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Heat island study over Madras city and neighbourhood

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सार — चलते-फिरते सर्वेक्षण के द्वारा मद्रास और उसके आस-पास के क्षेत्रों में सतह ताप के आधार पर आर्द्रता और पवन के 77 स्थलों से आठ दिनों से अधिक के आंकड़े एकत्रित करके मद्रास में ऊष्मा द्वीप की विशेषताओं का मूल्यांकन किया गया है। अधिकतम उष्मा द्वीप की तीव्रता लगभग 4°C पाई गई है। आर्द्रता प्रतिमान समुद्री प्रभाव के अतिरिक्त ऊष्मा संचयिका के ऊपर न्यूनतम दिखाई पड़ा। शहरी क्षेत्रों में ग्रामीण क्षेत्रों की अपेक्षा मिश्रित ऊंचाई अधिक पाई गयी है। जो यह दर्शाता है कि शहरी क्षेत्रों में ग्रामीण क्षेत्रों की तुलना में अधिक मिश्रित गहराई होने के कारण प्रदूषण की कम संभाव्यता है।

ABSTRACT. Based on surface temperature, humidity and wind data collected from 77 points over a period of eight days in and around Madras using mobile surveys, the heat island characteristics at Madras have been assessed. The maximum heat island intensity is seen to be about 4°C. The humidity pattern apart from showing maritime influence also indicates a minimum over the heat pocket. The mixing height is found to be more over urban area than over rural area indicating lower pollution potential over the former due to the mixing over a larger depth than in the latter.

Key Words — Heat island, Air pollution, Mixing height.

1. Introduction

The study of urban climatology is a relatively recent field of climatology. It has developed as a result of man made inadvertent climate modification (Duckworth and Sandberg 1954, Holzworth 1967, Munn 1970, W.M.O. 1986). Such inadvertent modifications mainly arise due to population concentration, rapid urbanisation and industrialisation and due to development of dense mass transportation systems.

Studies over various parts of the globe established beyond doubt that urbanisation causes changes in the atmosphere immediately adjacent to them.

In general almost all the meteorological parameters such as temperature, humidity, wind, rainfall, net radiation are modified due to urbanisation. Also they affect the low level lapse rate, and result in updraft, turbulence etc. The fact that some places are warmer in a city than its surroundings forming a "heat island" is well-known. The effect of urbanisation on temperature field has been studied in great detail by various workers in India for some of the principal metropolitan and industrial cities. The following section gives a brief resume of earlier heat island studies carried out over India.

2. Earlier studies over India

Mapping of the urban temperature fields were undertaken, perhaps, for the first time in India during 1973 over the industrial city of Pune by Daniel and Krishnamurthy (1973) and the metropolitan city of Bombay by Philip *et al.* (1973) using mobile surveys in winter months around the minimum temperature epoch.

Maske *et al.* (1978) extended the study for Pune and analysed the characteristics of the heat island. Mukherjee and Daniel (1976) studied the temperature distribution on a cool night over Bombay which included the study of vertical temperature distribution based on TV tower observations and routine RS/RW observations. Bahl and Padmanabhamurthy (1977, 1979) studied the heat and humidity islands at Delhi by mobile surveys. Krishnanand and Maske (1978) also undertook similar studies for Delhi by extending the observation over different months.

Sastry (1982) studied such effect in the case of the industrial city of Visakhapatnam. Pradhan and Menon (1986) studied the heat island effect over Bhopal and indicated that even over a small city like Bhopal the effect of urbanisation is pronounced and temperature intensity over the heat island was found to be of the order of 6.5°C during the winter months.

Padmanabhamurthy (W.M.O. 1986) has analysed the isotherms and isopleths of dew point temperature on a typical day at Calcutta during the winter month, February 1977.

