551.509.53 : 551.524.36 : 631

FORECASTING OF MINIMUM TEMPERATURE FOR AGROMETEOROLOGICAL ADVISORY SERVICES (AAS)

1. Area specific forecast on frequency and intensity of low temperature as well as frost is important in operational agrometeorology to prevent damage to field crops as well as horticultural crops. In this direction, forecasting of the minimum temperature above 22° N latitude, was studied through the daily meteorological data obtained from 8 various agrometeorological advisory services (AAS) units. The advection data were collected from the stations adjacent to the AAS units. The study is based on correlation and regression analysis and their statistical tests. The air temperature is important factor for the growth and yield of crops and that extreme of heat and cold waves are injurious to both plant and animal kingdom (Subbaramayya and Vaidya 1974). Forecast of heat and cold waves and other important weather hazards are essentially required, because often they lead to fall in crop output, if it occurs during critical phenophases of the crop development, would, therefore, be of practical value

TABLE 1

Details of location of AAS units and stations under study

S. No.	Name of AAS units/stations	Latitude (° N)	Longitude (° E)	Altitude (m)	Distance in kms from AAS units
1.	Bhopal	23 16	77 25	499	
	Guna	24 19	77 19	478	278
2.	Jaipur	26 49	75 48	390	
	Alwar	27 30	76 35	271	151
3.	New Delhi	28 04	77 10	228	
	Karnal	29 43	76 28	245	119
4.	Chandigarh	30 44	76 51	370	
	Bilaspur	22 01	74 40	587	92
5.	Lucknow	26 45	80 53	128	
	Lakhimpur	27 54	80 48	147	134
6.	Patna	25 30	85 15	52	
	Chapra	25 47	84 44	58	50
7.	Guwahati	26 35	90 52	105	
	Rangia	26 26	91 37	60	60
8.	Gangtok	27 20	88 37	1756	

to agriculturists (Monral 1983). Northern region of India, generally above 20° N latitude, is prone to low temperature effect in winter, because wind in the lower levels of atmosphere over the region is mainly from the northerly direction, which are relatively cold and dry. Many times during the winter season minimum temperature falls below normal by 5 to 6° C over this region, this continues for a longer period. At the same time places *viz*., Srinagar, Banihal, Qazigund, Gulmarg, Jammu (IAF) and Mount Abu are there where the minimum temperature falls to 0° C or even less. Occasionally, frost point is also reached and cereals, horticultural crops are adversely affected. Below 22° N also, a few stations experience frost (*viz*., Kodaikanal, Ootacamund). Forecast on the frequency and intensity of low temperature as well as frost can be obtained by analysing climatological data through some area-specific models. In the present study such vital forecast, which are of immense utility in the bi-weekly Agrometeorological Advisory Services (AAS) bulletins are attempted to develop, area-wise advisories. The AAS network for this study is Bhopal, Jaipur, New Delhi, Chandigarh, Lucknow, Patna, Guwahati, and Gangtok. These are considered representatives of northern/northwest belts as well as eastern region of India (above 22° N). Thus the stations are very much prone to low temperature effect in winter months (December to February). Since these low temperature remains for longer duration, cereal crops like wheat, jowar, millets as well as horticultural crops like apple, orange, mango, onion, grapes etc. are adversely affected whenever there is a sudden fall in minimum temperature during winter months.

2. Forecasting the minimum temperature based on statistical techniques like regression have been attempted by many research workers (Kohli and Sinha 1975; Raj 1989; Singh and Jaipal 1983; Subbaramayya and Vaidya 1974). Klein and Hammons (1975) suggested as, many as 43 meteorological parameters as prescriptors (potential predictors). In this study, for predicting the minimum temperature in an AAS unit, suitable choice of parameters is essentially required.

