ON THE NON-SIMULTANEITY OF MAGNETIC STORMS.

By Rev. Luis Rodés, S. J.

Dr. Bauer in a study based chiefly on data collected by Faris, reached the conclusion that "magnetic storms do not begin at precisely the same instant all over the Earth." The abruptly beginning ones, investigated by him, appeared to progress more often towards the east than towards the west, with a velocity such that it would require, on the average, about four minutes to encircle the Earth at the equator.[1]

I should like to call attention to the fact that in the case of five well-defined storms which occurred subsequent to those examined by Bauer, namely, those of January, February and May, 1919, March, 1920, and May, 1921, I have found a simultaneous beginning at Tortosa and at Honolulu, which lies 158 degrees to the west, within the limits of measurement. The photographic paper at Tortosa runs at the rate of 2.8 minutes to the millimeter and the base line is shown every hour by an electric lamp in connection with the astronomical clock, hence, I do not think we can be in error by a minute. The measures for each storm were accurately made by the writer, and the corresponding times of the beginning as registered at the other stations were kindly communicated to me by Col. E. Lester Jones, director of the U. S. Coast and Geodetic Survey, at Washington, and by Capt. R. L. Faris, acting director.[2]

Table 1 gives the times of beginning of 15 storms in comparison with the times registered at Tortosa. The storm of August 11, 1919, began simultaneously at Lukiapang, Tortosa and Porto Rico, a range of 186 degrees in longitude, while the other stations have apparently registered it progressively earlier.

The last two storms (March 22, 1920, and May 13, 1921) began very suddenly and simultaneously at Tortosa, Cheltenham, Tucson, Sitka and Honolulu, representing a range of 171 degrees.

[1] *Terr. Mag.*, vol. 15, 1910, pp. 221-232; R. L. FARIS, vol. 15, 1910, pp. 93-105; see also L. A. BAUER, vol. 15, 1910, pp. 9-20.

[2] I am indebted to Sir Frederic Stupart for the data of Agincourt; to Prof. J. M. Baldwin for those of Melbourne; to Mr. W. H. Cullum for those of Tucson, and to Rev. J. de Moidrey for information respecting Lukiapang.

It would seem probable that, as the time record has been more accurately kept during recent years, the results would indicate a simultaneous beginning all over the Earth. There are, nevertheless, some cases in which a propagation is strongly suspected. In such cases, which will be the first observatory to register the magnetic storm? I do not know of any answer to this question.

The author has tried a hypothesis which rests to some extent on facts. If a magnetic storm is due to the Earth's entering a cloud of electrical particles projected from the Sun, the case will be similar to that of the Earth's entering the Moon's shadow during an eclipse, and the storm will first be registered at those observatories which are nearer the "front meridian," as I have designated the one which, because of the Earth's rotation, happens to be foremost in direction of movement at the moment the storm begins. (See *A*, Fig. 1.) Accordingly, an observatory which registers the storm at six o'clock local time should be the first of all to record it; next would follow those nearer to it on either side, and last of all the one at which the storm began at 18^h local time.

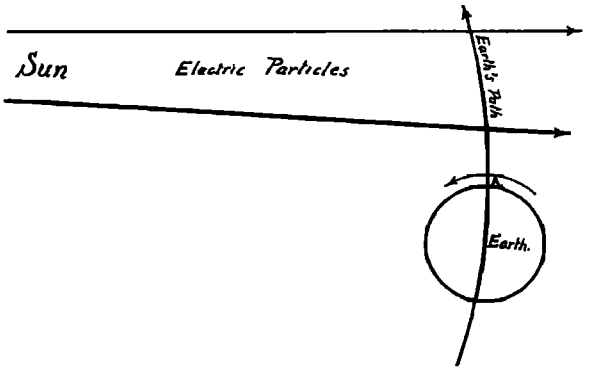

FIG. 1.

