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A study of squalls at Madras Airport

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सार — सन् 1959 से 1979 तक (1972, 1973 को छोड़कर) के आंकड़ों का उपयोग करते हुए मद्रास हवाई अड्डे पर अल्पकालिक झंझाओं की बारम्बारता तथा तत्संबंधी स्थलीय मौसम परिस्थितियों में परिवर्तन का "सांख्यिकीय अध्ययन किया गया है। अध्ययन से संकेत मिलता है कि मद्रास हवाई अड्डे पर ये अल्पकालिक झंझाएं मुख्यत: ग्रीष्म के छ: महीनों में (अप्रैल से अक्टूबर तक), दक्षिण-पश्चिम मानसून मासों में उत्तर-पश्चिमी चतुर्थांश से तथा मानसून के लौटने वाले मौसम में उत्तर-पूर्वी चतुर्थांश से आते हैं और प्रत्येक झंझा के आने पर तापमान औसतन 2.5 अंश कम हो जाता है। उपरि पवन के आंकड़ों की तुलना से यह पता चलता है कि इन अल्पकालिक झंझाओं का 700 मि० बार वायुमण्डलीय दाब पर पवनों की दिशाओं से तथा 850 से 500 मि० बार वायुमण्डलीय दाब के बीच माध्य पवन से निकटतम सहसंबंध है।

ABSTRACT. A statistical study of the frequency of squalls at Madras Airport and the changes in the ground weather conditions associated with them has been made, using the data for the years 1959-1979 (except 1972, 1973). The study indicates that the squalls at Madras Airport predominantly occur during the summer half of the year (April-October) from the northwest quadrant in southwest monsoon months and from northeast quadrant in the retreating monsoon season, with an average temperature drop of 2.5 deg. C associated with them. The comparison of the upper wind data shows that the squall directions are best correlated with the directions of the wind at 700 mb and also with the mean wind in the 850 to 500 mb layer.

1. Introduction

Madras experiences squalls in association with the passage of rain-bearing convective clouds during the wet months of the year, mostly from April to November. Ramakrishnan and Ganapathiraman (1953) made a comparative study of the squalls recorded at Madras Harbour and Madras Nungambakkam Observatory and also discussed two case studies giving the rate of propagation of squalls between the two stations. Soundararajan and Raghavan (1962) discussed the case of a severe squall which occurred at Madras (Meenambakkam) on 17 August 1961.

Dekate and Bajaj (1966) have made a climatological study of the squalls at Bombay Airport and also of the direction of the environmental winds at different levels in the upper atmosphere and the direction of the squalls, with a view to obtain some prognostic tool for the prediction of the squall direction. Jayaram (1969) made a study of the direction of the thundersqualls and the direction of winds at different levels over Hyderabad Airport in the hot weather season (April-June). A similar attempt has been made in this study and the results have been presented in this paper. A Dines P.T. Anemograph was installed at Madras Airport in April 1951 at an altitude of 26.3 m agl. In this study the data from this anemograph for the years 1959-1971 and 1974-1979 were utilised to present the statistical aspects of the squalls occurring at Madras Airport.

2. Statistical analysis

2.1. *Frequency of squalls* — The number of squalls occurring in different months during the above mentioned 19 years is presented in Table 1. It can be seen from the table that squalls are most frequent during the monsoon months from June to September with July having the maximum number of squalls. Nearly 25 per cent of the squalls have occurred in the month of July with an average frequency of 5 squalls in this month. No squall was recorded in the month of January during these 19 years.

It is noticed that squalls occur not only in association with thunderstorms but also in association with large convective clouds which have not culminated into thunderstorms. In fact it was noticed that more than 45 per cent of squalls recorded are not associated with thunderstorms. So, for some of the statistical presentations, the squalls have been divided into two categories : (1) squalls associated with thunderstorms (TS) and (2) those not associated with thunderstorms.

