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A simple thermodynamical model to estimate the rate of depletion of nocturnal low level inversion layer

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सार - निम्न स्तरीय प्रतिलोमन धरातलीय हो या ऊँचाई का प्रदूषित कणों के विसर्जन और विमानन मौसम विज्ञान में इसकी भूमिका महत्वपूर्ण रहती है। धरातलीय प्रतिलोमन की उच्च स्तर तक बढ़ने की दर और ऊँचाई के प्रतिलोमन की आधार स्थिति के कारण प्रतिलोमन की तीव्रता में कमी आती है, जिससे वातावरण की स्थिरता में भी कमी आती है और इसके परिणामस्वरूप प्रदूषकों का उर्ध्वाधर मिश्रण होता है। इस शोध पत्र में भूमंडलीय विकिरण और उर्ध्वाधरीय तापमान प्रोफाइल का प्रयोग करते हुए एक सरल तापगतिकीय मॉडल का प्रस्ताव (*i*) धरातलीय प्रतिलोमन की उच्च स्तर तक बढ़ने की दर और (*ii*) ऊँचाई के प्रतिलोमन की आधार स्थिति का आकलन करने के लिए रखा गया है। इस प्रकार से आकलित की गई प्रतिलोमन की गहनता का प्रयोग प्रदूषण/कोहरा विसर्जन मॉडल में किया जा सकता है। यह मॉडल सरल है और प्रचालनात्मक रूप से व्यवहार्य है। मॉडल की परिसीमाओं पर भी चर्चा की गई है।

ABSTRACT. The low level inversion, be it that of ground based or elevated, plays a significant role in the dispersion of polluted particles and in aviation meteorology. The rate of rise of the ground based inversion top and the base of elevated inversion causes the decrease of inversion strength and thereby permits vertical mixing of pollutants as the stability of the atmosphere is reduced. A simple thermodynamical model using the global radiation and vertical temperature profile has been proposed to estimate the rate of rise of (*i*) the ground based inversion top and (*ii*) the base of the elevated inversion. The depth of inversion thus estimated can be used in the pollution/fog dispersion models. The model is simple and operationally practicable. The limitations of the model are also discussed.

Key words — Inversion, Global radiation, Fog, Thermodynamics, Dispersion of pollutants, Mixing height, Boundary layer, Aviation, Meteorology.

1. Introduction

The lowest part of the atmosphere which intensively exchanges heat, mass (water, pollutants) as well as momentum with the earth's surface is called as the atmospheric boundary layer (Sorbjan, 1989). The study of the atmospheric boundary layer (ABL) plays an important role in forecasting not only weather phenomena but also the pollution potential and their dispersion and diffusion. The unstable atmospheric conditions typically encountered during the afternoon causes mixing within bulk of boundary layer which is intense enough to make the conservable scalars such as potential temperature (θ) and virtual potential temperature (θv) distributed with height. The layer over which this occurs is called the mixing layer, according to Pal Arya (1988).In otherwords, mixing layer is used to designate a layer of the atmosphere in which there is significant mixing, eventhough the conservable properties may not be uniformly mixed. As such the turbulent planetary boundary layer (PBL) is also a mixing layer, a large part of which may become well mixed during unstable conditions. Hence the height of PBL is always less than or equal to that of ABL.

Due to radiative cooling, low level inversion develops on any calm and cloudless night. These inversions may be either ground based or of elevated nature. The base of elevated inversion acts as lid hampering the upward spreading of pollutants from the low level sources. The surface inversion inhibits vertical motion and the pollutants often travel a long distance without vertical mixing and spreading. These are then fumigated to the ground level as soon as the inversion is punctured due to insolation, resulting in large ground level concentration of pollutants. Hence the knowledge of low level inversion (ground based and elevated) helps in understanding the dispersion of pollutants.

