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Nocturnal increases in surface temperature

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ABSTRACT. The surface temperature during some clear nights at Bombay Airport are observed rising, instead of falling, under fine weather conditions. The cases of nocturnal rise in surface temperature of the order of 2°C and more occurring in an hour have been analysed and discussed.

The study reveals that nocturnal rise in surface temperature is caused by the transfer of momentum and heat downward from layers aloft in the inversion layer. This transfer is caused by the turbulence which is caused mainly due to the limiting wind shear developed between surface and layers aloft. The land breeze circulation plays a significant role in increasing or decreasing this turbulence at the surface.

1. Introduction

The knowledge of surface temperature is very important for the planning and safe operation of modern jet aircrafts. At Bombay Airport, a large number of international and national jet flights take off during night and early morning. Normally the night surface temperature in fine weather period is expected to continuously deccrease and there should be no difficulty in forecasting the same. However, it was observed that on many occasions, the nocturnal surface temperature increased instead of decreasing, and on some occasions, the rise was very significant. The nocturnal inversions lead to inhibition of vertical interchange of air. Under such conditions the momentum lost by surface friction is not readily replaced from layers above. The wind speed and the degree of turbulence during the night near the ground decrease sharply, resulting in calm winds, while the wind speed above the surface generally increases rapidly with height. The inversion results in strong wind shears, in the surface boundary layers. Blackadar (1957) and Thomson (1968) have shown that these strong wind shears, which develop within the inversion layer themselves supply the turbulent energy to overcome the stability. In some cases the inversion may not get established or may be destroyed. In other cases, the inversion and shear both may break down and reform again or the inversion may build-up slowly. Sutton (1953) has shown that nocturnal inversion is generally not steady. The gradient of inversion and wind shear increases simultaneously, finally a limiting value is reached at which point temperature and velocity gradient collapse, resulting in rise in surface temperature associated with sudden rise in surface wind speed and turbulence.

Ramdas (1943), has studied nocturnal fluctuations in surface temperature at Poona and has associated it with the turbulence caused by the katabatic flow. Mukherjee *et al.* (1975-1976) studied rise in nocturnal surface temperature of the order of 0·2 to 2·0° C and have postulated that a puff of air coming from nearby hills causes turbulent mixing in inversion layer which results in rise in temperature.

At a coastal station, land breeze circulation can cause turbulence in the inversion layer, resulting in transfer of heat and momentum from layers aloft and thereby the rise in nocturnal surface temperature. Thus, nocturnal increases in surface temperature can occur due to the turbulent character of the wind caused by shears, katabatic flow or land breeze circulation. However, other artificial and mechanical causes cannot be ruled out.

In the present study the increases of temperature of the order of 2°C and more occurring within an hour have been studied and statistically analysed. An attempt has also been made to explain the physical and dynamical causes underlying the phenomena. This may provide some guidance for the forecasting of such rises in surface temperature.

2. Data used

The nocturnal rise in surface temperature of the order of 2°C and more occurring within an

TABLE 1

Frequency of nocturnal rise in surface temperature (>2°C) within an hour in various months during 1970-1975

Temp. (°C)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
2-2·9	5	25	30	8	9	11	2	90
3-3·9	0	5	10	5	1	1	0	22
4-4·9	0	1	2	3	2	1	0	9
5-5·9	0	2	1	0	0	0	0	3
6.6·9	0	0	0	0	1	0	0	1
Total	5	33	43	16	13	13	2	125

TABLE 2

Frequency of nocturnal rise in surface temperature during various hours of the day (October to April of 1970-1975)

	Time (GMT)								Total
	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	
Frequency	1	6	8	18	23	29	15	25	125

TABLE 3

Frequency of nocturnal rise in surface temperature within an hour of the order of 2°C and more associated with the surface wind spead and direction

