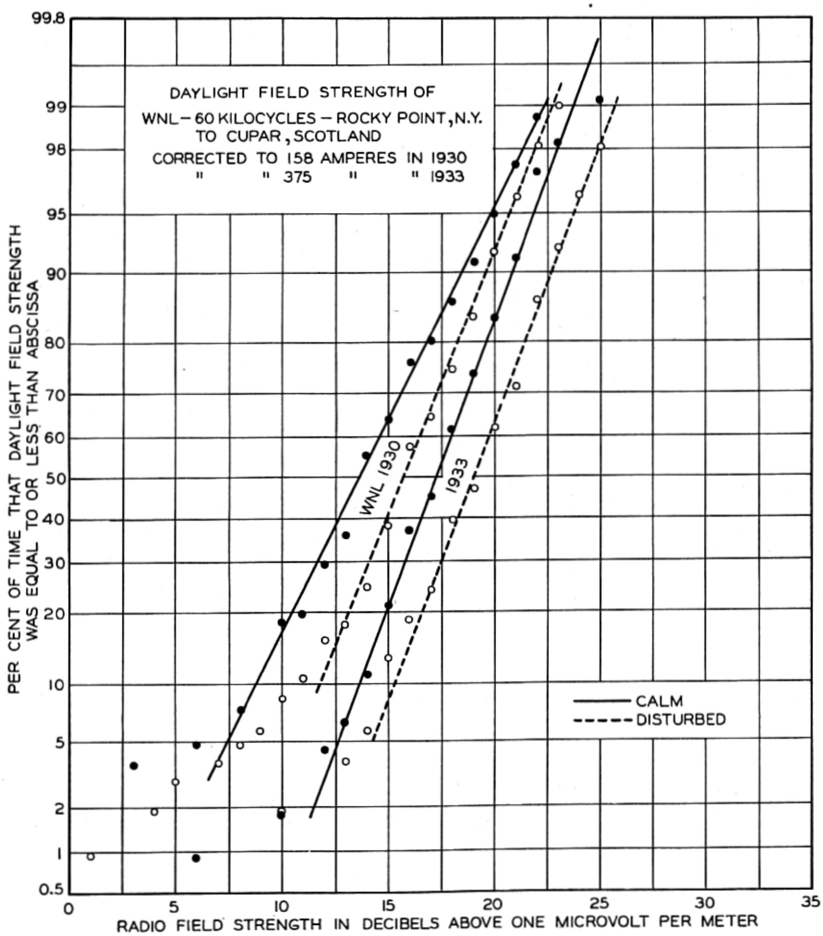

Fig. 7—Cumulative distribution of daily averages of long-wave radio field strength on days of magnetic calm and on days of magnetic disturbance. Daylight transmission path, WNL.

overlapping.) The year 1930 was magnetically more disturbed than 1933. Because of the few days' lag (Fig. 5) of the increase in daylight field strength behind magnetic storms, the full effect that accompanies magnetic disturbances is not revealed by these curves.

No consistent relationship between night-time long-wave fields and magnetic disturbance is obtained from similar analyses. Lowered night-time fields on East–West (GBT, GBY) transmission were found to accompany magnetic disturbances in both quiet and disturbed years. However, from Fig. 8, it is seen that on West–East (WNL) trans-

