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'Warm' and 'Cold' Cloud Rain in Calcutta during southwest monsoon season

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ABSTRACT. On the basis of findings, by radar, of heights of tops of rain-giving clouds over Calcutta area during southwest monsoon season, and noting the associated precipitation features in different instances, estimates have been made of the relative contributions to the season's rainfall by 'Warm' and 'Cold' clouds. The study has shown that, although the percentage contribution by warm rain to the season's total rainfall in Calcutta area is higher than that over the more continental region around Delhi, the net yield of rainfall from warm clouds in this area also is quite small.

1. Introduction

That rain often falls from warm clouds, and that such rain occurs more frequently over maritime regions in the tropics, is now a well verified fact of observation. Little factual data are, however, available till now as regards how much rain or what percentage of the season's rainfall over a given locality occurs from warm clouds. Alpert (1955) drew attention to this lack of quantitative information relative to different areas in the tropics and stressed the desirability of proper rain-cloud census being carried out, to provide required dependable information in this regard. A plausible estimate of the relative yield of rain from clouds of three types — cold stratiform, cold convective and warm convective clouds was attempted, with reference to cloud conditions in and around Delhi, on the basis of observations made by radar of rain cells classified according to their vertical structures, their average areal extents, and associated mean rates of precipitation (Ramana Murty *et al.* 1960). The findings showed that, on the average, only about 1·8 per cent of rainfall during southwest monsoon season occurs from warm clouds, although the frequency of occurrence of rain from warm clouds in the area around Delhi was as high as 41 per cent. This very small contribution by warm rain at a given station was considered to be due primarily to the very limited areal extent of a warm convective cloud and its restricted life period. Indeed, in course of the study undertaken at Delhi (Srivastava and Kapoor 1961) on the size distributions of raindrops in precipitation occurring from the three types of clouds, there was not a single occasion during one whole monsoon season when an overhead warm convective cloud was shedding rain over the observation site during the period of watch from 1000 to 1700 IST.

With a view to finding out if the warm rain contribution over the maritime region around Calcutta is substantially greater than that over Delhi region, the study was undertaken, utilising all available information about cloud features, on the basis of hourly observations made at Dum Dum by the 3·2-cm radar, NMD 451. Data for three monsoon seasons, 1962 to 1964, have been studied in this connection.

2. Criterion used for classification of raining clouds

The categorisation of clouds under the three types have been made on the simple and straightforward basis, as below.

1. The raining cloud has been treated as warm if the height of top of the precipitation cell, as recorded by the radar, is 6·0 km or less. In cases when no height determination of the particular rain cell over or near station was made by the radar, the height has been taken as less than 6·0 km, and the cloud treated as warm. Further, all warm rain situations have been considered as rain falling from a convective type cloud, as both theoretically and also from observations, occurrence of significant rain from a warm stratiform cloud is rather a rare phenomenon.

2. Rain cells covering a limited area at a time, and reaching height 7·0 km and more and giving showers lasting for a relatively short period, usually less than half an hour, have been treated as associated with cold convective type clouds.

3. Occasions of rainfall continuing for a fairly long period, often for one hour and more, and associated with precipitation field covering quite a wide area, with the recorded heights of tops of rain cells 7·0 km or more, have been taken as occurring from cold stratiform clouds. In most such cases, rain was found to be falling simultaneously