2.2. *Speeds of squalls* — The frequencies of squalls of different speeds are given in Table 2. It can be seen that about 90 per cent of the squalls of both types have speeds less than 75 kmph. Squalls of speeds greater than 100 kmph associated with thunderstorms were not come across during the 19-year period. Only 2 squalls with speeds greater than 100 kmph were found on non-thunderstorm days, the maximum speed

TABLE 1
Occurrence of squalls in different months

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1959	0	0	0	0	1	1	2	0	1	3	0	0	8
1960	0	0	0	0	1	4	3	4	6	2	1	0	21
1961	0	0	0	0	2	1	10	5	7	3	0	0	28
1962	0	0	0	0	1	5	7	7	8	0	0	0	28
1963	0	0	0	2	3	4	1	9	6	4	3	0	32
1964	0	0	0	0	2	6	4	4	3	2	3	0	24
1965	0	0	0	3	0	6	9	3	1	1	1	1	25
1966	0	0	0	1	0	5	10	3	4	4	9	0	36
1967	0	0	1	1	1	5	8	13	5	1	0	2	37
1968	0	0	0	2	2	2	7	0	2	2	0	1	18
1969	0	0	0	0	4	4	8	1	3	3	2	0	25
1970	0	1	0	0	3	4	6	9	3	0	1	0	27
1971	0	0	0	2	4	6	3	1	1	1	0	0	18
1972						Missing							
1973						Missing							
1974	0	0	0	0	2	3	2	5	0	2	1	0	15
1975	0	0	0	0	1	3	2	4	4	0	0	0	14
1976	0	0	0	0	0	0	7	5	2	0	0	0	14
1977	0	0	0	1	1	3	2	3	3	3	6	0	22
1978	0	0	0	2	1	2	6	3	1	0	0	0	15
1979	0	0	0	1	0	0	1	0	0	0	0	0	2
Total	0	1	1	15	29	64	98	79	60	31	27	4	409
Average	0.0	0.05	0.05	0.80	1.5	3.4	5.2	4.2	3.2	1.6	1.4	0.2	21.5
Percentage frequency	0.0	0.2	0.2	3.7	7.1	15.6	24.0	19.3	14.7	7.6	6.6	1.0	100.0

TABLE 2
Frequency of squalls of different speeds

Direction	≤50 kmph				51-75 kmph				76-100 kmph				>100 kmph				Total			
	A		B		A		B		A		B		A		B		A		B	
	f	p	f	p	f	p	f	p	f	p	f	p	f	p	f	p	f	p	f	p
N	5	2.3	8	4.2	21	9.5	14	7.4	2	0.9	0	0.0	0	0.0	0	0.0	28	12.7	22	11.6
NNE	0	0.0	2	1.1	5	2.3	5	2.6	3	1.4	0	0.0	0	0.0	0	0.0	8	3.6	7	3.7
NE	2	0.9	4	2.1	5	2.3	8	4.2	0	0.0	1	0.5	0	0.0	0	0.0	7	3.2	13	6.9
ENE	1	0.5	2	1.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	0.5	2	1.1
E	2	0.9	2	1.1	2	0.9	3	1.6	0	0.0	0	0.0	0	0.0	0	0.0	4	1.8	5	2.6
ESE	2	0.9	1	0.5	1	0.5	2	1.1	1	0.5	0	0.0	0	0.0	0	0.0	4	1.8	3	1.6
SE	1	0.5	0	0.0	2	0.9	2	1.1	2	0.9	0	0.0	0	0.0	1	0.5	5	2.3	3	1.6
SSE	1	0.5	0	0.0	1	0.5	3	1.6	0	0.0	0	0.0	0	0.0	0	0.0	2	0.9	3	1.6
S	0	0.0	2	1.1	1	0.5	1	0.5	0	0.0	0	0.0	0	0.0	0	0.0	1	0.5	3	1.6
SSW	1	0.5	2	1.1	1	0.5	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2	0.9	2	1.1
SW	3	1.4	3	1.6	10	4.5	4	2.1	0	0.0	0	0.0	0	0.0	0	0.0	13	5.9	7	3.7
WSW	2	0.9	1	0.5	13	5.9	11	5.8	2	0.9	1	0.5	0	0.0	0	0.0	17	7.7	13	6.9
W	4	1.8	8	4.2	30	13.6	21	11.1	5	2.3	5	2.6	0	0.0	0	0.0	39	17.7	34	18.0
WNW	4	1.8	6	3.2	28	12.7	25	13.2	3	1.4	5	2.6	0	0.0	1	0.5	35	15.9	37	19.6
NW	9	4.1	6	3.2	25	11.4	16	8.5	5	2.3	3	1.6	0	0.0	0	0.0	39	17.7	25	13.2
NNW	3	1.4	3	1.6	11	5.0	5	2.6	1	0.5	2	1.1	0	0.0	0	0.0	15	6.8	10	5.3
Total	40	18.2	50	26.5	156	70.9	120	63.5	24	10.9	17	9.0	0	0.0	2	1.1	220	100.0	189	100.0

