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SUN, EARTH, AND SHORT-WAVE PROPAGATION
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THE RADIO CLUB OF AMERICA
11 West 42nd Street ★ ★ ★ New York City

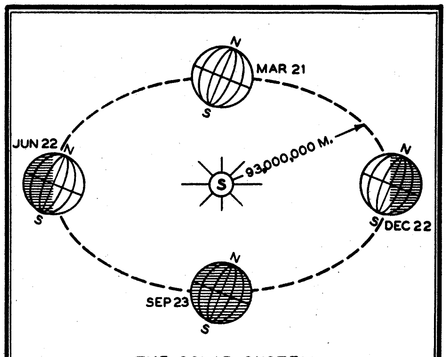
SUN, EARTH, AND SHORT-WAVE PROPAGATION

Effects of the Solar System upon Long-Distance, Short-Wave Communications

BY HENRY E. HALLBORG*

SHORT wave communications circuits girdle the earth. They are practical symbols of the effectiveness of skywave transmission. The signals which they radiate bounce between the radio ceiling and the earth, or sea, carrying an ever increasing portion of the world's interchange of intelligence. Their stage is broadly the solar system. Concurrently, they react to changing conditions on the solar surface, and to the relative positions of neighboring planets. We must not overlook the major astronomical and geophysical aspects of the sun and the earth, if we would better understand short wave propagation.

Elementary astronomy shows us four cardinal positions of the earth, namely, winter, spring, summer and fall, in the earth's annual 600-million-mile journey around the sun. These cardinal positions are reproduced in Fig. 1. The earth's orbit is slightly elliptical, having a mean radius of 93 million miles. About January 1st, perihelion, we are 3 million miles closer to the sun than at aphelion, about July 1st. The radio ceiling is therefore most highly ionized in January. This is verified by brief use of abnormally high frequencies over long distances during this month, although the tilt of the earth's axis away from the sun causes shorter and colder days in the northern hemisphere.



THE SOLAR SYSTEM

RELATIVE DISTANCES OF PLANETS FROM THE SUN AND ORBITAL PERIODS OF ROTATION IN REFERENCE TO THE EARTH

PLANET	SOLAR DISTANCE	PERIOD-YRS.
MERCURY	.4	.25
VENUS	.7	.58
EARTH	1.	1.
MARS	1.5	1.94
ASTEROIDS	2 TO 4	5.2 MEAN
JUPITER	5.2	11.8
SATURN	9.5	29.2
URANUS	19 2	85
NEPTUNE	30.1	164
PLUTO	39.6	250

FIG. 1. THE EARTH'S ORBIT AND THE FORMATION OF THE SEASONS

Fig. 1 also contains a tabulation of the distances, and rotational periods, of the principal members of our solar system. The rotational period of Jupiter, our largest planet, is of particular interest in connection with the sun spot cycle, which so intimately affects short wave propagation. Jupiter makes the journey around the sun in 11.8 years. The average length of a sun spot cycle is 11.1 years.

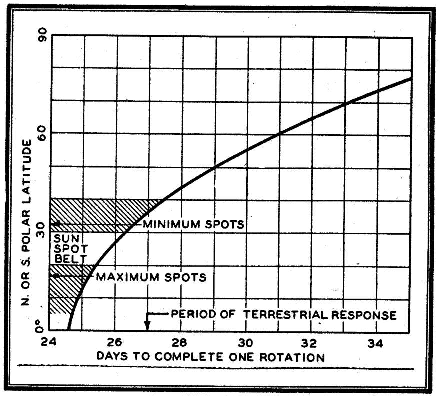


FIG. 2. THE SOLAR ROTATION CYCLE

In an electronic sense the sun is the filament, and the earth the plate, of a vast electronic tube of which the vacuum is supplied by outer space. The sun provides the radiations which energize and sustain our radio roof. The sun is an incandescent gaseous body whose rotational period varies with solar latitude. It completes one rotation in 24.6 days at the equator, and in 35.6 days at solar latitude 80°. New solar surfaces of varying radiative properties are continuously being presented to the earth. The particular solar area that causes the most prolonged variations of the radio roof is the sun spot belt. This is located on the sun, north and south of the solar equator, between latitudes 5° and 40°. Spots on the sun first appear at the higher latitude, and, during the course of the 11-year cycle, work downward toward latitude 5°. The new cycle starts with a rather abrupt recurrence of spots at the higher latitudes. The actual numbers of spots observed are at a maximum around solar latitude 16°. Spots provide a convenient means for measuring the rotational period of the sun. The solar period in terms of measurable effects on terrestrial magnetism is 27 days, which is the accepted solar rotational cycle. Fig. 2 contains a graphical summary of the above mentioned solar data interpolated from Doctor C. G. Abbot's most interesting book "The Sun."

Sun spot areas are the seats of sustained radio roof disturbances which not infrequently last from 3 to 5 days. These disturbed periods are known to radio men as *magnetic blankets*. A more sudden and annoying type of disturbance is the *drop-out.* This may be as completely effective as the opening of a switch, for periods of from 2 to 20 minutes. Drop-outs are caused by sporadic solar eruptions of hydrogen, and the lighter solar gases. Eruptions often precede the formation of a sun spot group. Viewed from the edge of the solar disc both sun spot and flare types of solar activity would appear as prominences. The quiescent, or stable type, may accompany a sun spot area, whereas the eruptive or flare type may occur anywhere on the solar disc. The effect of a flare on the earth, however, is at a maximum when it occurs near the center of the solar disc. Typical solar prominences are shown in Fig. 3. The quiescent type may recur after a 27-day rotational cycle. The flare type has no recurrence cycle.