2.1. Among other factors, daily variation in the minimum temperature at a place is mainly governed by (*i*) advection of colder air mass from north, (*ii*) moisture content of air near surface, (*iii*) low and medium clouds, (*iv*) presence of inversion layer near ground and upper air temperature, (*v*) nature of the underlying surface due to vegetation and trend due to advancement of season, etc. Spatial variations are governed mainly by (*i*) latitude, (*ii*) elevation, (*iii*) surface and (*iv*) local conditions. In the present study the following parameters, have been chosen are assumed to influence the minimum temperature.

2.1.1. *Advection* (T_a) - The pressure gradient is set up from higher latitude to lower latitude from north to south direction during winter particularly in the lower atmospheric levels. Depending upon distance and lower level wind force it is reasonable to expect that air from location north of the stations will get advected towards the south of station in 24, 36 or 48 hrs.

2.1.2. *Persistence factor* (T_n) - Hence, forecasting mechanism cannot ignore this factor for higher skill score.

TABLE 2

Linear correlation coefficients (r), '*t*'-values and degrees of freedom as obtained in the selected AAS units

S. No.	Name of AAS units/stations	Parameters	r	'*t*' value	DF
1.	Bhopal	T_n	0.698	38.25	1533
		T_a	0.63	30.76	
		T_d	0.57	27.63	
		T_c	0.44	19.40	
		Cl	0.28	11.64	
2.	Jaipur	T_n	0.68	20.51	478
		T_a	0.51	12.59	
		T_d	0.58	15.54	
		T_c	0.52	13.36	
		Cl	0.27	6.09	
3.	New Delhi	T_n	0.75	41.54	1316
		T_a	0.59	26.40	
		T_d	0.55	23.73	
		T_c	0.56	24.52	
		Cl	0.27	10.28	
4.	Chandigarh	T_n	0.74	37.17	1164
		T_a	0.59	25.13	
		T_d	0.51	20.40	
		T_c	0.56	23.18	
		Cl	0.26	9.38	
5.	Lucknow	T_n	0.69	35.04	1388
		T_a	0.65	31.65	
		T_d	0.51	21.88	
		T_c	0.55	34.72	
		Cl	0.31	12.16	
6.	Patna	T_n	0.73	30.28	799
		T_a	0.64	23.52	
		T_d	0.61	21.52	
		T_c	0.63	22.80	
		Cl	0.18	5.31	
7.	Guwahati	T_n	0.70	17.39	318
		T_a	0.61	13.79	
		T_d	0.51	10.62	
		T_c	0.31	5.84	
		Cl	0.27	5.06	
8.	Gangtok	T_n	0.83	57.06	1499
		T_d	0.59	28.14	
		T_c	0.51	22.95	
		Cl	-0.03	1.14	

Weather in tropics is of persistence in nature irrespective of any disturbances.

2.1.3. *Moisture content* (T_e) - The surface dew point temperature reflects the moisture content of air mass near the ground. A higher dew point denotes incursion of warm, moist air mass, whereas a lower dew point temperature would indicate advection of dry and colder air from the north. This factor has been considered in the model.

TABLE 3

Regression equations obtained for the AAS stations

S. No.	Name of AAS Units/stations	Regression equations
1.	Bhopal	Tnf = -1.71 + 0.35T_n + 0.01T_a + 0.34T_d + 0.13T_e + 0.89Cl
2.	Jaipur	Tnf = -4.31 + 0.44T_n - 0.11T_a + 0.46T_d + 0.14T_e + 1.62Cl
3.	New Delhi	Tnf = -4.21 + 0.37T_n + 0.02T_a + 0.39T_d + 0.16T_e + 2.75Cl
4.	Chandigarh	Tnf = -4.00 + 0.33T_n + 0.18T_a + 0.39T_d + 0.17T_e + 2.83Cl
5.	Lucknow	Tnf = -4.29 + 0.27T_n + 0.11T_a + 0.34T_d + 0.23T_e + 2.66Cl
6.	Patna	Tnf = -4.8 + 0.33T_n + 0.03T_a + 0.40T_d + 0.27T_e + 3.19Cl
7.	Guwahati	Tnf = -3.74 + 0.41T_n + 0.07T_a + 0.31T_d + 0.22T_e + 2.13Cl
8.	Gangtok	Tnf = -1.03 + 0.70T_n + 0.22T_d + 0.04T_e - 0.03Cl

