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A study of Squalls at Santacruz Observatory, Bombay

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ABSTRACT. This paper contains a study of squalls at Santacruz Observatory, Bombay based on eight years of data. George (1950) has already made a study on the squalliness of monsoon showers at Juhu Observatory, Bombay based on five years' data. It is seen that the frequency of squalls at Juhu is about four and half times that at Santacruz. Possible reasons for this have been discussed.

In recent years it has been established that the direction of a squall caused by convective cloud are related to the wind direction at some level or to the mean wind in the layer in which the cloud is embedded. Wind directions at different levels and the direction of the vector mean wind between different layers have been compared with the directions of squalls and some useful results from prediction point of view have been obtained.

1. Introduction

Bombay experiences surface squalls in association with showers during the monsoon season. These squally winds are a major feature of the weather during this period. Squalls also are experienced in pre- and post-monsoon seasons generally associated with thunderstorm activity. George (1950) made a study of the squalls at Juhu (Bombay) for the period 1944 to 1948 from the data of autographic charts. The Dines P.T. anemograph was then available there. The anemograph was shifted to Santacruz airport in 1948. The Santacruz site of the anemograph is at a distance of two kilometers and at an angle of 87 degrees from its former location. In the present study, data of Santacruz for the period of eight years 1955 to 1962, were taken and statistical analysis was made. The results obtained from the Santacruz data are discussed in this paper. These have been compared with the results of George (1950) for Juhu.

Comparative study between direction of squalls recorded with upper air data of Santacruz obtained by Rawin ascent has been made and some useful results from prediction point of view have been obtained. The preliminary results of the study are discussed in this paper.

The definition of the squall used in the present study is same as the definition used by the India Meteorological Department for routine observational and climatological purposes and as defined in the World Meteorological Organisation procedures. This has also been followed by George (1950).

2. Statistical analysis

1. *Number of squalls* — In the five years' data of his study the total number of squalls found by George (1950) were 434 with an average of 86·2 squalls per year. The extreme values being 29 squalls in 1947 and 132 in 1946. The number of squalls recorded during eight years of the present study are 149 with an average of 18·6 squalls per year. The extreme values are 7 squalls in 1956 and 30 during the years 1958 and 1959. Thus there appears to be a significant difference in the frequency of squalls at Juhu and Santacruz.

This significant difference needs to be explained. 75 per cent of the squalls recorded during the period in the present study are from a westerly direction (SW to NW). About 73 per cent of squalls are of speed of less than 65 km (36 knots), *i.e.*, with speeds within 20 km/hr of the lower limit for taking them as squalls as per definition. Percentage frequency of low speed squalls obtained by George (1950) is of the same order. Every cumulus shower is generally accompanied by downdrafts which in turn cause gusty winds at the surface; some of which attain speeds, which can be taken as squalls. Juhu, which is situated more to the west gets exposed to the squally winds earlier than Santacruz as these winds are predominantly from a westerly direction. Consequently, the total frictional effects on these winds will be much less at Juhu than what they are by the time they reach Santacruz. Therefore, the gusty winds due to downdrafts are likely to cross the minimum speed prescribed for the definition of a squall more often at Juhu than at Santacruz. The large difference between the squalliness of the surface wind at Juhu and Santacruz as shown by statistical analysis reflects more on the general higher speeds of the gusty winds caused by the cumulus downdrafts. Probably the average difference is of the order of 10 to 20 km/hr.

An example will clarify the above reasoning. Fig. 1 shows a section of the Pressure Tube anemogram of 20 July 1962. It can be seen from it that a number of downdrafts affect the station during the period. However, only two of them (marked a and b) could be termed as squalls as per the definition of squalls, even though the nature of the gusts are almost identical in all the downdrafts. If now we assume