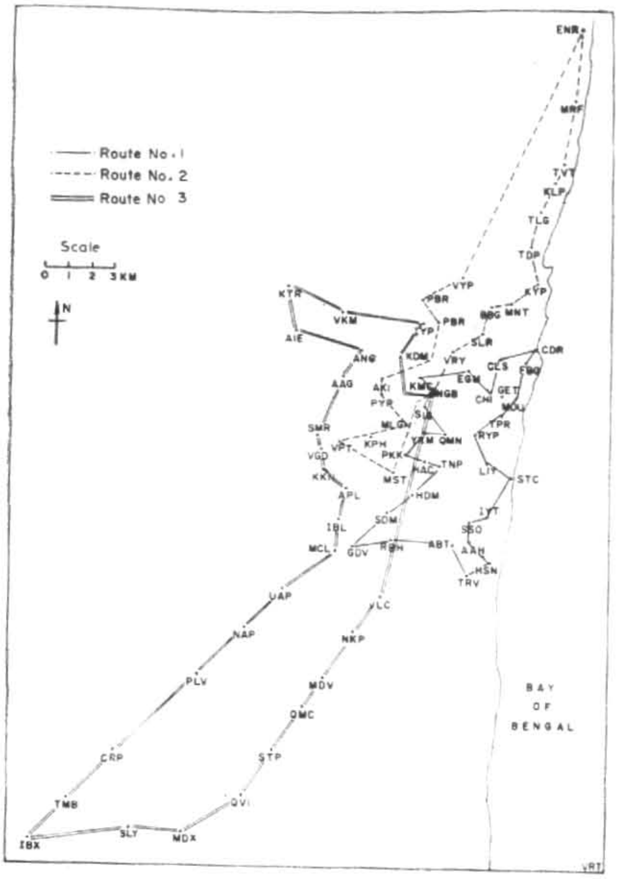

Fig. 1. The mobile survey routes and the observational points

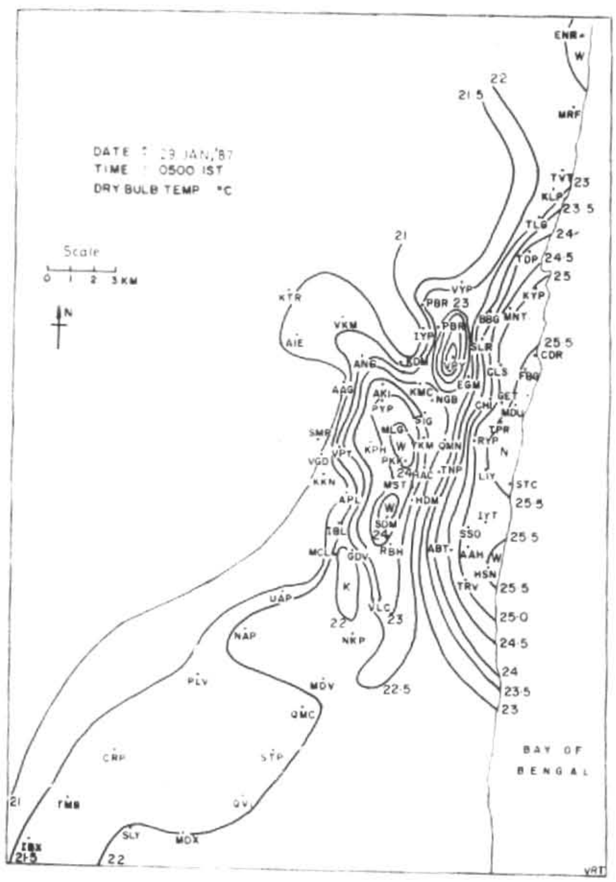

Fig. 2(a). Isothermal pattern of 29 January 1987

In all the above studies existence of warm pockets and cool pools has been indicated. The magnitude of heat island intensities at these places vary from 0.6°C over Visakhapatnam to 10°C over Pune and to 11°C over Bombay, the intensity, size, shape and position of warm pockets depending upon the topography, urban morphology, proximity to large water body, stability, intensity and depth of surface inversion, wind speed, etc.

However, no such study has been undertaken so far over Madras city which is the fourth largest metropolis in India.

3. A brief description of the Madras metropolis

Madras, a comparatively new city, owes its genesis to Andrew Cogan and Francis Day of the British East India Company, the settlement being founded nearly three and a half centuries ago.

