

Numerical Weather Model based Visibility Prediction: A Requirement of Future

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ABSTRACT

Every year, fog during the winter season in North Indian plains disrupts the life and property the people. In real time monitoring of fog, we use INSAT derived operational products and imageries to monitor its spatial extent. The prediction of visibility during fog event with sufficient lead time is a challenging task. However, with the support of Numerical Weather Prediction (NWP) outputs, visibility can be predicted in advance up to 36 hours. Therefore, in the year 2015 as a pilot phase, India Meteorological Department (IMD) started to generate operationally Weather Research and Forecasting (WRF) model visibility with 36 hours lead time. In this paper, WRF model derived visibility has been compared with the actual visibility (January and February-2015) at three lead times (12, 24 and 36 hours) and compared at 0000 and 1200 UTC. The time selection is based on the large number of flights being operated during these hours. The results obtained from the limited data sets are quite encouraging and shows that 24 hour prediction is better in comparison to those at 12 and 36 hours for Jai Prakash Narayan Airport (JPNI) at Patna. 24 hours lead time prediction is better followed by 12 and 36 hours respectively. After verifying these forecasts with those at other airports with larger data sets, the method can be utilized in operational forecasting. The intensity of fog and visibility at Patna Airport is also affected by the local moisture advection and persistency and frequency of synoptic scale systems occurring during winter time. Similar study for other airports with more number of foggy days can improve the model forecast accuracy and skill of the visibility prediction by applying suitable statistical adjustment to the existing algorithm.

Keywords: Visibility, Fog, Weather Research and Forecasting model, and Forecast accuracy.

1. Introduction

In every winter season (January and February), occurrence of low visibility phenomena like radiation fog mostly over northwest (NW) India is very common. Due to this weather event, on most of the days in winter, the horizontal visibility reduces appreciably which affects aviation, road, transportation, economy and public life. The low visibility events as per IMD criteria are classified mainly under three categories like, Fog, Mist and Haze with visibilities < 1 km, 1 to 2 km and 2 to 5 km respectively. If the visibility reduces further and passes ranges 500, 200 and < 200 meters, then the fog becomes moderate, dense and very dense respectively and it may cause diversion of routes, delays in flight operations and significant economic losses to the country. During winter season, mainly westward moving systems and localized availability of moisture over the area can cause both mist and fog occur simultaneously and remain quasi-stationary for few days (sometime 2-7 days)

depending on the movement and persistence of mid-latitude systems. This visibility information is further divided for operational forecasting in categories depending on the capability of the instrument as CAT-I, CAT-II, CAT-III-A,B,C as 550 m and above, 300 m to 549 m, 175 m to 299 m, 50 m to 174 m and below 50 m respectively.

There are many processes of and interactions involved in the formation, maintenance and dissipation of the fog events and therefore accurate prediction of radiation fog and its intensity is a very challenging task and similar type of fog conditions can generate different scenario of fog events (Lala, 1987). Fog occurrence during winter time affects the air traffic drastically and it is very difficult to predict quantitatively its occurrence, duration and intensity despite improvements in numerical weather prediction. The reason for this situation is that the fog phenomenon is dependent on complex microphysical and mesoscale processes in the planetary boundary layer that are forced by

prevailing synoptic regime (Chun et al., 1999). In the current scenario at Jai Prakash Narayan Airport (JPNI) Patna, air flight cannot land unless the runway visibility is less than 800 m. During winter time, due to the occurrence of wide spread fog, flight operations get delayed or rescheduled. In many countries, especially those in temperate latitudes, fog causes widespread dislocation and delays on several days each year (Kim et al, 2000). The evaluation of the results shows that the low visibility/fog forecasts from these models are still poor in comparison to those of operational precipitation forecasts from the same models. In order to improve the skills of the low visibility/fog prediction, several efforts have been made in the recent past by implementing rule based fog detection scheme (Zhou et al., 2011). Generally, radiation fog occurs when radiation cooling calms winds along with availability of sufficient moisture and visibility less than 1 km are present. The dissipation of fog starts when winds are high and inversion is lifted by sun light.

