Mausam, (1994), **45**, 3, 243-254

551.524.73.1

Nocturnal surface inversions in central eastern India

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(Received 9 March 1993, Modified 28 October 1993)

सार — भिलाई, बोकारो, दुर्गापुर और राउरकेला स्थित स्टील अथॉरिटी ऑफ इंडिया लिमिटेड के स्टील प्लांटों के समीप जनवरी, फरवरी और मार्च, 1990 के दौरान 40 रात्रिकालीन प्रतिलोमनों के मानीटरन से पता चला है कि मौसम की अनुकूल अवस्थाओं (स्वच्छ आकाश और हल्की पवनें) में प्रत्येक रात्रि को प्रतिलोमन की स्थिति बनती है। प्राय: रात के बढ़ने के साथ-साथ सतहीय प्रतिलोमन की ऊँचाई की मोटे तौर पर यह सीमा 100 मी० के 2/3 भाग तक तथा अधिकतम सीमा 520 मी० तक पाई गई है। सतहीय प्रतिलोमन की अधिकतम रिकार्ड की गई प्रबलता (सतह और अधिकतम सीमा के माध्य तापमान का अंतर) दुर्गापुर में 8.6 सें.°, भिलाई में 7.4 सें.° और बोकारो और राउरकेला दोनों स्थानों में लगभग 5.5 सें.° पाई गई है। वायुमंडल के निम्नतम 250 मी० भाग में तीव्रतम सतहीय प्रतिलोमन का तथ्यपूरक आकलन 10 सें.° से 12 सें.° तक हो सकता है। 4 सें.° से अधिक सतहीय प्रतिलोमन का अनुपात दुर्गापुर में 80 प्रतिशत, भिलाई में 55 प्रतिशत, बोकारो में 45 प्रतिशत तथा राउरकेला में 10 प्रतिशत पाया गया है। इन स्थानों में यह अंतर मुख्यालय से मानीटरन की अवधि में मौसम की अवस्थाओं की भिन्नता के कारण पाया गया है।

ABSTRACT. Monitoring of nocturnal surface inversions in the vicinity of Steel Authority of India Ltd. Steel plants at Bhilai, Bokaro, Durgapur and Rourkela in central eastern India, for 40 nights in January, February and March 1990, indicated that surface inversions developed every night when weather conditions were favourable (clear skies and light winds). The ceiling height of surface inversions generally increased as the night progressed, with roughly two-thirds higher than 100 m and a maximum recorded height of 520 m. The maximum recorded surface inversion strength (temperature difference between the surface and the ceiling) was 8.6C° at Durgapur, 7.4C° at Bhilai and around 5.5C° at both Bokaro and Rourkela. A reasonable estimate of the strongest surface inversion would be 10C° to 12C° in the lowest 250 m of the atmosphere. The proportion of surface inversions greater than 4C° was 80% at Durgapur, 55% at Bhilai, 45% at Bokaro and 10% at Rourkela. These differences between locations were caused largely by varying weather conditions during the monitoring period.

Key words — Nocturnal surface inversions, Inversion occurrence, Inversion height, Inversion strength.

1. Introduction

The dispersion of emissions of air pollutants is determined by conditions prevailing in the atmosphere into which the discharge occurs. The two atmospheric parameters that primarily influence dispersion are the temperature and wind regimes. A series of atmospheric soundings was therefore undertaken to measure vertical profiles of temperature, particularly inversion characteristics, and wind between the ground and heights up to 1 km, in the vicinity of SAIL (Steel Authority of India Ltd.) steel plants at Durgapur (23°34′N, 87°18′E, 100 m), Bokaro (23°38′N, 86°09′E, 220m), Rourkela (22°14′N, 84°53′E, 200m) and Bhilai (21°11′N, 81°21′E, 300 m). This was part of a World Bank funded modernisation project which included environmental management and pollution control. To monitor worst case conditions the soundings were conducted when inversion occurrence and development would be expected to be strong and atmospheric dispersion would be poor, during the months of January, February and March.

2. Instrumentation

Vertical soundings of dry bulb & wet bulb temperature and wind speed & direction were recorded using a 2A Tethersonde atmospheric profiling system, manufactured by Atmospheric Instrumentation Research Inc. This system comprises a balloon, an attached sensing instrument, a winch, a ground station, a printer and a cassette recorder. The winch and ground station can both be operated on either 240-volt A.C. or 12-volt D.C. power supply. Twelve-volt batteries were used at all four locations.

The aerodynamically shaped, orange coloured balloon is about 5 m long and 1m in diameter at its widest point. When filled with helium gas it can lift a payload of approximately 2 kg. The balloon is tethered to a winch on the ground by a Kevlar line, which has a breaking strain of 100 kg. The tether line is 1 km long so the balloon can attain an elevation of up to 1000 m in very light winds. In stronger winds the maximum height is restricted. The balloon is raised by slowly unwinding line off the winch. Should the line break, a pressure-sensitive puncturing device, fitted to the balloon, will cause it to deflate at an altitude above 1 km.

Suspended just beneath the balloon is an instrument which measures temperature, humidity, wind speed, wind direction and pressure (which can be converted to height). This instrument takes measurements