The development of Madras metropolis was very rapid between the early 60's and 80's of this century. But unfortunately, Madras city is also criticised as the city of unplanned growth which if continued would have disastrous effects on the rural environment and economy. The proper application of climatology in land use, urbanisation and building design can contribute to improved human health, environment, energy usage and other social and economic benefits.

Inspite of so much urbanisation in Madras, unlike other metropolitan cities like Calcutta, Bombay and Delhi, this city is still open to the skies and in some ways still seems a small town that has just kept spreading. If the urbanisation is checked and regulated properly it can still continue to maintain its environmental qualities. The present paper discusses the heat island study taken up over Madras city during a few winter days of 1987, to find out the effect of present urbanisation over Madras. This information will be useful for future planning and guidance.

4. Observational details

4.1. *Surface observation*

The effect of "heat island" will be at its maximum in the coldest season and around the minimum temperature epoch when clear skies, light winds and poor dispersion conditions prevail. Further, to study the heat island effect, close network of observatories needs to be established so that simultaneous observations can be made at all points. However, this requires considerable manpower and equipment. In the absence of such facilities the best alternative would be to conduct mobile temperature surveys during the period of time when the temperature curve is flat.

Keeping this in view, the temperature surveys were conducted for select days in January and February 1987

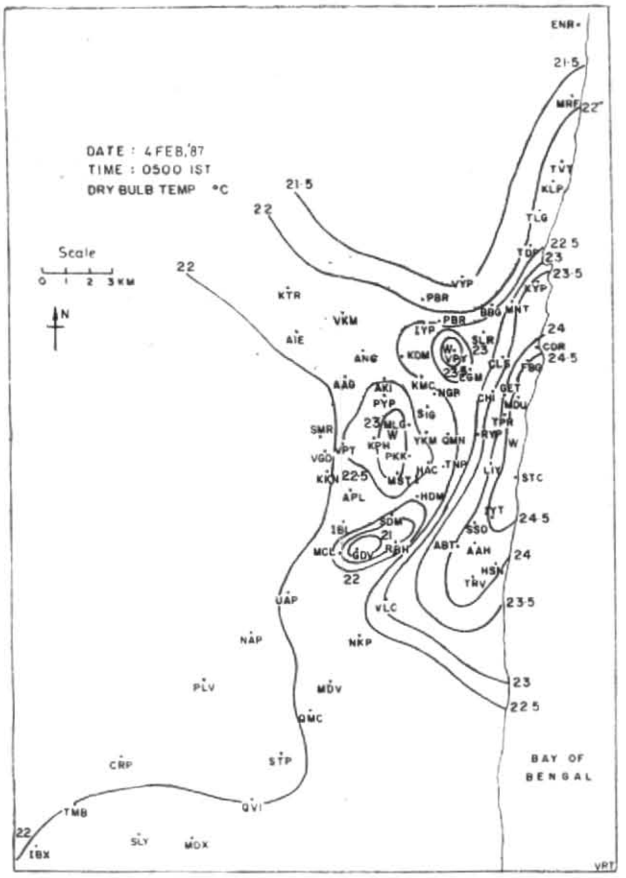

Fig. 2(b). Isothermal pattern of 4 February 1987

numbering, in all, eight days. Three mobile teams conducted observations of temperature, humidity and wind at three different routes using portable anemometer and windvane for wind speed and direction and whirling psychrometer for dry bulb and wet bulb temperatures and humidity calculations. Observations were taken at 77 points in and around Madras city on each day. Fig. 1 gives the routes of the mobile survey and also indicates the observational points.

The three teams started simultaneously from the Nungambakkam Observatory around 0330 IST after intercomparing their whirling psychrometers with the screen thermometers and all the three surveys ended also at Nungambakkam (Obsy). Further one of the mobile surveys also compared the mobile surface observations and the screen thermometer observations at Meenambakkam Observatory every day.