Winter Fog EXperiment (WiFEX) field campaign, is a multi-institutional initiative (IITM, Pune; IMD; NCMRWF, Noida); Airport Authority of India, GMR; Indira Gandhi International Airport and IISER) by the Ministry of Earth Sciences (MoES), Government of India to understand different physical and chemical features of fog and factors responsible for its genesis, intensity and duration. This experiment was conducted in a pilot mode at IGIA during last winter and will be continued from December 2016 till February 2017. The main scientific objective of this experiment was to study the characteristics and variability of fog events and associated dynamics, thermodynamics and fog microphysics, with the aim to achieve a better understanding of fog life cycle and ultimately improve capability in fog prediction.

Pithani et al. (2020) showed that NWP model accurately captured the near-surface meteorological conditions, particularly the low-level moisture, wind fields, and temperature inversion and failed to capture near-surface relative humidity and temperature. Aviation safety is an important issue and as per the International Civil Aviation Organization (ICAO) guidelines, takeoff and

landing of aircraft under visual flight rules (VFR) are not allowed when the visibility is less than 500 m. The performance of low visibility/fog predictions from the current operational 12 km NAM, 13 km-RUC and 32 km-WRF-NMM models at the National Centers for Environmental Prediction (NCEP) was evaluated using multi-rule-based fog detection scheme for all the three models (Zhou et al., 2011). Singh et al. (2018) used NCMRWF, Unified Model (NCUM) diagnostic visibility scheme to forecast visibility over plains of north India.

2. Data and Methodology

Actual data of visibility is taken from the JPNI airport Patna METAR reports. In current scenario, the visibility data is based on the specified landmarks as there is no provision for instrumental landing. WRF based visibility data have been taken from NWP section, New Delhi. The WRF model derived surface visibility data (experimental mode) are taken from IMD, Lodi Road, New Delhi. SW 99 (Stoelinga et al., 1999) proposed a method of surface visibility that depends on the hydrometeors concentration and is calculated using the following expression:

$$\frac{I(\chi_{obs})}{I\chi} = \exp \left[- \int_0^{\chi_{obs}} \beta(x) dx \right]$$

Or, $\chi_{obs}(km) = \frac{-\ln(0.02)}{\beta}$ where, β is the

extinction coefficient (km^{-1}) a function of number concentration of each type of meteor. In detail it can be defined as:

$$\beta = \beta_{cw} + \beta_{rw} + \beta_{ci} + \beta_{sn}$$

$$\beta_{cw}(\text{Cloud, liquid water, fog}) = 1.447C^{0.88},$$

$$\beta_{rw}(\text{rain}) = 1.1C^{0.75}, \beta_{ci}(\text{cloud ice}) = 163.9.1C^{1.00}$$

$$\text{and } \beta_{sn}(\text{snow}) = 10.4C^{0.78}$$

Visibility is affected by many meteorological parameters and therefore, Doran et al. (1999) at Forecast Systems Laboratory (FSL) developed a method for surface visibility prediction which is

Table 1. WRF configuration for IMD fog forecast.

Microphysics	PBL	Longwave	Shortwave	Land surface	Surface layer Physics
Lin et al.2017, (S. H.Chen&Sun, 2002)	YSU (Honget al., 2006)	RRTMG (Iaconoet al., 2008)	Dudhia (Dudhia, 1989)	NOAH LSM(Tewariet al., 2004)	Monin-Obukhov (Monin&Obukhov, 1954)

based on the relative humidity (R.H) and the dew point depression $T - T_d$ ($^{\circ}C$) is given below:

$$\chi_{obs} (mile) = 6000 \times \frac{T - T_d}{R.H^{1.75}}$$

3. WRF Model Configuration

IMD used combined approach methods by SW99 given in Table 1 and FSL schemes by adding suitable adjusting parameters. It is assumed that visibility not only depends on hydrometeors concentrations (Cloud liquid water, cloud ice, rain, snow etc) but also on relative humidity and dew point depression etc. These parameters also contribute to fog formation, maintenance and dissipation.