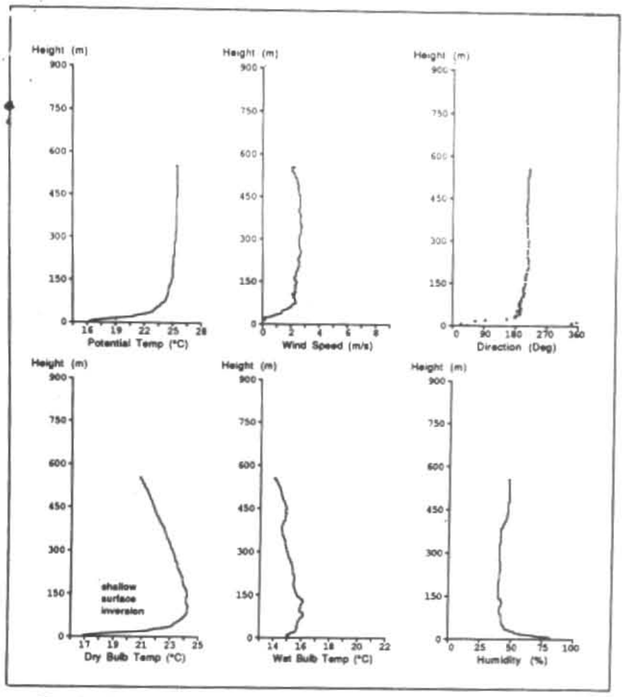

Fig. 1. Atmospheric profiles at Durgapur (2200 hrs) on 27 January 1990

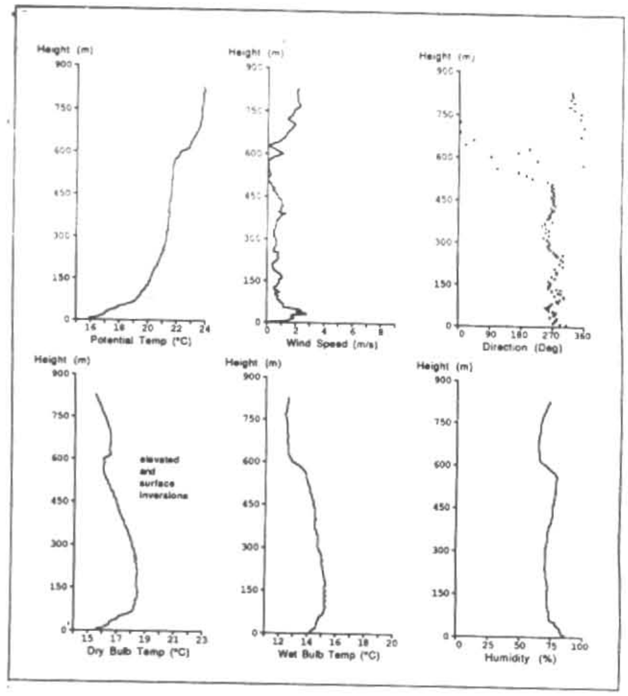

Fig.2. Atmospheric profiles at Bokaro (0600 hrs) on 12 February 1990

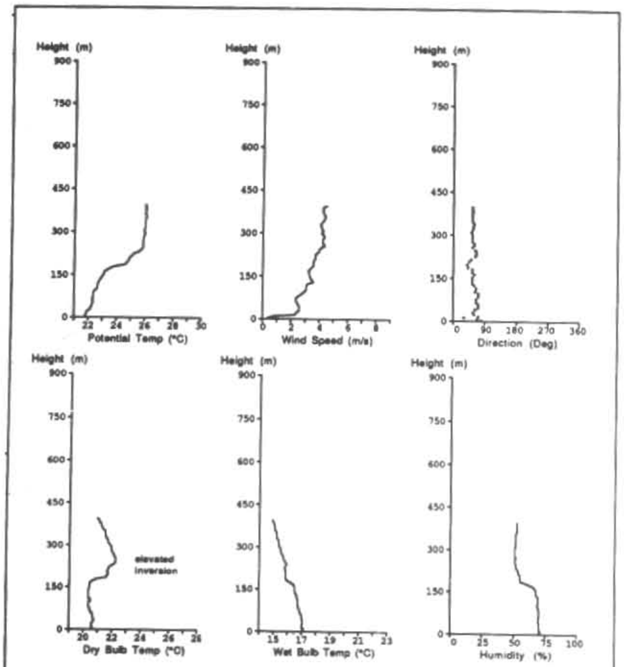

Fig. 3. Atmospheric profiles at Rourkela (0005 hrs) on 26 February 1990

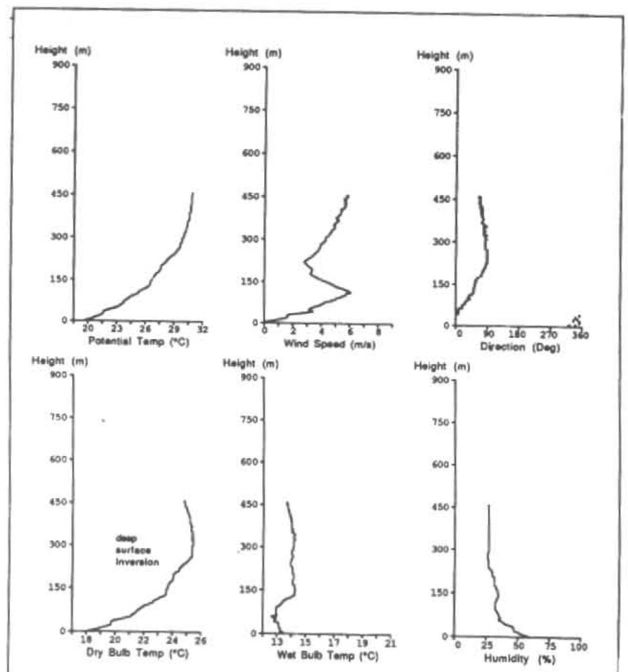

Fig. 4. Atmospheric profiles at Bhilai (0600 hrs) on 16 March 1990

TABLE 1

Variation of surface inversion ceiling (m) and strength (C°) with time at Durgapur

Night	Time (hours)						
	1800	2000	2200	2400	0200	0400	0600
1990				Ceiling (m)			
Jan 20/21	60	80	190	70	230	290	290
Jan 21/22	40	90	70	70	160	230	240
Jan 22/23	160	80	140	160	260	250	120
Jan 23/24	70	50	100	180	140	80	270
Jan 24/25	70	90	100	160	180	170	150
Jan 25/26	60	100	100	120	160	160	130
Jan 26/27	60	80	90	140	90	160	320
Jan 27/28	50	90	100	270	310	210	360
Jan 28/29	—	—	120	—	—	—	240
Jan 29/30	—	—	70	100	60	—	—
Average	70	80	110	140	180	190	240
S.D.	37	15	36	62	80	65	86
Maximum	160	100	190	270	310	290	360
Minimum	40	50	70	70	60	80	120
1990				Strength (C°)			
Jan 20/21	3.7	5.0	3.6	4.9	4.4	4.0	3.3
Jan 21/22	4.8	5.4	5.8	5.2	5.2	4.8	3.9
Jan 22/23	4.9	5.3	4.7	2.4	1.8	2.7	·4.0
Jan 23/24	4.6	4.8	4.0	4.8	5.5	6.6	5.2
Jan 24/25	4.1	6.0	5.5	4.9	5.5	5.0	3.7
Jan 25/26	5.0	5.2	3.6	3.7	4.5	4.0	4.1
Jan 26/27	4.6	5.8	5.9	3.5	4.6	4.9	4.4
Jan 27/28	5.6	6.7	7.4	7.1	6.8	7.2	7.8
Jan 28/29	—	—	6.9	*3.2	*1.6	—	8.6
Jan 29/30	—	—	4.5	5.0	4.7	*3.1	**1.5
Average	4.7	5.5	5.2	4.6	4.8	4.9	5.0
S.D.	0.6	0.6	1.3	1.3	1.3	1.4	1.9
Maximum	5.6	6.7	7.4	7.1	6.8	7.2	8.6
Minimum	4.1	4.8	3.6	2.4	1.8	2.7	3.7

* Excluded from analysis as strong wind forced sounding to be terminated before reaching ceiling.

** Excluded from analysis as recorded by airsonde.

every 15 sec and transmits FM signals (at 403.5 MHz) of recorded data to the receiving ground station. The ground station processes the incoming signals and outputs the data to a visual display unit, a printer and a cassette recorder.

Before the soundings commenced, details of the operations were supplied to the National Airports Authority who issued a NOTAM (Notice to Airmen) warning pilots to avoid flying in the vicinity. Since the soundings were conducted at night, flashing red, green and white lights had to be affixed below the balloon and laid out in a triangular pattern on the ground, as a further precaution to aircraft.

To avoid tangling the tether line or puncturing the balloon, an area clear of trees and power lines was required for operating the tethersonde system. Suitable sites were selected in each steel town at distances ranging between 3 km and 10 km from the plants.

3. Data presentation

Plotted in Figs. 1-4 are selected profiles recorded during the soundings conducted at the steel towns in January, February and March 1990. Profiles are presented of measured values of dry bulb temperature, wet bulb temperature, wind speed and wind direction as well as calculated values of relative humidity and potential temperature. Fig. 1 shows a strong, shallow surface inversion at Durgapur; Fig. 2 illustrates elevated and surface inversions in the same profile at Bokaro; Fig. 3 presents an elevated inversion at Rourkela; and Fig. 4 depicts a deep surface inversion at Bhilai.

Data on surface inversion ceiling heights and strengths (temperature difference between the ground and the inversion ceiling) are presented in Tables 1-4 (one for each location) and their frequencies are summarised in Table 5.

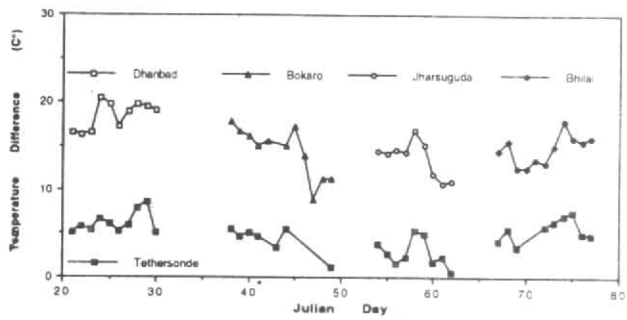

Fig. 5. Comparison of maximum measured (with tethersonde) surface inversion strength near steel plants and daily temperature excursion at proximate meteorological stations. 20 Jan-18 Mar 1990

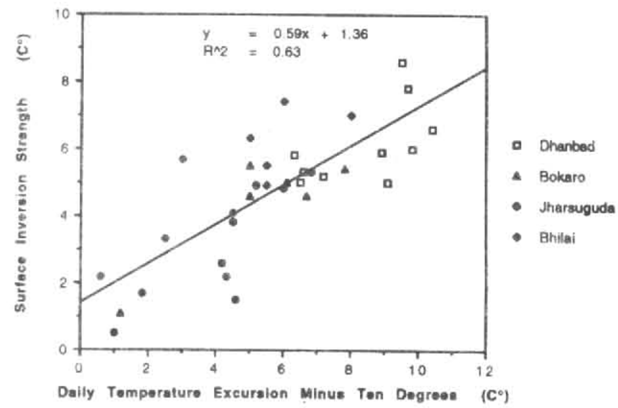

Fig. 6. Regression of maximum measured surface inversion strength near steel plants and daily temperature excursion at proximate meteorological stations. 20 Jan-18 Mar 1990