4.2. *Upper air soundings*

It is well known that the lower atmosphere up to the first few metres is affected due to differential heating. This urban boundary layer modification is also often reflected in the vertical temperature profiles. Also the study of ground layer inversions has assumed great importance due to the increase in air pollution concentration in these layers.

With this in view upper air observations of temperature and wind were also taken for this period. But here again due to logistic problems, upper air meteorological data were obtained from two observatories at Meenambakkam and Nungambakkam only. The routine radiosonde ascents are taken normally at Meenambakkam airport. Normal ascents are taken with balloons with too high a rate of ascent 20 km/hr which do not permit obtain the fine structure of temperature variation in the lower layers of the atmosphere. Hence special radiosonde ascents were taken with a slow rate of ascent of about 7 km/hr on the same days chosen for surface observations .The ascents were taken only up to 700 hPa (3.1 km) utilising special low level sondes with expanded pressure scale.

While a special radiosonde receiver was established at Nungambakkam for temperature/humidity observations, the wind observations were obtained by tracking the balloon optically.

Simultaneous ascents could not be taken due to interference of radiosonde signals from the two sondes. Therefore staggered ascents were taken, starting the ascents at 0300 IST at Nungambakkam and at 0345 IST at Meenambakkam. The time difference between these two ascents is not likely to make the observations uncomparable, as during the early morning hours, the meteorological parameters are normally stable and there is very little variation with time.

5. Discussion of the results

5.1. *Horizontal temperature distribution*

Figs. 2(a & b) give the isotherm analysis on 2 typical days of the survey days. The temperature readings, both dry and wet bulb taken by whirling psychrometer were first corrected with reference to the Stevenson screen thermometers. The mobile surveys in all the 3 routes were completed during a period $2\frac{1}{2}$ hours starting from 0330 IST and ending at about 0600 IST. The temperature values were reasonably approximated to one common time at 0500 IST to obtain a simultaneous temperature pattern. For this, small time lag corrections if required were applied based on the trend in the temperature changes as indicated by autographic charts of Nungambakkam and Meenambakkam.

5.1.1. *Heat pockets*

Examination of these figures indicates that the isotherms tend to run parallel to the coast and, perhaps, as a result of the maritime effect, the temperature shows a decreasing tendency from coast to land. Apart from this general pattern, the isotherms clearly indicate the establishment of a heat island over the built up and congested areas. The temperature differences between the periphery and central areas of the heat pockets are of the value 1.5° to 2.0° C on all the survey days, while the maximum intensity being 4.0°C.

The above figures indicate distinct heat pockets in the city area, the first around Mambalam and the second around Vepery and the third around Ennore industrial area.

Analysis of temperature patterns on all the 8 days indicate consistency, showing the location of the heat islands at almost the same places during all these survey

