551.510.52 (541.2)

Some experiments on the determination of the structure and refractive index of the lower troposphere (lowest 200 ft) over Dum Dum Airport, Calcutta

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(*Received 28 November 1957*)

ABSTRACT . The results of low level (lowest 200 ft) radiosonde sounding made on certain selected dates and at certain selected hours during the winter season of 1956-57 and pre-monsoon season of 1957 over Dum Dum airport are discussed. The results indicated the formation of ducts at certain hours. The variations of the meteorological data with the progress of night are shown in a tabular form.

The radarscope observations at the corresponding hours are also discussed. On two occasions in March and April 1957, the duct heights were abnormally high and prevailed for the whole night persisting till or even after sunrise. It is shown that these ducts extended horizontally in all directions to about 60 miles. Some radarscope observations during February—March 1956 are also discussed. On two occasions during February 1956 elevated ducts were noticed. These prevailed for the whole night. The attenuation produced by the appearance of thick fog over the station and its masking effect on the ground clutters are also discussed.

1. Introduction

In a recent communication, De *et al.* (1957) have reported the results of their study on the conditions for super-refraction at Dum Dum airport with a 3-cm radar. They tried to correlate the incidence of the condition of super-refraction on the one hand with the formation of fog/mist on the other. But, as the meteorological data for lower troposphere close to the ground were not available, no firm conclusion could be arrived at. The results of experiments and observations as reported in the present communication are intended to fill this gap to a certain extent. The experimental data are combined with the usual radiosonde data to obtain an unbroken profile of the *M*-value, which would reveal the presence of *M*-inversions. These inversions could be correlated with the occurrence of super-refracted echoes as observed on the radarscope. The observations on the lower troposphere could be extended only up to 200 ft. Only on one occasion it could be managed up to 650 ft with difficulty, while the normal radiosonde observations start from about 500 ft. Nevertheless, it was possible to derive some useful conclusions.

2. Description of observations

(*a*) *Radiosonde observations*—The lower level data were obtained manually by holding the radiosonde instrument at different levels above the ground. For this purpose the instrument was tied to a balloon which was allowed to rise by steps of 20 ft and held at the step heights for about 2-3 minutes till the meteorological elements of the radiosonde instrument assumed constant values. The transmitted data were then recorded by the usual recording equipment on the ground. Because of the difficulty of controlling manually the heights of the balloon at very high altitudes, it could not be raised to the desired level of about 1000 ft. The observations were generally limited to 200 ft. The results of the trial experiments on 1, 6, 12 and 16 November 1956 are shown in Table 1. On 16 November, the balloon, with some difficulty, was raised to 650 ft above the ground level in order that the results of this sounding could be compared with those of the routine radiosonde sounding which was to take place half an hour later. Unfortunately, the first height for which the temperature and humidity data were available from the record of the latter

TABLE 1

Low level sounding data

Height (feet)	1 Nov 1956 1900 IST		6 Nov 1956 1915 IST		12 Nov 1956 2000 IST		16 Nov 1956 1930 IST	
	T (°K)	T_d (°K)	T (°K)	T_d (°K)	T (°K)	T_d (°K)	T (°K)	T_d (°K)
0	299·7	298·7	295·2	293·6	295·6	293·8	296·6	293·1
20	299·8	297·2	294·9	293·6	295·2	292·5	296·6	293·9
40	299·8	297·2	294·9	291·2	295·7	292·0	296·5	294·1
60	299·7	297·5	296·1	290·9	295·9	293·2	297·1	293·9
80	299·8	297·2	296·5	290·5	295·7	292·0	297·5	293·9
100	299·7	297·5	296·8	290·5	296·3	291·3	298·0	293·9
120	299·7	297·0	296·5	290·5	296·1	291·8	..	..
140	299·7	297·0	296·8	290·5	296·6	292·5	..	..
160	299·7	296·6	296·5	290·5	296·6	292·5	..	..
180	299·7	296·6	296·5	290·0	296·9	293·0	..	..
200	299·7	296·6	296·8	298·5	297·0	293·5	299·5	293·7
300							299·5	293·7
400							299·2	293·9
500							299·2	293·9
600							299·0	294·5
650							298·4	294·6

T—Dry bulb temperature, T_d— Dew point temperature

was 983 ft. The results of the comparison are shown in Fig. 1.

In order to study the variations of temperature and humidity with the progress of night, the sets of subsequent observations were taken every alternate hour from 2000 IST till sunrise (2000, 2200, 2400, 0200, 0400 and 0600 IST). The observations were confined to the days on which ground fog or mist was expected to occur over the Dum Dum airfield. These were extended over the period December 1956 to May 1957 to get some idea of the variation of superrefraction conditions from the winter to summer months. The actual dates of observations which are described in details except one occasion are 26-27 and 28-29 December 1956, 28-29 January, 22-23 February, 18-19 March, 6-7 April and 24-25 May 1957.

The results of the several sets of observations are summarised in Tables 2(a) to 2(g). For the sake of comparison, the actual meteorological conditions as prevailed at the time of observations, *viz.*, surface wind, visibility, weather and clouds, are also shown in the tables.

(*b*) *Radar Observations during December 1956 to May 1957*—The 3-cm meteorological radar (De *et al.* 1957) is located in the Dum Dum airport area at a distance of about 1100 yards to the southsoutheast of the radiosonde station. The PPI scope pictures were taken at the corresponding hours of manual radiosonde observations, *i.e.*, at 2000, 2200, 2400, 0200, 0400 and 0600 IST.

