MAUSAM, **62**, 1 (January 2011), 41-50

551.575.1

Unusual long & short spell of fog conditions over Delhi and northern plains of India during December-January, 2009-2010

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(*Received 31 March 2010, Modified 9 June 2010*)

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सार – दिसम्बर–जनवरी के महीनों में कुहरा छाए रहना सामान्य घटना होती है जो केवल उत्तरी भारत में ही नहीं अपितु बंगलादेश और पाकिस्तान में भी होती है। कुहरे की अधिकतम बारंबारता दिल्ली और इसके समीपवर्ती क्षेत्रों में देखी गई है। इससे जनवरी 1969 से 1988 के दौरान अधिकतम तापमान भी प्रभावित हुआ, यह भिन्नता 20.6 से 21.5 डिग्री सेल्सियस के बीच रही और वर्ष 2005 के दौरान यह 18.9 डिग्री सेल्सियस तथा वर्ष 2010 में 19.03 डिग्री सेल्सियस रही। कुहरे का निर्मित होना और इसका लम्बे समय तक बना रहना मुख्य रूप से सतह पवन, सापेक्षिक आर्द्रता, न्यूनतम तापमान एवं इसकी अवस्थिति पर निर्भर करता है। अधिकतम घना कुहरा 285 घंटें, 190 घंटें और 176 घंटे का क्रमशः वर्ष 1998–99, 2002–03 और 2009–10 में रहा। माह जनवरी 2010 के दौरान 5 पश्चिमी विक्षोभ बने जिससे उत्तरी भारत में वायुमंडल में नमी की मात्रा में वृद्धि हो गई और सतह पवन की गति लगभग 5 नॉट्स या इससे कम रहा। इससे निचले स्तर एवं हिमतल में प्रतिलोमन की भी स्थिति हुई। कुहरा और हिमांकतल के बीच कोई महत्वपूर्ण संबंध नहीं देखा गया है। तथापि प्रतिलोमन की कुहरा के निर्मित होने में महत्वपूर्ण भूमिका रही है। उत्तरी भारत के विस्तृत क्षेत्र, बंगलादेश और पाकिस्तान के ऊपर कुहरा के मॉनीटरन के लिए उपग्रह से प्राप्त स्पष्ट चित्रों पर भी विचार किया जाना चाहिए।

ABSTRACT. Sheet of fog is a common scenario during December-January months, which not only occurs in northern India but also in Bangladesh and Pakistan. Maximum fog frequency is noticed in Delhi and adjoining areas. This also affected the maximum temperature during January 1969-88, it varied between 20.6-21.5° C and during 2005 it was 18.9° C and 19.03° C during 2010. Formation of fog and its sustainability mainly depends upon surface wind, relative humidity, minimum temperature and persistency. Maximum dense fog was 285, 190 and 176 hours in 1998-99, 2002-03 and in 2009-10 respectively. During the month of January 2010 there were 5 western disturbances which enhanced the moisture over northern India, surface wind speed remained around 5 kt or less. Inversion in lower levels and freezing level has also been taken into consideration. No significant relation was found between fog and freezing level. However, inversion layer played an important role in formation of fog. Visible satellite imageries have also been taken into consideration to monitor fog over vast area of northern India, Bangladesh and Pakistan.

Key words – Dense fog, Radiation cooling, Relative humidity, Horizontal & vertical wind anomaly, Surface wind, Lower level inversion and temperature.

1. Introduction

Northern parts of India experiences radiation fog very often in winter season every year. Some time fog becomes very dense. Generally fog season starts from the first week of November and continues till February. The frequency and intensity of fog become maximum in the months of December and January. The impact and significance of fog studied by various authors it ranges from severe interruption aviation & surface transport, health and agriculture sectors. Sometime, it results to causes serious accidents of surface transport and delay in flights and trains due to poor visibility, which causes huge economic loss and serious disruption in societal activities. Dependency of fog formation is on meso-scale and micro-physical level process. On synoptic aspects it is also difficult to forecast fog beyond 12 hours or so, it depends on various parameters, such as moisture availability in the lower atmosphere, surface winds, minimum temperature, dew point depression and cooling of water particles available in lower atmosphere mainly during night time over the region. Fog sometimes migrates over the area and works as a catalyst to enhance the fog over adjoining area.

