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Temperature Inversions in the Planetary Boundary Layer

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Temperature inversions of several types have been observed over Patiala during initial phases of setting up of an acoustic echosonde in Aug. 1980. Surface-based inversions and elevated layers have been observed to be predominantly nighttime phenomena. The thickness of the surface-based inversion is found to be around 100 m while the elevated layers have thickness varying from 20 to 180 m with a peak of occurrence between 30 and 60 m. The surface-based layer rises after sunrise. The total structure in the morning is found to be correlated with radiosonde observations. The water vapour in the atmosphere seems to play a role in controlling the thickness and intensity of the surface-based inversions.

1. Introduction

Temperature inversions of several types are known to exist in the lower planetary atmosphere[1-5]. The most frequent ones are the ground-based inversions formed due to the radiative cooling of the earth's surface at night[6-13]. The thickness of the ground-based inversion is usually of a few hundred metres and gets dissipated generally a few hours after the sunrise[14-16]. Elevated inversion forms that next class of inversion[10,17,18]. Another class among the elevated layers is the trade wind inversion occurring at height between 400 and 3000 m particularly towards the eastern side of the oceans, being highest over the equator and lowest around 20° latitude in both the hemispheres[3].

Temperature inversions also develop in several other modes. The subsidence inversion is associated with a developing anticyclone or high pressure area[19]. A persistent anticyclone may lead to a persistent elevated temperature inversion. The localized inversions are common in a valley, as cold air mass gets collected near the ground. The salient feature of the temperature inversions is that the inversions inhibit vertical mixing which leads to the development of large atmospheric inhomogeneities including the accumulation of pollutants below and within the inversions[20-22]. Consequently radio communication is affected in a number of ways[23-31] including the range and elevation errors in radar trackings[32,33]. The meteorological conditions are considered to be important in the design of stacks of major industries, refineries and thermal and nuclear power plants[34,35]. Over the Indian subcontinent the study of inversions has been taken up using radiosonde and tower measurement techniques[36-38]. However, the information on statistics of the inversions round the clock by using high resolution devices is very limited.

A monostatic echosonde pointing vertically upwards has the capability to provide round-the-clock observations regarding the thermal structure and velocity parameters of the lower atmosphere up to a height of 2 km with a resolution of about 10 m. The echograms display visually the height and intensity variation of the ground-based inversion, height, thickness and intensity variations of elevated inversions and other associated phenomena. The height of the probe can be extended by using a laser beam, technically known as lidar[39,40].

At Punjabi University, Patiala, an acoustic echosonde has been in operation since July 1980 probing up to an altitude of 1 km. The echograms are recorded round the clock. The present paper deals with the study of temperature inversions observed over Patiala.

2. Observations and Data Analysis

The echograms recorded during 12 Aug. 1980-11 Sep. 1980 have been utilized for the present study. It is supplemented by the radiosonde data available from the India Meteorological Department Radio Wind Observatory located on the same roof at a distance of about 50 m. The echograms are scaled to yeild the various parameters related to the inversion on hourly basis.

Fig. 1 shows the diurnal variation of the number of hours of data recorded for each hour interval during

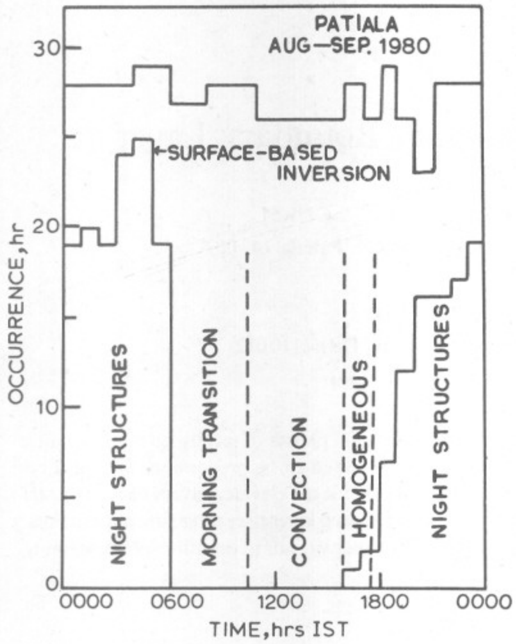

Fig. 1—Diurnal variation of the number of hours of data in each hourly interval during Aug.-Sep. 1980 at Patiala

