EFFECT OF SOLAR ACTIVITY ON IONOSPHERE AND EARTH'S MAGNETIC FIELD*

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ABSTRACT:—The paper deals with an analysis of radio fade-outs and magnetic storms with a view to correlating them with solar flares and sun-pot numbers. Data for the years 1946-1949 have been analysed. Dellinger fade-outs have been observed to be well correlated with salar flares. Based on the theory of corpuscular emission from solar disturbances, delayed types of fade-outs and magnetic storms have been observed to go together and the delay time gives an approximate measure of the speed of the corpuscles. Occurrence of a solar flare has also been found to agree with that of high sunspot number. The analysis of the magnetic character figure indicates that it has no regular relationship with sunspot numbers However, the central meridian passage of large sunspot groups is often found to be associated with flares, fade-outs and magnetic storms. Various correlations have been represented in the form of graphs and tables. A very high percentage of radio fade-outs has been found uncorrelated with solar flares and sunspot numbers. It has been postulated that such radio fade-outs may be caused by M-region activity

1. INTRODUCTION

It is known for a long time that certain disturbances happening in the sun produce significant changes in the ionosphere and in the earth's magnetic field. Solar disturbances are in the form of sunspots, bright chromospheric eruptions and very high frequency radio noise. In the ionosphere we have radio fade-outs, ionospheric storms, sudden phase anomaly on very long waves and fading of ionospheric signals. The magnetic disturbances are usually in the form of sudden variations in the horizontal intensity of the earth's magnetic field and the production of "Crotchets" in the magnetograms. Attempts have been made in the past to correlate the ionospheric and magnetic disturbances with solar flares and sunspot numbers but no regular relationship has yet been established. It has, however, been observed that certain brilliant solar flares have produced simultaneous radio fade-outs and magnetic storms. But when one attempts to analyse statistically the solar, ionospheric and magnetic data, any generalisation regarding the "cause and effect" relationship cannot be obtained. The object of this paper is to present one

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such statistical analysis of the data for radio fade-outs, magnetic storms, solar flares and sunspot numbers covering the period 1946 to 1949. For the purpose of clarity, we have divided the data in discrete groups and individual analysis has been presented. The data are considered not sufficient and as such the analyses might not yield highly satisfactory conclusions. Nevertheless, they may show some useful correlations.

In the present paper we have analysed the data for radio fade-outs as recorded at the receiving station of All India Radio in Delhi (latitude 28° 35′N, longitude 77° 5′E). These fade-out data are not based on any continuous records of signal strength. But as the reception conditions of regional and foreign stations are regularly checked round the clock throughout the year, the data may be considered to be fairly comprehensive. The data for solar flares and individual sunspot groups have been taken from Kodaikanal (latitude 10° 14′N, longitude 77° 28′E) observatory. A few flare data have also been noted from published reports of the observatories. The magnetic data are mainly the geomagnetic character figures as supplied by Greenwich (latitude = 50° N, longitude = 0°). The data for great magnetic storm have been taken from records at Alibag (latitude = 18° 45′N, longitude = 73°E) magnetic observatory. The sunspot numbers have been taken from the data published by Zurich Observatory in the Journal of Geophysical Research (previously named Terrestrial Magnetism and Atmospheric Electricity). The period under consideration is 1946 to 1949.

2. EFFECT OF SOLAR FLARE

In this section we shall summarise the more recent work on the correlation of ionospheric and magnetic effects supposed to be due to solar flares. It is known that certain types of solar flares give rise to a train of terrestrial effects including radio fade-outs. Different aspects of these effects have been discussed by Ellison (1949), Rydbeck and Stranz (1949). Some effects are simultaneous which are supposed to be caused by wave radiations (mainly ultraviolet). Almost simultaneously with the occurrence of a flare, a newly ionised layer is formed at a height of 70-90 km. This layer affects the sky-wave radio transmission in a profound manner. Depending upon the amount of ionisation, short wave transmissions are completely or partially interrupted. We shall describe this type of fade-outs in more detail in Section 3.

On very long waves the effect of this newly formed layer is completely different. These waves suffer almost mirror-like reflection from the edge of the layer and reflection is very much improved. Due to this reason, increase in low frequency atmospherics is also noticed. Bracewell and Straker (1949) have shown that on very long waves (16 kc/s) the phase difference between the ground wave and the reflected wave shows sudden change with the occurrence of solar flares. The nature of the sudden phase anomaly is such that it indicates sudden lowering of the reflecting layer and they are always observed whenever there is a flare even though the ionisation in the layer may not be sufficient to produce any noticeable fade-out in the high-frequency sky-wave transmissions. The correlation between the incidence of solar flare and the occurrence of sudden phase anomalies on very long waves is so satisfactory that the observation of the phase of the down-coming waves on very low frequencies provides a powerful tool unhampered by conditions of visibility for investigating the solar flares.

