ON THE RELATION BETWEEN LONG-WAVE RECEPTION AND CERTAIN TERRESTRIAL AND SOLAR PHENOMENA*

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Summary—*It is shown in the paper that there appears to be an inverse relation between long-wave reception on 75 kc per sec. and the temperatures at the transmitting and receiving stations, when the distance between them is not great. The explanation is offered that the variations i the temperatures and in the signal strength are due to a common source, the changes in the medium between the two places.*

If at all, only a direct relationship has been noticed between field intensity and the barometer reading at the receiving station.

There is found to be good correlation between atmospheric ozone in northwestern Europe and Bangalore reception, and between the two and sunspots. Little correlation is found between these and terrestrial magnetism as represented by the international magnetic character of day numbers. Analysis of the data on the basis of the 27-day period has yielded very satisfactory agreement between reception and sunspots, with a six-day period in reception for which no explanation is found.

The lag of one to two days between reception and sunspots occasionally occurring has been explained on the basis of the emission of high speed corpuscles from the sun. Regarding some of the differences between long- and short-wave transmission, the transmission of short waves is attributed to electron movement in the higher regions of the upper atmosphere and that of long waves to less mobile ions below. It is on this basis that the correlation between reception and ozone may be explained.

The paper is in connection with the signal intensity measurements of Madras (Fort) Radio working on 75 kc per sec., made at the Radio Laboratory of the Indian Institute of Science, Bangalore, between March 1926 and August 1927, a period of eighteen months.

1. INTRODUCTION

DURING the last few years, attention has often been drawn to the possible connection between the strength of received radio signals and some of the terrestrial and solar phenomena. In the undoubted influence of the sun on radio wave transmission, interest has been centered on the understanding of the relation of the spots on the sun to the field intensity of distant radio stations. Of the terrestrial phenomena are (a) local temperature and pressure, (b) atmospheric ozone, and (c) the earth's magnetism, with which relation is sought. The success that has attended long distance communication by the use of very high frequencies and some of the opposite effects observed in long and short waves by the same cause have stimulated interest in the study.

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In a general way, the problem can be considered to be a statistical one, depending on data accumulated for a considerable period over as much as possible of the radio spectrum, parallel to those on phenomena with which relation is sought. Such complete data do not exist for a short period of even a year. The statistical study has, for some time, receded into the background, due to the fruitful results obtained by the application of optical methods to the study of wave propagation sometimes under special conditions, as in the experiments of Breit and Tuve, Appleton and Hollingworth.

Of the statistical investigations, those of G. W. Pickard[1] and of L. W. Austin[2] are important both for their reliable observations and the fairly long period of time which they cover. Of special interest are the observations of Austin which date back to 1914.

Daily measurements of the received field intensity of Madras (Fort) Radio (VWO), on a test signal transmitted at 0800 I.S.T., have been going on since March 1926 at the Radio Laboratory of the Indian Institute of Science, the frequency of the transmission being 75 kc per sec. Bangalore is about 295 km from Madras, almost directly to the west of it. The method of measurement and some preliminary observations have been described elsewhere.[3]

Although the results in the paper relate to a period of eighteen months, the conclusions drawn can only be tentative in character and cannot partake of the nature of established facts. There have been occasional breaks in the field intensity measurements; in August 1926, the monsoon was responsible for the breakdown of the apparatus for some period, due to the high humidity in the air; traffic pressure

[1] G. W. Pickard:—
  (a) "Correlation of Radio Reception with Solar Activity and Terrestrial Magnetism," PROC. I. R. E., **15**, 83; February, 1927.
  (b) "The Relation of Radio Reception to Sunspot Position and Area," PROC. I. R. E., **15**, 1004; December, 1927.
  (c) "The Correlation of Radio Reception with Solar Activity and Terrestrial Magnetism, II," PROC. I. R. E., **15**, 749; September, 1927.
  (d) "Some Correlations of Radio Reception with Atmospheric Temperature and Pressure," PROC. I. R. E., **16**, 765; June, 1928.
  (e) "Discussion on Long Distance Receiving Measurements at the Bureau of Standards," PROC. I. R. E., **15**, 539; June, 1927.

[2] L. W. Austin:—
  (a) "Long Wave Radio Measurements at the Bureau of Standards in 1926 with Some Comparisons of Solar Activity and Radio Phenomena," PROC. I. R. E., **15**, 825; October, 1927.
  (b) "Radio Atmospheric Disturbances and Solar Activity," PROC. I. R. E., **15**, 837; October, 1927.
  (c) "On the Influence of Solar Activity on Radio Transmission," PROC. I. R. E., **16**, 166; February, 1928.

[3] K. Sreenivasan:—
  (a) "Madras (Fort) Radio Field Intensity Measurements at Bangalore," *Jour.* Ind. Inst. Sc., **9B**, 37, 1926.
  (b) "Intensity Variations of Madras (Fort) Radio Station," *Jour.* Ind. Inst. Sc., **10B**, 35, 1927.

during the latter half of December and the early part of January rendered the transmission of the test signals very irregular.

2. METHODS OF ANALYSIS

The methods of analysis followed in arranging and correlating the data of the various elements are mainly two. (a) Periodic averages of a weekly or monthly type or of both, are compared with respect to the variations therein. (b) With any one of the elements as a reference quantity, the variations of that quantity and of reception on either side of the maximum or minimum days of the former are studied. This method has been extensively used, a very interesting instance being the paper by Chree and Stagg in a study of the 27-day period in terrestrial magnetic phenomena. Further, to get rid of comparatively transient changes and bring the main similarity or dissimilarity between the two quantities under examination, considerable use has been made of the smoothing formula $(a+2b+c)/4$.

3. TEMPERATURE AND SIGNAL STRENGTH

The daily local temperature at Bangalore has been obtained from the Bangalore Meteorological Observatory and relates to 0819 I.S.T., 19 minutes after the signal has been transmitted. Those for Madras for the same time were obtained from the Madras Observatory. That the temperature of the room in which the signal is measured is not necessary will be evident at a later stage.[4]

Practically every experimenter in field intensity measurements has come to the general conclusion that the months October to January form a period of very pronounced changes in the daily intensities of radio stations, especially of long waves, in the band 100 kc per sec. to 12 kc per sec. At moderate distances, as Hollingworth[5] showed, the change may be either a decrease or an increase depending upon the position of the receiving station in the interference pattern produced by the ground and the downcoming rays. In general, at fairly big distances, the variations are an increase, including in this statement the Bangalore observations on Madras, though with only 295 km between them.

It is exactly this period of the year which is characterized by low temperatures, the hotter seasons being characterized by low field intensity. Austin's curves (loc. cit.) for Tuckerton and New Brunswick are very good examples of this.

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[4] C. Chree and Stagg, "Recurrent Phenomena in Terrestrial Magnetism," *Roy. Soc., Phil. Trans.*, **227**, 21–62, Aug. 3, 1927.

[5] J. Hollingworth, "Propagation of Radio Waves," *Jour.* I. E. E., **64**, 1926.

