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On determination of thickness of fog-layers over Calcutta Airport based on their thermal structure

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सार — कलकत्ता हवाई अड्डे पर 1973 से 1977 की अवधि में विभिन्न अवसरों पर छाई प्रातःकालीन कोहरे की परतों की मोटाई नापने का एक प्रयास किया गया है। परतों की तापीय तथा आर्द्रता संरचना के अनुसार कोहरे की परतों को चार वर्गों में बांटा गया है तथा उनके विशिष्ट लक्षणों को प्रस्तुत किया गया है। कोहरे की परतों की मोटाई न्यूनतम 20 मीटर तथा अधिकतम 1000 मी. हो सकती थी। ऐसा लगता है कि कोहरे की परतों में प्रक्षोभ-मान में घट-बढ़ उनके उर्ध्वाधर विस्तार से संबंधित हैं।

ABSTRACT. An attempt has been made to compute the thickness of morning fog-layers which formed over Calcutta Airport on different occasions during the period 1973-77. According to their thermal and moisture structure, the fog-layers have been grouped into four types and their characteristic features have been presented. The fog-layers could be as shallow as 20 m and as deep as 1000 m. It appears that varying degrees of turbulence in the fog-layers have a bearing to their vertical extent.

1. Introduction

Incidence of fog over Calcutta Airport may result out of cooling in the airmass in contact with the earth's surface or stirring of almost saturated airmasses at different temperatures. The cooling of air may be due to (*i*) loss of heat by the air in contact with ground due to outgoing radiation & (*ii*) loss of heat to the ground by warmer air that streams over a colder surface. The two types of cooling give rise to fog known as radiation and advection fog. In the majority of the fog over this airport, both the processes are in operation during the formation. In particular, the advection of warmer air from sea over colder ground in the first part of night followed by nocturnal radiative cooling, is very common and the fog so formed may be termed as advection radiation fog. From the stand-point of cooling the airport experiences only radiation fog.

Air from industrial localities are immensely polluted with combustion nuclei. Hygroscopic salt particles are found in high concentration in association with air which has trajectory over sea-surface. These constitute the main sources of the condensation nuclei at Calcutta Airport which is surrounded by a number of industries and is situated on the bank of river *Hooghly*. To the south of Calcutta is the Bay of Bengal which is about 65 km away from it. These condensation nuclei may begin to gather moisture at humidities much below saturation. The increasing relative humidity allows the hygroscopic particles in the air to start absorbing moisture more and more and increase in size. Neiburger and Wurtle (1949) illustrate this point with data of Los Angeles Airport where sea-salt particles were the main condensation nuclei. They found that the visibility becomes approximately constant below a humidity of 67.5 per cent and decreases almost uniformly as the relative humidity increases above this value, the decrease being due to condensation nuclei.

Basu (1954) compared the frequencies of fog in winter months December-March at the three stations Barrackpur, Calcutta Airport (Dum Dum) and Alipore situated on left bank of the *Hooghly* at decreasing distances from the Bay of Bengal. An explanation for the difference in frequencies has not been attempted by him. Mukherjee (1959) explained the role of atmospheric pollution in the observed differences in the frequencies of fog at those stations.

Kundu (1957) observed that radiation fog occurred over Safdarjung Airfield when relative humidities was as low as 75 per cent. Occasions of fog with relative humidities as low as 75 per cent are also not uncommon in Calcutta areas. So, in determining the height of a fog layer it may be expected that the vertical extent will be limited to that level where relative humidity is about 75 per cent.

2. Data

All available 00 GMT upper air ascents of Calcutta for the period 1973-77 were scrutinised to obtain those which were taken during fog. Only 27 such ascents could be identified. These ascents provided upper air data like directions and speed, dry-bulb (T) and dew-point temperature (T_d) at different levels at the interval of 50 mb starting from 1000 mb and including the ground level. Additional information of atmospheric pressure at the ground level, heights (Z) in geopotential

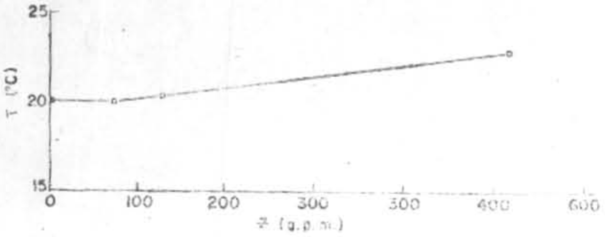

Fig. 1. Temperature (T)-height (Z) curve below inversion at 00 GMT of 4 March 1975