Another direct effect is the formation of geomagnetic 'Crotchet'. Fleming (1936) and McNish (1937) have pointed out that the magnetic effect is an augmentation of the normal daily variation over the sunlit hemisphere, probably due to increase in ionisation of the atmosphere, by ultraviolet light from the solar eruption, at the bottom of or below the E-layer.

After the discovery of the emission of solar radio noise, attempts have been made from time to time to correlate the emission of solar noise with radio fade-outs and happenings on the sun. It has been observed that variations in noise intensity are closely linked with sunspot activity. Allen (1947) has shown that the average intensity of solar noise at 1.5m wavelength follows the variation of the integrated projected area of sunspots. Better correlation has, however, been observed between noise intensity and the central meridian passage of large sunspots. This has been explained by directive emission of noise when sunspots are near the central meridian.

Allen (loc. cit) has analysed the records of short period increases in noise intensity over a year at 1.5m wavelength with a view to correlating them with visual phenomena. He remarks, "We could find no chromospheric or photospheric features which appeared to have an invariable physical connection, or high short period correlation, with the solar radio noise". Appleton and Hey (1946), on the other hand, have reported instances when large increases in solar noise at 4.7m wavelength were associated with solar flares. Covington (1948) has also observed substantial increase in noise intensity at 10 cm accompanied by sudden ionospheric disturbances which are usually attributable to solar flares.

Attempt has also been made to correlate the occurrence of radio fade-outs with the emission of noise-bursts at various wavelengths (Payne-Scott, Yabsley and Bolton, 1947). No conclusion has yet been arrived at. Considerable amount of data spread over a large number of years is needed before any correlation can be established.

Some effects of solar flare are delayed. These are considered to be due to corpuscular emissions. Magnetic storms and auroræ are the most conspicuous phenomena amongst the delayed effects. The time-delay depends upon the travel-time of the particles from the sun to the earth. F2-layer ionisation and layer-height show abnormal variations during and after a magnetic storm, thereby, adversely affecting radio transmissions on high frequencies.

Considerable attempt is now being made to correlate cosmic ray bursts with solar flares and sunspot activity. But no conclusive evidence regarding the increase in cosmic ray intensity after an intense solar flare (after a few minutes to an hour or so, depending on whether the constituent of the ray is high speed electron or proton) is yet available.

3. RADIO FADE-OUTS AND SOLAR FLARES

In this section we shall consider the radio fade-outs that may or may not have been caused by solar flares. Now, it is known that there are two types of fade-outs usually observed. In one type, suddenly within the space of a minute or so, short-wave (10-50 metres) channels of communication suffer a partial or complete interruption, at least if any part of them happens to lie in the sunlit hemisphere of the earth. These are termed Dellinger type, named after their discovery by Dellinger in 1935. In the other type, however, the process of interruption to communication service is rather slow and gradual. We shall first describe the Dellinger type.

Since in the Dellinger fade-outs, the propagation through sunlit hemisphere is affected, it can be deduced that the cause is a wave and not a particle effect. Some such fade-outs have been found to be synchronous with certain solar flares and their duration comparable with the visibility of the flare in Hα light. The immediate cause of the fade-out is the formation of a newly ionised non-reflecting layer at a height of 70-90 km, the cause of which is usually ascribed to the resonance line of hydrogen, Lymanα. This emission line (1215.7 A°) in a flare must have an intensity and a line width far exceeding those recorded in the visible spectrum for Hα. This in itself would not give rise to atmospheric ionisation ; but it so happens, as first noted by Chapman and Price (1937), that the resonance line of atomic oxygen has a wavelength of 1217.6 A°. The wide wings of Lα will certainly overlap this oxygen line for the greater part of the lifetime of a flare. The oxygen in the atmosphere will therefore be excited and in the denser part of the atmosphere (70-90 km) collisions will be sufficiently frequent to prevent re-radiation. Extra ionisation will therefore take place and as soon as the ionising agency is removed, the disappearance of the ionised layer takes place. As the cause of the fade-out is absorption by the newly formed layer, lower frequencies are more affected and in the case of a complete fade-out, higher frequencies are the first to recover.

3(*a*) ANALYSIS OF DATA

In this section we describe the analysis of the data for Dellinger fade-outs with a view to ascertaining their cause.