We now return to earth for our short

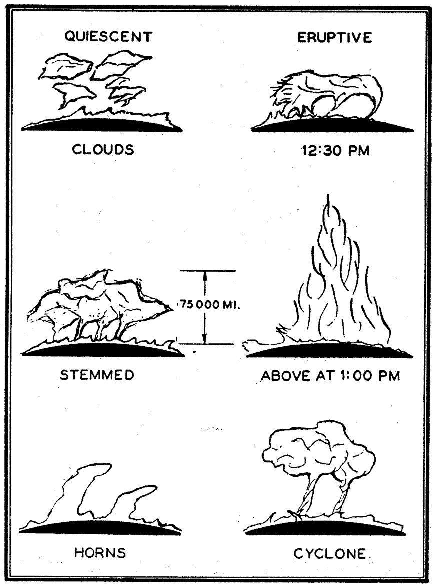


FIG. 3. SIX TYPICAL TYPES OF PROMINENCES AT SUN'S DISC

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* Radio Corporation of America, Camden, N. J. A paper delivered before the Radio Club of America Columbia University, January 15, 1942.

wave propagation study. Our atmosphere is normally thought of as the air we breathe, having maximum density at the earth's surface. The density drops to the vanishing point at the radio roof, several hundred miles above us. If we could be physically transported upward toward the radio roof a number of unique encircling layers would be encountered. The designations and distinguishing characteristics of these layers are illustrated in Fig. 4.

The first, and lowest, layer to be crossed is the *Troposphere.* It extends upward to a height of about 10 miles. It is the layer of earth-bound weather and human habitation. Within it, winds, clouds and thunderstorms exist, continuously generating, in some part of the globe, radio static. For each mile of our ascent the temperature would be observed to drop 17° F. The barometer at 3 miles altitude would read only one-half that at the earth's surface.

We would then enter a second layer, the *Stratosphere,* extending upward to a height of about 22 miles. The barometer here would read less than 1/10th that at the earth's surface. The thermometer would register − 67° F. This temperature would be found quite constant day and night, for which reason this envelope has also been called, the "isothermal layer."

Above the stratosphere, and extending upward to a height of about 40 miles, we would come upon the *Ozonosphere.* This layer contains free oxygen. It has the life prèserving property of absorbing the deadly actinic rays of the sun. In the process of absorption its daytime temperature rises to about 200° F. At night, in the absence of actinic rays, its temperature drops to that of the stratosphere, about − 67° F.

A fourth layer, the *Alto-Troposphere* would be encountered extending above the ozonosphere to a height of about 60 miles. This is a quasi-vacuous region of sporadic radio reflections and absorptions. It may be opportune here to observe that absorption not only involves temperature rise, but also expansions of free gases. Radio absorption screens and blankets are formed by solar radiations which penetrate to the Alto-Troposphere. Sunlight also suffers absorption in this layer. The region consequently undergoes wide temperature and volume changes between day and night. Air density here has dropped to such low values that breakdown of residual gases may be likened to the blue glow in a leaky radio tube. The layer is a dividing zone for sky wave transmission. Long waves are reflected by it. Short waves suffer varying degrees of absorption and penetration depending upon their relative frequencies.