Therefore, a hybrid approach suggested by Gulpepe et al. (2009) is used at IMD for generation of visibility forecast. It is defined as:

$$VIS_{G2009} = 0:87706 / (LWC \times N_d) 0:4903,$$

Where $N_d = -0:071T + 2.213T + 141.56$

LWC is the liquid water content which depends on the number density of droplets and which is a function of air temperature (T).

4. Results

During winter time (starting from mid December to mid February), JPNI airport Patna has been frequently affected by the low visibility phenomena (fog, mist or haze). The visibility over the area reduces considerably which sometimes badly affects the aviation services. The main type of fog is radiation fog but in some days it is mixed with local source advected moisture from the east. Local conditions increase the intensity and duration of the fog. Flight diversion or rescheduling affects the public life and loss of national income. Though the prediction of the fog intensity and duration in

advance is still very difficult, satellite based night time fog through red, green and blue (RGB) composite images is able to predict the areal extent almost on the real time. However, the stratus and fog discrimination issue yet to be resolved. The numerical prediction of fog is still a challenging issue and its complicity increases when we take regional and seasonal factors into account. The preliminary results of the current comparative study of actual and model generated visibility are quite encouraging. The analysis is done at three lead times (12, 24 and 36 hours) from 0000 and 1200 UTC actual visibility data at JPNI airport Patna. The subjective judgement in the actual visibility data has affected the results in this limited data set study. Figures (1 to 3) indicate the comparison of the actual visibility with the model predicted visibility. The bias (difference between actual and predicted) is shown in Figure 4 and Table 2. Comparison shows that the bias values lie between ± 1 km only in all the three lead times. It may be noted that the measurements of visibility at JPNI are not automatic; these are estimated by looking at the landmarks around the airport area with naked eyes. Due to this reason, there may be some human errors in the estimation of visibility. It is also well known that the visibility prediction is sensitive to the predicted mass concentrations of hydrometeors and moisture amount over the area.

5. Concluding Remarks

This pilot phase results of WRF model predicted visibility are very encouraging and show that the accuracy of the visibility forecast can be improved by applying a simple statistical adjustment to the existing algorithm. Geographical uniqueness or local influences in the model are properly adjusted by the local characteristics of the fog. The 24 hour lead time prediction shows good predictability at both 0000 and 1200 UTC. This is followed by 12 and 36 hours predictions respectively. Such results