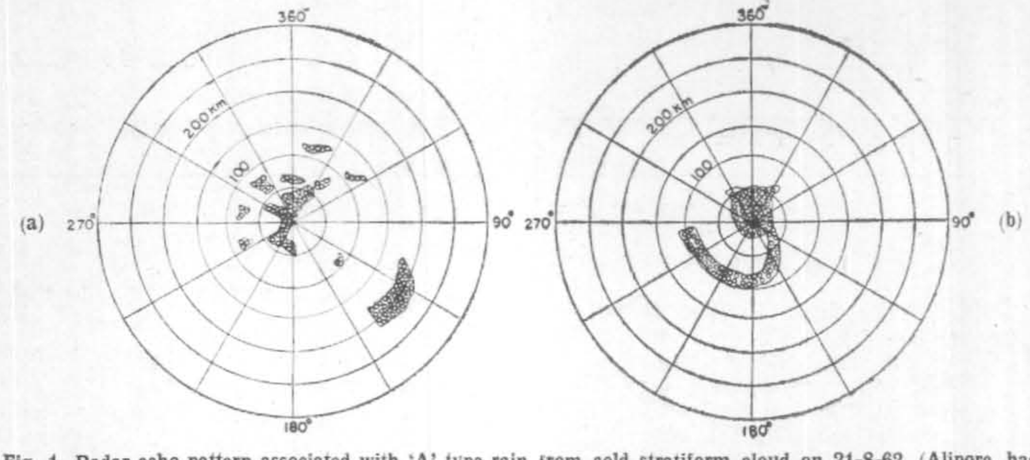

Fig. 1. Radar echo pattern associated with 'A' type rain from cold stratiform cloud on 21-8-62 (Alipore had 18·5 mm rain from 1528 to 1840 hrs and Dum Dum 21·7 mm from 1607 to 1805 hrs)

(a) Polar diagram showing distribution of precipitation cells based on radar observations between 1530 and 1545 IST. Observed height of precipitation cell at 360°/45 km was 13·2 km and that at 290°/0-45 km was 12·0 km

(b) Distribution of precipitation cells as observed between 1730 and 1745 hrs

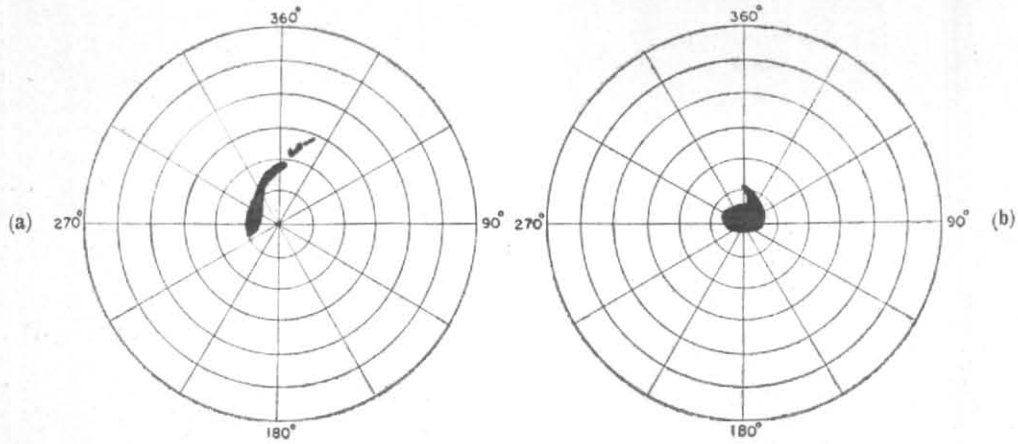

Fig. 2. Radar echo pattern associated with 'B' type rain from cold convective cloud on 18-8-62 (Dum Dum had 8·1 mm rain between 1730 and 1800 hrs. No rain at Alipore)

(a) Polar diagram based on radar observations between 1700 and 1725 hrs. Height of top of precipitation cell at 280°/50 km was 11·7 km

(b) Distribution of precipitation cells observed by radar between 1800 and 1815 hrs

