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# Squalls at Nagpur

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ABSTRACT. A statistical analysis of the squalls from self-recording instruments at Nagpur has been made and the various characteristics of these squalls are determined.

## 1. Introduction

A study of the squalls at Nagpur (airport) has been presented. A statistical analysis of the squalls bringing out monthly frequency, diurnal variation, maximum gust speed, duration, along with the pressure and temperature changes accompanying the squalls, has been made. This study is based on ten years' data (1954-1963) obtained from the autographic records at Nagpur (airport) Observatory.

## 2. Data

The squalls treated in this paper are those which have recorded a sudden increase in wind speed by at least three stages on B.F. Scale reaching 45 km/hr (28 mph) or more and lasting for at least one minute. A squall of 80 km/hr or more has been classified as a severe squall. The autographic records of Dines P.T. anemographs, of Friez microbarographs, and of S. and M. thermographs for the period 1954 to 1963 have been made use of for the analysis.

## 3. Results and Discussions

3.1. *Variation in the distribution of squalls* — Table 1 gives the number of surface squalls recorded during the ten years (1954-1963). For different months, the maximum number of days of squalls, the average number of days of squalls and average percentage frequency are given in Table 1 and also shown in Fig. 1. It will be seen that – (*i*) The squalliness is liable to vary widely from year to year as there were 51 squalls in 1962 while only 16 squalls were recorded in 1954, although the average number of squalls per year is 36, (*ii*) The frequency of the squalls increases with the advance of the year, from January onwards, reaching a maximum in June, the highest frequency so far recorded being 18 in the month of June 1960, (*iii*) During the year, 85 per cent of the squalls occur in the months of March to July and 50 per cent in May and June alone, (*iv*) The maximum number of severe squalls occur in the month of June and 93 per cent of severe squalls (gust speed $\geqslant$80 km/hr) are recorded in the months from March to June and (*v*) No squall has been recorded in the month of November (November has not, therefore, been included in the table).

3.2. *Diurnal Variation* — The number of squalls occurring in every 3-hour period of the day in different months is given in Table 2. The figures in the bracket indicate the above frequency expressed as percentage of the total occurring in each month. It is seen that — (*i*) On the average in a year, 69 per cent of the squalls occur between 1500–2100 IST, (*ii*) Roughly 50 per cent of the squalls occur during the period 1500–1800 IST in all months excluding December to March, (*iii*) 65 per cent of the severe squalls occur between 1500–2100 IST and 45 per cent between 1500–1800 IST and (*iv*) The period 0600–0900 IST is practically free from squalls except in October.

3.3. *Direction of squalls* — The direction of squalls has been considered to be the direction of the wind at the time of its peak value. Table 3 and Fig. 2 show the distribution of the squalls over the sixteen directions of the compass during the whole year. It is seen that — (*i*) On the average in a year 40 per cent of the squalls come from NW in all months, (*ii*) The quadrant west to north accounts for 68 per cent of the squalls in all the months during the year and (*iii*) 75 per cent of the total severe squalls approach from west to north quadrant and 50 per cent come from WNW and NW directions alone.

The cause of high frequency of thunderstorms associated with squalls affecting Nagpur from N/NW direction in pre-monsoon (March to May) has been investigated by Banerjee (1961)*.

3.4. *Maximum gust speed of squalls* — In Table 4, the number of the squalls with percentage frequencies (percentage in brackets) within specified limits of maximum or peak speed are given. The table shows that — (*i*) 51 per cent of squalls in the year have peak speeds between 50–64 km/hr and (*ii*) In the whole year, squalls only in March to June record peak speed $\geqslant$ 95 km/hr and this percentage is only 5. The highest speed recorded so far during the period of study was 137 km/hr on 27 March 1957 and 5 April 1955.

