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Frequency distribution of geomagnetic disturbance commencements at Alibag for the period 1921-1960

N. SIVASANKARA SASTRI

Colaba Observatory, Bombay

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ABSTRACT. Frequency distribution of times of commencement of geomagnetic disturbances at Alibag is studied. Hourly distribution of SSC (Storm Sudden Commencement) occurrences does not show any significant diurnal variation, however, a broad tendency for the frequency to be slightly higher during the day than the night is noticed. Hourly distribution of GC's (Gradual Commencements) show a definite preference for the hours 6 to 12 local time, with 50 per cent occurring during that interval. Monthly distribution of both SSC and GC occurrences show a slightly higher frequency for the equinoxial months.

1. Introduction

Moos (1910), in his monumental study of the magnetic data from Colaba (Bombay), analysed the distribution of times of commencement of what he called X-disturbances (disturbances with sudden commencements), numbering 113, of varying degrees of magnitude, that occurred during the period 1872-1904. While the times of commencement of disturbances seemed to be fairly distributed over all the hours of the day, he suspected a feeble tendency for them to crowd more about the noon hours, the maximum occurring at about 13 hours local time. Also, he found a tendency for the disturbances to be more frequent during the equinoxes than during the solsticial months. Newton (1948), in an elaborate study of 681 sudden commencement occurrences in Greenwich-Abinger records for the period 1879-1944, found in the diurnal distribution of SC'*s* in U.T. hours (*i*) a broad minimum centred at 8^h (*i.e.*,$8^h\ 0^m$—$8^h\ 59^m$), (*ii*) a general afternoon and night maximum broken by (*iii*) a secondary minimum at 18^h and in monthly distribution, lesser frequency during winter months (November to February) and higher frequency from March to September. Chakrabarty (1951) examined about 800 SC's from Alibag data for the period 1905-1944. He found, in the hourly distribution of all SC's and of those only which are followed by large or moderate disturbances, a minimum between 4^h and 7^h local mean time and again at about 17^h LMT and a prominent maximum between 9^h and 13^h local time. The features observed are common to both the distributions he considered, of which the distribution represented graphically as curve B is for SC's followed by moderate or great disturbances. It is contended that he has not made any distinction between SC's and SI's. But the distribution represented by curve B may be taken as for SC's only. He has not examined the frequency distribution of SC's subdividing the data according to seasonal groups and, also seasonal variation. An attempt is here made to study in greater detail the distribution of SSC (Storm Sudden Commencement) as well as GC (Gradual Commencement) occurrence of geomagnetic disturbances at Alibag (Lat. 18°38′N and Long. 72°52′E) during the period 1921-1960. No systematic variation in the hourly (local time) distribution of SSC's is observed which can be considered significant, though, a broad tendency for the frequency to be slightly higher during the day than during the night is noticed. GC's show a clear preference for the hours 6 to 12 local time and 50 per cent occur during that interval. A slightly higher frequency of occurrence is observed during the equinoxial months for both SSC's and GC's.

2. Data

The data are taken from the annual volumes published by the Observatory for the years 1921 to 1946 and, from the manuscripts of tabulations of magnetic disturbances for the years 1947 to 1960. The disturbances are classified in three main groups — great if the range in H (Horizontal Force) is greater than 150γ, moderate when the range is less than 150γ but greater than $65\,\gamma$ and slight if the range is less than 65γ.

Hourly distribution of SSC occurrences is computed for the period 1921 to 1960, for each of the twelve months of the year, in three groups, based on the relative magnitude of the disturbance that follows, namely, great, moderate and slight. For each of the three groups, hourly frequencies are computed for the three seasons by combining the corresponding hourly frequencies for the four months in each season and also for the group irrespective of the season. The three seasons are — D (December solstice) season comprising the months January, February, November and December, E (Equinoxial) season comprising the months March, April, September and October, J (June solstice) season comprising the months May, June, July and August. Finally, the table of hourly frequencies for different seasons, irrespective of the groups, as well as for all the SSC's is computed. These are

TABLE 1

Hourly distribution of frequency of occurrence of SSC's sub-divided (i) according to the intensity of the disturbance that follows and (ii) seasonwise and GC's