Western disturbances frequently affect western Himalayan region and adjoining plains of northwest India. The remnant of moisture or incursion of moisture due to western disturbances enhances the moisture level over the

TABLE 1

Criteria of Smog, Haze, Mist and Fog (shallow, moderate, dense and very dense)

Weather events	Meteorological conditions	Visibility ranges (in meters)
Smog	Pollutions and smoke remain suspended in the air near ground with wind remaining light but no humidity criteria	Visibility reduces but no specific range criteria
Haze	Relative humidity equals or less than 75%	2000 - 5000
Mist	Relative humidity at least 75%	1000 - 5000
Fog	Relative humidity more than 75%	Less than 1000
(*i*) Shallow fog	Relative humidity more than 75%	1000 - 500
(*ii*) Moderate fog	Relative humidity more than 75%	500 - 200
(*iii*) Dense fog	Relative humidity more than 75%	200 - 50
(*iv*) Very dense fog	Relative humidity more than 75%	< 50

region. Also, there is availability of abundance moisture sources in the Ganges, its tributaries and their various canals networks and from irrigated water over vast cultivated wheat fields in the region. In the northeast, river Brahmaputra and its tributaries and huge vegetation enhance the moisture over the region. Later it also helps to increase and persistence of fog. Fog conditions generally start in the evening and deepen during night/morning hours. Sometimes it persists throughout the day and emerges with cooling in next night. In such situation visibility decreases to 50 m or less. Besides manual observation, satellite visible imageries are very helpful in monitoring the fog conditions. Spread white grey shade with sharp edge in satellite visible imageries indicate fog. Occasionally, it can be seen over entire Indo-Gangetic plains and in some occasions upto Assam. Thickness of fog can also be estimated through these images according to its shades colour and persistency; it also helps to estimate the time of lifting. In this study all aspects are described in detail to understand the fog conditions over Delhi and northern parts of the country during the months of December and January.

For India, Table 1 provides fog related weather events and associated visibility ranges. During December-January, 2009-2010 IGI Airport, Delhi has recorded 176 hours of dense fog conditions (4 hours in December and 172 hours in January). Whole northern India was under the grip of dense fog for many days in January 2010. It caused severe interruption in transport, health and agriculture sectors. In Delhi 43 people were killed in fog related accidents, 2000 flight delayed, some cancelled and 1200 trains delayed while 700 were cancelled till 28th January 2010 (HT, 29 January 2010). A total of 285 hours of dense fog conditions were recorded in December-January period of fog season1998-99 and 190 hours in 2002-03. Whereas 176 hours were recorded in 2009-2010 when the visibility was less than 200 m. Diverted flights and number of dense fog hours during last 13 fog seasons are shown in (Fig. 1). Generally, impact of fog on city life is larger when the duration of fog becomes longer.

2. Data & methodology

Different aspects are taken into consideration for formation of fog and its persistence *i.e.*, synoptic, dynamical and satellite observations. Visibility less than or equal to 200 m and number of flight diverted from IGI Airport, New Delhi are taken from frequently asked questions related to aviation from IMD and Director General of Civil Aviation website *i.e.*, http://www.imd.gov.in/section/nhac/dynamic/fogvis1.htm and http://www.dgca.gov.in/dgca/LVP. Synoptic features mainly trough in westerlies, western disturbance and rainfall data are taken from weekly weather reports of Northern Hemisphere Analysis Center (NHAC) of India Meteorological Department (IMD). These are the main causes of moisture incursion and rainfall over northern plains. The minimum temperature, relative humidity and visibility data are taken from MO Palam and MO

