Investigation of Bias Correction Methods for Numerical Weather Prediction Forecasts of Maximum and Minimum Temperatures

BY

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Outline

- Objective of the study
- Bias Correction methods
- Data and Methodology
- Result and Discussions
  - spatial domain average
- Conclusions
Objective

The main objective of this study is to evaluate four bias correction methods for Maximum and Minimum temperatures forecasts from Numerical Weather Prediction (NWP) model over India.
Bias Correction methods

- In the bias correction, we estimate the systematic component of the NWP model forecast errors, based on the past forecast errors.
- The Model Output Statistics (MOS) approach is used to improve the NWP model output through bias correction.
- Drawback of MOS is that it requires a long training period of archived model data from an unchanged or static model.
- Today, NWP modeling centers make frequent changes to numerical procedures, physics, and resolution of models.
- To overcome this ever-changing NWP model base, we need to use a bias correction technique that update bias daily and depends on only the most recent past data for bias correction.
Bias Correction Methods

1. Linear Regression (LR)

\[ Y = aX + b \]

where \( Y = \text{Observation}; \quad X = \text{Forecast}, \)

\( a = \text{measure of multiplicative bias} \)

\( b = \text{systematic bias} \)

Computed from last 90 days forecasts and observations

The lagged Linear Regression (LR) method has been used in the past (e.g. Stensrud and Yussouf 2005), and it uses a least-squares line to model the trend in the bias of the forecasts over the training period at each grid.
Bias Correction Methods

2. Best Easy systematic (BES) mean

\[ BIAS = \frac{Q_1 + 2Q_2 + Q_3}{4} \]

Where $Q_1$, $Q_2$, and $Q_3$ are the first, second, and third quartiles of forecast errors ($F-O$).

- Computed from daily forecast error of the previous 90 days.

- Not sensitive to extreme values.

Woodcock and Engel (2005) evaluated the usefulness of the best easy systematic mean statistics (BES) bias correction methodology for the bias correction of 2-m maximum and minimum temperature forecasts over Australia.
Bias Correction Methods

3. Running Mean Error (RME)

\[ ME = \frac{1}{N} \sum_{k=1}^{N} [F - O] \]

*where...* \( N = 1, 2, \ldots, 15 \) *days*

Stensrud and Skindlov (1996) showed that a simple bias correction method using the previous 7-day Running Mean bias correction improved the direct model forecasts of maximum temperature.

Steed and Mass (2004) experimented with several different spatial techniques of applying bias removal to temperature forecasts from a mesoscale model. Their study showed that a bias removal method using a 2-week running bias had the least amount of error compared to periods of 1, 3, 4 and 6 weeks.

The previous 15 days forecast errors are averaged together using equal weight.
Bias Correction Methods

4. Nearest Neighborhood (NN)

\[ w(i) = \frac{1}{i + 1} \]

where \( i = 0, 1, 2, 3, \ldots 15 \) days

\[ wt(i) = \frac{w(i)}{\sum_{i=1}^{15} w(i)} \]

\[ b_{m} = wt(i) * b(i) \]

In the Nearest Neighbor moving average; all the previous forecast errors are averaged together using an exponentially increasing weighting so that the recent data has the largest weight.
In this study, the day-1 to day-5 maximum and minimum temperature forecast data from four operational global models for the period from 1 January to 30 September 2011 are used.

1. European Centre for Medium-Range Weather Forecasts (ECMWF), England
2. The U.S. National Centers for Environmental Prediction (NCEP)'s Global Forecasting System (GFS).
3. Japan Meteorological Agency (JMA) and
4. Indian Meteorological Department (IMD)'s Global Forecasting System (GFS T382)

The daily maximum and minimum temperature observation through Global Telecommunication system (GTS) from IMD over land is used for the study.
Verification of bias Corrected Forecast

**Mean error**

\[ ME = \frac{1}{N} \sum_{i=1}^{N} (F_i - O_i) \]

**Mean absolute error**

\[ MAE = \frac{1}{N} \sum_{i=1}^{N} |F_i - O_i| \]

**Root mean square error**

\[ RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (F_i - O_i)^2} \]

**Improvement Skill**

\[ SKILL(\%) = \frac{(MAE_{DMO} - MAE_{BIASCOR})}{MAE_{DMO}} \times 100 \]
Result & Discussions

Spatial distribution of Error pattern (Tmax/Tmin) for the period from 1 July - 30 September 2011

a) Mean Error
b) Mean Absolute Error
c) Root mean square error

Forecast Skill over
a) NW India
b) East India
c) Central India
ECMWF:
- DMO under predicts Tmax (order of 2-3 deg C) over most parts of India
- All the bias-corrected 24 hour maximum temperature forecasts show improvement over the direct model output (DMO).
- More improvement is noticed in both RME and NN bias correction methods as compare to LR and BES.

