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Climatology of inversions, mixing depths and ventilation coefficients at Delhi

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ABSTRACT . Daily estimates of morning and afternoon mixing depths, average wind speeds through mixing layer and ventilation coefficients during clear winter months (October-March) from 1970-1977 were calculated and monthly averages of these parameters for 7 years are presented and discussed. Daily estimates of ground inversions, lapse rate, mean wind through the inversion heights and their thickness were calculated from 1968 to 1977. Percentage frequency of ground based inversions of different height and wind speed ranges based on 00 and 12 GMT ascents for 10 years are also presented. Monthly percentage frequency and strength of inversions, their thickness averaged over 10 years is also depicted. Comparison of inversions at Delhi and Mathura are also made.

1. Introduction

The destiny of the pollutants from the moment they are released into the atmosphere till they reach the receptor is solely governed by the prevailing meteorological conditions. From the meteorological point of view pollutant concentrations are a function of (*i*) mixing depth, (*ii*) average wind speed through the mixing layer and (*iii*) turbulence in the atmosphere. These parameters undergo significant time and space variations. In an earlier paper, (Mandal and Padmanabhamurty 1976) the authors presented diurnal and monthly variations of mixing depths and inversions during the winter of 1975-76 at Delhi. The present paper is an extension of the above study depicting the climatology of mixing depths and inversions at Delhi. Also presented are a comparison of inversion heights, their intensities, surface and inversion top temperatures at Delhi and Mathura. Mathura is a small town situated at a distance of 150 km southeast of Delhi.

2. Methodology

(a) *Mixing depths*

Mixing depths were computed utilizing radiosonde data collected at Ayanagar, a rural locality near Delhi, according to Holzworth (1967). In determining morning urban mixing depths the temperature excess over rural area, as observed by Bahl and Padmanabhamurty (1977) were made use of. But for afternoon values the temperature at rural area itself is used (Ludwing 1970).

(b) *Mean layer wind*

The average wind speed through the mixing layer was calculated as a simple average of the wind speed aloft as determined by radio wind and the surface wind. Ventilation coefficient is obtained as a product of the mixing depth and mean wind speed through the mixing layer. In these calculations precipitation days are avoided.

(c) *Experiments at Mathura to determine inversion parameters*

Low level soundings were taken with tethered balloons during January-March 1977 at Mathura. The experimental area is a fairy flat country side. The tethered balloon set-up consists of 30 m^3 plastic balloon specially made by TIFR Balloon Facility at Hyderabad, nylon rope of sufficient strength to withstand speeds of 15 knots, mobile mechanical winch and an instrument packet containing radiosonde (RS) equipment tied to the tether 10 metres away from the balloon. The conventional RS ground equipment is used. The tethered balloon was reeledout of the mechanical winch and kept for a couple of minutes at desired height till the pressure, temperature and dew point are recorded. Then the tether was outhauled to the next level. The observations were taken at every 50 m upto 500 m and the tethered balloon is in-hauled collecting data at the same intervals. The total operation took about 90 minutes and the average of the two observations at every level is taken for the mean temperature profile. The inversion heights and temperatures at the top of the ground inversions were calculated from the data. Since the times of flighs at Ayanagar (Delhi) and Mathura are not the same, Mathura data was reduced to Delhi flight time for comparison purposes. This was possible from a knowledge of bihourly variation of inversion parameters at Mathura. Temperatures, inversion heights, temperature at the top of ground inversions and inversion strengths at Delhi from regular RS flights and Mathura data from tethered balloon experiments were tabulated for comparison.

3. Results and discussion

The morning and afternoon mixing depths and average wind speeds through the mixing layer and