From the list of fade-outs, recorded in the Receiving Station (Todapur) at Delhi for the years 1946-1949, 41 fade-outs are found to have clear Dellinger characteristics. Of these 12 were recorded during the forenoon period and 29 in the afternoon. Five forenoon fade-outs are found to coincide unmistakably with solar flares observed at Kodaikanal. Whereas, in the remaining seven, there is some uncertainty since the observations of solar flares are limited due to weather condition. For the afternoon period there is no coincidence since practically no solar flare data are available from Kodaikanal during this period. It is, however, observed that some of the outstanding flares recorded elsewhere and occurring during Indian day-light hours have not been reported from Kodaikanal Observatory, probably due to poor visibility. Unfortunately all such flare data cannot be utilised for our purpose as sometimes only the dates of occurrence are given. Even then eight of the twentynine afternoon fade-outs were found to coincide with flares.

The simultaneous occurrence of 13 fade-outs with solar flares is indicated in figure 1. In this figure time is reckoned from the start of the fade-out which is known correct to within a few minutes. Whereas, in the case of solar flare, time of start is not very often known. In some cases, only the time of peak intensity of the flare is given. If these uncertainty factors are taken into account, figure 1 clearly brings out the simultaneity of the occurrence of Dellinger fade-outs with corresponding solar flares. Since the fade-out data are not based on any continuous record of signal strength, variation with time of intensity in the received radio wave cannot be compared with the variation of Hα line-width of the solar flare. Attempts have been made by Bracewell and Straker (1949) to compare the amount of "Sudden phase anomaly" (in degrees) with the line-width of Hα emission during

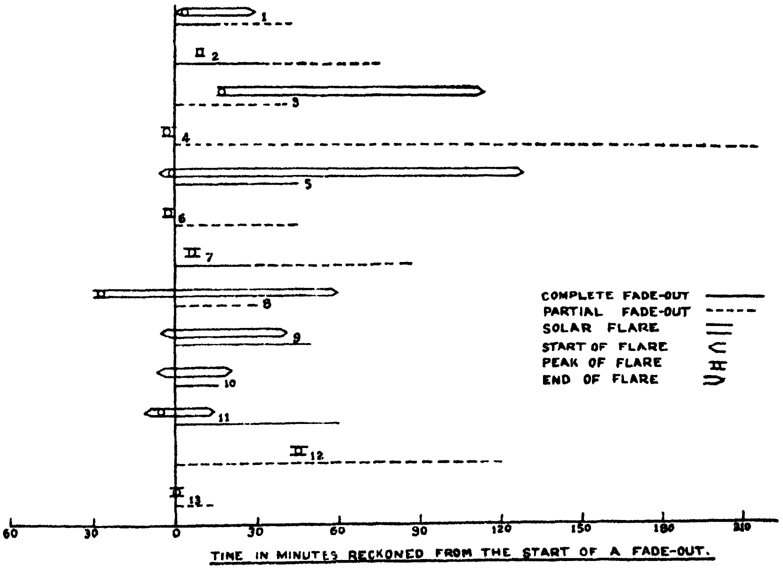

FIG. 1

Correspondance of flares with Dellinger fade-outs the solar flare of June 7, 1948. Ellison (1949) has shown graphically the correspondence between the intensity of solar radio noise and the line-width of Hα emission line during flares.

3. (b) OTHER FADE-OUTS

In the previous section we have seen the correspondence between Dellinger fade-outs and solar flares. In this section we shall analyse all the fade-outs, and attempt to find out how many of them may be ascribed to be due to ultraviolet emission from solar flares and how many due to corpuscular emission from them.

As many as 122 fade-outs were recorded during the years 1946-1949. These fade-outs were of various intensities and durations. The frequency ranges affected and the geographical locations of the transmitters so affected are also different in different cases.

Table I gives the number and duration of the following three classes of fade-outs:

(1) Fade-outs which more or less coincided with an observed solar flare (ultraviolet effect);

(2) Fade-outs which were observed 20 to 40 hours after an observed solar flare (corpuscular effect);

(3) Fade-outs unassociated with any observed solar flare. In considering solar flares, lower intensity flares were not discriminated against.

TABLE I.

Group No.	Nature	No.	Relative abundance	Total duration Hrs.	Mins.	Average duration Hrs.	Mins.
1.	Fade-outs which more or less coincided with an observed flare (Kodaikanal data).	11	9%	44	45	4	4
2.	Fade-outs which were observed 20 to 40 hrs. after an observed flare.	12	9.8%	39	54	3	19
3.	Fade-outs unassociated with any observed flare.	99	81.2%	269	48	2	43
	Total	122					

It will be seen from Table I that about 20% of the total number of fade-outs have either direct or delayed correlation with a solar flare. Such a low percentage of correlation does not necessarily prove that most fade-outs are unassociated with solar flares.