Spatial distribution of mean error (deg C) in maximum temperature
JMA:

- DMO under predicts Tmax (order of 3-4 deg C) over most parts of India.
- Bias-corrected 24 hour maximum temperature forecasts show improvement over the direct model output (DMO).
- Both RME and NN bias correction techniques show more improvement as compare to LR and BES.

Spatial distribution of mean error (deg C) in maximum temperature.
NCEP: (GFS T574)

- DMO over predicts Tmax (order of 3-4 deg C) over NW India and under predicts over peninsular India.

- Both RME and NN bias correction techniques show ME in the order of -0.5 to +0.5 as compare to LR and BES
DMO over predicts Tmax (order of 3-4 deg C) over North and central India and under predicts over peninsula.

Bias-corrected 24 hour maximum temperature forecasts show improvement over the direct model output (DMO).

But, more improvement is noticed in RME and NN bias correction techniques as compare to LR and BES.
Spatial distribution of ME in day-1 maximum temperature forecast in deg C from DMO (first row) and LR (second row), BES (third row), RME (fourth row) and NN (last row) bias correction methods of all the NWP models.
spatial distribution of ME in day-3 minimum temperature forecast (deg C) from DMO (first row) and LR (second row), BES (third row), RM (fourth row) and NN (last row) bias correction methods of all the NWP models.
ECMWF:

- DMO show MAE for Tmax in the order of 3-4 deg C over North East and coastal regions of India.
- MAE is less for all the four Bias-corrected 24 hour maximum temperature forecasts as compare to DMO.
- More improvement is noticed in both RME and NN bias correction techniques.
Spatial distribution of MAE in day-1 maximum temperature forecast in deg C from DMO (first row) and LR (second row), BES (third row), RME (fourth row) and NN (last row) bias correction methods of all the NWP models.
spatial distribution of MAE in day-3 minimum temperature (C) forecast from DMO (first row) and LR (second row), BES (third row), RM (fourth row) and NN (last row) bias correction methods of all the NWP models.
ECMWF:

- High RMSE is seen for DMO.
- RMSE for Bias-corrected maximum temperature forecasts show less over many parts of India.
- More improvement is noticed in both ME and NN bias correction techniques as compare to LR and BES.
spatial distribution of RMSE in day-1 maximum temperature forecast in deg C from DMO (first row) and LR (second row), BES (third row), RME (fourth row) and NN (last row) bias correction methods of all the NWP models.
Topographic Map of India (altitude in meter)

Study Area

North West India:
Long: 73 - 78E ; Lat: 24 - 29 N

East India:
Long: 83 - 88E ; Lat: 22 - 27 N

Central India:
Long: 77 - 82E ; Lat: 18 - 23 N
North West India

- Box-and-whiskers plots of ECMWF model mean errors (top panel) and MAE (middle panel) and standard deviation (bottom panel) from DMO and after bias correction.

- The boxes show the median and 25th and 75th percentiles, while the whiskers indicate below the 25th percentile and above the 75th percentile.

- Mean, Median and SDEV is less for NN
Box-and-whiskers plots of the ECMWF model mean errors (C) (top panel) and MAE (middle panel); and standard deviation (bottom panel) from DMO and BC forecast. The boxes show the median and 25th and 75th percentiles, while the whiskers indicate below the 25th percentile and above the 75th percentile.
Box-and-whiskers plots of the ECMWF model ME (top panel) and MAE (middle panel) & SD (bottom panel) in Min Temperature from DMO and bias corrected forecast.

Central India:

More improvement in ME, MAE and SD is noticed in NN bias correction methods as compared to other 3 BC methods.
Box-and-whiskers plots of the ECMWF model ME (top panel) and MAE (middle panel) & SD (bottom panel).

Mean, median and SD are less for NN BC method.
Box-and-whiskers plots of the ECMWF model ME (top panel) and MAE (middle panel) & SD (bottom panel) in Minimum Temperature from DMO and after bias correction.

