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Movement of premonsoon squall lines over Gangetic West Bengal as observed by radar at Dum Dum Airport

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ABSTRACT. Movement of 44 squall lines over the Gangetic West Bengal during the premonsoon season (March—May) of 1959-1961 as observed by a powerful 3-cm Japanese Radar at Dum Dum Airport (Calcutta) has been studied. It has been found that the movement of the squall lines cannot be explained by the upper wind alone. The direction of movement is generally within 90° to the right (looking down wind) of the 700-mb (10,000 ft) wind. The speed of movement is much more than that of the wind. It has been suggested that the well-known Regenerative Drift Process is responsible for such high speed of movement of the squall lines.

1. Introduction

With the advent of microwave age, much light has been thrown on the development, decay and movement of cloud cells. As regards the movement of individual cloud cells, it has been suggested by earlier workers (Byers and Braham 1949, Das *et al.* 1957) that the movement is controlled by the wind at 10,000 ft and above. But the movement of the squall lines still remains a problem to be solved.

During the premonsoon season (March—May), violent thundersqualls occur over the Gangetic West Bengal. The squall lines move generally from northwest to southeast, the prevailing upper wind being westerly. There are some occasions when these squall lines have been found to move against the direction of upper wind (De 1958). The purpose of the present paper is to find out if any correlation exists between the movement of the squall lines and the upper wind.

2. Data used

(*i*) *Radar data*—The observations were made with a high powered (250 KW peak) Japanese Radar (Type NMD-451A) operating on 3-cm wave band. The beam width of the radar is 1·2° in both vertical and horizontal. The maximum range from which echoes can be detected is about 300 km. The radar is operated for 15 minutes every hour as a matter of routine. Precipitation echoes as seen on the PPI scope are very carefully recorded every hour and plotted on a polar diagram. Height scanning (RHI or REI) of the significant development is also made whenever appropriate.

The observations made at Dum Dum airport (Calcutta) with the above mentioned radar during the premonsoon seasons (March-May) of 1959, 1960 and 1961 have been analysed and the results presented in this paper. The study relates to the squall lines which had life span of 3 hours or more, from their first appearance as lines (solid or broken) till they retained their identity as lines. 44 such squall lines which appeared initially in the northwest or northeast sector have been studied. It may be mentioned that there were a couple of occasions when the squall lines appeared in the southeast or southwest sector which have not been taken into account in this study.

TABLE 1

Station	Azimuth with respect to Dum Dum (deg)	Distance from Dum Dum (km)	Time of upper wind observation (IST)
Dum Dum	..	..	0530 1130 1730
Asansol	310	180	,,
Bhagalpur	333	320	,,
Bogra	017	270	,,
Agartala	059	320	,,

The radar observations on each of the above 44 occasions have been plotted on a polar diagram and motion of these lines calculated from the forward edge of the smoothed echo lines. A sample occasion for a squall line as seen on the radar scope at Dum Dum on 9 May 1959 is shown in Fig. 1.

(*ii*) *Upper air data*—The wind observations at 3 different levels (850, 700 and 500 mb) at a station nearest to the line in time and space have been utilised in this study. The details of the stations are shown in Table 1.

If the upper wind data of any of these stations at a particular level was not available, the general wind pattern, *i.e.*, the stream line, at that level as available from the upper air charts prepared at the Main Meteorological Office, Dum Dum has been taken into consideration.

The radar data and the wind data are shown in Tables 2 and 3 respectively.

(*iii*) *Analysis of the data*—From Table 2 it may be seen that there were 23 occasions in 1959, 8 occasions in 1960 and 13 occasions in 1961, totalling 44 occasions, which have been analysed for the study. The distribution of these occasions monthwise during the period of 3 years is as follows : March 9, April 7, and May 28 (total 44). It is apparent that the thunderstorm activity which develops into squall lines as shown on the radarscope at Dum Dum during the premonsoon season (March—May) is maximum during May. These 44 cases have been studied on the lines of an earlier work by Boucher and Wexler (1961) who analysed the data in respect of 27 precipitation lines at Blue Hill and 28 lines at Illinois.