TABLE 2

Variation of surface inversion ceiling (m) and strength (C°) with time at Bokaro

Night	Time (hours)						
	1800	2000	2200	2400	0200	0400	0600
				Ceiling (m)			
1990							
Feb 6/7	110	140	320	180	270	300	150
Feb 7/8	70	60	160	160	340	400	300
Feb 8/9	90	100	220	340	520	*410	230
Feb 9/10	60	60	190	170	340	180	260
Feb 11/12	30	150	200	360	240	280	130
Feb 12/13	50	140	240	90	100	130	330
Average	70	110	220	220	300	260	230
S.D.	29	41	55	108	139	106	80
Maximum	110	150	320	360	520	400	330
Minimum	30	60	160	90	100	130	130
				Strength (C°)			
1990							
Feb 6/7	1.7	4.5	3.1	4.3	5.4	5.3	4.3
Feb 7/8	3.5	3.9	1.6	2.3	3.0	4.0	4.6
Feb 8/9	4.1	3.8	4.0	3.8	5.0	*4.2	3.1
Feb 9/10	3.9	3.6	4.6	3.9	4.6	4.2	4.4
Feb 11/12	1.1	2.4	2.0	3.4	2.6	2.9	2.9
Feb 12/13	1.8	1.6	4.1	4.7	5.0	5.5	5.3
Average	2.7	3.3	3.2	3.7	4.3	4.4	4.1
S.D.	1.3	1.1	1.2	0.8	1.2	1.1	0.9
Maximum	4.1	4.5	4.6	4.7	5.4	5.5	5.3
Minimum	1.1	1.6	1.6	2.3	2.6	2.9	2.9

* Excluded from analysis as sounding terminated before inversion ceiling reached.

4. Measurement program

The aim of the measurement program was to take seven soundings a night for ten nights at each of the four steel towns, with the target times being 1800 hrs (1830 hrs at Bhilai), 2000, 2200, 2400, 0200, 0400 and 0600 hrs.

4.1. *Durgapur*

Soundings commenced at Durgapur, on the lawn of Tagore House, on the night of 20/21 January 1990 and continued for ten successive nights until 29/30 January 1990. The measurement program was adhered to apart from the last two nights, when the annual flower show being held on the lawn precluded soundings before 2200 hrs. The sounding at 0400 hrs on 29 January was cancelled due to strong winds. This resulted in a total of 65 soundings. Fig. 7 shows the tethersonde system and the hangar which was constructed at Tagore House for storing the inflated balloon when it was not being used during the daytime.

4.2. *Bokaro*

Soundings at Bokaro began, on the airstrip apron, on the night of 6/7 February 1990 and concluded on the night of 19/20 February 1990. The proposed program was followed for six of the first seven nights (totalling 42 soundings). Unseasonal, inclement weather conditions prevailed thereafter, with strong winds, overcast skies and rain (which tallied 80 mm at Bokaro in February 1990, the third highest total in 24 years of observations) limiting the number of soundings to only nine in the subsequent seven nights. Conditions during the second week were not conducive to the formation of strong surface inversions, so only the first 42 of the 51 soundings that were recorded are included in the following analyses.

4.3. *Rourkela*

Soundings at Rourkela commenced, on the parade ground of the Fourth Battalion of the Orissa Special Armed Police on the night of 22/23 February 1990, and continued for ten successive nights until 3/4 March 1990. The measurement program was adhered to except when rain, heavily overcast skies and strong winds prevented soundings being conducted on eleven occasions, making a total of 59 soundings. Apart from the first, fifth and sixth nights, the prevailing windy and cloudy conditions were not conducive to the development of strong surface inversions. Fig. 8 shows the tethersonde system on the parade ground with the power station for Rourkela Steel Plant in the background.

4.4. *Bhilai*

Soundings were conducted at Bhilai on the cricket ground north of the Bhilai Hotel, commencing on the night of 7/8 March 1990 and concluding on the night of 17/18 March 1990. Soundings were conducted on ten of these eleven nights. The proposed program was followed on eight nights, but strong winds, overcast skies and rain reduced the number of soundings to six, none and one on the nights of 9/10, 10/11 and 11/12 March respectively, making a total of 63 soundings. The single sounding on 11/12 March recorded lapse conditions above the surface and is not included in the following analysis.

5. Results

An appraisal of results from the soundings shows :

(i) Surface inversions were recorded in every sounding at Durgapur, Bokaro (in the first week) and Bhilai (except as above), and in 45 out of the 59 soundings at Rourkela.

(ii) Surface inversion ceiling heights generally increased as the effects of cooling at the surface penetrated to greater elevations during the course of the night. The trend was less pronounced at Rourkela.

(iii) Surface inversion ceiling heights varied from :

40 m to 360 m at Durgapur with approximately two-thirds exceeding 100 m;

30 m to 520 m at Bokaro with more than three-quarters exceeding 100 m;

20 m to 450 m at Rourkela with almost two-thirds exceeding 100 m;

30 m to 330 m at Bhilai with more than two-thirds exceeding 100 m.

(iv) At Durgapur, the strength of the surface inversion generally attained its maximum value at 2000 hrs to 2200 hrs. This attainment of maximum strength early in the night may have been caused by the air at the surface becoming saturated, resulting in the release of latent heat and a slower rate of cooling at the surface than at higher levels. At the other three locations, the strength of the surface inversion generally became greater as the night progressed, increasing from an average of :

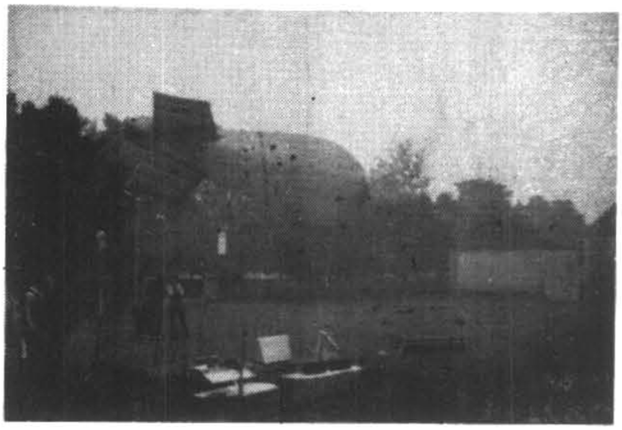

Fig. 7. Tethersonde system at Tagore House, Durgapur

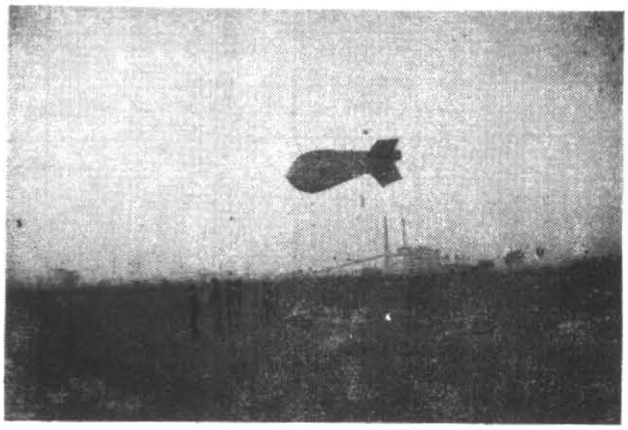

Fig. 8. Tethersonde system on parade ground of Orissa Special Armed Police at Rourkela with power station for steel plant behind

TABLE 3

Variation of surface inversion ceiling (m) and strength (C°) with time at Rourkela