Hours (75° East Meridian Time)	SSC's followed by disturbances of intensity			SSC's in season				GC's (All)
	Great	Moderate	Slight	*D*	*E*	*J*	All	
0—1	5	14	14	17	7	9	33	14
1—2	2	14	15	9	10	12	31	22
2—3	5	19	8	6	12	14	32	27
3—4	5	8	12	6	6	13	25	22
4—5	7	15	10	13	13	6	32	21
5—6	7	21	13	14	10	17	41	20
6—7	7	11	8	10	8	8	26	45
7—8	11	13	16	15	13	12	40	56
8—9	13	27	13	19	17	17	53	92
9—10	9	15	14	8	13	17	38	104
10—11	13	17	14	13	17	14	44	86
11—12	11	18	13	16	16	10	42	49
12—13	7	20	16	11	21	11	43	25
13—14	9	27	22	22	18	18	58	22
14—15	6	20	11	10	13	14	37	22
15—16	8	14	21	16	16	11	43	31
16—17	5	13	14	10	19	3	32	34
17—18	4	11	11	5	10	11	26	35
18—19	8	14	5	8	11	8	27	21
19—20	3	11	11	6	[illegible]	11	25	24
20—21	4	12	17	8	17	8	33	26
21—22	6	15	18	11	15	13	39	29
22—23	3	20	17	8	15	17	40	23
23—24	3	12	14	11	8	10	29	24
SSC's sum	161	381	327	272	313	284	869 Mean 36·2	
GC's sum	31	388	455	321	329	224	874 Mean 36·4	874

TABLE 2

Monthly distribution of frequency of occurrence of SSC's and GC's sub-divided according to the disturbance that follows

Intensity of disturbance	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Seasons			Year
													I	II	III	
SSC's																
Great	15	10	22	16	9	9	13	10	19	20	4	14	43	77	41	161
Moderate	26	28	38	37	37	31	30	30	38	33	37	16	107	146	128	381
Slight	30	36	30	25	23	36	27	29	19	16	21	35	122	90	115	327
All	71	74	90	78	69	76	70	69	76	69	62	65	272	313	284	869
GC's																
Great	1	4	7	2	1	1	0	1	3	9	1	1	7	21	3	31
Moderate	33	42	44	32	27	17	18	27	36	38	35	39	149	150	89	388
Slight	41	37	44	31	37	30	39	26	44	39	39	48	165	158	132	455
All	75	83	95	65	65	48	57	54	83	86	75	88	321	329	224	874

given in Table 1. Table 2 gives monthly distribution of frequencies in the three groups as well as for all the disturbances. The distributions, expressed as percentage frequencies, are presented graphically in Figs. 1 and 2. The time-reckoning refers to the 75° East Meridian Time which is 5 hours ahead of Greenwich Mean Time and about 10 minutes ahead of Alibag Local Time and hence, taken as representing the local time of the Observatory.

In the following discussion, day is taken to begin at 6^h and end at 18^h local time in all seasons. The hourly frequencies refer to the sixty minutes duration between that hour and the next, *e.g.*, 8^h refers to 8^h 00 to 8^h 59^m.

3. Discussion

(1) SSC's followed by great disturbances — (Figs. 1a and 2a) — The frequency of occurrence is higher (64 per cent) during the day than during the night, of which 40 per cent occur between 6^h and 12^h. The minimum number occur between 18^h and 24^h, except in *J*-season when the minimum is between 0^h and 6^h. The maximum hourly frequency occurs between 9^h and 11^h, in conformity with Chakrabarty's (1951) observation, but, earlier in

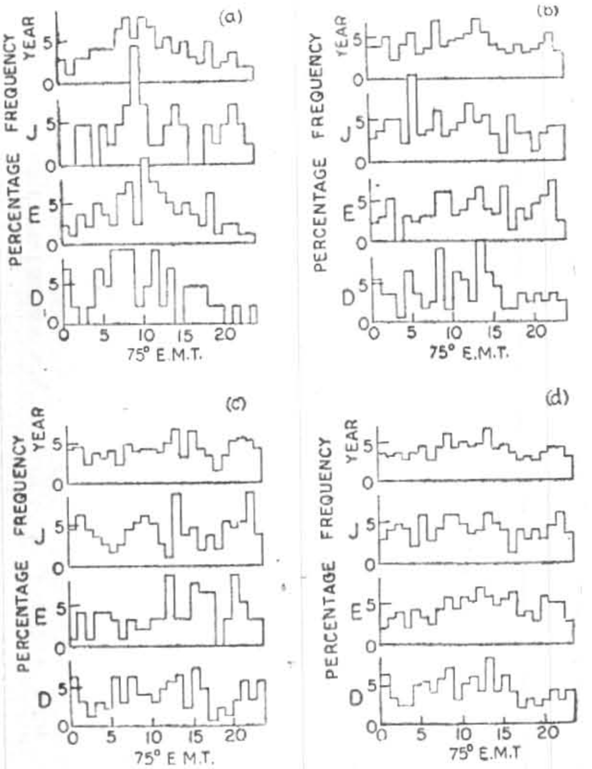

Fig. 1. Hourly distribution of SSC (Storm Sudden Commencement) occurrences at Alibag for the period 1921–60 in three different groups: SSC's followed by (a) great, (b) moderate and (c) slight disturbances and (d) for all SSC's