It may not be necessary to reproduce the PPI presentations for all the seven nights under discussion. The salient features of

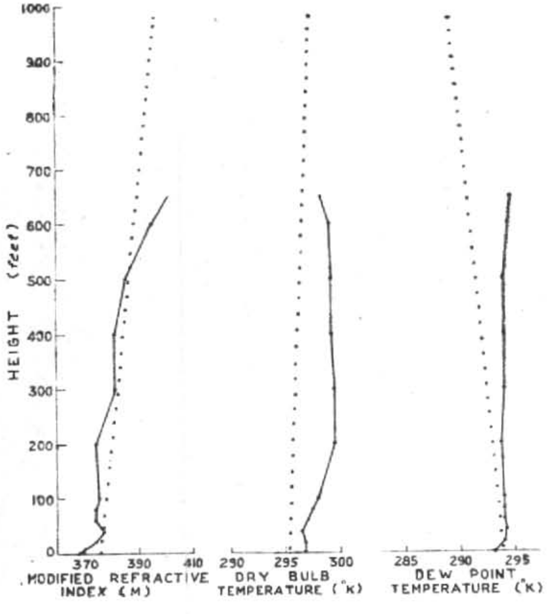


Fig. 1. Comparison of low level sounding upto 650 ft above ground level with the routine radiosonde sounding at Dum Dum airport on 16 November 1956

(Solid line—Low level sounding at 1930 IST, Dotted line—Routine radiosonde sounding at 2010 IST)

super-refraction as observed on the radarscope are given below—

(*i*) *28-29 December 1956*—The PPI presentations on this day were almost the same as on 26-27 December 1956. At 2000 IST, the ground clutters extended in all directions up to 20 miles. At 2200 IST the ground clutters were normal while echoes from 40—60 miles appeared in the SSE,S and SSW. At 2400 IST echoes from 50—60 miles appeared in the SE while those in the S and SSW appeared at 30—45 miles. At 0200 IST only a few echoes appeared at 60 miles in the SE. The ground clutter extension was also slightly decreased. At 0400 IST, only the reduced ground clutters appeared on the scope (at this time fog appeared over the station reducing the visibility to 800 yd). At 0600 IST the ground clutter extension was decreased to about 5 miles.

(*ii*) *28-29 January and 22-23 February 1957*—There is nothing interesting to report about the radarscope observations on these nights. Normal ground clutters were present on the scope except during the appearance of fog (Tables 2d and 2e) when they were very much reduced.

(*iii*) *18-19 March 1957*—The situation on this night is very interesting. Two of the radarscope observations are shown in Fig. 2. The radial lines in the pictures are due to interference from another radar (A.C.R.) working on the same waveband, *i.e.*, 3-cm and located in the same airport at a distance of about 300 yd from the meteorological radar. At 2000 IST (Fig. 2a) the echoes appeared at 25-45 miles in the E, SE and SW, the lie of the echoes being from 080°/40-45 miles through 180°/20-45 miles to 230°/40-45 miles. At 2200 IST, the echoes increased in number, the lie of the echoes being from 080°/35-45 miles through 180°/25-55 miles to 310°/30-65 miles. At 0200 IST echoes broke up into two patches, one from 080°/40-50 miles to 150°/60-70 miles, and another from 200°/40-50 miles through 270°/35-40 miles to 020°/35-45 miles. At 0400 IST the echoes almost encircled the station at a distance of 30-50 miles which continued practically unchanged up to 0600 IST (Fig. 2b), except that the echoes in NW appeared nearer the station.

(*iv*) *6-7 April 1957*—The progress of changes on this night was somewhat similar to that on the night just described. At 2000 IST the echoes appeared in a patch in the SE, S and SW, the lie being from 110°/30-40 miles through 180°/30-50

TABLE

Low level sounding

		Height						
		0	20	40	60	80	100	120
(a) 26-27 December								
2000 IST	*M*	358·1	355·8	348·0	347·1	344·4	346·2	342·8
	T	295·1	294·9	295·8	296·0	296·9	297·6	298·0
	e	20·8	20·0	18·3	18·0	17·5	18·0	17·1
2200 IST	*M*	364·6	362·3	362·9	359·7	357·6	358·4	359·2
	T	293·7	294·0	294·5	294·9	295·4	295·4	295·4
	e	21·9	21·1	21·3	23·5	20·1	20·1	20·1
2400 IST	*M*	361·5	360·4	361·1	359·4	358·4	358·3	358·5
	T	291·3	291·7	291·7	291·9	292·2	292·5	292·6
	e	20·2	20·0	20·0	19·4	19·1	19·1	18·9
0100 IST	*M*	361·9	362·7	365·5	366·3	367·7	366·5	367·3
	T	290·8	290·5	291·0	291·0	291·4	291·8	291·8
	e	20·1	20·0	20·7	20·7	21·0	20·6	20·6
0300 IST	*M*	356·1	358·6	359·3	358·2	359·3	360·1	357·5
	T	289·7	289·5	289·5	289·9	290·2	290·2	290·5
	e	18·4	18·8	18·8	18·5	18·3	18·3	18·0
0530 IST	*M*	358·6	355·6	357·9	359·4	360·8	361·6	361·7
	T	289·7	290·1	290·1	290·0	289·8	289·8	290·0
	e	19·0	18·3	18·7	18·8	19·1	19·1	18·8
0800 IST	*M*	364·5	365·3	361·0	361·8	362·3	366·1	359·0
	T	291·1	291·1	291·4	291·4	292·2	292·2	293·3
	e	20·8	20·8	20·1	20·1	20·0	20·7	19·3
(b) 28-29 December								
2030 IST	*M*	369·3	368·7	374·2	371·6	375·2	376·0	376·8
	T	294·3	294·5	294·5	295·0	294·5	294·5	294·5
	e	23·1	22·8	30·8	23·3	23·7	23·7	23·7
2200 IST	*M*	369·9	372·0	377·1	377·9	374·2	375·0	380·2
	T	293·7	293·5	293·5	293·5	293·5	293·5	293·5
	e	23·0	23·2	24·1	24·1	23·2	23·2	24·1
2400 IST	*M*	366·4	365·1	366·5	366·6	367·7	369·9	376·6
	T	292·5	291·8	291·7	291·8	292·3	292·4	292·3
	e	21·8	21·1	21·1	21·1	21·3	21·6	22·4
0200 IST	*M*	363·2	364·0	360·6	360·3	359·5	367·5	373·8
	T	291·5	291·5	292·4	292·8	293·0	293·3	293·3
	e	20·7	20·7	20·1	19·9	19·7	21·4	22·6

