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Heights of *Cb* clouds around Calcutta airport — Diurnal and seasonal variations

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सार — शोधपत्र में 1977–86 वर्षों की अवधि के दौरान कलकत्ता हवाई अड्डे के मौसम विज्ञान कार्यालय में एकत्र किए गए रेडार आंकड़ों के आधार पर, उक्त हवाई अड्डे के चारों तरफ 2,80,000 वर्ग किलोमीटर क्षेत्र में 6 कि. मी. या इससे अधिक की ऊपरी ऊंचाई पर विकसित कपासीवर्षी (*Cb*) मेघों का अध्ययन किया गया है। कपासीवर्षी (*Cb*) सेलों की कुल संख्या के ऋतुनिष्ठ, महीनेवार और घंटेवार वितरण और कपासी वर्षी *Cb*, कपासी वर्षी सेल (*Cb* cells) जो क्षोभमण्डल की ऊंचाई तक पहुँचे, के साथ उनकी उच्चतम ऊंचाइयों के दिनों की संख्या और उच्च कपासी वर्षी मेघों की रचना के अधिमानित स्थानों का परीक्षण व विवेचन किया गया है और उनके मुख्य लक्षणों को संक्षेप में बताया गया है।

ABSTRACT. Based on radar data collected at the Meteorological Office, Calcutta airport during the years 1977-86, a study has been made on cumulonimbus (*Cb*) clouds with top heights at 6 km or more developed over an area of 2,80,000 sq. km around the said airport. The seasonal, monthwise and hourly distribution of the total number of *Cb* cells and their top heights, number of days with *Cb*, *Cb* cells that reached tropopause height and the preferred places of formation of high *Cb* clouds have been examined and discussed and the salient features have been summarised.

1. Introduction

A cumulonimbus (*Cb*) cloud, giving lightning and thunder, is one of the most spectacular weather phenomena and is caused by great instability present in the atmosphere. Such clouds pose serious hazards to air navigation due to severe turbulence, heavy electric discharge, icing etc. Violent surface phenomena like squalls, hailstorms, excessive rainfall etc associated with *Cb* clouds may cause damage to property and even loss of life. As the vertical extent of *Cb* clouds has a direct bearing on the intensity of the associated weather phenomena, it is highly essential to have a precise knowledge of the heights of tops of *Cb* clouds, particularly in respect of those places where they develop frequently. Here we have taken Calcutta airport and 300 km around as the area of our study.

A considerable volume of literature on the studies on *Cb* tops by Indian authors is already available. Study in this field was first made by Ramamurthy (1955) who analysed B.O.A.C. comet debriefing reports. The first study of echo tops by utilizing radar data was done in India by Kulshrestha (1962) for an area around Delhi. Since then similar studies have been made by many authors with the available radar data of various stations in the country. However, the works of Despande (1961, 1964), De (1963), Bhattacharya and De (1966), Badekar and Agarwal (1970), Mukherjee and Chaudhury (1970), Natarajan and Ramasastry (1970) and Mukherjee and Kumar (1976) may be mentioned in this connection.

The present work is similar to the work by Mukherjee and Chaudhury (1970) covering only *Cb* clouds with tops above 8 km in pre-monsoon months (March–May) for areas around Calcutta. In this work all convective cells whose tops reached a height of 6 km or more and all the four seasons have been considered.

2. Data used and methodology

Cloud observation data collected at Meteorological Office, Calcutta airport by an X-band BEL radar during the period of 10 years from 1977 to 1986 have been utilised for this study. This radar has a maximum range of 400 km and allowing for inherent limitations, it may be taken as reliable within a radius of 300 km. This represents an area coverage of 2,80,000 sq. km around Calcutta (Fig. 1). The heights shown by radar have not been corrected for errors due to finite width of the radar beam, keeping in view the observation by Cornford and Spavins (1973).

