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Low level temperature profile from screen temperature

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ABSTRACT. A simple mathematical model for vertical temperature profile during clear and calm night time inversions, utilising screen air temperature data is presented. The model was tested at Delhi and Mathura and found to be reasonably good for pollution studies in the absence of actual data.

1. Introduction

The dispersion of air borne pollutants is governed by the height and magnitude of inversions (Slade 1968, Pasquill 1962). Direct measurement of temperature in the vertical either by tethered balloons or kytoons is cumbersome, hence interest is still centred round mathematical models of forecasting temperature profiles from conventionally available data. A model of general validity of time evolution of temperature profiles should take care of heat transfer along the vertical direction in air which includes different processes ranging from molecular conduction to radiative exchange, free and forced convection and latent heat transport.

2. Methodology

The radiative temperature change can be computed as

$$\frac{\partial T}{\partial t} = k\left(\frac{\partial^2 T}{\partial z^2}\right) \tag{1}$$

This expression may be considered as nocturnal heat transfer during night time calm periods. The thermal flux across any plane z is defined by

$$f = k\,\frac{\partial T}{\partial z}$$

where k is the thermal conductivity of the medium

$$\frac{\partial f}{\partial t} = k\,\frac{\partial^2 f}{\partial z^2} \tag{2}$$

The following assumptions are made :

(*i*) k = constant

(*ii*) The starting time of the process is reckoned from the time the diurnal thermal wave at the surface attains its maximum value before decreasing. At this moment $\frac{\partial T}{\partial t} = k\,\frac{\partial^2 T}{\partial z^2} = 0$ from which we have $\frac{\partial T}{\partial z}$ = constant under the assumption k=constant. On integration we obtain $T\ (x, 0) = \beta z +$ constant, where β also is a constant (Sutton 1953, Slade 1968).

(*iii*) Time evolution of the top z_i of the stable layer with base at ground follows a parabolic law

$$z_i = a\,(t)^{1/2}$$

Our experimental measurements gave for the constant a, a numerical value of 45 with z_i expressed in metre and t in hours.

(*iv*) Above z_i the effect of radiation from the surface reduces to a very small value and turbulent processes, from which a decrease of temperature is to be expected will become dominant. So somewhere in the proximity of z_i it is likely a value

$$\frac{\partial T}{\partial z_i} = 0$$

(*v*) During the whole nocturnal period, as a first approximation, the coefficient k can be considered constant (Haltiner and Martin 1957) in the lower layers and poorly correlated to wind speed.

(*vi*) The magnitude of the temperature inversion between $z = z_i$ and $z = 0$ at any time is about half the amplitude of the temperature wave near the ground at the same time.

(*vii*) If water vapour condensation near the ground does not occur, the fall of temperature of the earth's surface after sunset upto next dawn is described by a parabolic function of time.

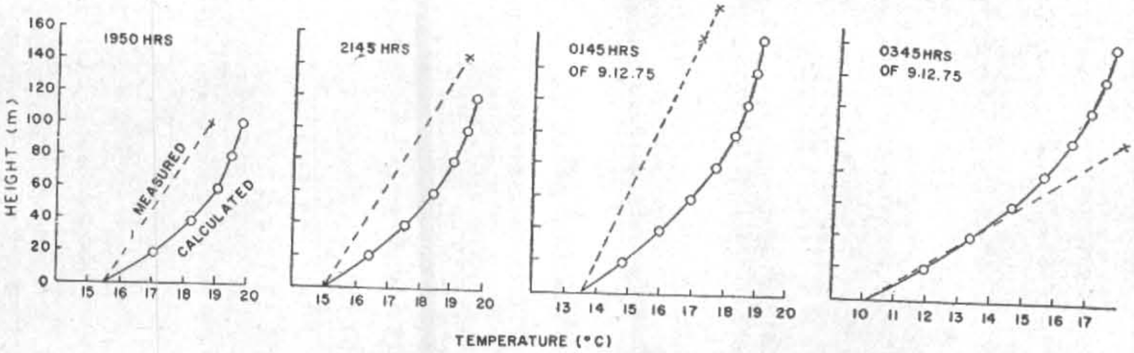

Fig. 1. Comparison of temperature profile with the calculated one for 8 December 1975 for different hours during night time at Yahya Nagar