In each group, distribution in the three seasons *D* (December Solstice), *E* (Equinoxial) and *J* (June Solstice) as well as in the year is separately given

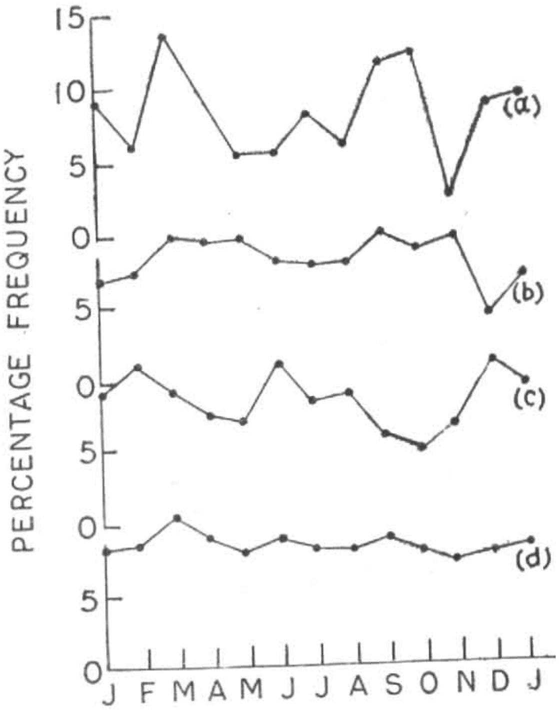

Fig. 2. Monthly distribution of SSC occurrences at Alibag for the period 1921–60 in three groups: SSC's followed by (a) great, (b) moderate and (c) slight disturbances and (d) for all SSC's

D-season (between 6^h and 9^h). The highest hourly frequency observed is at 9^h in *J*-season (15 per cent). Generally there is a post midnight minimum and also late night minimum except in *J*-season when the minimum is at 16^h —17^h separating the maxima at 14^h and 21^h . Nearly half of the disturbances occur in *E*-season and the rest are divided equally in the other two seasons.

The monthly maxima are in March and October with a broad minimum from April to July, and, the lowest minimum occurs in November. Of the total number of disturbances, great disturbances are about 18 per cent.

(2) SSC's followed by moderate disturbances—(Figs. 1b and 2b)—The frequency of occurrence is slightly higher (55 per cent) during day, but in *J*-season it is same for both day and night, when the maximum (31 per cent) occurs between 0^h and 6^h . Minimum occurs between 18^h and 24^h in *D* and *J*-seasons but, between 0^h and 6^h in *E*-season. Maximum hourly frequency occurs at 8^h and 13^h and minimum, at 3^h and 16^h , which is in fair agreement with Chakrabarty's (1951) finding. The highest hourly frequency ocurs at 13^h in *D*-season, 22^h in *E*-season and 5^h in *J*-season. The frequency of moderate disturbances is about equal in *E* and *J*-seasons and lowest in *D*-season.

The monthly frequency is lowest in December, but from March to November the occurrences are more or less evenly distributed with a shallow minimum around July. Of the total number of disturbances, moderate disturbances are more frequent (44 per cent).

(3) SSC's followed by slight disturbances — (Figs. 1c and 2c) — These are slightly more frequent during day (55 per cent) in *D* and *E*-seasons but almost equal in *J*-season. The maximum of occurrence is between 12^h and 18^h in *D* and *E*-seasons but, between 18^h and 24^h in *J*-season. In *E*-season the cccurrences are 63 per cent during the period 12^h and 24^h of which the maximum (39 per cent) occur between 12^h and 18^h . Maxima of hourly frequency occur between 13^h and 15^h and, 20^h and 22^h , separated by a minimum around 18^h . A minimum occurs at 2^h except in *J*-season, when it is at 5^h . A pronounced midnight maximum occurs in *D*-season. Slight disturbances are about 38 per cent of the total. The least (28 per cent) occurs in *E*-season, being almost equal in the other two seasons. This is in contrast with what is

