Prediction of Radiative Fog Events over Indo-Gangetic Plains of India

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ABSTRACT

Radiative fog formation is a complex phenomenon which involves local physical and microphysical processes and takes place under specific meteorological conditions. The present study aims to quantify the ability of a global numerical weather prediction (NWP) model to analyze and forecast the conditions favourable for radiative fog formation over northern plains i.e. Indo-Gangetic (IG) plains of India. The ground based observations from the stations lying over IG plains of India are used to identify the meteorological conditions favourable for the formation of radiative fog. This is accomplished by setting the thresholds to the key meteorological variables such as -2 m temperature and dew point temperature, dew point depression and 10 m wind speed. The same thresholds are applied to meteorological variables from the model to evaluate the ability of the global NWP model to reproduce these conditions. The observations during the study period indicate that use of these threshold leads to detection of the radiative fog events. It is also found, that with this simple methodology model is able to detect the meteorological conditions leading to observed radiative fog. The spatial plots of visibility forecast available from the model predicts the drop in visibility during the fog event.

Keywords: *Fog Event, Radiative, Visibility, Meteorological, IG Plains and NWP Model.*

1. Introduction

The plains of northern India known as the IG plains of India are very often affected by radiation fog during winter season (December and January). Fog generally starts from the month of November and continues till February. However, the frequency and intensity of fog is maximum in the months of December and January (Singh and Kant 2006). Low visibility due to fog in these months causes disruption in aviation services, surface transportation and leads to accidents over the parts of northern India. A number of studies have been conducted on fog in India since past years (Kundu 1957, Gupta 1987, Tulsidas and Mohapatra 1998). The studies conducted in recent years highlight the socio-ecnomic concerns due to increase in fog occurrence over northern parts of India (Jenamani 2007, Syed et al. 2012). Observational studies are carried out using ground based observations (Ghude et al. 2017) and satellite observations (Sasmita et al. 2011) to understand the fog life cycle and improve the capability of fog prediction. Some of the studies conducted in recent years focus on the prediction of fog with different approaches such as statistical

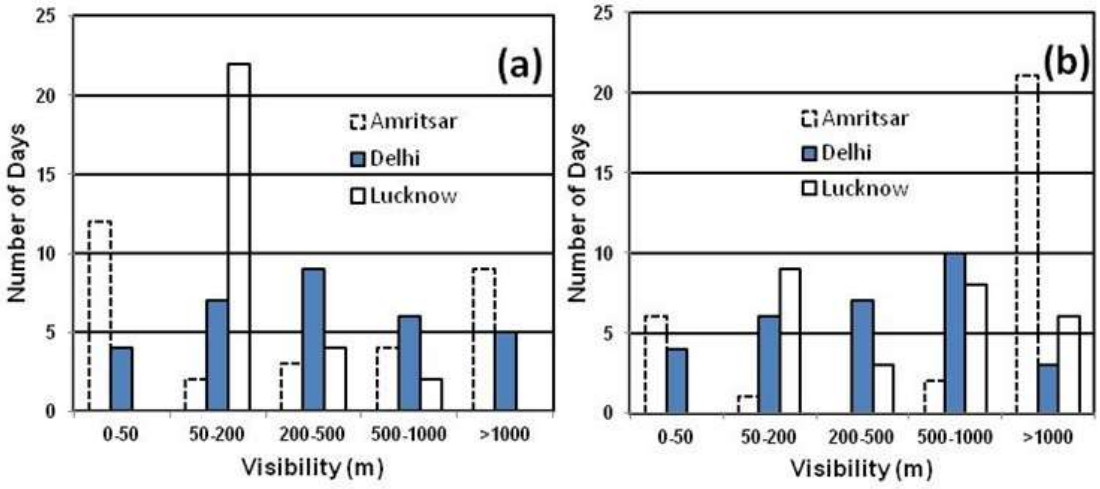

Figure 1: Observed Visibility from METARS at 00UTC at Amritsar, Delhi and Lucknow during (a) December 2016 and (b) January 2017.

(Dimri et al. 2015, Pasricha et al. 2003), diagnostic (Goswami and Sarkar 2017, Payra and Mohan 2014) and numerical weather prediction (NWP) models (Aditi et al. 2015, Pithani et al. 2018).

Inspite of continuous efforts in the field of NWP modeling, to predict fog and associated low visibility conditions, the prediction of fog using operational NWP models remains a challenge (Gultepe et al. 2007). This is due to the fact that formation of fog depends on micro-physical and meso-scale processes that act within the boundary layer and is also influenced by the prevailing synoptic regime. The current operational models are not able to diagnose and correctly predict these interactions. The operational global NWP model of National Centre for Medium Range Weather Forecasting (NCMRWF) is known as NCMRWF Unified Model (NCUM). The performance of NCUM has been analyzed to predict fog and visibility over IG plains of India (Aditi et al. 2018). However, the study of radiative fog events over IG plains has not been carried out by NCUM.

