523·78 : 550·384(544)

On the variation in the horizontal intensity of the Geomagnetic Field at Phalodi (Rajasthan) during the Solar Eclipse of 30 June 1954

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(*Received 2 September 1957*)

ABSTRACT. Detailed analysis of hourly mean values of the horizontal force at Phalodi from 26 June to 7 July 1954, has been made with a view to isolating an eclipse-effect, if any. It is seen that 30 June 1954—the day of the eclipse—was magnetically not very calm. As such, the eclipse effects could not be disjoined from the hourly values pertaining to the eclipse period.

All the bays and other big and small magnetic fluctuations (accidental or otherwise) have also been tabulated from the Phalodi H.F. magnetograms for the period 22 June to 7 July 1954, in respect of their time-extent and magnitude. The bivariate frequency table of these fluctuations is also presented. The fluctuations occurring during the period of the eclipse are studied in relation to the frequency table. Important statistical parameters of the series of the magnitudes of the fluctuations are compared with the individual fluctuations for the eclipse period and their mean.

A fall of 10 γ in the horizontal force, appearing 16 minutes after the totality at Phalodi was a likely eclipse-effect. But when all the fluctuations occurring during the control period are studied and a picture of the accidental oscillations of the geomagnetic field is formed, it becomes difficult to say that the drop of 10 γ was definitely due to the eclipse.

1. Introduction

The question regarding the effect of a solar eclipse on the geomagnetic field has been a matter of discussion for many decades now. Dr. L. A. Bauer of the Department of Terrestrial Magnetism, Washington, D.C., organised several expeditions to the track of totality to take special magnetic observations during solar eclipses (Bauer 1932). Bauer (1900) felt, on the basis of his observations, that there was a definite evidence of the effect of solar eclipses on the geomagnetic field. Bemmelen (1905) was convinced after examining observations from several eclipses that an eclipse effect did exist. Chree (1913), however, was equally emphatic that the solar eclipses had no perceptible effect on the geomagnetic field, quoting the eclipse of 17 April 1912. Chapman (1933) considered the problem theoretically and indicated the type and order of the eclipse-effect. Bartels and Chapman (1940) stressed the importance of further examination of the question. Gama (1948) discussed at length the magnetic effects observed in Brazil during the solar eclipse of 20 May 1947. Malurkar (1954) made a study of the geomagnetic records at Colaba and Alibag (India) on the days of a solar eclipse whose track of totality passed near Bombay and Alibag. A preliminary report on the observations made at Phalodi during the solar eclipse of 30 June 1954, has appeared earlier (India met. Dep. 1956).

2. Arrangements

It was after about 40 years that the path of totality was situated in a part of India at the time of the solar eclipse of 30 June 1954. The track of totality started from Nebraska (USA) and passed over Ontario, Quebec and Labrador (Canada), South Greenland, South Iceland, Shetland island, South Scandinavia, U.S.S.R., South Caspian Sea, Iran, Baluchistan and Sind (West Pakistan), and over Rajasthan (India). This afforded a unique opportunity for taking special magnetic observations in India to study the effect of the eclipse on the geomagnetic field. The path of totality in India was very limited.

The above paper was presented at the Fortyfifth Session of the Indian Science Congress held at Madras in January, 1958

It passed over the desert area with very few stations where facilities for establishing a temporary magnetic observatory could be available. Of these, Jaisalmer, Phalodi and Jodhpur happened to be on or very near the track of totality. These stations were, therefore, inspected for preliminary site selection. Phalodi (Lat. 27° 08′N, Long. 72° 22′E), on the path of totality, was found quite suitable and was finally selected. A temporary magnetic station for recording and observing the geomagnetic field during the period 22 June to 8 July 1954 was established there.

3. Circumstances of the eclipse

The total solar eclipse of 30 June 1954 began on earth at 15^h $30 \cdot 8^m$ IST and ended at 20^h $33 \cdot 4^m$ IST. At Phalodi the eclipse began at 18^h 32^m $9 \cdot 4^s$ IST. The totality started at 19^h 25^m $49 \cdot 7^s$ IST and lasted for 68·6 seconds upto 19^h 26^m $58 \cdot 3^s$ IST. The end of the eclipse could not be seen as the sun set at 19^h 39^m IST while the eclipse was still on.