Temp. (°C)	Wind speed (kt)	wind direction (degrees)													Total
		330-360	360-030	030-060	060-090	090-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	Calm/ var.	
2-2·9	<5	2	1	6	2	3	1	1	1	2	0	1	1		90
	>5	2	3	6	13	0	0	0	0	0	0	0	2	43	
3-3·9	<5	1	0	3	4	0	1	0	0	0	0	0	0	5	22
	>5	0	1	0	7	0	0								
4-4·9	<5	0	0	0	0	0	0	0	0	0	0	0	0	0	9
	>5	0		2	7										
5-5·9	<5	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	>5	0			3										
6-6·9	<5	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	>5	0			1										
Total		5	5	17	37	3	2	1	1	2	0	1	3	48	125

TABLE 4

Frequency of nocturnal rise in surface temperature in association with rise or fall of dew point

Rise in temp. (°C)	Dew point (°C)										Total
	0-0·9	1-1·9	2-2·9	3-3·9	4-4·9	5-5·9	6-6·9	7-7·9	8-8·9	9-9·9	
2-2·9	+13 —25 3*	+2 —22	+3 —11	—3	—4	—2	0	—2	0	0	90
3-3·9	+1 —1 1*	+1 —6	—5	—4	—1	0	0	—1	0	—1	22
4-4·9	0	0	—5	0	—1	—1	—1	—1	0	0	9
5-5.9	0	0	0	0	—1	—2	0	0	0	0	3
6-6·9									—1		1
Total											125

*No change

hour has been taken from the current weather registers of Bombay Airport for the period 1970 to 1975 for the months of October to April, when the weather is fine. Corresponding inversion data and the upper level winds have been taken from RS/RW and pilot balloon ascents at Santacruz Observatory.

While compiling the number of cases of nocturnal rise in temperature of the order of 2°C or more within an hour, two or more cases of such rises during one night are noticed. All these cases have been taken into account separately. There are in all 125 cases during the period of six years under study.

3. Analysis and discussion

Table 1 gives the frequency of rise in nocturnal surface temperature in various months. It is clearly seen from the table, that the highest number of nocturnal rises in surface temperature are in the month of December followed by November, January, February, March, October and April respectively. The frequency is more in winter months, *viz.*, November, December and January. It may be noted in this connection that the surface pressure gradient, the frequency and strength of land breeze is of higher order in these months as compared to that of summer months. Table 1 is in conformity with observations of Thomson (1968) for diurnal range of temperature in Scottish Glens.

Table 2 gives the frequency of rise in nocturnal temperatures during various hours. It is clearly seen from the table that, most of the cases of rise in temperature occur after 19 GMT, 75 per cent cases occur during the period 20 to 24 GMT, which is as per Blackadar (1957) the most favourable hour for the occurrence of maximum wind aloft, thereby resulting in existence of large shears and consequent transfer of momentum and heat downwards. It is observed by Dekate (1968), that the land breeze at Bombay becomes prominent after 18 GMT. Table 2 is in conformity with the observations of Blackadar and Dekate.

Table 3 gives the frequency of rise in nocturnal surface temperature of various magnitudes, with respect to surface wind speed and direction, at the time of rise. It is clearly seen from the table, that the maximum cases of rise of temperature of the order of 2° to 3·9°C occur when the wind is calm or variable followed by wind from 030° to 090° direction with wind speed 5 to 10 kt and less than 5 kt respectively. In cases of temperature rise of 4°C and more the wind is mostly from 060° to 090° direction with wind speed more than 5 kt. This suggests that temperature rise of 2° to 3·9° takes place even in calm winds but significant temperature rises, that is 4°C and above take place only when wind is sufficiently turbulent and from northerly direction, *i.e.*, in association with land breeze.

Table 4 gives the frequency of rise in nocturnal surface temperature in association with rise and fall of dew point temperature. It is clearly seen from the table that in 100 cases the dew point has fallen, in 21 cases it has risen and in 4 cases there is no change in dew point. It is also seen from the table that the maximum rise in dew point is of the order of 2°C in which cases the surface temperature rise is not more than 3°C. In general, higher the rise in temperature, more is the fall in dew point. This fall in dew point associated with rise in temperature suggest that the air is brought down from the inversion layer aloft.