This paper summarizes an exploratory study on the performance of NCUM for a case of thick and wide spread radiation fog observed over IG plains of India during December 2016. The purpose of this study is to evaluate the ability of the model to predict meteorological conditions favourable for fog formation and to identify the weaknesses in the model. For the selected case, fog formed on the night of 9th December and covered large part of northern plains including Amritsar, Delhi and Lucknow. Fog persisted for several hours during daytime at all the stations. The study analyzes the forecast capability of global NWP model for a dense radiation fog.

The paper has been organized in different sections; next section describes the available observations. Section 3 discusses the relevant physical mechanisms that are involved with

fog event. The performance of global NWP model to predict the fog event is explored in Section 4. The conclusions of the study are summarized in Section 5.

2. Source of Data

The IG plains of India encompass a number of cities lying in northern and eastern parts. The meteorological observations over three stations Amritsar, Delhi and Lucknow during December 2016 and January 2017 are utilized in present study. Firstly the foggy days are identified at three stations based on the visibility observations available from the METARS of the selected stations. The days are further classified as very dense, dense, moderate, shallow and clear when the observed value of visibility is 0-50 m, 50-200 m, 200-500 m, 500-1000 m and greater than 1000 m respectively.

During December, few clear days are observed over Amritsar and Delhi however Lucknow observed fog for all the days. Highest number of dense fog days is observed over Lucknow, whereas Amritsar observed highest number of very dense fog days and Delhi observed maximum number of moderate fog days (Figure 1a). In the month of January, maximum numbers of clear days are observed over Amritsar, shallow fog events occurred for maximum days over Delhi and highest numbers of dense fog events are observed over Lucknow (Figure 1b).

The time series of visibility at 00 UTC during December 2016 for the three stations is shown in Figure 2. The observed visibility reduced below 200 m at all the stations on 2nd, 8th, 12th, 24th and 26th December. The longest dense fog spell is recorded from 7th - 10th December at all the three stations when the observed visibility reduced to 200 m, zero and 300 m over Amritsar, Delhi and Lucknow respectively. It remained zero and less than 100 m over Amritsar and Lucknow respectively till 10th December. The observed visibility over Delhi is in range of 100-300 m from 7th -10th December except on 9th December when it is found 600 m. The study analyzes the processes involved in formation of dense fog during 7th -10th December over large parts of IG plains of India.

Figure 3 shows the INSAT-3D fog images at 00 UTC of 7th-10th December. Fog is observed over northern parts of the country including Punjab, Haryana, Delhi, Uttar Pradesh and Bihar at 00 UTC for all the days. The spatial extent of fog is increasing from eastern to western parts of the IG plains of India from 00 UTC of 7th December to 00 UTC of 10th December.

3. Processes Involved in Fog Formation during 7th-10th December 2016

This section analyses the processes involved in formation of fog during 7th -10th December using the meteorological observations available at the three stations. Clear sky condition is one of the most favorable conditions for the formation of radiative fog. The cloud cover data is available at an interval of three hours from the synoptic

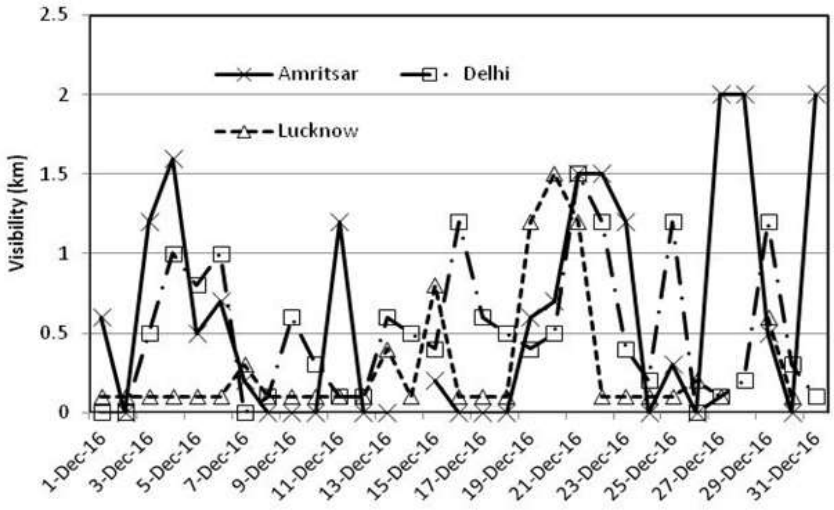

Figure 2: Time Series of Observed Visibility from METARS at 00UTC at Amritsar, Delhi and Lucknow during December 2016.