To determine if the interrelation between the two is purely restricted to the receiving station temperature or if there is any relation with the temperature at the transmitting station as well, the two temperatures were plotted together with the rather unexpected result that the curves march almost parallel to each other. Evidence of this can be seen in the detailed curves *a* to *j* of Fig. 1, where the daily deviations

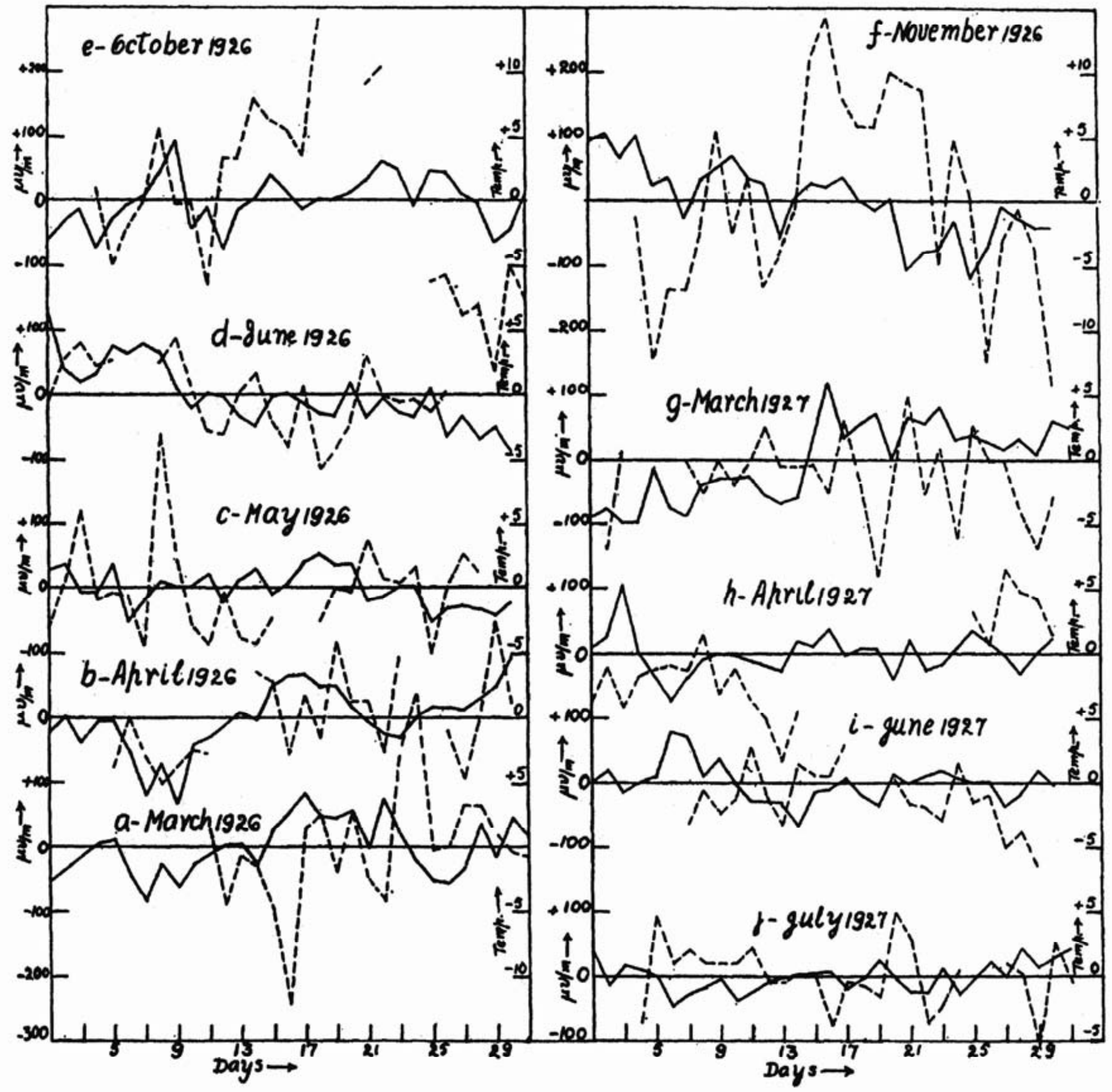

Fig. 1

from monthly averages are plotted. Even in the matter of details, the agreement between the weekly averages plotted in Fig. 2 as the ratio $100/T$ is very close. With monthly averages, the parallelism between the two temperature curves is hardly broken. (Fig. 3)

These curves show a broad inverse relation between temperature (at either station) and field intensity. Of closer similarity there is none, due obviously to the masking influence of other factors of both terrestrial and solar origin. That the inverse relation is not a purely local matter, but is due to changes that are common to the temperature throughout the distance between the stations is the chief point of interest. In view of this, it is legitimate to expect that in the results of Austin too, the transmitting station temperature will have parallel changes with those at the receiving station.

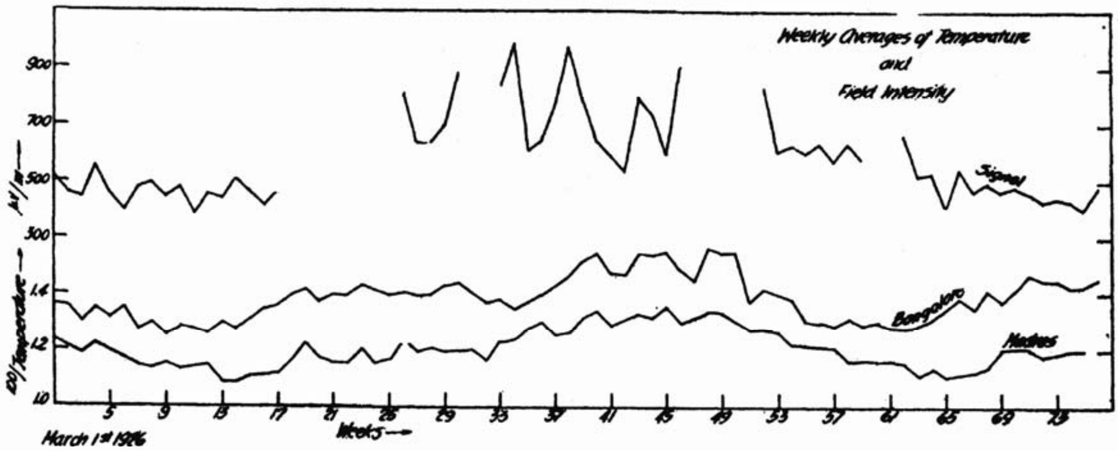

Fig. 2

The intervening medium between the two places undergoes changes which are reflected in those of the temperatures at the two stations, so that the inverse relation between field intensity and temperature is not strictly of a local character but is due to the non-local type of changes occurring between the two stations.