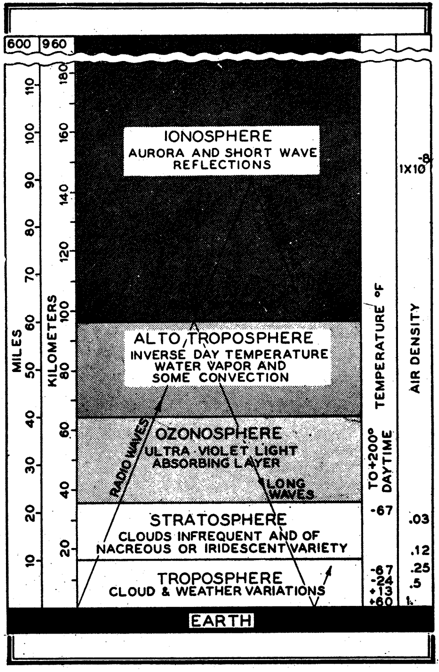


FIG. 4. THE EARTH'S ATMOSPHERIC SHELLS

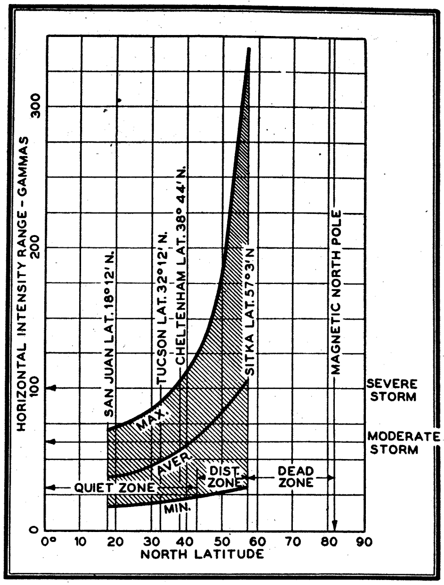


FIG. 6. 1931 VARIATION OF HORIZONTAL INTENSITY RANGE WITH N. LATITUDE

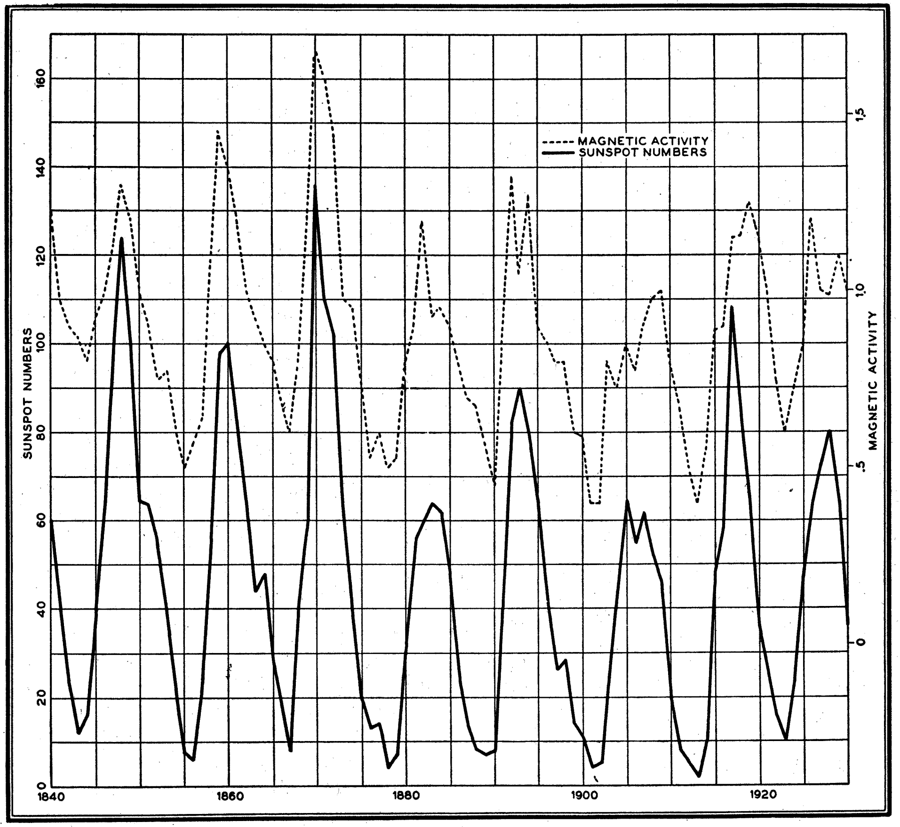


FIG. 5. ANNUAL MEANS OF MAGNETIC ACTIVITY AND RELATIVE SUNSPOT NUMBERS DURING THE PERIOD FROM 1840 TO 1930

The fifth and last layer to be entered, the *Ionosphere,* extends upward from 60 miles to an indefinite upper height. Here are found free ions, practically a perfect vacuum, and two major stratifications of free ions. The lower stratification, at a mean height of about 75 miles, is the well known Kennelly-Heaviside layer, or E layer. The upper stratification, or F layer, has a mean height of about 200 miles. By virtue of absorption and expansion it separates into two layers, F_1 and F_2, in the daytime. These layers are well known to the radio profession. Daily, seasonal and secular variations of the ionosphere are the subject of periodical publications, notably by the National Bureau of Standards, and the Carnegie Institution.

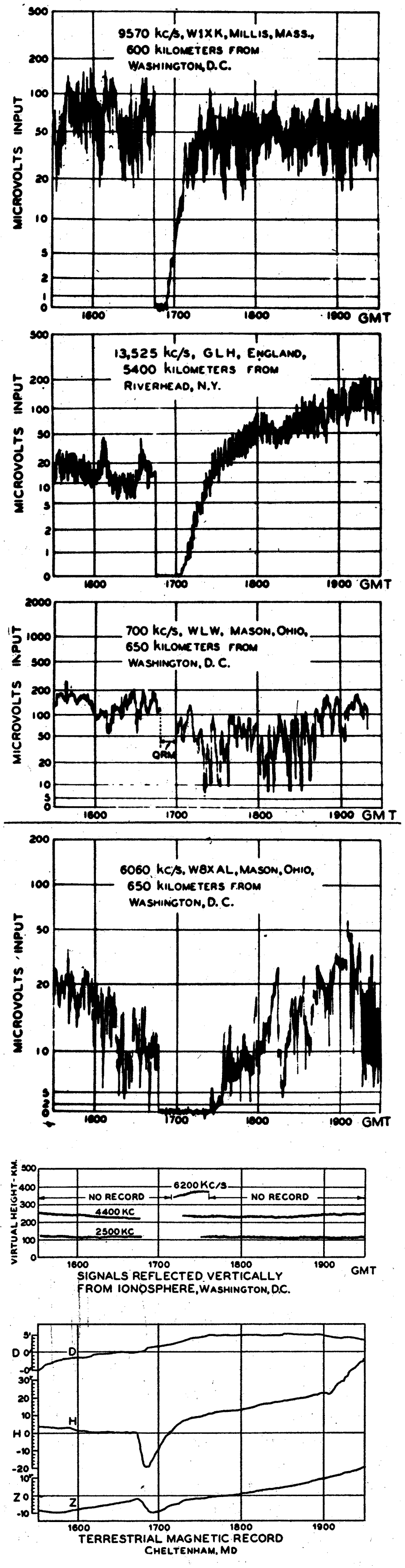


FIG. 8. EFFECTS OF A FLARE TYPE OF DISTURBANCE, AS SHOWN BY RECORDINGS MADE AT THE BUREAU OF STANDARDS, WASHINGTON, D. C., APRIL 8, 1936

Dr. J. Bartels of the Carnegie Institution has provided a most interesting century long correlation between magnetic and solar activity. This covers the period from 1835 to 1930. It is reproduced in Fig. 5 from data originally published in the March, 1932, Journal of Terrestrial Magnetism and Atmospheric Electricity. The long period interrelationship between magnetic activity, and relative sun spot numbers is convincingly indicated by these data.

