

Diurnal and seasonal variations of Squalls in India

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ABSTRACT. In this paper the diurnal, monthly and annual frequencies of squalls at 22 stations of India based on available records up to 1962 have been discussed. The mean seasonal percentage frequencies and the mean frequencies of occurrence of squalls from different directions in eight points of compass have also been worked out. Maps showing percentage frequencies of squalls with reference to their duration and maximum speed reached have been prepared and a comparison between the mean annual frequency of squalls and all India thunderstorm frequency has been made.

1. Introduction

Ramaswamy and Majumdar (1950) had studied the general characteristics of 410 squalls which passed over the Peshawar Observatory during 1927-43. The changes in pressure, temperature and other elements which occurred during the passage of the squalls were also discussed by them. Some studies of squalls at individual stations (Ramakrishnan 1957, Bhalotra 1957 and Ramamurthy 1962) and one all India study (Ramakrishnan and Gopinatha Rao 1954) based on 11 stations and mostly on 5 years' data have also been done previously. However, squall is such a varied phenomenon that a study based on 5 years' data of a few stations can hardly give an all India picture. Raghavan and Nagarkar (1963) have also given squall frequencies and directions based on available 1948-1960 data. In the present paper the climatological studies of the squalls which occurred over India during the 15-year period, 1948-1962, based on the anemograph records of 22 stations has been presented. For the purpose of study the standard definition of squall, *i.e.*, a sudden increase of wind speed by at least 3 stages on the Beaufort Scale, reaching at least 22 knots and lasting for at least one minute has been taken into account. The diurnal variation of the occurrence of squalls, their frequencies of occurrence from various directions during the different seasons have also been discussed. A map showing the mean number of thunderstorms has also been given and a comparison between the frequencies of occurrence of thunderstorms and squalls, over various parts of India has been made.

2. Data Utilised

For this study squall data of only those stations which have at least five years' anemograph data have been used as it is considered that occurrence of squalls is such a varied phenomenon that any study which is based on a record of less than 5 years will not give even an approximate picture of the true conditions. Further, data of only one observatory

were utilised where two or more observatories were available in the same city, *viz.*, Bombay and Calcutta. For these two cities, the data of only Santa-cruz and Dum Dum have been utilised, these being the airports. In all data of 21 stations have been extracted from the India Weather Review for varying periods from 1948-1962 and that of one station, *viz.* Cochin, for the period 1943-1952 have been taken from the study by Ramakrishnan (1957). The Cochin data of Port Trust authorities for the period 1943 to 1952 had to be utilised as no squall data for the period 1948 to 1962 for Cochin or any other station on the west coast near Cochin were available. The map showing the mean number of thunderstorms is the one which has been prepared by the office of the Deputy Director General of Observatories (Climatology and Geophysics), Poona on the basis of 30 years' data (1931-1960).

3. Monthly and annual frequency of Squalls

Table 1 gives the mean monthly and annual frequencies of squalls at 22 stations. In this table, the information about height of the station, its latitude and longitude and the period of data actually used has also been given. Fig. 1 shows the mean annual frequency of squalls at various stations on which isolines have been drawn tentatively to show approximate squall frequencies in various parts of India. In this connection it may be mentioned that the number of stations for which data are available at present are too few to have any firm demarcation of areas of various frequencies. However, a picture as best as possible has been drawn from the available data. It is well known that the frequencies of thunderstorm is highest over this region, particularly in Assam and since many thunderstorms are associated with squalls it can be safely inferred that squalls frequency over this region would probably be the highest. However, this statement could only be verified if and when anemograph records of one or two stations of this region become available.