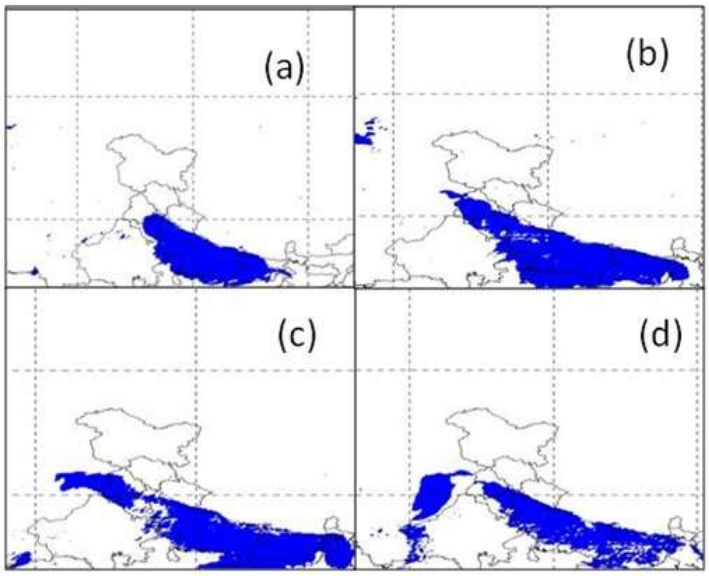

Figure 3: INSAT-3D Fog Image at 00 UTC on (a) 07th (b) 08th (c) 09th and (d) 10th December 2016.

reports at Amritsar, Delhi and Lucknow. The analysis of cloud cover data for 7th -10th December signifies that no cloud cover is present at any of the stations and mostly the sky is clear. It is found 40% over Amritsar, and zero over Delhi on 7th Dec and it is zero percent for all the days. No cloud cover was found over Lucknow except less than 20% at 06UTC of 7th Dec (Figure 4). The value of 113% means that sky is covered with fog and is not visible (WMO, 1995). Thus, clear sky conditions prevailed for all the three days.Other factors responsible for fog formation include the decrease of wind speed,

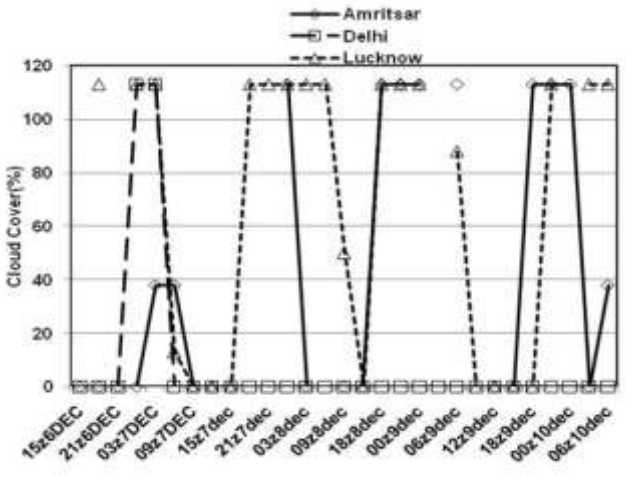

Figure 4: Cloud Cover over Amritsar, Delhi and Lucknow for 07th -10th December 2016.

dew point depression, minimum temperature and increase of dew point. A strong relationship is found between these parameters and occurrence of fog. Fog is likely to occur when wind speed is less than 2.5 m s^{-1}, minimum temperature is less than 9.0 ^{0}C and dew point depression is less than 6.0 ^{0}C and dew point temperature is more than 6.0 ^{0}C. Figure 5 shows the hourly variation of temperature, dew point temperature, dew point depression and wind speed over Amritsar, Delhi and Lucknow during 14 UTC of 6th December to 07 UTC of 10th December It is clear that dew point depression is close to zero for maximum number of hours including 00 UTC of 7th - 10th December over Amritsar (Figure 5a). The difference between temperature and dew point temperature is less than 2.0 ^{0}C for maximum number of hours over Delhi (Figure 5b). The dew point depression is close to zero for maximum number of hours over Lucknow (Figure 5c). The analysis of wind speed at the three stations reveals that calm wind conditions with wind speed less than 2.0 m s^{-1} prevailed over all the stations during 00 UTC of 7th -10th December (Fig. 5d). Thus, the meteorological conditions are favourable for occurrence of radiation fog over the three stations lying in the northern plains of India.

4. Prediction of Radiative Fog Event using NCUM

The operational global model of NCMRWF known as NCUM is utilized in the present study to predict the fog event and associated meteorological conditions. The horizontal resolution of model is 17 km and it has 70 vertical levels. The model analysis is prepared four times (00, 06, 12 and 18UTC) a day using 4D-Var data assimilation scheme (George et al. 2016). A deterministic ten day forecast is generated everyday based on 00 UTC analysis. The visibility forecast is also available from NCUM at an interval of three hours. Visibility from NCUM is predicted using a diagnostic scheme based on relative humidity and aerosol content. The details of visibility diagnostic scheme are described in detail in (Aditi et.