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The pollution dispersion models that are widely used such as Gaussian plume model, Box model and Gradient-transport K model require an in-depth knowledge of rate of vertical diffusion which in turn depends on the up-wind speed, mixing height and atmospheric thermal structure (WMO, 1970, 1972 & 1982). Since the direct measurements of urban vertical tracer elements are not readily available, the vertical diffusion are estimated from the ground concentration based the relationship

$$\frac{\chi}{Q} = \frac{1}{2}\frac{C}{Lu}$$

Where χ - average concentration
Q - pollutant emission rate
L - mixing height
C - average linear dimension
u - average wind speed

Hence the determination of height to which a buoyant pollutant with an initial exit velocity from a source will rise is very vital in the pollution dispersion studies. The meteorological variables of importance for pollution dispersion are wind, turbulence (if made available through LIDAR/SODAR) and temperature gradient (to work out the mixing height and the order of temperature inversion). The introduction of potential temperature is of obvious advantage in calculating the inversion strength, which is defined as $\partial\theta_v/\partial z$ (Pal Arya, 1988). The increase of pollutant concentration depends on inversion layer, the source and the height of emission (WMO, 1972).

The concentration of pollutants in the low level coupled with strong low-level inversion causes formation of fog exploiting the availability of moisture. Since the fog reduces the visibility to as low as 50 m or so, the dispersal of fog and pollutants are of serious concern in aviation meteorology. The fog will be dispersed with the advent of insolation and/or puncturing of the inversion layer. The rate at which the base of the elevated inversion layer or the height of the ground based inversion layer is lifted may help the environmental engineers to assess the concentration and/or dispersion of pollution potential. On the other hand, the rate of reduction of inversion strength may help the aviation meteorologist to issue trend forecast on the improvement in visibility and dispersion of fog. A simple model to find out the rate of rise of inversion base (top) in the case of elevated (ground based) inversion is attempted in this paper.

2. Data

The upper air temperature (RS/RW) data of 0000 UTC for the period January, February and October to December 1984-88 has been collected from the National Data Centre (NDC), Pune. Since the upper air temperature profile are available only at standard pressure levels, every 50 hPa intervals and at specific levels satisfying significant criteria, it is very difficult to work out the inversion thickness (as there is every chance that the inversion is unnoticed in between these levels). As such frequencies of ground based and elevated inversion computed based on special low level ascent flights during the period 1970-74 have been considered from the published records of the India Meteorological Department (IMD, 1983) to identify the months having high frequencies of low level inversion. Since the percentage frequencies are relatively more during January and February, this study is confined to these months only. The temperature at surface, 0.15 km, 0.30 km, 0.6 km, 0.9 km and 1.5 km at 0000 UTC during the period January, February1984-88 have been collected from the records available at RS/RW station, Meenambakkam, Madras which are not normally archived at the NDC, Pune. The global and diffused radiation data for the same period were obtained from the National Data Centre, Pune.

The surface wind and relative humidity data for the period January and February 1995-98 have been collected from the current weather register of airport meteorological office, Meenambakkam airport, Madras. The 0000 UTC low-level upper air data for period January - February 1995-98 has been collected from the records maintained at RS/RW observatory, Madras.

3. Methodology and computation

The percentage frequency of the ground based inversion was 24 % only with the average rise of temperature within the inversion layer (of average thickness 250 m) being 0.4° C. The maximum thickness was 600 m. The maximum rise of temperature in the inversion layer was 2.7° C. The stack height from where the pollutants are released on the northern side of RS/RW observatory is around 100 m only. Hence the emission from the stack is almost confined to the ground based inversion and may rise only upto some height in the inversion layer (WMO, 1974). Atmospheric stagnation of pollutants depend upon the amount of emission from high and low level pollutant sources, their diurnal variation and the diurnal variation of meteorological factors such as heights of inversion base and top, patterns of air flow etc (Berlyand *et al.* 1972 in WMO, 1974). The Pasquill's stability criteria are applicable only upto 50 m above ground as they depend mostly on surface wind speed and cloudiness and to some extent the solar zenith angle during daytime. As such using the stability conditions as worked out from the Pasquill's classes in the Gaussian plume model or Gradient - transport K model may not yield the desired results. Even assuming that the depth of elevated or ground level inversion is known through the conventional RS/RW ascent data, if the rate at which the base/top of inversion rise (as in the case of elevated /surface inversion) is known and incorporated in the diffusion and dispersion of pollutant models, the results would be better. A simple thermodynamical model to estimate the rate of lifting of inversion top (base) of ground based (elevated) inversion, as the case may be, is proposed in the following sections.