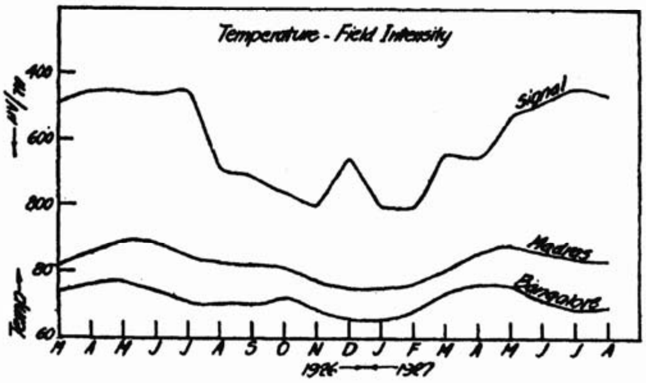

Fig. 3

Of interest are the curves of daily departures from monthly means, although they sometimes give contradictory results (Fig. 1). During some months, such as November 1926, the daily variations of intensity are very big; but they are not accompanied by as pronounced changes in temperature. In this month, Bangalore temperature shows a gradually diminishing tendency; the field strength decreases in the first week, then increases rapidly and as rapidly gets low with a suggestion of a six-day period. During March 1927, however, the temperatures at both places are generally on the increase while signal strength variations, though big, show an increasing and then a decreasing character just opposite to what we had for November, 1926.

Although it may appear contradictory to the inverse relationship, the curves for the months April, June, and October 1926 indicate that the broad variations in both temperature and field intensity are similar; but during the "steady" months, especially in May 1926, when the day-to-day intensity variations are comparatively smaller than in the winter months, the inverse relation is better brought out. April 1927 is another instance of the "steady" months.

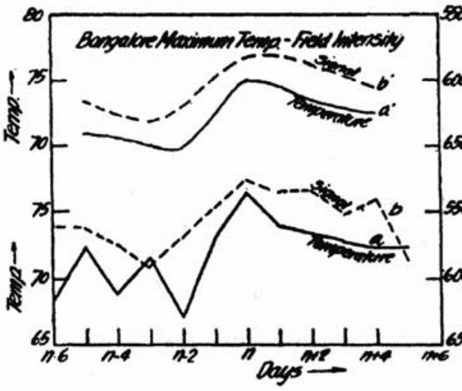

Fig. 4

The second method of study is to select the day in the month on which the temperature has been highest for the whole month. Call this day n; the day previous to it is $n-1$ and the one after it $n+1$ and so on. The temperatures on these days are written under the corresponding number and the average of each is calculated to give the general variation of temperature on either side of day n, for the whole period of 18 months. For these same days of each month, the field strength is also correspondingly written down and the average variation of signal intensity is calculated from these readings. In Fig. 4, the curves a and b refer to temperature and field intensity, respectively. The scale for b increases from top to bottom, in order to indicate better the inverse effect. The curves a' and b' in the same figure obtained by using the smoothing formula $(a+2b+c)/4$ show in a much more pronounced manner that as temperature increases, field intensity decreases and vice versa.

Fig. 5 relates to a similar analysis with minimum temperature day. Here the similarity between the two quantities is very slight, with only a trace of the inverse.

Whether taken over long periods or judged by the second method of average daily variations, there is evidence to conclude that increase or decrease of temperature is generally attended by the opposite variation in signal intensity.

The question naturally arises whether such an inverse effect is evident with long distance observations, say, over more than 1500 km. Signal intensity variations are primarily connected with the state of ionization in the upper regions; the duration of sunlight and the angle of sun's rays at any two places far from each other vary so much all along the path that any similarity in temperature variations, due even to this cause alone, is non existent. So far, in long distance measurements, no results in this matter have been obtained, due certainly to numerous other influences that prevent any useful comparison.

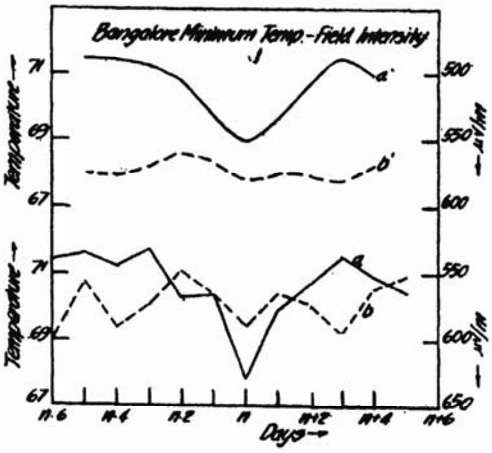

Fig. 5

Temperature and Atmospherics. On the other hand, the close correlation between local temperature and intensity of atmospheric disturbances found by Austin (loc. cit.) is perhaps due to the fact that the latter are bound up with the electric potential gradient of the air in the locality. Proof of this is forthcoming in the observations made at the Central College, Bangalore, by Prof. A. Venkata Row Telang. Low humidity and high temperatures produce high potential gradients of as much as 300 volts per meter or more, even at comparatively low heights from the ground; and atmospheric disturbances are likely to be violent under such conditions. Disturbances due to high potential gradients of a strictly local character are more numerous than those due to others and are distinct from the ones caused by agencies like near or distant thunderstorms.

4. BAROMETRIC PRESSURE AND FIELD INTENSITY

In examining the dependence or, more correctly, the relation between field intensity of Madras and the changes in the barometer readings (supplied by the Bangalore Observatory) at 0819 I.S.T., we notice in the curves for monthly averages (Fig. 6) what appears to be a direct relationship between the two. Between March and July, 1926, the pressure steadily decreases while signal intensity is practically constant. July is also characterized as being the month of lowest barometer reading for the whole year. From July onward, however, there is good measure of similarity between the two curves. The smoothed curves a' and b' of Fig. 6 give the main variations for the whole period under queston.

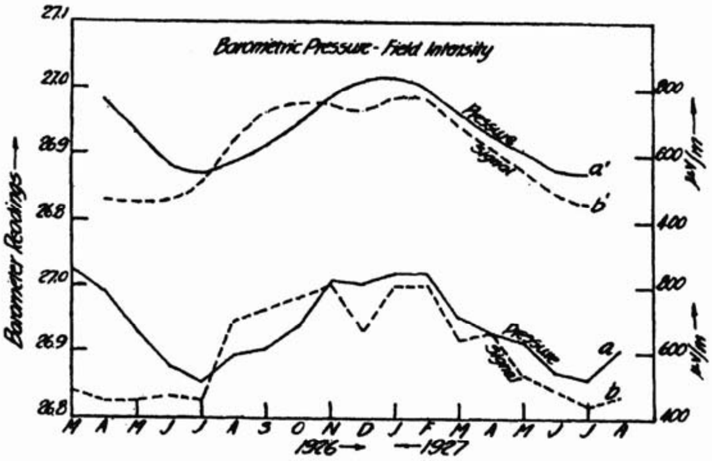

Fig. 6

As with temperature, Figs. 7 and 8 respectively give the average daily variations of pressure and field intensity on either side of the maximum and minimum pressure days of each month for the eighteen months from March, 1926, to August, 1927.