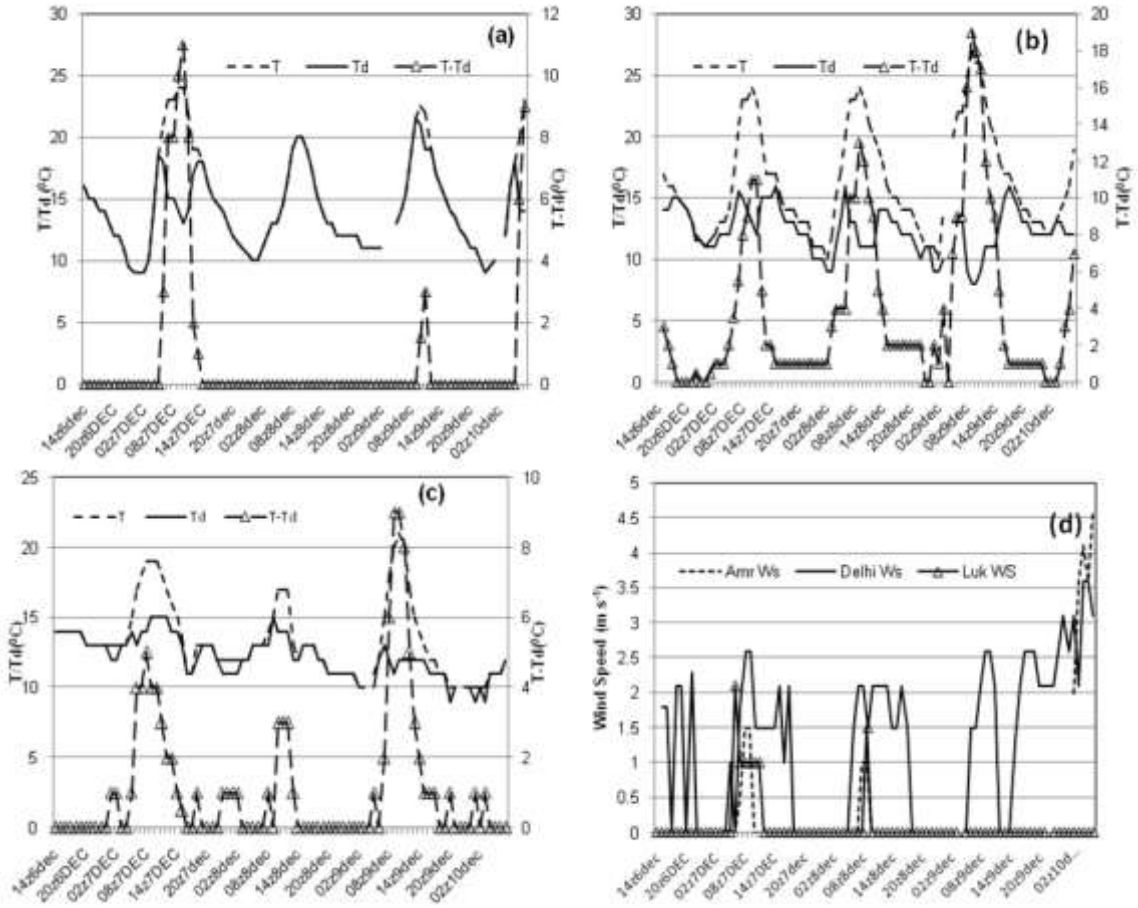

Figure 5: Time Series of Observed Temperature (T), Dew Point Temperature (T_d) and Dew point Depression (T-T_d) at (a) Amritsar (b) Delhi, (c) Lucknow and (d) Wind Speed from 07th-10th December.

2018). Figure 6 shows the analysis of wind at 850 hPa for 00UTC of 7th-10th December from NCUM. During the fog event an anticyclone is observed over north western part of the country and low wind speed conditions prevailed over north to northeast part of the country (Fig.6). The prevailing northerly cold winds contributed to decrease in temperature over the region. The high pressure system dominated the synoptic situation from 7th-10th December resulting in clear skies and weak wind conditions favorable for formation of radiative fog over northern parts of India.

The spatial plots of Day-1 forecast of visibility from NCUM at 00 UTC of 07th -10th December is shown in Figure 7. The predicted values of visibility are less than 1 km at 00UTC for 7th -10th December over northern plains of India indicating the fog over the region which is in agreement with INSAT-3D fog image (Figure 3). The drop in visibility below 1 km is predicted over eastern parts on 7th December (Figure 7a). Visibility is predicted below 500 m over large parts of U.P. and it is predicted in the range of 50-200 m over few parts of U.P. on 8th December (Figure 7b). The predicted values