TABLE 1

Monthly and annual mean frequency of Squalls

Station	No. of years of data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Amritsar (31°38'N, 74°52'E, 232 m a.s.l.)	5 (1958-62)	0.4	0.2	2.2	3.0	4.2	5.2	3.8	3.8	3.2	0.6	0.8	0.4	27.8
Delhi (28°35'N, 77°12'E, 212 m a.s.l.)	15 (1948-62)	0.6	0.7	2.0	2.7	7.6	5.4	2.3	1.5	0.9	0.7	0.2	0	25.2
Lucknow (26°45'N, 80°53'E, 122 m a.s.l.)	9 (1954-62)	0.1	0.2	1.0	0.8	2.2	4.0	2.2	1.3	0.6	0.6	0	0	13.2
Jaipur (26°49'N, 73°48'E, 385 m a.s.l.)	12 (1950-62)	0.1	0	0.7	1.3	2.2	2.3	1.0	1.1	0.5	0.3	0.1	0	9.1
Jodhpur (26°18'N, 73°01'E, 217 m a.s.l.)	15 (1948-62)	0	0.2	0.9	0.7	2.3	3.5	2.6	1.5	1.7	0	0	0.1	13.4
Allahabad (25°27'N, 81°44'E, 98 m a.s.l.)	15 (1948-62)	0.3	4.0	1.7	0.7	1.8	2.3	1.4	0.9	1.0	0.5	0	0.2	11.3
Gaya (24°45'N, 84°57'E, 110 m a.s.l.)	12 (1951-62)	0.5	0.5	1.0	2.5	4.0	4.6	2.3	2.0	1.6	1.3	0	0.1	20.3
Bhopal (23°17'E, 77°20'E, 523 m a.s.l.)	11 (1952-62)	0.8	0.4	1.6	2.0	3.0	4.5	1.8	0.9	0.9	0.9	0.2	0.1	16.3
Ahmedabad (23°04'N, 72°38'E, 55 m a.s.l.)	10 (1953-62)	0.1	0.1	0.6	0.5	0.7	4.5	2.3	1.9	1.7	0.2	0.4	0	13.0
Baroda (22°18'N, 73°15'E, 38 m a.s.l.)	12 (1948-59)	0.1	0.1	0.2	0.1	0.6	2.8	1.5	1.2	0.6	0.2	0	0	7.2
Jamshedpur (22°49'N, 86°11'E, 129 m a.s.l.)	12 (1951-62)	0.5	0.7	4.4	4.2	6.3	6.2	2.7	1.7	2.0	0.5	0	0.1	29.2
Dum Dum (22°39'N, 88°27'E, 4 m a.s.l.)	15 (1948-62)	0.2	0.6	2.6	4.3	5.9	5.9	1.7	1.6	2.8	1.2	0	0	26.8
Nagpur (21°06'N, 79°03'E, 308 m a.s.l.)	13 (1950-62)	0.2	0.5	2.9	2.7	5.1	9.7	3.5	1.9	2.1	1.2	0	0.1	31.2
Jagdarpur (19°05'N, 82°02'E, 553 m a.s.l.)	5 (1958-62)	0.2	0	0.8	2.2	3.0	1.2	0	0	0	0.2	0	0	7.6
Gopalpur (19°16'N, 84°53'E, 17 m a.s.l.)	12 (1951-62)	0.3	0	0.3	1.5	2.1	2.1	0.7	0.6	0.8	1.0	0.3	0	9.7
Bombay (Santacruz) (19°05'N, 72°52'E, 8 m a.s.l.)	10 (1953-62)	0	0	0	0.1	0.7	4.8	6.6	3.2	1.5	0.2	0	0	17.1
Poona (18°35'N, 73°55'E, 587 m a.s.l.)	15 (1948-62)	0	0	0.9	1.6	2.8	0.8	0.3	0.1	0.5	0.9	0.1	0	7.9
Visakhapatnam (17°43'N, 83°14'E, 3 m a.s.l.)	14 (1948-61)	0.1	0.1	0.4	1.2	3.1	3.1	1.5	2.0	2.9	1.6	0.3	0.1	16.2
Begumpet (17°27'N, 78°28'E, 53 m a.s.l.)	9 (1954-62)	0	0.4	1.7	4.6	5.7	5.4	6.4	3.1	2.2	0.2	0	0.1	29.9
Madras (13°00'N, 80°11'E, 16 m a.s.l.)	15 (1948-62)	0.1	0	0.1	0.3	2.2	3.8	5.7	5.5	3.1	2.3	0.9	0.3	24.3
Bangalore (12°57'N, 77°38'E, 888 m a.s.l.)	14 (1949-62)	0	0.1	0.8	3.0	5.0	2.4	2.7	2.4	0.5	0.7	0.1	0	17.8
Cochin (09°53'N, 76°14'E, 2 m a.s.l.)	10 (1943-52)	0.1	0.2	0.9	2.2	5.6	24.3	17.3	12.0	5.3	1.9	0.7	0.3	70.8

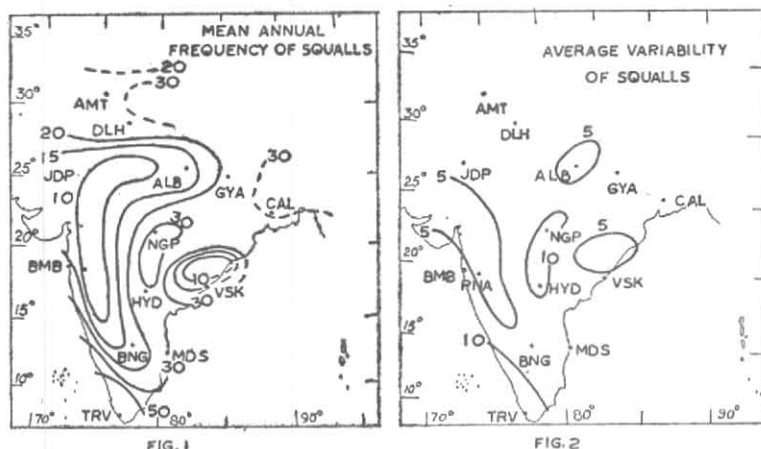


FIG. 1

FIG. 2

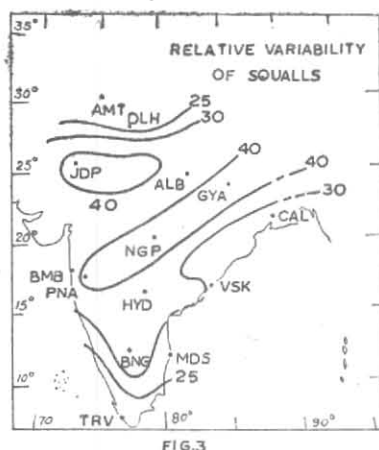


FIG. 3

Table 1 and Fig. 1 reveal that the least annual frequency of less than 10 occurs in (1) Poona—Sholapur—Nasik region just east of the Western Ghats and this region is continued over Baroda, east Gujarat, south Rajasthan and northwest Madhya Pradesh and (2) Jagdalpur—Gopalpur region. The highest frequency of over 50 squalls is over Kerala coast. Over inland area the highest frequency of over 30 is experienced over Begumpet—Nagpur region and, it is presumed, it also occurs over the region of west Bengal east of Jamshedpur, East Pakistan and Assam, but this assumption could not be verified due to the absence of records over this region. Hence the 30 frequency line has been shown as dotted over this region in Fig. 1. Another region where frequency of over 30 could be expected as revealed by the high frequency shown by Amritsar is Himachal Pradesh and hilly regions of East Punjab. It is also assumed that the squall frequency over Jammu and Kashmir would be less than 20 as the thunderstorm frequency here is low. Hence a dotted 20 line is also drawn demarcating this region.

