Mausam, (1989), **40**, 2, 193-196

551.501.796 : 551.511

Studies of atmospheric boundary layer of Delhi using acoustic sounders at two locations

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(*Received 9 November 1987*)

सार — दिल्ली के वायुमंडलीय परिसीमा स्तर के अध्ययन के लिए जनवरी से मार्च 1986 के दौरान, 10 कि. मी. की दूरी पर स्थित किंचित भिन्न-भिन्न स्थलाकृति वाले दो स्थानों पर एक ही समय में दो अल्पशक्ति वाली एक स्थितिक सोडार प्रणालियों को काम में लाया गया है। इस सूचना को खतरनाक वायु प्रदूषण वाली स्थितियों के निदर्शन करने और मेसोस्केल गतिकों का अध्ययन करने के लिए उपयोगी माना जाता है। परिज्ञापन आंकड़ों को सतह पवन वेग और तापमान के मौसम विज्ञान संबंधी प्रेक्षणों द्वारा पूरा किया गया। इन आंकड़ों से ऐसे विशेष लक्षण दिखाई दिए हैं जो उदीयमान रात्रिकालीन प्रतिलोमन तथा परत के परिज्ञापनों दिवाकालीन संवहनी तापीय पिच्छकों, चपटे, छोटे तथा ऊंचे नुकीली चोटी की सतह पर आधारित रात्रिकालीन प्रतिलोमन संरचनाओं तथा प्रक्षुब्ध स्तरित, उन्नत और तरंगित संरचनाओं दोनों के लिए ही समान है। इन लक्षणों के विस्तृत अध्ययन में कुछ भिन्नताएं भी देखी गई हैं अर्थात् इन संरचनाओं की ऊंचाइयों में और दो स्थानों में उनके घटने के समय में अंतर देखा गया है। दो स्थानों पर विशिष्टताओं में प्रेक्षित भिन्नताओं का कारण स्थलाकृति और मध्यवर्ती मसोस्केल प्रवाह को माना गया है।

ABSTRACT. Two low power monostatic sodar systems have been operated simultaneously at two slightly different topographical locations 10 km distance apart during January to March 1986 to study the atmospheric boundary layer of Delhi. The information is considered useful in modelling hazardous air pollution situations and studying mesoscale dynamics. The sounding data were supplemented by meteorological observations of surface wind velocity and temperature. The data have exhibited characteristic features common to both the sounders of the rising nocturnal inversion layer, daytime convective thermal plumes, flat, short and tall spiky top surface based nocturnal inversion structures and turbulent stratified, elevated and wavy structures. A few differences in the detailed study of these features, *viz.*, in the heights of these structures and in the time of their occurrence at two sites have also been noticed. The observed differences in the characteristics at the two sites have been attributed to the topography and intervening meso-scale flow.

1. Introduction

An indigenously developed monostatic acoustic echo sounder system (Singal and Gera 1982) has been operating at the National Physical Laboratory (NPL) in west Delhi for the last many years. Through data analysis from this system, we have already demonstrated the potential of acoustic echo sounding to probe the atmospheric boundary layer and gain information about meso-meteorology (Aggarwal *et al.* 1980), weather nowcasting (Singal *et al.* 1984) and atmospheric stability (Singal *et al.* 1985) etc. Now in order to study the effect of topography on the height and structure of the thermal boundary layer, and to differentiate the propagation of meso-scale phenomena from local phenomena (on the sodar echograms in the form of elevated, multi-layer and wavy structures), we have installed another monostatic sodar system similar to the one already available at the National Physical Laboratory at another site in Delhi.

The new site is in northeast Delhi (Fig. 1) at the Central Pollution Control Board Laboratories, Mukherjee Nagar (MKN). The two stations are separated by about 10 km. Both places have almost similar acoustical environments, density of population and vehicular traffic. However, they have slightly different topography and soils; while NPL has low level hills covered with green vegetation towards southeast just beyond 500 m and vast open green fields interspaced with tall trees and building structures on the northeast up to 2 km, Mukherjee Nagar is surrounded by vast open fields in the northeast sector, river *Jamuna* in the eastern sector and in the southwest.