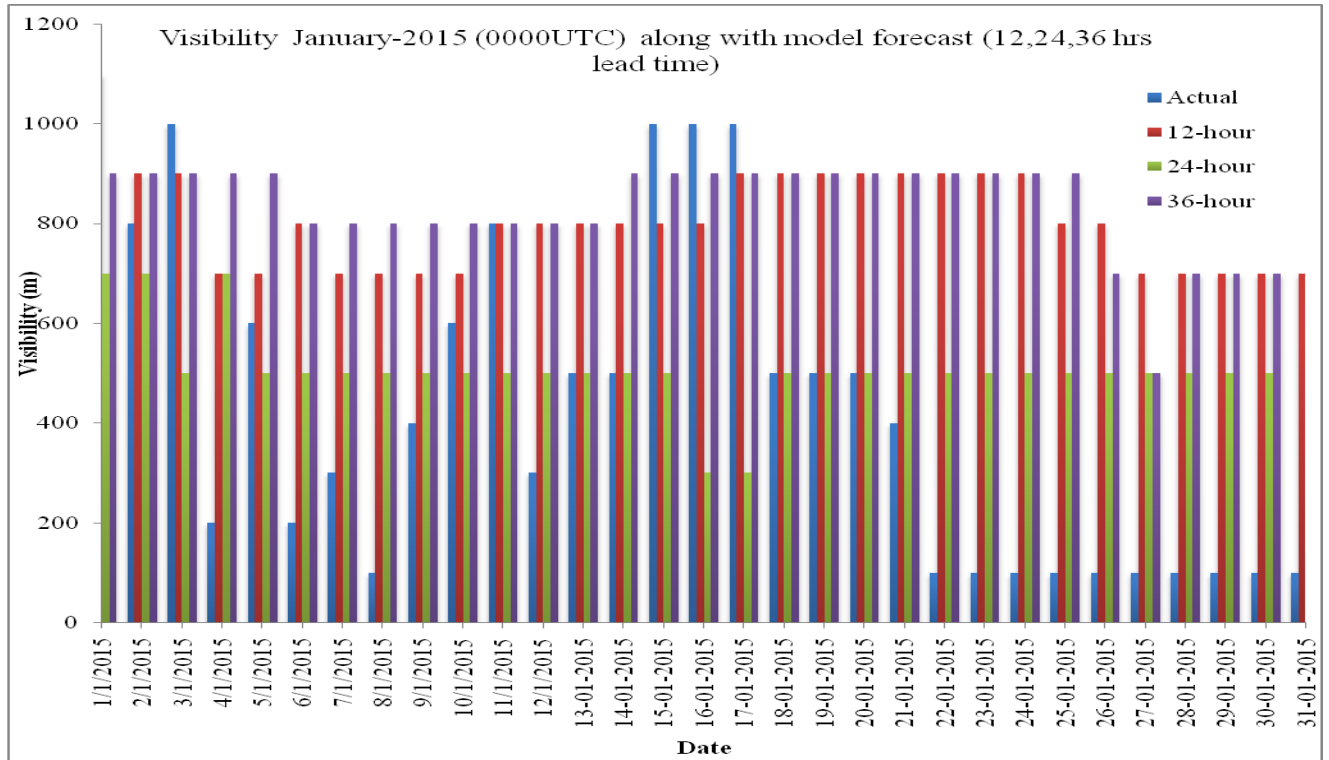


Figure 1: Visibility (meter) of JPNI airport Patna (January-2015) at 0000 UTC.