the period Aug.-Sep. 1980. On an average 27 hours of data per hour have been recorded. The missing hours are mainly due to the power failures, rain and system maintenance operations. The occurrence of surface-based inversions is also marked in Fig. 1. There are occurrences of stable (inversions), unstable (plumes), homogeneous (no-structure) and mixed structures also. The mixed structure occurs after sunrise when the convection is capped by the rising inversion. It is seen that out of a total observational period of 654 hr the inversions prevail for a maximum number of times (53%). It is followed by convection (30.4%), mixed layer (15%) and homogeneous structure (1.6%) only.

Thus we have mainly three types of inversions, namely, ground-based, elevated and rising inversions.

3. Ground-based Inversions

The ground-based inversions were typically observed on radiosonde observation at 0515 hrs IST for several days. It shows that the height and intensity of the surface-layer have a high degree of variability (Fig. 2). The ground-based inversion may be completely missing on a typical night. The echosonde observations of ground-based inversions are shown in Fig. 3 [(a) and (b)]. A ground-based inversion is easily identified on the fascimile record as a dark continuous patch from the ground to a certain altitude, the upper boundary varying with time. The ground-based inversion once formed persists for several hours. On 2 Sep. 1980 (night) no other phenomenon in the upper region along the ground-based inversion has been observed; whereas for the night of 25-26 Aug. 1980 [Fig. 3(b)] shows the presence of elevated layers and wave motion at the top of the surface-based inversion. Here the ground-based inversion also shows a high degree of variability.

Of the total night structures observed at Patiala, surface-based inversions have been observed to occur for 60% of the time and its diurnal variation is shown in Fig. 1. It shows that the surface-based layer is predominantly a nighttime phenomenon with its maximum occurrence in the early morning hours. It remains attached to the ground but soon after sunrise it rises up slowly and gets detached from the surface. It evolves itself to an elevated layer and finally dissipates in a few hours after sunrise.

The diurnal variation of the average thickness of the ground-based inversion is plotted in Fig. 4, which shows that ground to 100 m is the thickness during pre-

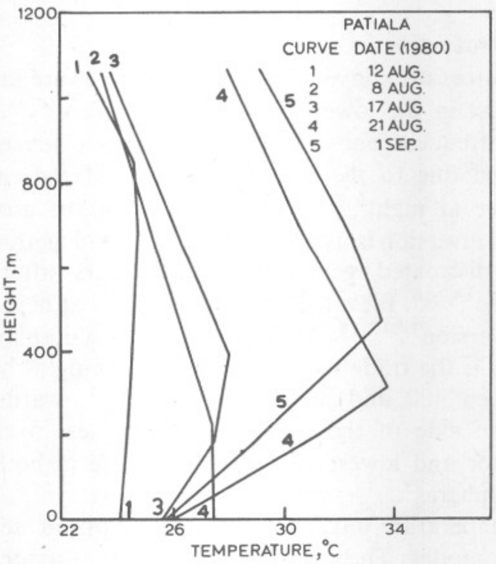

Fig. 2—Surface-based inversion as observed on radiosonde data

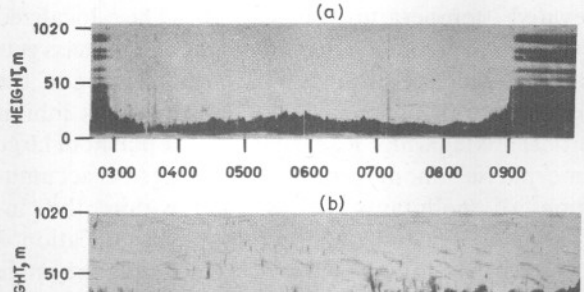

Fig. 3—(a) Variation in the thickness and intensity of the surface based inversion with time on 2 Sep. 1980; and (b) elevated layers and wave motions at the top of the inversion during the night of 25/26 Aug. 1980