Both acoustic sounding systems have the same receiving sensitivity, operating at the same audio frequency of 2200 Hz and handling the same power. The acoustic antennae have ninety degree side lobe rejection of 55-60 dB compared to the main lobe. The recording is made in both cases on a moist electro-sensitive paper. The ambient noise at both the locations is more or less the same (average noise level during day time is 70 dB). Echoes scattered from thermal inhomogeneities in the height range of 700 m have been received.

2. Analytical studies of sodar echo structures

Acoustic sounder systems at the two sites have been operated simultaneously from January to March 1986. The observations pertain to about 1000 hours at each of the two sites spread more or less evenly over this period.

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In the following analysis, we discuss their broad common characteristic features as well as fine scale differences reflecting the effect of topography on the boundary layer structure.

In the morning due to the solar heating of the ground, the nocturnal surface based inversion layer erodes and starts rising as shown in the diagram (Fig. 2) with the formation of sharp spikes under it known as thermal plumes. With the passage of time the capping nocturnal inversion layer gets dissipated while the thermal plumes pervade all over the facsimile record. The height of the thermal plumes keeps on increasing till noon, remains more or less invariant till 1400 hours when it starts decreasing.

A study of the base height of the capping layer has been made with time. A look on the plot of Fig. 3 shows that the capping layer shows, on average, a rising trend at both the sites and erodes before noon (slight variations in level and slopes of the mean hourly observations can be seen which is most probably due to meagre data). However, a careful observation of the onset time of the capping inversion layer shows that it is different for the two sites. The onset time of the morning layer on a clear day is earlier at NPL site while on a foggy day, it is earlier at Mukherjee Nagar site with a corresponding effect on the dissipation time. The most probable delay period for the phenomena to occur is from one half hour to one hour although a delay of more than two hours has also been seen to happen.

A study of the maximum height of the thermal plumes has also been made. It has been observed that the mean height (maximum) of the thermal plumes is 145 m at NPL site while it is 165 m at Mukherjee Nagar.

During night almost daily a surface based layer, due to nocturnal radiation inversion, and with almost flat or short spiky top or tall spiky top, has been seen (Figs. 2 b & c) at both the places. An analysis of the observed structures shows that the mean height of the surface based layer generally increases with the passage of time, with the difference that the mean height of the nocturnal boundary layer at Mukherjee Nagar is almost uniformly higher by about 30 m at all hours of the night compared to the corresponding height at NPL site (Fig. 4). The regular increase in the height of the nocturnal boundary layer after a day of strong solar heating, is in agreement with expectations of model suggested by Blackadar (1957). It has been further seen that tall spikes occur generally in the early morning hours at Mukherjee Nagar site while they occur at any time of the night at NPL site.

Sometimes stratified and elevated layer structures, with or without undulations superposed over them, have also been seen during night time (Figs. 2 d & c) at both the sites. Stratified layers are considered to be associated with the presence of wind shear in the inversion boundary layer, while elevated layers represent advection of cold air mass, the top of the fog layer or the presence of strong wind shear of local or meso-scale origin. Studies of the structures on the two sites show that at Mukherjee Nagar stratified layers occur generally in the early morning hours while elevated layers occur at all times of the night time, on the other hand at NPL site both stratified and elevated layers occur only sporadically.