As it does not seem possible that a cloud at a distance of 150 million kilometers in free space has an effective transversal velocity greater than 2 kilometers per second, caused by the solar rotation by which it was projected, a rough approximation of the time required for the Earth to become involved in the cloud can be easily obtained from its orbital velocity; this amounts to about six and a half minutes, a little longer than that found experimentally by Bauer. It may be that when half, or even a greater part of the

TABLE 1.—*Greenwich times of beginnings of 15 magnetic storms, and differences as compared with times at Tortosa.**

Number...	Station.... (S)	Latitude	Longitude	12 W. 1910 Oct. 12-14 18h		11 E. ah. 1910 Oct. 19 (8)7h		6 E. ah. 1911 Mar. 20 (5)0h		5 E. ah. 1914 Jul. 5-6 (6)1h		10 W. ah. 1914 Oct. 27 16h		12 W. ah. 1916 Aug. 22 (4)18h		11 E. ah. 1916 Aug. 25 (7)19h		11 E. ah. 1917 Aug. 25 (3)19h		0 ah. 1917 Sep. 5 (1)6h		12 W. ah. 1919 Jan. 3 (1)18h		11 E. ah. 1919 Feb. 27 19h		0 ah. 1919 May 21 6h		1 W. ah. 1919 Aug. 11 (1)6h		3 W. ah. 1920 Mar. 22 (1) 9h		7 W. ah. 1921 May 13 (1)13h		Mean (S-T)
				S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	
		° ′	° ′	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
1	Mel..	37 49	S 144 58	E 30	0	....	....	....	....	....	....	15	−3	30	+3.4	....	....	44	+2	5	−3	10	0	25	+1	30	+5	55	−3	8	−2	9	−1	−0	05
2	Anti .	14 36	N 121 10	E 33	+3	....	....	....	....	....	....	9	(−9)	20	(−6.6)	....	....	34	(−8)	23	(+15)	6	−4	20	−4	13	(−12)	55	−3	10	0	6	−4	−2	0
3	Luk .	31 21	N 121 01	E	....	....	....	....	....	....	....	14	−4	25	−1.6	....	....	34	(−8)	10	+2	12	+2	25	+1	25	0	58	0	....	....	....	....	−0	08
4	Wath.	30 20	S 116 01	E	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	55	−3	9	−1	9	−1	−1	7
5	All...	18 38	N 12 52	E	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	11	+1	+1	0
6	Tort..	40 49	N 0 30	E 30	0	13	....	49	....	29.4	....	18	0	26.6	0	44	....	42	0	8	0	10	0	24	0	25	0	58	0	10	0	10	0	0	0
7	R'co .	18 08	N 65 25	W	....	....	....	....	....	....	....	17	−1	30	+3.4	....	....	41	−1	9	+1	11	+1	27	+3	23	−2	58	0	10	0	9	−1	+0	3
8	Chel .	38 44	N 75	50W	....	....	....	....	....	....	....	....	....	27	+0.4	....	....	41	−1	8	0	11	+1	26	+2	24	−1	57(9)	−1	10	0	10	0	+0	04
9	Tor...	43 39	N 79	23W 27(a)	−3	....	....	....	....	....	....	21	+3	26	−0.6	....	....	30(c)	(−12)	8	0	10(b)	0	24	+0	....	....	57	−1	9	−1	10	0	−0	3
10	Tuc..	32 15	N 110	50W	....	....	....	....	....	....	....	....	....	27	+0.4	....	....	41	−1	8	0	10	0	25	+1	24	−1	57	−1	10	0	10	0	−0.2	
11	Sit...	57 03	N 135	20W	....	....	....	....	....	....	....	21	+3	26	−0.6	....	....	41	−1	8	0	11	+1	26	+2	25	0	56	−2	10	0	10	0	+0	2
12	Hon .	21 19	N 158	03W	....	....	....	....	....	....	....	15	−3	26	−0.6	....	....	41	−1	7	−1	10	0	24	0	24	−1	57	−1	10	0	10	0	−0.8	
13	Apia .	13 48	S 171	43W	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	9	−1	(−1)	
Sum of residuals, S-Tortosa....					0	....	....	....	....	....	....	....	−14	....	−2.4	....	....	....	−31	....	+14	....	+1	....	+6	....	−12	....	−15	....	−4	....	−7			
Sum, omitting figs.in parentheses....						....	....	....	....	....	....	....	−5	....	+4.2	....	....	....	−3	....	−1	....	+1	....	+6	....	0	....	−15	....	−4	....	−7			
Mean deviation from Tort. time....						....	....	....	....	....	....	....	−0.7	....	+0.5	....	....	....	−0.4	....	−0.1	....	+0.1	....	+0.6	....	0	....	−1.4	....	−0.4	....	−0.6	−0.30		