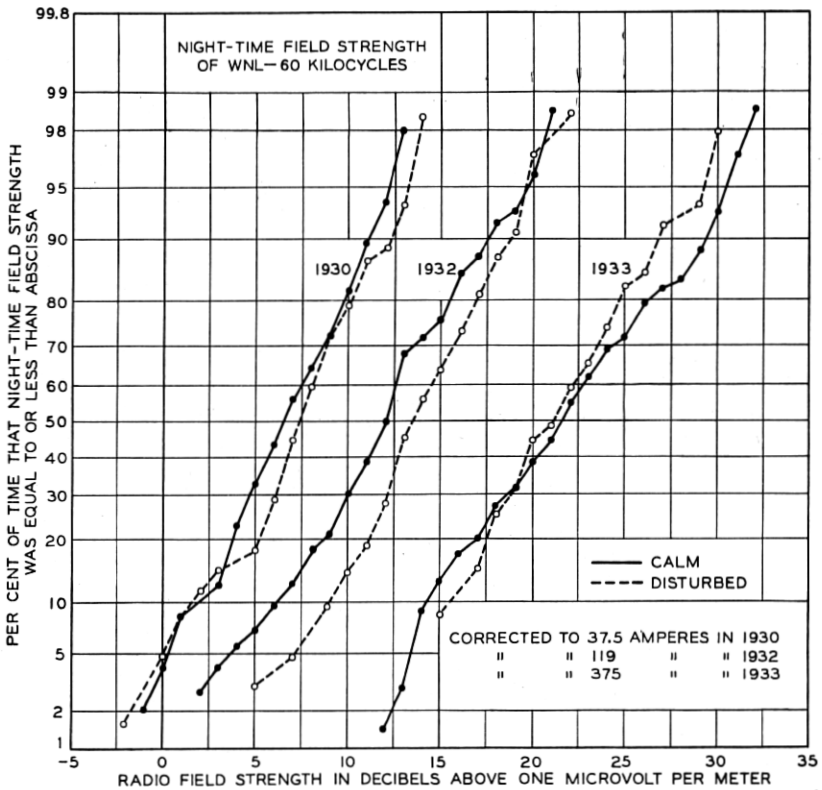

Fig. 8—Cumulative distribution of daily averages of long-wave radio field strength on days of magnetic calm and on days of magnetic disturbance. Night-time transmission path, WNL.

mission, the same result appears only in 1933, whereas in 1930 and 1932 night-time fields averaged higher on disturbed days than on calm days. No reason for this inconsistency has been found.

Correlation with Weather

Other investigators have shown some relation between long-wave field strength and temperature [16] and barometric pressure at short distances.[17] Because of the greater range of weather conditions, the relation is expected to be more obscure on long distance transmission. However, on European signals (15 to 20 kc.) received at Washington from 1924 to 1929, during the periods from September 15 to May 15, there appears [18] "to be a decided drop in signal intensity (measured at 10:00 A.M. and 3:00 P.M.) coincident with heavy rainfall, rising tempertue, and falling barometer, at the receiving station at the time of general storms, and an increased signal intensity as the storm center passes and is followed by clear and colder weather." A conclusion was presented [18] that "either radio waves are subject to large absorption in the lower atmosphere, due to a degree of ionization not known to exist, or surface storms are influenced by conditions existing at great heights."

Disturbed weather conditions may be part of the reason for disturbed transatlantic long-wave (60 kc.) radio reception, but the authors favor the hypothesis that local weather storms are more a symptom of disturbed conditions in higher regions. The same could be said of earth currents.[19] However, since reflection probably occurs at the surface of the earth one or more times on the transatlantic paths, as will be discussed more fully in a paper now in preparation, signals using these paths probably encounter surface weather conditions and earth current influences at least three times.

Correlation with Meteor Showers

An attempt was made to find some correlation between meteor showers and long-wave radio transmission. The sketchy nature of the available meteor data does not provide a satisfactory basis for such a study. Comparison of monthly average meteor hour rates [20] with monthly average radio transmission showed little or no promise of significant relations. Although meteors probably do exert an influence on radio transmission [13, 21, 22] by causing random variations of the received signal, due to changes in ionization of the transmission path, the evidence for major changes in field strength at times of meteoric activity apparently is lacking in our data.

During the four-month period centering on the Perseid shower,* Pickard [23] observed a considerable depression in the day reception of long-wave signals from Nauen (23 kc.) and a considerable increase in medium-wave signals at night from WBBM (1330 kc.), with maximum effects close to the day of meteor shower maximum. No such effect was detected, however, in the data on the long-wave transatlantic radio telephone circuits for the period from 1923 to 1933. In fact, as shown in Fig. 4, if the Perseid shower could be credited with having con-

* According to Olivier in Bulletin No. 8, the American Meteor Society (quoted also in reference 23), the Perseid shower is by far the longest and largest annual meteor shower and extends about 17 days on each side of August 11.

siderable effect on long-wave radio transmission, the effect would apparently be an increase in field strength in daytime, opposite to the result observed by Pickard on signals from Nauen. For the period covered by the curves in Fig. 4, the increased daylight field strength in August is not explained by correlation with the curves of magnetic activity.