The curves a and b in the two figures may apparently lead one to think that there is an inverse relation between pressure and field strength. But the curves of monthly averages have distinctly shown a direct connection. That this is more probable will be realized if a forward shift of two days is given to the field intensity curve. This has been done in Fig. 7, giving a' and b', and they show the appreciable similarity between pressure and signal intensity. The two-day shift has been incorporated in the smoothed curves a'' and b''.

With the variations of the two quantities on either side of the day of minimum pressure as shown in Fig. 8, there appears to be little agreement. The forward shift too appears to be one day instead of two. However, the interesting fact is that pressure always lags behind reception, indicating that pressure variations are in no way the cause of signal strength changes.

The statement occasionally made that there is no connection between pressure and reception is perhaps due to this uncertain lag, which undoubtedly causes indefiniteness except in cases of prolonged observations. Even then, the relationship is none too marked, nor absolutely definite.

Unlike pressure, there is no lag between temperature and field intensity as we have already seen. The day of lowest temperature is also the day of highest signal strength and vice versa. It is therefore difficult to say whether or not reception changes are caused by temperature variations.

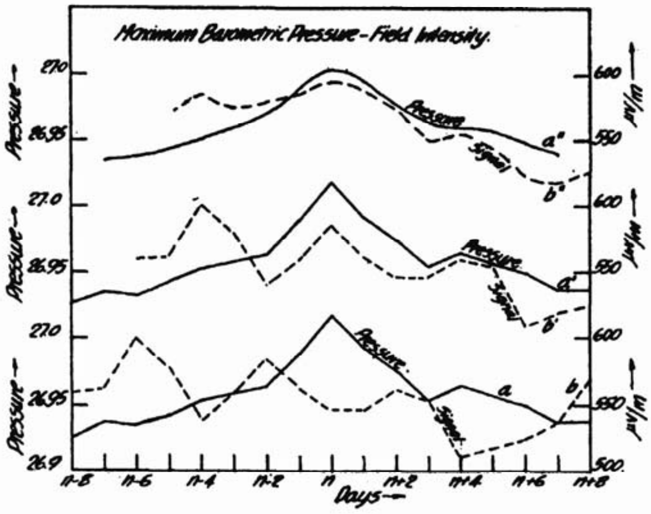

Fig. 7

5. ATMOSPHERIC OZONE AND FIELD STRENGTH

The interest, evident of late, in regard to the presence of ozone in the atmosphere of the earth is shown by the attempts that have been made to understand its relation to a variety of things, such as weather, solar phenomena, and earth's magnetism. The formation of ozone by light in the band spectrum of oxygen from 1300 to 1850 A.U. and the breaking up of ozone into oxygen between 2300 and 2900 A.U.,—the latter figure corresponding to the limit of the sun's ultra violet spectrum[6]—are properties which are likely to have definite relation to the state of ionization of the upper atmosphere.

Apart from the ozone values determined at about half a dozen places in northwestern Europe by Dobson[7] and his associates, there is little information to be obtained. Of the condition of ionization of the gas, the hourly changes in its ionization, the velocity of the ionized molecules in the field of the earth, any changes in the average height at which the ozone layer exists, and other information, nothing is known. Further, there seems to be no method yet devised to determine

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[6] E. O. Hulburt, "Ionization in the Upper Atmosphere of the Earth," *Phys. Rev.*, **31**, 1018, 1928.

[7] The author understands that ozone measurements have recently been started at Kodai Kanal and a few other places in the lower latitudes.

these. It seems possible that radio wave propagation experiments might be of some help in this direction.

Clayton[8] pointed out the possible existence of some relation between atmospheric ozone and solar phenomena. The properties of the gas in relation to ultra violet radiation from the sun immediately suggests an examination of its possible relation to radio reception. With the figures for ozone values for northwestern Europe kindly supplied by Dr. Dobson, an analysis of the variations of Madras signal strength in relation to the ozone content of the atmosphere was undertaken and the results communicated in a letter to *Nature*.[9]

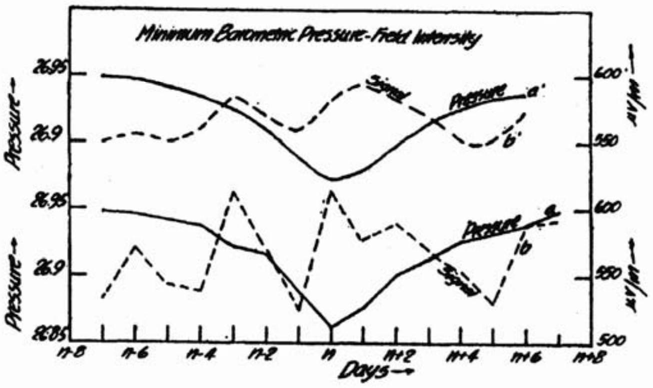

Fig. 8

The period of comparison was limited to the six months from March to August 1927, which was the only interval common to both the measurements. The conclusions arrived at in the paper regarding this matter would have been more reliable if comparison over the whole period were possible, especially with local values of ozone.

The curves *a* and *b*, Fig. 9, represent the variations in the weekly averages of field intensity and ozone value. Except for the ninth and tenth weeks, the curves march almost parallel to each other, particularly from the eleventh week. The reason for the sudden shooting up of signal strength in the ninth week and its equally rapid decrease in the tenth is not understood, as no corresponding pronounced change occurs in any other terrestrial or solar elements. The parallel changes in the two quantities show up much better in the curves *a′* and *b′* (Fig. 10) of smoothed values. If the values for the two abnormal weeks are omitted, the correlation, in the smoothed values, between field intensity and ozone is 0.88 ± 0.023, representing a very satisfactory measure of agreement, in view of the nature of the phenomena.

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[8] H. H. Clayton, "Atmospheric Ozone and Solar Variability," *Nature*, **120**, 153, 1927.

[9] K. Sreenivasan, "Long Wave Radio Reception and Atmospheric Ozone," *Nature*, **122**, 613, 725, 1928.

The inference naturally arises that there is a direct relation between the ozone present in the air and long-wave intensity even when averages over short periods like a week are taken. From the ionization theory of propagation, as far as it is understood, it appears that an inverse relation might be anticipated between ozone and short-wave reception. This is likely, as very high frequency waves in traveling into much higher heights than that at which the ozone layer is estimated to exist get attenuated in penetrating through it.

Long-wave intensity is proportional to the conductivity of the conducting layer. The curves therefore indicate that the variation of the ozone content is proportional to that of conductivity. From this, it appears that the ionization of the ozone in the atmosphere is proportional to the ozone content therein.