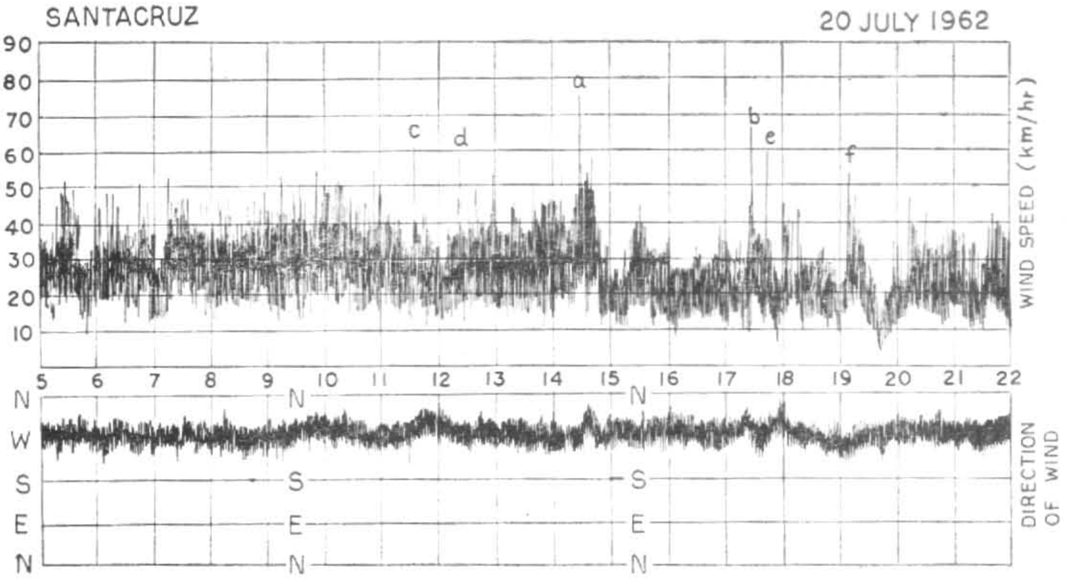

Fig. 1. Section of Dynes P. T. anemograph showing a number of gusts caused by cumulus downdraft

that all the gusts were only 10 km/hr higher at Juhu, the number of squalls would increase by 4 (marked c, d, e, and f).

Therefore, it can be stated that essentially the squally nature of the surface winds during strong monsoon conditions at both the places is same. On the other hand the remarkable deceleration suffered by the mesoscale type of wind flow due to surface friction as shown by the above comparison of Juhu and Santacruz is worth noting. The gradients of speed are apparently as much as 4 knots/km.

2. *Analysis of Santacruz data* — Squalls at Bombay occur chiefly in the summer months of the year, the maximum frequency is in the month of July. Squalls during winter — November to March — are extremely rare and no squalls have been recorded during these months in these 8 years. Table 1 gives the number of squalls monthwise with the percentage frequency of their occurrence.

Generally, squalls during pre- and post-monsoon seasons are from an easterly direction and squalls during SW monsoon season are from a westerly direction. Table 2 gives the percentage frequency and the number of squalls from different directions in each month.

As already mentioned in the earlier section, squalls at Bombay are comparatively mild, unlike the squalls experienced in association with Nor'westers of northeast India, duststorms of northwest India and summer thunderstorms of the Deccan. The maximum speed recorded in the period under study is 90 km/hr (48 knots). Generally the squall speeds are between 45 to 70 km/hr (24 to 38 knots). Table 3 gives the frequency of the speed of squalls. It is worthwhile to note that there is no significant difference in the speeds of squalls in the SW monsoon season and squalls of the other seasons.

Duration of squalls is usually 1 to 2 minutes. Table 4 gives the percentage frequency of squall period in different months.

As already mentioned, the total number of squalls during the monsoon period are much less at Santacruz than at Juhu; but the percentage frequency presented in the above tables agrees broadly with those found by George (1950) for his Juhu data. In the pre- and post-monsoon seasons there is no significant difference in the absolute number of squalls between Juhu and Santacruz. Similarly there is no significant difference in the number of squalls from an easterly direction.

3. Temperature and pressure changes accompanied by squalls

As found by George (1950) temperature changes during SW monsoon squalls are found to be insignificant. The variation is found to be very small if any (0 to 1·0° C). Even in the pre- and post-monsoon seasons, the temperature drops caused by the squalls is comparatively much less than those generally recorded in other thunderstorm areas. The fall in temperature in pre- and post-monsoon seasons is generally 2 to 3° C with a maximum change of 4·3° C recorded on one occasion in May 1956.

The pressure changes are equally insignificant. In most of the cases no change has been noticed. On

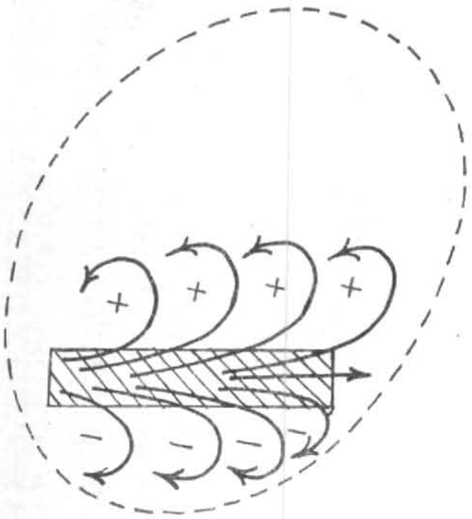

Fig. 2. Schematic representation of the spread out of the cold air (After Fujita 1962)