TABLE 4

Results of analysis of partial regression coefficient as obtained in the selected AAS units

S. No.	Name of AAS unit/stations	Parameters	Partial reg. coeff.	'*t*' value	DF
1.	Bhopal	T_n	0.35	11.24	1533
		T_a	0.006	0.27	
		T_d	0.34	19.03	
		T_c	0.13	10.37	
		Cl	0.89	3.31	
2.	Jaipur	T_n	0.44	8.07	478
		T_a	0.11	1.87	
		T_d	0.46	11.61	
		T_c	0.14	3.16	
		Cl	1.62	2.32	
3.	New Delhi	T_n	0.37	12.50	1316
		T_a	0.02	0.61	
		T_d	0.39	17.81	
		T_c	0.16	10.11	
		Cl	2.75	7.52	
4.	Chandigarh	T_n	0.34	10.57	1164
		T_a	0.002	0.63	
		T_d	0.39	16.32	
		T_c	0.18	10.54	
		Cl	2.82	7.61	
5.	Lucknow	T_n	0.27	9.00	1388
		T_a	0.11	2.88	
		T_d	0.34	16.80	
		T_c	0.23	13.27	
		Cl	2.66	8.01	
6.	Patna	T_n	0.33	9.91	799
		T_a	0.03	0.79	
		T_d	0.40	16.78	
		T_c	0.27	12.90	
		Cl	3.90	7.93	
7.	Guwahati	T_n	0.41	6.71	318
		T_a	0.01	1.15	
		T_d	0.31	8.23	
		T_c	0.22	6.30	
		Cl	2.13	4.05	
8.	Gangtok	T_n	0.70	42.19	1499
		T_d	0.22	12.58	
		T_c	0.04	2.04	
		Cl	0.03	0.29	

TABLE 5

Analysis of variance as observed in the selected AAS units

Name of AAS unit/stations	SS	DF	MS	F	RMSE
1. Bhopal					
Regression	6704.7	5	1340.9	452.8	0.07
Residual	4517.5	1529	3.0		
Total	11222.2	1534			
MCC = 0.77, which accounts for 59.8% of total variance in yield					
2. Jaipur					
Regression	3281.4	5	656.3	145.7	0.15
Residual	2134.9	474	4.5		
Total	5416.3	479			
MCC = 0.78, which accounts for 60.7% of total variance in yield					
3. New Delhi					
Regression	7686.5	5	1537.3	514.8	0.08
Residual	3918.1	1342	3.0		
Total	11604.6	1317			
MCC = 0.81, which accounts for 66.7% of total variance in yield					
4. Chandigarh					
Regression	6133.3	5	1226.7	425.6	0.08
Residual	3348.5	1160	2.9		
Total	9481.8	1165			
MCC = 0.80, which accounts for 64.8% of total variance in yield					
5. Lucknow					
Regression	7154.3	5	1430.9	441.5	0.08
Residual	4485.4	1384	3.2		
Total	11639.7	1389			
MCC = 0.78, which accounts for 61.5% of total variance in yield					
6. Patna					
Regression	3880.0	5	776.0	289.1	0.09
Residual	1585.5	795	2.0		
Total	5465.5	800			
MCC = 0.84, which accounts for 71.0% of total variance in yield					
7. Guwahati					
Regression	1123.5	5	224.7	99.6	0.13
Residual	708.3	314	2.3		
Total	1831.8	319			
MCC = 0.78, which accounts for 61.4% of total variance in yield					
8. Gangtok					
Regression	5515.5	4	1378.9	992.1	1.06
Residual	2079.1	1496	1.4		
Total	7594.6	1500			
MCC = 0.85, which accounts for 72.7% of total variance in yield					

2.1.4. *Cloud (weighted) over the station at 1200 UTC (Cl)* - Persistence of low and medium cloud during evening hours would prevent escape of long wave and infrared radiation into the space during night which leads to higher night temperature. When these clouds are absent, there is large fall in night temperature. The factor finds a place in the analysis through arbitrary weighing.