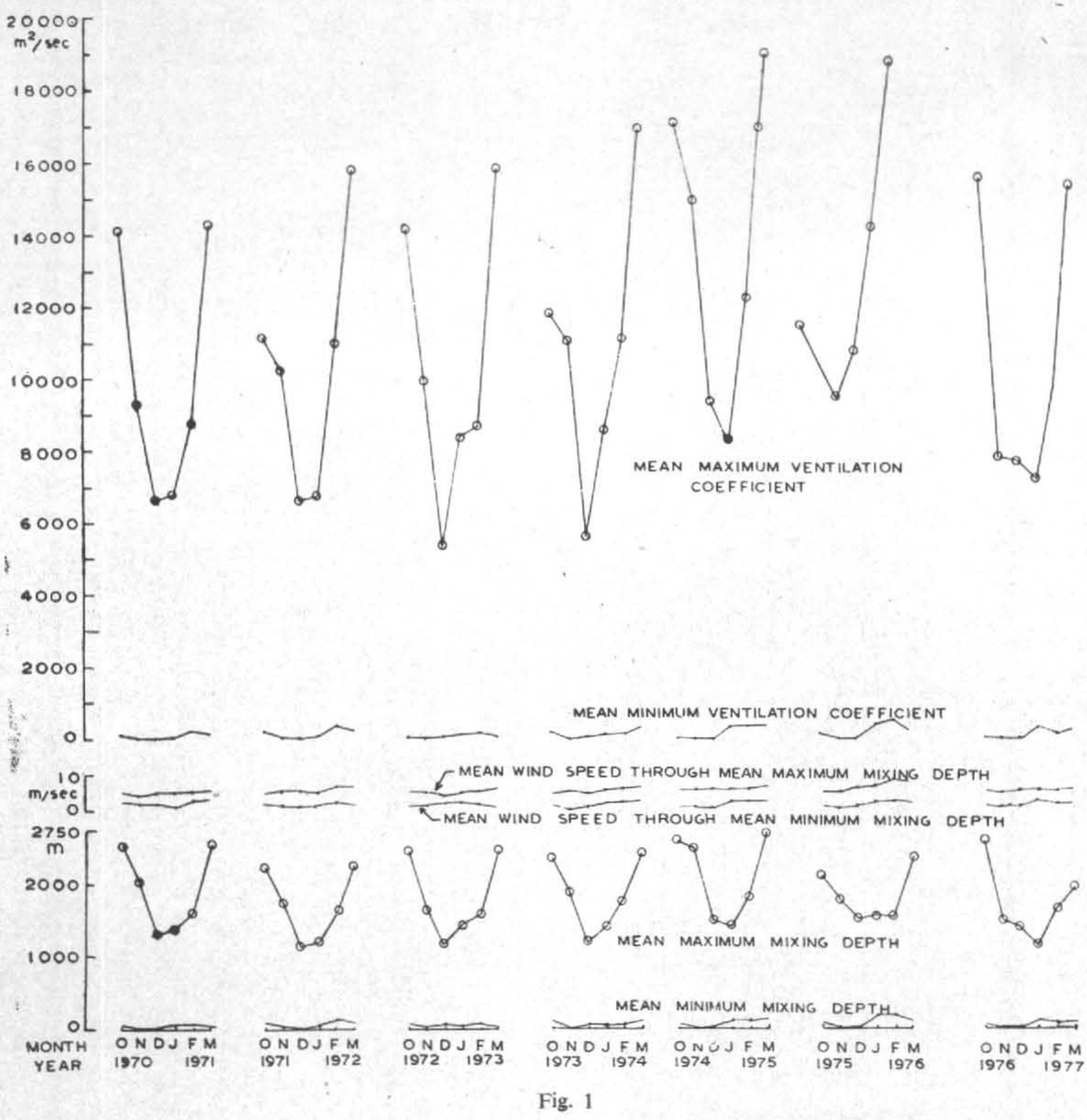


Fig. 1

ventilation coefficients for clear winter months (October-March) from 1970 to 1977 at Delhi are presented in Fig. 1.

(*i*) *Mixing depths*

Morning mixing depth varied slightly from month to month with minimum in November and maximum in February. It also varied from year to year. The average monthly minimum mixing depth over 8 years is 20 m in November and maximum of 109 m in February. The range of mixing depth is generally very small due to frequent occurrence of intense ground inversions.

Afternoon mean mixing depths (Fig. 1) show large variation from October to March. They are lower in December and January and higher in March and October. Afternoon mean monthly mixing depth (Fig. 2) attains a minimum value in December and maximum in March. The lowest value recorded in December is due to frequent early morning strong ground inversions. It also varied widely for year to year.