4. Observations

The following instruments were used—(*i*) Eschenhagen H.F. Variometer, (*ii*) Eschenhagen V.F. Variometer, (*iii*) Quartz Horizontal Magnetometer (QHM) and (*iv*) Magnetometric Zero Balance (BMZ). The variometers were provided with suitable photographic recording drums for obtaining continuous photographic records of H.F. and V.F. The recording speed was 15 mm hr^{-1}. These recorders were not provided with automatic time-marking arrangements. The time marks were given by cutting off the light manually at definite timings. The sensitivity of the instruments were as follows—

Variometer	Sensitivity
Horizontal Force	$34 \cdot 2\gamma$/cm
Vertical Force	$56 \cdot 5\gamma$/cm

The variometers were installed in two $8' \times 8'$ size rooms on the ground floor of the P.W.D Rest House. The temperature in these rooms was almost constant, about 99°F, quite free from diurnal variation. The temperature variation for the full period of observations was of the order of 3°F. The observations with QHM and BMZ for determining the base-line values of the H and V magnetograms, were taken daily in two double-roofed tents in the open compound of the Durbar High School, about 300 yards from the variometer rooms in the P.W.D. Rest House. After preliminary setting of the instruments, continuous photographic recording of H.F. and V.F. with Eschenhagen variometers and absolute observations of H and V with QHM and BMZ commenced on 22 June 1954, and were continued upto 8 July 1954.

5. The Phenomenon

According to Bauer (1900), the effect of a solar eclipse on the geomagnetic field should be a diminution of departures from the mean value for the night hours due to the diurnal variation. When the disc of the sun is covered by the moon, night hours are temporarily interposed among the day hours: the electron and ion content of the ionosphere suddenly drops down, the conductivity decreases and the ionospheric currents flowing in the *E*-layer (origin of sq.-field) are modified and, as a consequence, a diminution of the departures of the diurnal variation of the horizontal force takes place for the period of the eclipse. Chapman's theoretical investigation (1933) based on idealised conditions, gives $0 \cdot 28$ H' as the eclipse-reduction to be expected in H at totality, where H' is the departure of the horizontal force from its value a few hours before dawn.

6. The Data

The hourly mean values of the horizontal intensity centred at full hours of GMT from 26 June to 7 July 1954, as determined from the Phalodi H.F. magnetograms (Table 1), have been analysed for a probable eclipse-effect. Each hourly mean value is ascribed to the centre of the respective hour-interval (which is a full hour of GMT). Besides the hourly values, all the bays and other big and small magnetic fluctuations (accidental or otherwise) from the mean diurnal curve

TABLE 1

Observed hourly values of H.F. (in γ) at Phalodi

35,200γ + tabular values (γ)

Hours (GMT)	June 1954					July 1954							Mean	Departure from the Mean of Means (Grand Mean)
	26	27	28	29	30	1	2	3	4	5	6	7		
0	31·5	34·6	32·5	23·0	35·3	71·9	42·8	34·4	50·9	44·7	55·0	29·3	40·5	+ 2·1
1	34·2	30·5	22·3	21·2	35·6	47·2	44·5	40·6	50·2	43·3	52·9	31·0	37·8	− 0·6
2	39·0	25·7	13·0	22·6	37·3	43·1	44·5	44·4	55·0	41·3	56·3	30·7	37·7	− 0·7
3	41·4	24·3	09·3	25·7	41·4	34·2	48·6	49·5	60·1	41·3	58·7	29·3	38·7	+ 0·3
4	49·6	30·8	19·9	23·0	38·3	31·5	56·5	58·4	65·6	43·0	59·1	35·5	42·6	+ 4·2
5	62·6	37·0	32·2	25·7	37·3	17·8	57·8	69·3	68·3	49·5	63·2	43·0	47·0	+ 8·6
6	67·8	42·8	32·9	26·7	40·7	03·5	59·5	67·6	70·3	63·8	62·1	43·7	48·5	+10·1
7	62·3	38·7	19·5	27·4	(47·2)	12·0	54·4	74·5	73·4	77·2	54·6	41·3	48·5	+10·1
8	57·5	32·2	16·5	37·3	(45·2)	27·4	49·6	67·8	73·4	77·2	44·4	42·0	47·5	+ 9·1
9	54·1	31·2	09·6	38·7	(45·5)	37·3	54·4	70·0	73·8	77·2	45·0	37·5	47·9	+ 9·5
10	49·3	28·1	06·9	35·9	(52·0)	32·5	51·3	63·2	64·2	72·1	30·3	26·2	42·7	+ 4·3
11	45·2	22·6	10·6	31·8	(48·6)	28·4	47·2	53·9	53·9	64·2	14·3	07·4	35·7	− 2·7
12	43·1	16·5	07·9	25·3	(39·7)	23·3	44·2	47·4	48·1	55·0	09·1	17·0	31·4	− 7·0
13	42·4	14·4	05·9	23·3	(40·4)	20·9	44·5	44·3	38·5	47·8	17·0	18·7	29·8	− 8·6
14	42·4	27·7	05·2	22·3	(35·6)	23·6	37·3	42·6	36·8	43·3	26·6	20·1	30·3	− 8·1
15	39·7	30·8	07·9	23·3	(37·7)	26·7	40·1	42·6	40·3	41·3	29·0	21·1	31·7	− 6·7
16	40·4	27·1	06·2	20·2	(38·7)	31·5	38·0	40·3	41·3	46·4	23·8	24·5	31·5	− 6·9
17	38·0	24·0	07·9	22·3	38·0	33·6	38·3	39·9	42·6	53·2	27·3	28·6	32·8	− 5·6
18	34·6	21·2	11·0	28·1	40·7	35·6	38·3	45·4	42·6	54·6	33·1	30·0	34·6	− 3·8
19	31·5	20·6	16·5	26·4	43·1	40·4	38·0	46·7	43·0	51·2	24·5	28·3	34·2	− 4·2
20	37·7	25·7	14·7	29·8	46·2	41·1	39·4	48·1	42·3	51·5	20·8	26·6	35·3	− 3·1
21	40·4	29·1	16·5	33·2	44·5	41·8	40·7	48·8	43·7	49·8	27·6	27·3	36·9	− 1·5
22	36·6	38·3	17·8	(33·9)	47·6	40·4	43·1	51·5	44·7	51·2	29·0	27·3	38·5	+ 0·1
23	33·9	36·6	19·5	35·3	60·6	41·1	44·5	55·0	43·0	53·2	30·7	27·3	40·1	+ 1·7
Mean	44·0	28·8	15·1	27·6	42·4	32·8	45·7	51·9	52·7	53·9	37·3	28·9	38·4 (Grand Mean)	