The sum of the deviations, without regard to sign, divided by their number is the mean deviation μ also called average variability (AV) in climatology. Thus

$$AV = \mu = \frac{\sum |d|}{n} \tag{1}$$

where $\sum |d|$ means the sum of the absolute values, ignoring signs.

$$\mu = (|d_1| + |d_2| + \dots + |d_n|) / n$$

The average variability gives a good measure of variations of a phenomenon and hence in order to find variations of year to year occurrence of squalls at different stations average variability has been calculated for each of the stations and these values are given in Fig. 2.

From Fig. 2 it is seen that the highest yearly average variability of more than 10 is experienced by the Begumpet—Nagpur section and the Kerala coastal section. The least variability of less than 5

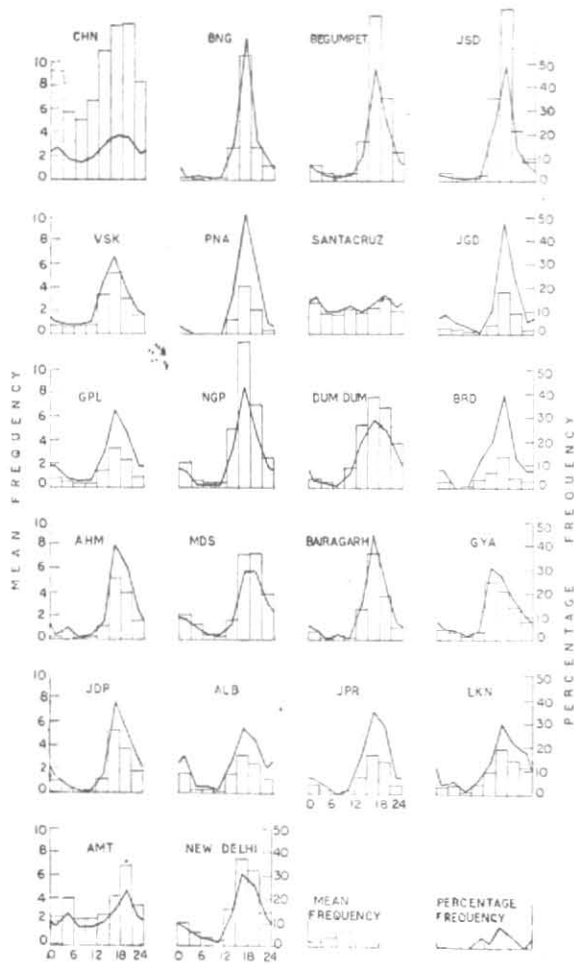


Fig. 4. Diurnal variation of squalls

is experienced by practically the same regions which had the least squall frequencies.

However, the average variability of a station

$$\frac{\sum |a_i - \bar{a}|}{n} = AV$$

depends naturally upon the arithmetic mean \bar{a} . Hence, for comparison purposes a variability value which is not dependent on the arithmetic mean is much better. Therefore, the relative variability (Vr) which is the average variability expressed in per cent of arithmetic mean has been calculated for each of the stations

$$Vr = 100 \frac{AV}{\bar{a}} = \frac{100}{n} \frac{\sum a_i - \bar{a}}{\bar{a}} \quad (2)$$

*In the above only the annual frequencies are given, as in most of the stations the pattern of diurnal variation in the Summer and Monsoon seasons which are the main squall seasons, is practically same. However, a point of interest is that in the case of the north Indian and east coast stations outside southeast Peninsula, the squalls occur somewhat earlier during the monsoon season than during the hot weather season while in the case of Madras which is representative of southeast Peninsula the squalls occur later during the monsoon period than during the hot weather

Fig. 3 gives the values of relative variability of squalls over India. It can be seen from this map that the Kerala coast which had the highest value for average variability becomes the region of least relative variability (about 20 per cent). The north-west India and the east coast of India are also regions of comparatively low relative variability. The region of maximum variability (> 40 per cent) is (i) over Rajasthan and (ii) over an area inclined with its axis running across India from Poona to Gaya through Nagpur. In this connection it may be mentioned that Jaipur gives an unusually high value (79.8 per cent) of relative variability.

4. Diurnal variation of Squalls

In order to see the diurnal variation of squall frequencies, 3-hourly frequencies* starting from 00 IST have been prepared with respect to the time of starting of squalls. These frequencies have been shown in Fig. 4 with the help of histograms. In this figure the histogram shows the mean frequency of occurrence of squalls while the continuous line shows the percentage frequency of occurrence in the various 3-hourly periods. The mean frequency only depends on the actual number of occurrence of squalls during the particular 3-hour period irrespective of the yearly frequency, but the percentage frequency also depends upon the yearly total of squalls occurring at the station. Thus it can be seen that at Bangalore the mean frequency for the period 15 to 18 IST is 10.5 but the percentage frequency is 60 per cent since the annual frequency is only 17.5. However, for Cochin the mean frequency for the same period is higher, *i.e.*, 12.9 but the percentage frequency is much lower (18 per cent) because the annual frequency at this station is 70.3. As the mean frequencies vary so widely from one station to another, percentage frequency comes very handy in comparing the behaviour of squalls at various stations.

The following interesting features could be seen, from these histograms —

1. The stations of central India and Peninsula—Jodhpur, Ahmedabad, Baroda, Bhopal, Nagpur, Jagdalpur, Begumpet and Bangalore—generally show a distinct peak between 15 and 18 hours and this 3-hour period accounts for 40 to 60 per cent of squalls. The squall frequency during the morning period 3 to 12 hrs is practically negligible.

2. The east coast and north Indian stations except Amritsar also show distinct peak frequency but this peak is flatter and is appreciably less (about 30 per cent) when compared to stations under (1) as it exists over a longer period (15 to 21 IST). These stations also show a minima between 3 and 12 IST.