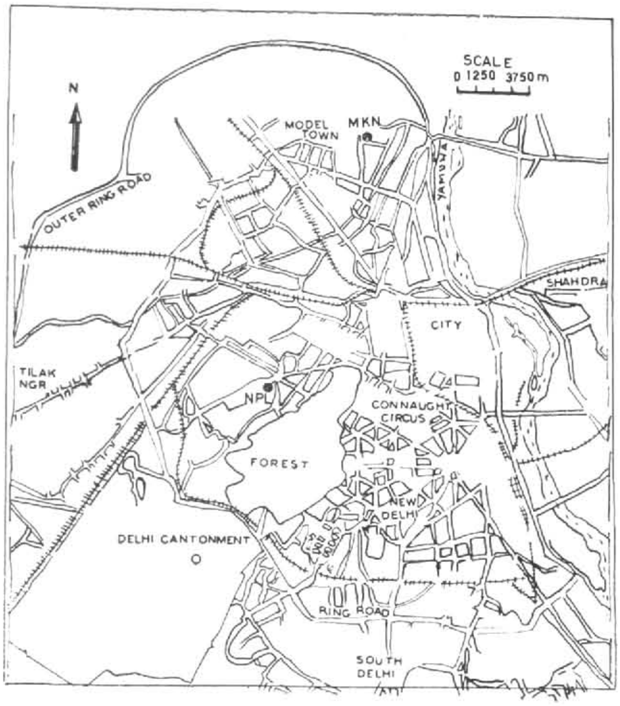

Fig. 1. Map of Delhi showing locations of the two acoustic sounders

3. Studies of meso-scale phenomena

As observed in the previous section, on the acoustic sounder the imprints of the passage of a meso-scale phenomena can be seen in the form of wide spread elevated, stratified or shear induced wavy structures. An elaborate study of these structures has been made and a typical case study is given in Fig. 5 to elucidate this study.

During the night of 28-29 Jan 1986 there has been sporadic rainfall with turbulent medium to light wind blowing alongwith the advection of cold air mass (temperature drop is in steps during the night). The nocturnal solar structures at the two sites show general similarities with the difference that the rainfall has been a little heavier and more frequent at NPL. This heavier rainfall has been responsible for suppressing the meso-scale flow at NPL after midnight, seen in the form of turbulent wavy structures above the surface based layer. However, it can be clearly seen that there is a delay of 65 minutes for the phenomena to be registered at Mukherjee Nagar. A theoretical estimate of this delay in case of the passage of a meso-scale phenomena has also been made on the basis of a knowledge of the geographical locations of the two sites in conjunction with the prevailing wind speed and direction at Mukherjee Nagar. This comes to 58 minutes, a value close to the observed delay.

Evaluation of time delay and flow characteristics of various other sodar observed meso-scale phenomena occurring during January to March 1986 have also been made for comparative studies. The data given in Table 1 shows that the observed and estimated delay times for all the cases agree within the limits of the assumption that the flow velocity of meso-scale phenomena and prevailing winds are the same.

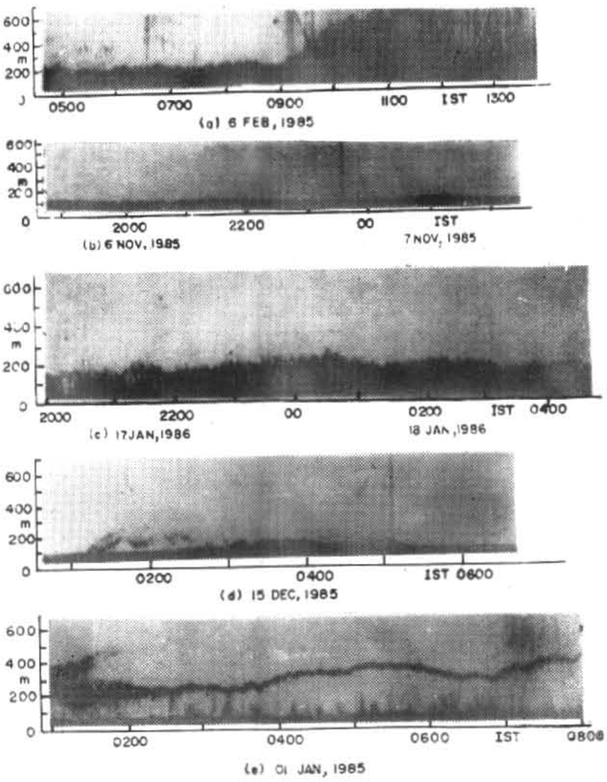

Fig. 2. Sodar echograms showing : (a) eroding nocturnal inversion layer and formation of thermal plumes, (b) flat or short spiky top surface based layer due to nocturnal radiation inversion, (c) tall spiky top surface based layer, (d) stratified layer structure and (e) elevated layer structure