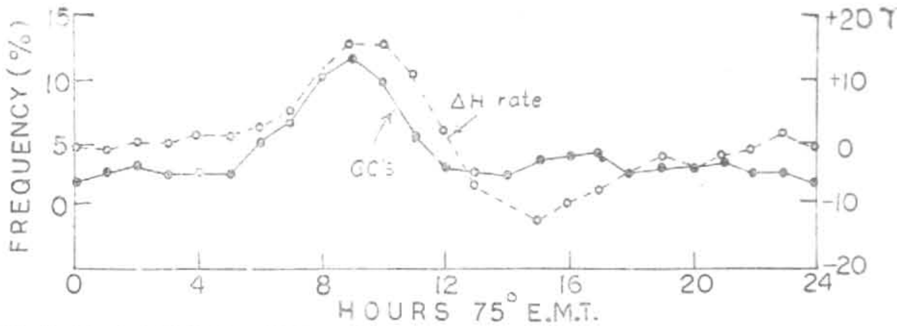

Fig. 3. Hourly distribution of GC (Gradual Commencement) occurrences at Alibag for the period 1921-60 (solid curve). Derivate curve of mean quiet-day *H* at Alibag for the year 1959 is also given for comparison (dotted curve)

observed in the case of SSC's followed by great disturbances, where the maximum of occurrence is in *E*-season. The monthly maxima occur in February, June and December, separated by a minimum in May and a deeper minimum around October.

(4) Considering all the SSC occurrences without distinction of magnitude of the disturbance that follows (Figs. 1d and 2d) — 55 per cent occur during day except in *J*-season when the frequency is almost the same for both day and night. The maximum of occurrence is between 12^h and 15^h and the minimum between 18^h and 21^h. A minimum of hourly frequency occurs between 2^h and 4^h and maxima occur at 8^h and 13^h. There is, in all seasons, a broad minimum between 16^h and 20^h and a night maximum between 20^h and 24^h. The highest and lowest number of occurrences in a month are in March and November respectively. The frequency is slightly greater in *E*-seaon (36 per cent) with a corresponding lowering in *D*-season (31 per cent).

(5) There is a maximum of hourly frequency of SSC's at 0^h in *D*-season and a minimum, around midnight in *E*-season for disturbances of all magnitudes.

(6) The hourly and monthly distributions of occurrence of disturbances of all magnitudes with gradual commencement (GC's) are also studied. It may not be possible always to determine precisely the exact time of commencement of disturbances with gradual commencement. However, in the data under study, the times of commencement of such disturbances are given by the hour, the earliest, in which disturbance is perceptible. As the unit of time interval is the hour, it is not incorrect to study the hourly distribution of the times of gradual commencement occurrence of disturbances. The hourly and monthly distributions of frequency are given in Tables 1 and 2 respectively. These distributions, as percentage frequencies, are graphically represented in Figs. 3 and 4 respectively.

There is a sharp rise in the hourly frequency of GC occurrences (Fig. 3) from 6^h, attaining a maximum at 9^h and, equally sharp fall upto 12^h local time. About 50 per cent of GC's occur during that interval (6^h to 12^h). For the rest of the hours the distribution is almost even with a slight rise at 17^h. Maximum monthly frequencies (Fig. 4) occur in March, September-October and December, with a broad minimum centred around June. The same features are noticed when the monthly frequencies are arranged in groups according to the intensity of the disturbance. This is in conformity with Newton's (1948) observation of a pronounced maximum in March and October and an extensive summer minimum comparable with the winter minimum for small magnetic storms not associated with SC's. The contrast between maximum and minimum is more pronounced for the group of great disturbances of which 68 per cent occur in *E*-season and 22 and 10 per cent, in *D* and *J*-seasons respectively. Of the total number of disturbances, slight disturbances (52 per cent) predominate, followed by moderate disturbances (44 per cent) and the great disturbances are (4 per cent), the least.

(7) When all the disturbances are considered, without reference to the mode of commencement, 10 per cent are great and the rest are distributed equally between slight and moderate magnitudes. Of the great disturbances about 80 per cent begin with a sudden commencement, whereas, disturbances of moderate or a slight intensity are equally likely to have a sudden or a gradual commencement.