have been tabulated from the Phalodi H.F. magnetograms for the period, 22 June to 7 July 1954 in respect of their time-extent and magnitude (Table 2a). The bivariate frequency distribution of these fluctuations is presented in Table 2(b). The fluctuations occurring during the period of the eclipse are given separately to see what is the probability of their being a genuine eclipse-effect. The general distribution of bays and other accidental fluctuations of the geomagnetic field for the control period being the one summarised in Table 2(b), could the fluctuations occurring during the eclipse be called real eclipse-effects? Whether the fall of 10γ in the H.F. which appears 16 minutes after the totality at Phalodi (as seen from the magnetogram) could be ascribed to the eclipse?

7. The Method

Any attempt at quantitative determination of eclipse-effects on the geomagnetic field, must take into account the normal diurnal variation of the magnetic element under consideration for the day of the eclipse at the place of observation. In the earlier investigations, the effect of a solar eclipse was often determined by comparing the variations of the eclipse day with those of the preceding and succeeding days, provided that they were all magnetically calm. This method will be of little use in the present investigation, since the hourly values of H on the day of the eclipse (30 June 1954) are uniformly high as compared with the corresponding hourly values for the preceding and following days. The Alibag hourly values for the same period show a similar trend.

We shall now explain how the mean (normal) diurnal variation of H has been determined. The daily means of H (being the mean of the 24 hourly values for each day) have been computed. The means of the hourly values for the period 26 June to 7 July 1954, have also been determined. The mean of these 24 hourly means has been worked out (grand mean). Now the grand mean is subtracted from the hourly means and we get the mean departures from the grand mean. These departures serve as the basis for building up mean diurnal variations. They are added on to the daily means to obtain the mean (normal) diurnal variation for each day. Thus a table of normal hourly values of H is constructed for the whole period under investigation (Table 3). In Table 4 are presented the departures from normal of the observed hourly values of H. In other words, Table 4 gives the scatter of the horizontal force about its assumed normal values. The last column of this table gives the mean absolute value of these deviations for each hour and the last row gives the sum of absolute deviations for each day. In computing these hourly means, the deviations recorded during the eclipse hours (0700 to 1600 GMT) have been omitted. A detailed examination of this table has been made with a view to isolating the eclipse-effect, if any.