M—Modified refractive index, *T*—Dry bulb

2

and prevailing weather

(feet)				Weather			
140	160	180	200	Surface wind	Present weather	Visibility (n.m.)	Clouds
1956							
343·5 298·0 17·1	344·3 298·0 17·1	345·0 298·0 17·1	345·8 298·0 17·1	Calm	..	4·0	5 *Cs*/25000′
359·9 295·4 20·1	362·2 295·2 20·4	364·1 295·2 20·6	363·7 295·2 20·4	SW/2 K	..	3·0	3 *Ci*/25000′
359·8 292·5 19·1	360·6 292·5 19·1	358·0 292·7 18·4	360·8 292·7 18·8	Calm	..	3·0	2 *Ci*/25000′
368·3 291·8 20·6	368·8 291·8 20·6	369·5 291·8 20·6	370·3 291·8 20·6	Calm	Clouds forming	3·0	2 *Ci*/25000′
358·2 290·5 18·0	359·0 290·5 18·0	356·8 290·8 17·5	357·8 290·8 17·5	Calm	Fog, sky discernible	900 yd	2 *Ci*/25000′
362·0 290·1 18·7	362·8 290·1 18·7	362·8 290·2 18·6	368·3 290·2 19·6	Calm	Fog has been thicker during preceding hour	200 yd	2 *Ci*/25000′
359·0 293·4 19·2	354·4 294·9 18·3	350·7 295·7 17·7	357·1 294·3 18·5	Calm	,,	50 yd	3 *Ci*/25000′
1956							
377·5 294·5 23·7	378·3 294·5 23·7	379·0 294·5 23·7	379·8 294·5 23·7	SW/1 K	..	4·0	*Nil*
380·9 293·5 24·1	381·7 293·5 24·1	382·4 293·5 24·1	383·2 293·5 24·1	Calm	..	3·0	*Nil*
375·5 292·4 22·5	377·1 292·8 22·9	368·6 292·8 20·8	372·4 292·8 21·5	WNW/1 K	..	3·0	*Nil*
374·5 293·3 22·6	367·7 293·5 21·0	368·4 293·5 21·0	369·2 293·5 21·0	Calm	Haze	2·5	*Nil*

temperature (°K), *e*—Vapour pressure (millibars)

TABLE

		Height						
		0	20	40	60	80	100	120
								(b) 28-29 December
0400 IST	M	360·0	365·1	365·5	362·4	360·9	355·4	
	T	290·3	292·4	292·6	293·4	293·6	294·3	Observations
	e	19·6	21·2	21·2	20·6	20·2	19·0	
0600 IST	M							
	T	Observations abandoned due to instrumental trouble						
	e							
								(c) 28-29 January
2000 IST	M	360·8	357·9	358·0	358·8	359·5	363·5	364·1
	T	293·6	294·0	294·1	294·1	294·1	294·1	294·1
	e	20·9	20·1	20·0	20·0	20·0	20·8	20 8
2200 IST	M	365·8	364·8	366·3	366·1	369·7	371·4	371·9
	T	293·0	292·6	292·8	293·0	293·2	293·4	293·6
	e	21·9	21·2	21·5	21·3	22·0	22·3	22·3
2400 IST	M	360·3	362·7	363·4	366·4	368·8	368·9	370·5
	T	290·8	290·5	290·5	291·0	291·4	291·9	292·1
	e	19·8	20·0	20·0	20·7	21·2	21·2	21·5
0200 IST	M	360·3	361·1	363·4	366·4	367·1	370·3	370·1
	T	290·8	290·8	290·5	291·0	291·0	291·6	291·4
	e	19·8	19·8	20·0	20·7	20·7	21·4	21·2
0400 IST	M	357·8	354·8	353·4	361·3	362·8	363·6	364·4
	T	289·7	288·5	287·9	289·8	290·0	290·0	290·0
	e	19·0	17·6	17·0	19·1	19·4	19·4	19·4
0600 IST	M	357·8	358·4	361·3	363·0	364·9	365·7	369·5
	T	289·7	289·4	290·0	290·2	290·5	290 5	291·2
	e	19·0	18·7	19·4	19·6	20·0	20·0	20·9
								(d) 22-23 February
2000 IST	M	377·5	382·9	383·6	378·0	388·9	388·4	389·9
	T	298·0	297·1	297·1	297·1	296·4	296·4	296·3
	e	26·3	27·0	27·0	25·5	27·6	27·4	27·5
2200 IST	M	389·9	388·2	385·0	389·9	391·6	392·4	391·9
	T	297·0	296·9	297·4	297·3	296·2	296·2	296·2
	e	28·4	28·2	27·5	28·1	28·2	28·2	27·9
2400 IST	M	385·3	380·7	381·2	382·0	382·7	388·3	389·1
	T	296·3	296·0	295·9	295·9	295·9	295·7	295·7
	e	27·5	26·1	26·0	26·0	26·0	27·1	27·1

M—Modified refractive index, T—Dry bulb

2 (*contd*)

(feet) 140	160	180	200	Weather: Surface wind	Present weather	Visibility (n.m.)	Clouds
1956—*contd*							
abandoned due to instrumental trouble				Calm	Fog, sky discernible	800 yd	*Nil*
				SE/2 K	Fog has been thicker during preceding hour	110 yd	*Nil*
1957							
368·5 294·1 21·5	367·0 294·4 21·2	366·7 294·7 21·0	367·5 294·7 21·0	S/4 K	..	5·0	*Nil*
372·6 293·6 22·3	373·4 293·6 22·3	374·6 293·2 22·3	375·4 293·2 22·3	SW/1 K	..	5·0	*Nil*
370·2 292·3 21·3	371·0 292·3 21·3	371·7 292·3 21·3	372·5 292·3 21·3	Calm	..	4·0	*Nil*
370·8 291·4 21·2	371·6 291·4 21·2	372·3 291·4 21·2	373·1 291·4 21·2	Calm	Mist	1·0	*Nil*
365·1 290·0 19·4	365·9 290·0 19·4	366·6 290·0 19·4	372·9 291·3 21·0	Calm	Fog has been thicker during preceding hour	10 yd	4 *St*/200′
366·8 292·2 20·5	364·9 292·8 20·1	365·6 292·8 20·1	366·4 292·8 20·1	SW/1 K	,,	10 yd	2 *St*/200′
1957							
389·9 296·4 27·4	389·1 296·8 27·1	388·9 297·1 27·0	389·7 297·1 27·0	SSE/5 K		5·0	*Nil*
393·9 296·0 28·1	394·7 296·0 28·1	395·4 296·0 28·1	394·9 296·2 27·9	SSW/5 K		4·0	*Nil*
389·8 295·7 27·1	393·0 295·7 27·6	392·6 295·7 27·3	392·3 295·5 27·0	SSW/3 K		3·0	*Nil*