All convective cells (hereinafter called cases) whose tops reached at a height of 6 km or more were considered for the study. The station generally takes hourly observations at every (H—20) hours (GMT). It also takes half-hourly or special observations whenever required. However, all cases of the main observation taken during the period from (H—29) to (H+30) hours were considered as cases of H-hour observation. All the observed cases were counted and tabulated hourwise and monthwise against heights (km) of the tops. As the available

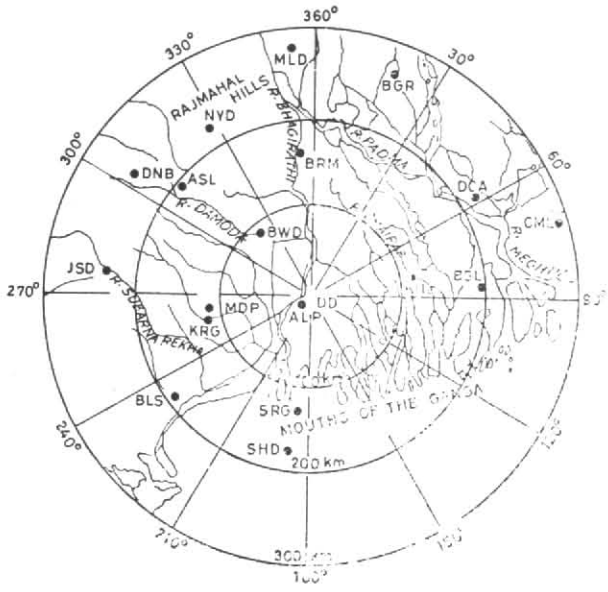

Fig. 1. Calcutta airport and 300 km around

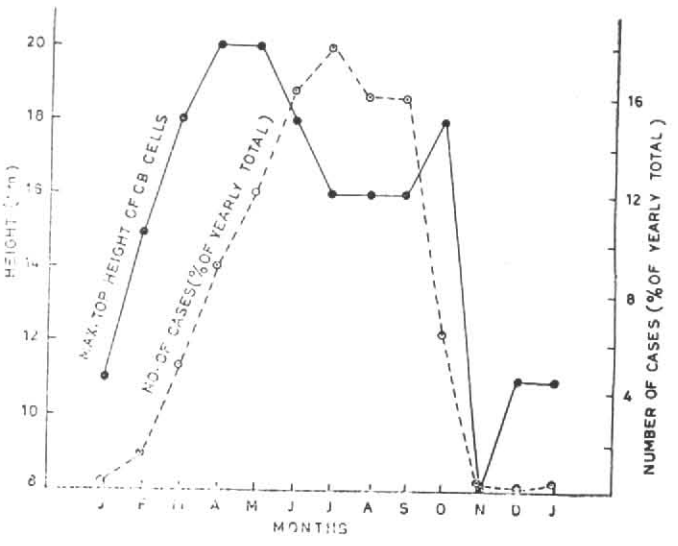

Fig. 2. Monthwise maximum top heights of *Cb* cells around Calcutta and the monthly total number of cases shown as percentage of the year

TABLE 1

Hourly distribution of total number of cases with top height at 6 km or more during 10 years, 1977-86

Hour (GMT)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (hourwise)
01	6	7	20	33	57	137	143	139	115	47	1	3	708
02	4	4	16	39	65	146	142	134	120	35	1	2	708
03	3	17	34	56	72	182	157	137	136	43	2	3	842
04	4	20	48	55	85	210	200	172	161	58	0	1	1014
05	3	17	45	62	89	231	229	211	218	77	2	0	1184
06	5	27	42	68	131	281	319	304	298	120	7	2	1604
07	4	19	48	66	159	300	395	355	347	151	7	1	1852
08	7	18	70	119	216	392	485	403	419	172	10	0	2311
09	8	24	103	226	349	417	501	426	458	198	8	1	2719
10	17	54	127	283	403	440	476	455	472	203	8	1	2939
11	15	38	175	346	404	432	526	423	443	173	8	2	2985
12	18	40	181	334	409	403	436	376	420	165	7	2	2791
13	7	42	169	304	367	346	403	322	341	121	3	3	2428
14	4	29	150	263	285	307	318	296	267	106	3	3	2031
15	3	37	122	238	235	253	277	237	250	97	3	2	1754
16	5	30	98	184	195	220	229	189	202	71	3	2	1428
17	1	28	85	138	142	176	170	178	161	58	2	3	1142
18	1	21	62	91	112	121	137	139	131	46	1	2	864
19	2	5	27	56	99	103	106	119	114	44	1	0	676
20	0	6	18	41	66	81	76	95	81	30	1	0	495
21	1	6	17	33	71	88	94	94	86	33	1	0	524
22	0	6	13	32	54	86	113	103	88	26	0	2	523
23	0	6	8	23	47	101	103	114	81	29	0	5	517
24	1	6	14	40	53	121	140	128	110	35	1	4	653
Total :													
Monthwise	119	507	1692	3130	4165	5574	6175	5549	5519	2138	80	44	34692
Seasonwise	626			8987			22817				2262		
% of annual total	1.8			25.9			65.8				6.5		