(*ii*) *Ventilation coefficients*

Morning and afternoon mean ventilation coefficients are also shown in Fig. 1. Ventilation coefficients also show both monthly and yearly variation. Afternoon ventilation coefficients are lower in December and January and higher in March. However, peak values do not coincide with that of mixing depth because of ventilation coefficient dependence on wind speed. But morning ventilation coefficients are lower in November and December and higher in March. Average monthly morning and afternoon ventilation coefficients over 8 years are shown in Fig. 2.

(*iii*) *Inversion at Delhi and Mathura*

The inversion heights and surface winds at Delhi and Mathura and mixing depths at Delhi are shown in Table 1. It can be seen from the table that the inversion heights and surface winds at Mathura are generally less than corresponding heights and surface winds at Delhi. The temperature at the top

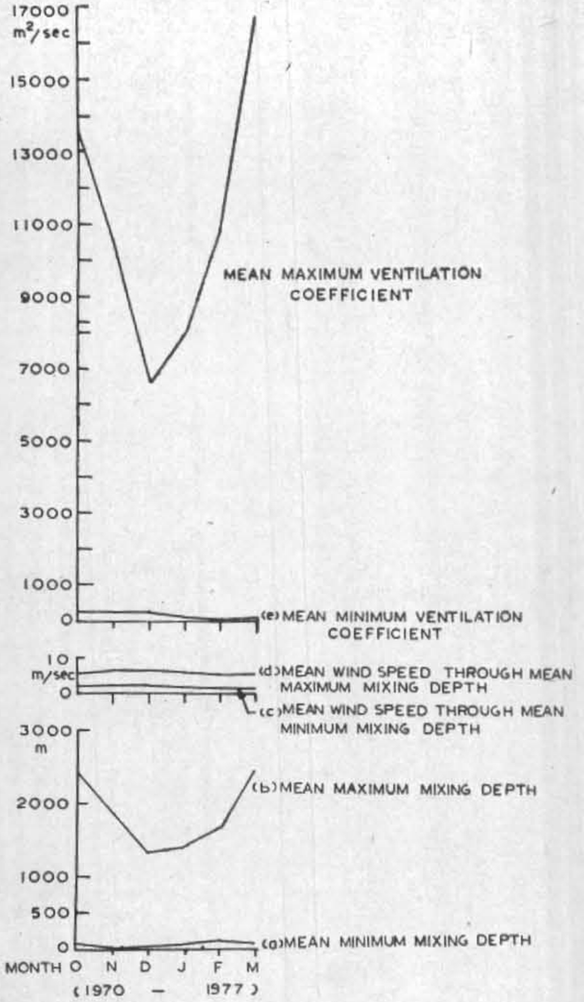


Fig. 2. Averaged for 7 years

of inversions at Delhi and Mathura shown in Fig. 3(a) indicates that they are linearly related. A least square regression line with slope 1.17 confirms that there is fairly close correspondence between the two. The intercept (–2.2) indicates that inversion top temperatures at Delhi are slightly greater than that at Mathura.

Surface temperatures of Delhi and Mathura (Fig. 3b) also show close relationship. The regression line yielded a slope of 1.157 and intercept of –4.4. This indicates surface temperature of Delhi is greater than that of Mathura.

In Fig. 3(c) are shown the relation between inversion heights at Delhi and Mathura. The slope of .55 and intercept of 58.9 of the regression line indicates that the inversion heights of Delhi are greater than those at Mathura.

The relation between the inversion strengths at Delhi and Mathura shown in Fig. 3(d) also yielded a linear regression line with a slope of .715 and intercept of 4.27 indicating that inversion strengths at Mathura are greater than those at Delhi.