Terrestrial magnetic range is normally measured as a difference between maximum and minimum deflections in a unit of time. Terrestrial magnetic range increases sharply with proximity to the earth's magnetic poles. Disturbance on short wave circuits likewise has long been known to increase with proximity to the earth's magnetic poles. A study of this effect was made by the author from terrestrial magnetic data of North American magnetic observatories supplied for the year 1931 by the U. S. Coast and Geodetic Survey. The recorded range values were evaluated to correspond to observed moderate and severe radio circuit disturbances. The results are plotted in Fig. 6. Some uncertainty has always existed as to the exact bearing of the magnetic north pole. At the time these data were plotted the published location was 71° N. The method of applying the radio-magnetic relationship remains valid, however, whatever the actual location of the magnetic pole. An application of the data of Fig. 6 to radio circuits working to and from New York City can be made to Fig. 7, an azimuthal map of the world with New York City as its center. Based upon the curve marked "average" of Fig. 6, "dead" and "disturbed" zones can be laid out on the map. They would picture mean magnetic conditions for the year 1931. The Dead Zone would be delineated on Fig. 7 by a radius equal in length to the intersection in Fig. 6 of the severe storm level with the magnetic pole, and with the curve marked Average. This radius measures about 13° of latitude. Similarly, the Disturbed Zone would be defined by the intersection of the moderate storm level with the Average curve of Fig. 6. If the radius of Fig. 6 had been taken to intersect with the curve marked Maximum instead of to the Average curve the dead zone would then overlap the disturbed zone on Fig. 7 and the storm period disturbed zone would approach the equator. On the other hand, during quiet conditions, application of the

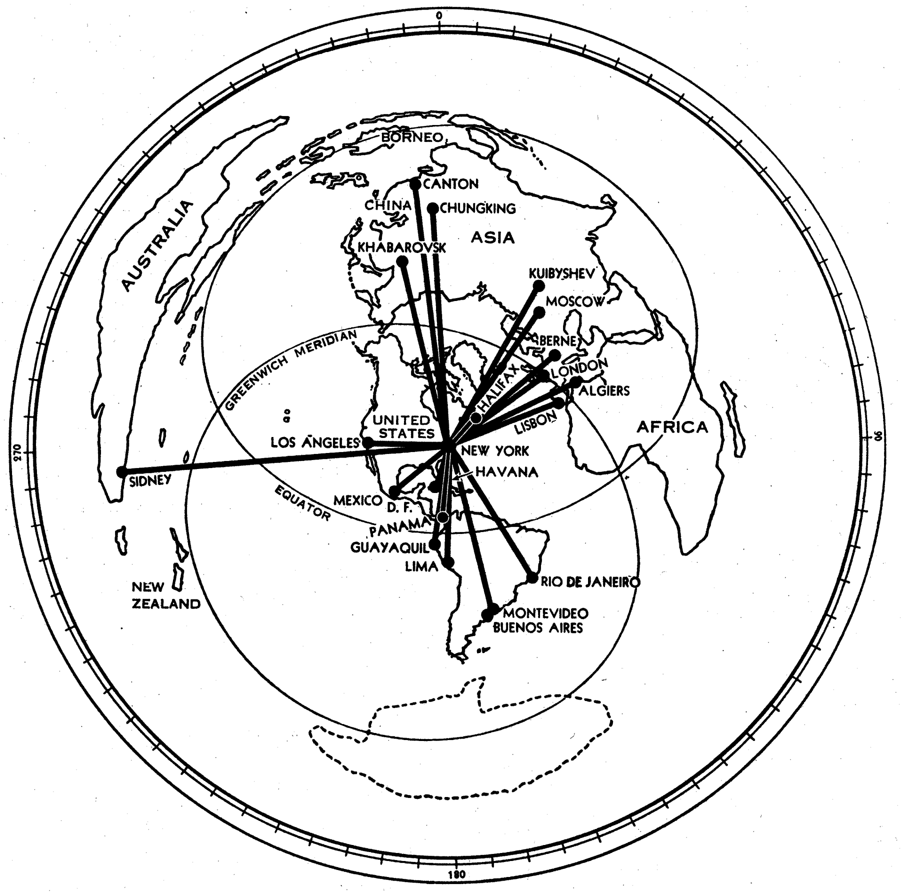


FIG. 7. AZIMUTHAL MAP OF THE WORLD, WITH NEW YORK AS THE CENTER

curve marked MINIMUM of Fig. 6 would produce no intersection with either the moderate or severe storm level, hence no dead zone would exist on quiet days.