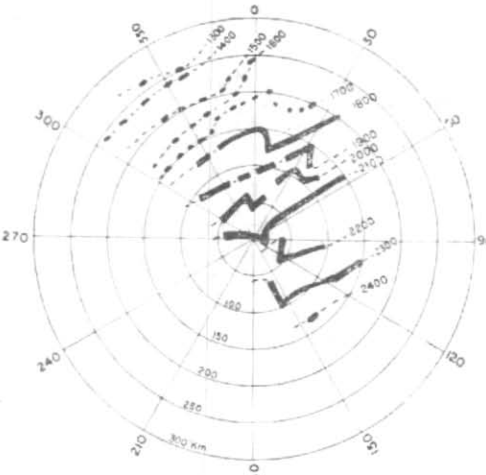

Fig. 1. Tracing of Storm Detecting Display at Dum Dum on 9 May 1959

Time is indicated in IST

3. Appearance of lines

On most of the occasions the squall lines have been found to owe their origin to isolated or scattered precipitation cells. An hour or so later, these cells increase in size and number, come closer together and are so arranged as to form a line. Initially a squall line is found to be a broken one, *i.e.*, there are gaps in between different portions of the line. But later it becomes more compact and forms a solid line.

It is well known that the length of a precipitation line depends on the characteristics of the radar used and also on the distance of formation of the line from the observing radar. The radar used for this study has

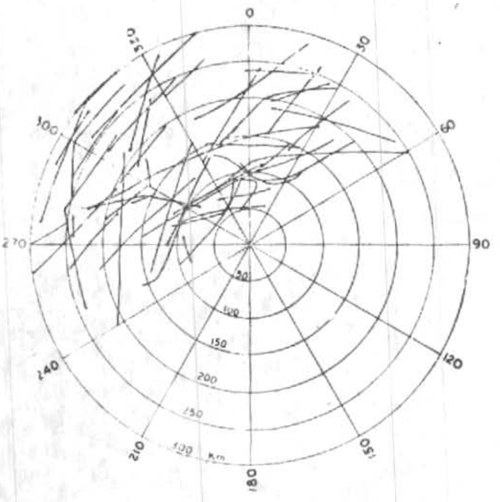

Fig. 2. Initial Location

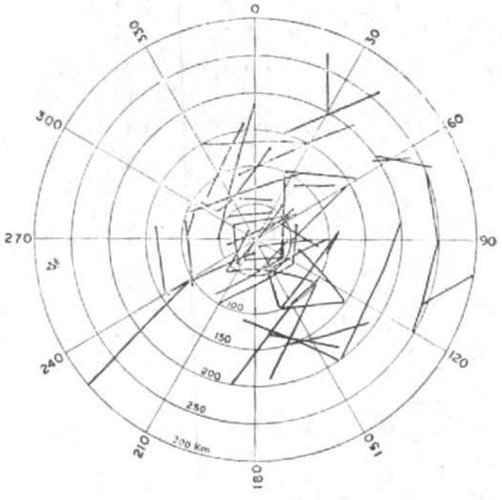

Fig. 3. Final Location.

Squall lines as detected on the radarscope at Dum Dum during premonsoon season (March-May) of 1959-31

got a maximum range of 300 km, the effective maximum range being 250 km. From theoretical considerations, the maximum length of the precipitation line, with this radar at a distance of 240 km should be about 140 km. The above expectation has come out fairly true. It can be seen from Table 2 that the average length of the squall line at its initial formation is about 140 km, the minimum and maximum length being 40 and 400 km respectively.

4. Locations of the lines

The initial locations of the lines as detected on the radarscope are shown in Fig. 2. It is seen that in most of the cases, the lines appeared in the W-NW-N-NE sectors at distances ranging from 100 to 250 km. The coverage of the lines is from 240° through 360° to 060°, the maximum concentration being 270° through 360° to 030°.

The locations of the lines at the final stage before they lost their identity as lines are shown in Fig. 3. It is seen that most of the lines moved to southeast and remained within 100 km around the station. This means that most of the lines disappeared while they moved near the coast of Bay of Bengal which is only about 110 km to the southeast of the radar station. It may be mentioned in this connection that most of the lines appeared between 1400 and 1900 IST, *i.e.*, during the time of maximum convection. As such, after the convective activity had subsided, the lines became less active and ultimately disappeared. The above idea finds its support in the data presented in Table 2 which shows that most of the lines dissipated between 2000 and 2300 IST. Some of the lines, however, disappeared due to range attenuation.