A=Associated with thunderstorm, B=Not associated with thunderstorm, *f*=Frequency, *p*= Percentage

TABLE 3

Frequency of squalls from different directions

Direction	A	B	A		B		A				B				A			B			A		B	
	Mar	Feb	Apr	May	Apr	May	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Oct	Nov	Dec	YT	pf	YT	pf
N	0	0	1	4	2	0	1	2	9	6	4	2	7	3	4	1	0	3	1	0	28	12.7	22	11.6
NNE	0	0	1	1	0	1	3	1	0	0	1	0	1	1	1	1	0	0	3	0	8	3.6	7	3.7
NE	0	0	1	2	0	1	1	0	0	0	1	0	0	0	2	1	0	1	10	0	7	3.2	13	6.9
ENE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	1	0.5	2	1.1
E	0	0	1	0	0	0	0	0	1	0	0	0	1	1	0	2	0	1	2	0	4	1.8	5	2.6
ESE	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1	1	0	0	2	4	1.8	3	1.6
SE	0	0	1	0	1	0	0	1	0	0	1	0	0	0	3	0	0	0	1	0	5	2.3	3	1.6
SSE	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	0	0	2	0.9	3	1.6
S	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0.5	3	1.6
SSW	0	0	0	1	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0.9	2	1.1
SW	0	0	0	2	0	0	2	4	4	0	2	2	2	0	1	0	0	1	0	0	13	5.9	7	3.7
WSW	1	0	1	0	0	0	2	2	8	2	5	6	2	0	1	0	0	0	0	0	17	7.7	13	6.9
W	0	0	1	5	0	0	5	11	4	9	9	11	5	9	3	1	0	0	0	0	39	17.7	34	18.0
WNW	0	0	1	2	0	0	4	8	9	9	5	17	8	6	2	0	0	1	0	0	35	15.9	37	19.6
NW	0	0	2	3	0	2	4	10	11	9	5	12	4	2	0	0	0	0	0	0	39	17.7	25	13.2
NNW	0	0	1	3	0	2	2	4	2	2	2	5	0	0	1	0	0	1	0	0	15	6.8	10	5.3
Total	1	1	11	23	4	6	26	43	48	37	38	55	31	23	21	8	2	10	19	2	220	100.0	189	100.0

A=Associated with TS; B=Not associated with TS; YT=Yearly total; pf=Percentage frequency.

recorded being 136 kmph on 20 November 1960 at 1505 IST from southeasterly direction. Even this squall occurred in association with strong prevailing easterly winds of 65 kmph prior to the occurrence of the squall.

2.3. *Direction of squalls* — The frequencies of squalls of the two types from different directions are given in Table 3. It is observed that during the southwest monsoon months the squalls occur predominantly from northwest quadrant with maximum frequency being of those from westnorthwesterly direction. During the post-monsoon (northeast monsoon) season the squalls are more numerous from the northeast quadrant even though a small percentage of these do occur from a westerly direction. The annual percentage frequency of squalls indicates that the squalls at Madras Airport can occur from any direction with maximum frequency being from the northwest quadrant and second though much less conspicuous maxima being from the northeast quadrant.