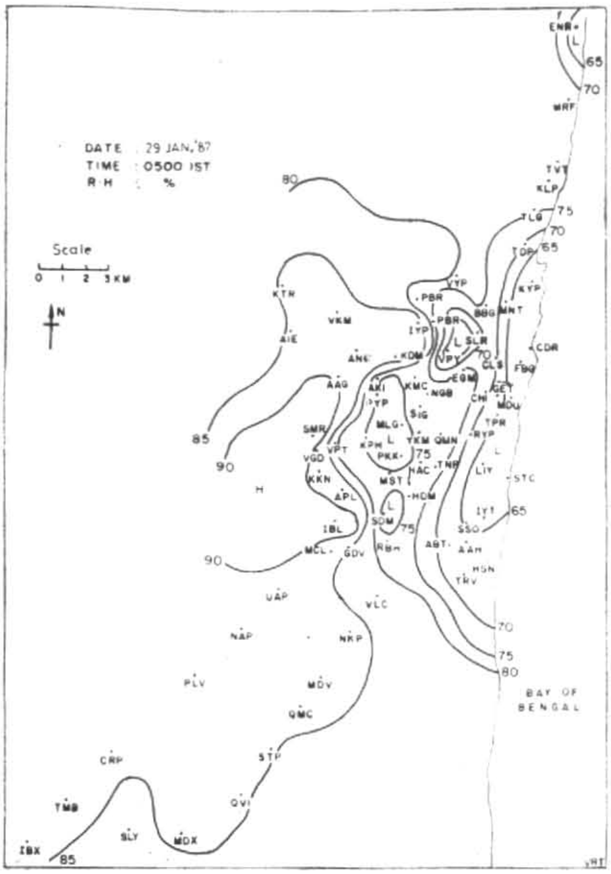

Fig. 3(a). Isohume pattern of 29 January 1987

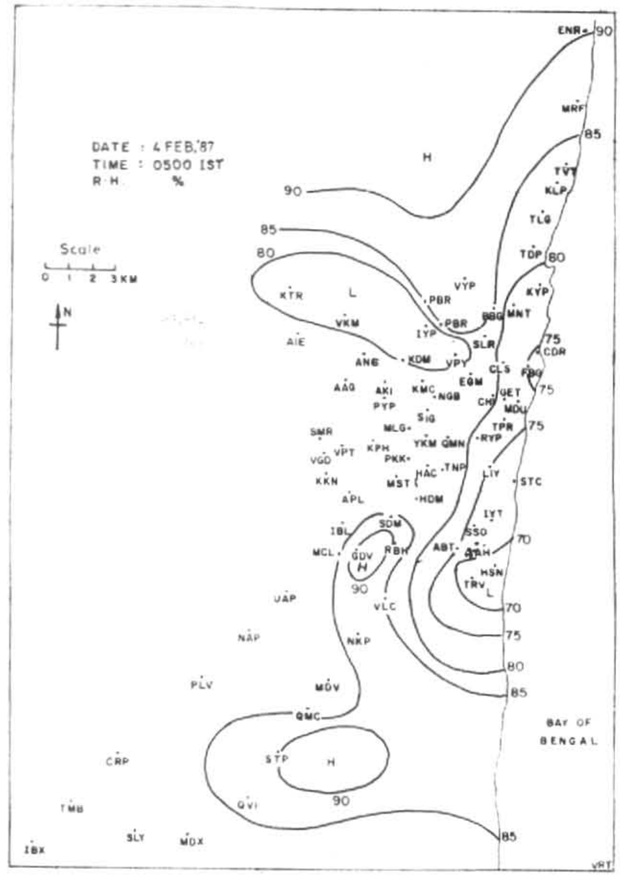

Fig. 3(b). Isohume pattern of 4 February 1987

days, though there are slight day-to-day variations in the extent of the heat pockets.

5.1.2. *Cool pools*

It is interesting to note that the survey has brought out the cooler land temperature adjoining the well ventilated and comparatively open areas. One such distinct cold pocket is seen in the area near the Raj Bhavan, Guindy which is quite expected considering the vegetative cover and vast open areas.

5.2. *Humidity distribution*

Humidity contrasts are quite important in determining the comfort conditions in the tropics. Figs. 3(a & b) depict the isohumes, *i.e.*, isopleths of relative humidity, on those mobile survey days. The isohumes pattern indicates a pattern opposite to that of isotherms showing maximum humidity value over the interior, decreasing towards the coast. Also, the heat pockets in general correspondingly show a minimum humidity value while the cool pools show higher humidity value.

5.3. *Surface wind*

The wind observations were taken with a portable windvane and an anemometer. On almost all the days the spot observations indicated calm conditions. Only a few spots on some days indicated winds of value less than 4 knots.

5.4. *Vertical temperature distribution*

Figs. 4(a & b) give vertical temperature distribution for these days of observations both for Meenambakkam and Nungambakkam.

In general, the upper air temperature observations at Nungambakkam which is within the Madras city indicate that the air over Nungambakkam is much warmer than the air over Meenambakkam area, located in rural neighbourhood of Madras city in the planetary boundary layer within 1.5 km. This feature was present on all the 8 days. Perhaps, this aspect is to be attributed more to the maritime influence than to urban effect. But as regards the near surface boundary layer temperature structure, though some of the earlier studies (Duckworth and Sandberg 1954, Clark 1969) were suggestive of the urban induced temperature modifications, the present data is insufficient for clear identification of any such urban induced modification in the vertical temperature profiles.

