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Ground inversion at Bombay airport

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ABSTRACT. In this study the frequency, thickness and intensity of ground inversions in the morning over Bombay, during various non-monsoon months, have been worked out. The percentage frequencies are more than 90 during winter months of November to February, rapidly decreasing in summer months, being less than 20 during May. The study reveals that inversions during winter are steep but thickness is less whereas in summer these are weak but thickness of the inversion layer is more.

The influence of land and sea breeze circulation on inversions has also been discussed. The study suggests that nocturnal inversion over Bombay on some occasions, gets weakened or partially broken, particularly after 1900 GMT and its vertical profile is not continuous. It is rather zig-zag.

An attempt has also been made to identify synoptic situations which inhibit formation of inversions over Bombay.

1. Introduction

The study of ground layer inversions has assumed great importance in the last decade because air pollution level in these layers has started reaching critical limits in the highly industrialised and urbanised cities like Bombay. The study of ground inversions is important not only to health physicist but to an aviator also. Intense ground inversions put constraint on the safety and economy of large jet carriers too. The Commission for Aeronautical Meteorology during its extra-ordinary session in 1974 recommended that information on the existence or expected existence of marked temperature inversions in the lowest levels of the atmosphere say upto 300 metres a.g.l. should be provided to pilots before departure. When the temperature rise is 10 deg. C or more in this layer it is considered as significant for these flights.

In the present study, the frequency, intensity and thickness of ground inversions over Bombay during various non-monsoon months has been

worked out. An attempt has also been made to identify synoptic systems which inhibit growth of inversions over Bombay and the influence of land and sea breeze circulation on the vertical growth and weakening of these nocturnal inversions, has also been discussed.

2. Data used

Ground inversion data from January 1972 to May 1978 for the non-monsoon months, *i.e.*, January to May and October to December have been obtained from 0000 GMT temp. messages of Santacruz Observatory. The heights are in millibars. Synoptic patterns have been reproduced from *Indian Daily Weather Reports*.

3. Analysis and discussion

In Table 1 mean thickness of inversion layer, mean temperature rise in the layer and mean negative lapse rate per 100 mb have been worked out, for various non-monsoon months. The percentage frequencies of inversions during these

TABLE 1

Monthly mean values of inversion layer thickness, temperature rise in the layer, lapse rate per 100 mb and percentage frequency for different months

	Jan	Feb	Mar	Apr	May	Oct	Nov	Dec
Inversion layer thickness (in mb)	47.75	52.84	62.29	65.17	58.23	49.41	47.11	49.75
Temperature rise in the layer (in °C)	5.4	4.5	4.0	2.6	1.4	3.2	5.1	4.8
Lapse rate per 100 mb (in °C)	11.5	8.5	6.5	4.0	2.4	6.5	8.5	9.6
Percentage frequency	96	93	91	69	19	61	91	97

TABLE 2

Mean monthly surface wind speed, mean daily minimum temperature, monthly average of surface wind speed greater than 16 kt, wind direction and speed at 500 ft a.g.l. at 00 GMT and percentage frequency of inversion

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Mean monthly surface wind speed (in kmph) irrespective of direction	8.5	8.2	8.5	9.1	9.3	10.4	10.5	10.0
Daily minimum temperature (in °C)	22.9	19.8	17.7	16.3	16.9	20.2	23.8	26.2
Monthly average of surface wind >16 kt in days	15	14	11	11	17	21	22	24
Mean wind direction and speed at 500 ft a.g.l. at 00 GMT	6	6	6	3	2	6	5	8
Percentage frequency of inversion	61	91	97	96	93	91	69	19

TABLE 3

Highest value of inversion thickness and temperature rise for different months and significant inversion

Inversion thickness		Temperature rise		Significant inversion cases		
Date	(mb)	Date	(°C)	Date	(°C)	(mb)
19 Jan 1973	120	29, 31 Jan 1974	11.2	9 Jan 1972	10.4	26
28 Feb 1976	130	1 Feb 1974	13.8	30 Jan 1973	10.4	28
19 Mar 1977	133	3 Mar 1974	12.2	31 Jan 1974	11.2	29
26 Apr 1977	162	23 Apr 1974	9.1	9 Feb 1974	11.4	27
12 May 1972	163	19 May 1974	6.0	15 Jan 1975	10.0	15
20 Oct 1977	111	17 Oct 1976	9.0	28 Jan 1976	10.2	31
9, 17 Nov 1976	105	5 Nov 1976	9.8			
6 Dec 1977	95	12 Dec 1973	10.2			