2.4. *Diurnal variations* — In the monsoon months the squalls occur generally between 1400 and 2200 IST though a few squalls have been observed even upto 0200 IST. Maximum frequency of occurrence is between 1600 and 2000 IST. By September the favourable time of occurrence extends upto 0600 IST. In the post-monsoon months of October and November and pre-monsoon months of April and May there is no particular favourable time of occurrence.

2.5. *Duration* — The data show that 89 per cent of the squalls have a duration of less than 10 minutes and even the bulk of these are limited to a duration of 6 minutes or less. About 8 per cent of the squalls have been observed to have a duration of 10 to 20 minutes. On rare occasions the duration exceeds 20 minutes. Squalls of duration more than 20 minutes are observed predominantly during the monsoon months.

2.6. *Temperature changes* — Temperature falls of 2 to 4 deg. C were observed on about 45 per cent of the occasions. On 40 per cent of the occasions the fall is less than 2 deg. C. In about 11 per cent of the occasions the fall ranged between 4 and 6 deg. C. In an extreme case, fall of 11.2 deg. C was registered on 29 May 1960. The speed of the associated squall was 90 kmph from west recorded at 1630 IST. On only one occasion a slight rise of 0.3 deg. C was observed, it occurring on 7 Sep 1959 at 0510 IST.

In the case of squalls not associated with thunderstorms the pattern is similar. On about 35 per cent of the occasions, a fall of 2 to 4 deg. C was noticed; on 46 per cent of the occasions the fall was less than 2 deg. C and on about 18 per cent of the occasions the fall was 4 to 6 deg. C. The extreme fall of 9.2 deg. C was recorded on 15 Aug 1963 at 1508 IST. The associated squall speed was 50 kmph from north.

On two occasions, one on 5 Aug 1962 at 2310 IST and the other on 11 November 1977 at 2240 IST a