*It was observed by him that the elevated terrain situated to the northwest of Nagpur (Pachmarhi hills etc) is very effective in generating thunderstorms sequences which affect Nagpur in course of their movement southeastwards. This fact is true not only for pre-monsoon months but for the whole year

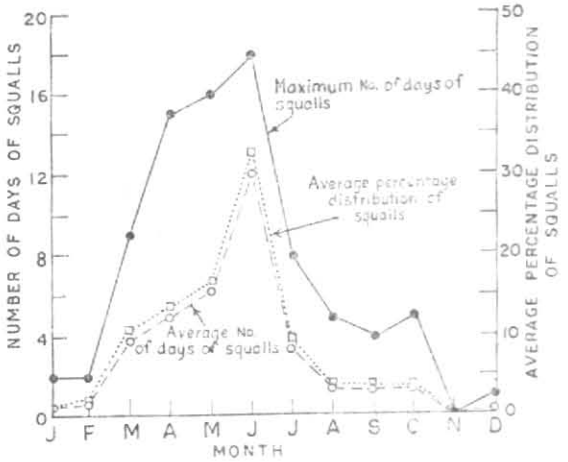


Fig. 1. Frequency of occurrence of squalls

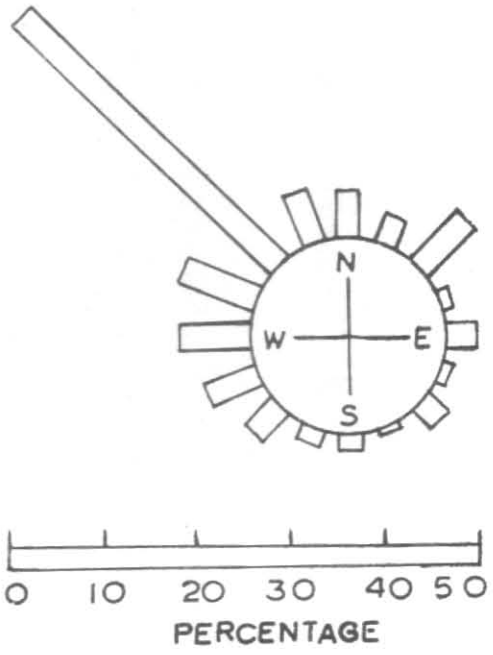


Fig. 2. Directional distribution of squalls (percentage)

TABLE 1

Frequency of Squalls

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1963 | — | 4 | 4 | 15 | 6 | 10 | — | 1 | — | — | — | 40 |
| 1962 | — | 2 | 7 | 6 | 16 | 12 | 6 | 1 | 1 | — | — | 51 |
| 1961 | — | — | 3 | 3 | 9 | 8 | 5 | 2 | 1 | 5 | — | 36 |
| 1960 | 2 | — | 5 | 4 | 4 | 18 | 6 | 2 | 4 | — | — | 45 |
| 1959 | — | — | 1 | 3 | 7 | 15 | — | 5 | 2 | 2 | — | 35 |
| 1958 | — | — | 1 | 5 | 2 | 11 | 4 | — | 1 | 1 | — | 25 |
| 1957 | — | — | 9 | 9 | 8 | 15 | — | 1 | 1 | — | — | 43 |
| 1956 | — | — | 4 | 1 | 5 | 11 | 8 | 1 | 2 | 1 | 1 | 34 |
| 1955 | 1 | — | 4 | 4 | 2 | 14 | 4 | — | — | 5 | — | 34 |
| 1954 | — | — | 1 | — | 4 | 7 | 2 | 1 | 1 | — | — | 16 |
| Total | 3 | 6 | 39 | 50 | 63 | 121 | 35 | 14 | 13 | 14 | 1 | 359 |
| Max. No. of days of squalls | 2 | 2 | 9 | 15 | 16 | 18 | 8 | 5 | 4 | 5 | 1 | |
| Average percentage distribution of squalls | 1 | 2 | 11 | 14 | 17 | 33 | 10 | 4 | 4 | 4 | — | |
| Average number of days of squalls | 0·3 | 0·6 | 3·9 | 5·0 | 6·3 | 12·1 | 3·5 | 1·4 | 1·3 | 1·4 | 0·1 | |
| Total severe squalls. Gust speed ⩾80 km per hr | — | 1 | 9 | 11 | 8 | 13 | — | 1 | — | 1 | — | 44 |