The observation of flares is highly dependent upon weather conditions and for a better correlation, if any, one needs observing flares in any climatic condition. For this purpose the sensitive method of detecting a flare by sudden phase anomalies on very long waves may prove useful and when systematic data are available over a large number of years, better correlation between radio fade-outs and solar flares may be obtained. Furthermore, on a very long distance circuit, the receiving point lying in the dark hemisphere may report a fade-out when a flare has actually affected the propagation condition in that part of the ionosphere lying on the sunlit side. In this case the flare data may not be ordinarily available. Again, for the delayed type of radio fade-out, the corresponding solar flare may not necessarily be observable at the receiving point. All these factors indicate a poor correlation between radio fade-outs and solar flares. A world-wide coordination of fade-out and flare data is therefore necessary for the purpose of a more effective correlation between the two data.

Table II shows the correlation between flares of different intensities and the radio fade-outs associated with them. It will be observed from the table that relatively small number of flares of intensity 3 has been effective in producing larger number of fade-outs, simultaneous or delayed.

TABLE II

Flare type (intensity)	Number observed	Relative abundance	Simultaneous fade-outs	Relative abundance	Delayed fade-outs (20-40 hrs)	Relative abundance	Percentage correlation
1	141	79·7%	6	54·5%	7	58 3%	10%
2	23	13.0%	1	9.1%	2	16.7%	13%
3 and 3+	13	7·3%	4	36.4%	3	25·%	54%
Total	177		11		12		

The last column in the Table II shows the percentage of solar flares (out of the total number of each individual type observed) effective in producing a corresponding fade-out. Here again it will be seen that in 54% of intensity 3 flares a corresponding fade-out is observed. It must, however, be remembered that the classification of flare types in different intensity groups is purely arbitrary and the same flare, while being observed at the same time, has been classified differently by different astronomers. Continuous photography of Hα line-width during a flare has been attempted in a few exceptional cases and the intensity of a flare has not yet been given a quantitative basis. It may, however, be noted from the above analysis, that although type 1 flares are not usually associated with a corresponding fade-out, type 3 flares are fairly well correlated.

4. SUNSPOT NUMBERS AND SOLAR FLARES

In previous sections we have discussed the correlation between the occurrence of solar flare and a corresponding radio fade-out. It may be of interest to see whether the probability of occurrence of a flare can be foreseen. As it is also known that these flares usually occur in the vicinity of active sunspot groups (particularly of bipolar groups) it will be worth investigating how the number of flares of differing intensity varies with the sunspot number. (The mechanism of formation of such flares and the probable mechanism of emission of ultraviolet and corpuscular radiations are outside the scope of the present paper).

Figures for Provisional Zurich Sunspot number and Kodaikanal solar flares have been grouped (1946-1949). Table III shows the number of flares of different types against days on which sunspot number was lying between certain limits (*i.e.* 0-50, 50-100 etc.,). Figure 2 shows a plot of total number of flares against sunspot numbers. The number of days on which the sunspot number was lying within those limits is also shown in the same figure by the dotted curve. The dashed curve indicates the number of radio fade-outs.

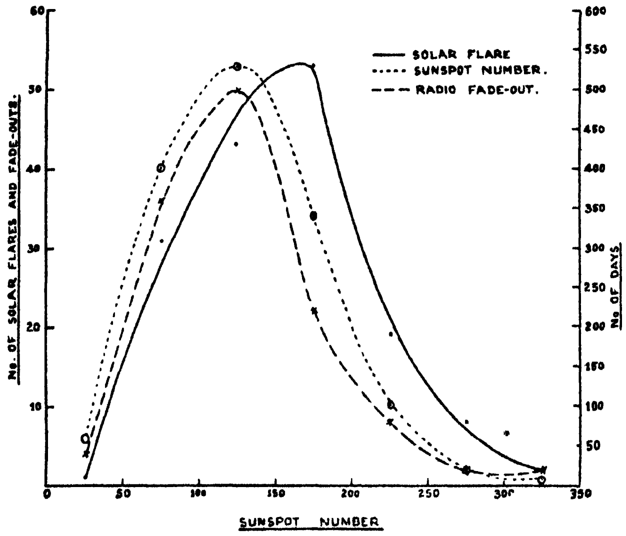

FIG. 2

Dependence of flares and fade-outs on sunspot number

It will be seen from figure 2 that the largest number of flares was observed on those days when the sunspot number was lying between 150 and 200, whereas, the largest number of days were found to indicate a sunspot number lying between 100 and 150. The correlation between the fade-out curve and the sunspot number curve is not very significant since it is quite probable that large number of days will produce larger number of fade-outs. To further clarify this point, Table III shows the percentage of days having certain sunspot number effective in producing a flare or a fade-out. It will be seen from this table that the days having higher sunspot numbers are more effective in producing relatively higher number of flares. But for radio fade-outs no such generalisation can be made. It should, of course, be remembered that the occurrence of flares is dependent more on the activity of sunspots than on the number of spots. In a later section we have shown the correspondence of the central meridian passage of large sunspot groups with radio fade-outs, solar flares and magnetic storms.