temperature (°K), *e*—Vapour pressure (millibars)

TABLE

		Height						
		0	20	40	60	80	100	120
								(d) 22-23 February
0200 IST	*M*	387·6	390·3	389·6	394·5	393·3	393·3	394·9
	T	296·3	296·6	296·8	296·6	296·3	296·6	296·3
	e	28·1	28·6	28·3	29·2	28·6	28·6	28·6
0400 IST	*M*	381·3	377·9	377·1	376·2	376·6	377·4	377·2
	T	294·7	293·8	293·5	293·2	293·1	293·1	293·0
	e	26·0	24·6	24·1	23·7	23·5	23·5	23·4
0600 IST	*M*	372·6	372·9	372·0	374·2	373·5	375·9	377·2
	T	293·0	292·8	292·5	292·6	292·5	292·8	293·0
	e	23·4	23·1	22·7	22·8	22·7	23·1	23·4
								(e) 18-19 March
2000 IST	*M*	361·5	360·2	360·9	360·4	361·1	361·2	362·7
	T	299·1	298·9	298·9	298·9	298·9	298·7	298·9
	e	23.0	22·4	22·4	22·1	22·1	21·8	22·1
2200 IST	*M*	354·9	353·3	355·0	355·4	356·1	356·0	356·8
	T	297·4	297·4	297·4	297·6	297·6	297·4	297·4
	e	20·8	20·5	20·5	20·4	20·4	20·2	20·2
2400 IST	*M*	370·7	367·3	366·8	368·9	369·6	370·6	372·6
	T	298·0	297·0	298·0	298·0	298·0	297·9	298·0
	e	24·7	23·6	23·4	23·7	23·7	23·9	24·0
0200 IST	*M*	374·6	375·4	371·9	372·7	373·4	378·4	375·0
	T	296·9	296·9	297·1	297·1	297·1	296·9	297·1
	e	25·2	25·2	24·3	24·3	24·3	25·2	24·3
0400 IST	*M*	375·1	364·4	365·7	366·5	381·5	369·4	377·3
	T	297·0	297·0	296·8	296·8	296·8	296·9	297·0
	e	26·0	22·7	19·4	19·4	26·0	23·2	25·1
0600 IST	*M*	380·2	387·6	385·7	385·7	390·4	387·2	390·8
	T	297·5	296·8	297·0	297·1	296·9	297·1	296·9
	e	26·8	28·0	27·5	27·3	28·2	27·3	27·9
								(f) 6-7 April
2000 IST	*M*	405·2	396·4	400·6	401·4	402·1	402·9	403·7
	T	300·8	300·5	300·3	300·3	300·3	300·3	300·3
	e	34·0	31·6	32·3	32·3	32·3	32·3	32·3
2200 IST	*M*	391·9	393·8	395·3	391·6	394·9	392·9	396·5
	T	299·9	299·4	299·7	299·7	299·9	299·9	299·9
	e	30·5	29·6	30·9	29·8	30·5	29·8	30·5

M—Modified refractive index, *T*—Dry bulb

2 (*contd*)

(feet)				Weather			
140	160	180	200	Surface wind	Present weather	Visibility (n.m.)	Clouds
1957—*contd*							
395·0 296·2 28·5	394·7 296·2 28·2	395·4 296·0 28·1	396·2 296·2 28·2	SSW/2 K	Clouds forming	3·0	4 *Sc*/2500′
377·9 293·0 23·4	378·7 293·0 23·4	379·4 293·0 23·4	381·5 293·2 23·7	Calm	Fog	110 yd	3 *St*/500′
384·4 294·0 24·9	382·5 293·7 24·4	382·4 293·5 24·1	384·0 293·7 24·4	Calm	Fog has been thicker during preceding hour	100 yd	2 *Ac*/10000′
1957							
363·4 298·9 22·1	361·9 298·7 21·5	369·1 298·9 23·1	368·3 298·9 22·7	SSW/8 K		5·0	*Nil*
357·5 297·4 20·2	355·7 297·1 18·5	361·8 297·1 20·7	362·5 297·4 20·8	SW/7 K		4·0	*Nil*
374·6 298·0 24·4	372·6 297·9 23·6	373·6 297·9 23·9	379·7 297·7 24·9	SW/8 K		4·0	*Nil*
377·6 296·9 24·5	378·4 296·9 24·6	379·1 296·9 24·6	375·9 296·9 23·7	SW/7 K		3·5	*Nil*
391·3 296·8 27·7	383·4 296·9 25·8	383·5 296·8 25·7	384·9 296·9 25·8	SW/8 K		3·0	*Nil*
392·7 296·9 28·2	392·8 297·0 28·1	394·2 296·9 28·2	401·4 296·9 29·7	SW/6 K		3·0	*Nil*
1957							
404·2 300·5 32·0	397·1 300·8 30·7	400·9 300·5 31·2	398·9 300·8 30·7	S/10 K	Clouds dissolving	5·0	1 *Sc*/2500′ 1 *Ac*/10000′
399·1 299·7 30·9	399·9 299·7 30·9	396·1 299·7 29·8	401·4 299·7 30·9	S/7 K		4·0	1 *Ci*/30000′

temperature (°K), *e*—Vapour pressure (millibars)