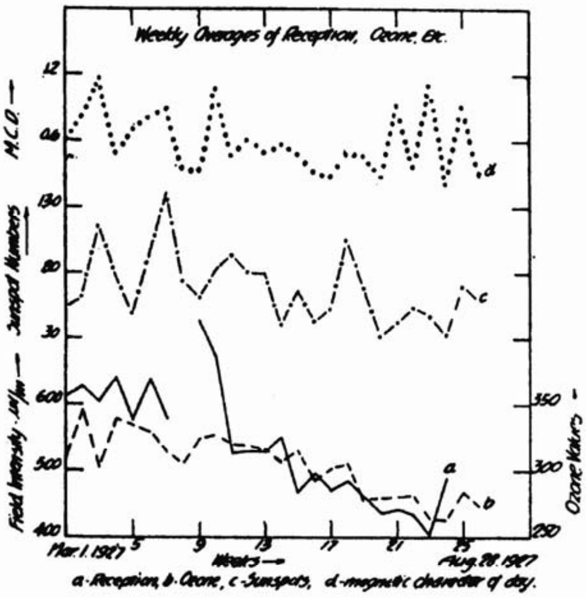

Fig. 9

It is appropriate that, during the period of similarity between field intensity and ozone, a comparison should be made with the variations of the magnetic elements. Curve *c*, Fig. 9, gives the weekly averages of Wolfer's sunspot numbers, while *d* shows those of the international mean magnetic character of day. But for the peak of the eighteenth week, the sunspot curve shows the same general tendency to decrease as the ozone and intensity curves do. After the eleventh, the peaks and troughs in the ozone and sunspot curves occur together, though the ratio of amplitudes in the variations is not constant. The corresponding smoothed curve is *c′*. A further examination into this question cannot fail to yield interesting results.

It is explained that variations in sunspots generally mean changes in the high velocity (charged or neutral) corpuscles and the electromagnetic radiations streaming out of the sun. If a correspondence between ozone and sunspots is quite definitely established, it will facilitate a better understanding of the relation between reception and sunspots. On the other hand, there seems to be no tangible relation between field intensity or ozone to terrestrial magnetism, as represented by the international mean magnetic character of day numbers, as curves *d* in Figs. 9 and 10 show. Neither in general variation nor in details is there any direct or inverse relation that can be definitely traced. This is the more remarkable as one would think that terrestrial magnetic changes would be expected to be accompanied by fluctuations in reception.

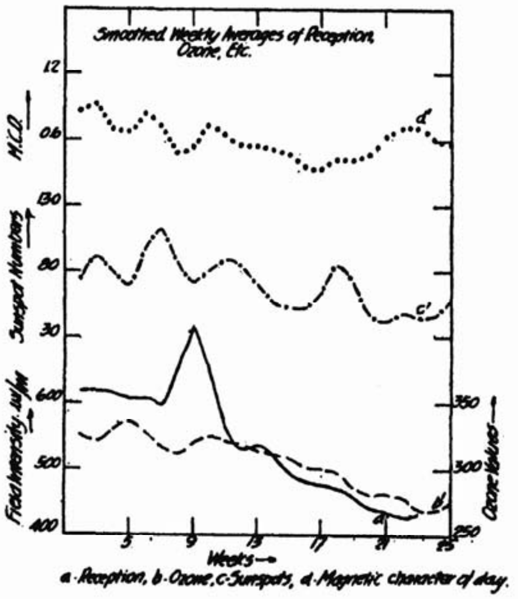

Fig. 10

As pointed out in the letter in *Nature*, already referred to, the close correlation between ozone and reception on 4 km is striking in view of the great distance of about 8000 km, from Bangalore and Madras to the stations in northwestern Europe, where the ozone values have been observed. The conclusion seems to be warranted that changes in atmospheric ozone partake of the nature of a world phenomenon. That this is not so has been pointed out by Dobson. The reasons given are (a) that ozone values have an annual variation in higher latitudes, (b) that the corresponding variations in lower latitudes are correspondingly small, and (c) that no evidence has been found of any world wide variations in the amount of ozone.

While great care has to be exercised in coming to any definite conclusion on this point, the similarity between the curves is so marked over a comparatively considerable period of time, that the correlation may not be found to be spurious after an examination of further data.

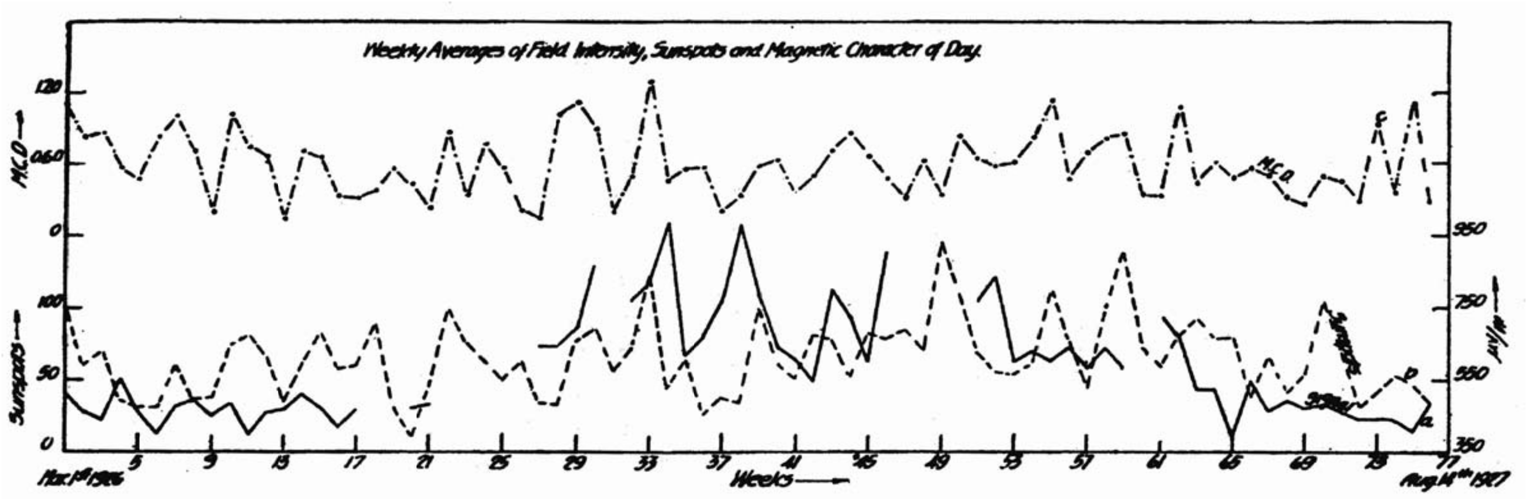
Weekly Averages of Field Intensity, Sunspots and Magnetic Character of Day.
M.C.D →
120
0.60
0
Sunspots →
100
50
0
Mar 1st 1926
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
Weeks →
Aug 14th 1927
950
750
550
350
μV/m →
M.C.D.
Sunspots
c
b
a