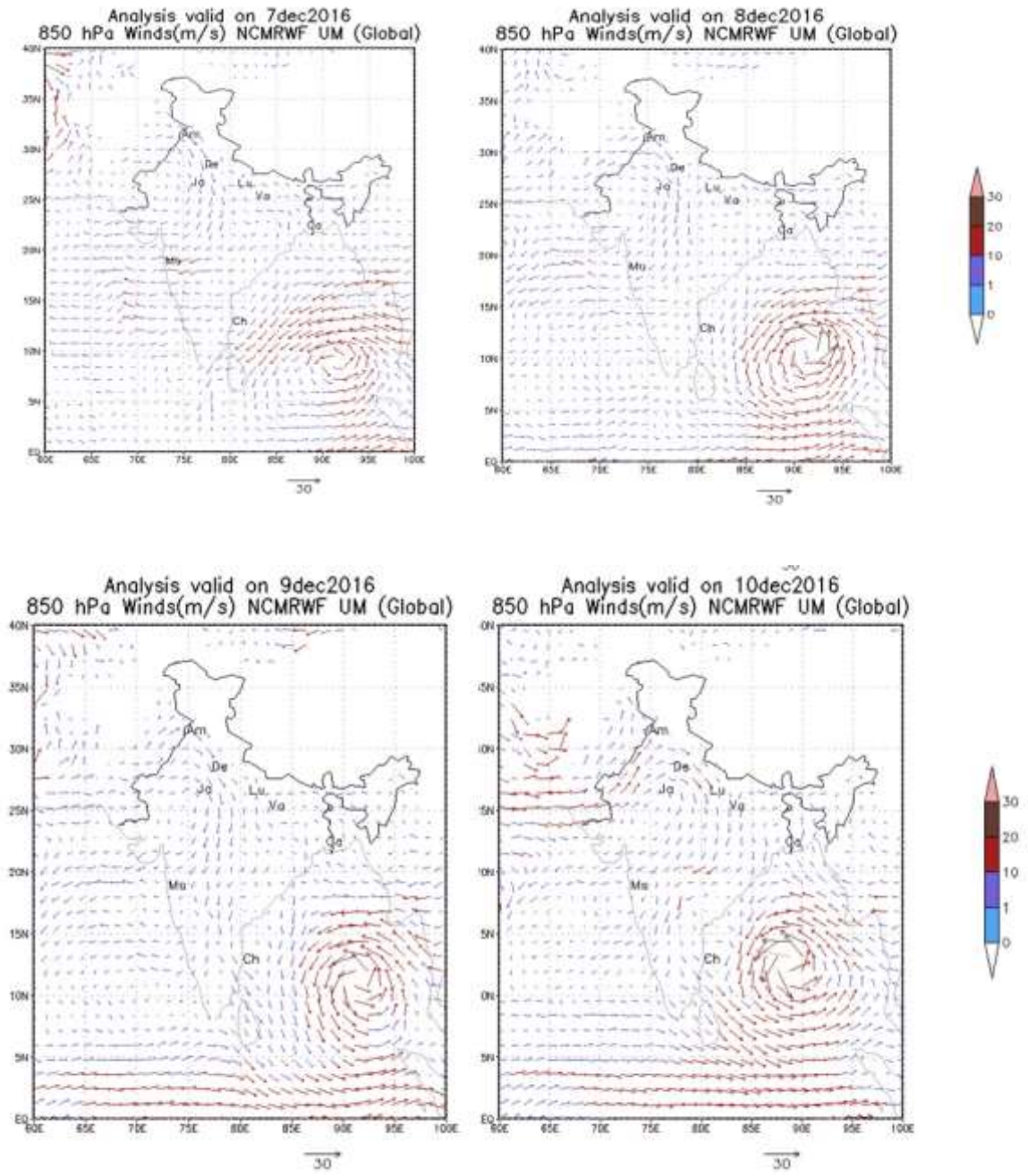

Figure 6: NCUM Analysis of Wind at 850 hPa from NCUM on (a) 07th (b) 08th (c) 09th and (d) 10th December 2016.

of visibility are found in the range of 50-200 m over large parts of U.P. and less than 50 m over few parts of U.P. on 9th (Figure 7c) and 10th December (Figure 7d). Moderate to dense fog is predicted over Varanasi every day whereas moderate fog is predicted over Lucknow on 7th December, no fog is predicted over Delhi and moderate fog is predicted over Amritsar on 9th December. Thus, the spatial plot of visibility from NCUM predicts the drop in visibility indicating fog over plains of north India. However, the areas of visibility predicted less than 500 m is limited. It has been found that visibility forecast from NCUM strongly depends on the values of predicted relative humidity (Aditi et al. 2018). Thus, the spatial plot of Day-1 forecast of surface relative