(1) Very definite in *H*, *Z* and *D*. (3) The peak in *H* and *Z* at the beginning. (4) Very definite in *H* and *Z*; *D* 3 min. later. (5) Very definite in *H*. (6) Very definite in *H* and *Z*. (7) Very definite in *H*, *Z* and *D*. (8) Very definite in *H*. (9) This value was communicated by letter; the value given in *Terr. Mag.*, Sept., 1919, by Geo. Hartnell is 58m. a. Indefinite beginning value for *H*. b. In *H*. c. Uncertain.

*In the first row of this table is given for each storm the position of the "front meridian," as defined by the author in the text; *ah.* stands for "ahead."—*Ed.*

TABLE 2.—*Times of sudden beginnings of magetic storms, 1906-09.*

Date	Mag. El.	Porto Rico	n	Chel-tenham	n	Bald-win	n	Sitka	n	Hono-lulu	n	Merid-ian ahead	Time-Differences (n-1)				Sum	
		m		m		m		m		m			m	m	m	m	m	m
1906																		
Jul. 29	D	....		56.0	(4)	54.4	(3)	55.4	(2)	54.9	(1)	11 E	+0.5	−0.5	+1.1	.....	+1.1	
19h	H	58.1	(5)	57.8		54.4		55.4		54.9			+0.5	−0.5	+2.9	+3.2	+6.1	
	Z	....		58.1		55.6		58.4		54.0			+4.4	+1.6	+4.1	.....	+10.1	
Aug. 7	D	....		39.3	(2)	39.3	(1)	38.6	(3)	39.9	(5)	7W	0.0	.....	−0.7	+0.6		−0.1
13h	H	37.2	(2)	39.9		38.7		37.1		37.8			+1.2	−1.5	−1.6	−0.9		−2.8
	Z	....		....		42.3		38.6		39.0			.....	.....	−3.7	−3.3		−7.0
Dec. 21	D	34.5	(5)	31.1	(4)	33.1	(3)	29.3	(1)	30.3	(1)	9 E	.....	+3.3	+1.3	+4.7	+9.3	
21h	H	34.5		32.0		32.5		26.9		27.3			.....	+5.4	+4.9	+7.4	+17.7	
	Z	33.9		35.3		35.5		30.2		29.1			.....	+5.9	+5.7	+4.3	+15.9	
1907																		
Feb. 9	D	14.3	(3)	14.0	(2)	15.2	(1)	12.3	(2)	10.4	(1)	8W	−0.5	+1.2	+1.5	.....	+2.2	
14h	H	12.8		13.4		14.3		11.4		11.9			−1.7	+0.3	−0.3	.....		−1.7
	Z	14.6		16.4		18.2		12.9		16.4			−4.4	−0.9	−2.7	.....		−8.0
Jul. 10	D	24.4	(3)	23.6	(2)	24.4	(1)	22.5	(2)	21.8	(1)	8W	−0.6	+0.5	+1.3	.....	+1.2	
14h	H	24.7		24.2		22.6		22.2		20.9			+0.5	+2.5	+3.0	.....	+6.0	
	Z	25.6		25.4		25.0		24.6		25.8			−0.8	0.0	+0.2	.....		−0.6
Oct. 13	D	45.4	(1)	42.3	(2)	41.8	(3)	40.2	(4)	41.8	(5)	2W	−3.1	−3.6	−5.2	−3.6		−15.5
7h	H	42.4		44.1		43.6		40.2		41.5			+0.7	+1.2	−2.2	−0.9		−0.2
	Z	44.5		47.7		....		42.6		45.7			+3.2	.....	−1.9	+1.2	+2.5	