5. Life time of the lines

It has been mentioned earlier that only those squall lines which formed during the premonsoon seasons of 1959-61 and whose life time was 3 hours or more have been analysed. Out of 44 such lines, 9 (20½%) lasted for 3 hours, 11 (25%) for 4 hours, 9 (20½%) for 5 hours and the remaining 15 (34%) lasted for 6 to 10 hrs. Frequencies of squall lines with different life times are shown in Fig. 4. It is seen that the frequency is maximum (25%) for 3-4 hours duration of the lines. The above finding may be compared to that of Boucher and Wexler (1961) who found that in the case of Blue Hill lines the frequency is maximum (43%) at 3-4 hours.

TABLE

S. No.	Date	Time (IST)	Initial line formation			Movement			
			Location and extent	Type	Length (km)	Av. speed (km/hr)		Whole life	
			Azimuth(deg)/Range (km)			1st hr	First 2 hrs.	Av.speed (km/hr)	Dir. of motion (deg)
1	25-3-59	1700	255/85 —280/90	Broken line	45	15	15	20	270
2	27-3-59	0230	355/230—020/250	,,	100	20	30	35	340
3	,,	0645	020/140—035/240	,,	100	40	30	30	360
4	,,	2100	350/120—010/ 80—035/120	,,	60	20	20	20	340
5	31-3-59	1200	275/150—350/ 80—040/180	,,	290	15	25	30	340
6	1-4-59	1300	270/115—340/130—095/80—340/ 50	,,	200	25	25	25	360
7	,,	2000	339/130—005/200—030/240	,,	150	30	25	30	340
8	15-4-59	1600	260/250—285/180	,,	150	30	30	30	270
9	20-4-59	1630	310/210—335/280	,,	150	40	50	35	320
10	30-4-59	0800	005/300—025/350	,,	100	30	25	30	340
11	4-5-59	1500	345/80 —030/100—045/200	,,	100	20	25	32	340
12	6-5-59	1400	330/130—005/240	,,	150	30	35	43	320
13	8-5-59	1600	285/110—320/ 60—345/100	,,	150	50	40	35	290
14	9-5-59	1400	305/230—335/250	,,	150	30	35	35	320
15	10-5-59	1400	310/300—320/300	Solid line	80	30	35	35	320
16	16-5-59	1400	010/200—025/240	Broken line	100	20	20	20	340
17	22-5-59	1700	360/80 —020/150	,,	80	20	25	30	340
18	23-5-59	1400	335/150—025/150	,,	150	30	20	30	360
19	26-5-59	1400	325/75 —020/ 85	,,	70	25	15	20	360
20	27-5-59	1700	265/340—295/350	,,	250	30	35	40	290
21	29-5-59	2000	260/300—290/200	,,	175	60	40	40	270
22	30-5-59	1300	290/260—315/260	,,	150	30	45	45	290
23	31-5-59	1300	275/240—300/275—320/275	,,	300	50	45	35	290
24	2-3-60	1700	270/300—360/150—030/180	,,	400	40	35	35	340
25	7-3-60	1900	280/240—295/160—310/ 80	,,	150	25	25	25	320
26	20-3-60	1700	255/100—300/ 55—355/105	,,	150	10	20	20	320
27	5-4-60	1200	280/200—300/160—310/180	Solid line	100	40	30	25	320
28	13-5-60	1800	010/180—055/240	Broken line	200	20	15	25	050
29	15-5-60	1700	280/280—300/270—310/300	,,	125	30	50	40	290
30	17-5-60	1500	010/160—020/260	Solid line	120	40	25	25	320
31	20-5-60	1500	290/120—330/ 80—360/120—060/250	Broken line	300	20	30	35	290
32	25-3-61	1600	290/175—295/150	,,	40	40	45	40	320
33	30-4-61	1630	255/145—330/170	Solid line	180	40	40	40	320
34	1-5-61	1430	305/270—350/320	Broken line	225	70	65	60	290
35	,,	1430	290/180—310/180	,,	50	65	50	45	290
36	,,	1915	250/160—250/140—290/100—025/ 60	,,	200	60	50	40	290
37	2-5-61	1430	295/200—325/200	,,	100	45	50	45	320
38	3-5-61	1600	260/220—320/120	,,	180	50	60	60	320
39	11-5-61	1630	330/80 —010/120	,,	80	20	20	20	320
40	12-5-61	1700	305/80 —325/240	,,	100	40	40	40	320
41	13-5-61	1430	240/220—310/220	,,	200	20	20	30	320
42	14-5-61	1800	335/180—350/200—015/280	,,	150	20	25	30	340
43	23-5-61	1430	250/240—280/260—310/230	,,	250	20	40	30	340
44	31-5-61	1400	330/230—345/260	,,	80	20	25	30	320