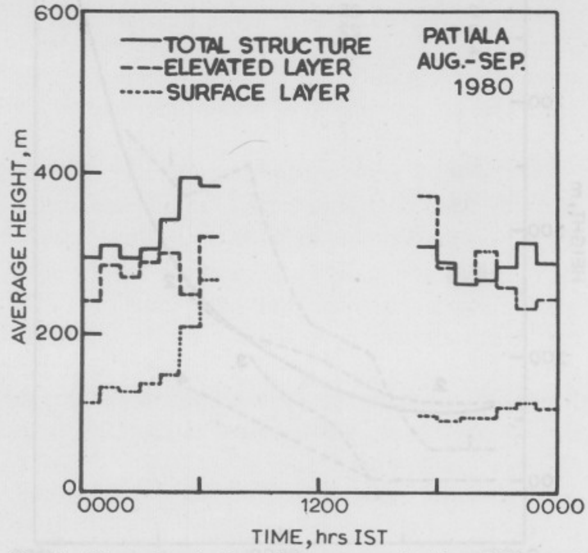

Fig. 4—Diurnal variation of the average height of the total structure, elevated layers and surface layers

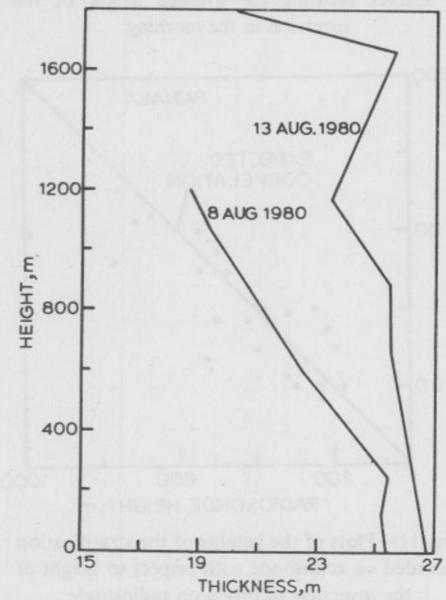

Fig. 5—Elevated inversion as recorded radiosonde data at Patiala

midnight period while during post-midnight it increases to 150-200 m.

4. Elevated Inversions

Fig. 5 shows the observation of elevated inversions recorded over Patiala using radiosonde observation. Fig. 6 shows the facsimile records of elevated layers. These can easily be recognized from the facsimile records as dark patches of some thickness extending upwards from certain heights. Fig. 6(a) shows a single elevated layer of varying thickness moving up and down. Fig. 6(b) shows a large number of elevated layers with varying thicknesses and intensities. In Fig. 6(b) several wave motions and instabilities associated with the elevated layers are also seen.

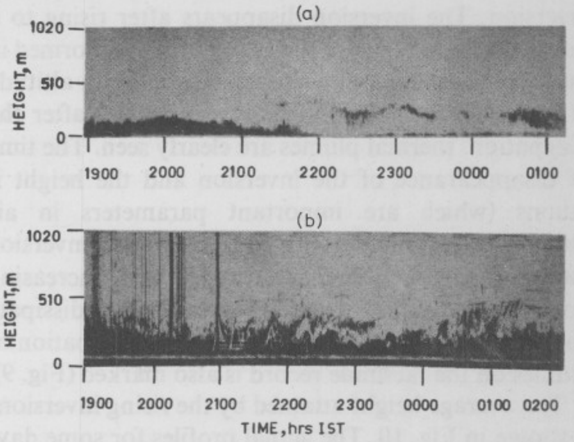

Fig. 6—Facsimile records of: (a) elevated layer of varying thickness moving up and down on 5 Sep. 1980; and (b) large number of elevated layers of varying thickness and intensities on 22/23 Aug. 1980