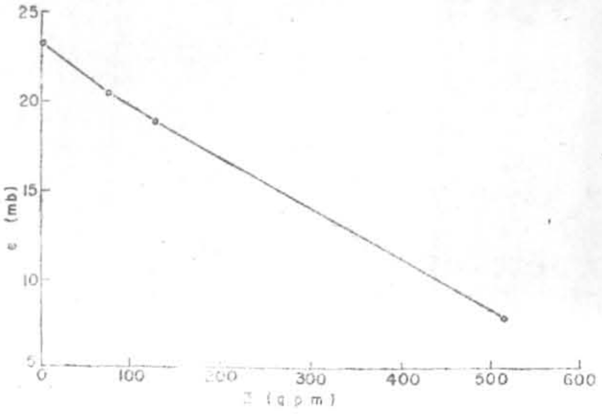

Fig. 2. Water vapour pressure (e)-height (Z) curve below inversion at 00 GMT of 4 March 1975

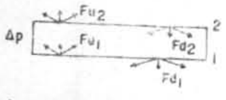

Fig. 3. An atmospheric slab of unit cross-sectional area

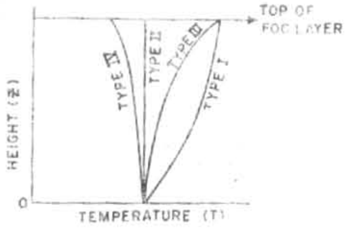

Fig. 4. Schematic diagram of different types of vertical temperature profiles within fog layers

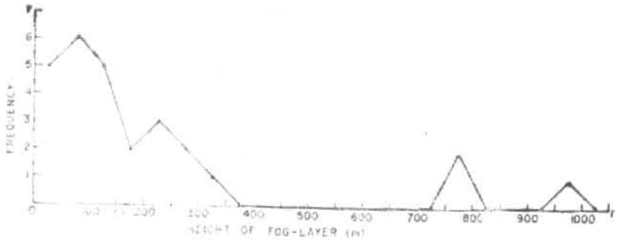

Fig. 5. Frequency distribution of fog-heights

metre of the different upper levels, amount and type of the clouds, present and past weather were also included in the data. Water vapour pressure was found out, wherever necessary, from hygrometric tables given by Kiefer, Paul J (1941).

The methodology adopted for computing thickness of fog-layer has been illustrated below with the help of a sample upper air ascent of Calcutta at 00 GMT on 4 March 1975.

3. Thickness of fog-layer

Relative humidities in percentages at surface and other higher levels were computed from the upper air data by using the formula :

$$\mathrm{RH}=e/e_s\times(100)$$

where RH = Relative humidity in percentage,

e = Water vapour pressure at temperature T,

e_s = Saturated vapour pressure at T.

Computation of relative humidity values was continued upto levels where the relative humidities were even less than 70 per cent. Water vapour and saturated water vapour pressure for the different levels of the morning ascents were also found out.

To obtain temperature and water vapour pressure for different levels in the vertical like 90 per cent, 85 per cent, 80 per cent...... which are not directly available in the upper air data, the following procedure was adopted.

Temperature-height (T-Z) and water vapour pressure-height (e-Z) curves above ground for each ascent was obtained. Figs. 1 and 2 show the T-Z and T-e curves of the morning ascent of 4 March 1975. In this connection Kiefer's multi-pressure hygrometric chart drawn with basic coordinates of temperature and vapour pressure on a linear scale was consulted.

Temperature (T) and water vapour pressure (e) at different relative humidity levels were plotted on the above chart to obtain T-e curve for each ascent. Now the values of T and e were picked up for the above mentioned additional relative humidities as mentioned in para 2 of section 3. In the case of non-isothermal fog-layer, the values of height in g.p.m. for the different relative humidity levels were found out from T-Z curves and in the case of isothermal fog-layer the same were found out from e-Z curves.

Thus, temperatures, height (in gpm) and water vapour pressure at all the desired relative humidity levels for each ascent were obtained. Table 1 gives the above elements at various desired levels for the morning ascent of 4 March 1975.