TABLE III

Sunspot No. lying between	No. of days	No. of solar flares	% of days	No. of fade-outs	% of days
0-50	59	1	1.7	4	6.8
50-100	402	31	7.7	36	9
100-150	529	43	8	50	9.4
150-200	341	53	16	22	6.5
200-250	101	19	19	8	8
250-300	19	8	42	2	10
300-350	8	2	25	2	25

5. CHARACTER OF GEOMAGNETIC FIELD AND RADIO FADE-OUTS.

There is another class of fade-outs which do not possess the Dellinger characteristic and is generally attributed to the F2-layer. There is no sudden onset and reception generally starts becoming poorer gradually and sometimes signals disappear altogether. Very often reception conditions remain subnormal for a considerable length of time, higher frequencies being affected more than the lower frequencies. Magnetic and ionospheric disturbances producing this type of fade-outs often go together, the ionospheric disturbances sometimes continuing for a considerable length of time after the magnetic disturbances have subsided. This point will be further discussed in the next section.

ANALYSIS OF DATA

Fade-outs other than those of Dellinger type recorded during the years 1947-49 were considered. Table IV gives the number of fade-outs taking place on days, the geomagnetic character figure for which or for the previous day (whichever value is higher) lies between certain limits (*i.e.* 0-0.5, 0-5-1.0 etc.). It will be seen from this table that the fade-out is more frequent on those days having higher character figure. Though the number of days having a character figure lying between 0.5 and 1 greatly outnumbers that having higher character figure, the largest number of fade-outs is observed on the days having character figure lying between 1 and 1.5. Furthermore, the number of days having character figure between 2.0 and 2.5 is very small, still the number of fade-outs observed during these small number of days is quite high. This trend both in respect of complete and partial fade-outs shows that magnetic storms and radio fade-outs could have the same origin.

TABLE IV

Character figure	Number of fade-outs Complete	Partial	Total	No. of days	% of days
0–0.5	0	0	0	237	0
0.5–1.0	1	9	10	568	1.6%
1.0–1.5	2	9	11	248	5%
1.5–2.0	3	7	10	38	26.3%
2.0–2.5	1	6	7	7	100%

N.B. Character figure 2.5 is regarded as indicative of the most disturbed condition of the earth's magnetic field.

6. MAGNETIC STORM, RADIO FADE-OUT AND SOLAR FLARE

In this section we shall describe radio fade-outs during and after great magnetic storms. These storms disturb the geomagnetic field throughout the world including the dark hemisphere and sometimes continue for days. Chapman and Ferraro (1931-1933) have suggested that the corpuscles emitted from a disturbance in the sun cannot penetrate into the earth's atmosphere and these form a current ring round the earth. These corpuscles ultimately drift towards the polar regions following the magnetic lines of force. During the formation of the current ring and the drift of the stream of corpuscles, the magnetic field of the earth is disturbed and a magnetic storm is in progress. It is, therefore, seen that a magnetic storm which is being caused by the incidence of corpuscular radiation is a delayed process since the particles take considerable time to reach the earth from the sun. The ionospheric storms that generally accompany magnetic storms are also possibly caused by the incidence of these charged corpuscles. Now, these storms which are characterised by lowering of the F2-layer critical penetration frequency and increase in the layer height, are naturally expected to be more severe at higher latitudes and particularly in the auroral zones. During worst disturbances stratification of the F2-layer has been known to occur. Table V gives a number of magnetic storms recorded at Alibag Magnetic