**TABLE 2**

**Diurnal distribution of squalls**

| | 00—03 | 03—06 | 06—09 | 09—12 | 12—15 | 15—18 | 18—21 | 21—24 IST | Total |
|---|---|---|---|---|---|---|---|---|---|
| | Number (Percentage) | | | | | | | | |
| Jan | — | — | — | — | — | — | 1 (33) | 2 (67) | 3 |
| Feb | — | 1 (17) | — | — | — | 1 (17) | 2 (33) | 2 (33) | 6 |
| Mar | 7 (18) | 1 (3) | — | — | — | 10 (25) | 13 (33) | 8 (21) | 39 |
| Apr | 5 (10) | 1 (2) | — | — | 3 (6) | 24 (48) | 14 (28) | 3 (6) | 50 |
| May | 4 (6) | 2 (3) | — | — | 6 (9) | 27 (43) | 16 (26) | 8 (13) | 63 |
| Jun | 7 (6) | 2 (2) | — | 1 (1) | 22 (18) | 64 (53) | 21 (17) | 4 (3) | 121 |
| Jul | 2 (6) | — | — | — | 6 (17) | 18 (51) | 8 (23) | 1 (3) | 35 |
| Aug | — | — | — | — | 3 (21) | 10 (72) | — | 1 (7) | 14 |
| Sep | — | — | — | 1 (8) | 3 (23) | 6 (46) | 3 (23) | — | 13 |
| Oct | 1 (7) | — | 1 (7) | — | 2 (14) | 9 (65) | 1 (7) | — | 14 |
| Dec | 1 (100) | — | — | — | — | — | — | — | 1 |
| Total | 27 (7) | 7 (2) | 1 (—) | 2 (1) | 45 (13) | 169 (47) | 79 (22) | 29 (8) | 359 |
| Squalls with gusts speed ≥80 km/hr | 6 (14) | — | — | — | 6 (14) | 20 (45) | 9 (20) | 3 (7) | 44 |

3.5. *Pressure changes durings qualls* — Pressure changes accompanying the squalls together with their percentages, in brackets, in all the months of year are given in Table 5. It may be seen that — (*i*) 56 per cent of the squalls in the year are accompanied by pressure rise of <2 mb, (*ii*) (*a*) There was no change of pressure during the passage of 29 per cent of the squalls, (*b*) 'No pressure change' tendency is more prominent in the monsoon months, *i.e.*, June to August, (*iii*) 15 out of 158 cases of squalls recorded a rise of pressure ≥ 2 mb in the months of February to May and (*iv*) 8 per cent of the total squalls are associated with decrease in pressure less than 1 mb and 2 per cent between 1 to 2 mb.

The highest rise of pressure of 4·1 mb was recorded on 20 May 1962 and highest fall of pressure of 1·3 mb was recorded on 21 April 1962 and 28 February 1963.

3.6. *Temperature changes in squalls* — Frequencies of fall of temperature caused by the passage of squalls in different months are given in Table 6 with their percentage within brackets. It may be noticed that — (*i*) In 75 per cent of the squalls, dry bulb temperature fell by less than 6°C and (*ii*) In 16 per cent of the cases of squalls in April and May, the fall is over 8°C. Highest fall of 15·2° C has been recorded on 19 June 1960.

From March to July, there have been 10 cases of rise of temperature with the passage of squalls in the period under study. A rise of 6·2° C has been recorded on 6 May 1962 with the peak wind gust 47 km/hr. There was no rain and a fall of 1·0°C in wet bulb was recorded during the squall. There was a fall of pressure by 0·1 mb which might have been due to rise in the temperature. Jean and Clarence (1961) have reported warming and drying back of the line of thunderstorm at 850-mb level. Such a high rise in temperature may be due to downrush of air from the trailing edge of the squall as reported above and the squall with more severity must have taken place in the direction other than that recorded at the station.