Night	Time (hours)						
	1800	2000	2200	2400	0200	0400	0600
				Ceiling (m)			
1990							
Feb 22/23	20	170	30	320	290	140	210
Feb 23/24	60	90	90	90	130	200	260
Feb 24/25	—	30	60	20	60	150	190
Feb 25/26	—	—	120	L	L	L	L
Feb 26/27	80	90	140	140	180	310	450
Feb 27/28	i	190	200	360	150	220	270
Feb 28/Mar 1	L	130	L	30	90	—	L
Mar 1/2	50	140	—	i	100	70	110
Mar 2/3	30	L	L	80	L	—	150
Mar 3/4	—	—	—	L	—	—	—
Average	50	120	110	150	140	180	230
S.D.	24	54	61	137	76	82	111
Maximum	80	190	200	360	290	310	450
Minimum	30	30	60	20	60	70	110
				Strength (C°)			
1990							
Feb 22/23	0.8	2.4	0.3	3.9	3.8	3.1	3.6
Feb 23/24	0.3	1.0	0.5	1.3	1.9	2.6	2.6
Feb 24/25	—	0.4	0.7	0.7	0.7	0.8	1.5
Feb 25/26	—	—	2.2	L	L	L	L
Feb 26/27	1.1	1.5	3.0	4.2	3.3	3.3	5.4
Feb 27/28	i	2.4	4.6	4.9	3.8	3.4	3.1
Feb 28/Mar 1	L	0.6	L	0.4	1.7	—	L
Mar 1/2	0.5	2.2	—	i	1.1	0.6	0.6
Mar 2/3	0.5	L	L	0.4	L	—	0.5
Mar 3/4	—	—	—	L	—	—	i
Average	0.6	1.5	1.9	2.3	2.3	2.3	2.5
S.D.	0.3	0.9	1.7	2.0	1.3	1.3	1.8
Maximum	1.1	2.4	4.6	4.9	3.8	3.4	5.4
Minimum	0.3	0.4	0.5	0.4	0.7	0.6	0.5

i — isothermal, L — lapse

2.7C° at 1800 hrs to 4.4C° at 0400 hrs at Bokaro;

0.6C° at 1800 hrs to 2.5C° at 0600 hrs at Rourkela:

1.9C° at 1800 hrs to 5.1C° at 0600 hrs at Bhilai.

(v) At Durgapur, the surface inversion strength ranged from 1.8C° to 8.6C°, with more than three-quarters of the inversions exceeding 4C°. Surface inversion intensities (average temperature gradient between the surface and the ceiling) were higher at Durgapur than at the other plants and exceeded 10C°/100 m when the inversions were shallow early in the evening on 21, 23 and 27 January 1990 (*see* Fig. 1). At the other three steel towns, the strength of the surface inversion ranged from :

1.1C° to 5.5C° at Bokaro with almost half of the inversions exceeding 4C°;

Up to 5.4C° at Rourkela with approximately 10% of the inversions exceeding 4C°;

0.9C° to 7.4C° at Bhilai with more than half the inversions exceeding 4C°.

(vi) There was generally good agreement between wind velocities recorded by the tethersonde at Durgapur and deduced from pilot balloon observations by the India Meteorological Department at Panagarh Airport, some 20 km southeast.

6. Weather

Table 5 compares results from the four steel towns and shows considerable differences in their measured surface inversion regimes. The maximum recorded surface inversion strength was 8.6C° at Durgapur, 7.4C° at Bhilai and around 5.5C° at both Bokaro and Rourkela. The proportion of inversions greater than 4C° was 80% at Durgapur, 55% at Bhilai, 45% at Bokaro and 10% at Rourkela. To ascertain if such differences really exist between the four sites or whether they were caused by varying prevailing weather conditions when monitoring, reference was made to observations at meteorological stations near the plants.

A good indicator of the potential strength of nocturnal surface inversions is the difference between the maximum temperature on the previous day and the minimum temperature overnight — the daily temperature excursion. The most proximate stations where daily temperature excursion data readily available are India Meteorological Department stations at Durgapur, Panagarh (20 km southeast of Durgapur) and Jharsuguda (100 km southwest of Rourkela), and steel plant stations at Bokaro and Bhilai. Unfortunately the minimum thermometer at Panagarh malfunctioned in February 1989 and remained out of commission for more than one year so the required data were not available there. Observations at Durgapur showed so little variation from one day to the next that they were deemed suspect. Recourse was therefore made to the India Meteorological Department station at Dhanbad (100 km northwest of Durgapur). Compiled in Appendices I and II are maximum and minimum temperatures recorded at Bokaro and Bhilai respectively for 15 months from January 1989 to March 1990. Data from the India Meteorological Department stations at Dhanbad and Jharsuguda have not been reproduced here.

Fig. 5 is a time series plot comparing the temperature difference, recorded as the maximum in the vertical profile each night by the tethersonde and observed between the maximum and minimum temperature at the proximate meteorological station, for the period of tethersonde monitoring from 20 January to 18 March 1990. This figure graphically displays the close correspondence between the maximum surface inversion strength and the daily temperature excursion. It also shows that the prevailing weather conditions during the monitoring program were most conducive to development of strong surface inversions when soundings were conducted at Durgapur, then progressively less favourable at Bhilai, Bokaro and Rourkela. This indicates that the varying inversion regimes observed at the four steel towns were attributable more to prevailing weather conditions than to inherent site characteristics.

Fig. 6 is a regression plot of the maximum surface inversion strength and the daily temperature excursion (*minus* ten degrees), which shows that the correlation between these parameters accounts for more than 60% of the variance.

The daily temperature excursion data for the proximate meteorological stations in Appendices I and II provide an indication that the monitoring period encompassed the most suitable weather conditions for maximum development of nocturnal surface inversions and enable a coarse prediction of how much stronger than the measured values extreme surface inversions might be. In 1989, daily temperature excursions were generally greatest in the months from January to April, with the maximum value occurring in April at Dhanbad, in March at Bokaro, and in February at Jharsuguda and Bhilai. These 1989 maxima

TABLE 4

Variation of surface inversion ceiling (m) and strength (C°) with time at Bhilai

Night	Time (hours)						
	1830	2000	2200	2400	0200	0400	0600
				Ceiling (m)			
1990							
Mar 7/8	60	110	140	80	130	220	330
Mar 8/9	70	70	70	190	110	230	280
Mar 9/10	30	—	170	130	120	80	90
Mar 11/12	L	—	—	—	—	—	—
Mar 12/13	50	70	150	150	140	130	230
Mar 13/14	80	140	140	150	110	150	160
Mar 14/15	50	90	100	140	130	270	320
Mar 15/16	60	70	80	170	130	280	320
Mar 16/17	60	80	130	140	110	160	320
Mar 17/18	50	110	120	110	100	200	240
Average	60	90	120	140	120	190	250
S.D.	14	25	33	32	13	66	84
Maximum	80	140	170	190	140	280	330
Minimum	30	70	70	110	100	80	90
				Strength (C°)			
1990							
Mar 7/8	1.4	3.2	2.9	2.4	3.8	4.1	4.0
Mar 8/9	3.1	4.1	1.7	5.2	4.2	5.2	5.5
Mar 9/10	0.9	—	3.3	2.5	2.8	1.9	2.0
Mar 11/12	L	—	—	—	—	—	—
Mar 12/13	1.7	4.1	3.5	4.7	5.7	4.9	4.5
Mar 13/14	1.4	3.7	4.8	4.2	6.3	6.0	6.2
Mar 14/15	2.3	2.0	5.4	5.3	6.7	6.1	7.0
Mar 15/16	2.6	4.7	6.3	4.9	5.2	6.6	7.4
Mar 16/17	2.3	4.1	4.3	4.0	3.3	4.2	4.9
Mar 17/18	1.8	3.5	1.7	1.7	1.8	4.6	4.8
Average	1.9	3.7	3.8	3.9	4.4	4.8	5.1
S.D.	0.7	0.8	1.6	1.3	1.7	1.4	1.6
Maximum	3.1	4.7	6.3	5.3	6.7	6.6	7.4
Minimum	0.9	2.0	1.7	1.7	1.8	1.9	2.0

L — lapse

were approximately 3C° higher than the maximum daily temperature excursions occurring during the sounding program at Durgapur, Bokaro and Bhilai, while the difference at Rourkela was 6C°. Fig. 6 indicates that the maximum recorded surface inversion strength was roughly 10C° lower than the daily temperature excursion, which suggests the maximum inversion strength might be expected to be in the vicinity of 10-12C°.