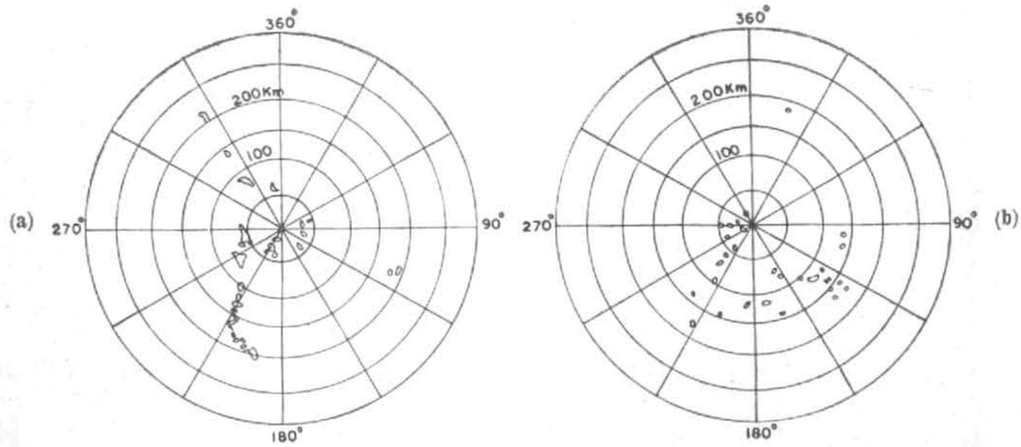

Fig. 3. Radar echo patterns associated with 'C' type rain from warm convective cloud on 3-8-62 and 16-8-62

(a) Precipitation cell distribution, as observed during 0630-0645 hrs on 3-8-62. Height of top of tallest precipitation cell at 230°/20 km was 6·0 km (Alipore had rain 0·2 mm between 0637 and 0644 hrs)

(b) Precipitation cell distribution as observed during 0300-0315 hrs on 16-8-62. Height of top of tallest precipitation cell at 270°/40 km was 5·3 km (Dum Dum had rain 0·5 mm between 0223-0235 hrs) both over Dum Dum and Alipore during at least a major part of the precipitation period.

For purposes of the above classification, rain situations at the two observatories, Dum Dum and Alipore, have been linked with radar determination of heights of tops of precipitation cells lying within 30 km from the respective station. The distance between the two observatories is about 18 km.

3. Analysis of rain spells at Alipore and Dum Dum observatories and their association with the three broad types of clouds

Self-recording raingauge charts of Dum Dum and Alipore observatories for July, August and September during the three years, 1962 to 1964, have been analysed, and each spell of rainfall at either of the two observatories classified under three groups A, B and C depending upon their being associated with cold stratiform, cold cumuliform and warm convective clouds respectively. Rain occurrences, with short breaks for a period of 15 minutes or less, have been treated as coming under one and the same rain spell, provided the associated cloud also came under the same broad type.

Particulars relating to raining clouds, as seen on the radar, have been compiled on the basis of polar diagrams prepared as a routine by the Radar Unit of Dum Dum Meteorological Office, giving as faithful a representation as possible of rain cell distributions as depicted on the radarscope, during each observation made at hourly intervals. Besides PPI picture, the diagram also gives details relating to the more prominent amongst rain cells seen — their heights of tops, azimuth, and distance from the radar. Polar diagrams, representing radar echo patterns associated with rain from clouds belonging to the three classes, A, B and C, are shown in Figs. 1, 2 and 3. With the Dum Dum radar maintaining watch round the clock, it has been possible to link most rain situations with the particular cloud system from which rain was falling, except in a few instances when, due to power failure or other similar difficulties, scanning by radar could not be made. Rain occurrences on such occasions have been left out of account for purposes of this study.

4. Results of analysis and brief discussions thereon

Tables 1 (a), (b) and (c) give particulars about total amount of rainfall, total duration of precipitation, and total number of rain spells, coming under the three categories, A, B and C, separately for the two observations at Dum Dum and Alipore, during each of the three monsoon months, July, August and September. Certain features relating to warm rain spells, *viz.*, their frequency distribution during three 8-hour periods, (*i*) 00 to 08, (*ii*) 08 to 16 and (*iii*) 16 to 24 IST have also been added. The tables also include certain derived data, such as mean rate of rainfall, and average duration of a rain spell under each of the three types of rainfall. Similar data relating to the three monsoon months together are shown under Table 1 (d).