8. Discussion of Results

The abnormal changes (departures) in the horizontal force during the eclipse will be made up of two components, one attributable to the eclipse and the other to the accidental oscillation of the geomagnetic field. Table 4 gives us an idea of the magnitude of the inherent accidental fluctuations (positive as well as negative) of the geomagnetic field, from its normal course. It is seen from Table 4 that the largest positive as well as negative deviations occurred on 1 July 1954, which happened to be magnetically disturbed. The magnitudes of these deviations were $+37\cdot0\gamma$ and $-39\cdot4\gamma$ for 0 hr and 6 hr respectively. It may be remarked that 1 July 1954, was magnetically the most disturbed day in the whole period of observations. The sum of the absolute hourly deviations for that day equals $263\cdot2\gamma$, while that for 30 June 1954, it is $144\cdot8\gamma$. On 2 July its value is lowest being only $71\cdot7\gamma$. Thus, 30 June 1954 too was not very calm. The last column of the table gives the mean deviation ($\triangle$f) for each individual hour and may be ascribed to the intrinsic field action. It can be both positive and negative. If we denote by $\triangle$e and $\triangle$f, the contribution of the eclipse and that of the

TABLE 2 (a)

Bays and other magnetic fluctuations tabulated from the Phalodi H.F. magnetograms

Date	Time-extent (min.)	Magnitude (γ)	Date	Time-extent (min.)	Magnitude (γ)	Date	Time-extent (min.)	Magnitude (γ)	Date	Time-extent (min.)	Magnitude (γ)
1954 June 22	40	−2·7	June 25	32	−3·4	June 29	20	+2·4	July 5	100	+5·1
	48	−3·8		44	−4·8		20	+2·4		200	−13·3
	44	+3·4		76	−9·2	30	64	+4·8		68	−4·8
	28	+3·4		120	−13·0		20	−2·4		32	+2·7
	32	+3·8		84	+6·2		56	−4·4		60	+6·8
	45	+5·1	26	100	−9·2		[124	+9·6		30	+3·8
	22	+3·4		22	−3·1		62	−5·8		64	+4·4
	20	−3·4		16	−2·7		51	−4·8		60	−5·1
	30	+3·4		44	−4·4		80	−9·6]	6	173	−19·8
	48	+5·8		42	−5·8		48	+6·2		288	−23·3
	21	−3·4		60	−5·8	July 1	204	+33·5		60	+6·8
	37	+3·4		87	+3·8		400	−47·5		32	+5·1
	40	+2·7		18	−3·8		32	−2·1		100	+9·6
	14	−4·1		60	+4·1		36	−3·1		28	−13·0
23	54	−4·1		36	+6·8		36	−2·4		40	−4·1
	16	−2·4		44	+4·8		28	−2·7		13	−2·4
	16	−2·4		18	+5·8		40	−3·4		12	+2·7
	28	−2·4		160	+13·0		36	−2·7		36	+4·4
	20	−2·7		60	+3·8		60	+4·4		72	+6·5
	13	−3·1	27	160	−7·2		48	+6·2	7	90	+8·5
	16	−2·4		80	−3·8	2	40	+3·8		28	+3·4
	36	−3·1		30	−4·1		36	+2·7		13	+2·4
	12	−2·4		30	+2·4		32	−3·1		36	−3·4
	32	−4·1		119	+12·7		108	−6·2		164	−26·0
	17	−6·2		84	−4·4		76	+8·2		48	+2·7
	36	−3·4		60	−4·8		60	+3·4		46	+2·7
	60	−3·8		304	+20·2		48	−4·4		40	+3·1
	33	+7·2	28	180	−13·7		28	−2·7		44	+3·8
	76	+13·0		76	+7·5	3	44	+2·7		52	+5·8
	20	−5·8		88	+4·4		36	+3·4		20	+2·4
	17	−9·6		64	+7·9		21	−4·1		44	+3·1
	18	−4·4		44	+6·8		132	−10·9			
	40	−2·7		43	+4·1		50	−5·5			
	30	+6·2		48	+5·8		44	+2·7			
24	24	−3·4		44	+3·8		100	−3·4			
	36	+3·1		23	+3·4		52	+6·2			
	40	−3·4	29	34	+4·1	4	24	+3·4			
	45	−2·7		164	−16·4		40	−3·8			
	48	−2·7		32	+2·7		40	+3·4			
	48	+3·4		28	+2·7		52	+2·7			
	53	+3·1		24	+2·4		60	−3·4			