3.1. *Rate of rise of elevated inversion base*

Based on the first law of thermodynamics, the conservation of energy and the principle of hydrostatic equilibrium, the rate of diabatic heating/cooling of an air parcel can be related to the rate of change of enthalpy and geopotential (Wallace and Hobbs, 1977; Haltiner and Martin, 1957) *i.e.*

$$\frac{dH}{dt}=\frac{d}{dt}\left(C_pT+\phi\right) \qquad (1)$$

Where $\frac{dH}{dt}$ is the diabatic heating/cooling rate

CpT is the enthalpy and

ϕ is the geopotential.

But $\frac{dH}{dt}$ is the sum of effects due to absorption of insolation, absorption and emission of terrestrial radiation, release of latent heat of condensation of water vapour and the exchange of heat with the surroundings due to mixing by conduction and convection (sensible heat exchange) *i.e.*

$$\frac{dH}{dt}=\frac{dH_N}{dt}-L\frac{dw}{dt}+S_h \qquad (2)$$

Where $\frac{dH_N}{dt}$ is the net radiative heating rate

$-L\frac{dw}{dt}$ is the latent heat release exchange from vapour to liquid and

S_h is the sensible heat exchange. But

$$\frac{dw}{dt}=\left(\frac{dw}{dt}\right)_p+\left(\frac{dw}{dt}\right)_E \qquad (3)$$

Where $\left(\frac{dw}{dt}\right)_p$ is the effect of phase change between vapour and liquid and

$\left(\frac{dw}{dt}\right)_E$ is the effect of exchange of water vapour molecules with surrounding by conduction and convection.

$$\therefore -L\left(\frac{dw}{dt}\right)_p=-L\left(\frac{dw}{dt}\right)+L\left(\frac{dw}{dt}\right)_E=-L\left(\frac{dw}{dt}\right)+S_m \qquad (4)$$

Where $S_m=L\left(\frac{dw}{dt}\right)_E$ is the latent heat release due to exchange of water vapour molecules with surrounding by conduction and convection.

From (2), (3) and (4) we get

$$\frac{dH}{dt}=\frac{dH_N}{dt}-L\left(\frac{dw}{dt}\right)+S_m+S_h \qquad (5)$$

i.e.

$$\frac{d}{dt}\left(C_pT+\phi\right)=\frac{dH_N}{dt}-L\left(\frac{dw}{dt}\right)+S_m+S_h$$

$$\frac{d}{dt}\left(C_pT+\phi+Lw\right)=\frac{dH_N}{dt}+S_m+S_h \qquad (6)$$

$(C_pT+\phi+Lw)$ is the moist static energy. For the atmosphere as a whole the moist static energy is conserved. *i.e.*

$$\frac{d}{dt}(CpT+\phi+Lw)=0$$

Now we assume that just after sunrise, the rate of net terrestrial radiation $\frac{dH_N}{dt}$ is almost zero so also the contribution due to exchange by molecular conduction and convection (S_m), the incoming solar radiation immediately after the sunrise is completely absorbed and well mixed in the mixing layer. For this purpose the mixing layer height is defined as the height above the surface where the temperature profile first becomes inversion ; or if none, isothermal ; or if none, more stable than the pseudo adiabatic lapse rate; or if none below 700 hPa level, as unlimited (Wurech *et.al.* 1972). The rate of change of geopotential and latent heat release is practically negligible in small increment of time just after sunrise.

$$\therefore \frac{d}{dt}(CpT) = S_h \tag{7}$$

Integrating this equation from surface to mixing layer height over an unit column, we get

$$\frac{d}{dt}\int_0^{top} \rho\, C_p T dz = \int_0^{top} \rho\, S_h dz$$

Where ρ is the density. Since the sensible exchange of heat during early hours may be confined only to the single source of energy, *viz*, the global radiation (which is the sum of direct and diffused radiation), the term on the right hand side can be replaced by the global radiation (Wallace and Hobbs,1977). Hence

$$\frac{dT}{dt} = \text{Global radiation} \Big/ \int_0^{top} \rho\, C_p dz \tag{8}$$