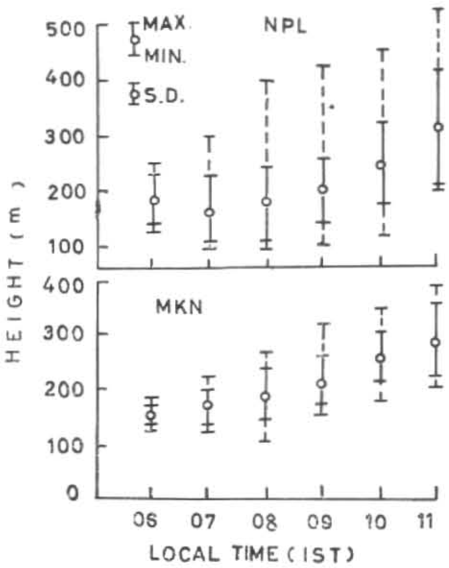

Fig. 3. Plot of the mean, standard deviation and maximum and minimum height of the eroding nocturnal inversion layer (morning capping layer)

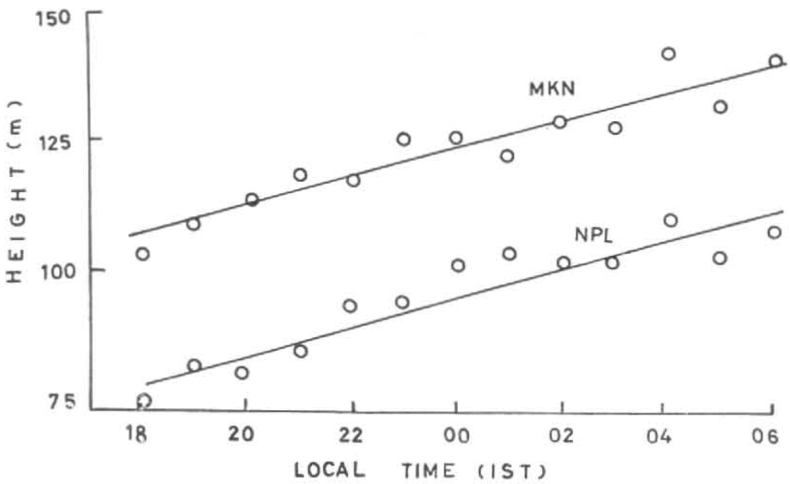

Fig. 4. Plot of the nocturnal boundary layer height as a function of time for both Mukherjee Nagar and NPL sites