7. Comparison with previous investigations

Previous observations of surface inversions in India have been reported by Sivaramakrishnan *et al.* (1971), Padmanabhamurty and Mandal (1979, 1980) and India Meteorological Department (1982, 1983). Sivaramakrishnan *et al.* (1971) analysed daily radiosonde data from 15 stations in the India Meteorological Department's network for five years from 1965 to 1969. In the triangle formed with Calcutta, Nagpur and Lucknow as apexes, which encompasses the four steel plants, the occurrence of nocturnal surface inversions generally exceeded 90% in the months from November to March, with half to three-quarters of the surface inversions having ceilings between 200 m and 500 m and approximately 10% exceeding 600 m. The analyses of Sivaramakrishnan *et al.* (1971) were updated by India Meteorological Department (1982, 1983) in an evaluation of radiosonde data from 19 stations for the succeeding five-year period from 1970 to 1974. Occurrence frequencies in the latter five years were lower by up to 20%. Partition of inversion ceilings into 100 m intervals indicated that more than half were between 200 m and 400 m above ground level.

TABLE 5

Surface inversion characteristics and frequencies of ceilings and strengths at Durgapur, Bokaro and Bhilai, 20 January-18 March 1990

Location	Monitoring period 1990	Nights soundings conducted	Soundings undertaken	Soundings with surface inversions (%)	Highest surface inversion (m)	Strongest surface inversion (C°)	Frequencies (%) of surface inversions with ceilings in range (m)				
							< 100	100 - < 200	200 - < 300	300 - < 400	≥400
Durgapur	20/21 Jan - 29/30 Jan	10	65	100	360	8.6	36	41	18	5	0
Bokaro	6/7 Feb - 19/20 Feb	9	51	96	520	5.5	20	37	19	19	5
Rourkela	22/23 Feb - 3/4 Mar	10	59	76	450	5.4	40	36	15	7	2
Bhilai	7/8 Mar - 17/18 Mar	10	63	98	330	7.4	31	50	13	6	0

Location	Monitoring period 1990	Nights soundings conducted	Soundings undertaken	Soundings with surface inversions (%)	Highest surface inversion (m)	Strongest surface inversion (C°)	Frequencies (%) of surface inversions with strength in range (C°)								
							<1	1 - <2	2 - <3	3 - <4	4 - <5	5 - <6	6 - <7	7 - <8	≥8
Durgapur	20/21 Jan - 29/30 Jan	10	65	100	360	8.6	0	2	3	13	38	28	8	5	2
Bokaro	6/7 Feb - 19/20 Feb	9	51	96	520	5.5	0	12	14	27	32	15	0	0	0
Rourkela	22/23 Feb - 3/4 Mar	10	59	76	450	5.4	38	18	13	22	7	2	0	0	0
Bhilai	7/8 Mar - 17/18 Mar	11	63	98	330	7.4	2	15	14	13	31	11	11	3	0

Radiosondes are designed to provide information on conditions in the upper atmosphere. They are not intended to provide detailed data on surface inversions in the lower atmosphere and their sampling rate lacks the resolution to precisely determine fine structure. Between January and March 1977, Padmanabhamurty and Mandal (1979) conducted low level soundings, with a sensor attached to a tethered balloon, at Mathura, 150 km southeast of Delhi. They reported inversion strengths of up to 9C° at Mathura and 7C° at Delhi, where some 80% of surface inversions recorded by radiosondes over ten years between 1968 and 1977 had ceilings between 100 m and 300 m.

Results from the SAIL soundings are in very good agreement with findings from these earlier investigations.

8. Conclusion

Monitoring for 40 nights in January, February and March 1990 indicated that surface inversions developed every night when weather conditions were favourable (clear skies and light winds). The ceiling height of surface inversions generally increased as the night progressed, with a maximum recorded height of 520 m and roughly two-thirds higher than 100 m. The maximum recorded surface inversion strength (temperature difference between the surface and the ceiling) was 8.6C° at Durgapur, 7.4C° at Bhilai and around 5.5C° at both Bokaro and Rourkela. The proportion of inversions greater than 4C° was 80% at Durgapur, 55% at Bhilai, 45% at Bokaro and 10% at Rourkela. These differences between locations were caused largely by varying weather conditions during the monitoring period.

For modelling atmospheric dispersion under assumed worst case stability conditions the measurements indicate that a reasonable estimate of the strongest surface inversion would be 10C° to 12C° in the lowest 250 m of the atmosphere.

Acknowledgements

The Steel Authority of India Ltd. kindly gave permission for this paper to be published. The organisation and assistance provided by the Environmental Management Division at Calcutta, the Environmental Control Department at Durgapur, the Environmental Control Department at Bokaro, the Environmental Engineering Department at Rourkela and the Environmental Management Department at Bhilai, in undertaking the atmospheric soundings, is gratefully acknowledged. Special thanks are reserved for the all people who helped with the measurements and rendered friendship and hospitality throughout the long, cold nights. They contributed substantially to the success of the study and the enhancement of the first author's knowledge of India.

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APPENDIX 1

Daily temperature excursion (°C) at Bokaro

1989

Date	Jan Max	Jan Min	Jan Diff	Feb Max	Feb Min	Feb Diff	Mar Max	Mar Min	Mar Diff	Apr Max	Apr Min	Apr Diff
1				26.7	7.2	19.5	34.4	13.9	20.5	30.6	16.1	14.5
2				27.8	7.8	20.0	35.0	16.1	18.9	33.3	17.8	15.5
3	23.3	10.0	13.3	30.6	9.4	21.2	34.4	14.4	20.0			
4	24.4	10.0	14.4	30.6	10.0	20.6	33.3	14.4	18.9	37.8	21.1	16.7
5	22.2	10.0	12.2	30.0	10.0	20.0	33.3	13.3	20.0	37.8	20.0	17.8
6	23.3	10.6	12.7							36.7	17.8	18.9
7	23.3	10.0	13.3	32.8	12.2	20.6	33.3	11.7	21.6	36.7	17.2	19.5
8	24.4	10.0	14.4	32.2	14.4	17.8	32.8	12.2	20.6	36.7	20.0	16.7
9				31.1	15.6	15.5	33.3	14.4	18.9	37.8	20.0	17.8
10	28.3	10.6	17.7	28.9	12.2	16.7	31.1	17.8	13.3			
11	23.3	7.8	15.5	27.8	12.2	15.6	28.3	13.3	15.0	38.3	18.9	19.4
12	22.2	6.7	15.5	27.8	12.8	15.0	33.3	16.1	17.2	41.1	23.9	17.2
13	20.0	4.4	15.6							38.3	22.2	16.1
14	21.1	5.0	16.1	27.8	8.9	18.9	28.9	13.3	15.6	38.9	20.0	18.9
15	19.4	3.3	16.1	28.9	10.0	18.9	32.2	14.4	17.8	38.9	18.9	20.0
16				30.6	13.3	17.3	31.1	16.1	15.0	40.0	18.9	21.1
17	22.8	5.6	17.2	28.9	13.3	15.6	31.1	15.6	15.5			
18	22.8	8.3	14.5	30.0	13.3	16.7	33.3	16.7	16.6	41.1	20.0	21.1
19	21.7	6.1	15.6	30.0	13.9	16.1	33.9	16.7	17.2	42.2	23.3	18.9
20	22.8	6.1	16.7							41.1	22.2	18.9
21	23.3	6.7	16.6	29.4	9.4	20.0	35.0	17.2	17.8	41.1	23.3	17.8
22	24.4	8.3	16.1	23.3	7.2	16.1	35.0	18.9	16.1	40.0	22.2	17.8
23				27.8	8.3	19.5				41.7	22.2	19.5
24	22.2	7.2	15.0	28.9	10.0	18.9	38.3	20.0	18.3			
25				25.6	8.9	16.7	38.3	20.0	18.3	42.8	22.8	20.0
26	23.3	5.0	18.3	25.6	10.0	15.6	37.8	21.7	16.1	42.2	26.7	15.5
27										41.1	25.6	15.5
28	25.6	6.7	18.9	31.1	10.0	21.1	36.7	20.0	16.7	41.7	24.4	17.3
29	26.1	8.9	17.2				33.3	19.4	13.9	38.9	23.9	15.0
30							28.9	16.7	12.2	38.9	24.4	14.5
31	26.1	6.7	19.4				27.2	15.0	12.2			
Maximum			19.4			21.2			21.6			21.1
Minimum			12.2			15.0			12.2			14.5