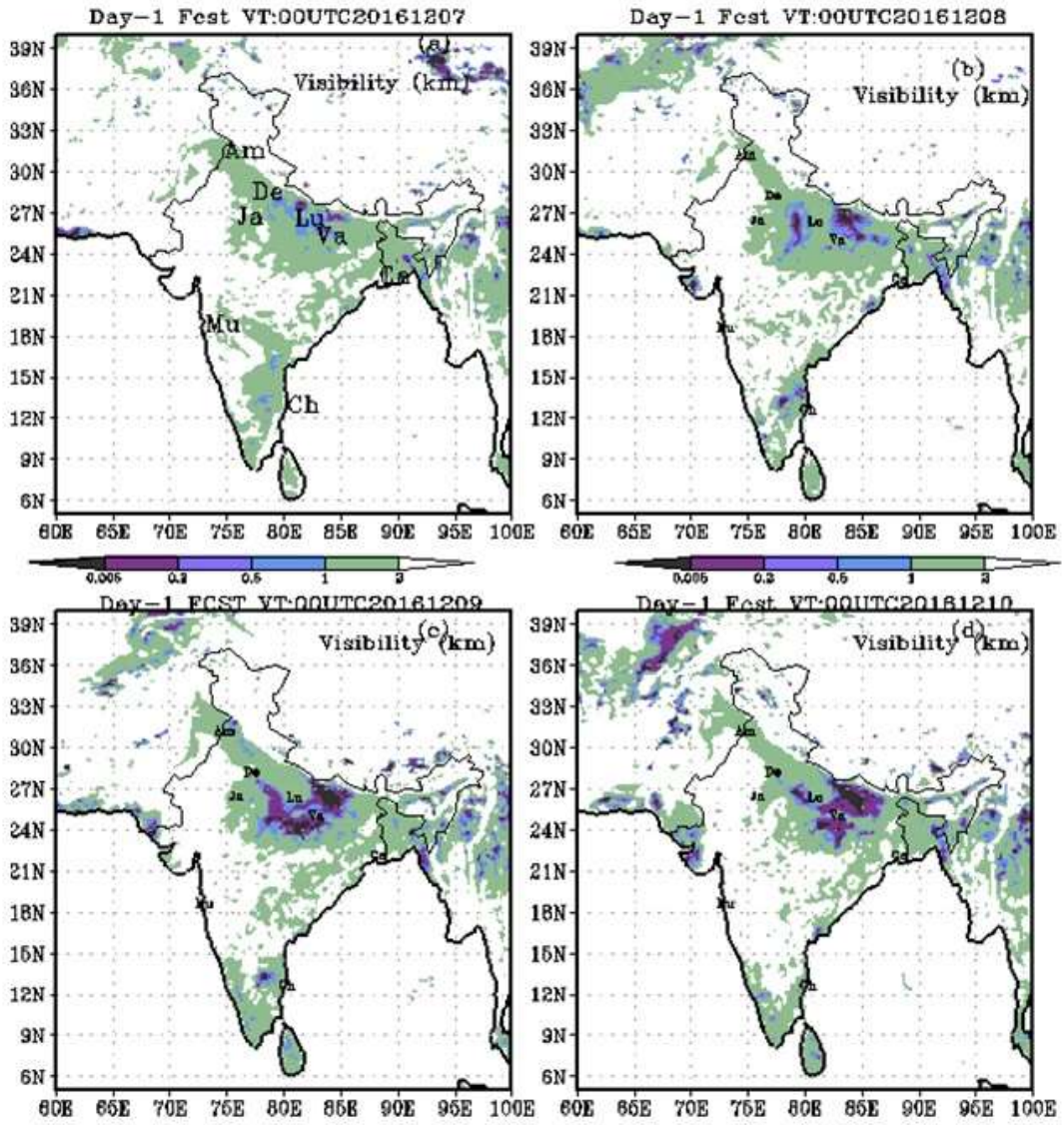

Figure 7: Day-1 Forecast of Visibility from NCUM at 00UTC on (a) 07th (b) 08th (c) 09th and (d) 10th December 2016.

humidity for 00 UTC of 7th -10th December is shown in Figure 8. The predicted values of relative humidity are close to 100% in the areas where visibility is predicted between 50-200 m and less than 50 m corresponding to dense and very dense fog respectively is predicted. Thus, NCUM predicts dense to very dense fog over the areas where predicted relative humidity is close to 100%. The relative humidity is predicted between 95%-97% over plains of north India including Amritsar and Delhi which is sufficient for fog formation, as fog occurs when relative humidity is more than 75% (Singh 2011). However, the spatial forecast of visibility predicts drop in visibility below 200 m over a region when the relative humidity is predicted more than 95% over the region (Fig. 8). This is due to the limitations of visibility