3. Santacruz shows a practically flat frequency without any distinct peak, the frequency for all the eight 3-hourly periods varies between 10 and 17 per cent. Cochin also bears some similarity to Santacruz although at Cochin the frequency between 12 to 21 IST is appreciably more than that between 3 and 12 IST.

4. The frequency distribution at Amritsar is different from those at other north Indian stations as it is much flatter and shows two peaks. Further, Amritsar is the only station which shows quite appreciable squall frequency (about 30 per cent in all) between 3 and 12 IST.

5. It is also seen from the frequencies of Gaya, Jamshedpur and Dum Dum that the squalls occur later as we proceed from Gaya to Dum Dum. This supports the findings given in the *India met. Dep. Tech. Note*, No. 10 (Nor'westers of Bengal). Further although Gaya frequency indicates that the squalls over north Bihar and north Bengal occur earlier than at Calcutta, this probably is not a fact, because according to the histograms showing the diurnal variation of thunderstorms over Bengal and neighbourhood, given in *India met. Dep. Tech. Note*, No. 10, the majority of thunderstorms occur over north Bengal and neighbourhood between 18 and 06 IST, while the main thunderstorms frequency period at Calcutta is between 12 and 24 IST. Since squalls are usually associated with thunderstorms, it can readily be inferred from the above that the squalls over north Bengal and neighbourhood occur later than those at Calcutta.

5. Direction of Squalls

Figs. 5(a), 5(b), 5(c) and 5(d) show the mean frequencies of directions in eight points of compass from which the squalls occur during the seasons, Winter (December to March), Hot Weather (March to May), Southwest Monsoon (June to September) and Post monsoon (October and November) respectively at various stations. Within the station circle of each station seasonal mean frequency and the percentage frequency of the annual total has also been shown.

These figures show the following features —

- (i) No squall appears to occur in Poona — Bombay region in winter months,
- (ii) The maximum frequency of more than 50

per cent is noticed in Poona — Bangalore region during Hot Weather months,

(iii) Over 80 per cent of squalls occur over west coast region and Gujarat during the monsoon season June to September,

(iv) During the post monsoon months, October and November, the squall frequency is comparatively less but the main squall region is east coast up to Gopalpur,

(v) Generally more squalls occur from northwest than any other direction in summer months. However, over northwest India an appreciable number come also from southwest,

(vi) During monsoon months, W/NW is generally the main direction of occurrence of squalls. However, over NW India and Rajasthan N/NE appears to be the main direction.

6. Squall frequencies with respect to maximum wind speed reached

Fig. 6 shows the percentage frequencies of squalls with reference to the maximum speed recorded within the various specified ranges. The percentage frequencies have been worked out for 4 ranges, viz., (1) ≤ 30 , (2) 31-40, (3) 41-60 and (4) > 60 kts for each of the stations and the histograms have been plotted.

The following salient features could be seen from this figure —

(1) For most coastal stations as well as for Ahmedabad, Bangalore and Central India station of Bhopal, squalls having a speed of more than 60 kts have not been recorded, during the period to which the data refer. For west coast stations and Bangalore even the frequency of squalls having speed of more than 40 kts is very low (< 10 per cent). Hence it can be safely inferred that over 90 per cent of squalls over west coast are mild ones.

(2) Over Punjab and adjoining northwest parts of India, a majority of squalls are severe ones, having maximum speed of over 40 kts, 6 per cent of these or approximately 2 per year having speed exceeding 60 kts.

(3) Over west Rajasthan and Delhi, over 40 per cent of squalls have maximum speed of > 40 kts.

(4) Over Uttar Pradesh, Bihar and Bengal 25 to 30 per cent of squalls have speed more than 40 kts while about 40 per cent of squalls have speed of 30 kts or less.

(5) Over east coast about 20 to 25 per cent of squalls have a speed of more than 40 kts. At Madras the frequency of squalls having speed of 30 kts or less is less than 25 per cent.

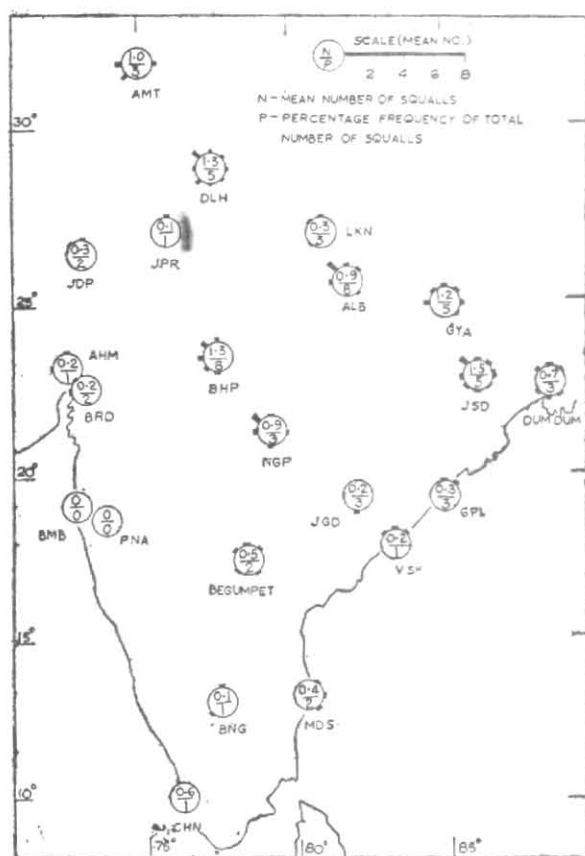


Fig. 5(a). Squall direction
Winter (December to February)