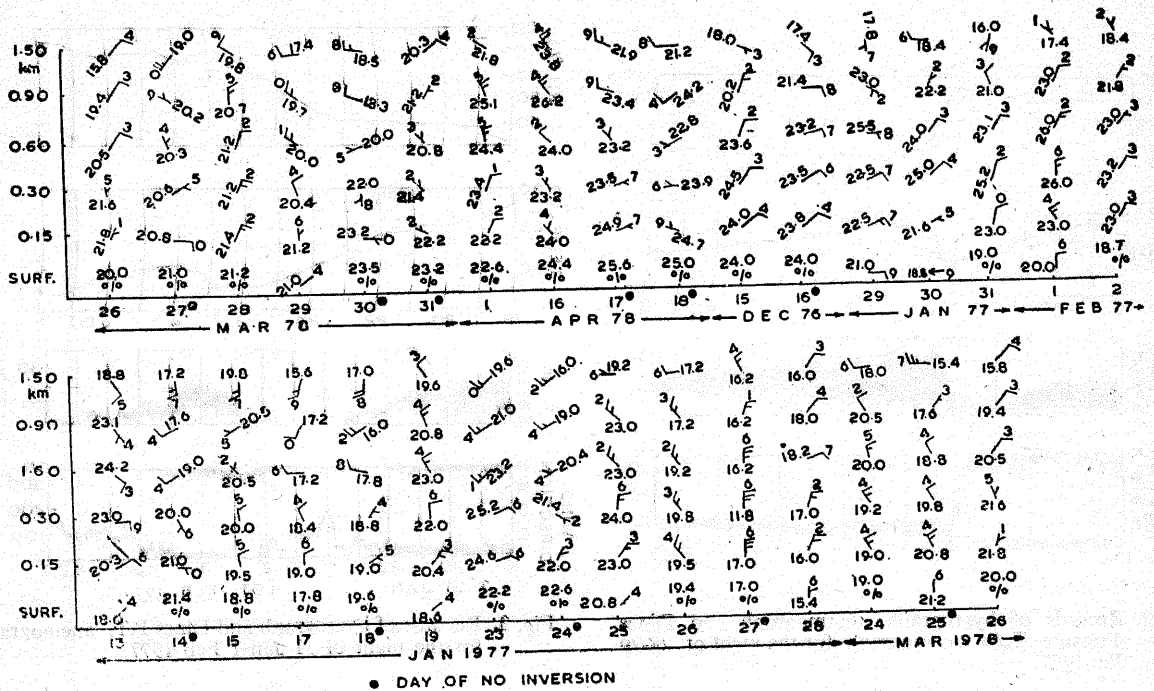


Fig. 1. Vertical section of winds and temperatures at 00 GMT

months have also been worked out. The Table 2 gives correlation of the percentage frequencies of inversion with mean wind velocity at 500 ft a.g.l., mean surface wind and mean daily minimum temperature etc.

3.1. Bombay experiences generally clear skies and light surface winds, in the morning hours, particularly during winter months of November to February. These conditions are most suitable for radiative cooling resulting in ground inversions. In other non-monsoon months of October and March to May also the weather is very often clear to partly cloudy with light to moderate winds in the morning and, therefore, ground inversions form very often in these months also.

3.2. As seen from Table 1 the percentage frequencies are maximum and more than 90 in the winter months of November to February and even March follows the same trend. However, there is a sharp decrease in the summer months of April, May and October and frequency is lowest, i.e., less than 20 in the month of May. The table further shows that inversions are intense or steep during winter but their thickness is less whereas in summer the thickness is more but intensity is less.

3.3. Actually radiational cooling takes place for longer periods in winter months causing inversion conditions to persist for longer duration in winter than summer. Thus the temperature differences in the inversion layer are more in winter. In fact Saha and Ananthakrishnan (1976) in their study for Poona have also shown

that inversion conditions persist for longer duration in winter (17 hours in January) than in summer (12 hours in April) and that the intensity of inversion is more in winter than in summer.