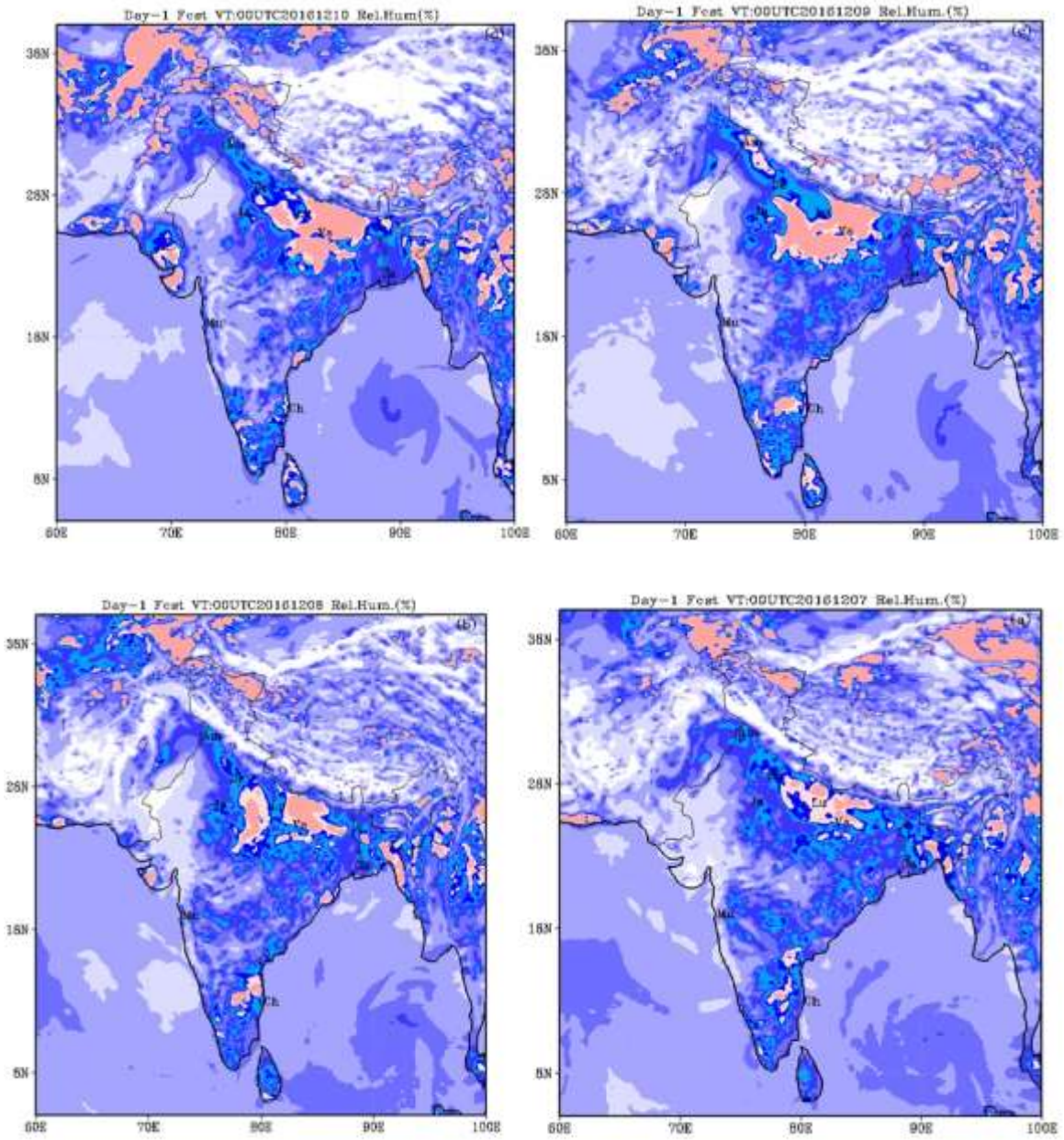

Figure 8 : Day-1 Forecast of Relative Humidity from NCUM at 00UTC on (a) 07th (b) 08th (c) 09th and (d) 10th December 2016.

parameterization scheme used in the model (Aditi et al. 2018).

As discussed in the previous section radiative fog occurs when wind speed is less than 2.5 m s^{-1} and dew point depression is less than 6.0 ^{0}C. Thus, the forecast of temperature, dew point temperature and wind speed are analyzed for 07th-10th December for the three selected stations Figure 9. It is clear that the difference between temperature and dew point temperature is $\leq$ 2 ^{0}C at all the stations in early morning hours (00-03UTC) and less than 6.0 ^{0}C for majority of hours during 07th-10th December (Figure 9 a-c). The predicted wind speed is less than 2 m s^{-1} over Delhi and