2.1.5. *Surface dry bulb temperature* (T_d) - The dry bulb temperature at 1200 UTC also plays crucial role in modifying the temperature pattern during night. This represents the heat content of the 'atmosphere, approximately, near ground at the time of sunset. Other factors remaining same, this temperature will show the magnitude of fall that could take place during the night till the sunrise. It is also incorporated in the regression analysis.

2.2. *Data and method of analysis* - The present study uses daily weather data from December to February for Bhopal, Jaipur, New Delhi, Chandigarh, Lucknow, Patna, Guwahati, and Gangtok based on 8 to 20 years

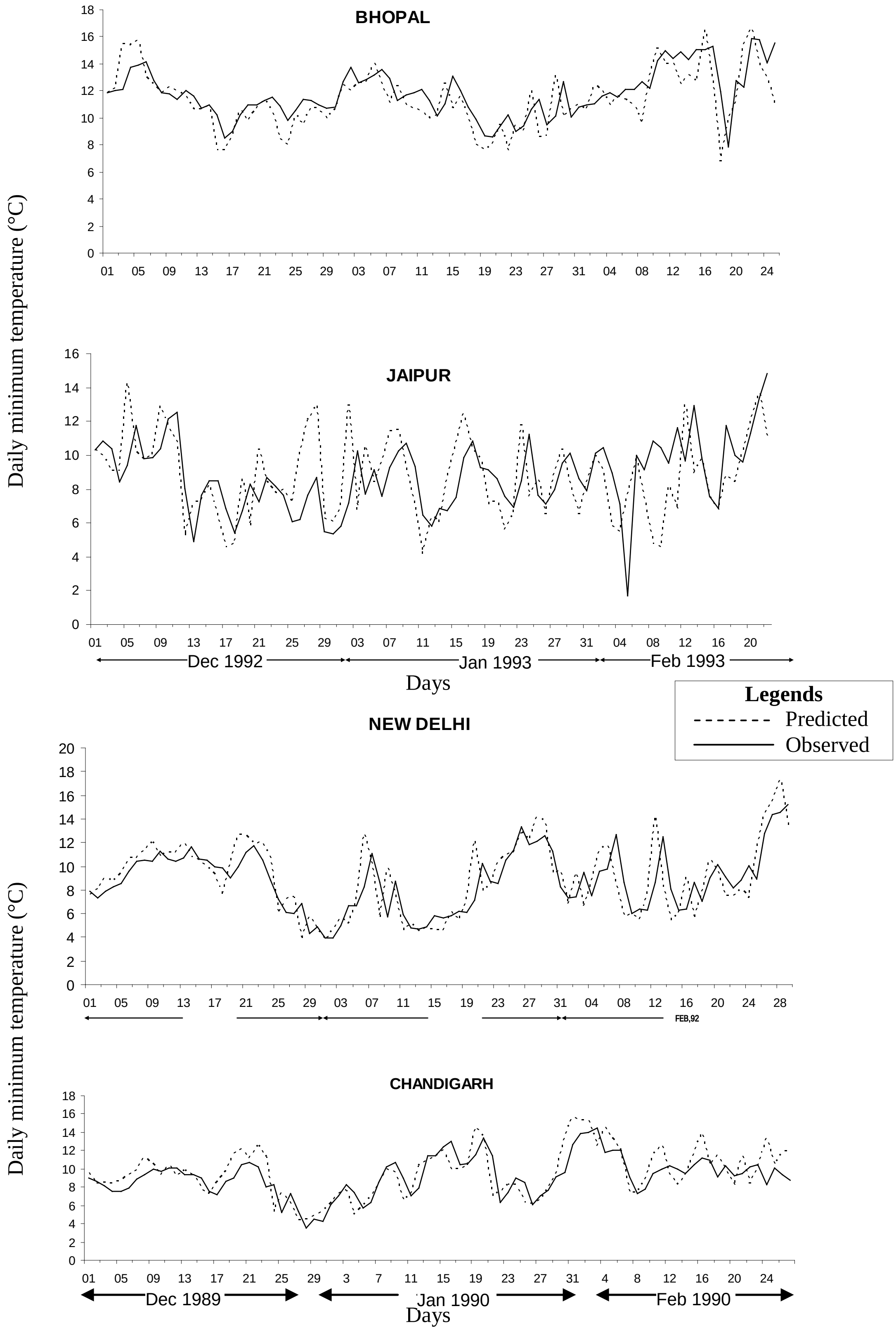

Fig. 1. Predicted and observed daily minimum temperatures

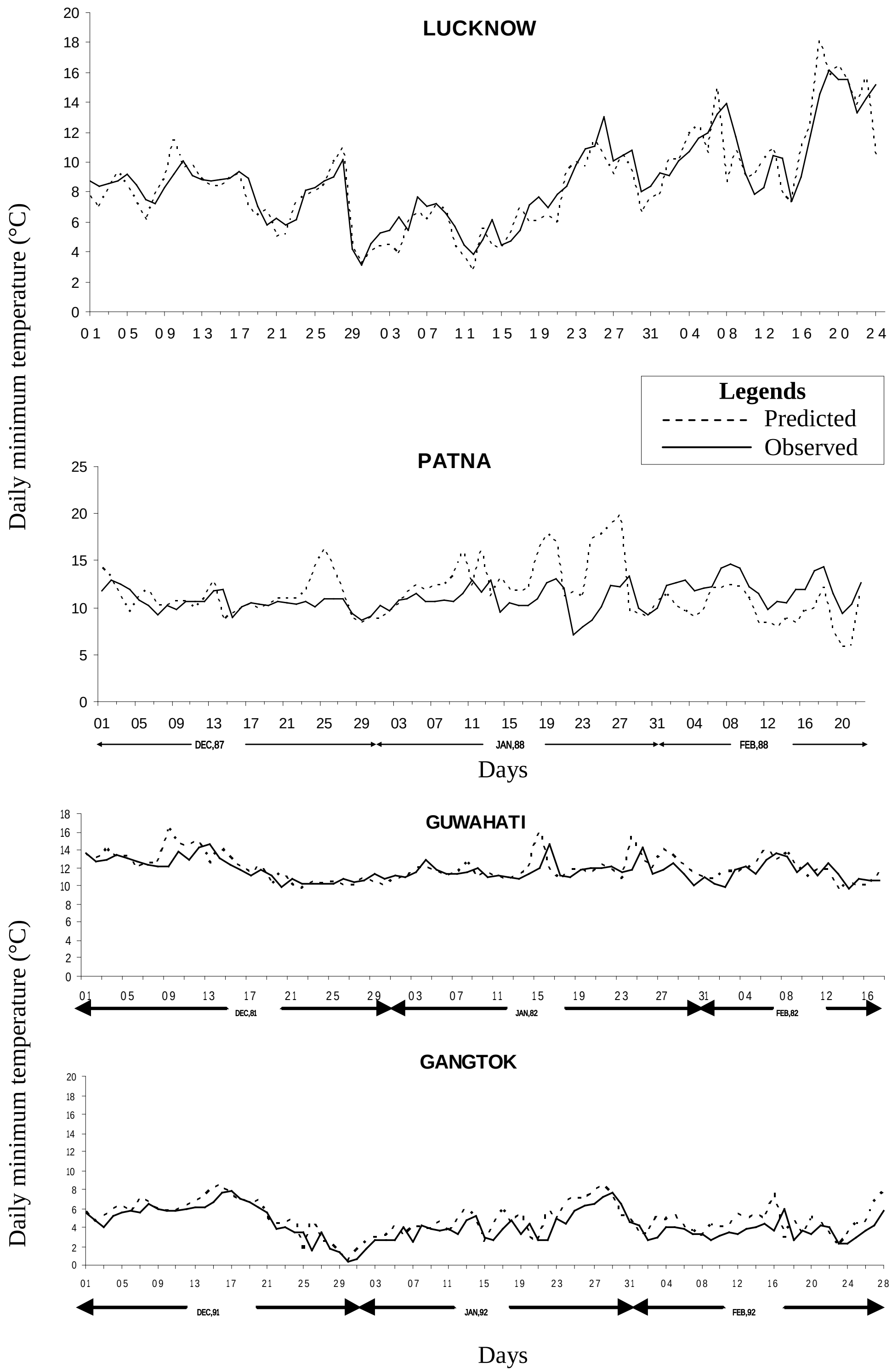

Fig. 1(Contd.). Predicted and observed daily minimum temperatures

period. For persistence, the minimum temperature (T_n) during (i-1)th day is taken to forecast the minimum temperature for the i^{th} day. Dew point temperature and surface dry bulb temperature refer to 1200 UTC observation of the (i-1)th day. Similarly, cloud amount refer to 1200 UTC observation of the (i-1)th day. The low and medium clouds amount were assigned weight of 1.0 and 0.7, respectively, in view of their decreasing importance as the level increases (Singh and Jaipal, 1983).