- ME, MAE and SD is less for NN bias correction method in all day-1 to day-5 forecast over Central India.
Maximum temperature

Box-and-whiskers plots for ECMWF, JMA, NCEP and IMD model

MAE (C) in maximum Temperature over central India
Box-and-whiskers plots for ECMWF, JMA, NCEP and IMD model

MAE (°C) in minimum Temperature over central India
The 24 hour maximum temperature forecasts over Central India using DMO and Bias Corrected ECMF during July 2011. The NN bias corrected forecast is reasonably very close to the observed temperature during the period.
The 24 hour maximum temperature forecasts over Central India using DMO and Bias Corrected JMA during July 2011.

The NN bias corrected forecast is reasonably very close to the observed Max temperature during the period.
The 24 hour maximum temperature forecasts over Central India using DMO and Bias Corrected NCEP GFS during July 2011. The NN bias corrected forecast is reasonably very close to the observed Max temperature during the period.
The 24 hour maximum temperature forecasts over Central India using DMO and Bias Corrected IMD T382 during July 2011. The NN bias corrected forecast is reasonably very close to the observed Max temperature during the period.
Maximum Temperature Forecast improvement in % (MAE): Central India

All the four bias correction methods have significant improvement in forecasting maximum temperature from 25 to 45% over the DMO. There is a significant difference in improvement between bias correction methods but NN method performs best.
All the four bias correction methods have significant improvement in forecasting minimum temperature from 10 to 40% over the DMO forecasts.

On the whole, the NN BC method shows higher skill compared to other three bias correction methods for minimum temperature forecasts.
Maximum Temperature Forecast improvement in % (MAE) over East India

All bias correction methods have significant improvement in forecasting maximum temperature from 15 to 55% over the DMO forecast.

NN BC method shows higher skill compared to other three bias correction methods for maximum temperature forecasts.
All bias correction methods have significant improvement in forecasting minimum temperature from 25 to 35% over the DMO forecasts.

On the whole, the NN BC methods show smaller error and higher skill compared to other three bias correction methods for minimum temperature forecasts.
Summary

- All the four bias correction methods for maximum and minimum temperatures forecasts have smaller ME, MAE and RMSE values over Indian regions for all day-1 to day-5 as compared to DMO.

- More improvement is noticed in the NN bias correction method as compared to the other three BC methods.
Part-II

Location Specific Forecasting of Maximum and Minimum Temperature using (NN) Bias corrected output of GFS T574
1. Objective

The main objective of this study is to verify the skill of Direct model output (DMO) and Bias Corrected (BC) GFS T574L64 model forecast for location specific forecast of maximum and minimum temperature over India.
2. Data Source

- The output from Global Forecasting System (GFS) T574L64 operational at India Meteorological Department (IMD), New Delhi is used for obtaining location specific quantitative forecast of maximum and minimum temperatures for 100 synoptic stations, representing different geographical regions of India in the medium range (24 to 120 hr) time scale during May 2012 - Feb 2013.
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Table 1: Meteorological Stations selected for the location specific study
Meteorological subdivision of India; Topography and distribution of stations

REGIONS AND METEOROLOGICAL SUB-DIVISIONS

- NORTH WEST
- NORTH EAST
- CENTRAL
- EAST
- WEST
- SOUTH

Topography and distribution of stations

- 50
- 100
- 200
- 300
- 500
- 750
- 1000
- 3000
- 5000

INDIA METEOROLOGICAL DEPARTMENT
3. Bias Correction

The Nearest Neighborhood (NN) statistical bias correction has been applied at station level in the 24 to 120 hour GFS location specific forecast of maximum and minimum temperature for 100 synoptic stations over India during summer (May -August 2012) and winter (November 2012 -February 2013) season.

The bias $b_k(t)$ for each station $(k)$ and each lead-time $(t)$ is defined as:

$$b_k(t) = f_k(t) - O_k(t)$$

The systematic bias $B_k(t)$ at each station is computed daily by applying the weight coefficient $w_{tk}(t)$ at each forecast hour as,

$$B_k(t) = W_t(t) * b_k(t)$$

The new bias-corrected model forecast $F_k(t)$ will be generated by applying the bias $B_k(t)$ to current direct forecasts $f_k(t)$ at each station,

$$F_k(t) = f_k(t) - B_k(t)$$
Verification Methods

**skill score (SS)**

In addition to ME, MAE and RMSE error, we consider a skill score (SS) defined in terms of mean-squared error (MSE).

\[
SS = 1 - \frac{MSE_f}{MSE_c}
\]

where

\[
MSE_f = \frac{1}{N} \sum_{i=1}^{N} (F_i - O_i)^2
\]

\[
MSE_c = \frac{1}{N} \sum_{i=1}^{N} (O_i - O_i)^2
\]

A detailed description of mean squared skill score (SS) is provided by WMO (2002).