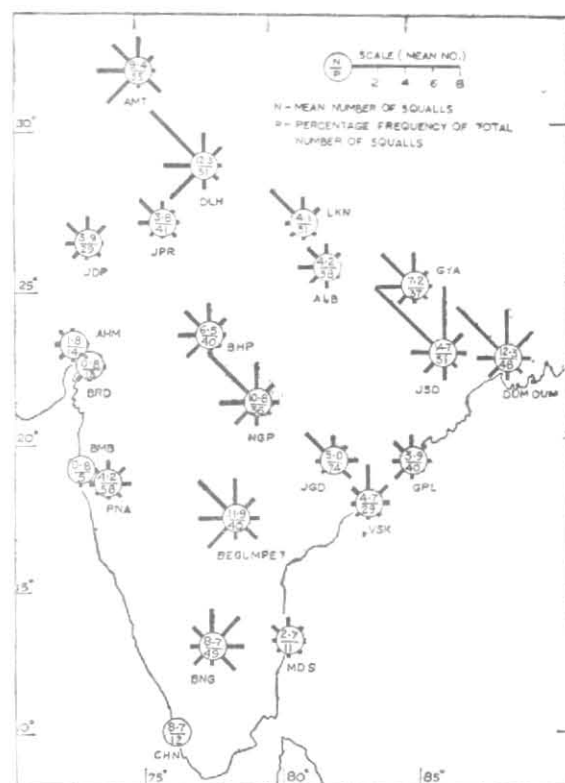


Fig. 5(b). Squall direction
Summer (March to May)

7. Squall frequencies with respect to their duration

Fig. 7 shows the percentage frequencies of squalls with reference to their duration. The percentage frequencies have been worked out for the ranges (i) ≤ 10 , (ii) 11 to 20, (iii) 21-30 and (iv) > 30 minutes for each of the stations and these are shown with the help of the histograms.

Fig. 7 shows the following salient feature. —

(i) Excepting Cochin the data of which have been discussed subsequently the west coast and Gujarat stations have about 98 per cent squalls having ≤ 10 min duration. As Fig. 6 has already shown that over 90 per cent of squalls over this area have maximum speed of less than 40 kts, it can be safely assumed that a large majority of squalls over this region are mild ones and of short duration.

(ii) For Hyderabad—Sholapur—Poona area also about 90 per cent squalls are ≤ 10 min duration. Further in this area squalls of duration half an hour or over do not occur, i.e., they are purely transient in character.

(iii) The maximum frequency of long duration squalls having duration > 30 min (about 10 per

cent) occurs over east India as is shown by the frequencies of Dum Dum, Jamshedpur and Gaya. Still it could be seen that 50 to 60 per cent squalls in this area have duration ≤ 10 min.

(iv) Other areas where the frequencies of long duration squalls are appreciable are west Rajasthan and east coast round about Madras.

(v) In central India, Uttar Pradesh, Delhi and Punjab stations 70 to 80 per cent squalls have ≤ 10 min duration; while the frequency for long duration squalls is also not negligible.

(vi) The most surprising squall frequencies are those of Cochin which do not even remotely fit with the data of any other station. A comparison of this with another west coast station, Santacruz shows that whereas 98 per cent of squalls at Santacruz are of ≤ 10 min duration, for Cochin this frequency is only < 12 per cent. In this connection it may be mentioned that the Cochin data are not departmental but are that of Cochin Port Trust Office as presented by Ramakrishnan (1957). The frequency of 68 per cent of squalls having duration > 30 min is very difficult to explain and if the original figures as published are seen it is also found that

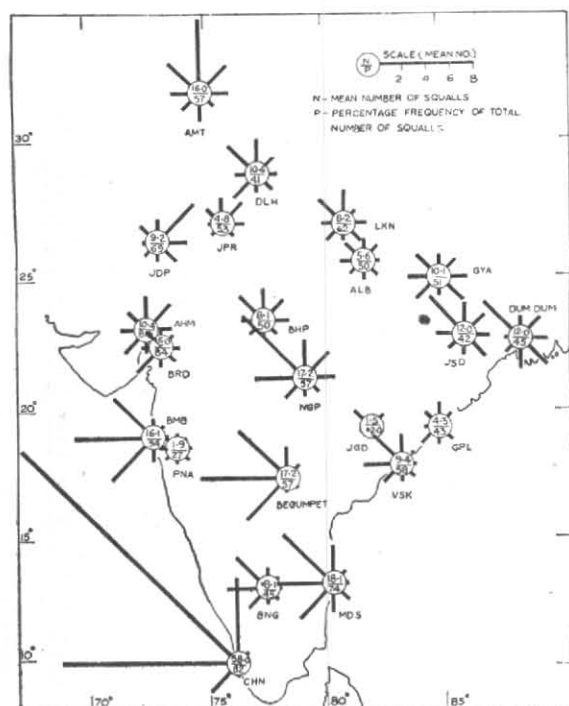


Fig. 5(c). Squall direction
SW Monsoon (June to September)

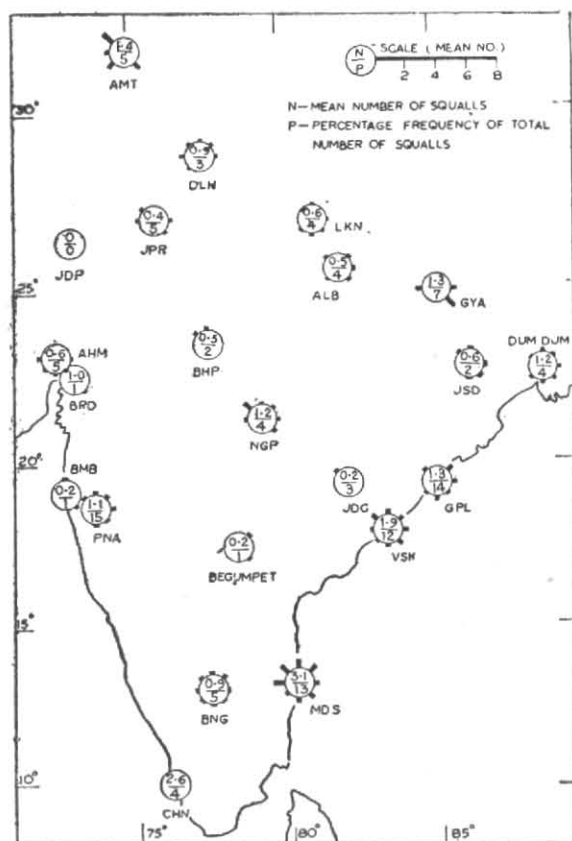


Fig. 5(d). Squall direction
Post monsoon (October, November)