TABLE

		Height						
		0	20	40	60	80	100	120
								(f) 6-7 April
2400 IST	*M*	392·9	388·6	391·2	386·2	384·3	386·6	388·8
	T	298·8	298·4	298·0	298·0	298·2	298·0	298·0
	e	30·3	28·9	29·2	27·9	27·3	27·6	27·9
0200 IST	*M*	392·3	392·0	389·8	390·6	391·3	390·5	388·4
	T	299·2	298·5	298·5	298·5	298·5	298·7	298·7
	e	30·3	29·7	29·1	29·1	29·1	28·8	28·1
0400 IST	*M*	391·7	388·3	390·3	385·4	391·7	391·3	389·5
	T	298·1	297·4	297·6	297·8	297·6	297·4	297·6
	e	29·7	28·4	28·8	27·6	28·8	28·4	27·9
0600 IST	*M*	394·6	393·4	395·7	396·1	396·9	397·6	397·2
	T	298·6	298·5	298·3	298·7	298·5	298·7	298·5
	e	30·6	31·0	30·3	30·4	31·4	30·4	31·0
								(g) 24-25 May
2000 IST	*M*	413·3	430·3	433·2	436·4	439·1	439·1	440·7
	T	304·3	304·3	304·0	303·9	303·0	303·1	303·0
	e	37·5	41·6	41·8	42·2	42·5	42·3	42·5
2200 IST	*M*	351·3	352·8	353·5	353·6	355·0	353·7	354·5
	T	303·2	302·9	302·9	303·2	302·9	302·9	302·9
	e	34·8	35·1	35·1	34·8	35·1	34·2	34·2
2400 IST	*M*	404·6	402·4	395·5	396·3	397·0	409·1	409·6
	T	302·7	301·5	301·0	301·0	301·0	300·8	301·0
	e	34·7	33·5	31·4	31·4	31·4	34·0	34·1
0200 IST	*M*							
	T	Observation abandoned due to instrumental trouble						
	e							
0400 IST	*M*							
	T	Observations abandoned due to instrumental trouble						
	e							
0530*IST	*M*	410·9	..	..	..	416·1	..	..
	T	300·8	..	..	..	300·1	..	..
	e	35·5	..	..	..	35·5	..	..

*Data computed from routine radiosonde ascent. *M*—Modified refractive index,

2 (*contd*)

(feet) 140	160	180	200	Weather: Surface wind	Present weather	Visibility (n.m.)	Clouds
1957—*contd*							
394·7 298·2 29·2	391·2 298·2 28·2	396·2 298·2 29·2	395·4 298·4 28·9	SSW/6 K		4·0	2 *Ci*/25000′
393·6 298·5 29·1	392·8 298·7 28·8	389·4 299·0 27·9	387·3 299·0 27·2	SSW/8 K		4·0	*Nil*
390·2 297·6 27·9	391·0 297·4 27·8	391·7 297·4 27·8	392·5 297·6 27·9	SSW/6 K		4·0	*Nil*
399·2 298·5 31·4	400·0 298·5 31·4	397·7 298·7 29·7	401·5 298·5 31·4	S/5 K		3·0	1 *Sc*/2500′ 5 *Ci*/25000′
1957							
438·8 303·1 42·9	439·6 303·1 42·9	440·3 303·1 42·9	441·1 303·1 42·9	S/12 K		6·0	*Nil*
355·3 303·2 34·4	354·0 303·2 33·5	354·7 303·2 33·5	356·4 302·9 33·8	SSW/12 K		6·0	*Nil*
296·6 301·4 31·0	..	409·6 301·4 33·7	409·2 301·5 33·5	SSW/12 K		6·0	*Nil*
				SSW/12 K		5·0	*Nil*
				SW/6 K		5·0	*Nil*
.. .. ..	.. .. ..	.. .. ..	(at 330′) 414·3 298·3 32·3	S/8 K		6·0	T *Ci*/30000′

T—Dry bulb temperature (°K), *e*—Vapour pressure (millibars) miles to 220°/35-45 miles. Apart from these, some scattered echoes appeared in the remaining sectors at 40-80 miles. At 2200 IST the echoes almost encircled the station from 20-65 miles, the situation remaining almost the same at the subsequent hours.

(*v*) *24-25 May 1957*—There is nothing important to mention about the PPI presentations on this night. At 2000, 2200, 2400 and 0200 IST, some scattered echoes appeared here and there at distances ranging from 30-70 miles. At 0400 IST the echoes increased in number and lay in SW-NW-NE sectors. At 0600 IST the echoes almost half-circled the station, the lie of the echoes being from 220°/60 miles through 300°/55 miles to 050°/50 miles.

(*c*) *Radar Observations during February-March 1956*—We may also include here the results of radar observations on some selected occasions during February-March 1956. These observations were taken on 16-17, 22-23, 25-26, 26-27, 27-28 February, 29 February-1 March, 1-2 and 3-4 March 1956.

PPI pictures were taken at every alternate hour from 2000 IST till sunrise. The salient features of super-refraction as observed on the radarscope are almost the same as described earlier. Super-refracted echoes appeared on these days, by about 2000 IST. These were noticed as scattered echoes here and there at distances of 20-50 miles. On some occasions the echoes encircled the observing station. On two occasions (16-17 and 26-27 February 1956) the situations were interesting. The echoes nearly encircled the station by 2200 IST at a distance of 20-40 miles which continued almost unchanged upto 0600 IST.

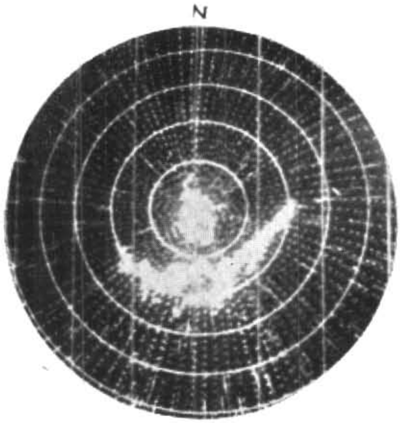
(*i*) *16-17 February 1956*—Two of the PPI pictures on this night are reproduced in Fig. 3. At 1945 IST (Fig. 3a), apart from the extended ground clutters, the echoes appeared at 40-55 miles in the SE and at 20-30 miles in the S, SW and W. At 2200 IST the echoes almost encircled the station at a distance of 20-40 miles and these remained encircled up to about next morning (Fig. 3b), the distribution pattern slightly changing during the period.