Nature and Sources of Data

The long-wave radio telephone data used in this study are measurements of field strength at the receiving stations, and each individual observation is a simple physical measurement. The data taken before 1927, although relatively meager, were observations made under controlled conditions, a single-frequency signal being employed. Since 1927 the data, while much more abundant, had to be taken under operating conditions with speech transmission. However, since such measurements can be made on a commercial circuit only when in the judgment of the operating forces it is desirable and feasible to establish that circuit, it is inevitable that the overall picture will be distorted by the requirements of practical circuit operation. This could readily obscure such minor effects as correlation with meteoric showers, and would be likely to introduce some discrepancies between day and night behavior.

Sources of the data used in Figs. 2 and 3 are as follows:

Ultra-violet and sunspot data from *Terrestrial Magnetism*, **39**, 234, September 1934.
Solar limb-prominences data from *Astronomische Mitteilungen*, **130**, 217, 1933, and from **131**, 23, 1934.
Data for the Washington measurements—for 1923, figure by correspondence with the Bureau of Standards; for 1924 to 1930, reference 24; for 1931–1932, reference 25; observations were discontinued in 1933.
Magnetic character data, "*C*" measure, from volumes 29 to 39, inclusive, of *Terrestrial Magnetism*.
Magnetic activity, u_1 measure, from references 10, 26, and 28.

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APPENDIX I

Measures of Terrestrial Magnetic Activity "C" and "u_1"

Characterization (C)

"Terrestrial-magnetic activity at a given station, and in a certain interval, may be defined as an expression for the frequency and intensity of magnetic disturbances in that interval. There are many ways in which this general definition may be expressed as a numerical measure. *Characterization*, the simplest, is now widely used. In this measure every observatory assigns, from the character of its photographic records, to each interval of 24 hours, between successive Greenwich midnights, a character-figure, '0' for quiet, '1' for moderately disturbed, and '2' for greatly disturbed days. The average for all collaborating observatories (the number of which increased from 30 to about 45, since this measure was begun in 1906) is the international magnetic character-figure C." [10]

"A primary desideratum is to arrive at a clear idea of exactly what it is we want to measure. If our object is simply to discriminate between the days of a single month, with a view to selecting for special purposes the five quietest or five most disturbed days of the month, it is very doubtful whether the existing scheme of international 'character' figures can be improved on. Its simplicity and the small amount of labor it entails are great recommendations. The disadvantages it seems to me to possess are: 1. The significance of any particular 'character' figure, *e.g.*, 1.5, is variable; it connotes decidedly less disturbance in a quiet than in a disturbed year. Also, while the mean 'character' figure for the year does to a certain extent wax and wane with disturbance, the variation seems to me inadequate. 2. The assigning of 'character figures' at an individual station is largely a psychological process, depending on the temperament and knowledge of the judge. The standards in use at different stations at the same time are widely different, and the standard in use at any particular station may vary largely from time to time. The 'character' figures supplied by any two stations do not suffice for a satisfactory intercomparison of the stations, and if we wish to compare one year or season with another the international 'character' figures leave a great deal to be desired." [27]

The "C" measure of magnetic activity may be inferior as a basis for comparing years, but is relatively safe for comparing short intervals such as days within a month. For comparing longer intervals a different measure is desirable, having a homogeneous standard of evaluating magnetic activity from year to year and for all time. This standard measure was called "u," from which was derived the "u_1" measure used in this paper.

u_1 *Measure*

"A short *definition of u* may be repeated as the average change, taken without regard to sign, measured in the unit 0.0001 c.g.s. = 10γ, of the daily means of horizontal intensity on the magnetic equator of the earth. The monthly means of u_1 are derived from those of u:

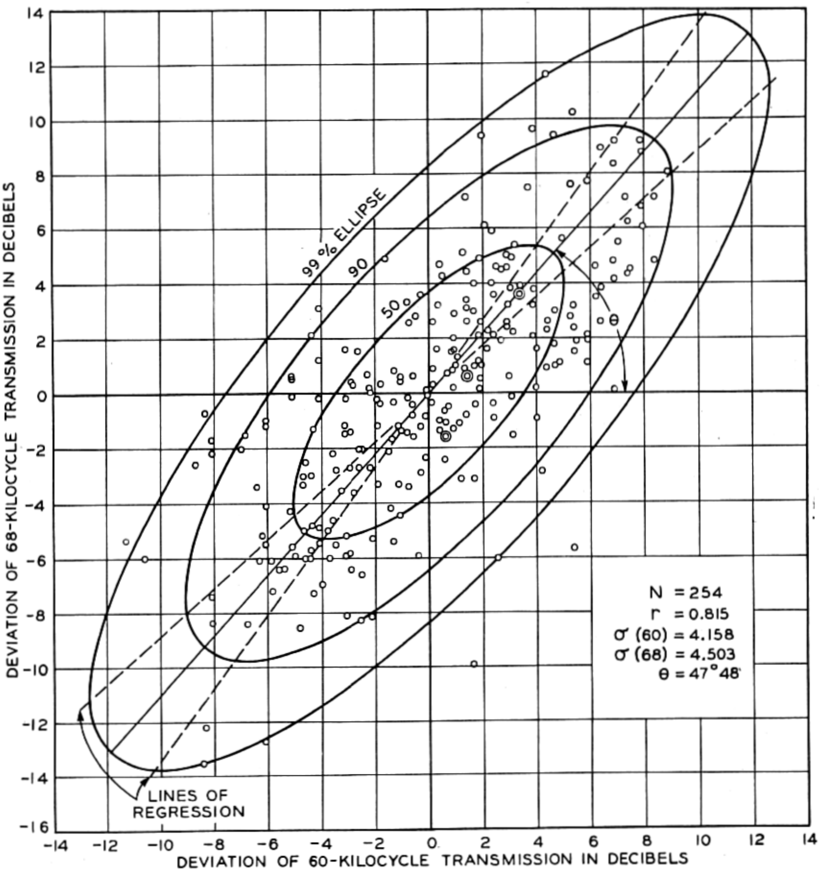

Fig. 9—Correlation diagram of scattering from mean of daily averages of radio transmission over all-daylight paths for the 254 days from May 5, 1931 to March 31, 1932, when GKA–GBY (Rugby, England) was transmitting on 68 kc. and WNL (Rocky Point, N. Y.) was transmitting on 60 kc.

For values of u from 0.0 to 0.6, $u_1 = 100u - 30$.

For higher values,[10]

$$0.6 \text{ to } 1.6,\ u_1 = 30 + 100(u - 0.6) - 30(u - 0.6)^2,$$
$$1.6 \text{ to } 3.6,\ u_1 = 100 + 40(u - 1.6) - 10(u - 1.6)^2,$$
$$3.6 \text{ to } \infty,\ u_1 = 140,$$

u_1 increases less rapidly, approaching asymptotically the limiting value 140. The quantity u_1 has been introduced in order to obtain a measure of activity which has a frequency-distribution similar to that of the relative sunspot-numbers, and therefore is more suitable for research on correlations between terrestrial-magnetic activity and solar activity." [26]

APPENDIX II

Data for East–West transmission were combined with data for West–East transmission for two illustrations, Figs. 4 and 5, given in this paper. Two unpublished studies by the authors of this paper showed that the correlation between transmission from Rugby to Houlton on 68 kilocycles and transmission from Rocky Point to Cupar on 60 kilocycles was very high, 0.80 ± 0.01. The scatter diagrams for these studies were so similar that only one is shown here, Fig. 9. For transmission on 60 kilocycles in both directions the correlation was 0.76 ± 0.02. These results are considered sufficient justification for combining East–West and West–East radio transmission data to obtain average curves.