an appreciable frequency (15 per cent) has duration of more than 2 hours. Also from Fig. 5 it could be seen that 82 per cent of squalls, *i.e.*, an overwhelming majority occurs during the monsoon season only. As in this season the surface winds at Trivandrum are many a times very strong, often 15 to 20 kts, it appears that once a squall satisfying the normal definition occurred most of them might have been shown as continuing till the wind force became appreciably less and were not shown as having ceased as soon as the mean wind force became less than 22 kts. As the strong monsoon coastal winds are also very gusty as frequent gusts of 22 to 25 kts and over normally occur when the actual mean force is about 15 kts, this could easily mask the time of cessation of squall if we are not carefully looking for it.

8. Comparison of squalls and thunderstorm frequency

Fig. 8 shows the mean annual thunderstorm frequencies based on data of 1931-1960. Thunderstorms are recorded when thunder is heard at the station. For this the thunderstorm cell can be situated in any direction with respect to the station. However squall occurs when the wind speed at the station satisfies certain specified criteria and is associated

with convective cloud at an advanced stage of formation. Further, for squalls hitting a station the thunderstorm cell should be situated in favourable direction with respect to the station so that the downdraft when it occurs reaches the station. Hence, it is normally to be expected that thunderstorm frequency should normally be more at a station than squall frequency. However, when we compare this with Fig. 1 we see that although in a broad way the squall and thunderstorm frequencies compare well which should normally be expected as most of the squalls are associated with thunderstorms, some interesting differences are also noticed. These are given below.

(1) The highest frequencies of squall occur in Trivandrum—Cochin sector of west coast, although the maximum thunderstorm frequencies are shown by the Bengal—Assam region.

(2) Santacruz squall frequency is more than twice that of Poona although more thunderstorms occur at Poona than at Santacruz. In fact the squall frequency of Santacruz as well as of Cochin is more than the thunderstorm frequencies at these stations.

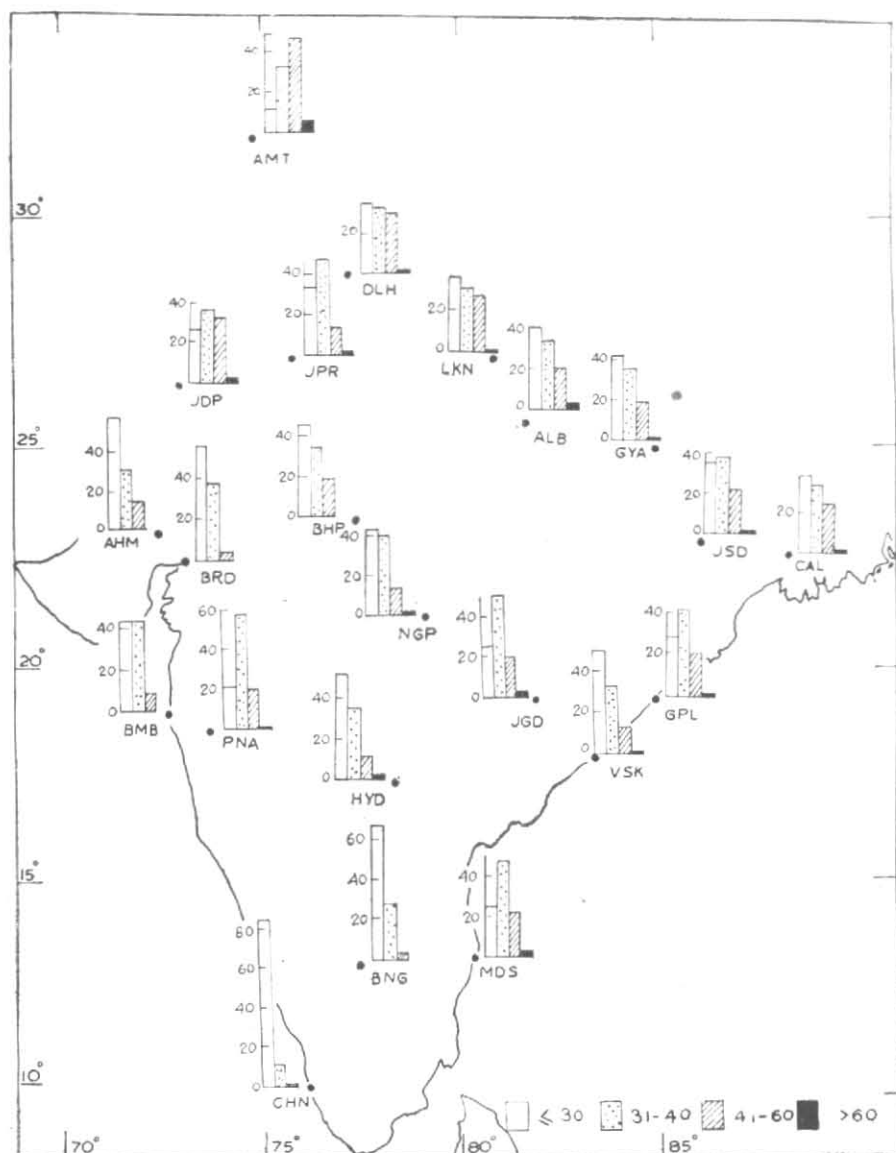


Fig. 6. Percentage frequency of squalls with respect to maximum speed reached — in knots

(3) The thunderstorm frequency of Nagpur—Begumpet tract is moderate (30 to 50) but this area shows one of the highest frequencies of squalls.