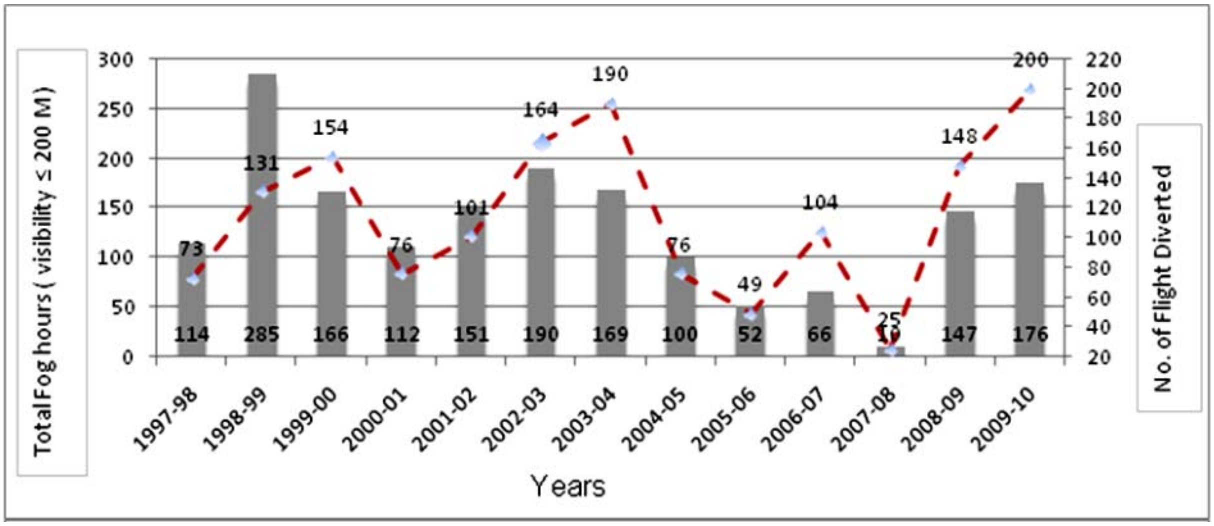


Fig. 1. Dense fog (visibility <200 m) in December & January and flight diverted from IGI airport, New Delhi

Safdarjung, New Delhi. Observations of T-ϕ gram of 0000 UTC of (Ayanagar) Delhi are taken into consideration for day-to-day surface wind, to calculate the inversion layer and observed freezing level etc. NCEP/NCAR re-analysis NCEP/NCAR reanalysis data of December 2009 & January 2010 are also used to show the horizontal vector wind flow pattern anomaly, vertical winds and upper layer soil moisture anomaly. Visible Imageries of 0300 and 0600 UTC are taken from Satellite Meteorology Division of IMD to observe area coverage, density and duration of fog over entire or parts of northern plains and northeast India.

Different methods are available for fog forecasting, *i.e*., Model Output Statistics (MOS), persistence, synoptic and statistical model output. Statistical guidance is a mean by which one may attempt to estimate or quantify meso-scale variation with reference to occurrence of fog. The statistical guidance from the current operational NWP models has the basic inability to provide adequate information for reliable prediction of fog 06-24 hours in advance (Croft *et al*., 1997). Persistence forecast has good percentage of success but fails during the transition period of fog spell. In recent past, development process of forecasting visibility for a place Hindon near Delhi, Madan *et al*., (2000) attempted for objective method applying different approaches such as auto regression, multiple regression, climatology and persistence. In the regression equation they used local meteorological parameters such as surface wind, dry bulb & wet bulb temperatures and cloud amounts as predictors. But comparison with the realized visibility showed that forecast had larger deviation and the forecast beyond 6 hours from the initial time are not satisfactory. The model developed by them following climatology persistence method is found to provide better visibility forecast. Mohapatra and Das (1998) attempted to forecast fog over Bangalore Airport using different objective techniques such as persistence, synoptic, statistical (threshold value based on co-relation coefficients of predictors). Wilson (1988) worked out an objective method to predict weather element mainly fog by multiple discriminating analysis.

Using data for the 1960-98 of Indira Gandhi International (IGI) Airport Delhi, Singh *et al*., (1999) documented that there is a clear cut peak around 1430 UTC when visibility deteriorates below 800 m and improves around 0300 UTC both for January and December months. They also analyzed the climatology and trend of visibility in Delhi. The study showed that duration of fog has increased considerably. The average duration of visibility less than 800 m has increased from 0.3 hours/day during 1964-1968 to 8.98 hours/day during 1994-98 in both the months of December and January. Jenamani (2007) found average hours of maximum dense fog per day in January which reduces visibility to <50 m or less over the city was 0.5 hours/day in the beginning of the 1980s. This has been increasing slowly to 1.0 hour/day in subsequent 15 years till 1995, followed high increasing trend within the next small period of 5 years, with a value reaching to 2.0-3.0 hours/day. Thus, it can be safely concluded that incidence of fog shown significant increasing trend over Delhi in the last one to two decades.