1908																		
Mar. 26	D	40.5	(4)	42.6	(4)	....	(3)	....	(2)	42.4	(1)	11W	.....	.....	+0.2	−1.9		−1.7
17h	H	39.4		40.2		42.0		....		42.3			.....	−0.3	−2.1	−2.9		−5.3
	Z	43.8		44.1		45.8		....		45.9			.....	−0.1	−1.8	−2.1		−4.0
Aug. 19	D	10.0	(4)	15.0	(3)	14.0	(2)	14.9	(1)	14.7	(1)	6 E	−0.8	+0.2	−4.8	.....		−5.4
0h	H	14.2		14.4		14.0		14.6		14.7			−0.6	−0.2	−0.4	.....		−1.2
	Z	16.0		....		....		16.4		18.7			.....	.....	−1.5	.....		−1.5
Sept. 11	D	21.7	(1)	21.0	(2)	20.3	(2)	22.2	(3)	22.1	(5)	1W	−0.7	−1.4	+0.5	+0.4		−1.2
7h	H	20.8		20.9		20.7		20.2		21.5			+0.1	−0.1	−0.6	+0.7	+0.1	
	Z	23.2		23.1		23.7		22.9		24.5			−0.1	+0.5	−0.3	+1.3	+1.4	
Sept. 11	D	49.2	(5)	46.4	(4)	44.5	(3)	47.8	(2)	45.4	(1)	9W	+2.4	−0.9	+1.0	+3.8	+6.3	
21h	H	48.0		46.7		48.1		47.5		46.9			+0.6	+1.2	−0.2	+1.1	+2.7	
	Z	50.7		49.1		49.6		48.7		48.1			+0.6	+1.5	+1.0	+2.6	+5.7	
Sept. 28	D	42.7	(1)	43.0	(2)	41.5	(2)	42.5	(3)	42.1	(3)	3W	+0.3	−1.2	−0.2	−0.6		−1.7
8h	H	41.5		43.6		41.2		41.3		42.4			+2.1	−0.3	−0.2	+0.9	+2.5	
	Z	44.2		46.0		....		45.5		42.9			+1.8	.....	+1.3	−1.3	+1.8	
Sept. 29	D	34.0	(5)	34.3	(3)	31.4	(2)	....	(1)	30.9	(1)	5W	+0.5	+3.4	.....	+3.1	+7.0	
1h	H	31.9		33.4		31.4		....		30.0			+1.4	+3.4	.....	+1.9	+6.7	
	Z	34.3		34.3		33.2		....		31.5			+1.7	+2.8	.....	+2.8	+7.3	
1909																		
May 14	D	56.4	(1)	57.2	(1)	57.7	(2)	58.0	(3)	54.0	(5)	1 E	+0.9	+1.2	.....	−2.8		−0.7
4h	H	54.3		57.2		56.8		53.7		53.1			+1.1	−2.0	.....	−2.6		−3.5
	Z	58.4		58.3		60.7		60.7		56.4			+2.3	+2.3	.....	−2.0	+2.6	
Sept. 25	D	39.8	(1)	41.5	(2)	39.3	(2)	40.3	(3)	42.7	(5)	3W	+1.7	−0.5	+0.5	+2.9	+4.6	
8h	H	37.7		40.9		38.7		39.5		42.7			+3.2	+1.0	+1.8	+5.0	+11.0	
	Z	38.6		....		42.3		42.2		....			+3.7	+3.6	.....	.....	+7.3	
Sept. 25	D	39.8	(1)	42.1	(2)	40.8	(2)	42.2	(3)	46.3	(5)	6W	+2.3	+1.0	+2.4	+6.5	+12.2	
11h	H	39.8		43.3		41.1		39.8		45.4			+3.5	+1.3	0.0	+5.6	+10.4	
	Z	41.0		45.1		41.1		....		49.0			+4.1	+0.1	.....	+8.0	+12.2	
												Sums	+33.0	+31.4	+4.3	+43.1	+173.9	−62.1

Earth, is immersed in the electric cloud, induction phenomena are produced which advance the time of beginning at the other stations.