[ ]—Eclipse-time fluctuations

TABLE

Frequency table of

Time extent (minutes)	Magnitude in units of 0·1γ 20 to 29	30 to 39	40 to 49	50 to 59	60 to 69	70 to 79	80 to 89	90 to 99	100 to 109	110 to 119	120 to 129	130 to 139	140 to 149	150 to 159	160 to 169	170 to 179
10— 19	8	2	2	1	1	..	..	1	..	..	..	..	..	..	..	..
20— 29	10	9	1	1	..	..	..	..	..	..	..	1	..	..	..	..
30— 39	7	13	3	1	2	1	..	..	..	..	..	..	..	..	..	..
40— 49	9	12	6	4	3	..	..	..	..	..	..	..	..	..	..	..
50— 59	1	1	2	2	1	..	..	..	..	..	..	..	..	..	..	..
60— 69	..	4	6	2	2	1	..	..	..	..	..	..	..	..	..	..
70— 79	..	..	..	..	1	1	1	1	..	..	..	1	..	..	..	..
80— 89	..	2	2	..	1	..	..	..	..	..	..	..	..	..	..	..
90— 99	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..
100—109	..	1	..	1	1	..	..	2	..	..	..	..	..	..	..	..
110—119	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..
120—129	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..
130—139	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..
140—149	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
150—159	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
160—169	..	..	..	..	..	1	..	..	..	..	..	1	..	..	1	..
170—179	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
180—189	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..
190—199	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
200—209	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..
210—219	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
220—229	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
230—239	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
240—249	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
250—259	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
260—269	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
270—279	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
280—289	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
290—299	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
300—309	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
310—319	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
320—329	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
330—339	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

(400 minutes 475 units of 0·1 γ frequency = 1)

Total frequency = 150, excluding eclipse fluctuations

2(b)

the fluctuations

Magnitude in units of 0·1γ																
180 to 189	190 to 199	200 to 209	210 to 219	220 to 229	230 to 239	240 to 249	250 to 259	260 to 269	270 to 279	280 to 289	290 to 299	300 to 309	310 to 319	320 to 329	330 to 339	Time-extent (minutes)
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10— 19
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20— 29
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	30— 39
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	40— 49
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	50— 59
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	60— 69
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	70— 79
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	80— 89
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	90— 99
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	100—109
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	110—119
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	120—129
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	130—139
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	140—149
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	150—159
..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	160—169
..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	170—179
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	180—189
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	190—199
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	200—209
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	210—219
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	220—229
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	230—239
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	240—249
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	250—259
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	260—269
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	270—279
..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	280—289
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	290—299
..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	300—309
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	310—319
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	320—329
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	330—339

Total frequency = 150, excluding eclipse fluctuations

TABLE 3

Assumed normal hourly values of H.F. (in γ) at Phalodi

35,200 γ + tabular values (γ)

Hours (GMT)	June 1954					July 1954						
	26	27	28	29	30	1	2	3	4	5	6	7
0	46·1	30·9	17·2	29·7	44·5	34·9	47·8	54·0	54·8	56·0	39·4	31·0
1	43·4	28·2	14·5	27·0	41·8	32·2	45·1	51·3	52·1	53·3	36·7	28·3
2	43·3	28·1	14·4	26·9	41·7	32·1	45·0	51·2	52·0	53·2	36·6	28·2
3	44·3	29·1	15·4	27·9	42·7	33·1	46·0	52·2	53·0	54·2	37·6	29·2
4	48·2	33·0	19·3	31·8	46·6	37·0	49·9	56·1	56·9	58·1	41·5	33·1
5	52·6	37·4	23·7	36·2	51·0	41·4	54·3	60·5	61·3	62·5	45·9	37·5
6	54·1	38·9	25·2	37·7	52·5	42·9	55·8	62·0	62·8	64·0	47·4	39·0
7	54·1	38·9	25·2	37·7	52·5	42·9	55·8	62·0	62·8	64·0	47·4	39·0
8	53·1	37·9	24·2	36·7	51·5	41·9	54·8	61·0	61·8	63·0	46·4	38·0
9	53·5	38·3	24·6	37·1	51·9	42·3	55·2	61·4	62·2	63·4	46·8	38·4
10	48·3	33·1	19·4	31·9	46·7	37·1	50·0	56·2	57·0	58·2	41·6	33·2
11	41·3	26·1	12·4	24·9	39·7	30·1	43·0	49·2	50·0	51·2	34·6	26·2
12	37·0	21·8	08·1	20·6	35·4	25·8	38·7	44·9	45·7	46·9	30·3	21·9
13	35·4	20·2	06·5	19·0	33·8	24·2	37·1	43·3	44·1	45·3	28·7	20·3
14	35·9	20·7	07·0	19·5	34·3	24·7	37·6	43·8	44·6	45·8	29·2	20·8
15	37·3	22·1	08·4	20·9	35·7	26·1	39·0	45·2	46·0	47·2	30·6	22·2
16	37·1	21·9	08·2	20·7	35·5	25·9	38·8	45·0	45·8	47·0	30·4	22·0
17	38·4	23·2	09·5	22·0	36·8	27·2	40·1	46·3	47·1	48·3	31·7	23·3
18	40·2	25·0	11·3	23·8	38·6	29·0	41·9	48·1	48·9	50·1	33·5	25·1
19	39·8	24·6	10·9	23·4	38·2	28·6	41·5	47·7	48·5	49·7	33·1	24·7
20	40·9	25·7	12·0	24·5	39·3	29·7	42·6	48·8	49·6	50·8	34·2	25·8
21	42·5	27·3	13·6	26·1	40·9	31·3	44·2	50·4	51·2	52·4	35·8	27·4
22	44·1	28·9	15·2	27·7	42·5	32·9	45·8	52·0	52 8	54·0	37·4	29·0
23	45·7	30·5	16·8	29·3	44·1	34·5	47·4	53·6	54·4	55·6	39·0	30·6