An examination of data relating to the 3 individual months as in Tables 1(a), (b) and (c) shows that the percentage contribution by warm rain to the month's total is highest in August (11 per cent at Dum Dum and 8 per cent at Alipore), and is lowest in September (1·3 per cent at Dum Dum and 3 per cent at Alipore). We further note that in the region under study the average rate of rainfall from warm clouds is quite appreciable, ranging from 1·1 mm/hr (in September at Dum Dum) to 3·7 mm/hr (in August at Dum Dum and in July at Alipore). Also, the average duration of a spell of rainfall occurring from the warm clouds is nearly the same as that of rain from cold convective clouds, although the frequency of occurrence of warm rain is much less.

From data as in Table 1(d), giving comparative features of rain occurrences from clouds belonging to the three categories, during the three monsoon months taken together, we find that these are essentially the same at the two observatories, Dum Dum and Alipore, except that the number of warm rain spells are a little more at Alipore than at Dum Dum station situated further inland about 18 km to the northeast of Alipore. This slightly greater raininess of warm clouds over Alipore may perhaps be explained as being due partly to the more favourable micro-structure of maritime cumulii over Alipore, which is closer to the sea coast than over Dum Dum (Twomey and Squires 1959).

Combining data, as in Table 1 (d) for the two observatories at Dum Dum and Alipore, we get figures representing mean position for the Calcutta area in regard to precipitation features of the three types of clouds considered. These are shown in Table 2.

It is seen that the highest contribution (50 per cent) to rainfall in the Calcutta area is by cold stratiform clouds and that by warm convective clouds is 5 per cent only. The remaining 45 per cent is the contribution by cold convective clouds (class B). Comparing figures giving duration of rainfall under the three different classes, we see that more than half (55 per cent) of the total rainfall period is associated with class A, and that rain from warm convective clouds (class C) covers

TABLE 1

Features of rainfall coming under the three classes A, B and C

	Type of Cloud		
	A Class	B Class	C Class
	(*a*) July 1962 to 1964		
	DUM DUM		
(*i*) Month's total rainfall (percentage of total rainfall)	472·66 mm (55 per cent)	354·7 mm (40 per cent)	34·3 mm (4 per cent)
(*ii*) Duration of rainfall (percentage of total duration)	3606 min. (55 per cent)	2144 min. (33 per cent)	780 min. (12 per cent)
(*iii*) Rate of rainfall	7·9 mm/hr	9·9 mm/hr	2·6 mm/hr
(*iv*) No. of rain spells (average duration per rain spell)	19 (189 min.)	82 (26 min.)	39 (20 min.)
(*v*) Distribution of rain spells of Class C under three 8-hr periods (*i*) 00 to 08, (*ii*) 08 to 16 and (*iii*) 16 to 24 hrs			(*i*) 22 (*ii*) 11 (*iii*) 6
	ALIPORE		
(*i*) Month's total rainfall (percentage)	566·3 mm (50 per cent)	537·0 mm (46 per cent)	46·7 mm (4 per cent)
(*ii*) Duration of rainfall (percentage)	4831 min. (60 per cent)	2449 min. (30 per cent)	758 min. (10 per cent)
(*iii*) Rate of rainfall	7·0 mm/hr	13·1 mm/hr	3·7 mm/hr
(*iv*) No. of rain spells (average duration)	20 (241 min.)	75 (33 min.)	42 (18 min.)
(*v*) Distribution of rain spells of Class C under three 8-hr periods (*i*) 00 to to 08, (*ii*) 08 to 16 (*iii*) and 16 to 24 hrs			(*i*) 17 (*ii*) 16 (*iii*) 9
	(*b*) August 1962 to 1964		
	DUM DUM		
(*i*) Month's total rainfall (percentage)	123·5 mm (25 per cent)	309·3 mm (63 per cent)	55·7 mm (11 per cent)
(*ii*) Duration of rainfall (percentage)	1474 min. (36 per cent)	1709 min. (40 per cent)	9·6 min. (22 per cent)
(*iii*) Rate of rainfall	5·1 mm/hr	10·8 mm/hr	3·7 mm/hr
(*iv*) No. of rain spells (average duration)	9 (164 min.)	96 (18 min.)	37 (24 min.)
(*v*) Distribution of rain spells of Class C under three 8-hr periods (*i*) 00 to 08, (*ii*) 08 to 16 and (*iii*) 16 to 24 hrs			(*i*) 17 (*ii*) 12 (*iii*) 8
	ALIPORE		
(*i*) Month's total rainfall (percentage)	211·5 mm (34 per cent)	364·5 mm (58 per cent)	52·8 mm (8 per cent)
(*ii*) Duration of rainfall (percentage)	1934 min. (40 per cent)	2033 min. (46 per cent)	1001 min. (22 per cent)
(*iii*) Rate of rainfall	6·6 mm/hr	10·8 mm/hr	3·2 mm/hr
(*iv*) No. of rain spells (average duration)	10 (193 min.)	102 (20 min.)	55 (18 min.)
(*v*) Distribution of rain spells of Class C under three 8 hours periods (*i*) 00 to 08 (*ii*) 08 to 16 and (*iii*) 16 to 24 hrs			(*i*) 26 (*ii*) 15 (*iii*) 14