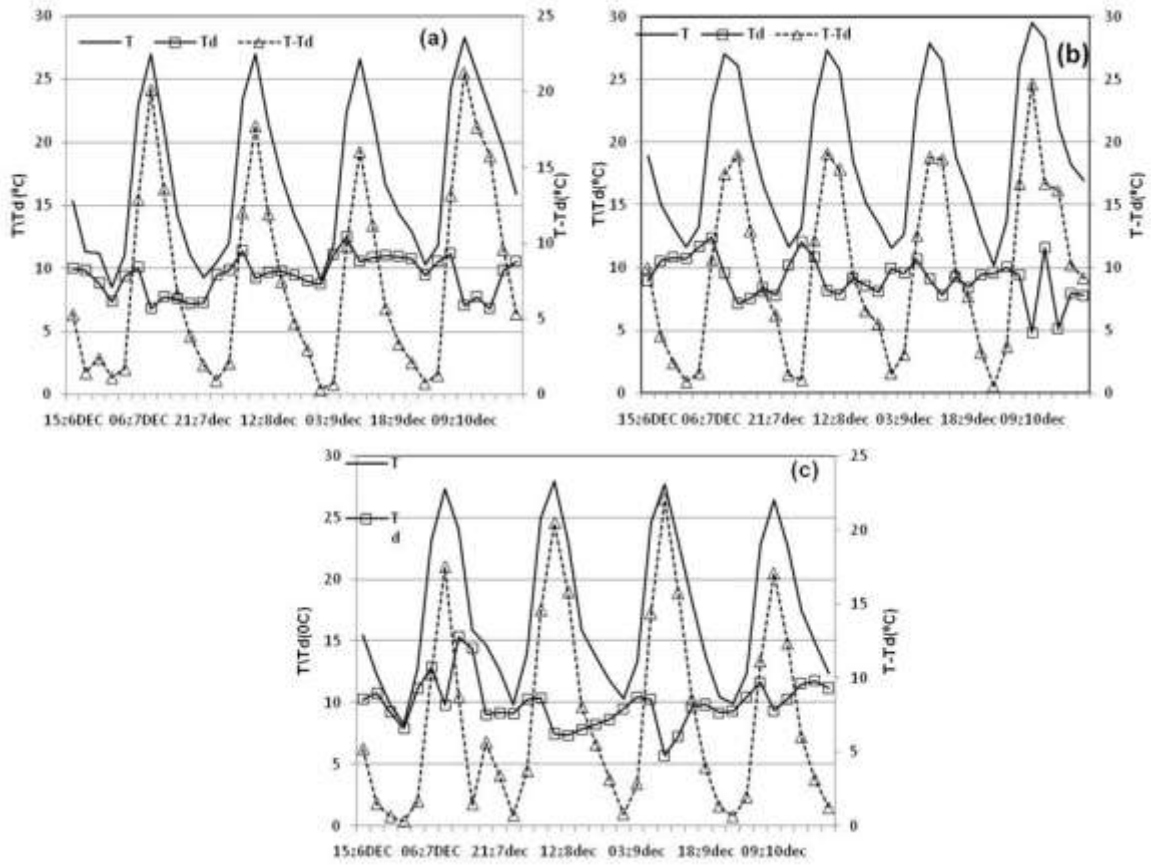

Figure 9: Time series of Forecast of Temperature (T), Dew Point Temperature (Td) and Dew Point Depression (T-Td) from NCUM at (a) Amritsar, (b) Delhi and (c) Lucknow during 07th-10th December.

Lucknow for most of the hours however it is predicted more than 2 m s^{-1} over Amritsar for majority of hours (Figure 9d). Thus, model is able to predict the meteorological conditions favorable for radiative fog events. The skill of the model in predicting the associated meteorological conditions (dew point depression (T-T_d < 6.0 ^{0}C) is computed using categorical statistics (Stanski et al. 1989) such as bias (B) and threat skill scores. The two scores are defined as:

B= (H+F)/(M+H)

T=H/(F+M+H)

Where

H= Number of Hits (T-T_d < 6.0 ^{0}C predicted and drop in visibility observed)

F= Number of False Alarm (T-T_d < 6.0 ^{0}C predicted but drop in visibility not observed)

M= Number of Misses (/T-T_d < 6.0 ^{0}C not predicted but drop in visibility observed)

When F=M=0 bias score and threat score becomes 1. Bias score less than 1 indicates that model has under forecasted otherwise over forecast.

Table 1. Skill Scores for Predicting (T-Td < 6.0 ^{0}C)

Station	H	F	M	B	T
Amritsar	17	1	7	0.75	0.68

Delhi	12	0	12	0.50	0.50
Lucknow	20	0	5	0.80	0.80

The results indicate that model has good skill in predicting the meteorological conditions favourable for fog formation however the forecast is slightly over predicted.

5. Summary and Conclusions

In this study, a radiative fog event is identified over IG of India using meteorological observations. The radiative fog event is simulated using the operational numerical weather prediction model NCUM. A dense fog event is observed over northern plains of India during 7^{th} -10^{th} December. The analysis of meteorological observations available at three stations Amritsar, Delhi and Lucknow reveals that the conditions are favourable for formation of radiative fog.

The wind field analysis at 850 hPa available from NCUM suggests prevalence of clear sky conditions with weak winds over northwest plains of India during 7^{th}-10^{th} December. Day-1 forecast of visibility from NCUM predicts the drop in visibility corresponding to dense fog over parts of northern India during 7^{th} -10^{th} December. The relative humidity is predicted close to 100% over parts of northern India and the drop in visibility is predicted below 200 m. NCUM is able to predict the dew point depression less than 2 .0 ^{0}C and low wind speed below 2 ms^{-1} over Amritsar, Delhi and Lucknow in the early morning hours during the fog event.

The study reveals that the model has capability of forecasting drop in visibility and the meteorological conditions favorable for fog formation. Further sensitivity studies are required to improve the visibility parameterization scheme.

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