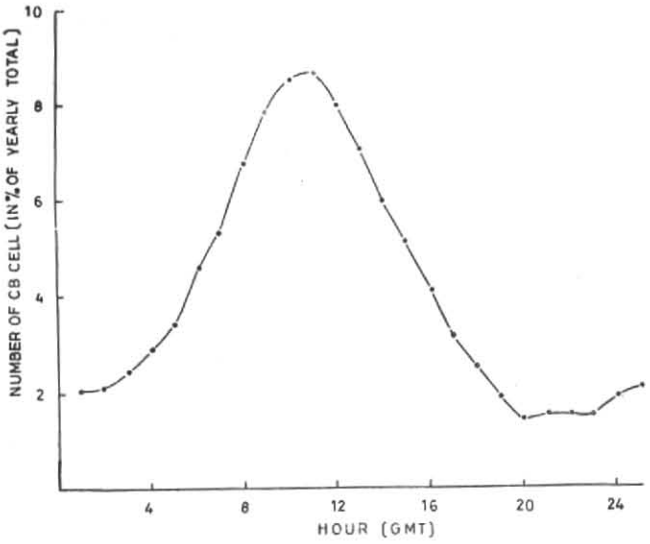

Fig. 3. Hourly variation of total number of *Cb* cells around Calcutta (shown as percentage of yearly one)

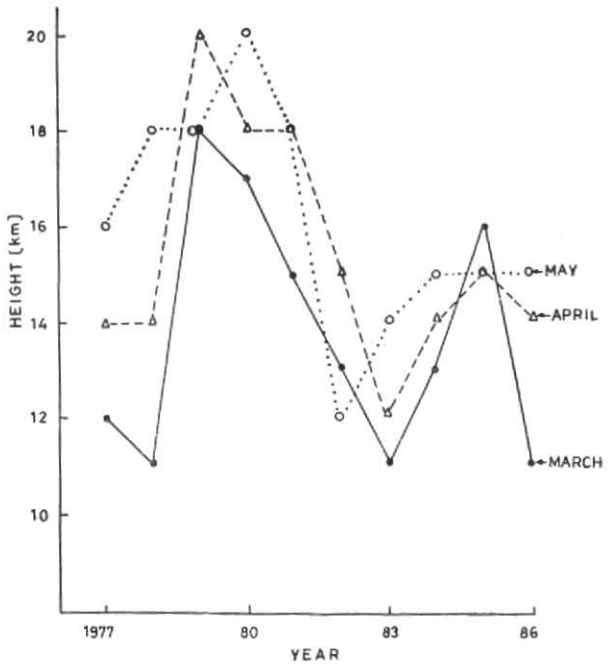

Fig. 4. Year-wise maximum top heights of *Cb* cells for March, April and May

record was not continuous on several occasions, the observed number of cases against a particular month was adjusted by multiplying with a factor depending on the total period of shortfall for the month. This was done for making comparative studies between the data of different months and different seasons.

The preferred areas of formation of very high *Cb* cells in different hours of the day of a particular month, their orientation and movements were examined by plotting the hourly maximum tops in polar diagrams and marking the areas of high tops.

The cases of penetration of tropopause were determined by considering the average heights of tropopause for the concerned months.

3. Analysis and discussions

3.1. *Total number of cases*

Table 1 shows the monthly and hourly distribution of the total number of cases for the period, 1977-86. It is seen that the number of cases is minimum in December and maximum in July. Actually, the number of cases is negligible in November, December and January. It is moderate in February and large to very large in other months. In Fig. 2 the monthly total number of cases have been shown as percentage of the yearly one. It is 0.3% in January and rise monotonically to 17.8% in July and then falls to about 0.1% in December. The rate of decrease in the number of cases from September to October and then to November is very remarkable. This indicates that October is the transitional month between highly moist SW monsoon season and dry post monsoon months of November and December.

