Prediction of winter minimum temperature of Kolkata using statistical model

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ABSTRACT. Five parameter multiple linear regression model for objective forecasting of minimum temperature of Kolkata (Alipore) with 12 hours lead period has been developed. The predictors are chosen from the available surface data of Alipore observatory and low level wind data of M. O. Kolkata. Model has been developed from data sample comprising of 237 days (in January and February, period: 1997 – 2000) after stationarity test of minimum temperature data of much longer period (1988–2004). The model is tested with independent sample of 178 days. Efficiencies of the model have been tested with statistical skill score and found to be positive. The model can be used by the forecaster for assessing prediction minimum temperature and modify if cloud cover and wind flow pattern are expected to change subsequently.

Key words – Skill score, Multiple correlation coefficient, Variance explained.

1. Introduction

Temperature of a place mainly depends on a number of meteorological parameters viz., net solar radiation received from the sun, cold/warm advection of air mass, cloud cover, local effects such as nature of soil, orography and topography of that place. Kolkata located on the southern part of Gangetic West Bengal often experiences changes of air masses – south/southeasterly warm and moist airmass from the Bay of Bengal and west/northwest cold and dry airmass from the land areas of Bihar and Jharkhand round the year. During winter months (January and February) series of Western Disturbance (WD) from NW India move across the country in a NE/E’ly direction and some of these extend as far as Kolkata causing light rain, cold spell, fog and haze in its neighbourhood and paralyse normal life. Sometimes minimum temperature suddenly drops down by six degrees Celsius or more. Such a condition however does not continue for long and local weather forecast of minimum temperature based on synoptic condition and trend values of some meteorological parameters may not yield good result on such occasions.

Many authors have carried out studies on minimum and maximum temperature. WMO (1966), Kendal and Stuart (1968), Panofsky and Brier (1968) provide detailed description of various forecasting techniques including the widely used statistical technique of multiple linear regression analysis. Klien and Hammons (1975) suggested a large number of meteorological parameters as the potential predictors for the prediction of maximum and minimum temperatures. Singh and Jaipal (1983), Raj (1989), Charantoris and Liakatas (1990), Vashisth and Pareek (1991), have attempted minimum temperature forecast using various techniques including Markov chains. Attri et al. (1995) have used multiple regression method for forecasting minimum temperature at Gangtok in Sikkim. Dimri et al. (2002) have attempted minimum temperature forecast on hilly station Manali in Himachal Pradesh using multiple linear regression models for prediction of maximum and minimum temperature during December to February.

Present study is an effort to develop deterministic statistical prediction model for day-to-day forecasting of winter minimum temperature of Kolkata (Alipore) 12 hrs.
in advance based on data available up to 1730 hr (IST) using multiple linear regression technique.

2. Data used and processing

Seventeen-year surface data (1988 – 2004) of Alipore Observatory for the months of January and February (JF) has been utilized. Data for the period from 1988 to 2001 has been utilized for developing the forecast model for predicting minimum temperature and the performance of the model has been tested with the independent data set of the remaining period from 2002-04. Thus development period (DP) and the testing period (TP) consist of 830 days and 178 days respectively.

2.1. Some properties of the predictand

It is seen from Table 1, minimum temperature of Kolkata of JF during the development period had a mean value of 15.7°C and SD of 3.3°C. The lowest value of minimum temperature of 8.4°C was registered on 14 Jan. 1989 whereas the highest value of 25.1°C was observed on 26 Feb. 2001. Thus range of variation of minimum temperature was found to be of the order of about 17°C. Fig. 1 gives the daily variation of normal minimum temperature based on existing Pentad normal (1931-60) of Kolkata (Alipore). From the graph it is seen that variation of temperature from 1988 to 1996 is more or less uniform but it shifts slightly to the higher side from 1997 to 2004. However variation during 1997 to 2004 (from data points 535 onwards) shows some uniformity/stability within it. The effective length of the DP series was reduced to 237 (1997-2000) instead of 830 (1988-2001) on the basis of its stationarity, randomness and persistence.

| Statistics | Temperature (°C) | Remarks          |
|------------|-----------------|------------------|
| Mean       | 15.7            |
| Median     | 15.7            |
| Highest    | 25.1            | 26 February 2001 |
| Lowest     | 8.4             | 14 January 1989  |
| Range      | 16.7            |
| SD         | 3.3             |

**Table 1**

Statistics of winter minimum temperature of Kolkata based on data of JF, 1988-2001 and other information on thirty year’s normal (1951-1980)
TABLE 2
Minimum temperature forecast model: Equation, predictor and reduction of variance

| S. No. | Predictor | Legend | Unit   | Time hrs. (IST) | Mean | SD  | Correlation | VE (%) | MCC |
|--------|-----------|--------|--------|----------------|------|-----|-------------|--------|-----|
| 1      | $T_{\text{min}}$ | Previous day minimum temperature | °C     | 0830           | 16.0 | 3.1 | +0.83       | 69.8   | 0.94|
| 2      | $T_{\text{max}}$ | Maximum day temperature on previous day | °C     | 1730           | 26.9 | 3.1 | -0.75       | 10.0   |     |
| 3      | Meridional component | Upper wind at 0.9 km on previous day | kmph   | 1730           | -8.3 | 12.8 | +0.49       | 4.7    |     |
| 4      | RH_{\text{min}} | Minimum day humidity on previous day | %      | 1730           | 45.1 | 11.5 | +0.11       | 2.6    |     |
| 5      | N         | Total cloud cover on previous day | okta   | 1730           | 2.4  | 2.6 | +0.23       | 1.1    |     |