(4) The Gopalpur—Jagdarpur minima on squall charts is not shown on thunderstorm chart.

9. Discussion of result and conclusion

Squalls when associated with thunderstorms occur as downdraft of winds which are initiated at (or near) the freezing level (Petterssen 1956). Since the air of the downdraft warms wet adiabatically as it descends through the cloud, and since the rain below the cloud base keeps the air near saturation, it is to be expected that the lowest temperature recorded

during the downdraft at the ground would not be very different from the potential wet bulb temperature. It has been shown by Fawbush and Miller (1954) that the maximum speed in squalls depends on the difference between the actual ground surface temperature and the temperature which downdraft attains on reaching the ground.

The above explains the occurrence of the winter, pre-monsoon and post monsoon squalls and even squalls which occur in the monsoon season associated with thunderstorms during the onset or revival of monsoons. However, these could not explain the west coast squalls which overwhelmingly occur in

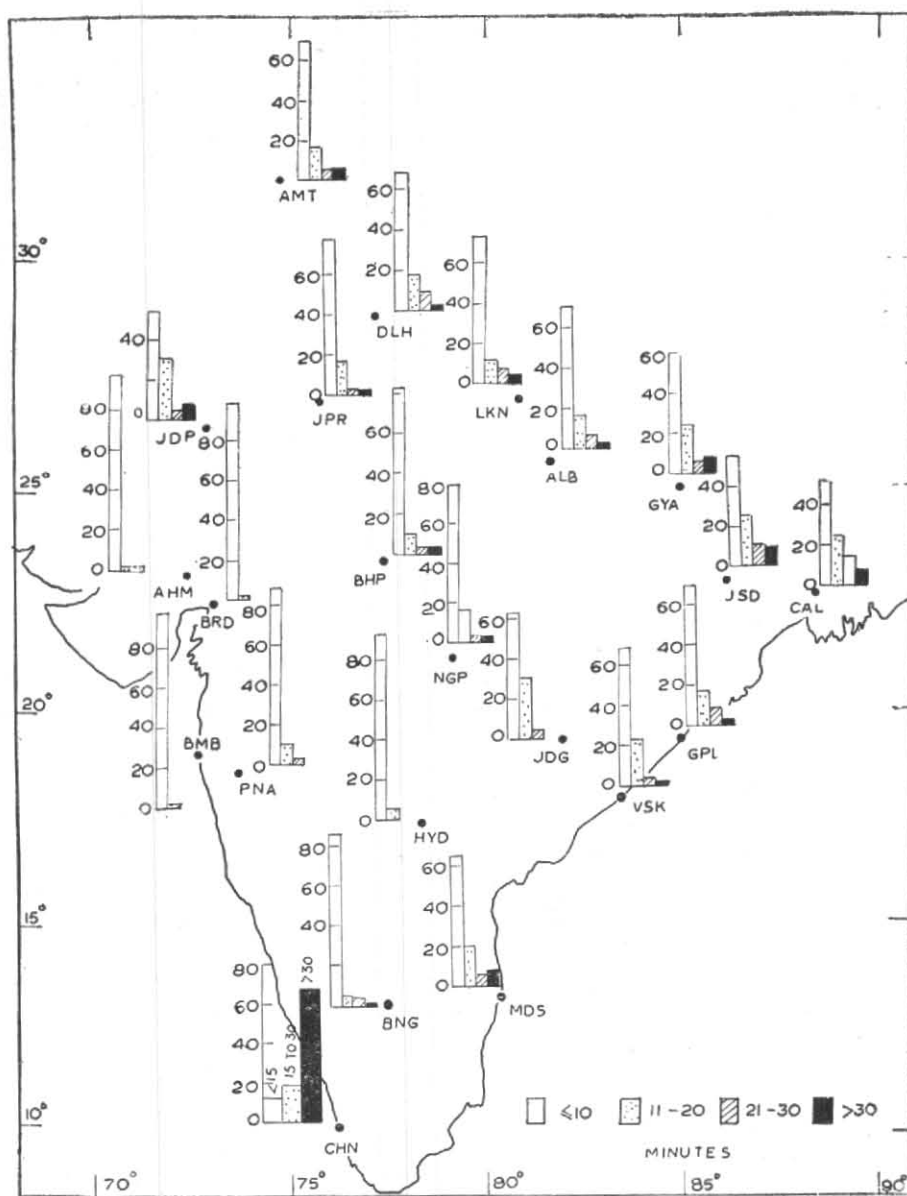


Fig. 7. Percentage frequency of duration of squalls

the monsoon season when the monsoon is strong. At this time we could not say that these are associated with thunderstorms as the thunderstorms do not usually occur, nor that the downdraft of these squalls starts at (or near) the freezing level since the freezing level is very high (about 17,000 ft), and although individual cumuliform cloud cells may be present in the stratified monsoon clouds, it is very doubtful that these reach such heights (17,000 ft), as, otherwise they would develop into thunderstorm cells as even during strong monsoon conditions the air above 15,000 ft can support instability.