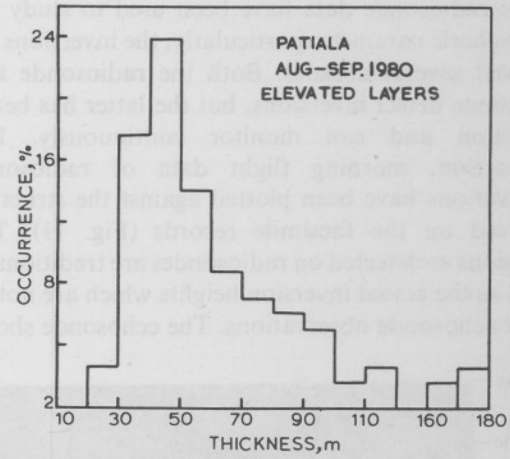

Fig. 7—Percentage occurrence of the thickness of the elevated layers in steps of 10 m

The elevated layer is also observed to be predominantly a nighttime phenomenon (Fig. 1) appearing soon after sunset with a peak of occurrence around midnight. It occurs usually with a ground-based inversion. There has been only rare occasions where only an elevated inversion occurs without any other temperature structure.

The variation of the height of the elevated layers is shown in Fig. 4. It shows that the height of the elevated layer is more or less constant within 250-300 m. The elevated layers are seen to move both upwards and downwards. After sunrise, the elevated layer rises slowly compared to the ground-based layer and hence, after sometime, both elevated and ground-based inversions merge into each other before dissipation.

The thickness of the elevated layer as observed for 113 samples is shown in Fig. 7. It shows that the thickness varies between 20 and 180 m with the most probable thickness being between 30 and 60 m.

5. Rising Inversion

Fig. 8 shows the rising inversions as observed on the facsimile records. The plumes are capped by the inversion. The inversion disappears after rising to a certain altitude. The surface-based inversion formed in the early morning hours rises slowly up to an altitude of around 600 m. Below the inversion and after the dissipation, thermal plumes are clearly seen. The time of disappearance of the inversion and the height it attains (which are important parameters in air pollution) are plotted in Fig. 9. It is seen that inversion attains higher and higher altitudes with increasing time. Most of the inversions are seen to dissipate between 0900 and 1100 hrs. The time of dissipation of plumes on the facsimile record is also marked (Fig. 9).

The average height attained by the rising inversions is shown in Fig. 10. The actual profiles for some days are also plotted. It shows that the slope of the rise increases with time.

6. Comparison with Radiosonde Observations

The radiosonde data have been used to study the atmospheric parameter particularly, the inversions for the past several decades. Both the radiosonde and echosonde detect inversions, but the latter has better resolution and can monitor continuously. For comparison, morning flight data of radiosonde observations have been plotted against the structure observed on the facsimile records (Fig. 11). The inversions as detected on radiosondes are traditionally taken as the actual inversion heights which are not so as per echosonde observations. The echosonde shows

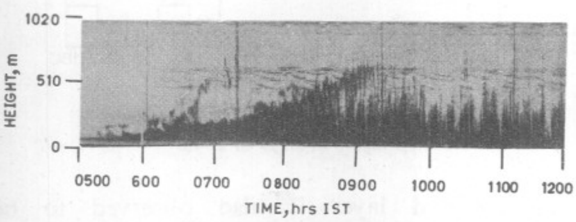

Fig. 8—Facsimile records of rising inversion rising up to an altitude of 600 m, and of thermal plumes after dissipation on 21 Aug. 1980