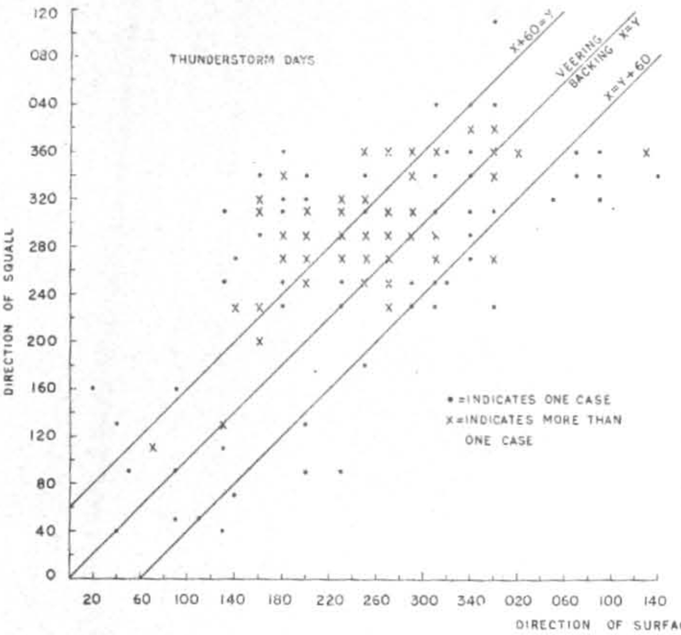

Fig. 1. Scatter diagram

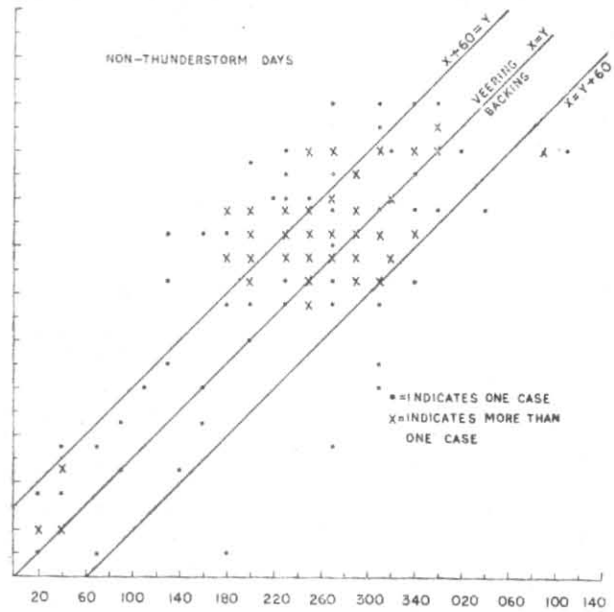

Fig. 2. Scatter diagram

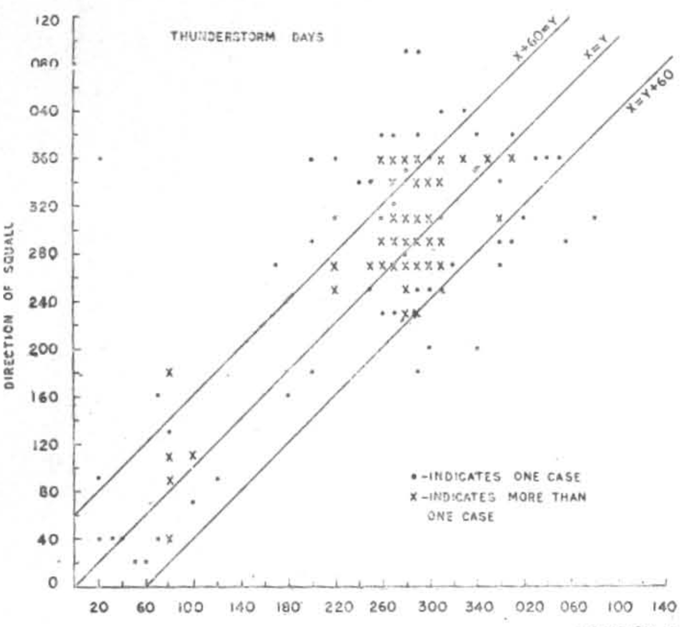

Fig. 3. Relationship between the direction of wind at 700 mb and direction of squall

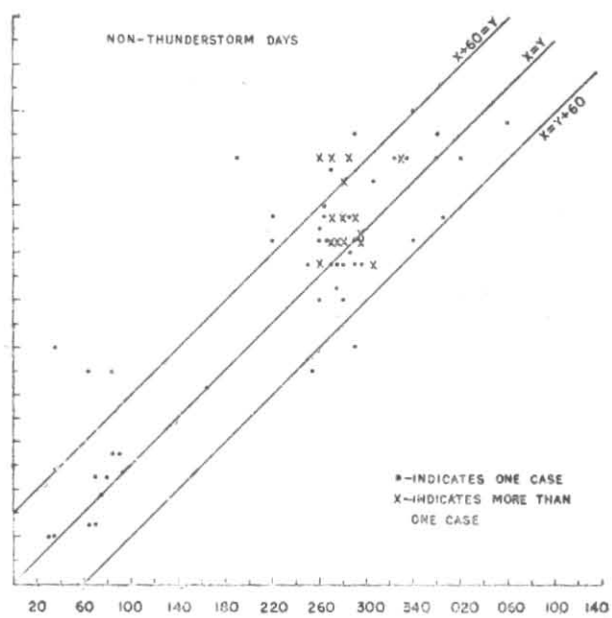

Fig. 4. Relationship between the direction of mean vector wind (850-500 mb) and direction of squall

slight rise in temperature was noticed, the rise being 0.4 and 0.1 deg. C respectively.

2.7. *Pressure changes* — The changes in surface pressure recorded in association with the passage of squalls both on thunderstorm and non-thunderstorm days are described below.