TABLE 4

Scatter (observed—normal) of H.F. about the corresponding assumed normal hourly values (γ)

Hours (GMT)	June 1954					July 1954							Mean (△f)
	26	27	28	29	30	1	2	3	4	5	6	7	
0	−14·6	+ 3·7	+15·3	− 6·7	− 9·2	(+37·0)	− 5·0	−19·6	− 3·9	−11·3	+15·6	− 1·7	12·0
1	− 9·2	+ 2·3	+ 7·8	− 5·8	− 6·2	+15·0	− 0·6	−10·7	− 1·9	−10·0	+16·2	+ 2·7	7·4
2	− 4·3	− 2·4	− 1·4	− 4·3	− 4·4	+11·0	− 0·5	− 6·8	+ 3·0	−11·9	+19·7	+ 2·5	6·0
3	− 2·9	− 4·8	− 6·1	− 2·2	− 1·3	+ 1·1	+ 2·6	− 2·7	+ 7·1	−12·9	+21·1	+ 0·1	5·4
4	+ 1·4	− 2·2	+ 0·6	− 8·8	− 8·3	− 5·5	+ 6·6	+ 2·3	+ 8·7	−15·1	+17·6	+ 2·4	6·6
5	+10·0	− 0·4	+ 8·5	−10·5	−13·7	−23·6	+ 3·5	+ 8·8	+ 7·0	−13·0	+17·3	+ 5·5	10·1
6	+13·7	+ 3·9	+ 7·7	−11·0	−11·8	(−39·4)	+ 3·7	+ 5·6	+ 7·5	− 0·2	+14·7	+ 4·7	10·3
7	+ 8·2	− 0·2	− 5·7	−10·3	(− 5·3)	−30·9	− 1·4	+12·5	+10·6	+13·2	+ 7·2	+ 2·3	(9·3)
8	+ 4·4	− 5·7	− 7·7	+ 0·6	(− 6·3)	−14·5	− 5·2	+ 6·8	+11·6	+14·2	− 2·0	+ 4·0	(7·0)
9	+ 0·6	− 7·1	−15·0	+ 1·6	(− 6·4)	− 5·0	− 0·8	+ 8·6	+11·6	+13·8	− 1·8	− 0·9	(6·1)
10	+ 1·0	− 5·0	−12·5	+ 4·0	(+ 5·3)	− 4·6	+ 1·3	+ 7·0	+ 7·2	+13·9	−11·3	− 7·0	(6·8)
11	+ 3·9	− 3·5	− 1·8	+ 6·9	(+ 8·9)	− 1·7	+ 4·2	+ 4·7	+ 3·9	+13·0	−20·3	−18·8	(7·5)
12	+ 6·1	− 5·3	− 0·2	+ 4·7	(+ 4·3)	− 2·5	+ 5·5	+ 2·5	+ 2·4	+ 8·1	−21·2	− 4·9	(5·8)
13	+ 7·0	− 5·8	− 0·6	+ 4·3	(+ 6·6)	− 3·3	+ 7·4	+ 1·0	− 5·6	+ 2·5	−11·7	− 1·6	(4·6)
14	+ 6·5	+ 7·0	− 1·8	+ 2·8	(+ 1·3)	− 1·1	− 0·3	− 1·2	− 7·8	− 2·5	− 2·6	− 0·7	(3·1)
15	+ 2·4	+ 8·7	− 0·5	+ 2·4	(+ 2·0)	+ 0·6	+ 1·1	− 2·6	− 5·7	− 5·9	− 1·6	− 1·1	(3·0)
16	+ 3·3	+ 5·2	− 2·0	− 0·5	(+ 3·2)	+ 5·6	− 0·8	− 4·7	− 4·5	− 0·6	− 6·6	+ 2·5	(3·3)
17	− 0·4	+ 0·8	− 1·6	+ 0·3	+ 1·2	+ 6·4	− 1·8	− 6·4	− 4·5	+ 4·9	− 4·4	+ 5·3	3·2
18	− 5·6	− 3·8	− 0·3	+ 4·3	+ 2·1	+ 6·6	− 3·6	− 2·7	− 6·3	+ 4·5	− 0·4	+ 4·9	3·8
19	− 8·3	− 4·0	+ 5·6	+ 3·0	+ 4·9	+11·8	− 3·5	− 1·0	− 5·5	+ 1·5	− 8·6	+ 3·6	5·1
20	− 3·2	0	+ 2·7	+ 5·3	+ 6·9	+11·4	− 3·2	− 0·7	− 7·3	+ 0·7	−13·4	+ 0·8	4·6
21	− 2·1	+ 1·8	+ 2·9	+ 7·1	+ 3·6	+10·5	− 3·5	− 1·6	− 7·5	− 2·6	− 8·2	− 0·1	4·3
22	− 7·5	+ 9·4	+ 2·6	+ 6·2	+ 5·1	+ 7·5	− 2·7	− 0·5	− 8·1	− 2·8	− 8·4	− 1·7	5·2
23	−11·8	+ 6·1	+ 2·7	+ 6·0	+16·5	+ 6·6	− 2·9	+ 1·4	−11·4	− 2·4	− 8·3	− 3·3	6·6
Sum of absolute deviation	138·4	99·1	113·6	119·6	144·8	263·2	71·7	122·4	160·6	181·5	260·2	83·1	