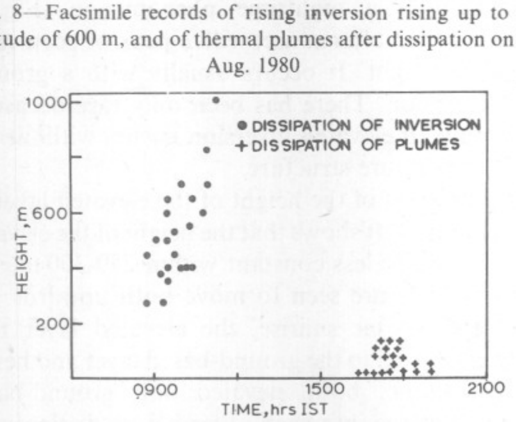

Fig. 9—Plots of height of dissipation versus time for inversions and plumes

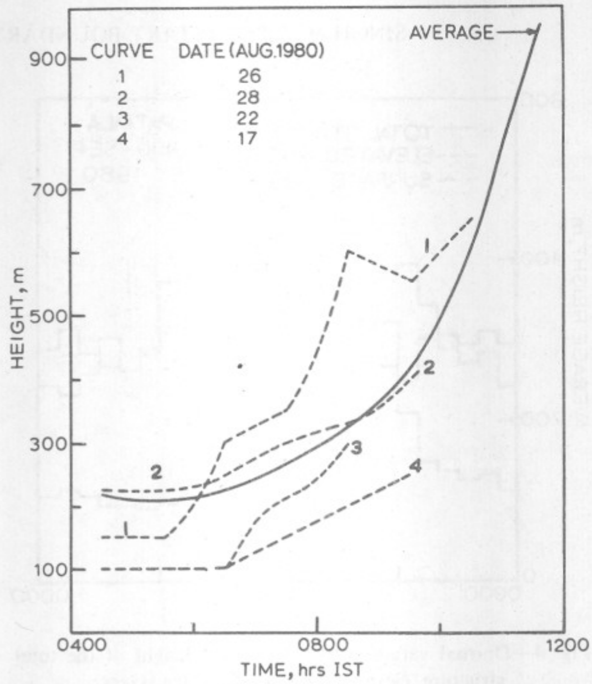

Fig. 10—Curves showing the average height of the rising inversion in the morning

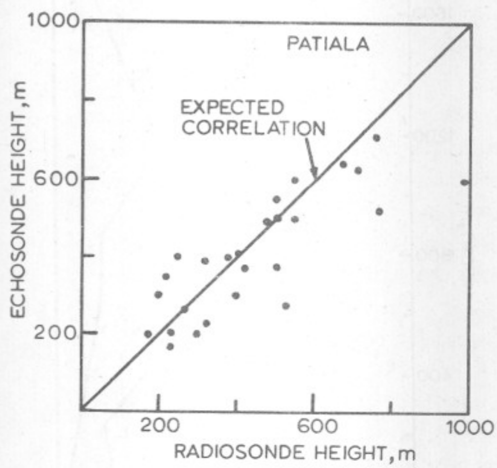

Fig. 11—Plots of the heights of the stratification recorded on echosonde with respect to height of the inversion recorded on radiosonde

that the surface-based inversions are not that thick over Patiala as could be inferred by radiosonde.

7. Discussion

During daytime the atmosphere is in convective state characterized by the appearance of thermal plume structure on the facsimile echograms. The unstable convective state of the atmosphere usually turns slowly towards stable condition as the night approaches. The changeover from convective to stable (inversion) conditions occurs in the following three ways.

(i) Generally the thermal plume activity diminishes in the evening and no echo returns are observed indicating the atmosphere to be homogeneous. The homogeneous condition then turns out slowly towards inversion.

(ii) On certain occasions thermal plume structure decreases to a lower altitude and it turns out to be an inversion layer of small thickness. This has been seen on days when the evening is marked by a cold wind on the ground or the fall in the temperature in the evening is abrupt.

(iii) On rare occasions the thermal plume structure is suppressed sharply at any time of the day (Fig. 12) and inversions, both ground-based and elevated, are developed. This has been observed on days on which a severe cold storm associated with rain has struck Patiala.

The ground-based inversion starts forming in the evening as the temperature near the surface decreases. With the temperature decrease the water vapour in the atmosphere condenses near the ground releasing the latent heat which in turn warms the atmosphere and the surface-based inversion either disappears or decreases in height and intensity. At Patiala the land is grassy all around, resulting in high water vapour content in the atmosphere during daytime. On a clear night as the cooling starts the air near the ground gets saturated and forms dew which is seen in the night as early as 2000-2200 hrs. The latent heat so released enhances the temperature of the air near the ground. This results in a very slow increase in the thickness of the ground-based inversions (Fig. 13). The night of 15/16 Aug. 1980 was very clear but humid at lower levels. The formation of surface-based inversion is a very slow process. On many occasions the ground air temperature has been observed to rise by 0.2° due to the condensation process of the air, and if wind blows