Table 3 which gives the values of maximum thickness recorded for each month, significant inversion cases and highest temperature rise in the inversion layer also confirms this fact. In winter months only, the temperature rise exceeds 10 deg. C and it is found significant mostly in the month of January, taking 30 mb thickness equal to 300 m.

3.4. However, what is not well understood is why thickness of inversion is more in summer than in winter. The land and sea breeze circulation appears to influence the thickness of inversion. During summer sea breeze circulation continues till late night and at times throughout night and is well marked. The inversion top is carried upward with the sea breeze circulation. On the other hand in the winter months, land breeze circulation is predominant in the night. But land breeze circulation is feeble and of small thickness and, therefore, the thickness of inversion is small in winter months.

3.5. Table 2 enables to find out how the percentage frequencies of inversion are related with various other parameters such as mean wind speed, mean wind velocity at 500 ft a.g.l. and mean minimum temperature. The mean wind velocity at 500 ft a.g.l. for various months suggests that with easterly component, i.e., wind

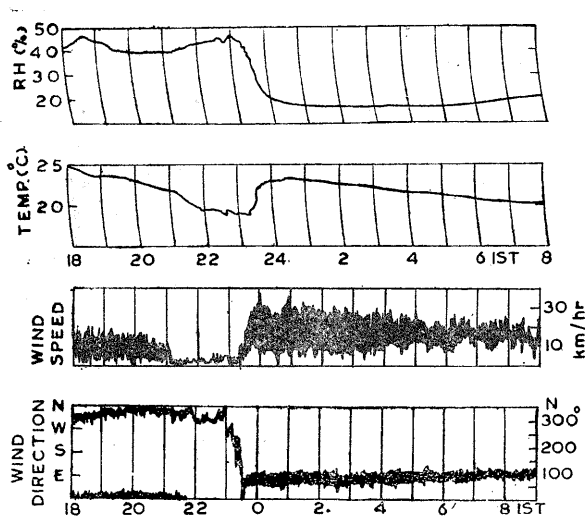


Fig. 2. Records of hygrograph, thermograph and Dines Pressure Tube anemograph for the night of 28-29 Jan 1977

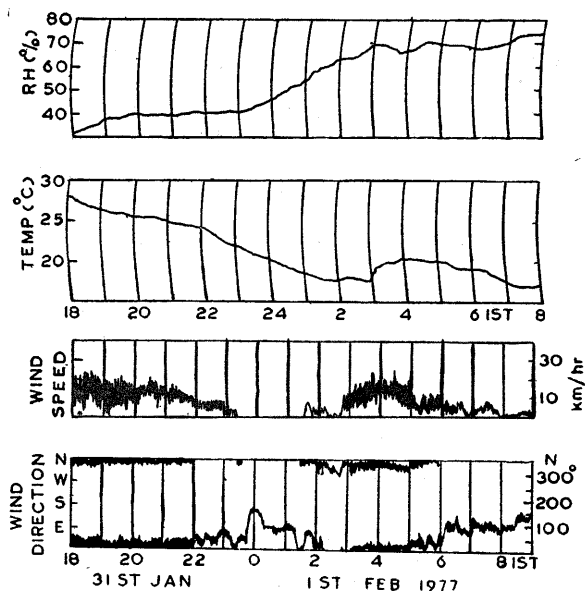


Fig. 3. Records of hygrograph and Dines P.T. anemograph for the night of 31 Jan-1 Feb 1977

from land, the frequencies are more and with westerly component, *i.e.*, wind from sea, the percentage frequencies decrease. Actually the wind from land is stable and favours development of inversion and opposite is the case with wind from sea. Similarly we can see that generally percentage of inversions will be less with higher wind speed and surface temperature.

3.6. A few interesting observations have been made while analysing the data in Fig. 1.

These observations are:

- (i) Strong vertical wind shear inhibits formation of inversions as on 27 January 1977.
- (ii) If winds at lower levels are from sea, *i.e.*, with westerly component, there is hardly any chance of inversion as on 31 March 1978 and 18 April 1978.
- (iii) Even when surface and adjoining layer winds are from land but are light and winds above are from sea, the chances of inversion formation are less as on 14, 18 and 24 January 1977 and 17 April 1978.