The potential temperature is mathematically defined as

$$= T\left(\frac{1000}{p}\right)^{\frac{R}{C_p}} \tag{9}$$

in usual notations. Taking logarithmic differentiation *w.r.t.* time *t*, we get

$$\frac{1}{\theta}\frac{d\theta}{dt} = \frac{1}{T}\frac{dT}{dt} - \frac{R}{C_p}\frac{1}{p}\frac{dp}{dt}$$

or $$\frac{d\theta}{dt} = \frac{\theta}{T}\frac{dT}{dt} - \frac{R}{C_p}\frac{\theta}{p}\frac{dp}{dt}$$

For a typical value of $\theta = 285°$ K, $T = 295°$ K, $R = 287$, $Cp = 1004$ in standard units, $p = 1000$ hPa, $dT/dt = 2°$ K / hr and $\frac{dp}{dt} = 1$ hPa/hr, we find that $\frac{R}{C_p}\frac{\theta}{p}\frac{dp}{dt}$ is at least 1 order of magnitude less than $\frac{\theta}{T}\frac{dT}{dt}$ and hence $\frac{R}{C_p}\frac{\theta}{p}\frac{dp}{dt}$ is neglected (by scale analysis considerations).

$$\therefore \frac{d\theta}{dt} = \frac{\theta}{T}\frac{dT}{dt} \tag{10}$$

Again taking logarithmic differentiation of equation (9) *w.r.t* height *z*, we get

$$\frac{1}{\theta}\frac{d\theta}{dz} = \frac{1}{T}\frac{dT}{dz} - \frac{R}{C_p}\frac{1}{p}\frac{dp}{dz} = \frac{1}{T}\frac{dT}{dz} - \frac{R}{C_p}\frac{1}{p}(-g\rho)$$

or $$\frac{d\theta}{dz} = \frac{\theta}{T}\left(\frac{dT}{dz} + \frac{g}{C_p}\right) = \frac{\theta}{T}(\Gamma - \nu) \tag{11}$$

Where $\Gamma = \frac{g}{C_p}$ is dry adiabatic lapse rate (DALR)

$= 9.8°$ K/km

$\nu = -\frac{dT}{dz}$ is the lapse rate (negative temperature gradient)

Assuming that the inversion caps the mixing layer and denoting Z_B as the base of the elevated inversion, then the rate of rise of inversion base is

$$\frac{dZ_B}{dt} = \left(\frac{d\theta}{dt}\right) \Big/ \left(\frac{d\theta}{dz}\right)_{inversion} = \frac{\theta}{T}\frac{dT}{dt} \Big/ \frac{\theta}{T}(\Gamma - \nu)_{inversion}$$

or $$\frac{dZ_B}{dt} = \frac{dT}{dt}\frac{1}{(\Gamma - \nu)_{inversion}} \tag{12}$$

Now $\frac{dZ_B}{dt}$ can be computed. The term $(\Gamma - \nu)$ is a measure of static stability, which appears in the numerator of Richardson number. Higher the static stability, the lesser the chances of turbulence for a given kinetic energy. Under nocturnal inversion, the value of ν is negative (and hence the denominator, *viz.*, static stability factor is relatively higher) causing very slow rise of inversion base. Conversely, when ν is positive the static stability parameter approaches zero (which happens during strong convection) and/or even negative (super adiabatic lapse rate conditions), the rate of depletion of inversion layer is quite high. This again confirms the onset of turbulence, as the numerator of the Richardson number is extremely small or mostly negative (less than the critical Richardson number, *viz.*, and 0.25) under this condition. Hence it is quite logical that when ν approaches Γ, the inversion lifting rate blows up very fast.