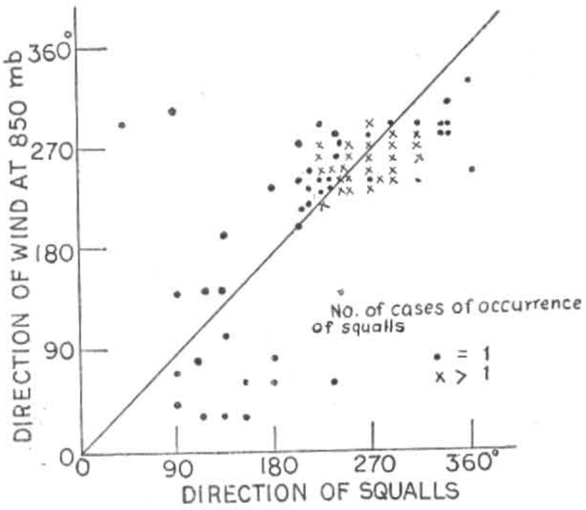

Fig. 3. Scatter diagram showing the relationship between direction of squalls and the direction of wind at 850 mb

rare occasions changes of about 0·5 to 1 mb were observed in pre- and post-monsoon months.

4. Dependence of squall direction on upper winds

Although the predominant direction of squalls at Bombay is westerly, squalls from other directions also occur on a number of days. Hence for the prediction of the squall direction it is necessary to consider the synoptic conditions also.

Number of studies have been made to correlate the speed and direction of squalls to the velocity of the clouds. Byers and Braham (1949) have shown that the relationship between the cloud movement and the vector mean wind of the cloud layer holds good for the Ohio data. Newton and Hatz (1958) found good relation between the direction of movement of radarscope echoes of rainstorm and the direction of the mean wind in the layer 850 to 500 mb. The results of Atlas (1963) and Browning and Ludlam (1962) have shown that the movement of convective clouds are closely related to the vector mean wind in the layer in which the cloud is embedded. Venkataraman and Bhaskara Rao (see Ref.) have also got similar results in their mesoscale study of thunderstorm over Delhi area. It is also well known that maximum speed of the convective downdraft occurs in the direction towards which the cloud is moving. So a relationship exists between the upper winds and the squall directions. This principle is tested in the present study by comparing the observed squall directions with directions of winds at different levels and the directions of mean wind in some layers. Direct comparisons between squall directions and the direction of winds at 850, 700 and 500 mb were made and the scatter diagrams for these are given in Figs. 2, 3 and 4 respectively. It can be seen that the best correlation is obtained with the 700-mb wind direction. In this comparison the upper winds used were of the nearest synoptic time (00Z or 12Z).

The Decca type 3-cm radar type 41 Mark II having only PPI scope with vertical beam width 4° and horizontal beam width 0·75° (at present installed at Santacruz airport) has got maximum vertical elevation of 12°. Hence it has not been found possible to obtain the vertical extent of the cloud near the station. However, the non-thunderstorm type of convective cloud which causes squalls in monsoon seasons generally extends up to 6 km a.g.l. while the thunderstorm clouds generally attain heights greater than 9 km. Hence the vector mean wind between 850 and 500 mb for the non-thunderstorm squall days and vector mean wind between 850 and 300 mb on thunderstorm squall days were calculated. Scatter diagrams showing the correlation between the directions of these winds and corresponding squall directions of these winds are shown in Figs. 5 and 6 respectively.

Mean deviation — defined by $m = \frac{1}{n}\left[(\pm)^2 \Sigma\, \delta d\right]$

and average deviation $\left(\text{defined by } m' = \frac{1}{n}\Sigma\, \delta d\right)$

have been calculated for the data in Figs. 3 and 5.

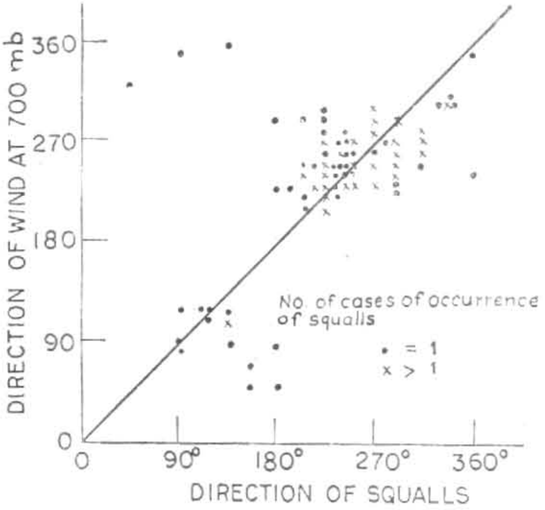

Fig. 4. Scatter diagram showing the relationship between direction of squalls and the direction of wind at 700 mb