From Table 1 and Fig. 2, it is clear that the four months of the SW monsoon season, *i.e.*, June to September contribute 65.8% of yearly total number of cases whereas the first two and the last two months of the year together contribute only 2.1% of the same.

Regarding diurnal variation of total number of annual cases we see that the minimum number occurs at 2000 GMT and the maximum number at 1100 GMT. For individual months the minimum number generally occurs between 2000 & 2300 GMT and maximum between 1000 and 1300 GMT excepting November (0800) and December (2300). In Fig. 3 the hourly total number of cases for every month have been shown as percentage of the yearly total. It is clear that the total number of cases increases after 0200 GMT and becomes maximum at 1100 GMT and then gradually falls to the minimum at 2000 GMT and then remains more or less the same upto 2300 GMT. It increases slightly between 2300 and 0100 GMT and then remains constant up to 0200 GMT.

It is interesting to know that about 75% of the cases occur during the 12-hr period from 0600 to 1700 GMT, about 47% during 6-hr from 0800 to 1300 and 25% in 3-hr from 1000-1200 GMT while 1100 GMT alone contribute about 9%. This characteristic is most prominent during the summer months and least during the SW monsoon months. The reason may be due to the fact that the temperature effect is most prominent in the afternoon hours while the effect of moisture is prominent at any time when it is available.

TABLE 2

Monthly and seasonal distribution of total number of *Cb* cells (around Calcutta) attaining a certain height or more during the period 1977-86

	Height (in km)														
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
January	119	74	45	19	15	4									
February	507	364	241	109	52	22	18	7	6	1					
Winter season	626	438	286	128	67	26	18	7	6	1					
March	1692	1392	1034	706	566	279	258	78	69	55	10	4	3		
April	3130	2517	2035	1376	1120	582	523	218	189	146	39	23	17	1	1
May	4165	3310	2617	1711	1415	718	663	313	256	206	40	34	30	5	3
H.W. season	8987	7219	5686	3793	3101	1579	1444	609	514	407	89	61	50	6	4
June	5574	3852	2655	1437	1062	375	320	114	96	64	8	5	2		
July	6175	3689	2233	1168	854	328	305	113	91	62	7				
August	5549	3431	2168	1032	778	257	233	61	41	19	1				
September	5519	3706	2469	1121	754	233	202	18	10	3	2				
Monsoon season	22817	14678	9525	4758	3448	1193	1060	306	238	148	18	5	2		
October	2138	1281	774	320	217	64	60	12	7	6	2	1	1		
November	80	27	9												
December	4	19	10	8	3	1									
Post monsoon season	2262	1327	793	328	220	65	60	12	7	6	2	1	1		
Annual total	34692	23662	16290	9007	6836	2863	2582	934	765	562	109	67	53	6	4

3.2. *Top heights of cases*

Table 2 shows the monthly distribution of total number of cases attaining a certain height or more. The monthwise maximum heights are plotted in Fig. 2. It is seen that the maximum top height of *Cb* clouds around Calcutta is 11 km in January, 15 km in February, 18 km in March and 20 km in April and May. This progressive increase in height is synchronous with the heating effect of the ground and incursion of moisture from the Bay of Bengal. After May the maximum top height reduces to 18 km in June, 16 km in July, August and September. It temporarily increases to 18 km in October, and then suddenly reduces to 8 km in November which is the lowest value of all monthly maximum top heights. The maximum top height for December is 11 km.

But it we consider the top heights of cases of individual years, the picture may be a different one. This will be evident from Fig. 3, wherein the maximum height attained by the echo tops for the months of March, April and May have been shown yearwise. In seven years, out of ten, the highest top height was minimum in March and maximum in May. In 1979 and 1982 it was maximum in April while in 1985 it was maximum in March.

3.2.1. *Seasonal distribution of top heights*

Winter season (*January and February*) — Only about 2% of the yearly total number of cases occur during this season. Out of the seasonal total during the winter only 11% developed to 10 km or more and 3% to 12 km or more while in 1 case it reached 15 km.