Hence, the mechanism of west coast squalls, which are of very short duration, is different from those of squalls which are associated with thunderstorms. It appears that a majority of the west coast monsoon squalls are somewhat akin to unusually gusty winds, which we often experience in other parts of India. These unusual gusts of west coast during strong monsoon conditions are classified as squalls when the normal wind speed is high (about 15 kts) and an unusual gust can easily raise speed by 3 stages on Beaufort Scale, thus satisfying the squall criteria. However, this explanation does not satisfy occurrence of all squalls on west coast as

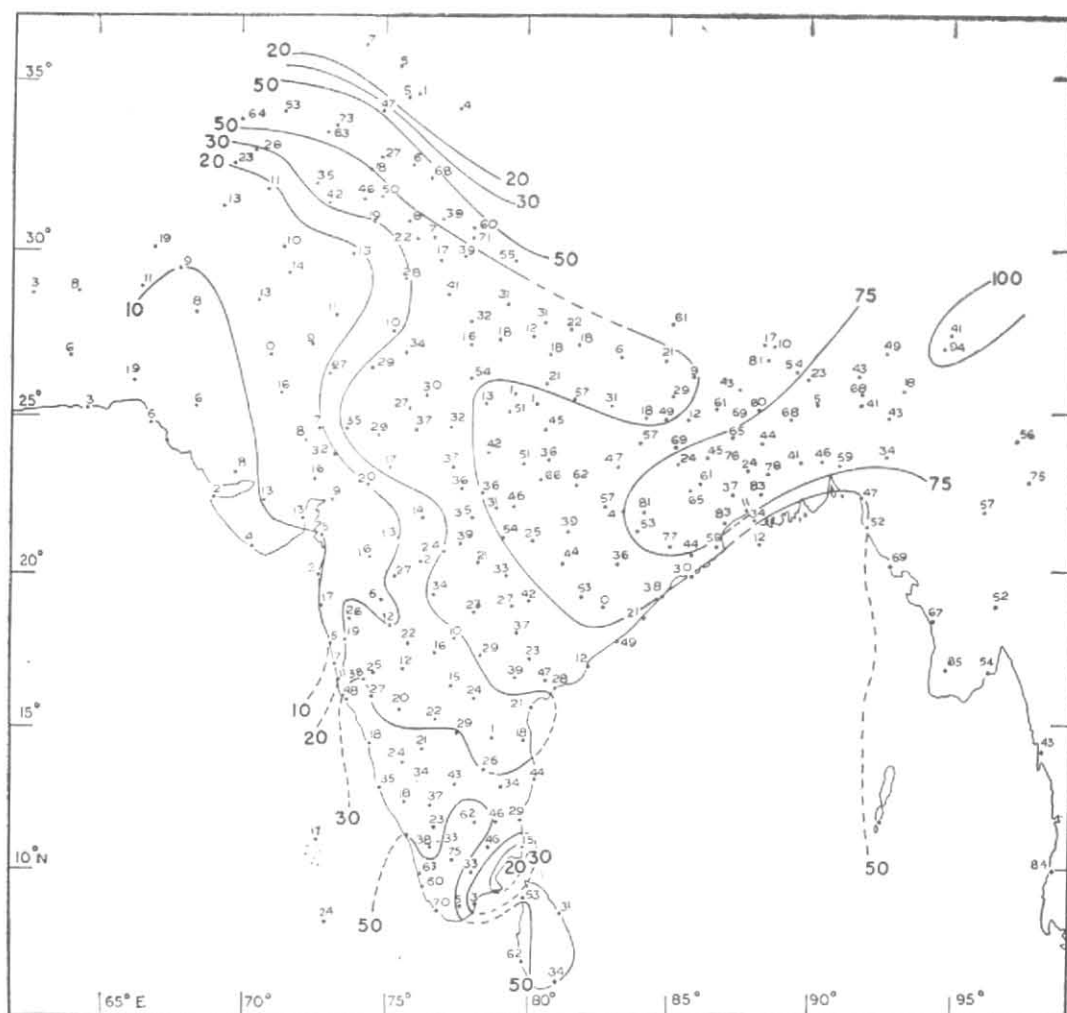


Fig. 8. Annual number of thunderstorms (1931—1960)

George (1950) points out that at Bombay during monsoons, many a times, there is a lull before the occurrence of squall which is invariably associated with showery precipitation. These squalls appear to be associated with downward draft from the individual cumuliform cells although the down draft

may be starting from a much lower level than the one stipulated by Petterssen (1956) for active thunderstorm cells. It is also seen that monsoon squalls of this type are only experienced on the west coast and they are not at all experienced on the leeward side of the Western Ghats.

REFERENCES

- | | | |
|-------------------------------------------|------|-----------------------------------------------------------------------------------|
| Bhalotra, Y. P. R. | 1957 | <i>Indian J. Met. Geophys.</i> , 8 , p. 81. |
| Fawbush, E. J. and Miller, R. C. | 1954 | <i>Bull. Amer. met. Soc.</i> , 35 , p. 14. |
| George, P. A. | 1950 | <i>Mem. India met. Dep.</i> , 29 . |
| Petterssen, S. | 1956 | <i>Weather Analysis and Forecasting</i> , Vol. II. McGraw-Hill Book Company, Inc. |
| Raghavan, K. and Nagarkar, N. D. | 1963 | <i>Curr. Sci.</i> , 32 , p. 534. |
| Ramakrishnan, K. P. | 1957 | <i>Indian J. Met. Geophys.</i> , 8 , p. 289. |
| Ramakrishnan, K. P. and Gopinatha Rao, B. | 1954 | <i>Ibid.</i> , 5 , p. 337. |
| Ramamurthy, K. | 1962 | <i>Ibid.</i> , 13 , 4, p. 485. |
| Ramaswamy, C. and Majumdar, K. C. | 1950 | <i>Mem. India met. Dep.</i> , 23 , Pt. 1. |