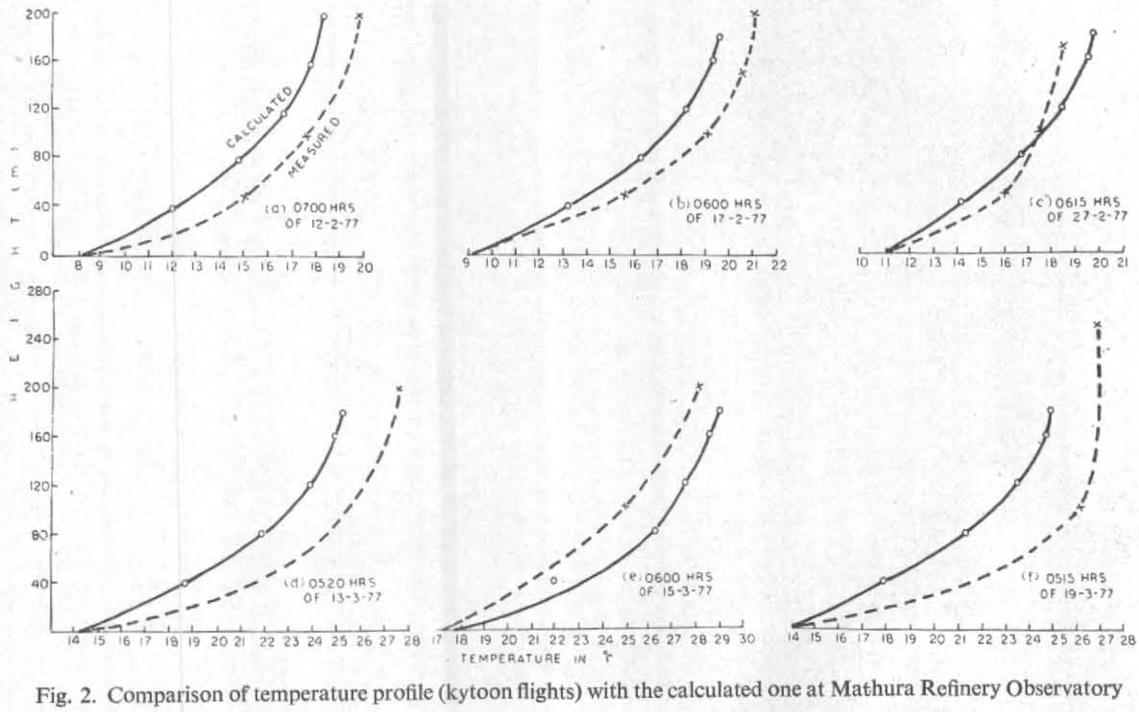

Fig. 2. Comparison of temperature profile (kytoon flights) with the calculated one at Mathura Refinery Observatory

(*viii*) Stable stratification persists till dawn provided the wind speed is low and with thin overcast (Anfossi *et al*. 1974, 1976).

The set of conditions in the problem are

$$\left.\begin{array}{l} f(0, t) = f_0 \\ f(z_i, t) = 0 \\ z_i = (4\,kt)^{\frac{1}{2}} \end{array}\right\} \qquad (3)$$

The solution of (2) with the boundary conditions of (3) is

$$f(z, t) = \frac{f_0}{1-\text{erfc}\,(1)}\left[\text{erfc}\left(\frac{z}{z_i}\right) - \text{erfc}\,(1)\right]$$

On integration it follows that :

$$T(z, t) = T(0, 0) - [T(0, 0) - T(0, t)] \left\{\exp\left[-\left(\frac{z}{z_i}\right)^2\right] - \left(\frac{z}{z_i}\right)(\pi)^{\frac{1}{2}} \times \text{erfc}\left(\frac{z}{z_i}\right) + 0.278\left(\frac{z}{z_i}\right)\right\} \qquad (4)$$

where,

$$z_i = (4kt)^{\frac{1}{2}} = 45\,(t),$$

$$T(0, 0) - T(0, t) = \frac{2 f_0}{k\,[1-\text{erfc}\,(1)]}\left(\frac{kt}{\pi}\right)^{\frac{1}{2}}$$

$$(\pi)^{\frac{1}{2}}\,\text{erfc}\,(1) = 0.278.$$

3. Experimental set-up

At Delhi temperature data as obtained by the conventional radiosonde was compared with the mathematical model. Since the levels from which the data could be obtained by the radiosonde are not close enough, experiments were conducted at Mathura with tethered balloons to obtain temperatures at closer intervals. These experiments could not be conducted at Delhi due to restrictions imposed by aviation activities.

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 wind speed 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 reeled out of the mechanical winch and kept for a couple of minutes at desired heights till the pressure, temperature and dew point are recorded. Then the tether was out-hauled to the next level. The observations were taken at every 50 m upto 500 m and the tethered balloon was in-hauled collecting data at the same intervals. The total operation took about 90 minutes and the average of the two observations at each level is taken for the mean temperature profile. These profiles were compared with the theoretical values of the model and the results are shown in Fig. 2.

4. Results and discussion

Temperature distributions $T(z, t)$ evaluated from (4) with the same value 3×10^3 cm^2/sec for k have been compared with our experimental data obtained from radiosonde and shown in Fig. 1. With the progress of the night the inversion height and temperature changed. Early night (1950 hr)—the departure of model temperatures from measured values ranged between 1.0° and 1.5°C and the inversion height is the same. After two hours, *i.e.*, 2145 hr, the predicted model, temperatures and experimental values agreed in inversion top temperature but differed in height by 20 metres. At 0200 hr the inversion height in the experiment further increased to 180 m—20 metres above the model value and the temperature difference of the inversion tops came out to be 1.5°C. Subsequently at 0400 hr the experimental height of inversion was 100 metres while the model predicted 160 metres—the temperature difference is only .4°C.

It may be seen from Fig. 1 that measured profile is a straight line since one observation at the ground and another at the inversion level are available. The authors opine that a better comparison between theoretical and experimental values could be made provided the height intervals of measurement are closer. The tethered balloon experiment provided the necessary imput. In Fig. 2 are presented the profiles of temperature both measured and computed on several days during the winter of 1976-77. In all cases the skies were clear, surface winds nearly calm (<2 kmph) and minimum temperatures were above dew point rendering no condensation. Except in one case (19 March 1977) the profiles closely resembled each other both in temperature and height of inversion. The departure appears to be associated with close proximity between dew point and minimum temperatures at the time of flight resulting probably in some invisible condensation. This supports the hypothesis on which the model is originally based.

5. Conclusions

The model used in the present paper appears to operate successfully during calm or light wind and clear nights with only screen temperature as imput. The model could substitute the temperature profile during calm, clear winter nights in the absence of temperature measurements.

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