A recording made at the Bureau of Standards, Washington, D. C., on April 8, 1936, and submitted for reproduction provides a graphic illustration of the effects of a flare type of disturbance in producing sudden drop-outs. The recording is reproduced in Fig. 8. Circuits having frequencies of 6.06 mc., 9.57 mc. and 13.525 mc. are seen to cut off promptly at 1640 GMT, and to stage varying degrees of recovery. A broadcast circuit, WLW, of .7 mc. is not affected by the flare, but records QRM during the drop-out interval. At the lower right a recording of the horizontal magnetic intensity trace at Cheltenham shows a steep dip, and gradual recovery, during the drop-out. Reflections by vertical incidence from the ionosphere are seen to cut off at the same instant, namely 1640 GMT, but the higher frequencies are the first to return. This characteristic is also the normal observation over point-to-point circuits. Penetrating radiations from the flare reach the alto-troposphere where they cause ionizations that set up temporary absorption screens in the normal path of the radio wave. The absorbing screen dissipates when the flare subsides, whereupon normal conditions return, since the normal reflecting layers remain unaffected.

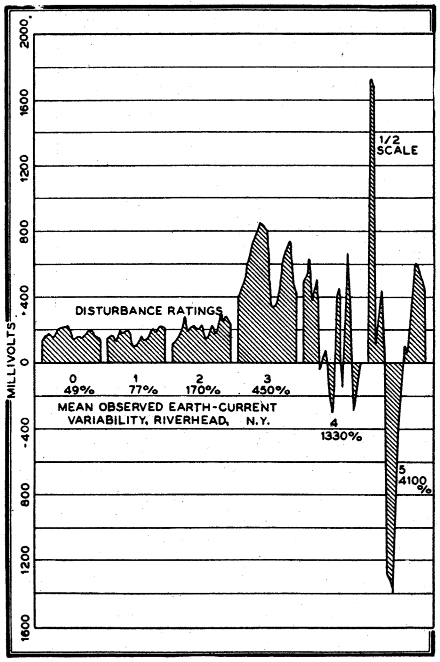


FIG. 9. TRACES CORRESPONDING TO RCAC SCALE OF DISTURBANCE RATINGS

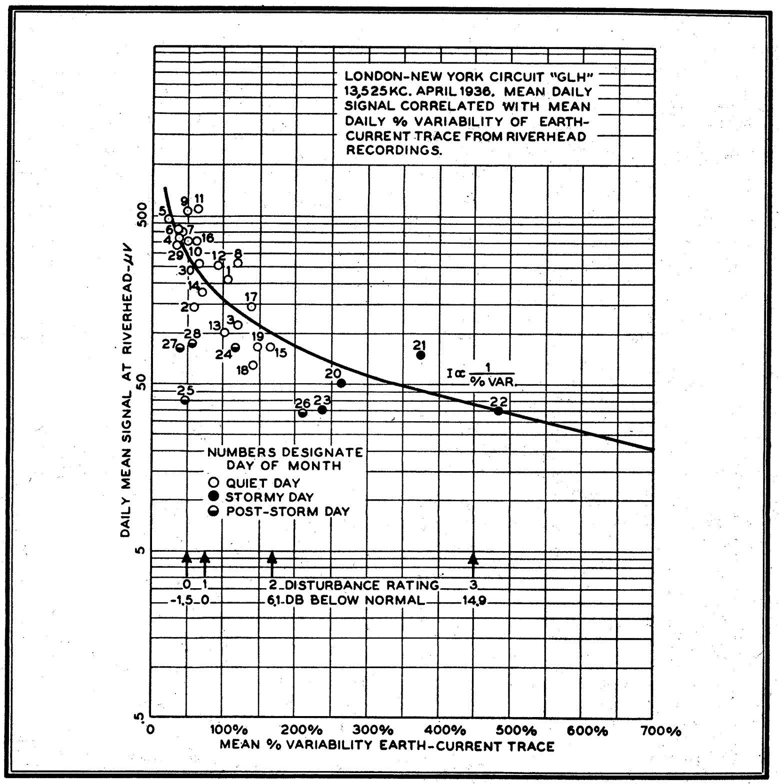


FIG. 10. SIGNAL VERSUS MAGNETIC ACTIVITY, GEOMAGNETIC N. LAT. 59° MEAN

A continuous record of short wave circuit disturbances is maintained on the world wide traffic channels of R.C.A. Communications, Inc. A disturbance rating scale of 0 to 5 is applied to each 8 hour watch. The scale numbers are defined, and evaluated in accordance with the following table:

NUMBER	DISTURBANCE	SIGNAL
0	Unusually Quiet	Unusual Strength
1	Normal Conditions	Strength Normal
2	Slightly Disturbed	Slightly Below Normal
3	Moderately Disturbed	Considerably Below Normal
4	Severely Disturbed	Nearly Out; But Still Audible
5	Complete Drop-out	Inaudible

The circuit disturbance ratings provide a continuous source of radio conditions reference. Plotted in sequences of solar rotations they indirectly chart the ranges of solar activity. They provide means for the prediction of probable propagation conditions during each new solar rotation. An additional source of ionosphere monitoring is maintained by R.C.A. Communications, Inc., in the form of an earth-current recorder at its Receiving Terminal, Riverhead, L. I., N. Y. This consists of a ground loop, 6 miles long, formed by utilization of an abandoned South American long wave antenna in which has been inserted a series resistor, through which induced earth-currents circulate. The voltage drop in this resistor is continuously recorded. The rate of change of earth-current is measured in terms of a variability unit, which expresses rate of change per hour as a percentage of increase of trace length. Typical earth-current traces are reproduced in Fig. 9. They are taken to correspond to mean values of circuit disturbance ratings from the 0 to 5 scale circuit records. Signal strength variation is found to follow quite closely an inverse variability law, which means that doubling of the variability should halve the signal.