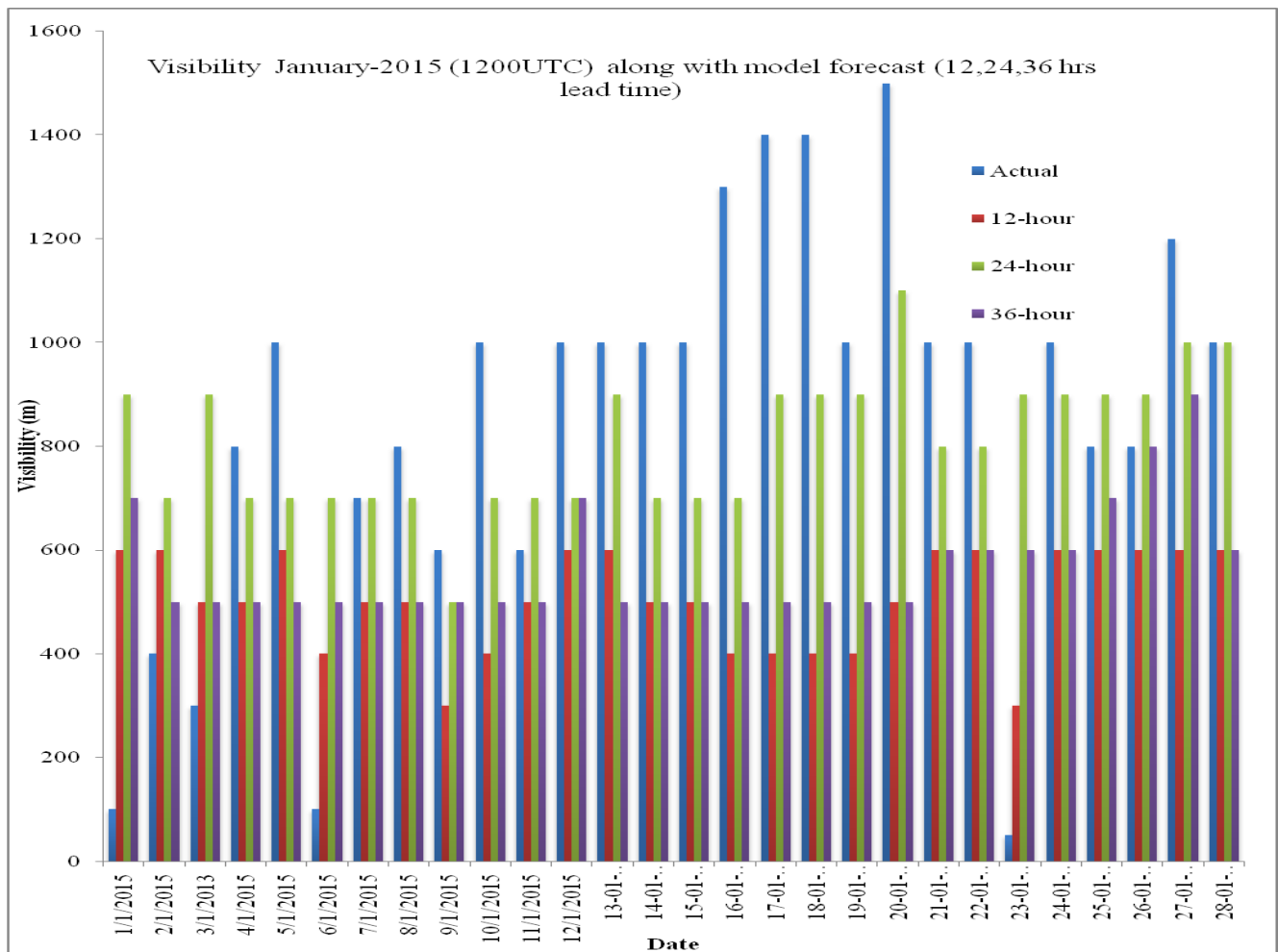


Figure 2: Visibility (meter) of JPNI airport Patna (January-2015) at 1200 UTC.