**TABLE 3**
**Direction of squalls**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Dec | Total | Squalls with speed ⩾80 km/hr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Number (Percentage) | | | | | | | |
| N | — | — | 3 (7) | 2 (4) | 4 (6) | 7 (6) | 1 (3) | — | 1 (8) | — | — | 18 (5) | 2 (5) |
| NNE | 1 (33) | — | — | 1 (2) | 5 (8) | 3 (2) | — | — | — | 1 (7) | — | 11 (3) | 1 (2) |
| NE | 1 (33) | — | 1 (3) | 1 (2) | 6 (9) | 9 (7) | 1 (3) | — | 4 (30) | — | — | 23 (7) | 2 (5) |
| ENE | — | — | 1 (3) | — | — | — | 1 (3) | — | — | — | — | 2 (0·5) | — |
| E | — | — | — | — | 2 (3) | 7 (6) | 1 (3) | 1 (7) | — | 1 (7) | — | 12 (3) | 2 (5) |
| ESE | — | — | — | — | — | 1 (1) | — | — | 1 (8) | 1 (7) | — | 3 (1) | — |
| SE | — | — | 2 (5) | — | — | 5 (4) | 1 (3) | — | 1 (8) | 1 (7) | — | 10 (3) | 1 (2) |
| SSE | — | — | — | — | 2 (3) | — | — | — | — | — | — | 2 (0·5) | — |
| S | — | — | 1 (3) | 3 (6) | 1 (2) | 2 (2) | — | — | — | — | — | 7 (2) | 1 (2) |
| SSW | — | — | — | 1 (2) | 1 (2) | 1 (1) | 1 (3) | — | 1 (8) | — | — | 5 (1) | — |
| SW | — | — | 1 (3) | 4 (8) | 3 (5) | 7 (6) | 3 (8) | — | — | — | — | 18 (5) | 3 (7) |
| WSW | — | 1 (17) | 3 (7) | 4 (8) | 5 (8) | 4 (3) | 2 (6) | 1 (7) | — | 1 (7) | — | 21 (6) | 1 (2) |
| W | 1 (33) | 1 (17) | 3 (7) | 3 (6) | 7 (11) | 8 (7) | 4 (11) | — | — | — | — | 27 (8) | 5 (11) |
| WNW | — | — | 3 (7) | 6 (12) | 3 (5) | 10 (8) | 4 (11) | 4 (29) | — | 1 (7) | — | 31 (9) | 6 (14) |
| NW | — | 4 (66) | 18 (46) | 23 (46) | 18 (29) | 46 (39) | 14 (40) | 8 (57) | 4 (30) | 7 (51) | 1 (100) | 143 (40) | 16 (36) |
| NNW | — | — | 3 (7) | 2 (4) | 6 (9) | 11 (9) | 2 (6) | — | 1 (8) | 1 (7) | — | 26 (6) | 4 (9) |
| Total | 3 | 6 | 39 | 50 | 63 | 121 | 35 | 14 | 13 | 14 | 1 | 359 | 44 |

With severe squalls, the fall of temperature (dry bulb) was over 4°C in 66 per cent of the cases and in 39 per cent cases it was over 8°C. There was no rise in temperature with the severe squalls.

The temperature fall in certain types of thunderstorms (non-frontal) has been correlated with the peak wind gust of the squall by Fawbush and Miller (1954) and details of its application will be discussed in another paper by the author.

3.7. *Duration and multiplicity of squalls*

(*a*) *Duration* — (*i*) 54 per cent of the squalls in the whole year lasted for 5 minutes or less, 45 per cent lasted for 6-15 minutes and 9 per cent of the squalls had durations of 16–30 minutes and (*ii*) There were only 6 squalls (2 per cent) in the ten-year period that lasted for 31–59 minutes.

(*b*) *Multiple squalls* — There were 53 days of multiple squalls. In the months of March to July as many as two or three squalls (four in April) occurred on the same day. In eight cases of the above, the directions of the first and subsequent squalls agreed, in twentynine cases the direction, however, varied from 20 degrees to 70 degrees, in nine cases it differed by 90 degrees and in six cases the variations were from 90 to 180 degrees.

**4. Weather phenomena associated with the squalls**

Analysis of the fundamental changes of the meteorological elements associated with these squalls make one infer that the squalls over the station are mainly due to the convective clouds passing over or near the station. The study shows that more than 80 per cent of the squalls are due to thunderstorms. Of the remaining, 75 per cent are rain squalls in June to August and with these convective cloud activity is also reported. Severe squalls are always accompanied with thunderstorms.