**Forecast climatology**

observed daily climatology 1981 -2005 is used. (IMD)
Result and Discussions

A quantitative inter-comparison of error statistics between Direct model output (DMO) and Bias Corrected (BC) minimum and maximum temperature forecast for 100 stations over India are discussed in this section.

Verification of

1) Minimum Temperatures
2) Maximum temperature at each meteorological stations during summer (May - August 2012) and winter (November 2012 - February 2013) seasons
The scatter diagram shows that the mean Error is in the order of -0.2 to +0.2 deg C for BC forecast, while it is in the order of -4 to +4 deg C for DMO in both summer and winter season for most of the stations.

The comparison also shows that the BC min temperature forecast produces bias values almost close to zero for most of the stations in summer as well as in winter.
The BC minimum temperature forecast shows MAE below 1.5 °C during summer and below 2 deg C during winter season for most of the station, while DMO MAE is below 2.5 °C in summer and below 3 °C in winter for most of the stations.

We observe also that only a few stations have a DMO MAE as low as that using the BC forecast.
The day-3 RMSE in minimum temperature forecast for all 100 stations indicates that the DMO RMSE is higher than BC RMSE in all the stations during both summer and winter seasons.
Improvement in % (MAE)

- The MAE skill score ranges from 0 to 100 with value of zero indicating no improvement skill and a value of 100 is for perfect forecasting skill.

- We observed a significant reduction of MAE in BC forecast as compared to DMO in all the stations during both summer and winter seasons.
The MSE skill score for BC forecast is better than both DMO and climatology reference forecast and its skill score values are greater than 0.6 for most of the stations during both summer and winter.

The DMO skill score value of less than or equal to zero is observed in some of the stations in both summer and winter seasons.

It is seen that the BC forecast skill scores for minimum temperatures is reasonably high for all the station in both the seasons.
The DMO maximum temperature mean error is between -6.0 °C and +4.0 °C in summer while it is between -4.0 °C and +2.0 °C in winter season.

It is also seen that the BC forecast produces ME values close to zero for most of the stations in both summer and winter seasons.
The scatter diagram shows that the MAE ranged from 1.5 °C to 4 °C for DMO and from 1 °C to 2 °C for BC at most of the stations in both summer and winter.

The MAE in winter season is lesser than that in summer season.
The DMO RMSE value varies between 3 °C and 4 °C, while the BC RMSE values ranges between 1.5 °C and 2.5 °C.
The BC forecast has significant improvement in forecasting maximum temperature, from 20 to 30% over the DMO forecasts. More improvement (more than 50 %) is noticed over SP India regions in both summer and winter season.
The maximum temperature forecasts skill score for most of the stations are varied from 0.7 to 0.9 for BC and from -0.4 to 0.8 for DMO in summer, while it is varied from 0.5 to 0.8 for BC and from -0.4 to 0.6 for DMO in winter.
Conclusion

- The statistical Bias Corrected GFS forecast shows significant reduction (35 to 50%) of error in minimum and maximum temperature as compared to the DMO over most of the stations during both summer and winter seasons.

- This study also indicates that the BC GFS forecast improves over the GFS DMO reasonably and hence can be used for location specific forecast in real time.
References


Thanks
The daily observed maximum and minimum temperature data from Global Telecommunication System (GTS) available at IMD are objectively analyzed at 1°x1° latitude-longitude grid.

The objective technique used for this analysis is based on the Cressman interpolation method (Cressman 1959).

The Cressman weight function used in the analysis is defined by

\[
W_{i,m} = \frac{R^2 - r_{i,m}^2}{R^2 + r_{i,m}^2}
\]

where \( R \) is the radius of influence and \( r \) is the distance of the station from the grid point.
North West India

- Box-and-whiskers plots of the ECMWF model ME (top panel) and MAE (middle panel) & SD (bottom panel) in Minimum Temperature from DMO and after bias correction.
- Mean, median and SD are less for NN BC method.