2

Time (IST)	Final line			Life time (hrs)	Date	S. No.
	Location and extent Azimuth (deg)/Range (km)	Type	Length (km)			
2100	210/80—030/10	Solid line	90	4	25-3-59	1
0645	055/200—070/260	Broken line	100	4	27-3-59	2
1400	170/130—140/180	Solid line	100	7	,,	3
2400	050/30—095/80	,,	60	3	,,	4
1700	150/10—090/100	,,	120	5	31-3-59	5
1700	230/300—240/100	Broken line	250	4	1-4-59	6
2330	035/80—055/130	Solid line	70	3½	,,	7
2300	240/160—190/20	,,	150	7	15-4-59	8
2300	270/50—360/180	,,	120	6½	20-4-59	9
1100	020/270—030/200	,,	80	3	30-4-59	10
2000	090/250—085/320—075/360	Broken line	100	5	4-5-59	11
2200	110/240—100/300	Solid line	60	8	6-5-59	12
2100	100/100—080/120	,,	50	5	8-5-59	13
2300	160/50—160/100—125/150—100/60	,,	200	9	9-5-59	14
2300	160/100—080/120	,,	150	9	10-5-59	15
1900	055/190—065/240	,,	60	5	16-5-59	16
2000	090/50—060/150	Broken line	100	3	22-5-59	17
2300	190/120—145/200—080/200	Solid line	300	9	23-5-59	18
2400	175/150—130/186	,,	150	10	26-5-59	19
2300	175/180-130/100-170/40-220/60-330/20	,,	300	8	27-5-59	20
2300	235/110—285/100	,,	100	3	29-5-59	21
1900	240/25-stn—050/70	,,	100	6	30-5-59	22
2000	220/40-stn—035/60	,,	110	7	31-5-59	23
2100	180/50—090/40	,,	50	4	2-3-60	24
2300	210/45—300/30—060/70	,,	125	4	7-3-60	25
2100	210/30—120/40—070/40	,,	80	4	20-3-60	26
1700	290/100—035/120	Broken line	150	5	5-4-60	27
2300	335/70—025/60	,,	50	5	13-5-60	28
2100	270/90—295/90	,,	40	4	15-5-60	29
1800	330/150—360/130—030/150	,,	150	3	17-5-60	30
2200	120/250—090/250—070/250	,,	250	7	20-5-60	31
2200	150/40—110/60—090/80	Solid line	60	6	25-3-61	32
2130	210/100—120/60—070/60	,,	150	5	30-4-61	33
1730	345/90—042/205	Broken line	150	3	1-5-61	34
1930	110/50—080/50	Solid line	50	5	,,	35
0045	190/200—150/100—120/100	,,	125	5½	,,	36
1830	265/35—055/55	Broken line	100	4	2-5-61	37
1900	215/95—120/45—025/95	,,	200	3	3-5-61	38
1930	310/50—030/40	Solid line	60	3	11-5-61	39
2000	305/90—305/70—010/130	Broken line	125	3	12-5-61	40
1830	310/80—350/160	,,	100	4	13-5-61	41
2200	015/150—040/260	Solid line	150	4	14-5-61	42
2030	240/145—280/135	,,	100	6	23-5-61	43
1900	025/100—060/160	,,	100	5	31-5-61	44