Fig. 11

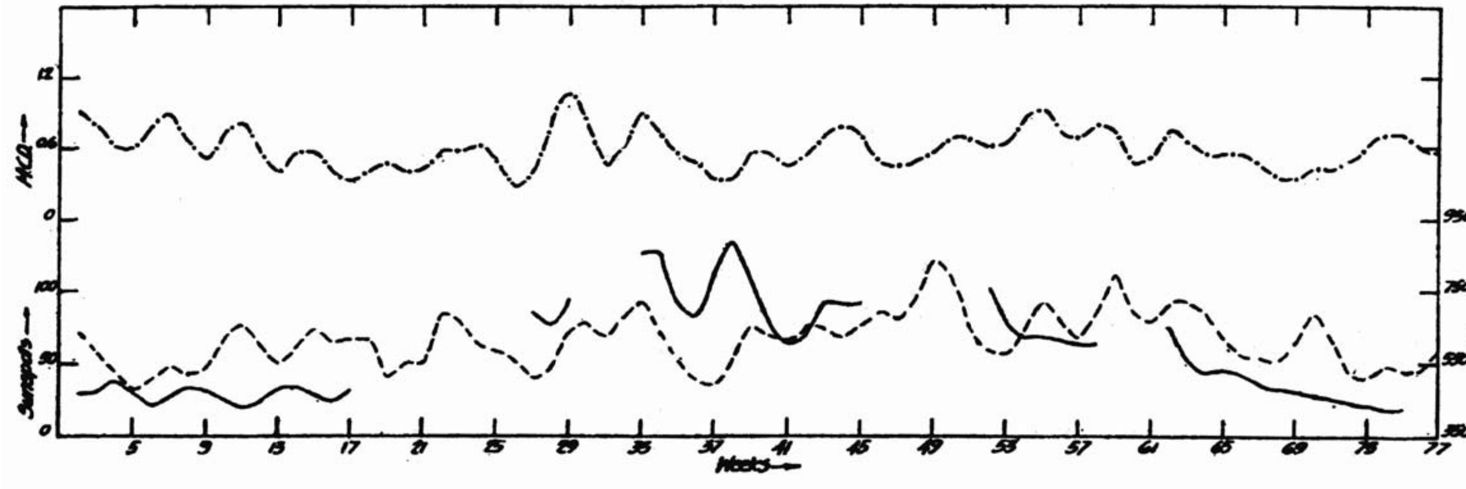
1.2
0.6
0
M.C.D →
100
50
0
Sunspots →
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
Weeks →
950
750
550
350
μV/m →

Fig. 12

Dobson estimates the height of the ozone layer at about 30 to 40 km. Eckersley's estimate[10] of the height up to which long waves travel is between 40 and 50 km. Hollingworth (loc. cit.) has given the limits as 75 and 90 km. If Eckersley's figure is taken, the existence of the ozone layer at about that height is of very great interest.

What part ozone plays in the ionization changes in the upper atmosphere at periods of sunrise and sunset would be interesting to know; at the equator, where the twilight period is very small, the changes in ionization take place rapidly while in the northern latitudes, where the period is of a few hours duration, there is much more gradualness in the change. Hollingworth[11] has shown that long waves undergo changes in intensity and polarization in a regular cyclical manner at these periods, when the transmitting station is at a moderate distance.

It is to be emphasized that the relation found between ozone and reception requires for confirmation prolonged observations at Bangalore on both ozone and signal intensity before it can be accepted as established.

6. TERRESTRIAL MAGNETISM, SUNSPOTS AND RECEPTION

In studying the variations in the field intensity of Madras in relation to terrestrial magnetism, considerable use has been made of the international numbers for the magnetic character of day. They represent the sum of the character of day figures of the forty-three magnetic observatories all over the world, cooperating under the international arrangement. Variations in declination and horizontal intensity were found more difficult for computation and were not therefore used; and for the study with sunspots, Dr. Wolfer's sunspot numbers have been used. It is to be remembered that the M.C.D. has no real physical basis by itself and from that point of view is perhaps unsuitable for comparisons of this kind.

In Fig. 11, *a*, *b*, and *c* represent from March 1st, 1926 to August 14th, 1927, the respective weekly averages of signal strength, Wolfer's sunspot numbers and the international numbers for the magnetic character of day (M.C.D.) The curves *a*, *b*, and *c* of Fig. 12 give the smoothed values obtained as described earlier. There appears to be no relation of any kind between reception and M.C.D., either of a direct or of an inverse nature. Analysis of daily values and monthly averages too have shown no connection whatever. A day of magnetic storm represented by a high character number is generally unaccompanied by any abnormality of reception even with some reasonable

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[10] Round, Eckersley, Tremellen, and Lunnon, "Report on Measurements Made on Signal Strength at Great Distances," *Jour.* I. E. E., **63,** 933, 1925.

[11] J. Hollingworth, "The Polarisation of Radio Waves," *Proc.* Roy. Soc., **119 A,** 444, 1928.

difference in time. The curves of smoothed values too (Fig. 12) show no relation between reception and M.C.D.

Further examination of this point was made by analyzing the readings on the basis of the five selected *D* days of the month. Following the method of Chree and Stagg (loc. cit.), each of these five *D* days of the month is given the number n; the succeeding days are $n+1$, $n+2$, etc.; while the days preceding it are $n-1$, $n-2$, etc. Under each number the values of the M.C.D. and signal strength for the corresponding dates are written side by side. The process is repeated for each of the eighteen months, thus giving ninety n days and an equal number of $n-1$, $n-2$ etc., and $n+1$, $n+2$ etc., days. The average of the two quantities for each of the days on either side of, and including day n, is taken. Thus we get their average daily variation on both sides of the *D* days. Table 1 for April 1927 is given to make the process clear. The *D* days for this month are 9th, 11th, 12th, 14th, and 24th. The readings for the rest of the months go one after another in the respective columns.

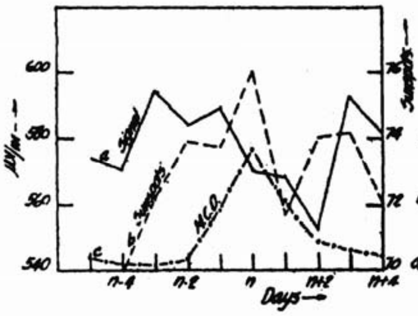

Fig. 13

The averages for the five days before and four days after day n—ten days in all—are given as curves in Fig. 13. No evidence of similarity or of any inverse relation is present. While the M.C.D. varies between the wide limits of 0.5 to 1.5, i.e., from a comparatively mild to a highly disturbed day, the maximum variation in sunspots is from 70 to 76, about 8 per cent, and that in field intensity from 550 to 590 μv per m, about 7 per cent. Earlier in the paper, it was seen that the ozone value too exhibited little relation with terrestrial magnetism as represented by the M.C.D. Reference to this will be made again a little later.