(*ii*) *26-27 February 1956*—The situation on this night was almost the same as that on the night described above. At 2000 IST, apart from the extended ground clutters, echoes appeared at 20-40 miles in the SE, S and SW. At 2100 IST the echoes almost half-circled the station. At 2200 IST the echoes increased in number. At 2300 IST the echoes encircled the station and continued almost unchanged, for the whole night till 0740 IST next day.

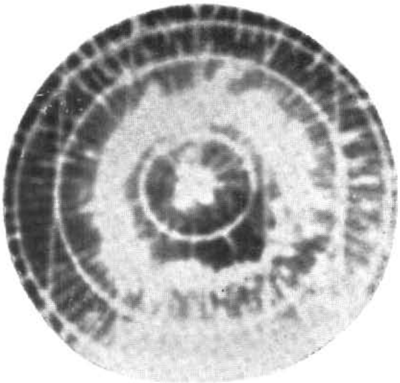
3. Discussion

(*a*) *General*—For propagation problems, the height gradient of the refractive index is of greater importance than its absolute values. If the refractive index falls off rapidly with height, the radio beam transmitted by the radar may be bent downwards. If this gradient is sufficiently large the radio beam may not leave the earth. The three factors which contribute to the decrease of the refractive index with height (Starr 1953) are : (*i*) the lapse rate of density of dry air under isothermal conditions due to gravity, (*ii*) the negative lapse rate of temperature and (*iii*) the lapse rate of water vapour. Of these, the contribution of the first one is small and may be neglected for practical purposes. The contribution by the second one is significant, but the most important contribution is that from the third, namely, lapse rate of water vapour.

(*b*) *On meteorological data*—The values of temperature and vapour pressure at different hours on the days under study for different heights are shown in Tables 2(a) to 2(g). The modified refractive indices (M) as calculated from a knowledge of these data are also

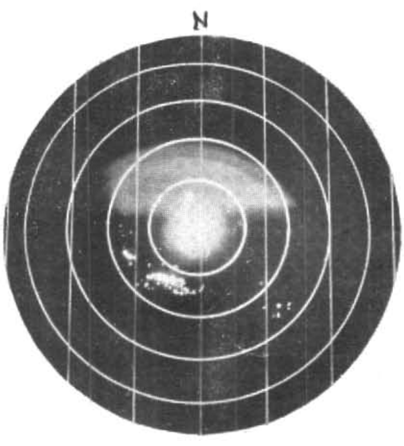


2000 **Fig. 2(a)** 20 M



0600 **Fig. 2(b)** 20 M

Figs. 2 (a) and 2 (b). PPI presentations of the storm detecting radar at Dum Dum airport on 18-19 March 1957



1945 **Fig. 3 (a)** 20 M

0500 **Fig. 3 (b)** 20 M

Figs. 3 (a) and 3 (b). PPI presentations of the storm detecting radar at Dum Dum airport on 16-17 February 1956

Figures in the bottom left and right hand corners indicate time in IST and range rings in miles respectively

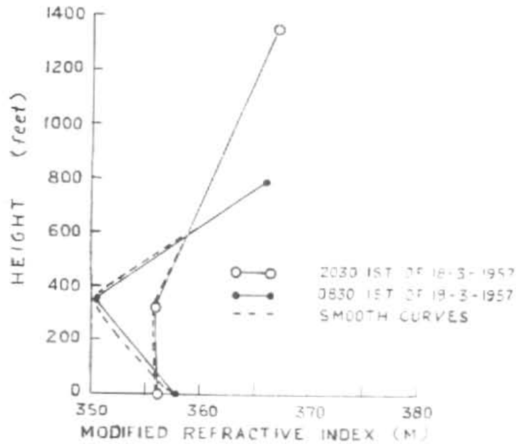


Fig. 4. M-profile at Dum Dum airport on 18-19 March 1957 as computed from routine radiosonde data

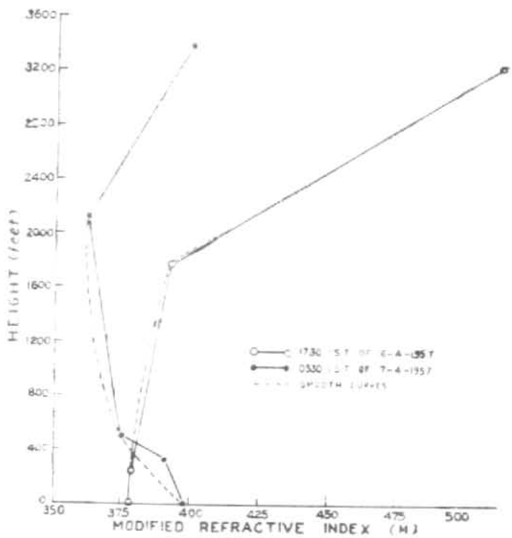


Fig. 5. M-profile at Dum Dum airport on 6-7 April 1957 as computed from routine radiosonde data