TABLE 1 *(contd)*

	Type of Cloud		
	A Class	B Class	C Class
	(c) September 1962 to 1964		
	DUM DUM		
(i) Month's total rainfall (percentage)	522·5 mm (64 per cent)	280·3 mm (34 per cent)	10·3 mm (1·3 per cent)
(ii) Duration of rainfall (percentage)	4051 min. (62 per cent)	1936 min. (30 per cent)	344 min. (8 per cent)
(iii) Rate of rainfall	7·7 mm/hr	8·7 mm/hr	1·1 mm/hr
(iv) Number of rain spells (average duration)	17 (238 min.)	68 (29 min.)	9 (38 min.)
(v) Distribution of rain spells of Class C under three 8-hour periods *(i)* 00 to 08, *(ii)* 08 to 16 and *(iii)* 16 to 24 hrs			*(i)* 3 *(ii)* 2 *(iii)* 4
	ALIPORE		
(i) Month's total rainfall (percentage)	467·6 mm (62 per cent)	270·9 mm (35 per cent)	18·9 mm (3·0 per cent)
(ii) Duration of rainfall (percentage)	3686 min. (63 per cent)	1620 min. (28 per cent)	494 min. (8·5 per cent)
(iii) Rate of rainfall	7·6 mm/hr	10·0 mm/hr	2·3 mm/hr
(iv) No. of rain spells (average duration)	19 (194 min.)	75 (21 min.)	16 (31 min.)
(v) Distribution of rain spells of Class C under three 8 hour periods *(i)* 00 to 08 *(ii)* 08 to 16 and *(iii)* 16 to 24 hrs			*(i)* 6 *(ii)* 4 *(iii)* 6
	(d) July to September 1962 to 1964		
	DUM DUM		
(i) Month's total rainfall (percentage)	1118·6 mm (52 per cent)	944·3 mm (43 per cent)	100·3 mm (4·6 per cent)
(ii) Duration of rainfall (percentage)	9131 min. (54 per cent)	5789 min. (36 per cent)	2030 min. (12 per cent)
(iii) Rate of rainfall	7·3 mm/hr	9·8 mm/hr	2·9 mm/hr
(iv) Number of rain spells (average duration)	45 (203 min.)	246 (23 min.)	85 (24 min.)
(v) Distribution of rain spells of Class C under three 8-hour perods *(i)* 00 to 08, *(ii)* 08 to 16 and *(iii)* 16 to 24 hrs			*(i)* 42 *(ii)* 25 *(iii)* 18
	ALIPORE		
(i) Month's total rainfall (percentage)	1245·4 mm (49 per cent)	1172·4 mm (46 per cent)	118·4 mm (4·5 per cent)
(ii) Duration of rainfall (percentage)	10451 min. (56 per cent)	6092 min. (32 per cent)	2253 min. (12 per cent)
(iii) Rate of rainfall	7·1 mm/hr	11·5 mm/hr	3·1 mm/hr
(iv) No. of rain spells (average duration)	49 (213 min.)	252 (24 min.)	113 (20 min.)
(v) Distribution of rain spells of Class C under three 8-hour periods *(i)* 00 to 08 *(ii)* 08 to 16 and *(iii)* 16 to 24 hrs			*(i)* 49 *(ii)* 35 *(iii)* 29