3.2. *A typical example to find out the rate of lifting of the base of elevated inversions*

The global radiation from 0600 to 0700 hrs (IST) on 2 February 1986 was 0.13 MJ/sq.m. The temperature difference between top and bottom of the elevated inversion layer between 544 m (950 hPa) and 1006 m (900 hPa) was 2.0°C. The mixing layer height was 544 m and the depth of the elevated inversion layer was 462 m. Assuming ρ as 1.225 kg/m^3,

$$\frac{dT}{dt} = (0.13 \times 10^6) / (1.225 \times 1004 \times 544)$$

$$= 0.194^\circ \mathrm{C} / \mathrm{hr}$$

$$(\Gamma - \nu) = 9.8 + (2.0/462) * 1000 = 14.13^\circ \mathrm{C} / \mathrm{km}$$

$$\frac{dZ_B}{dt} = (0.194 / 14.13) * 1000 = 13.7 \mathrm{~m} / \mathrm{hr}$$

By 0700 hrs (IST), the base of inversion rose by 13.7 m and the rise of temperature in the inversion layer was decreased by 0.194° C, as the global radiation was well mixed in the (ground based) mixing layer there was uniform rise of temperature from the surface to the top of the mixing layer. The new value of temperature rise in the inversion layer was 2.0 - 0.194 = 1.806° C. The global radiation between 0700 and 0800 hrs (IST) (0.83 MJ/sq.m) was absorbed in the new mixing layer of height 557.7 m (*i.e.* 544 + 13.7 m). The value of $\frac{dT}{dt}$ works out to be 1.21° C / hr. The new value of $(\Gamma - \nu)$ in the inversion layer was 13.83 °C/km. The rate of rise of inversion base was then $\frac{dZ_B}{dt}$ = 87.5 m/hr. At 0800 hrs (IST), the mixing height was 645.2 m, the depth of inversion layer was 360.8 m and the value of temperature rise in the inversion layer was 1.806 – 1.21 = 0.596° C showing that inversion had persisted still. By using the global radiation between 0800 and 0900 hrs (IST) (1.50 MJ / sq.m) and proceeding further, we obtained the value of $\frac{dT}{dt}$ = 1.89° C / hr and the rate of rise of inversion base $\frac{dZ_B}{dt}$ = 165.0 m / hr. The new value of temperature rise in the elevated inversion layer was – 1.294 °C (0.596 – 1.89 = – 1.294 °C). The negative value shows that the inversion is punctured and no longer existed at 0900 hrs (IST). Now the mixing layer height is extended to 645.2 + 165.0 = 810.2 m. The vertical profile of temperature between 0530 and 0900 hrs (IST) is shown in Fig. 1.

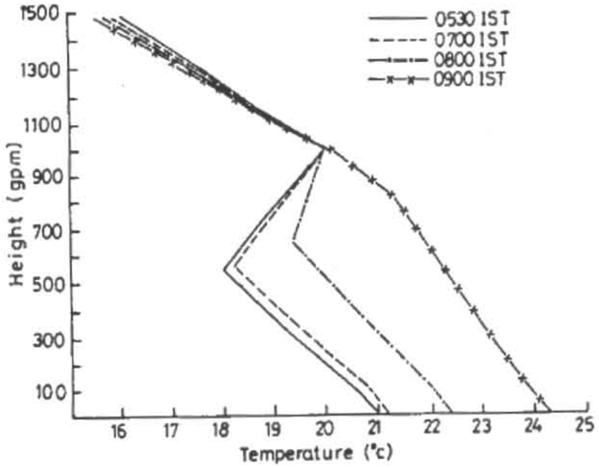

Fig. 1. Vertical temperature profile of the lower atmosphere over Madras on 2nd February 1986 showing the rate of raising of the base of the nocturnal elevated inversion layer

3.3. *Rate of lifting of the top of ground based inversions*

The method is almost similar to that discussed for the rise of base of elevated inversion in section 3.1 but for the assumption that the global radiation in this case is absorbed only at the surface (immediately after sunrise), since the vertical motion is almost inhibited in the ground based inversion layer in view of the stability prevailing in the lowest level of the atmosphere. As such we assume that the $\frac{dT}{dt}$ is contributing to rise of surface temperature only. Next, we proceed further in computing the $\frac{dZ_T}{dt}$, where Z_T is the height (top) of the surface inversion layer, as we did for $\frac{dZ_B}{dt}$ in sections 3.1 and 3.2. The rise of surface temperature and raising of inversion layer height causes the reduction of the inversion strength gradually till the inversion ceases. For the subsequent hour's data of global radiation, the temperature gradient $\frac{dT}{dt}$ is computed based on the assumption that the rise of temperature in the inversion layer is reduced by *dT/dt* (computed earlier) since *dT/dt* is added to the surface