Date	May Max	May Min	May Diff	Jun Max	Jun Min	Jun Diff	Jul Max	Jul Min	Jul Diff	Aug Max	Aug Min	Aug Diff
1	38.9	24.4	14.5	33.3	20.0	13.3	30.0	23.9	6.1	30.0	22.2	7.8
2	41.1	22.2	18.9	32.2	23.9	8.3	29.4	24.4	5.0	26.1	22.2	3.9
3	39.4	26.1	13.3	35.6	22.8	12.8	30.0			28.3	22.2	6.1
4	43.3	26.7	16.6	36.1	25.0	11.1	30.0	22.8	7.2	27.8	23.3	4.5
5	45.0	30.0	15.0				28.9	23.3	5.6	27.2	22.8	4.4
6	42.8	28.3	14.5	38.9	23.9	15.0	30.6	23.9	6.7	28.3	22.8	5.5
7	42.2	28.9	13.3	37.2	23.3	13.9	31.1	24.4	6.7			
8				38.9	24.4	14.5	32.2	24.4	7.8	30.0	23.3	6.7
9	42.2	25.6	16.6	37.8	23.9	13.9	33.3	23.3	10.0	31.1	23.3	7.8
10	41.7	24.4	17.3	38.9	27.2	11.7				32.2	25.6	6.6
11	41.7	22.2	19.5	38.9	26.1	12.8	33.3	24.4	8.9	31.1	24.4	6.7
12	42.2	25.0	17.2				34.4	25.6	8.8	31.1	23.3	7.8
13	41.7	26.1	15.6	37.8	26.7	11.1	33.3	24.4	8.9	31.1	23.9	7.2
14	39.4	25.6	13.8	35.0	25.0	10.0	31.1	24.4	6.7			
15				30.0	23.9	6.1	30.0	23.3	6.7	30.0	23.3	6.7
16	41.1	22.2	18.9	30.0	23.3	6.7	31.1	24.4	6.7			
17	40.0	25.0	15.0	34.4	23.3	11.1				31.7	24.4	7.3
18	34.4	25.6	8.8	36.1	22.2	13.9	31.1	23.3	7.8	31.1	23.9	7.2
19	35.0	23.3	11.7				33.3	25.6	7.7	30.0	23.3	6.7
20	35.0	23.9	11.1	34.4	22.2	12.2	33.3	25.0	8.3	30.6	22.8	7.8
21	37.8	26.1	11.7	30.6	23.9	6.7	27.8	24.4	3.4			
22				28.3	22.8	5.5	32.2	25.0	7.2	32.8	24.4	8.4
23	40.0	23.9	16.1	27.8	22.2	5.6	31.1	24.4	6.7	32.2	23.3	8.9
24	36.7	25.0	11.7	30.0	22.2	7.8				31.1	23.9	7.2
25	36.1	26.1	10.0	33.3	24.4	8.9	29.4	22.8	6.6	30.6	23.9	6.7
26	36.7	24.4	12.3				30.0	23.3	6.7	29.4	23.3	6.1
27	36.1	22.8	13.3	34.4	25.0	9.4	32.2	25.6	6.6	30.0	23.3	6.7
28	28.3	22.2	6.1	31.1	24.4	6.7	34.4	23.9	10.5			
29				30.6	23.9	6.7	33.3	25.0	8.3	32.2	24.4	7.8
30	36.1	22.2	13.9	30.0	23.3	6.7	31.7	22.8	8.9	31.1	25.0	6.1
31	34.4	25.6	8.8							32.2	24.4	7.8
Maximum			19.5			15.0			10.5			8.9
Minimum			6.1			5.5			3.4			3.9

Date	Sep Max	Sep Min	Sep Diff	Oct Max	Oct Min	Oct Diff	Nov Max	Nov Min	Nov Diff	Dec Max	Dec Min	Dec Diff
1	30.6	23.3	7.3	30.0	23.3	6.7	30.0	15.6	14.4	22.8	14.4	8.4
2	29.4	23.9	5.5				30.6	15.6	15.0	25.6	13.3	12.3
3	32.2	23.9	8.3				29.4	14.4	15.0	25.6	11.1	14.5
4				34.4	22.8	11.6	28.9	13.9	15.0			
5	35.0	23.9	11.1	33.9	23.9	10.0	28.9	13.3	15.6	26.7	10.0	16.7
6	33.3	25.0	8.3	32.2	22.2	10.0				24.4	11.1	13.3
7	31.1	24.4	6.7	32.8	22.8	10.0	32.2	15.0	17.2	23.9	7.8	16.1
8	32.2	23.3	8.9	31.1	21.7	9.4	30.6	13.9	16.7	23.3	7.2	16.1
9	31.1	23.3	7.8				29.4	13.9	15.5	23.3	8.3	15.0
10	33.9	24.4	9.5	32.2	21.1	11.1	27.8	11.1	16.7	23.3	7.8	15.5
11				31.1	21.7	9.4	26.7	10.6	16.1			
12	33.9	22.2	11.7	31.1	21.1	10.0	27.2	11.1	16.1	25.6	8.9	16.7
13	30.6	23.3	7.3	30.0	21.7	8.3				23.9	9.4	14.5
14	28.9	23.3	5.6	30.6	22.2	8.4	27.2	12.8	14.4	22.8	9.4	13.4
15	28.9	23.3	5.6	28.9	21.1	7.8				23.3	10.0	13.3
16	30.6	23.9	6.7				28.3	12.8	15.5	23.3	9.4	13.9
17	31.1	23.3	7.8	30.6	19.4	11.2	30.6	13.9	16.7	23.9	10.0	13.9
18				31.1	17.8	13.3	30.6	15.0	15.6			
19	33.9	23.9	10.0	30.6	17.2	13.4	27.8	12.2	15.6	23.3	9.4	13.9
20	33.3	23.9	9.4	30.0	16.1	13.9				23.3	9.4	13.9
21	33.3	24.4	8.9	30.6	16.7	13.9	27.2	11.7	15.5	24.4	11.1	13.3
22	32.8	24.4	8.4	30.0	16.7	13.3	26.7	11.1	15.6	25.0	11.1	13.9
23	33.3	22.8	10.5				26.7	10.6	16.1	25.6	11.7	13.9
24	31.1	23.3	7.8	30.6	17.8	12.8	26.1	11.1	15.0	26.7	12.8	13.9
25				30.0	20.6	9.4	26.7	11.1	15.6			
26	31.1	22.2	8.9	27.8	20.0	7.8	26.7	12.2	14.5	22.8	12.2	10.6
27	30.6	22.8	7.8	30.0	20.6	9.4				22.8	12.8	10.0
28	30.0	22.8	7.2	30.6	18.3	12.3	27.8	12.8	15.0	15.6	10.0	5.6
29	25.6	21.7	3.9	30.0	15.6	14.4	26.7	15.0	11.7	21.1	8.9	12.2
30	27.8	22.8	5.0				20.0	15.0	5.0	21.1	8.3	12.8
31				30.6	15.0	15.6				20.6	7.2	13.4
Maximum			11.7			15.6			17.2			16.7
Minimum			3.9			6.7			5.0			5.6