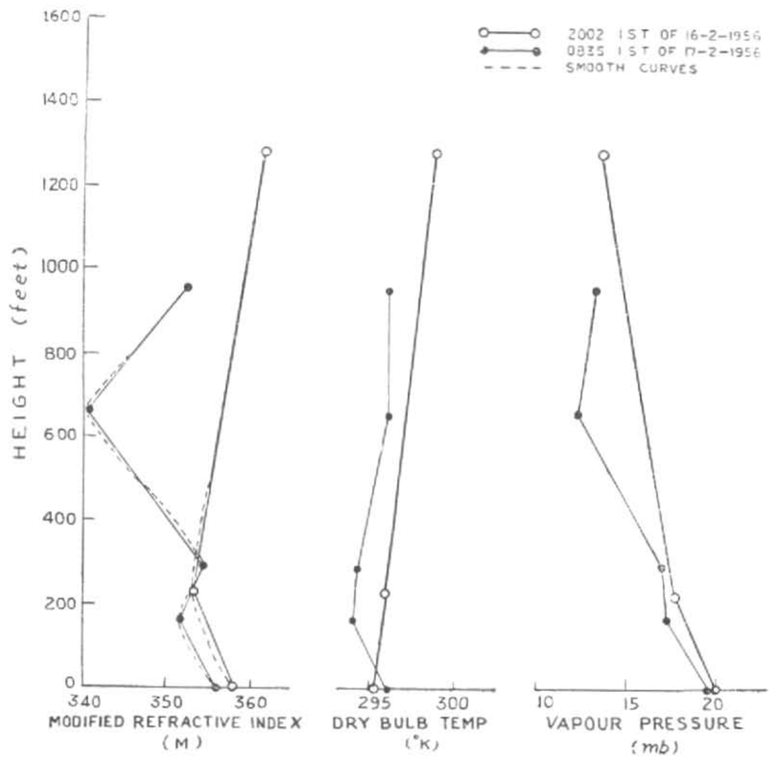


Fig. 6, Modified refractive index, temperature and vapour pressure profiles at Dum Dum airport on 16-17 February 1956 as obtained from routine radiosonde soundings shown in the same tables. It will be apparent from the tables that the M-inversions noticed between different levels are not maintained during the successive hours of observations. For example, the M-inversion noticed at 2400 IST on 26 December 1956 at 60-80 ft was not present one hour later, *i.e.*, at 0100 IST on 27 December 1956 (Table 2a).

It will be noticed that the lapse in M-values from ground to 20 ft which is always present at 2000 IST gradually decreases with the advance of night and after midnight the lapse is negative, *i.e.*, the M-value at 20 ft is greater than that at the ground. This is, however, contrary to what is expected from theoretical considerations. With the advance of night, the radiative cooling of the ground should tend to establish the inversion and, as such, one would expect the M-inversion to be more pronounced. It is probable that turbulence and the presence of the buildings etc near the place of observation prevented the establishment of this inversion.

An attempt was made to find out some correlation between the temperature distribution in the lower levels and the formation of mist/fog. Some relation could be found from the temperature values at ground and those at 100 ft above ground level. Emperically, when $T_{100'} - T_{\text{ground}} \approx 0^\circ \cdot 5$C, fog appeared over Dum Dum. However, any conclusion based on only a few observations is hazardous. More data are necessary for arriving at any firm conclusion.

(c) *On radarscope observations*—The two salient features of radar echoes are, general reduction of ground clutter intensity with the advance of the night and appearance of super-refracted echoes.

Regarding the first, the reduction may be ascribed to the general disappearance of the M-inversion close to the ground, within 20 ft already referred to. On two occasions, nights of 28-29 January and 22-23 February 1957, the reduction was very pronounced. This may have been due to the effect of the attenuation as discussed below.

The attenuation of radar echoes in the centimetre wavelength ranges produced by fog, cloud, rain, hail and snow have been calculated by Ryde (1946). It has been shown that in fine droplet clouds and fog for 0°C temperature, mass concentration of droplets 1 gm/m³ and visibility of 180 ft, the value of attenuation for 3-cm wave band is of the order of 0·099 db/km. At 20°C, the value is almost half. The mass concentration (Mc) is generally much more than 1 gm/m³ as assumed by Ryde. The values of Mc as obtained at Dum Dum airport on the days under report were between 12 and 22 gm/m³. Assuming these values and using the emperical relation of Ryde (Kerr 1951), *viz.*,

$$\text{Attenuation} \quad (\nu) = \frac{0 \cdot 438 \times Mc}{\lambda^2} \ \text{db/km},$$

the value of attenuation ν comes out to be between 0·58 and 1·07 db/km. These figures are much above those of Ryde and one could expect masking off, to a considerable extent, of echoes as obtained at Dum Dum airport on 28-29 January and 22-23 February 1957.

Regarding the distant super-refracted echoes it is to be noted that the lower tropospheric observations up to 200 ft did not show the presence of any marked and persistent inversion above the lowest 20 ft on any of the days of observations. Hence it may be inferred that the ducts responsible for super-refraction must have existed at heights more than 200 ft above the ground. However, except on the nights of 18-19 March and 6-7 April 1957, the echoes generally appeared from preferred directions. This shows that the elevated ducts, if these existed on these days, did not spread all round the airport. This means that the refracting medium was *not* homogeneously horizontally stratified all round the airport. Any conclusion regarding uniform spread of stratification drawn from radiosonde observations conducted at the airport station only is, therefore, hazardous. However, why the echoes appeared from preferred directions only is worth enquiring into. The distribution of the wind structure may be one of the causes. But analysis of the wind data over the airport on the