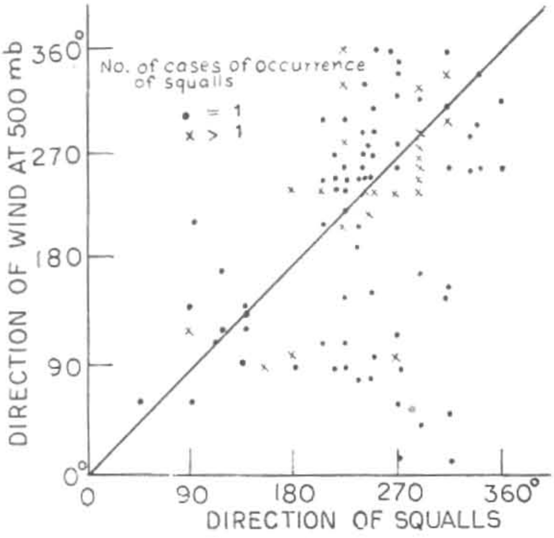

Fig. 5. Scatter diagram showing the relationship between direction of squalls and the direction of wind at 500 mb

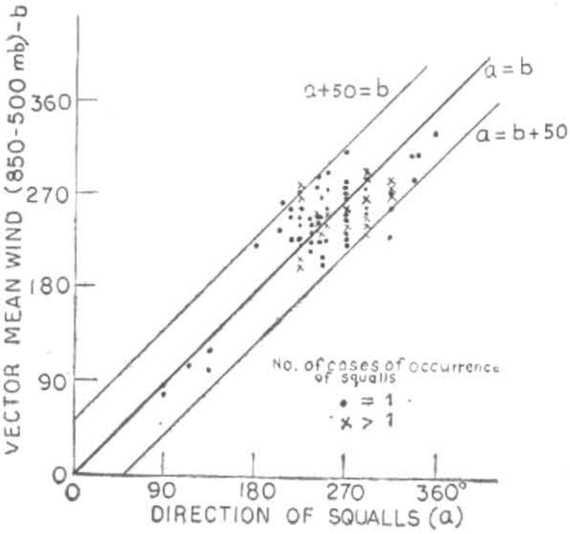

Fig. 6. Scatter diagram showing the relationship between the direction of squalls and vector mean wind — 850 to 500 mb

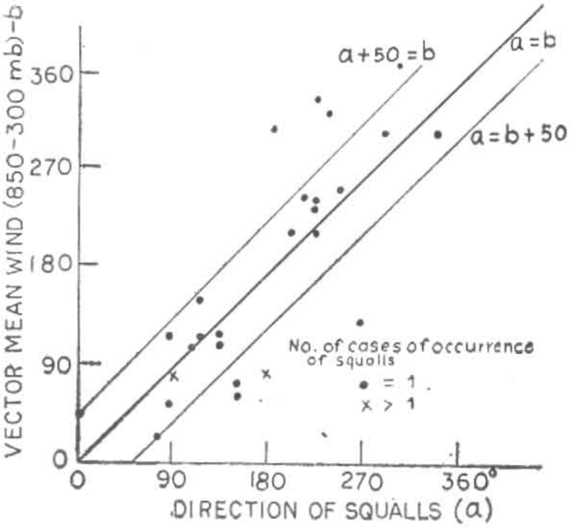

Fig. 7. Scatter diagram showing the relationship between direction of squalls and vector mean wind — 850 to 300 mb

These along with extreme values of deviation are shown in Tables 5 and 6.

It can be seen from the scatter diagrams and tables that there is a good relationship between the directions of vector mean winds in the layers in which the clouds are presumed to be embedded and the directions of the squalls. Equally good fit is found with the 700-mb wind direction as this more or less coincided with the mean wind direction on these days. So far as Bombay is concerned it appears that 700-mb wind direction is highly representative of the mean wind directions both on thunderstorm squall days and non-thunderstorm squall days.