accidental field action respectively to the deviations during the eclipse hours (0700 to 1600 GMT on 30 June), we can separate the eclipse-effect as in Table 5.

In Table 5, $\triangle e$ and $\triangle' e$ represent the possible eclipse-effects according as $\triangle f$ is —ve or +ve. Table 6 gives the departures of the hourly values (0700 to 1600 GMT on 30 June) from the early morning value for 2200 GMT on 29 June. 28 per cent of these departures have also been worked out, so that the results in the last columns of Tables 5 and 6 can be compared and Chapman's theory verified. It will be at once noticed that there is no agreement between the two sets of values. Further, the order of magnitude of the computed eclipse-effect appears small to be statistically significant. For, assuming the *E*-layer of the ionosphere as the seat of the daily magnetic variation, the eclipse reduction in *H* at totality, according to Chapman (1933), is of the order of 10γ. Also, an examination of the frequency table of the deviations (Table 7) will show that the distribution conforms to a normal pattern and that it is difficult to conclude with any degree of definiteness that the fluctuations registered during the eclipse were caused by the eclipse.

Referring back to Table 2(a), it will be of interest to make a comparative study of the individual absolute values of the magnitude of the fluctuations for the eclipse period and their mean with the mean of the entire series. The following inferences are noteworthy—

(*a*) The values of the magnitude of the fluctuations recorded during the eclipse are not exceptional in that they are neither the highest nor the lowest. Very high values of the magnitude exceeding three times the highest recorded during the eclipse, have occurred twice. The number of values of the magnitude exceeding 9·6γ (the highest value recorded during the eclipse)=14 (about 9 per cent of the total number of values).

(*b*) Individual and mean for the eclipse hours are compared with the mean of the given series thus:

(*i*) Mean of the absolute magnitudes for the entire series=5·749 γ
(*ii*) Standard deviation of the absolute magnitudes=5·663 γ
(*iii*) Standard error of the mean=0·456 γ

} based on 154 values

(*iv*) Mean of the absolute magnitudes for the eclipse hours=7·450 γ

The mean for the eclipse hours (7·450 γ) is not significantly different from the general mean. For, the individual values may be expected to lie within Mean ± 2 standard deviation on 95 per cent of the occasions, on the assumption of a normal distribution. The values during the eclipse are well within Mean ± 2 S.D.

