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Nucleus richness of cloud air and rainability of clouds*

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ABSTRACT. Considered theoretically, convective clouds formed in highly polluted air and, as such, in air over-rich in its condensation nuclei content, are less liable to precipitate than similar clouds forming in normally clean air. This aspect of relative raininess of clouds formed under differing nucleus state of air has been examined by comparative study of precipitation behaviour of thunder clouds during pre-monsoon months over Calcutta, grouped under three classes as discussed in the paper.

1. Introduction

In discussing informally, amongst themselves, about certain anomalous features of rainfall in relation to some specified meteorological situations, meteorologists sometimes speak of 'hard' and 'soft' zones, as they refer respectively to areas, (*a*) where, after several days of rainless and nearly cloudless weather, a well defined change in synoptic situation, favouring rainfall, occurs but, despite development of adequate clouds of right type, very little or no rain falls and (*b*) where, following active weather development and some rain on a day, precipitation activity continues on the same, or even on a more pronounced scale on the next one or two days, although noting certain improvement in the broad meteorological situation in some of these cases, not much rain was expected there again.

While no satisfactory explanation could be given to account for such anomalies in the precipitation behaviour of clouds in the two situations mentioned, on the basis only of the macro-physical, or meteorologial, state of the atmosphere, researches in recent years on cloud and rain physics, giving due consideration also to the associated micro-physical features of clouds in relation to rain formation in them, have led to some plausible and interesting conclusions in this regard. The finding which may be considered directly relevant to the features under examination is that over-abundance of nucleus population in cloud air tends to produce a negative effect on rain formation in clouds, more particularly in clouds of convective type.

Verification directly of the trend, as above, of rain activity of clouds under different micro-physical conditions, but in nearly the same or very similar meteorological situation, is not easy, because (*i*) necessary data relating to nuclei concentration are ordinarily not available, and also because (*ii*) it is not a simple matter to judge objectively the sameness or near identity of the synoptic situation in two instances. An attempt has accordingly been made to estimate the probabilities of rain occurrence and relative yield of rain from clouds in different nucleus states of air, as judged on the basis of certain indirect criteria.

2. Nucleus state of air and its influence on precipitation growth in clouds—Evidence in support of the hypothesis

A cloud consisting of uniform small droplets is essentially stable, and would not precipitate unless this unfavourable micro-physical state of the cloud could be modified suitably, by inducing formation in the cloud of a few droplets substantially larger than the average small ones. While this first essential condition of a certain width of the spectrum of droplet sizes for rain formation in a cloud was postulated by cloud physicists at the first phase on their enquiries into and researches on the subject, leading to the present attempted techniques of cloud modification by methods of cloud seeding, further studies in this field and actual measurements within clouds of droplet sizes and their concentration have since laid stress on yet another important condition of a suitable micro-structure of cloud, namely, that the median sizes of cloud droplets should be above a certain minimum limit. This is important because, to ensure quick enough rain drop growth during the rather limited life period of convective cloud, the collection efficiency of the relatively large cloud droplets, on collision with average small ones, should be reasonably high. According to theoretical determinations of the collection efficiency values for droplets of different sizes, it is now accepted generally that the minimum limit of the average size of droplets should be at least 7 microns radius. In this

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TABLE 1

Squall days of Class 'A'

(Thundersquall occurred at the station, after a gap of 7 days or more without a squall)

S. No.	Date	Nature of squall		Amount of rainfall
		Direction	Speed (kmph)	(mm)
1	5 Apr 1960	NNW	41	Nil
2	19 May 1960	NW	93	6·1
3	25 Mar 1961	NW	83	5·3
4	8 Apr 1961	NNE	63	Nil
5	28 Apr 1961	ENE	59	Nil
6	22 May 1961	NNE	52	Nil
7	12 Apr 1962	WSW	60	Nil
8	11 May 1962	NE	56	Nil
9	25 May 1962	W	84	Nil
10	11 Mar 1963	SW	50	17·2
11	18 Mar 1963	WSW	62	Nil
12	4 Apr 1963	ENE	75	2·2
13	21 May 1963	NNE	88	Nil
14	30 May 1963	WSW	63	27·5
15	19 Mar 1964	NNW	48	Nil
16	1 Apr 1964	NNW	72	Nil
17	15 Apr 1964	S	94	2·6
18	6 May 1964	S	59	4·8
19	21 May 1964	NW	87	21·5
		Average :	68	4·6
	(Total No. of days = 19)	No. of days with rain8 = (42%)		