The inverse variability law was applied to London Signal "GLH", 13,525 kc., during the disturbed month of April 1936. Mean daily signal strengths from signal recordings were compared to mean daily Riverhead earth-current variabilities during the working hours of the signal. The results are plotted in Fig. 10. Three types of days must be recognized for the proper analysis of the results, namely quiet days, storm days and post storm days. Post storm days are governed by residual ionization and absorption, consequently may be excepted in laying out the variability plot. The solid curve of Fig. 10 is obtained by applying the inverse variability law. The agreement is seen to be close enough to indicate that subnormal signals and earth-current variability are both proportional effects caused by terrestrial magnetic activity.

The amount of radio station power required to combat magnetic conditions has been a matter of speculation. The observed inverse relationship between signal and earth-current variability has provided the means for computing required antenna inputs over a given circuit corresponding to circuit ratings 0 to 5. A plot of computed antenna inputs in kilowatts needed to provide a commercial signal over the North Atlantic on a circuit having a mid point at 60° north geomagnetic latitude is shown in Fig. 11. The kilowatt antenna input required is seen to vary, in round numbers, from ½ kw. for circuit rating 0 to 4000 kw. for circuit rating 5. The 4000-kw. figure means that it is impractical to utilize a high latitude short wave circuit during conditions corresponding to rating 5. The ratio of power required for circuit rating 5 compared to circuit rating 0 is 8000 to 1.

The wide range of power required to produce a commercial signal over a circuit whose mid point geomagnetic latitude is 60° N logically leads to the question, what power ranges will be required over circuits whose mid points are nearer the equator? An answer to this question was obtained by deriving a relationship between earth-current variability and horizontal magnetic intensity ranges at equal latitudes. The derived relationship was then applied to horizontal intensity recordings from all the North American Magnetic Observatories. The results for the year 1939 are shown in Fig. 12. These data provide a direct comparison of power requirements for a circuit whose mid point latitude is 60° N geomagnetic, as compared to a circuit at 30° N geomagnetic. The comparison shows that under storm conditions 688 times as much power will be required for the high latitude station, and 7.5 times as much under quiet conditions. The signal improvements in field intensity for the low latitude station are correspondingly 26 to 1, and 2.7 to 1 respectively.