TABLE V

Sl. No.	Magnetic storm			Radio fade-outs				Remarks
	Date and time of start	Date and time of end	Intensity	Date and time of start	Time of end	Duration	Nature	
1.	7.2.46 15-48 IST	8.2.46 22-30 IST	Great	8.2.46 11-00 IST	12-30 IST	1 hr. 30 mins.	Partial	
2.	22.3.46 11-08	25.3.46 07-30	,,	25.3.46 09-30	12-30	3 hours	No trace of B. B. C.	
3.	28.3.46 12-05	29.3.46 22-30	Severe	28.3 46 16-00	21-00	5 hours	Complete	Flare observed on 27.3.46 at 09.40. Time difference between start of flare and start of storm =26 hours 25 minutes.
4.	22.4.46 12-28	24.4.46 17-00	Moderate	24.4.46 08-30	20-30	12 hours	Partial B. B. C. poor.	Ionospheric conditions remaining disturbed till about 17 hrs. after the end of the storm.
5.	6.5.46 09-00	8.5.46 01-30	,,	6.5.46 11-40	12-05	25 mins.	Partial, all S. W. Sts. subnormal	
6.	27.7.46 00-15	27.7.46 18-00	Strong	27.7 46 04-15	07-45	3 hours 30 mins	Complete fade-out of B. B. C. H. F. affected	Flare observed on 25.7.46 at 21.45 IST. Time difference between start of flare and start of storm = 26 hours 30 minutes.
				15-00	21-00	6 hours	All stations poor.	Ionospheric condition remaining disturbed till about 19 hrs. after the end of the storm.
				28.7.46 06-00	13-00	7 hours	Complete fade-out	

TABLE V (contd.)

Sl. No.	Magnetic storm			Radio fade-outs				Remarks
	Date and time of start	Date and time of end	Intensity	Date and time of start	Time of end	Duration	Nature	
7.	18.9.46 05–18	19.9.46 22–30	Moderate	18.9.46 08–00	17–00	9 hours	Partial B. B. C. SEAC Moscow poor.	Flare observed on 16.9.46 at 08.15. Time difference between start of flare and start of storm =45 hrs. 3 mins. Ionospheric conditions remaining disturbed till about 16½ hrs. after the end of the storm.
8.	21.9.46 22–41	23.9.46 24–00	,,	22.9.46 23.9.46 24.9.46	Throughout till 11–00 on 24.9.46			Ionospheric conditions remaining disturbed till about 11 hrs. after the end of the storm.
9.	2.3.47 09–29	4.3.47 15–00	,,	3.5.47 11–30	13–00	1½ hours	B. B. C. poor.	
				4.3.47 09–00	16–30	7½ hours	Complete. H. F. more affected.	Ionospheric conditions remaining disturbed till about 44 hours after the end of the storm.
				5.3.47 06–30	13–20	7 hours	B. B. C. poor complete between 11.30 & 13.30	
				6.3.47 07–30	13–00	5½ hours	B. B. C. poor	
10.	8.3.47 11–30	9.3.47 03–30	,,	10.3.47 09–00	13–00	4 hours	Partial	

TABLE V (contd.)

Sl. No.	Magnetic storm			Radio fade-outs				Remarks
	Date and time of start	Date and time of end	Intensity	Date and time of start	Time of end	Duration	Nature	
11.	15.3.47 14–12	16.3.47 22–00	Moderate	No	fade	out		Flare observed on 14.3.47 at 08.50. Time difference between the peak of the flare and start of the storm = 29 hours 22 minutes.
12.	17.4.47 17–54	19.4.47 04–00	Great	18.4.47 04–30	10–30	6 hours	B. B. C. nil till 09.30	
13.	14.6.47 01–20		Moderate	14.6.47 13–30	16–45	3¼ hours	Partial till 16.00 H. F. more affected. Complete after 16.30	
14.	17.7.47 23–18	19.7.47 01–30	Great	19.7.47 11–00	12–00	1 hour	Partial. All foreign sations. H. F. more affected	Flare observed on 16.7.47 at 07.45. Time difference between start of the flare and start of the storm = 39 hours 24 min. Radio fade-out was observed 10 hrs. 30 min. after the end of the storm.
15.	22.8.47 14–40	24.8.47 01–00	,,	25.8.47 08–00	13–30	5½ hours	Partial. All foreign stations	
16.	30.9.47 23–40	3.10.47 10–00	Moderate	No	fade	out		Flare observed on 2.10.47 at 09.30.
17.	9.11.47 14–26	10.11.47 09–30	,,	No	fade	out		Flare observed on 8.11.47 at 08.08. Time difference between start of the flare and start of the storm = 30 hrs. 18 minutes.

TABLE V (contd.)