The frequency of nocturnal rise in temperature of various magnitude with respect to wind shear between the surface wind at the time of rise and the wind at 0·15 km level recorded at 18 GMT is given in Table 5. It is seen from the table that no definite value of wind shear could be assigned to the temperature rises of the order of 2-3°C. This was further examined, and it was observed that most of the cases of strong shear of 15 kt and more were associated with wind from 330°-010° direction at 0·15 km level and shear for E/NE component of wind at 0·15 km level was less than 15 kt. Further it is seen from the table that for temperature rise of the order of 3°C and more the most favourable shear is 5 to 10 kt followed by shear less than 5 kt. It is seen from the table that 5-10 kt wind shear associated with E/NE wind direction at 0·15 km level at 18 GMT seems to be the favourable value for significant nocturnal rise in surface temperature. This initial value of 5-10 kt wind shear at 18 GMT seems to be in order for inversion with steep temperature gradient to build up and turbulence to start. This is in agreement with Blackadar (1957).

Durst (1933) has shown that as soon as the limiting shear is reached turbulence starts at the ground, and the condition for this turbulence start is —

$$R_i \left[\frac{g\,(dT/dZ + \Gamma)]}{T\,(dV/dZ)^2} \right] \leqslant 1$$

where R_i is the Richardson number, g acceleration due to gravity, dT/dZ the rate of change of temperature in the layer, Γ dry adiabatic lapse rate, T the mean temperature of the inversion layer at 00 GMT and dV/dZ is the wind shear.