**TABLE 4**
**Maximum gust speed of the squalls (km/hr)**

| | <50 | 50-64 | 65-79 | 80-94 | 95-109 | 110-124 | ≥125 | Maximum speed | Date | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Number (Percentage) | | | | | |
| Jan | 1 (3) | 2 (67) | — | — | — | — | — | 58 | 24-1-55 | 3 |
| Feb | — | 3 (50) | 2 (33) | 1 (17) | — | — | — | 90 | 25-2-63 | 6 |
| Mar | 3 (8) | 14 (36) | 13 (33) | 4 (10) | 4 (10) | — | 1 (3) | 137 | 27-3-57 | 39 |
| Apr | 6 (12) | 25 (50) | 8 (16) | 4 (8) | 4 (8) | 1 (2) | 2 (4) | 137 | 5-4-55 | 50 |
| May | 5 (8) | 31 (49) | 19 (30) | 5 (8) | 2 (3) | 1 (2) | — | 117 | 29-5-56 | 63 |
| Jun | 10 (8) | 67 (55) | 31 (26) | 12 (9) | — | 1 (2) | — | 113 | 17-6-60 | 121 |
| Jul | 7 (20) | 21 (60) | 7 (20) | — | — | — | — | 73 | 18-7-62 | 35 |
| Aug | 4 (29) | 8 (57) | 1 (7) | 1 (7) | — | — | — | 90 | 27-8-54 | 14 |
| Sep | 4 (31) | 8 (61) | 1 (8) | — | — | — | — | 79 | 7-9-60 | 13 |
| Oct | 3 (21) | 5 (36) | 5 (36) | 1 (7) | — | — | — | 80 | 1-10-55 | 14 |
| Dec | — | 1 (100) | — | — | — | — | — | 51 | 29-12-56 | 1 |
| Total | 43 (12) | 185 (51) | 87 (24) | 28 (8) | 10 (3) | 3 (1) | 3 (1) | 137 | 27-3-57<br>5-4-55 | 359 |

**TABLE 5**
**Pressure changes in squalls**

| | No change | Rise in pressure (mb) | | | | | Pressure fall | | Trace not available | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | <1·0 | 1·0-1·9 | 2·0-2·9 | 3·0-3·9 | ≥4·0 | <1·0 | 1·0-1·9 | | |
| | | | | | Number (Percentage) | | | | | |
| Jan | 1 (33) | 1 (33) | 1 (33) | — | — | — | — | — | | 3 |
| Feb | 1 (16) | 2 (34) | 1 (16) | — | 1 (16) | — | — | 1 (16) | | 6 |
| Mar | 2 (5) | 20 (51) | 9 (23) | 5 (13) | — | — | 1 (3) | 2 (5) | | 39 |
| Apr | 14 (28) | 22 (44) | 7 (14) | 3 (6) | 1 (2) | — | 2 (4) | 1 (2) | | 50 |
| May | 15 (23) | 29 (45) | 9 (15) | 1 (2) | 3 (5) | 1 (2) | 5 (8) | — | | 63 |
| Jun | 47 (39) | 51 (42) | 9 (7) | 1 (1) | — | — | 12 (10) | 1 (1) | | 121 |
| Jul | 14 (40) | 14 (40) | 3 (9) | — | — | — | 4 (11) | — | | 35 |
| Aug | 7 (50) | 4 (29) | — | — | — | — | 1 (7) | 1 (7) | 1 (7) | 14 |
| Sep | 3 (23) | 8 (63) | 1 (7) | — | — | — | — | — | 1 (7) | 13 |
| Oct | 2 (14) | 10 (72) | — | — | — | — | 2 (14) | — | — | 14 |
| Dec | — | 1 (100) | — | — | — | — | — | — | — | 1 |
| Total | 106 (29) | 162 (45) | 40 (11) | 10 (3) | 5 (1) | 1 (—) | 27 (8) | 6 (2) | 2 (1) | 359 |
| Squalls with gust speed ≥80 km/hr | 6 (14) | 17 (39) | 10 (23) | 4 (9) | — | 1 (2) | 5 (11) | 1 (2) | — | 44 |