The amount of scatter found in the best fit diagrams is inherent in such comparison, because we are not comparing the actual direction of the outflow in the central area of the downdraft in all the cases. The downdraft rushes ahead of the cloud as a miniature jet in sub-cloud layer and spreads out with a cyclonic shear to the left and anticyclonic shear to the right. A schematic representation of the out-flow given by Fujita (1963) is shown in Fig. 7. Thus the station away from the central area will record squall with directions which deviate from the original direction of the outflow, immediately below the cloud. Thus the direction of the squall at a station depends both on direction of the movement of the cloud and relative position of the station with respect to the cloud. On the other hand at a far away station, the deviation in the direction will be much greater, but as the speed of the outflow also decreases rapidly no squalls will be recorded. In other words squalls will be recorded only at such stations where the downdraft air reaches with only a small deviation in the direction.

The prediction implication of the above findings are that for long period forecast like TAFORS etc the forecast for the direction of the squall can be given with respect to forecast upper air conditions anticipated for the period for which the forecast is valid. Final adjustments for the directions can be made in short time forecast after determining the movement of the clouds with respect to the station with the help of the ground based radar or by visual observation.

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TABLE 1

Number of Squalls

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1955	0	0	0	0	0	0	4	8	6	0	0	0	18
1956	0	0	0	0	2	1	4	0	0	0	0	0	7
1957	0	0	0	0	1	7	6	1	0	0	0	0	15
1958	0	0	0	0	0	11	11	5	3	0	0	0	30
1959	0	0	0	1	1	11	16	0	0	1	0	0	30
1960	0	0	0	0	0	4	2	4	2	0	0	0	12
1961	0	0	0	0	2	5	4	2	3	1	0	0	17
1962				0	1	3	12	3	1	0	0	0	20
Total	0	0	0	1	7	42	59	23	15	2	0	0	149
Percentage frequency	0	0	0	0·6	4·7	28·4	39·6	15·4	10·0	1·3	0	0	100

TABLE 2

Frequency table of direction of Squalls

Direction	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Percentage frequency
N						1				1			2	1·3
NNE														
NE						2							2	1·3
ENE														
E					2	2							4	2·6
ESE					1	2							4	2·6
SE					1	2	1			1			5	3·3
SSE									2				2	1·3
S					2	2	3						7	4·8
SSW						3	1	1	1				6	4·0
SW						11	10	1	1				23	15·7
WSW						4	15	6	5				30	20·1
W						3	10	4	2				19	12·8
WNW						6	12	5	2				25	16·8
NW					1	2	6	5	1				15	10·1
NNW							1	1	1				5	3·3
Total				1	7	42	59	23	15	2			149	100·0

TABLE 3

Frequency table of velocity of Squalls (km/hr)

	≤45	46–50	51–55	56–60	61–65	66–70	71–75	76–80	81–85	86–90	91–95	Total	Highest velocity recorded
Jan												—	—
Feb												—	—
Mar												—	—
Apr		1										1	48
May			2	1	2		1			1		7	90
Jun		3	10	13	6	6	4					42	75
Jul		7	6	13	9	10	3	4	2	3	2	59	94
Aug	2	8	8	4	1							23	64
Sep	2	2	5	4	1							15	69
Oct	1			1								2	56
Nov												—	—
Dec												—	—
Total	5	21	31	36	19	16	8	4	2	4	2	149	—
Percentage frequency	3·3	14·2	20·3	24·3	12·8	11·5	5·8	2·6	1·3	2·6	1·3	100	—

TABLE 4

Frequency table of duration of Squalls (in min)

	1—2	3—4	5—6	7—8	9—10	11—12	13—14	15—16	17—18	Total
Jan										
Feb										
Mar										
Apr	1									1
May	4		1	1		1				7
Jun	35	3	1		1	1	1	1	1	42
Jul	52	4		1	1	1				59
Aug	22	1								23
Sep	14	1								15
Oct	2									2
Nov										
Dec										
Total	128	9	2	2	2	3	1	1	1	149
Percentage frequency	86·0	6·2	1·3	1·3	1·3	2·1	0·6	0·6	0·6	100·0

TABLE 5

Deviation for non-thunderstorm squalls

	Mean deviation	Average deviation	Extreme values Max.	Extreme values Min.	Percentage of squalls within 30° of wind	Percentage of squalls within 50° of wind direction
Wind at 700 mb	27·7	6·5	120	00	67·0	87·6
Vector mean wind of layers 850 to 500 mb	30·2	9·3	110	00	64·5	95·2

TABLE 6

Deviation for thunderstorm squalls

	Mean deviation	Average deviation	Extreme values Max.	Extreme values Min.	Percentage of squalls within 30° of wind	Percentage of squalls within 50° of wind direction
Wind at 700 mb	38·7	20·9	130	00	70·4	74.0
Vector mean wind of layers 850 to 300 mb	40·4	20·4	110	00	66·6	75·0