Hot weather season (*March-May*) — About 26% of the annual total number of cases occur during this season. Out of this seasonal total, nearly 35% developed to 10 km or more, 16% to 12 km, 5% to 15 km and about 1% reached or crossed the average height of tropopause (17 km). So we see that the percentage of tall *Cb* clouds is quite appreciable in this season.

Southwest monsoon season (*June-September*) — About 66% of the annual total number of cases occur during this season. Out of the seasonal total, about 15% develops to 10 km or more, nearly 5% to 12 km or more and 0.6% to 15 km or more. The number of cases developed in each of the monsoon months are nearly equal and the highest top heights attained in July, August and September are the same.

Post monsoon season (*October-December*) — A little more than 6% of the annual total number of cases develop during this season. Out of this seasonal total, nearly 95% of the cases develop in the month of October only. About 10% of the seasonal total develops to 10 km or more, 3% to 12 km or more while only 0.3% of the top heights reaches 15 km. Only a single case attained the height of 18 km in October (1240 GMT on 5 October 1978). No top height exceeded 8 km in November and 11 km in December.

It may be mentioned here that the number of cases developed in the months of March and October are nearly equal and the maximum top heights attained in these months are also equal (18 km). So, the transitional effects from winter to hot weather season and that from SW monsoon to post monsoon season are almost the same in respect of development of *Cb* clouds around Calcutta.

TABLE 3

Total number of days with daily maximum tops of *Cb* cells around Calcutta reaching the height of *x* (in km) or more during 1977-86

Month	Height *x* (in km)														
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Jan	16	13	7	3	3	2									
Feb	52	45	37	22	12	7	3	2	2	1					
Mar	134	122	111	83	71	56	48	22	18	15	6	4	3		
Apr	223	213	202	178	167	134	125	69	65	47	17	10	8	1	1
May	240	231	220	187	169	125	121	79	67	54	16	14	12	2	1
Jun	274	263	242	197	175	110	103	51	44	36	6	5	2		
Jul	292	277	217	146	123	70	61	31	24	18	2				
Aug	258	243	202	146	113	60	55	22	18	8	1				
Sep	260	247	203	154	112	71	59	10	6	3	2				
Oct	149	128	93	55	39	14	14	4	3	2	1	1	1		
Nov	20	13	4												
Dec	9	8	3	1	1	1									

3.2.2. *Hourly distribution of top heights*

It has been observed that cases may develop up to the highest top heights of 20 km during 1100-1300 GMT. Also the average maximum top height is found to be 15.2 km in May and 14.4 km at 1200 GMT if we consider all hours of the day and all months of the year respectively.

3.3. *Number of days with cases*

A day with *Cb* cells was counted against the highest (in km) top attained by the cells during that particular day. Such a maximum top height may be considered as 'daily maximum height'. The total number of days in each month during the period under study was counted and tabulated against the respective daily maximum height (Table 3). It is seen that the number of days with equal *Cb* tops (maximum) is almost same in April and May, but the number of cases with equal tops is much more in May than in April (Table 2). The number of days with cases is very few in winter and post monsoon seasons. Also the total number of days with *Cb* clouds is maximum in July but the number of days with daily maximum reaching 10 km or more is higher in June than any other month.

4. *Cases that reached tropopause height*

The monthwise and hourwise distribution of the number of cases when the top height reached or crossed the average height (17 km) of tropopause over Calcutta and neighbourhood have been shown in Table 4. It is seen that 34 number of cases occurred in May, 23 in April, 5 in June, 4 in March and only one in October during the years 1977-86. The average frequency per year is 7 out of which 6 occur in April and May.

TABLE 4

Monthwise and hourwise distributions of the number of *Cb* cells when they reached or crossed the average height of tropopause during 1977-86

Month	Hour (in GMT)								
	09	10	11	12	13	14	15	16	Total
Mar	1	1	0	1	0	0	1		4
Apr		2	4	7	8	1	1		23
May		3	9	9	8	5			34
Jun	1	1	1	1	0	0	0	1	5
Oct					1				1
Total	2	7	14	18	17	6	2	1	67

It may be mentioned here that although a higher number (87) of instances of tropopause crossing by *Cb* clouds has been found by Mukherjee and Chaudhury (1970) in May, and a similar number (22) in April they did not observe any tropopause crossing in March.