(8) A close resemblance is observed between the hourly frequency curve of GC occurrences and a curve representing the time derivative of $Sq(H)$. Hour to hour differences in the magnitude of quiet day mean H [the time derivative of $Sq(H)$] for 1959 are graphically represented alongside the hourly distribution of GC occurrence (Fig. 3) of disturbances for comparison. The significance, if any, of this resemblance is not understood.

(9) SSC hourly frequency distribution (for all disturbances) does not seem to be significantly different from hour to hour except for the intervals 8^h—9^h and 13^h—14^h. The frequencies for the intervals on either side of each of those intervals are again not significantly different from the hourly mean frequency, which indicate that the higher frequencies in the intervals 8^h—9^h and 13^h—14^h are just random occurrences. Thus, except for a broad tendency for the frequency to be slightly higher during the day than during the night, there is apparently no definite regularity of diurnal variation in the frequency of occurrence of SSC's.

This finding conforms to expectations. SSC's being world-wide in occurrence cannot be expected to show any significant tendency for diurnal variation in their frequency of occurrence. The slight tendency for the frequencies to be higher during the day time than during the night time may be attributed to the ionospheric currents believed to be responsible for part of the day-time SSC amplitudes. Akasofu and Chapman (1959) describe the concept of a storm SC as follows—

"The SC field at the earth's surface is partly formed by the initial retardation of a solar cloud or stream at a distance of few earth radii; this field change is transmitted in some way from that region, through the outer atmosphere and the ionosphere, to the earth's surface. This part of the SC field includes much of the D_{st} part or SC (+), in the lower latitudes. Another major part of the SC field, comprising most of the *DS* part, is due to a current system generated in our atmosphere mainly in polar latitudes; but these currents also extend over a large part of the earth. They are supposed to be produced by solar particles or possibly by shock waves from the solar stream, which enter the auroral ionosphere".

Small SSC's which are likely to go unnoticed during the night become prominent during the day on account of augmentation from associated ionospheric (*DS*) currents. This may be the reason for the slightly larger occurrence frequency of SSC's during the day.

As regards the frequency distribution of GC's there is a clear preference for GC's to occur between 6 and 12 hours local time. The frequency is especially large for the period 8^h to 11^h. During the hours 12 to 6 through night, the frequency is not much different from hour to hour.

The period 6^h to 12^h corresponds very nearly to the period of increasing *Sq* (*H*) and the period 8^h to 11^h coincides with the period when *Sq*(*H*) increases most rapidly. This suggests the possible association of GC's with *Sq* ionospheric currents.

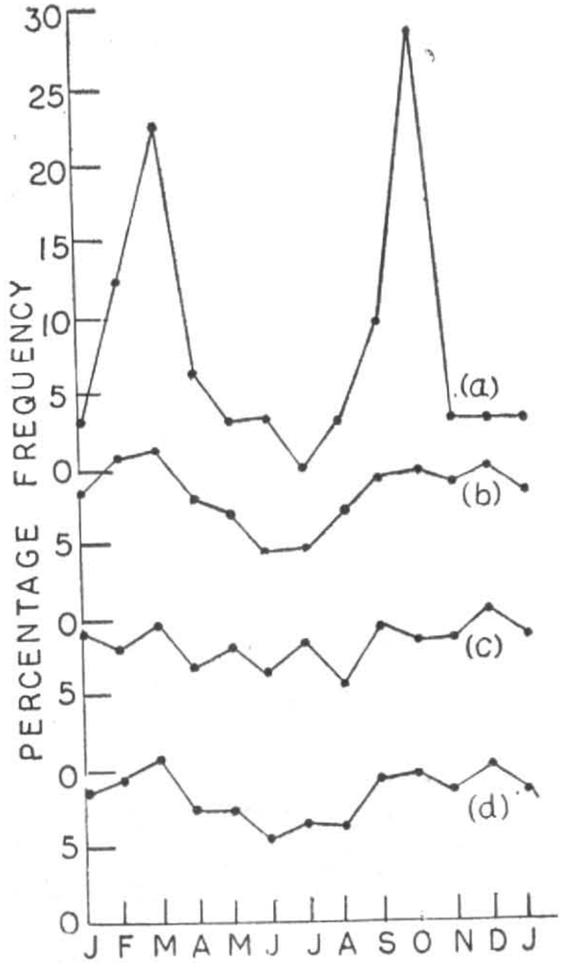

Fig. 4. Monthly distribution of GC occurrences at Alibag for the period 1921—60 in three groups: GC's followed by (a) great, (b) moderate and (c) slight disturbances and (d) for all GC's