Sl. No.	Magnetic storm			Radio fade-outs				Remarks
	Date and time of start	Date and time of end	Intensity	Date and time of start	Time of end	Duration	Nature	
18.	12.3.48 02—08	15.3.48 02—00	Moderate	13.3.48 15—30	18—30	3 hours	Partial. B. B. C. affected.	
19.	15.3.48 09—04	15.3.48 24—00	Fairly strong	15.3.48 10—30	19—30	9 hours	Partial. H. F. on W. stations more affected	
20.	21.4.48 04—36	22.4.48 20—30	Moderate	21.4.48 13—30	15—00	1½ hours	Partial; all frequencies affected	
21.	24.1.49 23—58	27.1.49 05—30	Moderately strong	25.1.49 08—00	14—00	6 hours	Partial; all S. W. stations affected.	Flare observed on 23.1.49 at 08.00. Delinger fade-out on 23.1.49. Time differnce between start of flare and start of storm =39 hrs. 58 minutes.
22.	11.5.49 07—34	11.5.49 17—30	Moderate	no	fade	out		Flare observed on 10.5.49 at 09.00. Time difference between start of flare and start of the storm =22 hrs. 34 mins.
23.	12.5.49 12—10	13.5.49 21—30	Strong	13.5.49 09—30	10—15	43 mins.	All stations subnormal; B. B. C. 15 Mc/s nil.	
24.	4.6.49 03—22	6.6.49 07—30	Moderate	5.5.49 14—25 16—20 17—25	14—30 16—45 17—35	5 mins. 25 ,, 10 ,,	21 Mc/s affected	

Observatory during the years 1946-1949 which were accompanied by fade-outs. Details of these fade-outs show that most of them were of considerable duration and in large number of cases transmissions originating from places at higher latitudes were only affected. Radio reception at higher frequencies was more disturbed and in a number of instances higher frequencies originating at higher latitudes were the only transmission circuits to be affected. In some cases, the ionospheric disturbances, as evidenced by radio fade-outs, continued quite often for some 10 to 20 hours after the end of magnetic storms. In one instance it was found to continue for as long as 44 hours.

In the Table V, any solar flare corresponding to an observed magnetic storm has been noted. The time difference between the start of the flare and the start of the storm has also been indicated in individual cases. The average time interval appears to be 30 hours. The average speed of the particles is therefore about 1400 km/sec An interesting feature in the above analysis is the fact that almost all the flares thus correlated with magnetic storms and radio fade-outs were situated within 45° of the central meridian thus confirming the hypothesis that corpuscular emission from a flare is confined to a narrow cone normal to the solar surface at the point of emission.

Corpuscular emission from the sun has been extensively studied during auroral displays. Recently, during the intense auroral storm of 18 – 20 August, 1950, Dr. Meinel of Yerkes Observatory has observed the spectral region of the $H\alpha$ line with a high resolution spectrograph, both with the spectrograph pointed towards the magnetic zenith and also towards the magnetic horizon. He found that the $H\alpha$ line photographed along the magnetic zenith was very unsymmetrical, the maximum being displaced by 10Å and the violet wing was shifted 71Å. This is attributed to the Doppler shift due to the motion of protons. The velocity of the protons entering the earth's atmosphere was thus found to be 3200 km/sec. These observations gave direct support to the corpuscular emission from the sun during aurorae and magnetic storms (Chapman, 1950).

7. SUNSPOT NUMBER AND CHARACTER OF THE GEOMAGNETIC FIELD

In the previous section we have seen that solar flares may be regarded as responsible for producing a very few geomagnetic storms. But it has been fairly well established that whatever cause produces the geomagnetic storm, the same could be responsible for the type of fade-outs described in the previous section since almost all the fade-outs occurred nearly at the same time as the magnetic storms (Table V). In this and the following sections we shall enquire whether sunspots have any influence on the occurrence of storms.

It has been experimentally observed in the past that active spot groups, generally of bi-polar type and of relatively bigger dimensions affect the geomagnetic field rather profoundly during certain period of the life of the spot-group. In the following section we have considered separately the effect of the central meridian passage of large sunspot groups. However, an analysis for all the days in the year 1948 of the relative sunspot numbers and magnetic character figures indicates that there is no regular relationship between sunspot numbers and magnetic index. This is in good agreement with the observed events since only the centrally situated active spot-groups are known to affect the geomagnetic field whereas, the daily sunspot numbers take into account all the spots, big or small, situated anywhere on the visible solar hemisphere. Moreover, there are too many minor disturbances in the magnetic activity. Hence a correlation between magnetic character figure and daily average sunspot number cannot be expected. But during long periods of greater sunspot activity, the geomagnetic field may be expected to be more disturbed. This has been dealt with in the next section.

8. EFFECT OF CENTRAL MERIDIAN PASSAGE OF LARGE SUNSPOTS

In the previous sections, while discussing the effect of sunspot numbers, we have considered only the relative number of spots. We have also seen that there is no close relationship between the daily sunspot number and the values of the magnetic activity. Intense magnetic storms are, on the contrary, decidedly correlated with individual large sunspots and vice versa.