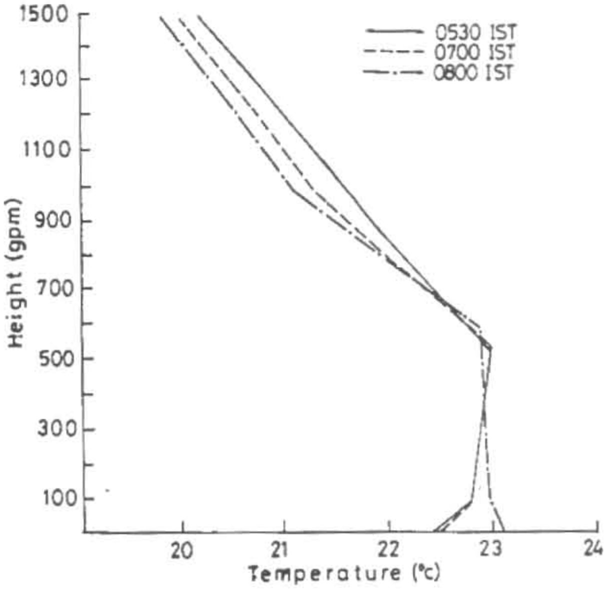

Fig. 2. Vertical temperature profile of the lower atmosphere over Madras on 13 February 1984 showing the rate of raising of the nocturnal surface inversion layer

temperature. Proceeding further, as usual, dT/dt and dZ_T/dt are computed till such time the lapse rate (negative temperature gradient) is established.

The atmospheric conditions favourable for the formation of fog are high relative humidity at lower levels, low level inversion, light wind speed of 2 to 8 kt and cloudless sky permitting nocturnal inversion (HMSO, 1994). The fog is considered as a major aviation hazard since it reduces the visibility to a few hundred meters. The clearance of fog is delayed by the concentration of pollutants stagnated in the absolutely stable low level inversion layer (WMO, 1974). The rise of inversion top causes the decrease of strength of inversion in view of the increased depth. Hence the chances of some vertical mixing in the lowest layer is feasible as the stability of atmosphere is reduced. The dispersion of pollutants vertically, to a certain extent, may also be plausible. As such the study of rate of rise of ground based inversion not only helps in understanding the dispersion of pollutants but also gives an idea about the dispersal of fog and improvement in visibility.

3.4. *A typical example to find out the rate of rise of height of surface inversion layer*

A case of 524 m surface inversion with the rise of temperature in the inversion layer 0.6°C was observed on 13 February 1984. The global radiation from 0600 to 0700 hrs (IST) was 0.06 MJ / sq.m. The dT/dt works out to 0.0930 °C/ km. The value of $\left(\Gamma - \nu\right)$ was 10.94° C/ km. Hence the $\frac{dZ_T}{dt}$ = 8.50 m / hr. Since the surface temperature rises by 0.093 °C, the value of rise of temperature in the inversion layer was diminished by 0.093 °C assuming that the temperature at the top of inversion was remaining the same. At 0700 hrs (IST), the order of inversion temperature in the inversion layer was 0.507° C. Now that the top of inversion has gone up by 8.5 m, the new value of $\left(\Gamma - \nu\right)$ is 10.75 °C / km and $\frac{dT}{dt}$ = 0.626 °C/ hr. The global radiation from 0700 to 0800 hrs (IST) being 0.41 MJ/sq.m, the rate of rise of inversion top $\frac{dZ_T}{dt}$ = 58.23 m / hr. At 0800 hrs (IST), the rise of temperature in the inversion layer was – 0.119 °C (0.507– 0.626 = – 0.119 °C) suggesting that the inversion layer was no longer existing in view of the negative temperature gradient and slow building up of the lapse rate. A typical graph of the temperature profile in the lowest layer of atmosphere at different time is shown in Fig 2.