TABLE 1

Air temperature, aqueous vapour pressure and height (in gpm) of different relative humidity levels at and above the ground on 4 March 1975 (00 GMT)

T (°C)	e (mb)	Z (gpm)	R. H. (%)
20	23.37	Surf.	100
20	21.0	60	90
20	20.61	74	88
20.1	20.0	100	85
20.3	19.1	129	80
20.6	17.2	185	75

4. Terrestrial radiation in fog

4.1. *Radiative heating or cooling of an atmospheric slab*

We first consider a horizontally uniform atmospheric slab of density ρ and having the pressure thickness $|\triangle P| = g\rho\triangle Z$ and bounded by the two horizontal boundaries, namely 1 and 2, each of 1 cm² cross-sectional area. Fig. 3 shows the atmospheric slab which may be a part of the fog-layer. It is assumed that due to horizontal uniformity no radiative fluxes flow through the sidewalls.

Let F_{u1}, F_{u2} and F_{d1}, F_{d2} be the upward and downward fluxes respectively at slab boundries 1 and 2. The radiative heating or cooling through the upper and lower slab boundaries is

$$\begin{aligned}\frac{\triangle Q}{\triangle t} &= F_{u1} + F_{d2} - (F_{u2} + F_{d1})\\ &= (F_{u1} - F_{d1}) - (F_{u2} - F_{d2})\\ &= F_{n1} - F_{n2}\end{aligned}$$

where $\triangle Q$ = amount of net radiative heat, in time $\triangle t$, F_{n1} and F_{n2} are the net fluxes at boundaries 1 and 2. Fluxes entering the slab are denoted by a positive sign and those leaving the slab by a negative sign. Expansion or contraction of the slab due to radiative heating or cooling is neglected here, and from the first law of thermodynamics

$$\frac{\triangle Q}{\triangle t} = g^{-1} \; c_p \,|\triangle p|\, \frac{\triangle T}{\triangle t}$$

and thus the rate of temperature change is

$$\frac{\triangle T}{\triangle t} = \frac{g}{c_p}\,\frac{F_{n1}-F_{n2}}{|\triangle p|} = \frac{g}{c_p}\,\frac{F_{n1}-F_{n2}}{p_1-p_2} \qquad (1)$$

where, p_1 and p_2 are pressures at boundaries 1 and 2.

Eqn. (1) shows that divergence of net flux $(F_{n1}-F_{n2})$ causes radiative cooling while convergence of net flux radiative heating.

4.2. *Terrestrial radiative transfer and moisture content at the top of fog-layer*

In the radiation and advection radiation fog, radiation is absorbed and emitted both upward and downward, with the result that the radiative surface is virtually moved upward while the layer below tends towards isothermal stratification. In terrestrial wave lengths fog of depth 50 m or more and of ordinary droplet size may be taken to approximate black-body. So, although all layers cool, the level near the fog-top will act as the virtual radiative surface, and from the Eqn. (1) it is clear that the strongest temperature gradient will be found across the upper surface of the fog and so, the weakest moisture gradient (vapour density gradient) will be observed in the same region by virtue of Eqn. (2) given below.

The vapour density D (also called absolute humidity) corresponding to aqueous vapour pressure e and air temperature T in °K is given by

$$D = \frac{e}{R_v T} \qquad (2)$$

where R_v is gas constant for water vapour. From the Eqn. (2), it is seen that vapour density is proportional to aqueous vapour pressure e in isothermal layer. So, at the top of fog within an isothermal layer, aqueous vapour pressure gradient will also be weakest (as within the fog-layer, e decreases with height).

During the vertical extension of fog, vertical transport of heat flux or moisture flux through turbulence is an important factor as far as the reversal of the vertical temperature or moisture gradient is concerned. In such cases where turbulence helps build up fog vertically, temperature gradient near the top of the fog will be a minimum.

5. Criteria for finding the top of the fog-layer

Fog over Calcutta is essentially radiation type. For the purpose of finding the top of fog-layers, the types of fog over Calcutta may be grouped under different types of thermal stratification as observed in them.

Types of thermal stratification :

Type I — Radiation and advection-radiation fog within the temperature inversion with temperature gradient increasing vertically upwards.