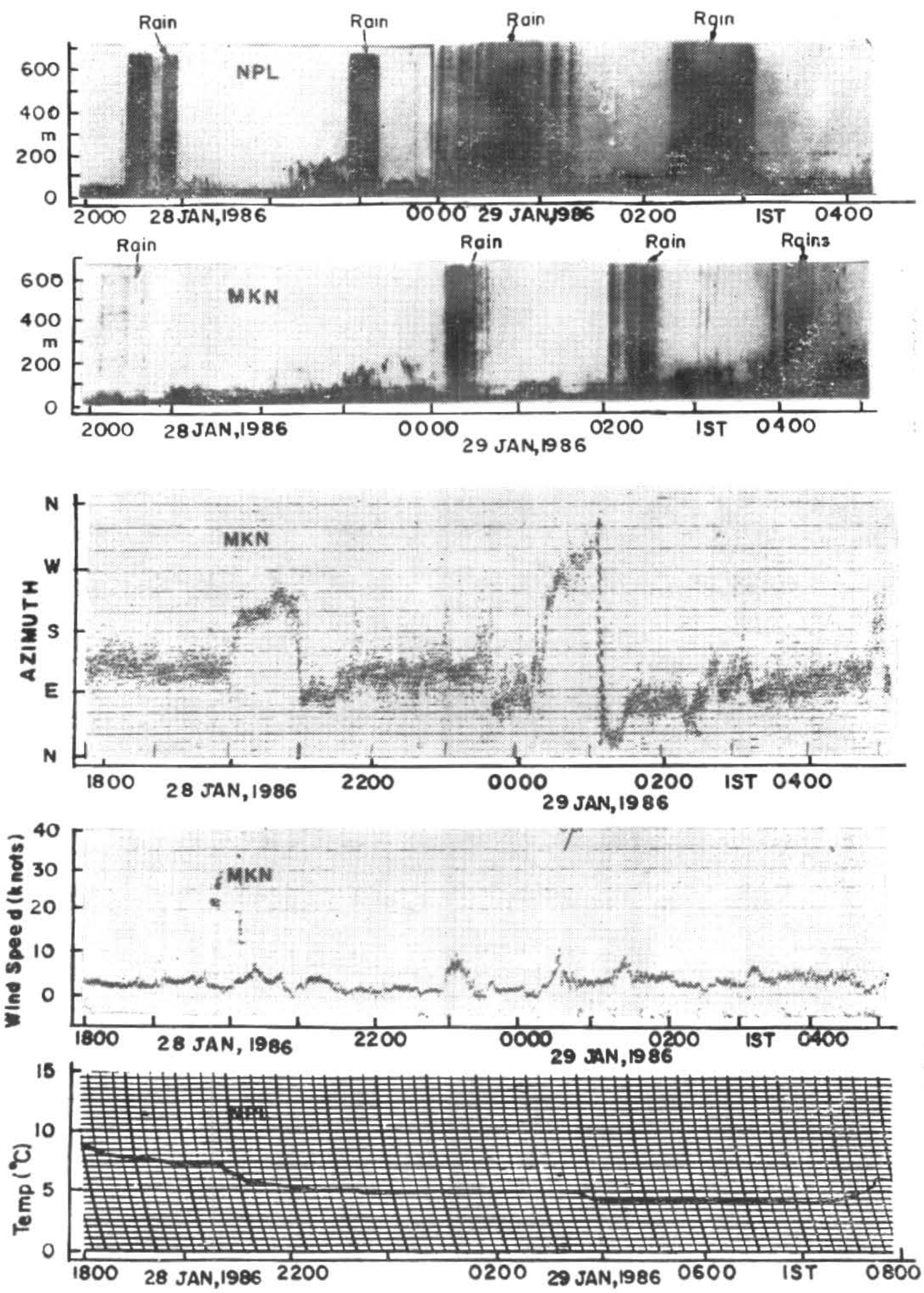

Fig. 5. Nocturnal sodar echograms recorded at NPL and Mukherjee Nagar sodar systems for 28-29 Jan 1986. Corresponding wind velocity and temperature plots at Mukherjee Nagar and NPL respectively are also given