5.5. *Inversion layers*

The study of boundary layer inversions has assumed great importance due to the increase in air pollution concentration in these layers due to high industrialisation and urbanisation.

From the temperature profiles given under Figs. 4(a & b) it is seen that multiple elevated inversions are

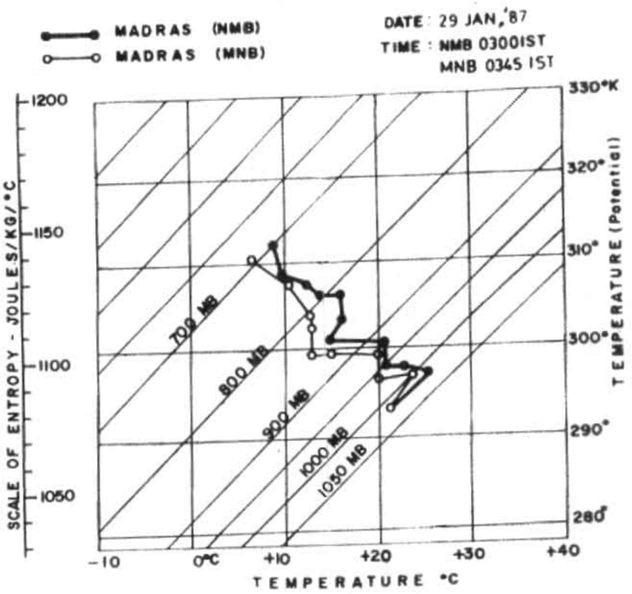

Fig. 4(a). Low level temp. profiles of rural and urban area (29 January 1987)

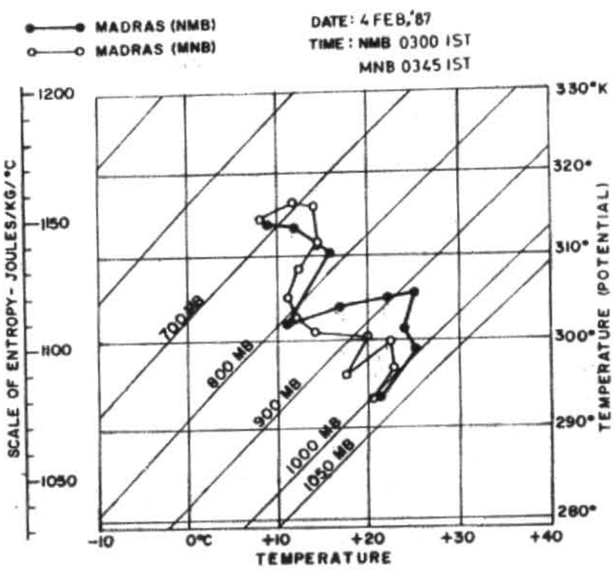

Fig. 4(b). Low level temp. profiles of rural and urban area (4 February 1987)

TABLE 1

Low level negative lapse rate in the inversion layer

Date (1987)	Nungambakkam (°C/100m)	Meenambakkam (°C/100m)
28 Jan	2.5	0.6
29 Jan	2.0	1.9
30 Jan	2.5	0.6
31 Jan	5.0	0.4
3 Feb	1.2	0.9
4 Feb	1.9	2.5
16 Feb	1.2	0.6
17 Feb	2.0	1.7
Mean	2.3	1.2