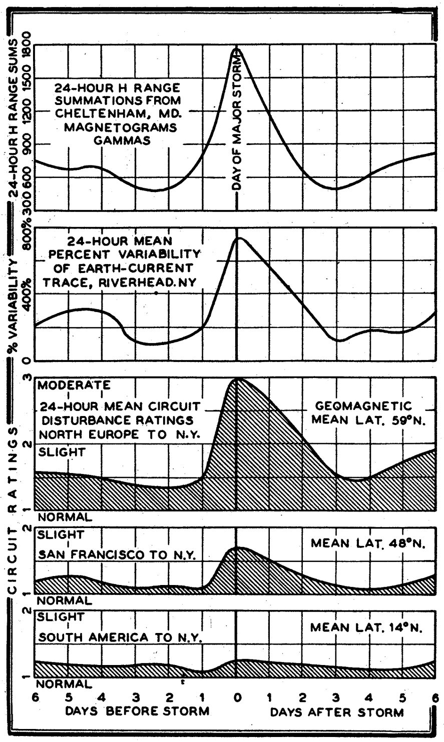


FIG. 13. DATA RECORDED AT RIVERHEAD

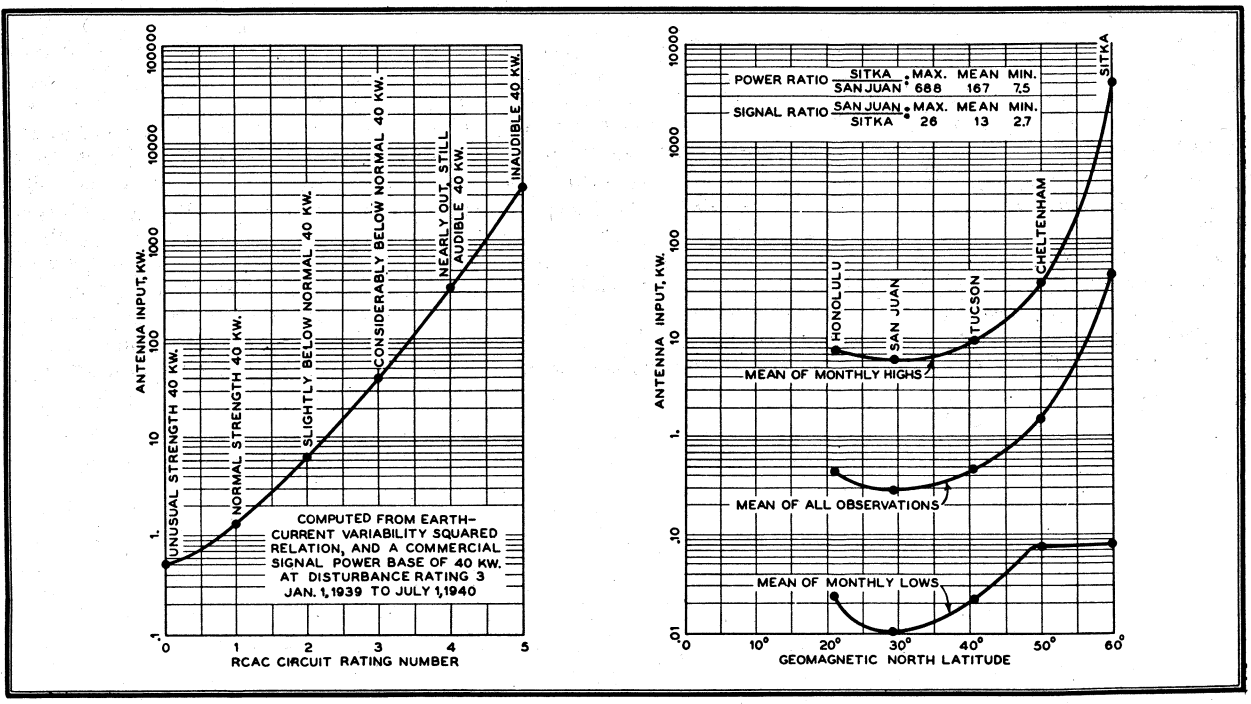
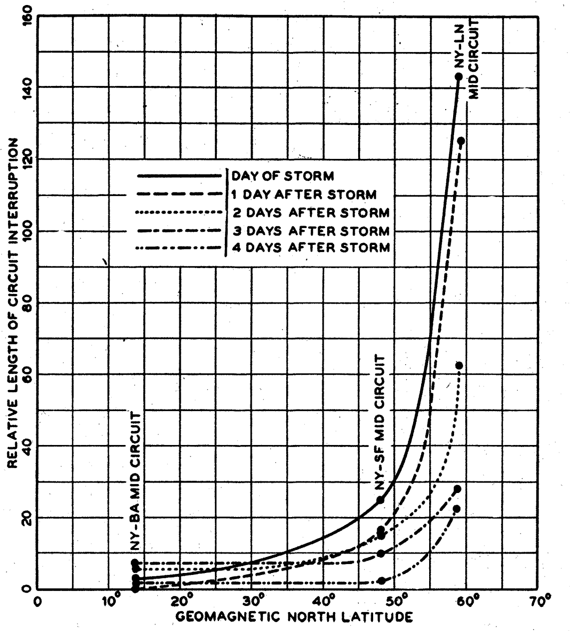


FIG. 11, LEFT. KW. ANTENNA INPUT FOR COMMERCIAL SIGNAL AT VARIOUS RCAC DISTURBANCE RATINGS ON NORTH ATLANTIC, MEAN GEOMAGNETIC LAT. 60° N. FIG. 12, RIGHT. COMPUTED RELATIONSHIP BETWEEN COMMERCIAL SIGNAL, ANTENNA POWER, AND MIDCIRCUIT GEOMAGNETIC LATITUDE. H RANGE DATA FOR THE YEAR 1939

Prevailing circuit conditions 6 days before, during, and 6 days after 16 major sun spot passages of 1939 and 1940 have been studied. A summary of the mean circuit ratings, and the corresponding Riverhead earth-current variability ranges, and Cheltenham horizontal magnetic intensity ranges are shown in Fig. 13. The improved operation of low latitude stations is quite evident. Riverhead earth-current variability is lowest two days before the storm day. North Atlantic circuits correspondingly show the lowest disturbance. Nature thus provides a practical warning of the storm to follow, a fact which has not been overlooked by the Operating Staff.

The persistence of residual ionization and absorption on high latitude sky wave circuits has previously been mentioned. This circuit characteristic was studied during the 16 major sun spot passages mentioned in the preceding paragraph. The results for circuits whose mid points have various geomagnetic latitudes are shown in Fig. 14. This figure plots relative lengths of circuit interruptions against the geomagnetic mid point latitudes of the circuits. Circuit interruptions are seen to increase sharply at about 55° N geomagnetic latitude. The New York-London circuit is more disturbed on the 3rd day following a storm, than is the lower latitude New York-San Francisco circuit during the height of the storm. The low latitude New York-Buenos Aires circuit is relatively unaffected.

An example of a most spectacular solar rotation is shown in Fig. 15. It covers the period from March 17 to April 12, 1940. This period was outstanding in that it produced two major sun spot barrages, with associated aurora, and cable and radio interruptions for several days, in the



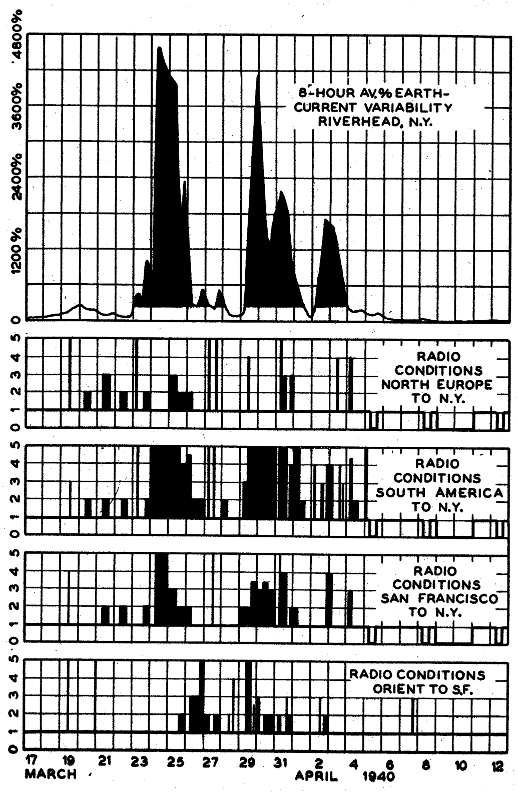


FIG. 14, LEFT. RELATIVE LENGTHS OF CIRCUIT INTERRUPTIONS DURING 16 MAJOR STORMS, 1939-1940.
FIG. 15, RIGHT. SPECTACULAR EXAMPLE OF SOLAR ROTATION OBSERVED MARCH 17 TO APRIL 12, 1940