TABLE 1

Inversion heights, surface wind at Ayanagar and Mathura and Urban Mixing Depth over Delhi on the days of tethered balloon ascents taken at Mathura

Date (1977)	Inversion ht. (m) at 0445 hr at		Urban mixing depth over Delhi (m)	Surface wind (m/sec) at	
	Ayanagar	Mathura		Ayanagar	Mathra
2 Feb	153	120	027	6.0	0.0
5 Feb	221	250	170	3.0	0.0
8 Feb	160	300	068	3.0	1.0
10 Feb	502	300	091	5.0	1.0
12 Feb	093	110	020	5.0	0.0
15 Feb	460	090	200	8.0	1.0
17 Feb	093	090	043	4.0	1.0
27 Feb	137	095	101	2.0	0.0
28 Feb	240	090	124	4.0	0.0
4 Mar	148	180	035	0.0	0.0
5 Mar	171	098	047	4.0	0.0
13 Mar	340	165	164	0.0	0.0
15 Mar	277	265	172	6.0	0.0
16 Mar	127	—	070	0.0	0.0
17 Mar	490	415	077	6.0	1.0
18 Mar	283	315	090	10.0	1.0
19 Mar	510	515	044	4·0	0.0
28 Mar	273	185	140	5.0	1.0

(iv) Ground based inversions and lapse rates at Delhi

Ground inversions at Delhi, their thickness and lapse rates calculated on the basis of 00 GMT data from 1968 to 1977 are shown in Table 2.

Percentage frequency distribution of inversions of different height ranges under different mean wind speeds through the inversion heights for ten years (1968 to 1977) are also given in Table 2. Percentage frequency of inversions is high in the height range 101-200 m and low in 401-500 m and above. This indicates that if the effective stack heights are above 200 metres their contribution to ground level pollution concentrations at Delhi would be negligible during night time stable conditions. Also at each height range the percentage frequency is maximum when wind speed is greater than 4 m/sec and minimum when the wind is calm. This points out that pollutants are likely to be transported away from the source when once they are released into the atmosphere. Occurrence of percentage frequency

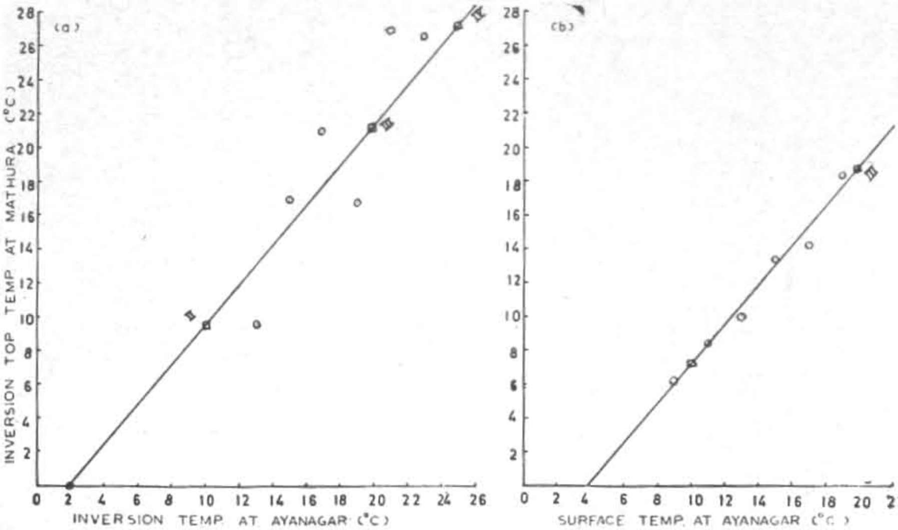
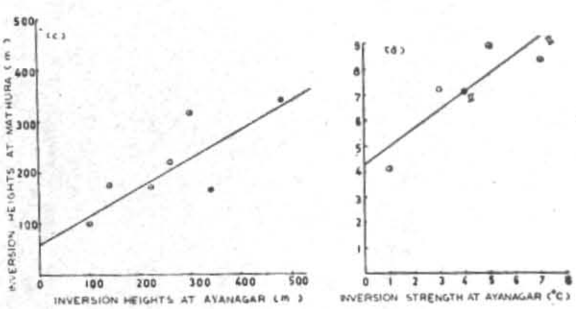