TABLE 3

S. No.	Date	Observed upper wind						Computed upper wind (speed) component normal to line		
		850 mb		700 mb		500 mb				
		Dir. (deg)	Speed (km/hr)	Dir. (deg)	Speed (km/hr)	Dir. (deg)	Speed (km/hr)	850 mb (km/hr)	700 mb (km/hr)	500 mb (km/hr)
1	25-3-59	200	10	290	20	300	10	08	13	05
2	27-3-59	300	30	270	30	290	30	19	05	15
3	,,	300	30	270	30	290	30	19	05	15
4	,,	290	20	270	30	290	30	10	05	15
5	31-3-59	270	30	260	30	270	40	15	10	20
6	1-4-59	270	15	270	20	270	40	13	17	35
7	,,	300	20	270	25	280	65	19	18	53
8	15-4-49	310	05	310	25	280	40	05	25	33
9	26-4-59	130	05	270	20	270	20	05	19	19
10	30-4-59	140	10	300	20	310	20	09	13	15
11	4-5-59	230	15	270	20	270	45	09	03	08
12	6-5-59	290	05	270	15	280	20	05	13	19
13	8-5-59	280	05	290	10	260	10	03	06	02
14	9-5-59	270	05	270	20	270	20	04	15	15
15	10-5-59	180	10	300	05	290	25	07	05	23
16	16-5-59	250	15	270	35	300	45	01	09	32
17	22-5-59	260	10	290	10	270	05	06	09	04
18	23-5-59	250	15	270	15	270	15	04	01	01
19	26-5-59	290	20	310	15	300	30	11	12	21
20	27-5-59	330	15	310	30	290	25	10	26	25
21	29-5-59	240	05	270	30	270	15	01	23	11
22	30-5-59	280	25	270	35	270	35	23	29	29
23	31-5-59	280	10	270	20	250	25	09	19	25
24	2-3-60	120	05	340	05	270	30	05	05	15
25	7-3-60	230	10	270	25	270	20	04	06	05
26	20-3-60	310	15	250	10	250	45	15	04	19
27	5-4-60	290	15	270	20	270	25	13	13	16
28	13-5-60	200	10	270	15	290	20	10	04	02
29	15-5-60	160	10	300	15	320	20	06	15	17
30	17-5-60	290	20	270	25	250	30	19	19	15
31	20-5-60	240	10	290	20	310	30	02	13	26
32	25-3-61	280	20	270	15	270	40	14	09	23
33	30-4-61	290	20	300	30	270	15	20	30	13
34	1-5-61	270	15	300	25	270	35	10	15	22
35	,,	200	05	290	35	270	40	03	27	20
36	,,	270	15	270	10	260	35	08	05	12
37	2-5-61	300	25	330	25	270	30	25	24	23
38	3-5-61	250	05	320	25	320	20	03	25	20
39	11-5-61	300	05	270	15	260	20	05	10	10
40	12-5-61	240	10	290	25	290	35	07	25	35
41	13-5-61	300	15	290	20	270	20	14	20	20
42	14-5-61	240	10	260	25	260	35	02	09	12
43	23-5-61	240	10	300	10	260	20	05	10	15
44	31-5-61	290	10	270	30	290	25	09	21	23

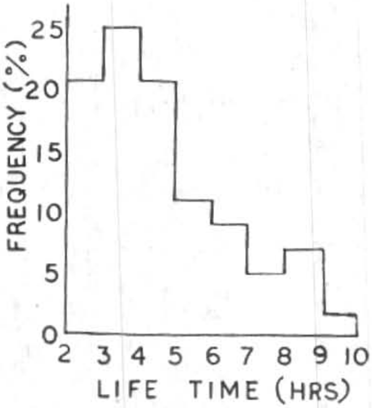

Fig. 4. Life time of the squall lines *vs* frequency (%)

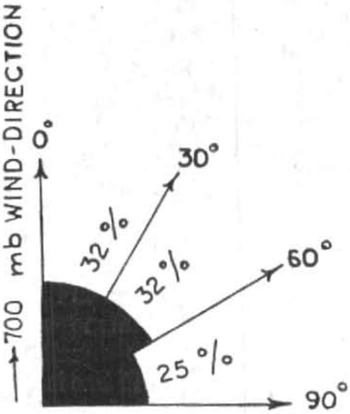

Fig. 5. Angular difference (%) between 700-mb wind direction and direction of movement of squall lines

6. Movement of lines

The average speed of these 44 squall lines has been worked out to be 33 km/hr, the minimum and maximum being 20 and 60 km/hr respectively. This is in agreement with the findings of earlier workers. Harper and Beimers (1958) found the average speed of 42 lines to be 22 mph (35 km/hr), while the values obtained by Swingle and Richards (1953) for 44 lines and by Boucher and Wexler (1961) for 27 lines were 25 mph (40 km/hr) and 22 mph(35 km/hr) respectively.