Akasofu and Chapman (1963) show that the growth of auroral electrojet can greatly enhance the equatorial electrojet which indicates that a part of the return current, spreading from the auroral zone to the ionosphere in low and middle latitudes, can extend to as far as the late afternoon side along the magnetic equator. Though GC disturbances are known to be caused by corpuscular streams from the Sun, the energies of these corpuscles are very small compared with those associated with SSC disturbances. Therefore, the original rise in *H*, resulting from the impact (itself gradual) of the corpuscles with the geomagnetic field, is necessarily very small. The origin of such disturbances is thus not noticed till ionospheric electric currents, set up with the damping of charged particles in auroral ionosphere, give rise to more prominent changes in *H*. Bourdeau (1963) observes, from the electron density values reported from one day-time and two night-time

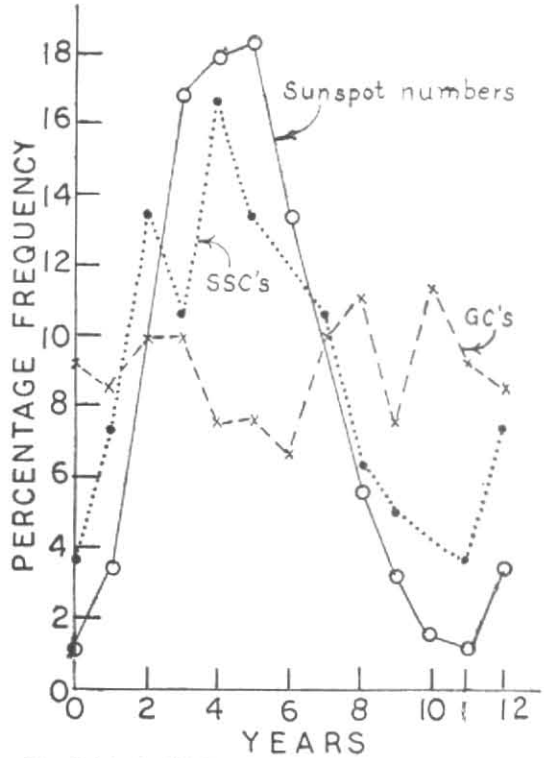

Fig. 5. Yearly distribution of SSC occurrences and GC occurrences as well as relative mean sunspot numbers in the solar cycle

rocket launchings, that day-time electron density values in the lower E-region are greater by about two orders of magnitude than the night-time values. Electron production starts with sun-rise (0600 hrs LT), in the upper regions of the ionosphere and by 0700 LT the lower F-region and E-region are 'filled in' by this process. The electron density rises rapidly throughout the E-region till 1000 to 1100 LT. As a result, the conductivity of the region increases by a factor over ten (Wright 1960) and consequently, the ionospheric electric currents from the auroral regions find easy paths towards the lower latitudes during these day-time hours. These currents enhance and make the magnetic field changes conspicuous and thus tend to give a much higher frequency of occurrence of GC's for these hours.

(10) There are three complete solar cycles in the period under study namely — 1924-1933, 1934-1944 and 1945-1954, of which the first and the third are of length of ten years. The yearly frequency of SSC as well as GC disturbances for the three cycles is computed. For the shorter periods the frequency in the 10th year is entered for the 11th year also, which may not involve much error as the extrapolation is near the minimum. Similar adjustment is made for the relative sunspot numbers also. The mean yearly frequencies of the three cycles are graphically represented along with the mean yearly relative sunspot numbers for the same cycles (Fig. 5).

As Newton (1948) found, the correspondence between the relative sunspot numbers and the frequency distribution of SSC disturbances is generally close. On the other hand, the distribution of GC disturbances has a broad minimum during the years of higher sunspot activity and a near steady high frequency of occurrence during the years of declining sunspot activity.

4. Summary

(*i*) The hourly distribution of SSC occurrences does not show any regular diurnal variation which can be considered significant, however, the frequency of SSC occurrence is slightly higher by day than by night.

(*ii*) SSC's occur most in E-season, except in the case of those followed by slight disturbance, and almost equally in the other two seasons.

(*iii*) The frequency of occurrence of disturbances with GC show a diurnal variation with a rapid rise and equally rapid fall in frequency between 6^h and 12^h local time with a maximum at 9^h and half the total number of GC's occur during that interval.

(*iv*) GC's show an annual variation with maxima in equinoxial months and minimum in the J-season.

(*v*) Of the total number of disturbances, those of great intensity are about 10 per cent and the rest divide equally into moderate and slight intensities.

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