Fig. 3 (a). Inversion top temperature

Fig. 3 (b.) Surface temperature



(c) Inversion height (d) Inversion strength

Figs. 3 (a-d). Relation between weather parameters at Ayanagar and Mathura

TABLE 2

Percentage frequency of occurrence of inversion during 1968-1977 at Delhi

Mean wind speed through inversion (m/sec)	Inversion at height range (m)					
	0-100	101-200	201-300	301-400	401-500	>500
	(a) 00 GMT					
00	00	00	00	00	00	00
0-2	1.0	6.3	4.3	1.9	0.6	1.0
2-4	2.1	11.9	7.2	3.6	1.4	1.2
>4	4.2	20.5	16.3	7.1	4.7	4.4
Total	7.3	38.7	27.9	12.6	6.7	6.6
	(b) 12 GMT					
00	00	2.6	00	00	00	00
0-2	2.5	10.3	3.9	1.3	00	00
2-4	7.7	18.0	5.1	1.3	00	00
>4	11.5	23.1	6.4	2.5	2.5	1.3
Total	21.7	54.0	15.4	5.1	2.5	1.3

of inversions based on 12 GMT ascents (Table 2b) shows maximum between height range 101-200 m and minimum in the height range 500 m and above and at every height range maximum frequency occurs when the wind speed is greater than 4 m/sec.

In Tables 3 (a) and 3(b) monthly percentage frequency of ground inversions averaged over 10 years (1968-1977) at 00 and 12 GMT respectively are shown. Inversions at 00 GMT are maximum in November and minimum in July. Inversions in different seasons shown in Table 3(a) point out that they are frequent (94 per cent) during winter and post monsoon season and are generally very low (25 per cent) in monsoon season. Morning inversions almost occur daily in winter. Evening inversion frequency (Table 3b) is very small.

The most frequent percentage frequency of thickness of inversion (Table 4) is in the height range 101-200 m from January to April and October to December and the maximum percentage frequency occurs in November when the morning minimum mixing depth is low. May to June and August to September have high percentage frequency in the height range 201-300 m. Inversions of thickness exceeding 1 km are rare.

Morning lapse rate (–ve) shown in Table 4(a) is high (20°-100°C/km) from October-December and January to March. November and December have highest percentage of –ve lapse rates in the range 20° 100° C/km. This shows that higher percentage of these lapse rates during October to March is due to intense inversions and as a result of which mixing depths will be less and pollutants will be confined in smaller volume for longer period. April to September have high percentage of –ve lapse rate in the range 1°–10° C/km showing less intense inversions and consequently high mixing depth.

TABLE 3

Percentage frequency of ground inversion during 1968-77

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Dec+Jan+Feb	Mar-May	Jun-Sep	Oct-Nov
(a) 00 GMT															
93	91	92	82	74	32	10	13	44	91	98	97	94	83	25	94
(b) 12 GMT															
1	1	1	0	0	0	0	0	1	2	12	09	04	00.3	00.2	07

TABLE 4

Percentage frequency of occurrence of mean monthly inversion at 00 GMT during 1968-77

Ht. range (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Dec+Jan+Feb	Mar-May	Jun-Sep	Oct-Nov
0-100	09	09	07	08	05	02	0	03	02	04	07	11	19	07	02	06
101-200	44	44	36	40	29	26	24	20	29	37	48	44	44	36	26	42
201-300	23	22	31	26	32	29	14	21	28	37	30	25	23	30	26	33
301-400	09	12	12	15	16	18	24	21	21	12	08	09	09	14	21	10
401-500	07	05	09	06	09	11	24	12	07	07	04	05	06	07	11	06
501-1000	06	08	05	05	09	14	14	23	13	03	03	06	07	06	14	03
>1000	01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 5

Percentage frequency of lapse rate (1968-77)

Lapse rate (°C/km)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan-Dec	Dec-Feb	Mar-May	Jun-Sep	Oct-Nov
(a) 00 GMT																	
1-10	21.4	23.8	17.6	25.2	43.9	62.2	86.2	79.4	53.2	20.4	12.5	11.4	26.4	18.4	28.2	62.9	16.3
10-20	25.4	22.8	30.0	30.3	29.2	29.4	13.8	20.6	26.2	32.2	19.1	20.6	25.9	22.8	29.8	25.3	25.4
20-100	52.9	53.4	52.0	44.0	26.9	8.4	0.0	0.0	21.6	46.9	67.7	66.6	47.2	58.0	41.7	11.8	57.8
>100	0.8	0.0	0.4	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.7	1.4	0.5	0.8	0.3	0.0	0.5
(b) 12 GMT																	
1-10	100	100	67	..	..	..	..	..	50	29	21	53	40	59	67	50	22
10-20	00	00	33	..	..	..	..	..	50	29	41	29	33	25	33	50	39
20-100	00	00	00	..	..	..	..	..	00	43	38	18	27	16	00	00	39
>100	00	00	00	..	..	..	..	..	00	00	00	00	00	00	00	00	00