connection, we note that the observed difference in the stability of continental, as against that of maritime clouds, appears to depend, to a large measure, on the difference in the median size of droplets in clouds over the two geographical regions, the size of droplets being appreciably larger and their number much smaller in maritime clouds. Experimental investigation, in the laboratory, of the effect of pollution on the initiation of rain in clouds, conducted by Gunn and Phillips (1957) has also demonstrated fairly convincingly the adverse effect of over-pollution of air on the rain process in clouds. Further, field studies by Twomey and Squires (1959) brought out clearly marked differences in the number and average size of cloud droplets in maritime cumulii, compared with continental cumulii, and the decidedly greater precipitability of the former than the latter.

3. Attempted qualitative estimate of the nucleus state of air in different situations — Criteria used for

Over areas inland, particularly during summer months, persistent dry weather and nearly cloudless sky, would lead to growing accumulations in air of impurities from terrestrial sources and, consequently, to increasing population of condensation nuclei in air. Carried up by vertical currents, which would get enhanced further because of the rising surface air temperature under conditions as above, the increase in nuclei content would progressively extend in a deeper layer of air. The result will be too many cloud droplets of very small sizes when, after a prolonged period of rainless and cloudless weather, rain giving clouds develop over the area on the first day.

In the absence of routine measurements of nuclei concentration in air from day-to-day, we have no ready means to judge the relative nucleus state of air on different days. We may, however, reasonably assume that air over a station would tend to get distinctly enriched in its nuclei content, following dry and virtually cloudless weather for a week or more. On the other hand, widespread cloud development and rain occurring in an area on a day would cause a good proportion of condensation nuclei present in air to be scavenged out, helping cloud air to become comparatively clean. This cleansing effect would perhaps be more marked if the weather on the day is in the nature of a thundersquall, the associated strong downdraft causing a good number of free nuclei suspended in air to be forced down to near the surface. That the nucleus state of air often tends to vary in the way as discussed above has been supported in a general way by data collected recently at Dum Dum on concentration of 'giant' nuclei (both non-hygroscopic and hygroscopic) present in air near surface at the station, under the programme of measurements started there by the Rain and Cloud Physics Research Centre, National Physical Laboratory, New Delhi, and later taken over by the Institute of Tropical Meteorology under the India Meteorological Department. For example, data collected showed that the average concentration of giant nuclei during a prolonged period of no thundersquall of rain at Dum Dum (one such period was from 27 March to 17 April 1967) was much higher (about 76/litre) than the observed concentration (abour 32/litre) on the four successive days of thundersquall or rain showers at the station, from 18 to 21 April 1967.

4. Analysis of data and results obtained

Considering, on the above lines, the relative nucleus state of air in different situations, and assuming that the meteorological situation is broadly the same or similar on days on which a thundersquall occurred at Calcutta (Alipur Observatory), the squall days at the station have been grouped under 3 classes, (A) days on which thundersquall occurred after a gap of 7 days or more without a squall—days on which the air may be considered to be extra-rich in its nuclei content, (B) days on which a thundersquall occurred after an interval of 2 to 6 days without a squall—days of medium nuclei concentration, and (C) days on which the squall at the station was preceded by one occurring on the previous day, or a few hours earlier on the same day—instances of low nuclei concentration in cloud air.

Tables 1, 2 and 3 give the details of the squall and associated rainfall on the three classes of days, categorised as above, on the basis of probable nuclei concentration in air, and associated raininess of the squall cloud in the three cases. An examination of data, as in the tables, brings out certain interesting features in regard to the ralative raininess of the squall clouds in the three situations under discussion. For example we note that, while less than half the number (42 per cent) of squall clouds on days belonging to class 'A' yielded measurable rain, there was rain on 71 per cent of squall days of class 'C', the percentage

TABLE 2

Squall days of Class 'B'

(Thundersquall occurred after a gap of 2 to 6 days without a squall)