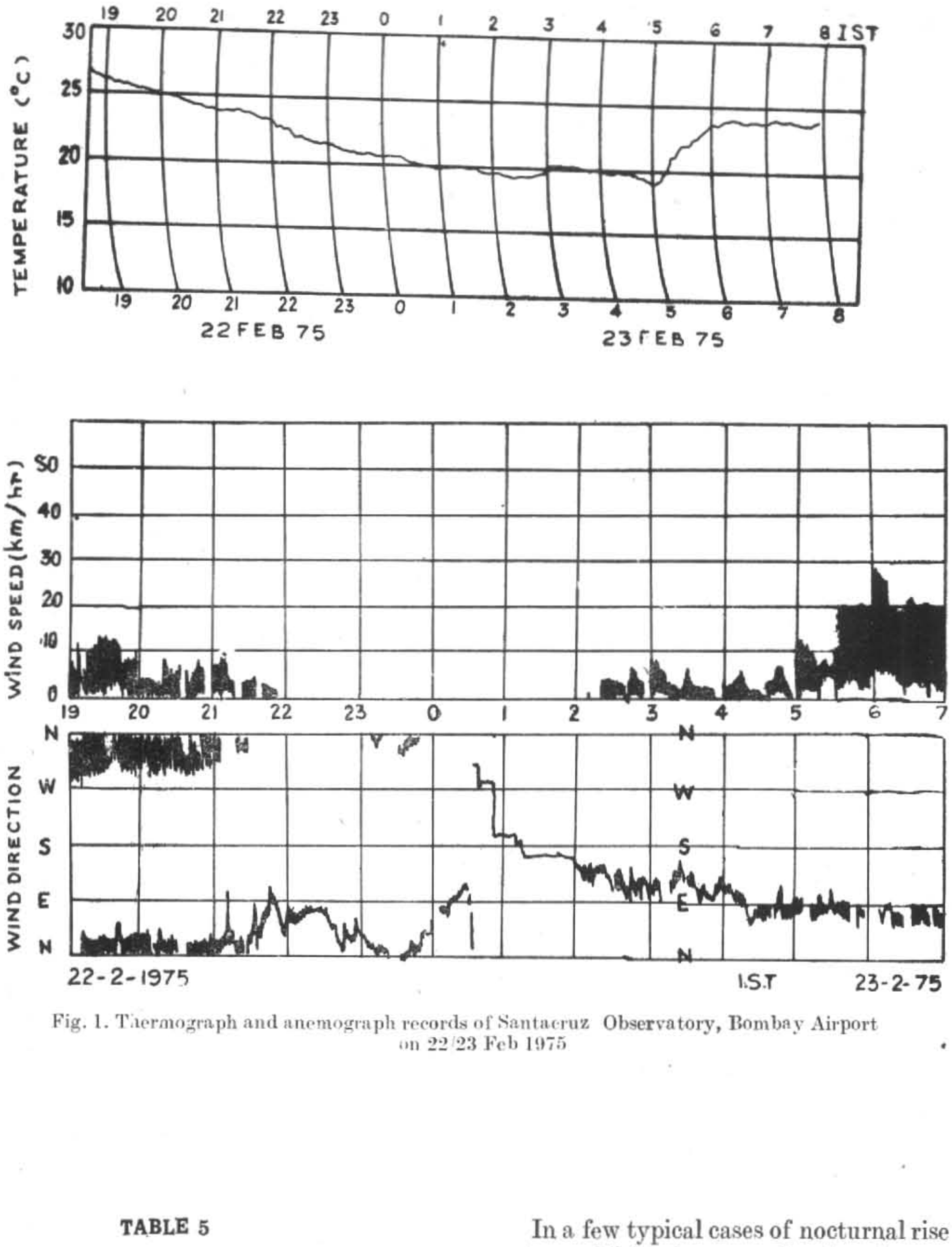

Fig. 1. Thermograph and anemograph records of Santacruz Observatory, Bombay Airport on 22/23 Feb 1975

TABLE 5

Frequency of nocturnal rise in surface temperature of various magnitudes with respect to wind shear between surface wind and wind at 0·15 km a. g. l.

Rise in temp (°C)	Wind shear (kt)					Remarks
	0-5	5·1-10	10·1-15	15·1-20	20·1-25	
2-2·9	21	33	24	9	1	Black-out 2
3-3·9	6	13	1	—	2	
4-4·9	2	6	1	—	—	—
5-5·9	—	1	2	—	—	—
6-6·9	1	—	—	—	—	—

In a few typical cases of nocturnal rise in temperature, Richardson number has been computed with inversion data of corresponding 00 GMT ascent and is presented in Table 6. It is seen that the value of R_i comes less than unity in these randomly selected cases except on 22 February 1975.

This case was further examined with respect to wind at 0·3 km level recorded at 00 GMT and Richardson number computed, value of R_i with wind at 0·3 km level recorded at 00 GMT was less

TABLE 6

Frequency of nocturnal rise in surface temperature of various magnitude with respect to wind shear between surface wind and wind at 0·15 km asl

Date	Thickness of inversion (mb)	Lowest surface temp. before the rise	Temp. of top of the inversion (°C)	Wind at 18 GMT ·15/·3 km level (Deg/kt)	Wind at 00GMT ·3 km level (Deg/kt)	Shear between surface and ·15 km level	R_i	Increase in nocturnal surface temp. (°C)	Computed increase of temp. (°C)
21 Nov 70	34	19·0	25·2	074/12 090/12		12	·58	5·0	4·6
4 Nov 74	50	21·2	26·4	032/10 052/12	050/21	12	·41	5·1	4·8
20 Nov 74	60	18·6	24·8	005/20 004/24	055/15	20	·15	2·4	5·6
5 Jan 75	51	16·3	26·0	346/23 342/15	080/13	23	·16	3·3	7·0
22 Feb 75	100	20·8	23·6	050/04 010/05	090/15	4 kt at ·15 of 18 GMT 15 kt at ·3 of 00 GMT	2·3 ·68	2·4	5·6
27 Mar 75	62	23·3	29·4	008/17 358/18	070/15	12	·43	4·2	5·7
20 Dec 75	47	20·6	24·6	052/13 070/13	080/15	13	·32	5·4	4·0

than unity. It is seen that in such cases the limiting shear was reached near about 00 GMT. In fact the strong turbulence at surface started at 2330 GMT as can be seen in Fig. 1 which gives the actual thermograph and anemograph record of the case under study. This appears to be in order and is in agreement with the findings of Blackadar (1957).