In both types, rise and fall of pressure were noticed. But on about 80 per cent of the occasions in both types only rises in pressure were noticed. The changes in pressure are generally small, being less than 1 mb in about 70 per cent of the cases. Only in about 6 to 7 per cent of the occasions, pressure rises of 1.0 to 2.5 mb are observed. In 17 to 18 per cent of the occasions no change was discernible. The pressure falls of less than 0.5 mb are noticed on 3 to 4 per cent of the occasions.

3. Comparative study of upper wind directions and directions of surface squalls

Earlier results by a number of authors, *e.g.*, Byers and Braham (1949), Neuton and Katz (1958), Browning and Ludlam (1962), Atlas (1963), Venkataraman and Bhaskara Rao (1966) have shown that a close relationship exists between the movement of convective clouds and the vectorial mean wind in the layer of the atmosphere in which they are embedded. Some of the earlier results have also shown that the downdrafts from the convective clouds which cause surface squalls flow-out in the direction towards which the clouds are moving. Venkataraman and Bhaskara Rao (1966), Dekate and Bajaj (1966) and Jayaram (1969) have combined the above two concepts and made a direct comparison between the squall directions and the directions of the upper winds. Similar comparisons were made in this study also and in addition comparisons were also made with the direction of the surface wind prior to the occurrence of squall and the squall direction. For comparison with the surface wind the data for the entire 19 years has been used while for the upper winds, the study has been restricted to the data for the 10 years from 1959 to 1968.

The scatter diagrams (Figs. 1 & 2) show the relationship between the direction of surface wind before the squall and the direction of the squall for thunderstorm and non-thunderstorm days. It can be seen from the diagrams that the squalls occur on most occasions from the same quadrant as the prevailing surface wind but the scatter is quite large. The dispersion of the points is less in the case of the scatter diagram between the direction of wind at 700 mb and the direction of squalls (Fig. 3) for the combined thunderstorm and non-thunderstorm days. This is so even when compared to that of 850 mb level winds (figure not shown).

Similarly scatter diagrams were prepared for comparing the direction of the squalls and the direction of the mean vectorial wind between 850 and 500 mb on non-thunderstorm days (Fig. 4) and the direction of squalls and the direction of mean vectorial wind between 850 and 300 mb on thunderstorm days (figure not shown). These diagrams have revealed that the scatter is much less in the former case than the latter.

The mean deviation, the average deviation, the extreme values of deviations between the squall directions and the directions of various parameters have been worked out and shown in Table 4. The correlation coefficients between the pairs of parameters compared and the best fit linear regression equations have been worked out and are also given in the above table. It is seen that the 700 mb wind direction is the best indicator of the squall direction. The data indicate that if 700 mb wind direction is used as the predictor, on 62 per cent of the cases the squall directions will be within 30 degrees of the predicted direction and on 82 per cent of the occasions the squall direction will be within 60 degrees. The correlation coefficient is also quite high being 0.83. The next best indicator is the direction of the 850-500 mb mean wind.

The regression equations thus obtained for the 850-500 mb mean wind and the 700 mb wind were tested for the squall data for the years 1980 and 1981. The results of verification shown in Table 5 indicate that on nearly 70 per cent of the occasions the predicted direction using the equation for the 850-500 mb mean wind and the actual squall direction are within 30 deg. and on 90 per cent of occasions within 60 deg. with the average deviation of 34 deg. The 700 mb wind when used as a predictor, the deviation from the actual squall direction will be within 30 deg. on 50 per cent of the occasions and on 80 per cent of occasions within 60 deg. with the average deviation of 39 deg. So even though the direction of the 700 mb wind has shown a better correlation with the squall direction for the data of 1959-68, the verification seems to indicate that the 850-500 mb wind is a better predictor.

4. Summary of results

(1) Highest frequency of squalls at Madras is in the southwest monsoon season (June to September).