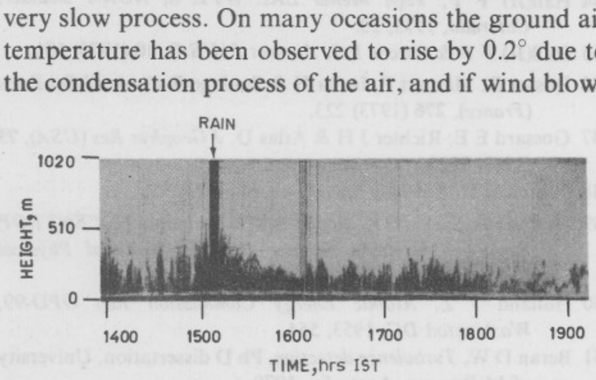

Fig. 12—Records of sudden suppression of thermal plumes due to rain on 30 Aug. 1980

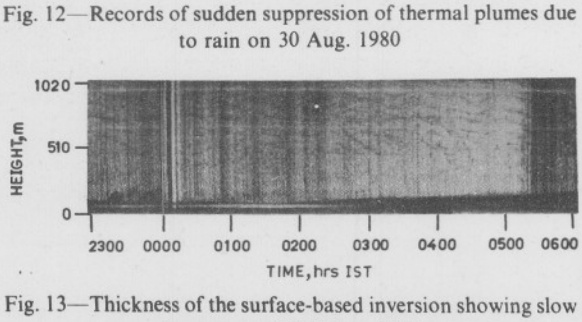

Fig. 13—Thickness of the surface-based inversion showing slow increase on 15/16 Aug. 1980

it cools the earth's surface due to the evaporation of the dew resulting in a strong inversion. Thus the presence of vegetation in a way inhibits the formation of inversion in a plane area.

The inversions are most predominant during winter and the pollution has also been observed to be maximum during this season[22]. The multiple layer echoes have been observed at most of the observing stations[11,17,41]. Frequently, wavelike undulations are observed in the multiple-echo returns. These undulations originate on KH-instabilities[42]. Kjelaas *et al.*[43] showed that these gravity waves propagate nearly with the speed and direction of the wind at the height of the waves.

The rising inversion after sunrise has been reported by many workers[6,7,44–46]. The rising envelop was termed as 'convective front' by Rosset *et al*[46]. Gossard *et al.*[47] and Emmanuel *et al.*[42] investigating the stable atmosphere observed that such dark streaks on FM/CW radar or echosonde could correlate with region of turbulence generated by the shear instabilities when $R_i < 0.25$. Hall[44] clearly observed that the shear instability turbulence is generated in this layer. Tennekes[48] has given models for the rising layer and its dissipation in the atmosphere.

The rising inversion has been observed to cause signal enhancement as high as 30 dB in the line-of-sight microwave communication links[23]. The rising layer can act as a reflector for microwave signal during its rise[49]. In the case of a rising inversion, inversion break-up and fumigation conditions are important parameters in the engineering design of power plant stacks and the short term ambient air quality standards[22,50].

The recorded structures are the result of temperature stratification or wind shears which result in the formation of a discrete mass of air having different temperatures to produce echo returns. These are observed only during nighttime with a peak of occurrence around midnight. Beran[51] detected frequent subsidence inversions using echosonde and Shaw[7] studied the subsidence inversions using both echosonde and radiosonde data. The elevated layer at around 1.5 km over Rajasthan has been observed to suppress convection and, therefore, inhibits the tendency for rising air current to form the clouds over the area[19].

8. Conclusion

The vegetation on the ground pumping a large amount of humidity into the atmosphere during daytime seems to be the important factor in controlling the thickness and intensity of the surface-based inversion at night. The ground moisture during daytime does not allow the surface temperature to go high. This observation leads to an important conclusion that in large cities vegetation should be given prime importance while planning a city, as the air pollution is essentially an urban problem. The echosonde shows the capability to detect several atmospheric features. The best use is to measure the temperature structure parameter C_T^2 and evaluate the heat flux.

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