For advection (T_a), daily temperature data of (a) Guna (for Bhopal), (b) Alwar (for Jaipur), (c) Karnal (for Delhi), (d) Bilaspur (for Chandigarh), (e) Lakhimpur (for Lucknow), (f) Chapra (for Patna) and (g) Rangia (for Guwahati) were collected. Latitude, longitude, height in meters above mean sea level and distance from the respective AAS stations in km are shown in Table 1. All the above stations are generally located at northern side of the respective AAS stations. As such advection term is not included. The near surface wind over these stations being light or weak (around 5 to 10 knots); hence, it is believed, that the air mass will take nearly 24 hrs to arrive at or adjacent to the respective AAS stations. As such, to forecast the minimum temperature at the AAS stations for the i^{th} day, the corresponding temperature at these stations for $(i\text{-}1)^{th}$ day is considered.

The technique followed is correlation and regression with the minimum temperature at the AAS stations on i^{th} day as dependent parameter and the factors mentioned earlier as independent parameters. The equation developed for all the agromet advisory services units, under study has been tested for independent data of one more winter season months from December to February.

3. For the areas, where damage due to the low temperature effect are more frequent are studied in detail from the data collected through various AAS stations. The regression equations obtained from this study for all the AAS stations are depicted in Table 3.

The linear correlation has been shown in Table 2, along with the '*t*' values for all the AAS stations under study. It is interesting to note that for all the stations under study, persistence factor bore a very high correlation ranging from 0.68 for Jaipur to 0.82 for Gangtok. Other terms of significance, after persistence, in governing the minimum temperature, according to the correlation seemed to be advection (T_a), which bore the correlation coefficient from 0.51 for Chandigarh to 0.65 for Lucknow, except Jaipur, where its correlation was slightly less than dry bulb temperature (T_d). T_d and T_c were also according to the correlation, significantly contributed in modifying the minimum temperature.