An attempt has been made to find out the correlation between the speed of the squall lines and that of the upper wind. For this purpose, the correlation coefficient of the average squall line speed and the component of wind normal to the line at 850 mb (5000 ft), 700 mb (10,000 ft) and 500-mb (20,000 ft) levels has been worked out. The details of the stations of which the wind data have been utilised have already been shown in Table 1. The correlation coefficients for these levels have been worked out to be 0·03, 0·43 and 0·16 respectively. It is thus seen that the maximum correlation, though not very satisfactory, exists at 700-mb (10,000 ft) level. It may be mentioned that Boucher and Wexler (1961) obtained a very high correlation coefficient (0·82) at 700-mb levels, with low values at higher and lower levels.

Another important aspect of the lines is the angular difference between the wind direction at the level where the correlation coefficient is the highest and the direction of movement of the squall lines. A plot of this angular difference is shown in Fig. 5. It is seen that in 89% cases, the difference is within 90°, the direction of movement of the lines being to the right of the 700-mb wind. The above finding is in agreement with that of Boucher and Wexler (1961).

7. Mechanism of line movement

Humphreys (1940) suggested that the movement of the cloud cells is controlled by the vector mean wind of the layer in which the cloud cells are imbedded. Byers and Braham (1949) have, however, observed greatest deviations from the above findings of Humphreys in the cases of very high clouds extending upto 30,000 ft or more. De (1958) reported that though the prevailing upper wind at 10,000 ft or so might control the movement of the individual cloud cells, it does not always do so in the case of squall lines. Das *et al.* (1957) also reported movement of two Nor'wester squall lines and found that the movement of these squall lines did not correspond to the upper wind.

Now, it is well known that a squall line consists of individual cloud cells formed very close to each other so as to constitute, often, a solid mass. It is, therefore, expected that movement of a squall line should correspond to the movement of these individual cells. But this movement alone cannot explain the movement of the squall line, because the life time of the squall line is much more than that of the individual cloud cells (De and Rakshit 1961). So, there must be other factor which contributes to the movement of the squall lines. Boucher and Wexler (1961) suggested that a propagation factor depending upon the rate of development and location of the new cells which ultimately form the line contributes appreciably to the movement of the line. The effect of the propagation factor should be traced on the radarscope in the form of scattered fresh cells, formed ahead of the line, which ultimately develop into a fresh line formation while the old line decays. In this way, two or three lines may be detected on the radarscope. In our case, only on rare occasions the fresh line ahead of the main line could be detected. It might be that the resolution of the radar set is not sufficient to detect a number of lines simultaneously on the radarscope.

From the above discussions, it is evident that the movement of the premonsoon squall lines cannot be explained in terms of mean wind of the layer in which the cloud cells are located. To understand the movement let us consider in details the life history of the cloud cells comprising the line. Once the cloud cells are formed, *i.e.*, during the premature stage, they are subjected to the wind shear of the appropriate layer. As a result they may be laterally displaced along the direction of the wind. When they have attained maturity, different portions of them are under the influence of wind fields at the corresponding layers. The situation thus becomes a very complicated one. At that time, *i.e.*, during the maturity stage, the downdraft becomes quite prominent and brings down cold air which results in regeneration of fresh cells. These cells ultimately grow in size and number and appear in the form of a new line ahead of the old line. This new line will be visible on the radarscope and will appear as if the old line has moved to the new position. As the regenerated cells form much ahead of the parent cells the speed of movement of the squall line will appear to exceed that of the wind. As stated earlier, the old line may not always be visible on the radarscope even though it exists, due probably to attenuation caused by the new line in front.

8. Concluding remarks

The following salient points in respect of the movement of the premonsoon squall lines over the Gangetic West Bengal, come out from the present study.

(*a*) A squall line appears initially as isolated or scattered cells which ultimately form a broken line at distances ranging from 100 to 250 km covering 240° through 360° to 060°.

(*b*) The average length of a squall line is about 140 km.

(*c*) $20\frac{1}{2}\%$ of the squall lines last for 2-3 hours, 25 % for 3-4 hours, $20\frac{1}{2}$ % for 4-5 hours and the remaining 34 % for 6-10 hours.

(*d*) The correlation coefficient of the squall line speed and wind normal at different levels is maximum (0·43) at 700-mb level with lower values at higher and lower levels.

(*e*) The angular difference between the wind direction at 700-mb level and the direction of movement of the squall line is within 90° on 89 % occasions, the latter being 90° to the right of the former.

(*f*) The speed of movement of the squall lines is much more than that of the upper wind. The former can be explained by the well-known Regenerative Drift Process.

9. Acknowledgement

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