1990

Date	Jan Max	Jan Min	Jan Diff	Feb Max	Feb Min	Feb Diff	Mar Max	Mar Min	Mar Diff
1				28.9	12.2	16.7	28.9	14.4	14.5
2	22.2	7.8	14.4	30.0	11.1	18.9	27.2	17.2	10.0
3	22.8	8.9	13.9	30.6	12.2	18.4	25.6	16.7	8.9
4	21.7	8.9	12.8	28.9	11.1	17.8	25.0	12.2	12.8
5	18.9	4.4	14.5						
6	21.1	5.0	16.1	28.3	10.0	18.3	26.7	11.7	15.0
7	23.3	6.7	16.6	27.8	10.0	17.8	25.6	12.2	13.4
8				27.8	11.1	16.7	24.4	14.4	10.0
9	26.1	8.3	17.8	28.3	12.2	16.1	26.7	12.2	14.5
10	25.0	8.9	16.1	28.3	13.3	15.0	29.4	13.3	16.1
11	23.3	7.2	16.1	30.6	15.0	15.6	30.0	13.9	16.1
12	22.8	6.1	16.7						
13	22.2	7.8	14.4	28.9	13.9	15.0			
14	21.1	8.9	12.2	30.0	12.8	17.2	30.6	16.1	14.5
15				27.8	13.9	13.9	30.6	16.1	14.5
16	27.8	8.3	19.5	23.3	14.4	8.9	26.1	16.1	10.0
17	26.1	8.9	17.2	25.6	14.4	11.2	28.3	16.7	11.6
18	25.0	9.4	15.6	25.6	14.4	11.2	29.4	17.8	11.6
19	26.7	10.0	16.7						
20	28.9	10.6	18.3	25.6	14.4	11.2	31.1	17.2	13.9
21	30.0	13.3	16.7	24.4	14.4	10.0	33.9	16.7	17.2
22				25.6	13.3	12.3	35.0	18.3	16.7
23	26.1	13.3	12.8	25.0	12.8	12.2	35.0	18.9	16.1
24	27.8	13.3	14.5	24.4	12.8	11.6	36.1	20.0	16.1
25				25.6	13.9	11.7	34.4	21.1	13.3
26	27.2	12.8	14.4						
27				27.8	13.9	13.9	30.6	13.9	16.7
28	26.7	12.2	14.5	27.8	15.0	12.8	28.3	16.7	11.6
29							25.6	17.2	8.4
30	29.4	10.6	18.8				23.9	17.2	6.7
31	31.7	15.6	16.1				26.7	17.8	8.9
Maximum			19.5			18.9			17.2
Minimum			12.2			8.9			6.7

APPENDIX II

Daily temperature excursion (°C) at Bhilai

1989

Date	Jan Max	Jan Min	Jan Diff	Feb Max	Feb Min	Feb Diff	Mar Max	Mar Min	Mar Diff	Apr Max	Apr Min	Apr Diff	May Max	May Min	May Diff	Jun Max	Jun Min	Jun Diff
1	29.5	12.0	17.5	34.5	14.0	20.5	38.0	20.0	18.0	39.0	21.5	17.5	45.0	29.0	16.0	43.5	32.0	11.5
2	29.5	13.0	16.5	35.0	16.0	19.0	37.5	21.5	16.0	39.0	23.5	15.5	43.5	30.0	13.5	42.0	29.5	12.5
3	30.0	14.5	15.5	34.5	14.5	20.0	37.0	19.5	17.5	39.5	23.5	16.0	41.0	21.0	20.0	42.5	31.0	11.5
4	29.0	14.0	15.0	34.5	14.0	20.5	35.5	19.0	16.5	39.5	23.5	16.0	43.0	25.5	17.5	42.0	32.0	10.0
5	28.5	13.0	15.5	35.0	17.0	18.0	36.0	19.0	17.0	39.0	22.0	17.0	42.0	26.5	15.5	38.5	30.0	8.5
6	31.5	13.0	18.5	34.0	16.0	18.0	36.5	19.5	17.0	38.5	21.5	17.0	42.5	28.0	14.5	38.5		
7	30.0	15.0	15.0	34.0	17.0	17.0	36.0	20.0	16.0	39.0	22.5	16.5	42.0	28.0	14.0	38.5	28.0	10.5
8	29.0	17.0	12.0	34.5	16.5	18.0	33.5	22.0	11.5	40.5	23.0	17.5	43.5	29.5	14.0	40.0	27.0	13.0
9	27.0	17.5	9.5	33.5	17.0	16.5	33.0	21.0	12.0	42.0	23.5	18.5	43.5	26.5	17.0	40.5	28.0	12.5
10	27.0	13.0	14.0	33.5	18.0	15.5	32.0	21.5	10.5	41.5	25.0	16.5	44.5	25.0	19.5	39.0	29.5	9.5
11	27.0	11.5	15.5	33.5	17.0	16.5	29.5	18.0	11.5	40.0	26.5	13.5	46.0	28.0	18.0	39.0	28.5	10.5
12	26.0	11.0	15.0	32.0	17.5	14.5	33.5	18.5	15.0	40.0	24.5	15.5	46.0	29.5	16.5	38.0	27.0	11.0
13	26.5	9.0	17.5	32.5	16.0	16.5	35.0	20.0	15.0	42.5	25.0	17.5	46.5	31.5	15.0	33.0	23.0	10.0
14	29.5	10.5	19.0	33.0	18.0	15.0	34.5	20.0	14.5	43.0	25.0	18.0	46.0	28.5	17.5	31.5	22.0	9.5
15	31.0	12.5	18.5	33.0	17.0	16.0	36.0	18.5	17.5	43.5	26.0	17.5	45.5	30.5	15.0	36.0	25.0	11.0
16	30.0	14.5	15.5	32.5	17.0	15.5	34.5	21.5	13.0	42.5	29.0	13.5	47.5	29.5	18.0	36.0	26.5	9.5
17	28.0	15.0	13.0	33.0	18.0	15.0	36.0	22.0	14.0	42.0	26.5	15.5	46.0	30.0	16.0	36.5	27.0	9.5
18	29.5	14.0	15.5	33.5	18.0	15.5	36.5	22.0	14.5	42.5	28.5	14.0	44.0	31.0	13.0	35.5	25.0	10.5
19	28.5	14.0	14.5	37.0	16.0	21.0	38.0	22.5	15.5	42.5	28.0	14.5	43.5	30.0	13.5	35.0	22.0	13.0
20	30.0	15.0	15.0	29.5	13.0	16.5	39.0	22.5	16.5	41.0	28.0	13.0	44.0	30.5	13.5	35.0	26.0	9.0
21	29.5	14.0	15.5	31.5	13.5	18.0	41.0	24.5	16.5	43.0	26.5	16.5	45.5	30.5	15.0	36.5	24.5	12.0
22	27.5	13.0	14.5	32.5	16.0	16.5	41.0	27.5	13.5	43.5	29.5	14.0	45.0	28.0	17.0	33.0	21.5	11.5
23	26.5	12.0	14.5	30.5	16.5	14.0	39.5	26.0	13.5	44.0	27.0	17.0	46.0	31.5	14.5	33.0	22.0	11.0
24	28.5	10.0	18.5	31.5	15.5	16.0	38.0	25.0	13.0	43.5	27.5	16.0	45.0	31.5	13.5	34.5	23.5	11.0
25	29.5	10.5	19.0	34.5	15.5	19.0	36.5	22.5	14.0	43.0	27.5	15.5	42.0	29.0	13.0	34.5	23.0	11.5
26	30.5	12.5	18.0	36.5	18.0	18.5	36.0	24.0	12.0	41.0	27.0	14.0	45.5	30.0	15.5	32.5	23.5	9.0
27	31.5	13.0	18.5	38.5	18.0	20.5	34.5	20.5	14.0	42.0	28.0	14.0	41.5	30.5	11.0	29.0	24.0	5.0
28	31.0	17.0	14.0	37.5	20.0	17.5	26.0	18.5	7.5	42.0	28.0	14.0	44.5	28.0	16.5	31.5	24.0	7.5
29	31.5	15.0	16.5				31.0	14.0	17.0	42.0	28.0	14.0	44.0	32.5	11.5	31.0	24.5	6.5
30	32.0	14.0	18.0				34.5	19.0	15.5	43.0	28.0	15.0	43.0	32.5	10.5	28.5	24.5	4.0
31	33.0	15.0	18.0				37.0	21.5	15.5				42.5	30.5	12.0			
Maximum			19.0			21.0			18.0			18.5			20.0			13.0
Minimum			9.5			14.0			7.5			13.0			10.5			4.0