TABLE 3

Data from routine radiosonde observations

Date	Time (IST)	Pressure (mb)	Height (ft)	Temperature (°K)	Vapour pressure (mb)	Modified Refractive Index (M)
16 Feb 1956	2002	1007	0	295·2	20·3	358·1
		1000	231	295·9	17·9	353·2
		966	1287	298·6	13·5	361·8
17 Feb 1956	0835	1009	0	295·8	20·0	356·0
		1002	165	294·0	17·4	351·8
		1000	290	294·2	17·1	354·4
		985	660	296·0	12·1	340·3
		965	957	296·0	13·2	352·1
22 Feb 1956	2002	1009	0	292·2	17·8	351·7
		1000	284	294·0	16·2	350·4
		985	785	296·5	13·3	349·6
		912	2970	292·9	10·3	403·7
23 Feb 1956	1015	1014	0	298·8	17·3	341·6
		1000	419	297·0	17·0	355·2
		944	2145	290·8	16·3	411·2
25 Feb 1956	2025	1012	0	294·2	19·9	359·0
		1000	370	302·2	9·7	315·6
		950	1881	298·0	1·3	328·9
26 Feb 1956	0805	1014	0	296·8	16·8	341·7
		1000	432	298·0	2·9	294·0
		968	1353	300·5	2·6	316·6
	2004	1011	0	296·9	19·3	352·0
		1000	320	297·0	16·7	350·0
		950	1871	297·6	14·3	384·6
		897	3630	298·5	12·3	428·2
27 Feb 1956	0825	1013	0	296·3	24·3	375·2
		1000	389	293·4	24·0	389·9
		997	462	293·0	23·4	391·3
		990	627	298·0	16·2	355·5
		955	1683	298·4	14·7	382·1
	2010	1011	0	294·8	19·8	357·2
		1005	149	304·0	31·5	396·0
		1000	330	303·5	28·4	389·5
		950	1858	298·4	2·0	330·6
28 Feb 1956	0840	1013	0	295·6	25·8	382·5
		1000	396	294·6	20·9	374·6
		970	1287	292·4	12·2	365·1
		953	1805	295·3	9·4	364·5
29 Feb 1956	2000	1010	0	299·8	21·9	358·6
		1000	277	300·6	20·7	357·6
		961	1584	302·9	13·1	363·5

TABLE 3 (*cont'd*)

Date	Time (IST)	Pressure (mb)	Height (ft)	Temperature (°K)	Vapour pressure (mb)	Modified Refractive Index (M)
1 Mar 1956	0830	1011	0	299·0	17·5	341·4
		1000	333	297·8	15·0	342·2
		950	1780	292·0	14·5	389·0
		920	2805	293·0	11·7	406·4
	2030	1008	0	299·0	11·8	316·2
		1000	253	300·0	8·6	309·3
		980	866	305·0	0·5	288·8
		950	1791	301·8	0·4	318·3
2 Mar 1956	0830	1014	0	297·0	4·8	290·4
		1000	432	296·5	3·5	298·0
		950	1977	295·0	2·7	447·1
3 Mar 1956	2030	1012	0	296·0	21·4	362·7
		1000	356	297·0	15·2	344·7
		960	1749	297·2	8·5	358·1
		928	2578	297·0	7·5	377·1
4 Mar 1956	0830	1012	0	297·3	24·9	375·8
		1000	369	295·7	24·6	387·8
		957	1713	291·0	19·7	413·1

relevant dates was not of much help. More study is needed to answer the question.

Let us now consider in some detail the situations on the nights of 18-19 March and 6-7 April 1957. At some stage the super-refraction echoes encircled the airport. The echoes on the two nights were almost similar in nature. The routine radiosonde data from which the M-values for these two nights have been calculated are shown in Figs. 4 and 5 respectively. From Fig. 4, it is seen that the M-value on the night of 18 March 1957 at 2030 IST at 320 ft was the same as at the ground. While on the next morning, on the 19th at 0830 IST (more than $2\frac{1}{2}$ hours after sunrise), there was M-inversion up to 350 ft. From this, it may be concluded that there was duct formation sometime after 2030 IST and the duct height was much above 400-ft level. From the radarscope observations recorded at Dum Dum it can be said that the duct started forming in S and SE directions sometime between 2030 and 2200 IST and spread all round the airport in the early morning hours of 19 March 1957 between 0200 and 0400 IST. This duct height was subsequently reduced after sunrise and ultimately disappeared with the advance of the day.

From Fig. 5, it is seen that on 6 April 1957 at 1730 IST there was no M-inversion. But the record on the 7th at 0530 IST indicates the presence of inversion at a high level (2130 ft above ground). This again leads to the conclusion that there was duct formation after 1730 IST on 6 April 1957. The radar-scope pictures showed that one could infer the formation of duct in a southerly direction at 2000 IST, which spread all round the airport by 2400 IST. The duct stratification then continued the whole night.

(*d*) *On observations during February-March 1956*—The meteorological data (temperature, pressure and vapour pressure) as obtained from the routine radiosonde observations in the evening at 2000 IST and the next morning at 0830 IST on the days under report are shown in Table 3. The corresponding M-values as calculated from these data are also shown in the table. It will be seen that on most occasions, M-inversions were present up to 300 ft or so. The situations on the nights of 16-17 February 1956 and 26-27 February 1956 are interesting. On the former night at 2002 IST M-inversian was noticed up to a height of 231 ft. But unfortunately the next point available was for 1287 ft and these showed an increase in M-inversion value. The next morning at 0835 IST there was ground M-inversion up to a height of 165 ft as well as an elevated M-inversion from 290 to 660 ft. These are shown graphically in Fig. 6. From the above as also from radarscope observations it can be inferred that the elevated M-inversion might have formed by 2200 IST and continued to exist for the whole night up to about 0835 IST next morning. The situation on the night of 26-27 February 1956 was almost the same as on the night described above. At 2004 IST ground M-inversion up to a height of 320 ft was noticed while elevated M-inversion from 462 to 627 ft was noticed next morning at 0825 IST. Here also it can be said that the elevated M-inversion might have started by about 2200 IST (the radarscope showing echoes almost encircling the station by this time) and continued to exist for the whole night till about 0825 IST next morning.

4. Concluding remarks

From the observations on the nights of 16-17 February 1956, 26-27 February 1956, 18-19 March 1957 and of 6-7 April 1957 it may be said that the ducts at elevated heights as shown by the routine radiosonde ascents at the Dum Dum airport were horizontally stratified and extended in *all directions* at least upto 60 miles from the airport. This statement could have been made unambiguously if the meteorological data up to 2000 ft above ground level were available between 2200—0600 IST.

5. Acknowledgements

The author is greatly indebted to Prof. S. K. Mitra, Emeritus Professor of Physics, Calcutta University for suggesting the problem. Thanks are also due to the members of the staff working in the Radar and Radiosonde section and to Shri B.U.C. Rao of the Meteorological Office, Dum Dum airport, for their assistance and co-operation.

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