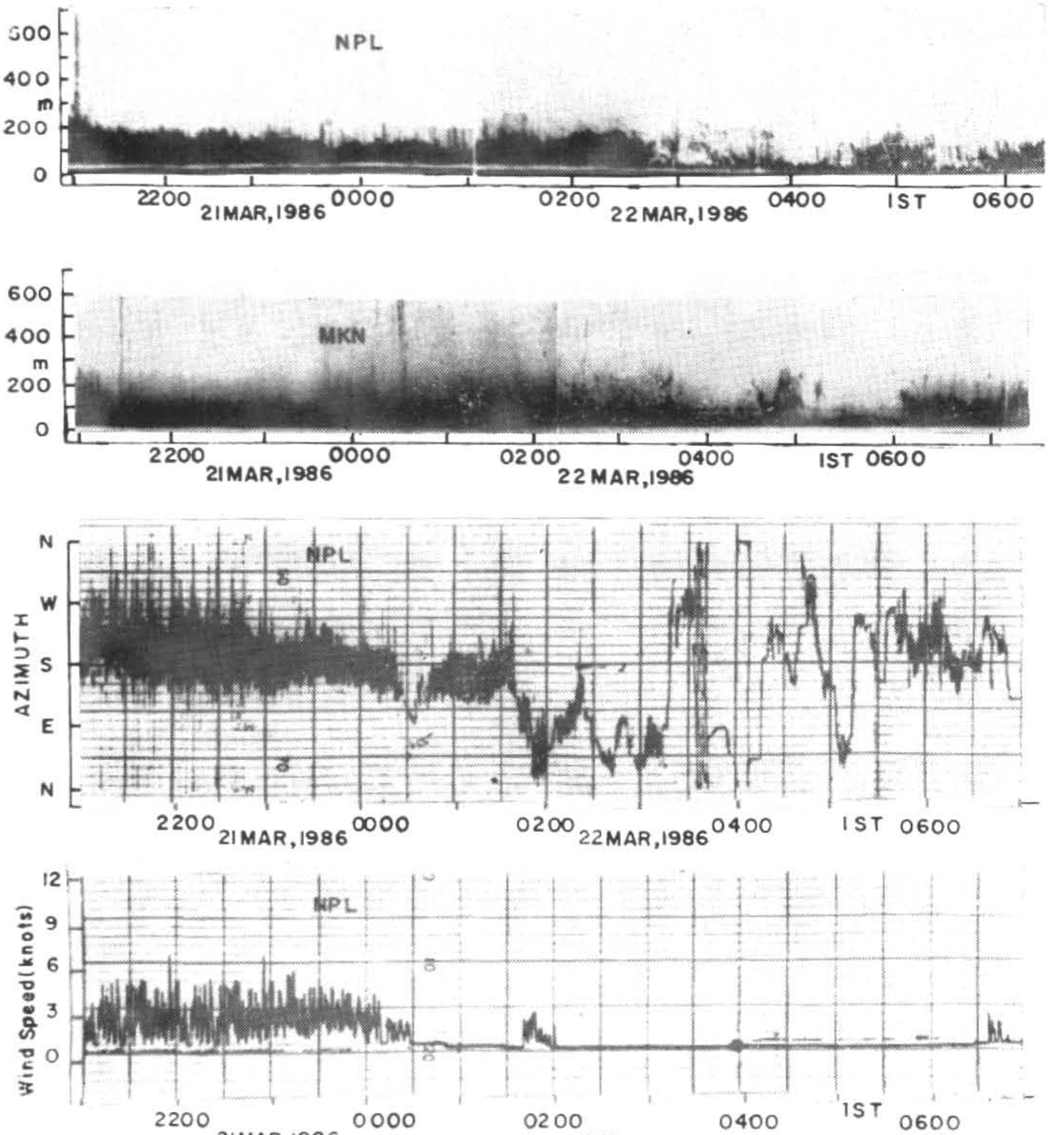

Fig. 6. Nocturnal sodar echograms recorded at NPL and Mukherjee Nagar sodar systems for 21-22 March 1986. Corresponding wind velocity plots at NPL are also given.

TABLE 1

Studies of propagation characteristics of sodar observed mesoscale phenomena

Date (1986)	Phenomena associated with	Time of obsn. at NPL (IST)	Wind velocity/speed (mps)/ Dir. (°)	Time delay for the phenomena at MKN (min.) Obs.	Cal.	Propagation velocity of phenomena between NPL and MKN (calculated from observed time delay) (m/sec)
28-29 Jan	Rain	2230	4/210°	+65	+58	2.57
13-14 Feb	Do.	2200	—	+20	—	4.15
	Do.	0330	—	—12	—	13.89
21 Feb	Changes in wind dir.	0700	5/100°	+18	+28	18.4
26 Feb	Do.	0500	3/200°	+45	+39	3.70
12 Mar	Do.	0410	4/60°	—69	—49	2.42
22 Mar	Do.	0200	6/180°	—18	—29	8.4