form of independent storms within 5 days of each other. The measured earth-current variabilities from recordings at Riverhead are plotted in comparison with the reported disturbance ratings on world wide circuits of R.C.A. Communications, Inc., for each day of the solar sequence. The following interesting facts may be observed from a study of the figure. A *flare* type of disturbance strong on all circuits occurred on March 19th, 5 days before the first major disturbance on March 24th, and a second on March 23rd one day before. A third flare on March 27th preceded by 2 days the second major disturbance of March 29th. Earth-current variabilities of over 4000% were recorded at Riverhead. High frequency outages of several days duration occurred on North Atlantic circuits. South American circuits, on the other hand, showed only moderate disturbances, except for the short period flare type of drop-outs which are normally more intense; but fortunately brief on the equatorial circuits. A period of absolute calm on April 9th and 10th completes the gamut of a most unusual solar rotation.

It is concluded from the evidence herein presented that the sun, the earth and the sky are truly co-actors on the stage of short wave propagation. The moods of the actors on the stage are fortunately calm and serene most of the time. The percentage of disturbances such as above described is well under one per cent per annum. In all fields of endeavor, perfection is quite remote. The remaining one percent may perhaps still be achieved in better understanding of wave propagation.

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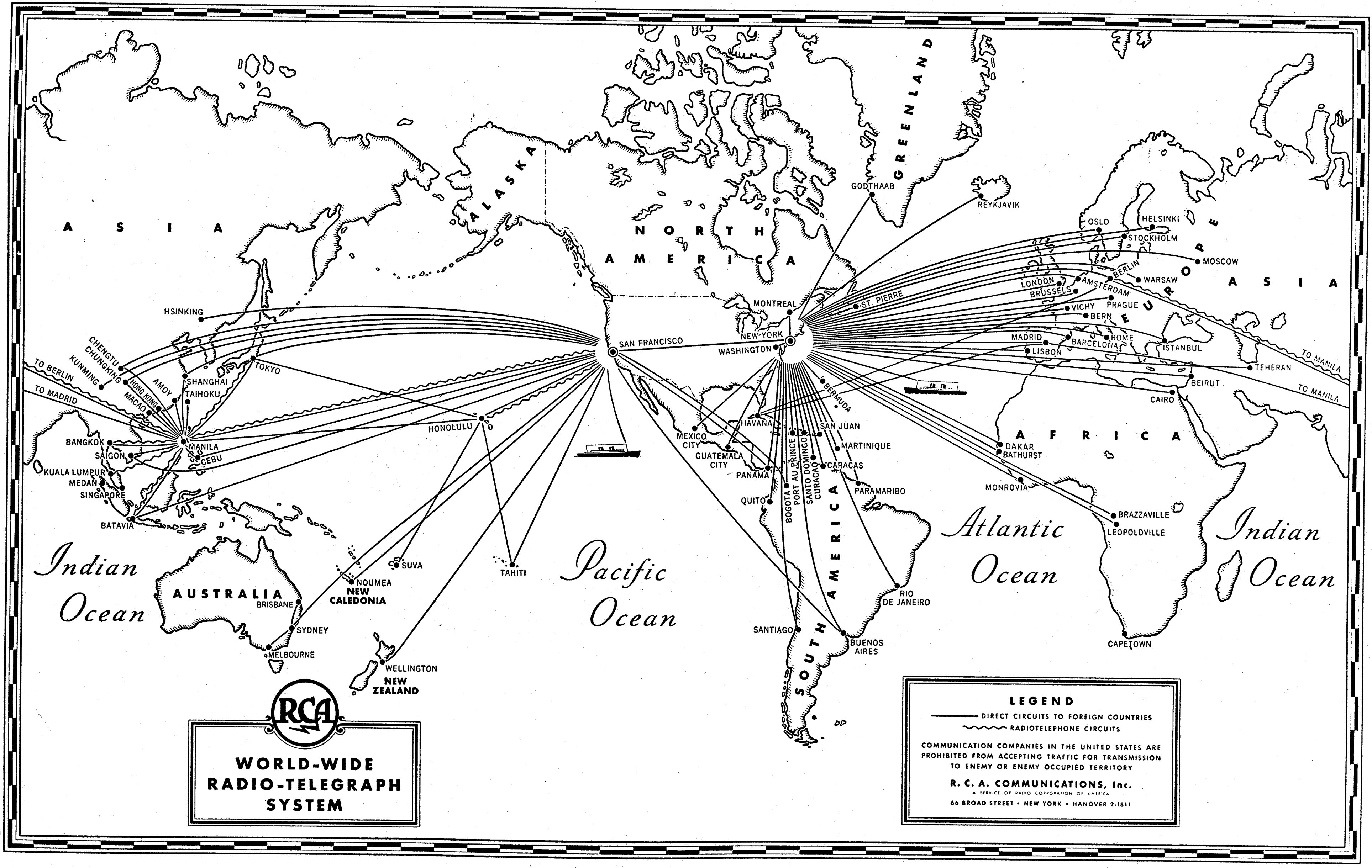

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