Type II — Fog in isothermal layer

The former type of stratification may give rise to an isothermal layer when the out-going radiation from the surface is not intense.

When fog in such stratification attains considerable height, turbulence plays a major role in transforming initial thermal condition of the fog-layer into the new one.

TABLE 2

Temperature gradients of successive atmospheric layers above ground on 4 March 1975 (00 GMT) and their comparison

Layers	L_{12}	L_{23}	L_{34}	L_{45}	L_{56}
Temp. difference in successive layers (°C)	0	0	0.1	0.2	0.3
Thickness of above layers (m)	60	14	26	29	56
Temp. gradient in above layers (°C/m)	0	0	$\frac{0.1}{26}$	$\frac{0.2}{29}$	$\frac{0.3}{56}$
Comparison of above gradients	$T_{gr}^{12} =$	$T_{gr}^{23} <$	$T_{gr}^{34} <$	$T_{gr}^{45} >$	T_{gr}^{56}
Height of the top of fog-layer (in gpm)	—	—	—	100	—

TABLE 3

Different types of fog-structures with its height above ground level, difference of temperature ($T_t - T_b$) and of aqueous vapour pressure ($e_t - e_b$) at the base and top, relative humidity (RH) at the top of fog-layer

Date	Type of fog-structure	Height (m) a.g.l. (Z)	Difference of Temp. (°C) and water vapour pressure (mb) Base $T_t - T_b$	Top $e_t - e_b$	Relative humidity (R.H.) at the top (%)
8 Jan 73	I	307	0.9	—3.21	80
9 Jan 73	I	204	0.2	—2.07	85
13 Jan 74	I	153	1.6	—1.10	80
14 Jan 74	III	59	0.5	—1.88	85
31 Jan 74	III	284	3.0	+1.52	85
3 Mar 74	III	244	1.3	—4.69	75
12 Mar 74	IV	49	—0.7	—4.59	80
16 Mar 74	III	114	1.2	—2.20	85
25 Jan 75	IV	994	—3.5	—6.29	85
4 Mar 75	I	94	0.1	—3.37	85
19 Mar 75	III	63	0.8	—2.80	80
21 Mar 75	III	216	3.0	—1.10	80
22 Mar 75	II	70	0.0	0.0	100
31 Mar 75	II	67	0.0	—1.52	90
13 Nov 75	II	46	0.0	—1.69	85
15 Nov 75	I	19	0.2	—0.48	90
16 Nov 75	III	134	3.1	+2.66	70
17 Nov 75	III	194	1.2	—2.98	70
5 Dec 75	III	119	0.0	—1.21	85
10 Dec 75	I	41	0.9	—1.18	85
14 Dec 75	I	107	1.0	—1.51	85
18 Dec 75	IV	754	—0.5	—3.80	75
24 Dec 75	I	39	1.0	0.57	90
5 Jan 77	I	66	4.6	1.67	75
13 Jan 77	III	784	0.9	—1.81	85
16 Jan 77	IV	294	—1.0	—4.11	85
25 Jan 77	I	104	1.0	—0.52	85

e_t = aqueous vapour at top in mb, e_b = aqueous vapour at pressure base in mb

T_t = temperature at top (°C), T_b = temperature at base (°C).

TABLE 4

Frequency of fog-heights and structure-types

Height range (m)	Frequency	Ht. range (m)	Frequency
00-50	5	600-650	0
50-100	6	650-700	0
100-150	5	700-750	0
150-200	2	750-800	2
200-250	3	800-850	0
250-300	2	850-900	0
300-350	1	900-950	0
350-400	0	950-1000	1
400-450	0	Type I	10
450-500	0	Type II	3
500-550	1	Type III	10
550-600	0	Type IV	4

Type III—A reversal of temperature gradient in the vertical will be noticed here. This reversal of temperature gradient may be attributed to the presence of considerable turbulence in the formative stage.

Type IV—A layer of positive lapse rate of temperature belongs to this class. Very shallow radiation or advection radiation fog may have this type of thermal structure under almost calm condition of surface wind.

Fog belonging to any of former types of structure may acquire the structure of type IV when mixing takes place through a deep layer by turbulence. The above patterns of thermal structure of fog are shown in Fig. 4.

Near saturation condition over the ground may give rise to a fog-layer with this type of thermal stratification when the airmass over ground is stirred considerably by turbulence.