Date	Jul Max	Jul Min	Jul Diff	Aug Max	Aug Min	Aug Diff	Sep Max	Sep Min	Sep Diff	Oct Max	Oct Min	Oct Diff	Nov Max	Nov Min	Nov Diff	Dec Max	Dec Min	Dec Diff
1	30.0	25.0	5.0	35.5	23.0	12.5	30.0	23.5	6.5	32.5	22.5	10.0	33.5	20.5	13.0	30.5	17.0	13.5
2	30.0	21.5	8.5	32.5	23.5	9.0	30.5	23.5	7.0	33.0	24.0	9.0	32.0	19.0	13.0	29.5	17.0	12.5
3	29.5	24.0	5.5	34.0	24.0	10.0	32.0	24.0	8.0	34.5	24.0	10.5	32.5	18.0	14.5	30.5	16.0	14.5
4	31.0	23.5	7.5	32.0	25.0	7.0	31.0	25.0	6.0	35.0	24.5	10.5	33.0	17.0	16.0	29.0	16.0	13.0
5	32.5	24.5	8.0	30.0	22.0	8.0	32.0	25.0	7.0	35.5	23.0	12.5	33.5	17.0	16.5	28.0	14.0	14.0
6	30.0	23.5	6.5	26.5	22.5	4.0	32.0	24.0	8.0	35.0	23.0	12.0	33.0	18.0	15.0	28.0	13.5	14.5
7	31.5	24.5	7.0	27.0	23.0	4.0	33.5	24.5	9.0	35.5	23.0	12.5	32.5	19.0	13.5	28.0	11.5	16.5
8	31.0	25.5	5.5	29.5	22.0	7.5	34.5	25.0	9.5	35.0	22.5	12.5	31.0	20.0	11.0	28.5	12.5	16.0
9	32.0	24.0	8.0	29.5	24.0	5.5	33.5	24.0	9.5	35.5	22.5	13.0	31.5	18.5	13.0	28.5	12.5	16.0
10	33.5	25.5	8.0	29.5	24.5	5.0	32.5	23.0	9.5	35.0	22.5	12.5	31.5	16.5	15.0	28.5	12.0	16.5
11	34.0	25.0	9.0	28.0	24.0	4.0	32.0	23.5	8.5	35.0	24.0	11.0	31.0	17.0	14.0	29.5	13.0	16.5
12	31.5	26.0	5.5	30.5	23.5	7.0	30.5	24.0	6.5	36.0	22.5	13.5	31.0	17.0	14.0	29.0	12.5	16.5
13	32.0	25.0	7.0	31.0	24.0	7.0	30.5	24.5	6.0	34.5	21.5	13.0	28.5	19.0	9.5	30.0	13.5	16.5
14	33.0	24.0	9.0	32.0	23.5	8.5	29.5	24.5	5.0	34.0	21.0	13.0	32.0	19.0	13.0	27.0	12.5	14.5
15	33.5	24.5	9.0	32.0	24.0	8.0	32.0	23.5	8.5	34.5	21.5	13.0	34.0	17.5	16.5	26.0	11.5	14.5
16	33.0	24.5	8.5	32.0	25.5	6.5	34.5	25.5	9.0	34.5	22.0	12.5	35.0	17.5	17.5	26.0	12.0	14.0
17	34.0	25.0	8.0	32.0	23.5	8.5	33.0	23.5	9.5	33.5	22.0	11.5	34.0	17.0	17.0	26.0	12.0	14.0
18	33.5	25.5	8.0	31.5	25.5	6.0	33.5	25.0	8.5	33.5	17.5	16.0	33.0	19.0	14.0	27.5	12.5	15.0
19	33.0	26.0	7.0	30.5	24.0	6.5	33.5	25.5	8.0	34.5	18.0	16.5	33.5	18.0	15.5	28.0	14.0	14.0
20	33.0	26.5	6.5	32.0	24.0	8.0	28.0	25.0	3.0	34.0	18.0	16.0	32.0	20.0	12.0	29.0	13.5	15.5
21	31.0	23.0	8.0	32.0	26.0	6.0	31.0	26.0	5.0	33.0	18.0	15.0	33.0	16.5	16.5	30.5	14.0	16.5
22	32.5	25.0	7.5	30.5	24.5	6.0	33.0	24.0	9.0	32.5	18.5	14.0	32.5	15.5	17.0	30.0	15.0	15.0
23	32.5	26.5	6.0	33.0	24.0	9.0	32.5	25.0	7.5	32.0	19.5	12.5	32.0	17.0	15.0	30.0	17.5	12.5
24	29.5	25.5	4.0	31.5	24.5	7.0	33.5	25.0	8.5	31.5	22.0	9.5	32.0	17.0	15.0	28.5	18.0	10.5
25	32.0	24.5	7.5	31.5	23.5	8.0	32.0	25.5	6.5	32.0	22.0	10.0	32.5	17.0	15.5	29.0	15.5	13.5
26	32.5	25.5	7.0	31.0	25.0	6.0	31.0	23.5	7.5	34.5	22.5	12.0	33.5	17.5	16.0	22.0	14.5	7.5
27	30.0	25.0	5.0	31.0	28.0	3.0	30.5	23.0	7.5	34.0	22.0	12.0	33.0	18.0	15.0	23.0	16.0	7.0
28	27.5	24.0	3.5	32.0	25.0	7.0	32.0	24.5	7.5	33.5	20.0	13.5	32.0	17.0	15.0	24.5	14.5	10.0
29	29.5	23.5	6.0	33.5	25.0	8.5	33.0	24.0	9.0	33.5	19.0	14.5	30.0	17.5	12.5	26.0	15.5	10.5
30	29.5	24.0	5.5	32.5	22.5	10.0	32.0	23.5	8.5	33.0	20.5	12.5	30.0	17.5	12.5	26.0	15.0	11.0
31	30.5	24.5	6.0	31.0	23.5	7.5				34.0	20.0	14.0				28.0	15.0	13.0
Maximum			9.0			12.5			9.5			16.5			17.5			16.5
Minimum			3.5			3.0			3.0			9.0			9.5			7.0

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Date	Jan Max	Jan Min	Jan Diff	Feb Max	Feb Min	Feb Diff	Mar Max	Mar Min	Mar Diff
1	28.0	17.5	10.5	33.5	17.0	16.5	32.0	21.5	10.5
2	30.0	16.5	13.5	32.5	18.5	14.0	31.5	20.0	11.5
3	29.0	16.0	13.0	32.0	17.0	15.0	30.0	18.5	11.5
4	30.0	16.5	13.5	32.5	16.0	16.5	32.0	17.5	14.5
5	29.5	16.0	13.5	32.5	18.0	14.5	34.0	19.0	15.0
6	29.5	17.0	12.5	32.5	17.0	15.5	33.5	20.0	13.5
7	30.5	15.5	15.0	33.5	17.0	16.5	33.0	18.5	14.5
8	31.0	16.5	14.5	34.0	18.0	16.0	34.0	19.5	14.5
9	31.0	17.5	13.5	33.5	20.0	13.5	34.5	19.0	15.5
10	29.5	16.0	13.5	33.0	20.5	12.5	34.0	21.5	12.5
11	31.0	14.5	16.5	31.5	17.0	14.5	34.0	21.5	12.5
12	31.5	13.5	18.0	33.0	18.5	14.5	31.0	17.5	13.5
13	32.0	14.0	18.0	33.5	18.5	15.0	33.0	20.0	13.0
14	32.0	14.0	18.0	33.0	18.0	15.0	33.5	18.5	15.0
15	31.0	15.0	16.0	25.5	18.0	7.5	36.0	18.0	18.0
16	30.0	15.0	15.0	28.0	17.5	10.5	36.0	20.0	16.0
17	31.0	13.5	17.5	29.5	18.0	11.5	36.5	21.0	15.5
18	33.0	14.0	19.0	30.5	18.5	12.0	37.5	21.5	16.0
19	33.0	14.5	18.5	30.0	17.5	12.5	37.0	22.5	14.5
20	33.0	15.5	17.5	31.0	16.5	14.5	37.0	22.5	14.5
21	32.0	16.0	16.0	30.0	16.5	13.5	38.0	23.0	15.0
22	32.0	17.5	14.5	30.0	16.0	14.0	37.5	25.0	12.5
23	32.0	17.0	15.0	31.0	15.0	16.0	37.0	26.0	11.0
24	32.5	16.0	16.5	33.0	16.5	16.5	34.5	23.5	11.0
25	32.5	16.0	16.5	33.0	19.0	14.0	35.0	19.5	15.5
26	31.5	16.0	15.5	32.0	17.0	15.0	36.0	20.0	16.0
27	32.5	14.0	18.5	34.5	19.0	15.5	36.0	20.0	16.0
28	33.5	15.0	18.5	34.0	20.0	14.0	36.0	21.5	14.5
29	33.0	17.5	15.5				37.5	23.0	14.5
30	33.0	17.5	15.5				37.0	22.5	14.5
31	34.0	17.0	17.0				37.5	24.0	13.5
Maximum			19.0			16.5			18.0
Minimum			10.5			7.5			10.5