Note—Highest rise of pressure of 4·1 mb was registered on 20 May 1962
Highest fall of pressure of 1·3 mb was registered on 21 April 1962 and 28 February 1963

**TABLE 6**

**Temperature changes in squalls**

| | Fall in temperature (°C) | | | | | | | Rise in temperature (°C) | | | | Trace not available | Highest fall | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0·0 | ⩽1·0 | 1·1—2·0 | 2·1—4·0 | 4·1—6·0 | 6·1—8·0 | >8·0 | ⩽1·0 | 1·1—2·0 | 2·1—4.0 | ⩾4·1 | | | |
| | Number (Percentage) | | | | | | | | | | | | | |
| Jan | 1 (33) | 2 (67) | — | — | — | — | — | — | — | — | — | — | 0·7 | 3 |
| Feb | — | 3 (49) | — | 2 (33) | — | — | 1 (17) | — | — | — | — | — | 10·7 | 6 |
| Mar | — | 10 (25) | 4 (10) | 5 (13) | 7 (18) | 6 (15) | 1 (3) | 2 (5) | 1 (3) | 2 (5) | — | 1 (3) | 10·5 | 39 |
| Apr | 4 (8) | 12 (24) | 3 (6) | 13 (26) | 6 (12) | 1 (2) | 10 (20) | 1 (2) | — | — | — | — | 13·8 | 50 |
| May | 3 (5) | 7 (11) | 10 (16) | 10 (16) | 15 (23) | 9 (14) | 8 (13) | — | — | — | 1 (2) | — | 12·8 | 63 |
| Jun | 8 (6) | 12 (10) | 19 (16) | 43 (35) | 19 (16) | 10 (8) | 8 (6) | — | 1 (1) | — | — | 1 (1) | 15·2 | 121 |
| Jul | — | 3 (9) | 7 (20) | 14 (40) | 7 (20) | 1 (3) | — | 1 (3) | — | — | — | 2 (5) | 6·2 | 35 |
| Aug | 2 (14) | 2 (14) | 4 (29) | 5 (36) | 1 (7) | — | — | — | — | — | — | — | 4·2 | 14 |
| Sep | 1 (8) | 1 (8) | — | 5 (38) | 6 (46) | — | — | — | — | — | — | — | 5·7 | 13 |
| Oct | — | 3 (22) | 2 (14) | 4 (28) | 3 (22) | 2 (14) | — | — | — | — | — | — | 7·0 | 14 |
| Dec | — | — | — | — | — | — | — | 1 (100) | — | — | — | — | — | 1 |
| Total | 19 (5) | 55 (15) | 49 (14) | 101 (28) | 64 (18) | 29 (8) | 28 (8) | 5 (2) | 2 (0·5) | 2 (0·5) | 1 (—) | 4 (1) | 15·2 | 359 |
| Squalls with gust speed ⩾80 km/hr | — | — | 4 (9) | 10 (23) | 9 (20) | 3 (7) | 17 (39) | — | — | — | — | 1 (2) | 15·2 | 44 |

Note—Highest fall in temperature was 15·2°C on 19 June 1960. Highest rise in temperature was 6·2°C on 6 May 1962

### 5. Conclusions

The different aspects of the squalls at Nagpur are summarised below —

Highest frequency of squalls at Nagpur is observed during the months of March to July, most of them occurring during the period 1500–2100 IST. The months November to January are practically free from squalls. The period 0600–1200 IST has insignificant activity of squalls. On the average every squall out of four in March and April and every eighth squall in May is of severe nature with gust speed ⩾ 80 km/hr and all such squalls are caused by thunderstorms. There is no correlation of pressure change with the speed of squalls. As regards temperature, the greater the severity of squall, the greater is the fall in temperature. Most of the squalls are associated with thunderstorms while a few of them are accompanied with showers in the monsoon months and even these are due to presence of convective clouds. Two or three squalls of comparable magnitude can occur in the months of March to July and in October on the same day. Mostly squalls affect Nagpur from west to north quadrant.

### 6. Acknowledgement

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