The writer has tried to ascertain whether this explanation is supported by facts and for this purpose has rearranged the data collected by R. L. Faris as given in Table 2.[3] To each station is assigned a number indicating the order of succession for the registration of each storm, according to the "front meridian" given in the eighth column; when the distance of two stations from the "front meridian" was practically equal, the same number has been given and the mean of their distances is used. In the ninth column are given the differences, second station minus first, third minus first, etc. Now, according to the hypothesis under consideration, these differences should be positive, and the results of Table 2 seem to favor this conclusion since the sum of all the differences is positive in each case, and the general positive mean is about three times greater than the negative one.

In order to obtain more definite results I have taken only the two stations, Cheltenham and Honolulu, which are separated by about 82 degrees of longitude; the first column of Table 3 gives the "front meridian" at the time of beginning and the stations are

TABLE 3.—*Comparison of recorded times of magnetic storms, 1906-1909, at Honolulu and Cheltenham.*

Front Merid.	Date	Hour	Honolulu	Cheltenham	b−a, or a′−a	
		h	m	m	m	m
XI E	1906, Jul. 29	19	54.6 a	57.3 b	+ 2.7	
VII W	Aug. 7	13	38.9 a	40.3* a′	+ 1.4	
IX E	Dec. 21	21	28.9 a	32.8 b	+ 3.9	
VIII W	1907, Feb. 9	14	12.9 a	14.6 a′	+ 1.7	
VIII W	Jul. 10	14	22.8 a	24.4 a′	+ 1.6	
II W	Oct. 13	7	43.0 b	44.7 a		− 1.7
XI W	1908, Mar. 26	17	43.5 a	42.3 b		− 1.2
VI E	Aug. 19	0	16.0 a	15.4* a′		− 0.6
I W	Sept. 11	7	22.7 b	21.7 a	+ 1.0	
VIII E	Sept. 11	21	46.8 a	47.4 b	+ 0.6	
III W	Sept. 28	8	42.5 b	44.2 a		− 1.7
V E	Sept. 29	1	30.8 a	34.0 b	+ 3.2	
II E	1909, May 14	4	54.5 a′	57.6 a		− 3.1
II W	Sept. 25	8	43.4* b	41.9* a	+ 1.5	
V W	Sept. 25	11	46.9 b	43.5 a	+ 3.4	
				Sum...	+21.0	− 8.3

*In deriving these quantities, the author appears to have used some method for supplying missing data in Table 2.—*Ed.*

[3]See GIUSEPPE GIANFRANCESCHI, S. J., "Velocità istantanea della Terra," Roma, *Mem. Acc. Nuove Lincei*, Ser. 2, vol. 4.

marked a or b (a, a', if the difference is negligible), according to their distance from it. Here again the sum of the positive differences b-a is nearly three times as large in absolute value as the sum of a-b.

There are still some very conspicuous exceptions to the rule given, but the agreement is close enough to justify further investigation of the subject.

It is also possible that some of the electric clouds are of cosmic character and have their own velocities. The movement of the whole planetary system, through space and the angle which the direction of the instantaneous apex[4] makes with the Sun-Earth line, might affect the results for such cases. It would be very desirable, were it possible, to compare the beginning of magnetic storms on different planets, but as there is no hope, for the present at least, of obtaining records of such storms, experienced on Jupiter or on Saturn, for example, we must confine our investigations to our own Earth, collecting as many carefully-recorded data as possible.

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[4]See footnote 1.