(2) About 45 per cent of the squalls are not associated with thunderstorm but are caused by downdrafts of large convective clouds which have not culminated into thunderstorms.

(3) High speed squalls (greater than 100 kmph) are rare at Madras Airport. 65 to 70 per cent of the squalls have wind speeds between 51 and 75 kmph. In general squalls from westerly direction are of higher speed than those from easterly direction.

(4) As can be expected from the general wind flow in different months, the squalls are predominantly from northwest quadrant in the hot weather and southwest monsoon seasons. In November they are mostly from northeast quadrant and in October they occur from all directions.

(5) Afternoon to early night is the period of maximum squall activity during the hot weather and the southwest monsoon seasons even though a few squalls occur in the late night also during the southwest mon-

TABLE 4

Deviation for thunderstorm/non-thunderstorm squalls

Direction of (x)	Deviation Mean	Deviation Average	Extreme values Max.	Extreme values Min.	Percentage of squalls within (of wind direction) 30°	31-60°	61-90°	Above 90°	C.C. (r)	Line of best fit (y=Squall direction)
Surface wind at P.T. Anemograph level for all days	58.00	34.20	180	000	31	35	18	16	0.66	$y=0.58x+137.0$
Wind at 700 mb for all days	34.64	—10.66	130	000	62	20	14	4	0.83	$y=0.86x+46.2$
Vector mean wind between 850 & 500 mb for all days	47.21	—16.17	131	000	54	27	13	6	0.80	$y=0.81x+68.5$
Vector mean wind between 850 & 300 mb for thunderstorm days	49.10	—16.83	163	000	46	28	11	15	0.51	$y=0.42x+175.9$

C.C.—Correlation Coefficient

TABLE 5

Verification of regression equations

Date	Time (IST)	Dir. of sq. (°)	850-500 mb mean wind: Sq. dir. by Reg. Eqn. (°)	850-500 mb mean wind: Dev. (°)	700 mb wind: Sq. dir. by Reg. Eqn. (°)	700 mb wind: Deviation (°)
28 May '80	1720	320	012 (372)	52	030 (390)	70
30 May 80	1025	270	032 (392)	122	043 (403)	133
7 Jul 80	1635	340	288	52	297	43
8 Jul 80	1650	320	288	32	287	33
10 Jul 80	1530	320	301	19	297	23
1 Aug 80	1915	230	288	58	297	67
6 Aug 80	0125	320	—	—	270	50
10 Aug 80	2218	270	296	26	278	8
11 Aug 80	1950	320	290	30	297	23
16 Oct 80	1750	020	032	12	072	52
6 May '81	1635	360	334	26	347	13
1 Jun 81	1715	290	271	19	253	37
2 Jun 81	1720	230	293	63	297	67
5 Jul 81	1550	270	279	9	287	17
23 Jul 81	1540	320	304	16	278	42
2 Aug 81	1740	290	302	12	297	7
3 Aug 81	1845	320	296	24	300	20
3 Aug 81	2155	270	296	26	300	30
8 Aug 81	1735	270	295	25	297	27
15 Aug 81	2140	320	290	30	297	23
Average				34		39

soon season and in May. In April, October and November they have no preferred period of occurrence.

(6) The duration of squalls is generally small being less than 10 minutes in 90 per cent of the occasions.

(7) The occurrence of squalls is accompanied generally by a temperature fall. On about 40-45 per cent of the occasions the associated fall in temperature is less than 2 deg. and in another 40 to 45 per cent cases the fall is between 2 and 3 deg. The average fall is 2.6 deg. C.

(8) On more than 80 per cent of the occasions there is a pressure rise with the onset of the squall and on more than 70 per cent of the occasions the rise is less than 1 mb.

(9) The comparison of the squall directions with the environmental wind directions indicate that the mean wind in the 850-500 mb layer gives the best indication of the likely squall direction. The next best indicator is the 700 mb wind.

(10) Predominant number of squalls occurs in different seasons from the same quadrant as the prevailing surface winds so that there is a reasonable correlation between the two.

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