Results of the partial regression analysis are also shown in Table 4. Each of the term considered in the analysis, in general, were significant when viewed with respect to their '*t*' values, except advection term (T_a), which surprisingly had the least significance for all the stations. ('*t*' values are 0.27 for Bhopal, 1.87 for Jaipur, 0.61 for New Delhi, 0.63 for Chandigarh, 2.88 for Lucknow, 0.79 for Patna and 1.15 for Guwahati). From the values of partial regression coefficient also, it looked that advection term was not very much responsible in governing the minimum temperature. Surprisingly, dry bulb temperature (T_d) seemed to be more significant than all other terms when viewed with respect to the partial regression coefficient and the values of student '*t*' test of all the AAS stations (except for Gangtok, where T_n seemed to be more significant than T_d) were significant.

Analysis of variance is given in Table 5. The 'F' values were found to be significant at 0.1 % level. The multiple correlation coefficients of all the AAS stations were ranged between 0.77 for Bhopal to 0.85 for Gangtok, which accounted for 59.8 to 72.8 % of variation in the minimum temperature, respectively. The root mean square errors of the forecast based on the equations from this study were ranged between 0.07 for Bhopal to 1.06 for Gangtok. The contribution by individual parameters was obtained by dropping the, parameters one by one. Here, also it was observed that the contribution due to dry bulb temperature recorded at 1200 UTC was found to be higher than other parameters for all the stations except Gangtok. For Gangtok the contribution in governing the minimum temperature T_d was next to persistence (T_n). Advection term was found to be the least significant in governing the minimum temperature.

4. The regression equations obtained in this study were applied to the independent data for one more winter season (immediately, succeeding the study period from December to February) for all the AAS stations under study, the results of which are shown in Fig. 1. It was found that more than 52% of the forecast were correct with ± 1° C deviation for all the AAS stations except at Jaipur, New Delhi and Patna and more than 75% of the forecast were correct with ± 2° C deviation for all the AAS stations (except for Jaipur and Patna, where the values were 63 % and 59 %, respectively). The estimated minimum temperature was found to be very close to the actual temperature for all the AAS stations except some isolated cases for some AAS stations like Jaipur, Chandigarh and Patna when difference between the forecast and actual minimum temperature was more. Root mean square error of all the AAS stations were lying in the range of 0.07 to 0.15, thus validating the use of the prediction equations.

5. The study on forecast of the minimum temperature revealed that the persistence and dry bulb temperature at 1200 UTC are the most important parameters, which can be used in temperature forecasting in tropics. Dew point temperature, low and medium clouds observed at 1200 UTC for all the AAS stations, probably exert equal influence on the minimum

temperature. Advection term is also equally important factor in governing the minimum temperature in tropics. The area specific, regression equations for forecast of the minimum temperature may be applied on experimental basis before making the models operational. However, the drawback of the regression equations developed here is that these are dependent on temperature data from other stations, hence, such regression equations can be used only by those forecasting offices, where such data are available.

Acknowledgement

The authors are thankful to Mrs. A. A. Kale, S.A. for her assistance in analysis of data and neatly typing the manuscript.

References

Klein, W. H. and Hammons, G. A., 1975, "Maximum-minimum temperature forecast based on model output statistics", *Mon. Wea. Rev.*, **103**, 796-806.

Kohli, M. S. and Sinha, M. C., 1975, "Forecasting of minimum temperature during winter for New Delhi", *Vayu Mandal*, **5**, 4, 88-90.

Monral, N. S., 1983, "Significant variation in maximum and minimum temperature at Bombay airport", *Mausam*, **34**, 2, 175-178.

Raj, Y. E. A., 1989, "Prediction of winter minimum temperature of Pune by analogue and regression methods", *Mausam*, **40**, 2, 175-180.

Singh, D. and Jaipal, 1983, "On forecasting night minimum temperature over New Delhi", *Mausam*, **34**, 2, 185-188.

Subbaramayya, I. and Vaidya, B. K., 1974, "Forecasting night minimum temperature", *Vayu Mandal*, **4**, 1, 21-22.

H. P. DAS
A. KASHYAPI

India Meteorological Department, Pune- 411005, India
(*13 April 2004, Modified 19 July 2006*)