$n-4$			$n-3$			$n-2$			$n-1$		
Date	M.C.D.	F.S.	Date	M.C.D.	F.S.	Date	M.C.D.	F.S.	Date	M.C.D.	F.S.
Apr.			Apr.			Apr.			Apr.		
5	29	638	6	10	640	7	37	635	8	37	691
7	37	635	8	37	690	9	57	600	10	31	638
8	37	690	9	57	600	10	31	638	11	58	590
10	31	638	11	58	590	12	40	560	13	37	495
20	4	—	21	2	—	22	1	—	23	35	—

n			*n*+1			*n*+2			*n*+3		
Date	M.C.D.	F.S.	Date	M.C.D.	F.S.	Date	M.C.D.	F.S.	Date	M.C.D.	F.S.
Apr.			Apr.			Apr.			Apr.		
9	57	600	10	31	638	11	58	590	12	40	560
11	58	590	12	40	560	13	37	495	14	76	578
12	40	560	13	37	495	14	76	573	15	34	580
14	76	573	15	34	580	16	5	580	17	1	790
24	49	—	25	34	—	26	9	675	27	4	—

Reception and Sunspots. In their main variation as shown by curves *a* and *b* of Fig. 11, there appears to be a direct relationship between reception and sunspots, an increase or decrease of sunspots being usually accompanied by a corresponding change in reception. It is to be strongly emphasized that there is little similarity between the curves in the matter of details, due perhaps to other influences on reception. There is also a shift of phase between the two sets of curves of no constant character; and even in the cases of similarity, the proportional changes of amplitude in the two quantities are not constant.

From the curves of smoothed averages (Fig. 12), the general characteristics are seen to be that from March to July 1926, the values are fairly constant varying only a little from the average. From July onward, they are on the increase till March 1927, when there is a steeper increase back to about the same value for the corresponding month of 1926.

7. THE 27-DAY PERIOD

In their analysis (loc. cit.) Chree and Stagg have found a 27-day interval in magnetic disturbances of any type and concluded that there is no definite departure from this period, whatever be the sunspot conditions prevailing. Further, the period of solar rotation in the region of the greatest number of spots is approximately 27 days. This coincidence is of help in the present study of the relation between solar phenomena and radio reception.

The whole period of 18 months has been divided up into twenty groups of 27 days each and the observational data arranged accordingly. The field intensities of the first days in each group are added and the average calculated. The readings for the second days in each group are similarly added and the average taken. The process is repeated for each of the 27 days. Thus a series of average daily values for the period is obtained, giving the mean day to day variation for the 27 days, removing almost all the undesired variations. Similarly we get the figures for sunspot numbers and the M.C.D. These give us Fig. 14 with the curves *a*, *b*, and *c* while *a*′, *b*′, and *c*′ give the smoothed values. The coefficient of correlation between sunspots and reception works out to 0.31 ± 0.117, from curves *a* and *b*, Fig. 14.

The agreement between the curves of sunspot and reception even in the matter of peaks and troughs is pronounced. On four of the days there is a phase shift of a day, with sunspots as the earlier occurrence. On the nineteenth day, however, the reverse is true. The ratio of field strength to sunspots for the averages over the whole interval is 8.86. The maximum ratio is 10.6 and the minimum 7.2, giving a maximum variation range of about 20 per cent. In view of the long period considered and the nature of the phenomena, the above is certainly satisfactory.

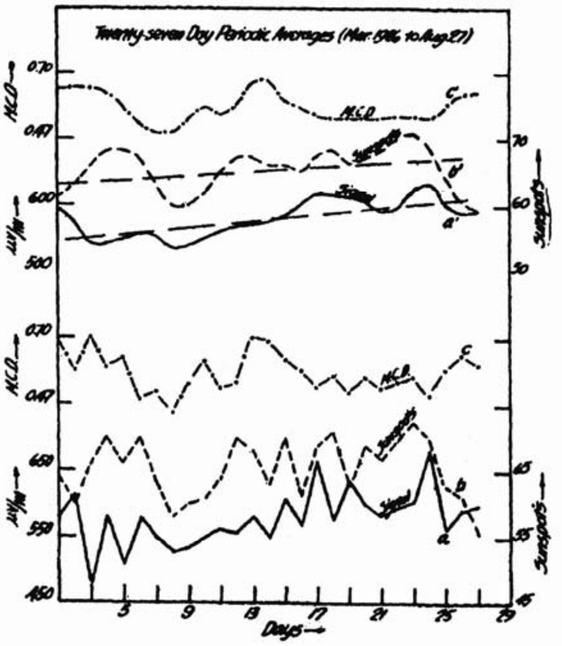

Fig. 14

In addition to the daily variations, a main steady increase in both the quantities is evident at a glance as Fig. 14 will show. This is better brought out in the smoothed curves *a′* and *b′* of Fig. 14. In this connection, it is necessary to point out that while the main general increase is a common feature and there is agreement in the details of peaks and troughs, the proportionate changes of amplitude are not the same right through.

Examining the curves of the M.C.D., there are a few days when the peaks and troughs correspond with those in the sunspot curve, otherwise there is no other feature of any interest.

The 6-Day Period. Curve *a′* (Fig. 14) exhibits what appears to be a six-day period. The peaks occur on the days 1, 6, 12, 17, and 24; and the troughs on the days 4, 9, 14, 21, and 27. No such shorter period is seen in the sunspot curve. This feature is more prominent when the 27-day periodic averages are made out for the 12 months from March 1926 to March 1927, as given in Fig. 15; the coefficient of correlation in this case is much higher, 0.73 ± 0.06.

While the appearance of this period seems definite from the curves, it is interesting to note that Austin has discovered a 9-day periodic variation of intensity with some stations. With the reasonable assumption of the absence of periods smaller than 27 days in solar and terrestrial magnetic disturbances, it follows that the shorter periodic variations of reception, if their existence is world wide, should be due to peculiarities of the locality itself. The Bangalore and Washington observations lead to this inference. What this local influence can be, it is difficult to see, unless it be temperature.

Variations in Amplitudes. With qualitative similarity in the changes in sunspots and reception, there is no constancy in the ratios of the amplitudes of such variations. A small increase in sunspots may result in an increase in reception. But a much bigger change in sunspots may not, and usually is not, accompanied by a proportionate increase in reception. This along with the phase shift of about two days suggests the following explanation.

On the Kennelly-Heaviside layer theory, the main cause of the changes in long-wave signal strength consists in the changes in the conductivity of the upper layers; the variations in ionization at these heights, apart from any radiations due to the earth's surface, are due to the ionizing agents emitted by the sun. These consist mainly of charged or neutral high speed corpuscles and the portion of the electromagnetic radiations which have ionizing properties, such as the ultra violet portion of the spectrum. Of the total emission, the earth gets its tiny share. The only pertinent point about the spots on the surface of the sun is that when some of these come in the direction of the earth, there is a change in the quantity of the ionizing agents reaching the earth. So, if every sunspot was equally effective in regard to the changes in atmospheric conductivity, then Wolfer's numbers would truly correspond with reception in direct proportion. In the absence of it, either all the spots are not equally active or the emission of the high speed particles or of changes in the electromagnetic radiations, due to some of the spots, are directed away from reaching the earth's surface. In such a case, Wolfer's numbers are accompanied by only a little or no change at all in field intensity.

In Figs. 14 and 15, there appears on a few days a lag of about two days between sunspots and signal strength, while for the most part of the 27 days there is full agreement. This can be accounted for on the assumption that the sunspots change only the number of the high velocity corpuscles shot out into the earth's atmosphere.