4. Growth and decay of inversion

4.1. *Vertical profile of inversion* — Unlike an inland station, the land and sea breeze circulation over Bombay causes certain amount of coupling and turbulence in the boundary layers even during night. The return current of land breeze circulation during night appears to cause cold air advection in the inversion layer over the station. The vertical profile of inversion may, therefore, get broken and become zig-zag type. Mukherjee and Daniel (1976) during their study of inversion over Bombay on a winter night have actually shown the inversion layer to be zig-zag type only.

4.2. *Growth and break-up of inversion* — Haurwitz (1941) while discussing nocturnal radiative cooling has stated that if wind starts blowing at the ground during nocturnal inversion it brings down potentially warmer air from layers above in the inversion layer. With the result the surface temperature rises (instead of falling) and the inversion weakens or breaks up partially or completely depending upon the strength of turbulence and surface wind. Manral *et al.* (1977) have studied such nocturnal rises in surface temperature over Bombay and have associated such rises with strong vertical wind shear. Daya

Kishan (1980) has, however, associated these nocturnal rises in surface temperature with the onset of strong and gusty land breeze. These studies suggest that over Bombay on some occasions the inversion gets weakened or broken partially due to onset of strong and gusty land breeze during night. Most of these cases occur in winter between mid-night and 0600 IST.

A typical case which occurred on mid-night of 28-29 Jan 1977 is given here (Fig. 2). Strong and gusty land breeze started by 2330 IST. The surface temperature rose by more than 4 deg. C. It can be seen that inversion between ground and 0.3 km was very weak. Due to the onset of strong land breeze the inversion nearly broke in the ground layer upto 0.3 km.

On the other hand if turbulence at the ground is associated with strengthening of mixed breeze during night, which dies out after some time, then the inversion once weakened will re-establish and steepen again after some time. A typical case is shown in Fig. 3. The surface wind became strong and gusty at about 0300 IST of 1 February 1977 and slowed down after 0600 IST. The surface temperature rose by 3 deg. C but after 0500 IST started falling again. The lowest was reached by 0730 IST. In this case the inversion between ground and 0.3 km does not appear to be broken down and it would be steepest around 0730 IST. Thus it is interesting to note that strong inversions over Bombay develop when winds are from land only, *i.e.*, land breeze type. However, if such winds pick up strength and cause turbulence at the ground these inversions weaken or break up partially or completely and such instances happen generally after mid-night till 0600 IST.

4.3. *Synoptic aspects* — From the radiosonde data of January-April 1977, the days when there was no inversion, the following synoptic situations were noted from *Indian Daily Weather Reports*:

(i) An induced low over Gujarat region or north Arabian Sea or a cyclonic circulation over Gulf of Cambay and adjoining areas.

(ii) A trough of low off Maharashtra, south Gujarat coast or cyclonic circulation over north

Interior Karnataka and adjoining south Madhya Maharashtra. Since a trough or low is associated with advection of unstable air over the areas it results in inhibition of inversion over the area.

Though these systems were located on other days also when inversion was present but then inversions were weak. In fact it can be inferred that the intensity and proximity of these systems to the station are mainly responsible for inhibition or formation of weak inversions.

5. Conclusion

(i) The percentage frequencies of occurrence of ground inversions over Bombay are maximum in the month of December, these are more than 90 per cent during the winter months of November to February. March also follows the same trend. However, there is a sharp decrease in hotter months of October, April and May, being least, *i.e.*, less than 20 per cent in May.

(ii) The thickness of inversion is less in winter months and more in summer months, being maximum in April, which is the second hottest month over the area. On the other hand the temperature rise in the inversion layer is more in winter than in summer. With the result the inversions are much steeper in winter than in summer.

(iii) The land and sea breeze circulations largely influence the growth and vertical profile of ground inversions over Bombay. The development of strong and turbulent land breeze during night results in weakening or partially/completely breaking up the inversion. Even the vertical profile is not continuous and is rather zig-zag and may be broken in between by lapse rate conditions as is clear from the actual observations made by Mukherjee and Daniel (1976).

(iv) The presence of a trough/low over the station or in its neighbourhood results in weakening or inhibition of inversions. Synoptically, well marked inversions over Bombay develop only when winds at lower levels are easterly, *i.e.* from land, in association with an anticyclone over the area.

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