TABLE 2

Features of rainfall coming under the three classes A, B and C
July to September 1962 to 1964 (Dum Dum and Alipore taken together)

	Type of clouds		
	A	B	C
(*i*) Month's total rainfall (percentage)	2364·00 mm (50 per cent)	2116·7 mm (45 per cent)	218·7 mm (5 per cent)
(*ii*) Duration of rainfall (percentage)	19582 min. (55 per cent)	11881 min. (33 per cent)	4183 min. (12 per cent)
(*iii*) Rate of rainfall	7·2 mm/hr	10·7 mm/hr	3·0 mm/hr
(*iv*) Number of rain spells (average duration)	94 (208 min.)	498 (24 min.)	198 (22 min.)
(*v*) Distribution of rain spells of class C under three 8-hr periods (*i*) 00 to 08, (*ii*) 08 to 16 and (*iii*) 16 to 24			(*i*) 91 (46 per cent) (*ii*) 60 (30 per cent) (*iii*) 47 (24 per cent)

TABLE 3

	Cloud type		
	A (per cent)	B (per cent)	C (per cent)
Calcutta	50	45	5
Delhi	52·6	45·6	1·8

some 12 per cent of the season's total rain period in the area. From figures, giving total of rainfall and total precipitation period, we get the average rates of rainfall from the three types of cloud under discussion, these being 7·2, 10·7 and 3·0 mm/hr for rainfall belonging to classes A, B and C respectively.

Considering figures giving distribution of warm rain spells over the area during the three 8-hour periods of the day, we see that the frequency of occurrences of such rain in the area is highest during early morning hours (00 to 08 hours). A plausible explanation for this may be that, for a warm convective cloud developing during these hours to about the same depth as during other hours of the day, the speed of updraft within cloud may be somewhat lower than that during the other two 8-hour periods, and also less turbulent mixing—both the factors favouring potential raindrops growing by coalescence mechanism, to start their descent through the cloud and grow further, before these reach the cloud top and suffer evaporation loss there. Another alternative explanation, which may hold good in certain instances is that radiation cooling of the top surface of the warm cloud during night, may cause some increase in lapse rate in the top layer of the cloud and help some further growth in height of the cloud resulting in the greater probability of rain from the cloud in question.

5. Findings relative to Calcutta and Delhi areas compared

Estimated percentage contributions to total monsoon rainfall in Calcutta and Delhi areas, by clouds of the three broad types A, B and C are given in Table 3.

It is seen that while percentage contributions to the season's rainfall by cold stratiform (type A) and cold convective (type B) clouds are essentially the same for both Calcutta and Delhi areas, there is a significant difference in the percentage contribution by warm convective (type C) clouds—that over Calcutta being nearly three times the estimated contribution in the area around Delhi. Considering the basic difference in the geographical positions of the two areas, and also in their locations with reference to the normally active field of southwest monsoon, the observed difference in warm rain contributions in the two regions is what one would also expect on broad theoretical considerations. In this connection, we may note that, as stated earlier, in cases when no height determination of a raining cloud over Calcutta area was made by the radar, the cloud in question has been treated as warm, and this may have led to some over-estimate of the contribution to the season's rainfall by warm clouds (type C). Further, some of the rain situations, seemingly associated with warm cloud, may really have been in continuation of rain from a cold cloud at the phase of its gradual dissolution, when the height of its top would be decreasing and that of its base increasing progressively. It is, however, believed that even allowing for such uncertainties in a few cases, the actual contribution by warm rain in Calcutta area may not differ materially from that estimated, namely, about 5 per cent of the season's total.