When the spots are few, if solar activity is violent the velocity of the particles shot out is very high, possibly as much as 1/10 of that of light. Neglecting any retarding influences on the way, these would enter the earth's atmosphere within a few hours and cause changes in the conductivity of the atmosphere, resulting in an almost immediate response in radio field strength variations. But when the velocity of the particles is comparatively low, a much longer time would be necessary to reach the earth's atmosphere. Even if their numbers were high, the velocity being low, the effective change in ionization of the earth's atmosphere in the region where long waves are supposed to travel is not great. The lag of two days would mean an average velocity for the particles of about 1/360 of the velocity of light. Further, the diffusion process from the heights at which these high velocity particles enter into the earth's atmosphere to the heights above the surface of the earth where long waves are believed to travel, is likely to take considerable time.

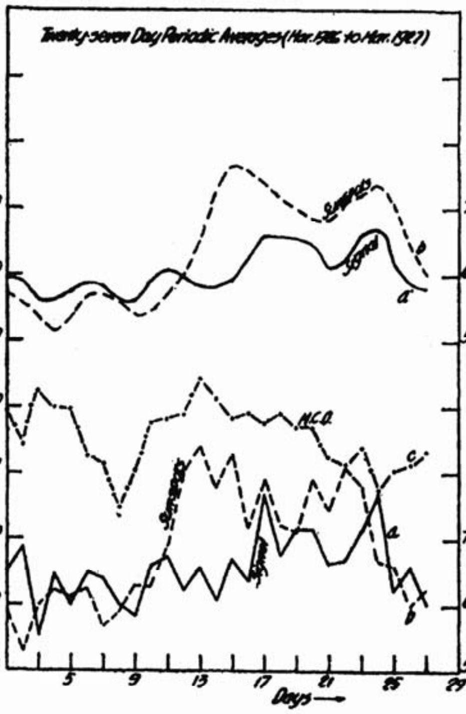

Fig.15

8. Certain Differences Between Long- and Short-Wave Transmission

It has often been pointed out that there are many differences in the transmission of long and short waves. Of these the present paper attempts an explanation of one or two only, mainly concerned with the subject matter of the paper.

We have, first of all, the phenomenon that during a time when short-wave propagation shows great abnormality, lower frequencies may exhibit none. A striking instance of this was in October 1926, when short-wave communication the world over broke down while long-wave reception was hardly affected. A milder instance was on July 8, 1928, when for over 24 hours, short-wave communication was very difficult.

Secondly, there is the occasional lag of about two days, at the most, between long-wave reception and sunspots, whereas short-wave propagation indicates almost instantaneous response.

Thirdly, we have the possibility of a true physical relation between long-wave reception and atmospheric ozone. With short waves, however, no such relation has been noticed. These three are not independent of each other and any explanation should consider them together.

Now, apart from the details of the constitution of the upper atmosphere about which complete definite knowledge is lacking, there are two points which can be safely taken as correct.

(a) At comparatively great heights, the density is so low that free electrons can exist with a long mean path; at lower heights, say 50 km, density is higher, and free electrons cannot exist, so that there are only ions of very much less mobility.

(b) All the measurements agree that short waves penetrate into greater heights than long waves. For the former, varying figures have been given, from 100 to 250 or 300 km. For long waves the highest figure given is between 75 and 90 km.

The suggestion is that short waves are propagated in an absorbing refractive medium consisting of free electrons, while for the transmission of lower frequencies the conductivity of the lower layers of less mobile ions is responsible.

The fundamental equation for the passage of a radio ray of velocity $\omega = 2\pi f$ in a cloud of electrons of density N and collisional frequency n is

$$I_z = NeV_z = \frac{Ne^2E(kn - i\omega)}{m(kn^2 + \omega^2)}$$

where e and m represent the charge and mass of the electron, while E the electric vector of the plane polarized ray is parallel to z. The displacement or condenser portion of the current is represented by the second term, while the first one represents the collisional momentum of the electrons, the two having a 90-deg. phase difference. The coefficient of collision differs little from unity. While the second term helps in the propagation of the wave, the first one robs the energy in the wave and thus attenuates it giving the familiar exponential term $\epsilon^{-\alpha d/\phi(u)}$ in its most general form. When $\omega \gg n$, the attenuation is small and the electrons execute a number of oscillations before colliding, a case of refraction with negligible absorption. But when the frequency of collision is high, that is, when $n \gg \omega$, the ray is attenuated rapidly.

Short-wave observations seem to agree with the above rough picture of propagation; for the increase in the density of the electron cloud due to increased sunspots or to any other agency is always attended with poorer short-wave reception, as demanded by theory. Larmor[12] suggested that the magnetic storm of October, 1926, might be attributed to the incursion of electrons—not necessarily a large number—into our atmosphere, tending to twist out all the usual ray paths. This seems hardly possible in view of the world wide blocking of short-wave communication. A more satisfactory explanation is that of absorption due to the additional electrons, as represented by the first term of the above equation. The number of them, while sufficient to have a pronounced effect on short-wave reception may not in any way affect long-wave transmission even if the velocities of the electrons were high; the smallness in their numbers would effectively prevent the ionization due to them from penetrating into the lower regions of long waves.

As remarked earlier, the effect of the spots on the sun coming in the direction of the earth is to cause a change in the ionizing agents of the earth's atmosphere, that is, in the high speed particles and in the electromagnetic radiations. The latter make their presence felt by the corresponding changes of ionization occurring almost immediately by variations in short-wave reception. The effect on long-wave transmission depends upon the magnitude of the change in the radiation. If of sufficient intensity to penetrate into the lower heights, there will be variations on long-wave propagation too.

In the case of high speed corpuscles, the number and the velocity of the particles determine the change. A large number with small velocities, besides taking a long time to travel to the earth's atmosphere, may not cause any serious changes in reception.

These considerations and the correlation between the Bangalore measurements on 4 km, with the ozone content of the atmosphere, give an indication that electrons are responsible for short-wave propagation while the less mobile and heavier ions take part in long-wave transmission. As though to support this view, we have the tantalizing estimate of the ozone layer at about 30 or 40 km. High sunspot numbers, poor short-wave reception, improved long-wave transmission

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[12] J. J. Larmor, "Magnetic Storms and Wireless Communication," *Nature*, 118, 662, 1926.

seem to go together with increase in the ozone value of the atmosphere and reduced temperature. The suggestion made above is qualitative. A quantitative treatment with experimental data for an extended period will no doubt take into consideration the action of the earth's field. Considerable data and analysis are necessary before some of the results of the paper can be accepted as established and beyond doubt.

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Addendum

Information so far obtained since January, 1929, from measurements of ozone at lower latitudes shows that its seasonal variations are quite small. Also the only figure, that due to Eckersley, for the height of the Heaviside layer, which at all approximated to that of the ozone layer, has been revised to lie between 80 and 100 km. This, of course, is the usually accepted view for long waves.