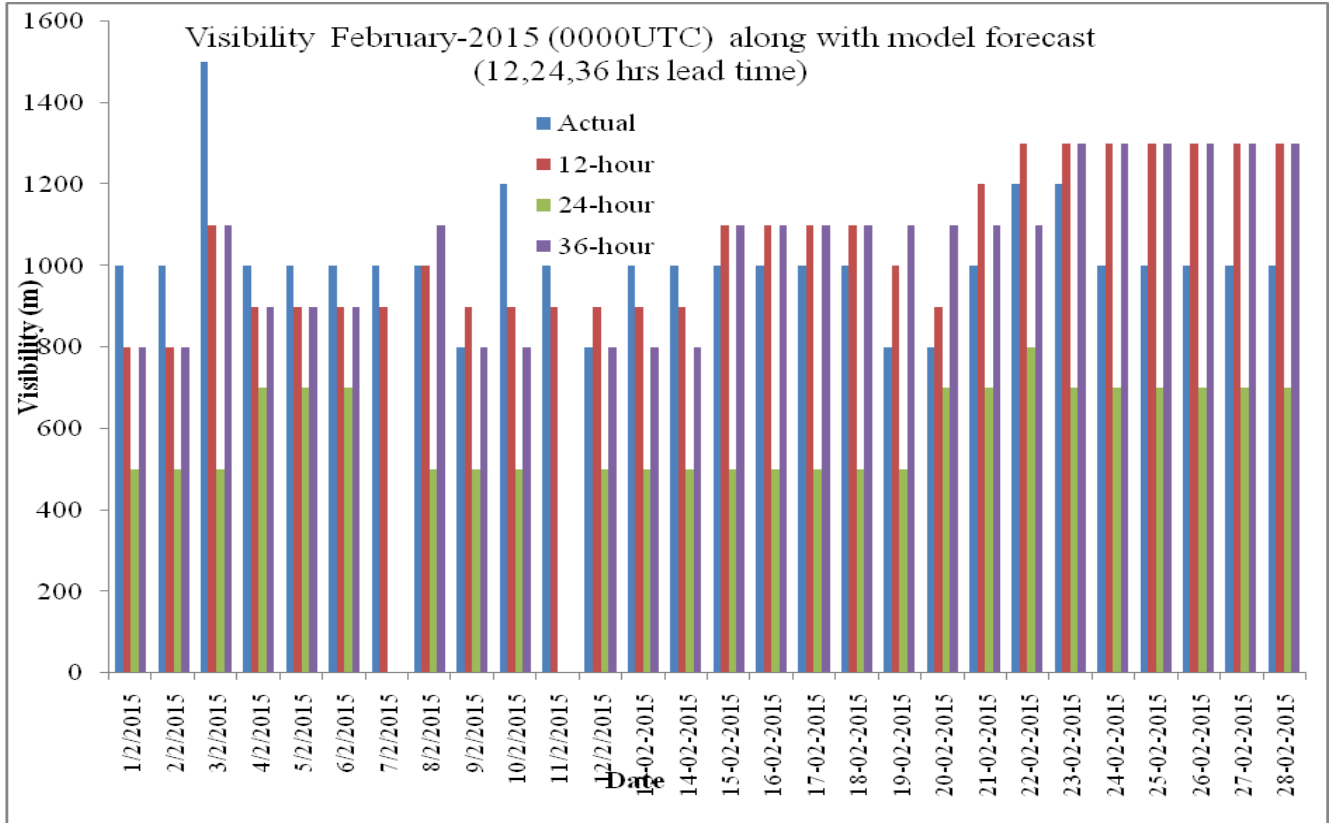


Figure 3: Visibility (meter) of JPNI airport Patna (February-2015) at 0000 UTC.