Other important differences in the comparative feature of rainfall in the two areas are — (*i*) decidedly higher rates of rainfall from clouds of types A and C in the Calcutta area (7·2 mm/hr and 3·0 mm/hr respectively) than those estimated for the region around Delhi (2·0 mm/hr and 1·3 mm/hr respectively) and (*ii*) appreciably longer duration, on the average, of a warm rain spell in the Calcutta area. The differences in regard to the character of warm rainfall in the two areas may perhaps be explained as being due essentially to Calcutta being in the maritime zone, where rain formation in a warm cumulus cloud would more readily be helped at an earlier stage of its development, because of more favourable microstructure of the cloud than in a similar cloud over the continental region around Delhi. As regards much higher rate of rainfall from cold stratiform clouds over Calcutta, we know from reports by aircraft pilots (this has also been confirmed by radar observations) that in many of the rain situations coming under class A over Calcutta and areas situated well within normally active monsoon field, the associated cloud system, although as observed from the ground appears as a long stretch of deep layer type cloud, is often punctuated at places by massive build-up of tall *Cb* cloud. It is this that accounts for the general character of rain from A-type clouds over Calcutta area being often more like that of rain occurring from clouds of type B, *i.e.*, cold convective clouds.

6. Possibilities of augmentation of monsoon rainfall in Calcutta area by methods of warm cloud seeding

For proper objective assessment of the potentialities of warm cloud seeding in Calcutta area it would be necessary, besides utilizing some of the findings of the present study to collect dependable statistics regarding percentage of warm convective clouds building upto heights of 4 to 6 km, and giving rain naturally, and of those dissolving before the stage of rain formation is reached. The collection of the desired data would necessitate organising systematic census of clouds of the type mentioned and their associated precipitation behaviour by observations made from aircraft flying over the area in question for a certain stated period daily during one whole monsoon season. In the absence of such statistics, we can only attempt a rough estimate of what the position might be, based on certain plausible assumptions. Taking that some 50 per cent of warm cumulii of moderate depth over Calcutta and neighbourhood fail to attain rain stage, and assuming that their failure to precipitate is due mainly to deficiency of giant hygroscopic nuclei in cloud air, and consequent unfavourable microstructure of clouds, the probable net increase in monsoon rainfall in the area, by carrying out positive seeding operations in all such clouds, would be no more than 5 per cent of the season's total.

Considering that, as discussed in preceding sections, the percentage contribution by warm rain over Calcutta area is fairly high, particularly during July and August, the estimated 5 per cent increase in the season's rainfall by warm cloud seeding is perhaps the maximum that can be expected during monsoon season as a whole. The potentialities of such seeding operations during the concluding month of the monsoon season, *i.e.*, September may, however, be somewhat greater. Also, from the observed trend of a little less rainability of precipitation efficiency of warm clouds over Dum Dum, compared with that of clouds over Alipore, we may perhaps infer that warm cloud seeding may be more effective in areas further inland, such as, over areas around Asansol or Bankura in West Bengal, or Hazaribagh and Ranchi in Bihar. In this connection, it would be useful to arrange systematic measurements during one monsoon season, of concentration of giant hygroscopic nuclii at one of the inland stations, like Jamshedpur, Ranchi or Asansol, and compare the data collected with those found from such measurements at Dum Dum, by the Rain and

Cloud Physics Division of the Institute of Tropical Meteorology in the India Meteorological Department.

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