In some cases the wind shear is very large at 18 GMT when the wind direction is mainly NNW'ly at 0·15 km level and the associated nocturnal rise in temperature was of the order of 2° to 3°C. The rise in temperature of the order of 2° to 3°C in association with strong wind shear when the wind direction at 0·15 km is NNW'ly can be explained by the fact that the land breeze during night is NE'ly, and is being opposed by prevailing NNW'ly which inhibits the increase of speed and generation of turbulence at the ground resulting in increase in temperature upto the order of 2° to 3°C. In case of shear in NE'ly the turbulence is taking place freely since the land breeze adds to it which results in nocturnal rises of temperature of the order of 2° to 6°C depending upon the inversion built up.

An attempt has also been made to evaluate theoretically the possible rises in temperature for the cases studied in Table 6 with the existing environmental conditions.

As a first approximation, it is assumed that when the turbulence starts within the inversion layer, a parcel of air from the top of the inversion layer descends dry adiabatically and (*i*) gets heated up at D.A.L.R. and reaches at the surface and (*ii*) mixing takes place at the base as a result of which it cools. The final temperature attained is the resultant of (*i*) and (*ii*). Mathematically

$$T_R = \frac{H_I \times \Gamma_d + T_T + T_b}{2} - T_b$$

where T_R, T_T, T_b are the surface temperature rise after mixing and the temperature of top and at the base of inversion before mixing respectively, H_I the height of the inversion in metres and Γ_d, the DALR, *i.e.*, 10°C/km. The computed values are presented in last column in Table 6.

It is seen from Table 6 that in some cases the culculated values are appreciably higher than the observed values. This is due to the idealization made in computation. However, this gives the possible range of maximum rise in temperature.

5. Synoptic aspect

It is of interest to observe the synoptic features associated with nocturnal rise in surface temperature.

The normal winds at lower levels during the winter months at Bombay are from E/NE direction which are in association with anticyclone over Gujarat area. Sometimes during the night this seasonal anticyclone shifts or weakens due to deep westerly troughs. In association with this strong NW/NNW'ly cold winds are reported at 0·3 km and 0·15 km level, surface wind remaining calm or light variable. In this case wind shear is in association with NW/NNW wind and the rises in temperature are only of the order of 2° to 3° C, since strong inversion is not allowed to be built up due to unfavourable atmospheric conditions.

6. Conclusions

From the above discussion it is concluded that the nocturnal rise in surface temperature at Bombay Airport takes place mainly due to setting in of turbulence in the inversion layer due to wind shear which results in transfer of heat and momentum downwards from inversion layers aloft and

(*i*) The highest number of nocturnal rise in surface temperature is in the month of December followed by November, January, February, March, October and April respectively.

(*ii*) Most of the cases of rise in nocturnal temperature occur after 19 GMT, 75 per cent cases occur in the period 20 to 24 GMT.

(*iii*) The land breeze circulation plays a significant role in increasing or decreasing the turbulence at the surface and (*a*) wind shear of 15 kt or more associated with NW or NNW wind at 0·15 km level observed at 18 GMT result in nocturnal rise in temperature of the order of only 2-3°C, (*b*) initial shear of 5-10 kt in association with NE wind at 0·15 km level observed at 18 GMT is sufficient to cause significant nocturnal rise in temperature.

(*iv*) The limiting value for starting of turbulence between surface and 0.15/.30 km level wind recorded at 18 GMT or 00 GMT respectively is given by $R_i \leqslant 1$.

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