TABLE 6

Inversion height and inversion strength during two or more ascents on a day at Ayanagar (Delhi)

Date	Time of obsn.	Inversion		Time of obsn.	Inversion	
		Ht. (m)	Strength (°C)		Ht. (m)	Strength (°C)
10 Oct 75	0430	184	3.7	0530	148	3.3
18 Nov 75	0430	238	5.5	0600	193	4.4
11 Jan 76	0430	732	4.0	0635	308	5.0
12 Jan 76	0430	170	3.2	0615	144	2.8
13 Jan 76	0450	234	3.6	0630	160	3.8
14 Jan 76	0430	314	4.0	0530	178	5.0
16 Jan 76	0430	359	5.7	0630	280	4.2
19 Jan 76	0455	200	4.8	0700	148	2.2
22 Jan 76	0430	200	3.9	0630	165	3.5
24 Jan 76	0430	450	1.4	0730	270	0.1
10 Feb 76	0430	342	1.6	0625	150	1.6
10 Feb 76	1630	—	1.6	1830	—	—
11 Feb 76	0430	208	4.4	0555	108	3.9
3 Mar 76	0430	545	5.9	1140	—	—
8 Mar 76	0430	420	2.3	0455	137	1.0
10 Mar 76	0430	185	3.7	1630	—	—
10 Mar 76	2330	176	3.0			
11 Mar 76	0430	244	2.8	0830	195	1.6
11 Mar 76	1645	—	—	2330	368	0.2
19 Mar 76	0430	321	3.1	0630	264	2.8
23 Mar 76	0430	388	4.8	1015	—	—
24 Mar 76	0430	263	6.5	0630	188	5.8
24 Mar 76	1630	—	—	2325	413	0.7
25 Mar 76	0430	348	6.2	1105	—	—
25 Mar 76	1630	—	—	2235	213	1.6
26 Mar 76	0430	238	5.2	1040	—	—
26 Mar 76	2325	416	0.7			
29 Mar 76	0430	272	4.3	1130	—	—
3 Apr 76	0430	162	6.8	1130	—	—
24 Apr 76	0430	110	3.4	1130	—	—
30 Apr 76	0430	938	1.1	0505	717	2.0
30 Apr 76	0615	428	3·9			
1 May 76	0430	345	5.5	0635	234	5.5
22 May 76	0430	328	3.1	0635	224	0.6
3 Jan 76	0430	237	3.2	0630	167	3.7
22 Mar 76	0430	188	2.4	1050	176	3.1
7 Mar 77	0445	486	5.8	0635	413	6.3
11 Mar 77	0445	285	7.2	0645	257	5.6
18 Apr 77	0445	300	1.3	0605	—	—

Very high –ve lapse rates exceeding 100°C/km are rare. Seasonwise distribution of lapse rates show that winter and post-monsoon seasons have high percentage of ve lapse rate in the range 20°-100° C/km and least percentage in June to September. January to September have high percentage of –ve lapse rate at 12 GMT (Table 5b) in the range 0-10 °C/km. High -ve lapse rates are rarely noticed in the afternoon.

(*v*) *Analysis of two or more consecutive ascents in a day at Delhi*

Inversion heights and inversion strengths when two or more ascents are taken in a day in Delhi for 32 days (from 1975 to 1977—Table 6) show that inversion heights and inversion strengths are generally high at 0430 hour and decrease with the advance of time. Mixing depths will thus gradually increase with march of time in a day.

4. Conclusion

The results indicate that more intense inversions occur at Mathura than at Delhi. Inversion heights at Mathura are less than that at Delhi. Intense ground inversion of less height at Mathura will cause low mixing depth than at Delhi. Low mixing depth, low wind speed and intense ground inversion lead to high pollution potential at Mathura.

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