3.5. *Preferred places of formation of high Cb clouds*

In order to examine whether there is any preferred area for *Cb* cells to grow very high, day to day hourly maximum tops from 0800 to 1500 GMT for the months from March to October were plotted on polar diagrams and areas of high tops were marked by drawing contour lines. Though the area of formation of high *Cb* cells at a particular day or time depends upon the prevailing synoptic situation and other meteorological factors, the above analysis gave a general idea regarding the sites of formation of high *Cb* cells at a particular hour of the month. The result of the observation is given ahead.

March — At 0800 GMT *Cb* cells up to 15 km high are generally observed in an area lying betwen Khulna and Dhaka in Bangladesh. Cells of similar heights are also observed over Midnapur and to the west of it. With the progress of time, very high *Cb* cells (15-18 km) start to develop in the SW to NW directions beyond 180 km from Calcutta. At 1100 GMT, 14-16 km high *Cb* cells are also observed between Malda and Berhampur. The general movement of the cells appears to be in a ESE'ly direction as a result of which heavy concentration of high *Cb* cells occur at 1200 GMT between SW and NW directions and at a distance of 60 to 140 km from Calcutta. These cells move to at a distance of about 80 km to the southeast of Calcutta by 1500 GMT. At this hour, new cells of 12-15 km high, may form in Burdwan area. Very high cells (16-18 km) are also observed to develop northeast of Dhaka. High cells are generally not observed to develop over Rajmahal hills and over the sea.

April and May — The areas of formation and the general pattern of the movements of high *Cb* cells in these months are nearly similar to those in March with the exception that :

(*i*) The cells are more numerous and comparatively higher in April and May.

(*ii*) 14-16 km high cells develop over the area of Rajmahal hills and in an area over the sea lying within75 km from the coast.

June — At 0800 GMT *Cb* cells develop very high (14-16 km) in an area lying between Midnapur and Burdwan and also near Contai. With the progress of the day, very high cells (15-18 km) also start developing in the area lying between Asansol and Jamshedpur. 14-17 km high cells are found to develop over the confluence area of the *Meghna* and the *Padma* and also to the northeast of Khulna by 1100 GMT. The general movements of these cells appear to be in ESE'ly direction resulting in heavy banking of tall *Cb* cells within 200 km to the SW-NNW of Calcutta at 1200 GMT. At 1500 GMT *Cb* cells up to 15 km high are found in the areas lying between Contai and Sagar Islands, south to Khulna, north to Krishnagar and northeast to Berhampur.

July-September — During these months of SW monsoon season, high *Cb* cells are generally not seen to develop over Rajmahal hills area. Cells up to 16 km high generally develop in the area bounded by Contai, Jamshedpur, Asansol, Malda, Barisal and the coast lines of Bangladesh and West Bengal. No specific movements of the cells could be ascertained during these months.

October — The preferred areas of formation of 14-18 km high *Cb* cells during this month are (*i*) Asansol-Dhanbad area, (*ii*) Midnapur Kharagpur-Balasore area and (*iii*) South 24-Parganas and lower Khulna.

4. Conclusion

From the above study it may be concluded that—

(*i*) Maximum number of convective cells are formed around Calcutta airport during the month of July and the minimum in December. Similarly, 1100 GMT gets the maximum number and 2000 GMT the minimum.

(*ii*) Top heights of *Cb* clouds may reach up to a height of 20 km in April and May but do not exceed 8 km in November.

(*iii*) Although the total population of convective cells with top heights at 6 km or more developing in the pre-monsoon season is only 39% of that occurring in the SW monsoon season, the total number of cells with top heights at 11 km or more is 32% higher in the pre-monsoon season than that in the SW monsoon season.

(*iv*) The transitional effects during March (from dry winter to hot pre-monsoon months of April and May) and October (from wet SW monsoon to dry post monsoon months of November and December) are similar towards formation of *Cb* clouds around Calcutta.

(*v*) As in the months of April, May and June crossing of tropopause by *Cb* tops may also occur in March and October.

(*vi*) There are some particular areas where *Cb* clouds grow very high depending on the month and hour of the day. The general movement of such clouds has been observed to be in a ESE'ly direction during the months of March, April and May and also in June before the onset of SW monsoon over the area.

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