TABLE 1

Statistical characteristics of relative humidity at late night and early hours over Madras airport during January- February 1995-98

Time (UTC)	Relative humdity (%)	
	Mean	Standard deviation
2100	88.39	6.1
2200	90.21	5.4
2300	91.87	5.1
0000	92.85	4.7
0100	93.59	4.5
0200	91.06	5.1
0300	85.30	6.6

4. Limitations and discussions

(*i*) In the model calculation, we assume that the heating rate is caused by global radiation only, ignoring the contribution by evaporative cooling and molecular conduction and convection, howsoever small they may be, just immediately after the sunrise. These assumptions may cause a small deviation from the actual surface temperature recorded at 0700 hrs (IST) from that calculated using the global radiation data of 0600 to 0700 hrs (IST).

The mean value of RH at surface was 94.4 % while at the top of the inversion was 89.9 % at 0000 UTC. The surface values of RH during winter at night and early

TABLE 2

Frequencies of order of nocturnal inversion over Madras airport during January & February 1995-98

Order of rise of temp. (°C)	Year										Total
	1995		1996		1997		1998		1995-98		
	Jan	Feb	Jan	Feb	Jan	Feb	Jan	Feb	Jan	Feb	
0.0	0	0	1	0	0	0	1	3	2	3	5
0.1-1.0	8	7	6	10	7	5	6	4	27	26	53
1.1-2.0	7	2	11	6	6	6	9	3	33	17	50
2.1-3.0	5	1	4	1	6	4	6	2	21	8	29
3.1-4.0	3	1	1	0	3	1	1	2	8	4	12
≥ 4.1	0	0	2	1	1	1	1	1	4	3	7
Total	23	11	25	18	23	17	24	15	95	61	156

TABLE 3

Frequencies of depth of nocturnal inversion over Madras airport during January and February 1995-98

Order of depth of inversion layer (m)	Year										Total
	1995		1996		1997		1998		1995-98		
	Jan	Feb	Jan	Feb	Jan	Feb	Jan	Feb	Jan	Feb	
≤ 100	0	0	0	0	0	0	0	0	0	0	0
101-200	0	1	0	1	0	1	0	1	0	4	4
201-300	10	4	16	9	10	11	12	8	48	32	80
301-400	13	6	7	6	13	3	11	6	44	21	65
401-500	0	0	2	2	0	0	0	0	2	2	4
≥ 501	0	0	0	0	0	2	1	0	1	2	3
Total	23	11	25	18	23	17	24	15	95	61	156

morning, based on the recent data of 1995-98 also confirms the prevalence of higher RH over Madras airport (Table 1). Absolutely calm surface wind prevails during winter nights and early hours (2100 to 0200 UTC) over Madras airport. Hence, the assumption that contribution by evaporative cooling is almost negligible is quite justified in view of the high relative humidity (RH) and calm surface wind prevailing during late night and early hours (Trewartha and Horn, 1980 and Critchfield, 1987).

(*ii*) Our computation is based on the hourly value of global radiation averaged at 15 minutes interval. As such the exact time at which the inversion is destroyed may not be worked out from this hourly data. However, for practical pollution dispersion model studies, by utilizing 15 minutes global radiation data and subsequently appending the new value of global radiation at every 15th minute, the exact time of puncturing of inversion can be computed.

(*iii*) The computation of the rise of ground based and elevated inversion reveals that the average rise of inversion base (top) is around 10 m/hr during the first hour after sunrise and 60 m/hr during the subsequent hour and the inversion is normally absent in about 2 hour after the sunrise.

(*iv*) The frequencies of nocturnal inversion based on the data of January and February 1995-98 (Tables 2 & 3) indicate significant increasing trend, in comparison to that of 1970–74 (IMD, 1983), presumably due to rapid urbanization. Hence the model proposed assumes operational importance.

(*v*) In view of cost factor, RS ascents are taken at a maximum of 2/day (0000 and 1200 UTC) at international level. Hence, as of now, we've no technique to identify the exact time of cessation of inversion. Hence this simple thermodynamical model may be used to get an estimate of depletion of inversion layer.

5. Conclusions

The model proposed is computationally and operationally feasible for estimating the rise of inversion base and inversion layer height in the lowest layers of the atmosphere. This will help in assessing the pollution potential and their dispersion when they are suitably incorporated in the pollution models. The puncturing of inversion and the rise of ground based inversion height may be used to forecast the clearance of fog and improvement in visibility.

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