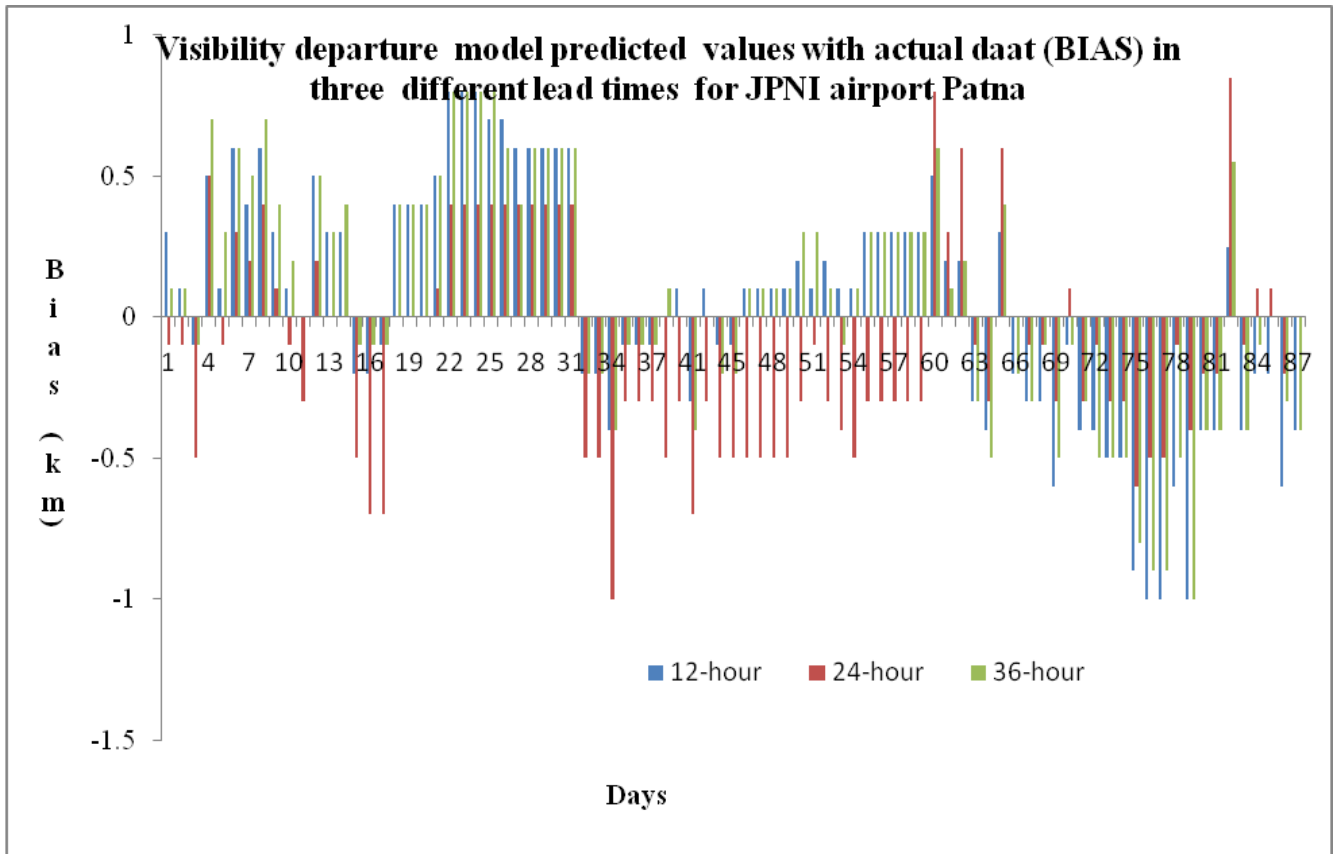


Figure 4: Visibility bias (km) for JPNI airport Patna.

Table 2. Statistics of visibility at JPNI airport Patna.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{(n_1-1)\sigma_1^2 + (n_2-1)\sigma_2^2}{n_1+n_2-2}}} \times \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

Here, t (Student t test), n1 = actual number of JPNI visibility observations: n2 =Model (WRF) based number of visibility observations (averaged over around JPNI airport: σ_1 =standard deviation (actual observation) σ_2 =standard deviation (model based observation): \bar{x}_1 =mean of actual observations: \bar{x}_2 =mean of model based observations.

Month	Visibility lead time (hours)	t -value	Average (meter)	RMSE	Test of significance at 95 % confidence level
January +February	12	0.78	394		NSG
January +February	24	2.32	359		SG
January +February	36	1.28	395		NSG

could be attributed to the local effects which have large uncertainties in the model analysis which needs further investigation and examination using large data sets.

Current efforts using NCMRWF NCU model diagnostic visibility scheme to forecast visibility over plains of north India and IITM WiFEX field campaign have contributed significantly to understand the microphysical processes involved in fog occurrences and visibility predictions.

The results of the model based visibility prediction at other airports over Indo Gangetic Plains (IGP) may differ due to local prevailing conditions and persistency of weather events and its interaction with surface and upper layers in the atmosphere. Low visibility phenomena are very common meteorological hazards in arid and semi-arid regions, especially in Northwest India in winter and terribly affect social, navigational and aviation sectors of the society. In future, the predictability of the model will be improved by performing the study with longer duration and more number of airports and accordingly the diagnostic scheme of the model will be modified. Nevertheless, these preliminary results are useful for planning for air flight operations in advance.

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