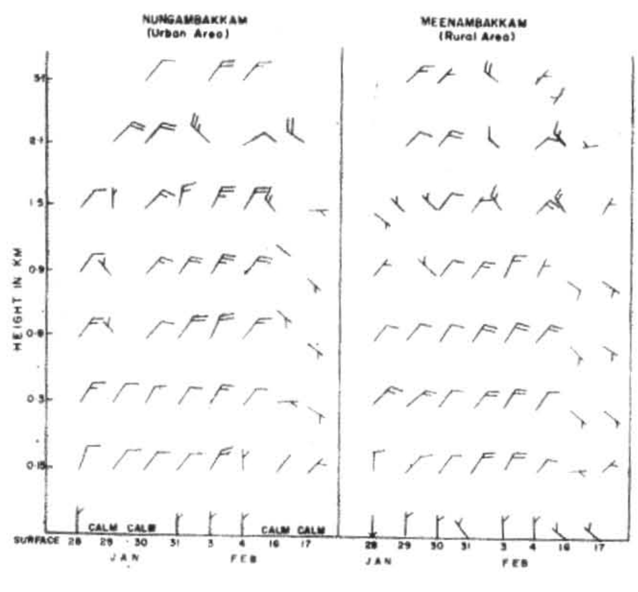

Fig. 5. Vertical distribution of winds

present over the urban area (Nungambakkam) on many days when compared to the near rural neighbourhood (Meenambakkam). Such characteristics were also reported by Davidson (1967) and Duckworth and Sandberg (1954) over New York and San Fransisco respectively.

5.6. *Lapse rate*

Table 1 gives the negative lapse rate in the lowest (inversion) layer both at Meenambakkam and Nungambakkam on all the survey days.

Comparison of lapse rates on all the days of the survey indicates that the lapse rate very close to the ground is being always more over the urban area (Nungambakkam) than over rural area (Meenambakkam). The mean value of the former is 2.3°C/100 m more than double that over the latter (1.2 °C/100 m). Above this layer there is a layer of near dry adiabatic lapse rate over both the rural and urban areas as seen from Figs. 4(a & b).

5.7. *Upper level wind in the lower tropospheric levels*

Fig. 5 gives vertical profile of the upper winds up to 3 km on the days of mobile survey at Nungambakkam and Meenambakkam.

Comparison of the wind observations does not indicate any marked difference between the rural and urban areas However, up to 0.6 km the winds are slightly stronger over the rural area than over urban area.

5.8. *Mixing height characteristics*

One of the causes of high concentration of pollutants is the low dilution capacity of the atmosphere. The dispersal capacity of the atmosphere in the vertical can be well understood from a knowledge of the mixing heights. The height through which such mixing extends depends primarily upon the initial vertical temperature structure and the heat input at the surface. Mixing heights are rarely measured directly but can be indirectly determined from the vertical temperature distribution with the assumption that in a thoroughly mixed unsaturated atmosphere the temperature lapse rate is dry adiabatic (Holzworth 1967, Padmanabhamurthy and Mandal 1981). Based on the temperature comparison between the heat pockets and the other areas an overall average value of 4°C may be added arbitrarily to the urban surface temperature to allow for the temperature gradient due to heat island effects (Padmanabhamurthy 1984). The actual graphical calculation can be seen in Holzworth (1967) & Munn (1970).

In the present paper mixing height is calculated pertaining to the mean temperature, *viz.*, (max+min)/2 instead of calculating either morning or afternoon mixing temperature of the day.

Calculation of the mean mixing heights averaged over the 8 survey days indicates a value of 135 metres over Meenambakkam and 170 metres over Nungambakkam. Over the urban heat pockets the estimated mean value is 410 metres indicating the distribution of pollution concentration over a larger depth in the urban induced heat islands than over the rural area.

6. Conclusions

The heat island study over Madras indicates the following features :

(*i*) There are distinct heat islands numbering three over the thickly populated commercial and industrial areas.

(*ii*) There is a cool pool over relatively ventilated and vegetative area.

(*iii*) The humidity distribution indicates opposite pattern showing low values over the heat pockets and high over cool pool.

(*iv*) The difference in temperature between the core and peripheral value of the heat island at the surface is generally of the value of 1.5° to 2.0°C. the maximum intensity being 4°C.

(*v*) The urban area shows multiple elevated inversions.

(*vi*) The mixing height is more over the heat islands when compared to rural areas.

(*vii*) The lapse rate in the lower layer which is negative is of higher value over urban area than over rural area.

(*viii*) Vertical distribution of wind indicates slight decrease in wind speed over urban area up to 0.6 km and above that level the wind speed over rural area shows lesser value than its urban counterpart.

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