VE (Variance Explained), MCC (Multiple Correlation Coefficient)

2.2. Introduction of predictors

The independent meteorological parameters (predictors) were identified in such a way that they are correlated and can explain most of the variance of minimum temperature (predictand). In other words all the chosen parameters that were found to be very much significant in qualifying Fisher’s $F$-test at 95% confidence level were considered for the final multiple regression equation for predicting minimum temperature. They are

(i) $X_1$ Minimum temperature record at 0830 hrs. (IST) of previous day

(ii) $X_2$ Maximum temperature record at 1730 hrs. (IST) of previous day

(iii) $X_3$ Meridional component of wind at 0.9 km at 1730 hrs. (IST) of previous day

(iv) $X_4$ Minimum relative humidity record (generally around 1430 hrs) of previous day

(v) $X_5$ Total cloud cover record at 1730 hrs. (IST) of previous day

3. Methodology

3.1. Multiple linear regression equation

The dependent predictand $y_i$ is fitted by a multiple linear regression model with $p$ nos. of independent predictors is given by

$$y_i = \beta_0 + \sum_{j=1}^{p} \beta_j x_{ij} + e_i$$

where $x_{ij}$’s are independent predictor variables with $j = 1, 2, 3, \ldots, p$ and $\beta_0, \beta_1, \ldots, \beta_p$ are the unknown coefficients of the independent variables and $e_i$ is an error term associated with $i$th of $n$ events. The prediction equation is given by

$$\tilde{y}_i = \tilde{\beta}_0 + \sum_{j=1}^{p} \tilde{\beta}_j x_{ij}$$

where $\tilde{y}_i$ is the predicted value (estimated value) of $y_i$, such that $\beta_0, \beta_1, \ldots, \beta_p$ minimizes the sum of squares of net errors, or in other words

$$\sum_{i=1}^{n} (y_i - \tilde{y}_i)^2 = \sum_{i=1}^{n} e_i^2 \text{ is minimum.}$$
3.2. **Skill score**

Skill score is a statistical tool to determine whether predicted values of dependent variable based on statistical method is superior and is defined as

\[
1 - \left( \frac{\text{RMSE}_m}{\text{RMSE}_p} \right)^2 \times 100\%
\]

where \(\text{RMSE}_m\) and \(\text{RMSE}_p\) are respectively the root mean square error of the model prediction and persistence: 24 hr. change on observed values of dependent variable.

A positive value of skill score indicates a better performance of the model over the persistence, whereas negative value of the skill score is clear indications that the model does not have any skill to even match the persistence.

4. **Discussion and result**

4.1. **Nature of distribution**

Nature of distribution of minimum temperature and its relationship with the potential predictors was carried out using developmental sample. Frequency distribution of minimum temperature is given in Fig. 2, which indicates that it is positively skewed in nature. Further studies showed that minimum temperature at Kolkata (Alipore) generally occurs between 0600 and 0700 hrs (IST) in the morning.

4.2. **Relation with potential predictors**

Correlation of minimum temperature with potential predictors, viz., minimum temperature one day before, maximum temperature, meridional wind component at 1730 hrs. of previous day, minimum day humidity on previous day and total cloud cover have been shown in Table 2. It is seen from the table that minimum temperature is highly correlated with maximum and minimum temperature of previous day. It showed very
TABLE 4

| Error range (°C) | Development data (JF 1997-2000) | Test data (JF 2002 to 2004) |
|------------------|---------------------------------|-----------------------------|
| No. of cases     | % Frequency                     | No. of cases    | % Frequency         |
| 0.0 – 1.0        | 160 67.51                       | 129 72.47                  |
| 1.1 – 2.0        | 61 25.74                        | 33 18.54                   |
| 2.1 – 3.0        | 16 6.75                         | 12 6.74                    |
| 3.1 – 4.0        | 0 0.00                          | 4 2.25                     |
| Total            | 237 100                         | 178 100                    |

ABS 0.86
RMS 1.08
P-ABS 1.39
P-RMS 1.78
SKILL (%) 63
CC 0.94

ABS, absolute error, RMS, Root mean square error, P-ABS, Absolute error assuming persistence, P-RMS, RMS error assuming persistence; SKILL, Skill score; CC, Correlation coefficient.

good correlation only with the meridional component of low-level wind at 0.9 km but not with the zonal component.