(*c*) The bivariate frequency (Table 2b) does not readily suggest any good degree of association between the time-extent of the fluctuations and their magnitude in general, and for the lower ranges of the magnitude in particular. A more detailed examination of the magnitude of the fluctuations and their time-extent, however, indicates that generally high values of the magnitude and high values of the time-extent appear well associated. The correlation coefficient between the magnitude and the time-extent of the fluctuations works out to be 0·863, a fairly high value. The fluctuation of — 9·6γ over an 80-minute interval during the eclipse turns out to be a part of the general behaviour of the geomagnetic field.

9. Conclusions

The eclipse-effect in the horizontal force could not be separated out of the hourly values pertaining to the eclipse hours, as the hourly values on the eclipse day (30 June 1954) happened to be uniformly high as compared to the corresponding values for the preceding and succeeding days. Again, when a detailed study of the fluctuations of the horizontal force for the eclipse hours is made in relation to the series of fluctuations

TABLE 5

30 June 1954 (GMT)	Δe+Δf (γ)	Δf (γ)	Δe (γ)	Δ′e (γ)
0700	— 5·3	9·3	+ 4·0	— 14·7
0800	— 6·3	7·0	+ 0·7	— 13·3
0900	— 6·4	6·1	— 0·3	— 12·5
1000	+ 5·3	6·8	+ 12·1	— 1·5
1100	+ 8·9	7·5	+ 16·4	+ 1·4
1200	+ 4·3	5·8	+ 10·1	— 1·5
1300	+ 6·6	4·6	+ 11·2	+ 2·0
1400	+ 1·3	3·1	+ 4·4	— 1·8
1500	+ 2·0	3·0	+ 5·0	— 1·0
1600	+ 3·2	3·3	+ 6·5	— 0·1

TABLE 6

30 June 1954 (GMT)	Departure of hourly values from 2200 GMT value on 29 June (γ)	28 per cent of the departure (γ)
0700	— 13·3	— 3·7
0800	— 11·3	— 3·2
0900	— 11·6	— 3·2
1000	— 18·1	— 5·1
1100	— 14·7	— 4·1
1200	— 5·8	— 1·6
1300	— 6·5	— 1·8
1400	— 1·7	— 0·5
1500	— 3·8	— 1·1
1600	— 4·8	— 1·3

TABLE 7

Intervals (γ)	Observed frequency	Expected frequency according to normal distribution	Intervals (γ)	Observed frequency	Expected frequency according to normal distribution
—42 to —39	1	0	0 to + 3	38·5	39·4
—39 to —36	0	0	+ 3 to + 6	33·5	34·7
—36 to —33	0	0	+ 6 to + 9	31·5	26·8
—33 to —30	1	0	+ 9 to +12	9	18·2
—30 to —27	0	0·1	+12 to +15	8·5	10·9
—27 to —24	0	0·4	+15 to +18	6·5	5·7
—24 to —21	2	1·1	+18 to +21	1	2·6
—21 to —18	3	2·6	+21 to +24	1	1·1
—18 to —15	1·5	5·7	+24 to +27	0	0·4
—15 to —12	7·5	10·9	+27 to +30	0	0·1
—12 to — 9	14	18·2	+30 to +33	0	0
— 9 to — 6	24	26·8	+33 to +36	0	0
— 6 to — 3	37	34·7	+36 to +39	1	0
— 3 to 0	58·5	39·4			

occurring throughout the control period, it is seen that the eclipse-time fluctuations are not exceptional. They rather fit in closely with the general pattern of the fluctuations of the horizontal force.

It is difficult to say that the drop of 10γ around totality over an eighty-minute interval was entirely due to the eclipse, especially in the light of the general distribution of the accidental oscillations of the geomagnetic field obtaining during the control period. Egedal and Ambolt (1955), however, state that definite eclipse-effects in the declination of the geomagnetic field during the solar eclipse of 30 June 1954 were observed. The present investigation does not seem to confirm the results of the studies of Egedal and Ambolt.

Incidentally, it may be mentioned that a rough examination of the hourly values of the horizontal force at Kakioka (Japan) and Madagascar (Africa) for the day of the eclipse, shows similar fluctuations to those observed at Phalodi. Further, it is noticed from the table of magnetic character-figure (IAGA Bulletin No. 12i, 1955) for June 1954, that 30 June was magnetically far from quiet.

10. Acknowledgements

The authors wish to express their sincere thanks to Shri S. L. Malurkar, Director, Colaba and Alibag Observatories, for suggesting the method of approach to the problem and for his valuable advice and encouragement. Thanks are also due to Shri K. N. Rao for discussions of statistical parameters.

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