Exhaustive analysis of large sunspot numbers and magnetic storms has been made by Greeves and Newton (1928) and Maunder (1904 etc.). The analysis reveals the interesting fact that the occurrence of large magnetic storms is associated with the presence of large spots in a sector between 26°E and 53°W. The average position is a meridian which at the time of commencement of the storm had passed the central meridian about one day before. It has further been observed that storms with sudden commencements are more closely correlated with sunspots than storms without this character.

In this section we present an analysis of the effects of the central meridian passage (CMP) of large sunspot groups. The data for sunspot activity have been mostly collected from the reports of Kodaikanal Observatory. Figure 3 shows the correspondence between the CMP of large spot-groups with radio fade-outs, solar flares and magnetic storms. The areas (in millionths of sun's visible hemishere) for individual spot-groups are known in very few cases which have been indicated along the line showing the CMP. We have considered three days on either side of the CMP of a spot-group and any flare, fade-out and magnetic storm occurring within these seven days has been shown in the figure. We have no quantitative basis for indicating the flare since the $H\alpha$ line-width has not been plotted in most of the flares. Only types 2 and 3 flares have been included. For the case of the magnetic storms, we have indicated the number of days through which the storms lasted ; their intensity has not been taken into account.

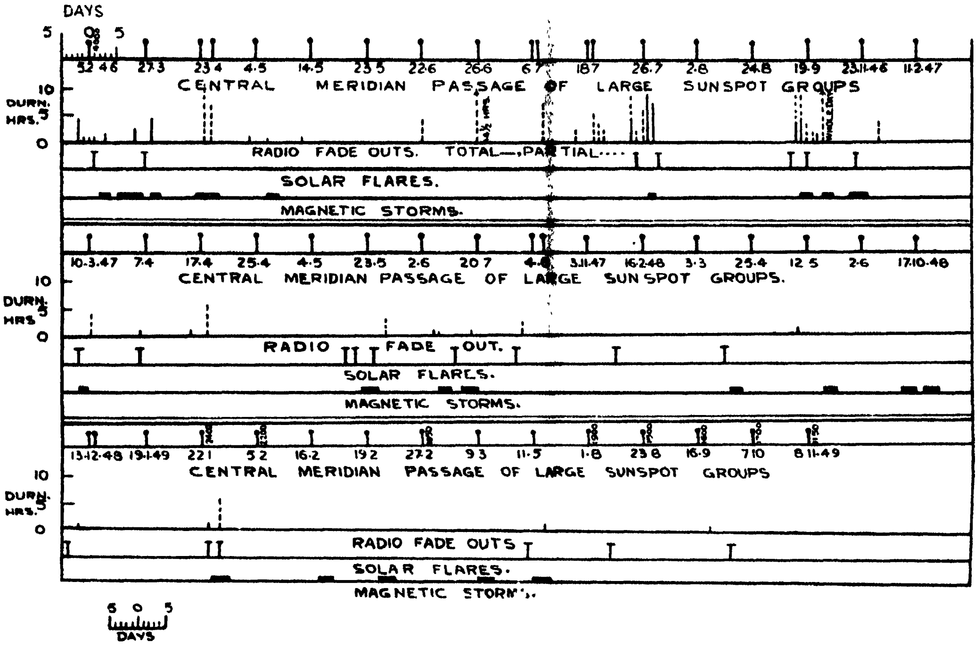

FIG. 3

Effect of central mardian passage of large sunspot groups

It will be evident from figure 3 that, considering the very meagre data at our disposal (four years), the central meridian passage of large spot-groups is often found to be associated with flares, fade-outs and magnetic storms. We refrain from making any statistical analysis since the data are considered to be very limited.

CONCLUSION

Our analysis indicates that a large number of the radio fade-outs are usually not correlated with solar flares and sunspot numbers although they appear to be well correlated with magnetic storms. Out of 122 fade-outs, 99 are unassociated with a solar flare and out of 177 flares, 154 do not produce either a simultaneous or a delayed fade-out. The correspondence between the radio fade-outs and magnetic storms is understandable since they are supposed to be caused by the same mechanism.

The high percentage of fade-outs unassociated with flares is suggestive of a new source of solar origin for the fade-outs. It seems plausible to attribute the occurrence of a fade-out (except those very few associated with flares) to the M-region activity. Recent experimental evidence indicates that the M-regions on the sun are likely to emit corpuscular radiation (Sengupta and Mitra, 1954). The speed of these corpuscules may very within wide limits. We wish to point out that there are a number of observations on record where the effect of M-region activity upon the F2-layer has been observed. The possibitity of the M-region emitting ultraviolet radiation cannot also be excluded. Detailed investigation regarding a possible correlation between the M-region activity and radio fade-outs is in progress.

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