As already mentioned in para 2 of sub-section 4.2, at the top of type II structure, aqueous vapour pressure gradient will be weakest. Near the top of type I structure temperature gradient will be maximum and near the top of type III and IV structures temperature gradients will be minimum. If the effect of turbulence is of such order that temperature gradient at various layers does not show a clear minimum then maximum of vapour density gradients will have to be found in order to locate the top.

6. Calculation of the thickness of fog-layer

Let the fog-layer above the ground be sub-divided, by the known humidity levels. Let L_{12}, L_{23},......, L_{ij},.. be the 1st, 2nd,.... *i*th, ... sub-layers, where L_{ij} correspond to the sub-layer between *i*th and *j*th humidity levels and T_{gr}^{ij}, e_{gr}^{ij} denote the average temperature and water vapour pressure gradients respectively in the sub-layer L_{ij}. The gradients T_{gr}^{ij} or

e_{gr}^{ij} were found out for each of the ascents. Relation between two consecutive gradients was also noted. From the comparison of the above gradients, the height of top of different kinds of fog-layers were obtained in the following way.

In the case where temperature gradient increased vertically, the lower boundary of the sub-layer of maximum temperature gradient was taken as the top of the fog-layer while in the case where temperature gradient decreased vertically, the upper boundary of the sub-layer of minimum gradient was taken as the top of the fog-layer.

For the isothermal fog-layer, the upper boundary of the layer in which water vapour gradient was minimum was taken as the top. Temperature (or water vapour pressure difference in mb in the case of isothermal fog-layer) the differences in °C, thickness (in gpm), the temperature gradient in °C. per metre (or water vapour pressure gradient in mb per metre) of successive sub-layers were found out in this way and gradient so obtained were also compared for each ascent. Now the height of the top of each fog-layer was obtained in the way already indicated. Table 2 shows the temperature difference (°C), thickness (in gpm), temperature gradient in deg. C per metre of successive sub-layers, comparison of the gradients and height of the fog-layer for the morning of 4 March 1975.

The type of fog-structure, its height above the ground level were found out in each case, and in doing so, possible morning incursion of moisture has not been taken into considerations. These information together with difference of temperatures and aqueous vapour pressure at the base and top and relative humidity at the top of fog-layer are presented in Table 3.

7. Discussion

7.1. *Frequency distribution of fog-heights*

The same together with the types of structures already mentioned is shown in the Table 4. The frequency distribution is depicted in Fig. 5. These show that 60 per cent of fog may reach upto height between 15 and 150 m whereas 85 per cent between 15 and 350 m. Only 3 fog-heights were found to lie in the range 750-1000 m.

7.2. *Possible role of turbulence*

Synoptic situations favourable for morning fog over Calcutta were studied by Roy (1951), Basu (1952), Gangopadhyaya and George (1959). Study of synoptic situation for the present cases reveal that in each of the previous nights of the fog occurrences mentioned in 7.1 an eastward moving weak low pressure area with cyclonic circulation from 0.6 to 0.9 km was either over Sub-Himalayan West Bengal or Bihar plateau in association with western disturbances. All the above synoptic situations and any other process which bring additional moisture over the place for fog to form in the morning produce mixing in the moist airmass to certain extent depending upon the process involved. It appears that varying degrees of turbulence are responsible for different thermal and moisture stratification and also for the height of the fog-layer to great extent.

Generally, fog of type I structure did not rise above 200 m and difference of temperature in it did not exceed 1°C. So, it seems that effect of turbulence inside the fog layer is not much as compared to fog belonging to other structures.

8. Conclussion

(*i*) In the majority of cases, the height of fog-layer lies between 15 and 350 m. The height may even rise to 750-1000 m under strong influence of turbulence.

(*ii*) The difference of temperature between base and top of the fog-layer can vary from —3.5° C to 4.6° C and the same for vapour pressure from —6.29 mb to 2.66 mb but such negative temperature and positive vapour pressure differences are very rare.

(*iii*) The top of a fog-layer has relative humidity 85 per cent or more in most of the cases whereas same having relative humidity as low as 70 per cent are not uncommon.

(*iv*) The fog-layers can be grouped under four different categories as per their thermal structure. The type 1 structures have less vertical extent compared to other structures where turbulence in varying degree is present.

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