Date	After a gap of (days)	Nature of squall		Amount of rainfall (mm)
		Direction	Speed (kmph)	
7 Mar 1960	5	NW	76	1·1
11 Mar 1960	4	NNW	70	2·4
24 May 1960	5	SSE	52	4·2
31 Mar 1961	6	ENE	58	Nil
30 Apr 1961	2	NW	88	15·5
6 May 1961	3	NE	57	Nil
10 May 1961	4	NW	51	5·5
25 May 1961	3	ESE	70	Nil
29 May 1961	4	N	100	5·5
15 Apr 1962	3	NW	58	Nil
17 Apr 1962	2	W	81	5·8
20 Apr 1962	3	NNE	67	19·5
25 Apr 1962	3	WSW	60	Nil
29 Apr 1962	4	NW	72	Nil
2 May 1962	3	SE	65	Nil
4 May 1962	2	NE	60	Nil
29 May 1962	3	SW	61	Nil
8 Apr 1963	4	SW	57	Nil
11 Apr 1963	2	WNW	69	2·1
14 Apr 1963	3	NE	76	Nil
19 Apr 1963	3	NNW	88	16·1
21 Apr 1963	2	WNW	61	8·2
24 Apr 1963	3	NE	45	Nil
26 Apr 1963	2	WSW	87	6·3
29 Apr 1963	3	NNW	67	20·0
3 May 1963	4	NE	47	28·3
6 May 1963	2	WSW	57	6·3
11 May 1963	5	NW	72	11·2
14 May 1963	3	N	84	2·7
20 Apr 1964	4	S	86	Nil
26 Apr 1964	3	N	55	8·5
9 May 1964	3	SSE	63	Nil
13 May 1964	2	NW	80	38·0
24 May 1964	3	NE	56	Nil
30 May 1964	6	NNW	70	6·0
		Average :	68	6·1

Total No. of days = 35

Number of days with rain = 20 (57 per cent)

TABLE 3

Squall days of Class 'C'

(Thundersquall occurred on the previous days or a few hours earlier on the same day)

S. No.	Date	Nature of squall		Rainfall
		Direction	Speed (kmph)	(mm)
1	1 Mar 1960	NW	63	4·2
2	2 Mar 1960	NNW	91	12·3
3	9 Apr 1961	WNW	60	3·4
4	1 May 1961	NNW	56	19·7
5	2 May 1961	NW	79	14·0
6	3 May 1961	NW	90	10·9
7	7 May 1961	NNW	56	0·3
8	11 May 1961	NNE	60	Nil
9	22 May 1961	NNW	48	36·3
10	21 Apr 1962	NNW	52	9·2
11	29 Apr 1962	ESE	68	Nil
12	2 May 1962	NNE	94	50·0
13	26 May 1962	NNW	85	2·5
14	29 May 1962	SW	58	1·8
15	9 Apr 1963	NE	84	Nil
16	15 Apr 1963	N	80	11·1
17	16 Apr 1963	NE	52	Nil
18	30 Apr 1963	NE	56	Nil
19	4 May 1963	N	51	Nil
20	20 Mar 1964	NW	69	Nil
21	16 Apr 1964	N	76	21·0
22	21 Apr 1964	W	67	3·2
23	22 Apr 1964	NNW	92	14·5
24	23 Apr 1964	NW	72	9·7
25	10 May 1964	NW	80	16·3
26	11 May 1964	SW	79	Nil
27	13 May 1964	SE	57	30·8
28	14 May 1964	NW	52	11·2
		Average :	69	10·1

Total No. of days = 28

Number of days with rain = 20 (71 per cent)

of raininess of squall cloud belonging to 'B' class days being intermediate between the two, 57 per cent. We also see that the average yield of rainfall occurring from the squall cloud on days belonging to the 3 categories, A, B and C, comes to 4·6, 6·1 and 10·1 mm per day respectively. In this connection, we further note that the average values of peak speed reached in squalls belonging to the 3 classes of days are respectively 68, 68 and 69 km/hr, showing that, on the average, the storm development was almost equally vigorous in the three cases and that, in this respect, the meteorological situations were comparable.