4.3. Regression model

Analysis of data following stepwise screening procedure led to the minimum temperature prediction model as given below:

\[ Y = (0.3130)X_1 + (0.6467)X_2 + (0.0394)X_3 + (0.0631)X_4 + (0.1446)X_5 - 9.1806 \]

4.4. Comparison of standard predicted values with observed minimum temperature of development period and testing of model with test period data

Fig. 3 presents the scatter diagram between standard predicted values of minimum temperature with the observed minimum temperature during the development period (JF 1997-2000). From the figure it is seen that most of the data points are very close to the regression line within about ± 1° C at 95% confidence level. Model developed for minimum temperature was tested with the test data (JF 2002-04). Basic statistics of observed and predicted minimum temperature of the model and the test period data set are given in Table 3 for comparison of mean, variance, highest, lowest value and range of minimum temperature. Range of observed minimum temperature during the test period is slightly more than that of the development period.

4.5. Error analysis

Error analysis of forecast values of minimum temperature for both developmental sample and the independent data set is given in Table 4. From the table it is seen that ± 72%, ± 91% and ± 98% of 12 hour forecast minimum temperature values are correct within ± 1° C, ± 2° C and ± 3° C respectively in the test sample.

4.6. Persistence of minimum temperature

Persistence of minimum temperature is also studied to see its effect on the model predictions and results are presented in Table 5. It shows change in observed minimum temperature in next 24 hour for both developmental sample and test data in different temperature range. It is seen that the model could inherit a variable nature even with a variation of ± 4° C or more in persistence of minimum temperature.
Fig. 4. Comparison of observed and predicted minimum temperature during JF (2002-04)

| S. No. | Date       | Observed values (°C) | Predicted values (°C) | Error (Obs. - Pred.) (°C) | Cloud cover (N) | Wind at 0.9 km. | Weather         |
|-------|------------|-----------------------|------------------------|----------------------------|-----------------|-----------------|-----------------|
|       |            |                       |                        |                            | Preday          | Day             |                 |
|       |            |                       |                        |                            | 1730 hrs (IST)  | 0830 hrs (IST)  |                 |
| 1.    | 28 Jan 2002| 19.5                  | 17.1                   | 2.4                        | 2               | 8               | 175             |
| 2.    | 29 Jan 2002| 13.7                  | 16.2                   | -2.5                       | 3               | 3               | 270             |
| 3.    | 22 Feb 2002| 14.4                  | 13.8                   | -2.6                       | 0               | 0               | 345             |
| 4.    | 01 Jan 2003| 11.2                  | 12.8                   | -1.6                       | 0               | 0               | 207             |
| 5.    | 20 Jan 2003| 9.3                   | 11.6                   | -2.3                       | 0               | 0               | 312             |
| 6.    | 02 Feb 2003| 17.0                  | 20.6                   | -3.6                       | 7               | 2               | 101             |
| 7.    | 20 Feb 2003| 18.2                  | 18.7                   | -0.5                       | 5               | 0               | 192             |
| 8.    | 25 Feb 2003| 19.3                  | 20.8                   | -1.5                       | 2               | 2               | 312             |
| 9.    | 26 Feb 2003| 23.1                  | 18.7                   | 5.4                        | 2               | 4               | 325             |
| 10.   | 19 Jan 2004| 19.7                  | 15.8                   | 3.9                        | 0               | 4               | 301             |
| 11.   | 22 Jan 2004| 19.3                  | 17.8                   | 2.5                        | 5               | 4               | 325             |
| 12.   | 01 Feb 2004| 19.3                  | 17.1                   | 2.2                        | 2               | 7               | 225             |
| 13.   | 06 Feb 2004| 16.0                  | 12.5                   | 3.5                        | 0               | 7               | 310             |
| 14.   | 20 Feb 2004| 21.8                  | 19.7                   | 2.1                        | 0               | 0               | 230             |
| 15.   | 28 Feb 2004| 22.6                  | 20.3                   | 2.3                        | 0               | 3               | 260             |

**TABLE 6**

Cases of predicted and observed minimum temperatures for error greater than 2° C during test period JF 2002-04
4.7. Comparison of observed and predicted minimum temperature during test period (JF 2002 – 04)

Minimum temperature forecast based on regression model along with its observed values for JF 2002-04 are shown in Fig. 4. The model responds well to the variation of minimum temperature, especially when sharp fall is expected.

The predicted minimum temperature carried absolute error of more than 2º C on 16 occasions, details are provided in Table 6. The comparison of data reveals that:

(i) Observed minimum temperatures were higher than the predicted values due to covering of the sky by clouds after 1730 hrs. (IST) on previous night. This was also due to sudden change of wind from North West to SE bringing more moisture for development of clouds, fog and mist in the morning.

(ii) Observed minimum temperatures were less than the predicted value when overcast sky condition became clear and wind direction also changed to NW from SE.

(iii) Two potential predictors – total cloud cover and meridional component of low level wind at 0.9 km can modify the minimum temperature values due to their marked variations after 1730 hrs and during the night. But the forecaster on the basis of analysis of 1200 UTC surface and upper air charts can modify values of these two predictors before making the final prediction at 2100 hrs (IST) to minimize the error.

(iv) Modification if any needed may be considered when cloud amount, low level wind flow is expected to change significantly during previous night based on satellite imagery and other synoptic situations before local forecast is issued at 2100 hrs (IST). This will minimize error in the prediction of minimum temperature and reduce subjectivity also.

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