4. Discussion

The distinct changes in the simultaneously observed thermal structures of the two places reflect upon changes in their respective stability conditions due to different topographic conditions. In this respect, let us have a look of the nocturnal sodar echograms of 21-22 March 1986 at the two places alongwith a plot of the wind velocity for the same period at NPL (Fig. 6). It can be seen (*i*) that while due to gustiness of wind, NPL sodar echograms show formation of tall spikes on the top of the surface based layer structure up to 0200 hours, the same is not true for the Mukherjee Nagar sodar echograms and (*ii*) that while the NPL sodar echograms show wind shear structure upto a height of about 200 m during 0240 to 0600 hours in concurrence with the recorded wind direction changes (wind speed not gusty and practically low), Mukherjee Nagar sodar echograms show the structure only sporadically during the same time. Both of these observations indicate that stability conditions are different at the two places.

Structural changes as above are considered to be local in origin due to the prevailing different weather conditions at the two places. The phenomena associated with the behaviour can be the interaction of the ongoing wind with the underlying terrain as also the different nocturnal heat radiations for the vegetative and non-vegetative growth (green house effect), modifying, thus, atmospheric turbulence characteristics differently at the two places.

In the context of the above results, it will be interesting to know that Fanaki (1986) has also reported results of two vertically sounding acoustic sounders operated simultaneously at two topographically different locations in Canada on the Syncrude site, west of the *Athabasca* river. One sounder was located at the lower Syncrude site near the frozen *Athabasca* river while the second sounder was located at the Mildred lake airstrip, 4 km northwest from the first sounder. The second sounder was thus situated 100 m higher than the first one. The topography around the sounder sites was slightly variable ranging from undulating to rolling land. The land was covered with trees averaging 15 m in height. It was observed from the data exhibited by the two sounders that a number of features were common characterizing the type of topography the sounders were situated in, while at the same time, the echograms showed a few differences close to the ground in the lower 300 m layer. The sounder echoes at the Syncrude site were denser than the one at Mildred lake considered to be due to mixing caused by wind, being more pronounced at the latter site. Further, the level of inversion layer was less than that observed at lower Syncrude, accounted to the two sounders being situated at different elevations, recording thus different heights for the same thermal turbulent atmospheric structure. Fanaki (1986) has, thus, considered heterogeneity of the atmosphere and terrain at the two acoustic sites to be responsible for the differences in inversion heights and behaviour, an observation which is considered to be responsible for the reported results also.

5. Conclusion

From the above studies it has been clearly seen that the atmospheric boundary layer at a place depends strongly on its topography. The topography of the two sodar sites, Mukherjee Nagar and NPL, have been slightly different although all other features were similar. These topographic changes have been responsible for a difference in the depth of the boundary layer as also for the relative onset time of the eroding nocturnal inversion layer. Topography has also been seen to affect the stability of the place.

It has also been seen that the establishment of two sodar systems at two different sites can be helpful to study the characteristics of a meso-scale phenomenon. In this context it can be stated that the establishment of another sodar system in another corner of Delhi representing three corners of a triangle, can be further helpful to study the origin of meso-scale flow and its other characteristics.

During the course of the analysis it has been found that it is very difficult to segregate the local weather effects from the imprints of meso-scale flow. The lack of adequate meteorological data at the local level has been strongly felt. At the initial stages it is considered that temperature, wind velocity and humidity measurements at three heights by sensors mounted on a mast at each of the places can be of help to understand and quantify the turbulence involved in the observed phenomena and the extent of similarities and differences to be expected on the sodar echograms at the two places.

Acknowledgements

The authors are thankful to the Director, National Physical Laboratory and Chairman, Central Pollution Control Board for encouraging us to carry out the studies of the boundary layer of Delhi. Thanks are also due to Dr. A. P. Mitra, Director General, CSIR for his continuous support and inspiration to carry out the above studies. They are also thankful to Mr. D.R. Pahwa and Dr. S. K. Aggarwal for helping them during the course of the work.

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