With a view to examining how the squall character and the associated rainfall in each individual case of squall occurrence on days belonging to class 'C' compare with those pertaining to the squall which preceded it, one more table (Table 4) has been added. Scrutiny of data in this table brings out certain further details which are clearly of interest. We see, for example, that in the 6 instances in which the squall on a C-class day followed a squall occurring on a day belonging to class A, the average rainfall associated with the former was much more than what accompanied the latter, even though the squall intensity on the

TABLE 4

Squall features and associated rainfall on days belonging to Class C, compared with those of squalls on the preceding day, or a few hours earlier on the same day

Date of occurrence of squall on class C days	Max. speed reached by squall on the day (km/hr)	Max. speed of squall which preceded (km/hr)	Rainfall on the day (mm)	Rainfall associated with squall which preceded it (mm)	Classification of the day to which the preceding squall belonged
1 Mar 1960	63	72	4·2	6·0	A
2 Mar 1960	91	73	12·3	4·2	C
9 Apr 1961	60	63	3·4	Nil	A
1 May 1961	56	88	19·7	15·5	B
2 May 1961	79	56	14·0	19·7	C
3 May 1961	90	79	10·9	14·0	C
7 May 1961	56	57	0·3	Nil	B
11 May 1961	60	57	Nil	5·5	B
22 May 1961	48	52	36·3	Nil	A
21 Apr 1962	52	67	9·2	19·5	B
29 Apr 1962	63	72	Nil	Nil	B
2 May 1962	94	62	50·0	Nil	B
26 May 1962	85	84	2·6	Nil	A
29 May 1962	58	61	1·8	Nil	B
9 Apr 1963	84	57	Nil	Nil	B
15 Apr 1963	80	76	11·1	Nil	B
16 Apr 1963	52	80	Nil	11·1	C
30 Apr 1963	56	67	Nil	20·0	B
4 May 1963	51	64	Nil	28·3	B
20 Mar 1964	69	48	Nil	Nil	A
16 Apr 1964	76	94	21·0	2·5	A
21 Apr 1964	67	86	3·2	Nil	B
22 Apr 1964	92	67	14·5	3·2	C
23 Apr 1964	72	92	9·7	14·5	C
10 May 1964	80	63	16·3	Nil	B
11 May 1964	79	8[illegible]	Nil	16·3	C
13 May 1964	57	80	30·8	38·0	B
14 May 1964	52	57	11·2	30·8	C

Total No. squall days of Class C = 28
(A = 6, B = 14, C = 8 cases)

	Squalls in different class days			
		Class days	Av. peak speed (kmph)	Av. rainfall (mm)
(*i*)	(*a*)	C	67	11·2
	(*b*)	A	69	11·2
(*ii*)	(*a*)	C	66	10·2
	(*b*)	B	69	9·1
(*iii*)	(*a*)	C	76	9·1
	(*b*)	C (preceding)	73	14·2

average was less on the C-class days. It may be noted that these are occasions on which contrasts in regard to condensation nuclei content of air are likely to be the maximum. On the other hand we see that on days when the squall on a C-class day was preceded by a squall belonging to a day of the same class—there are 8 such cases—only in 2 instances the yield of rainfall associated with the squall which followed was greater than that yielded by the squall cloud on the preceding day. Actually, in these cases, the average rainfall associated with the 8 pairs of squall were 9·1 and 14·2 mm respectively. This is understandable, because a C-type squall following one belonging to the same class means that the squall on the day is an instance of a squall occurring on the 3rd or 4th successive day and, naturally, the precipitation activity has to decrease at a certain stage. Comparing the features of squalls on C-class days following those belonging to B-class, we find that, out of 14 instances of squalls occurring in such a sequence, rainfall associated with the former was greater than that accompanying the latter in 7 cases, and less in 5 instances, rainfall in the 2 remaining cases being *nil* in both. Considering the averages based on all the 14 cases of such pairs of squalls, the rainfall was 10·2 and 9·1 mm per day belonging to C and B classes respectively.

Comparing, similarly, the rainfall features at Dum Dum on squall days belonging to the three classes A, B and C (the number of such days were 21, 30 and 18 respectively), we see that the percentages of cases in which the squall cloud gave measurable rain were 52, 63 and 90, the average amounts of rain yield per day being 2·8, 6·5 and 14·1 mm respectively.

5. Conclusion

The results of the study based on data relating to squall occurrences in Calcutta area and associated rainfall during a period of 5 pre-monsoon seasons provide a reasonably good support to the view currently held that nucleus richness of air is a factor which affects adversely the precipitation behaviour of clouds, more particularly clouds of convective type.

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