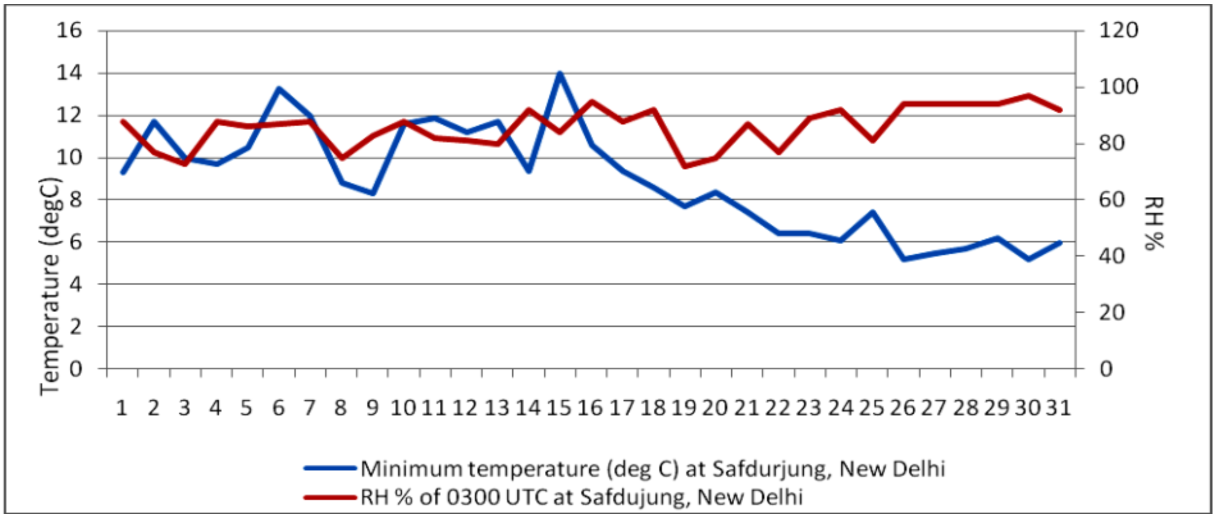


Fig. 2. Minimum temperatures and relative humidity (%) during 1-31 December 2009 at Safdarjung, New Delhi

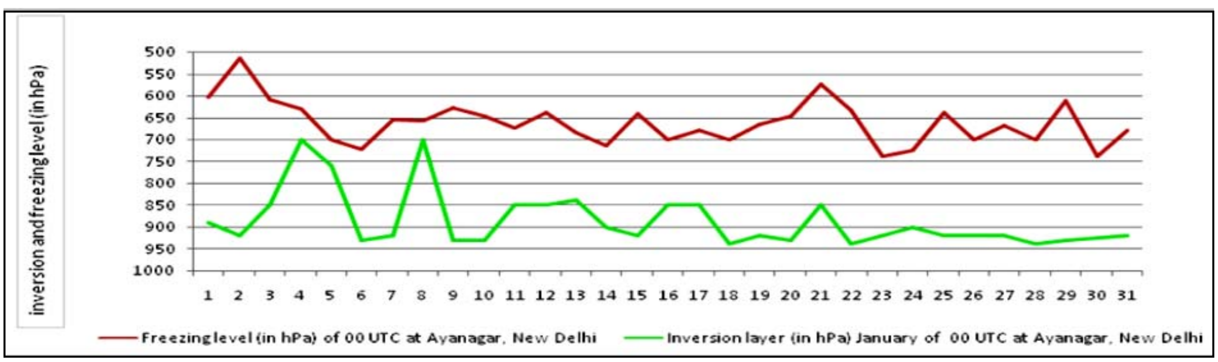


Fig. 3. Inversion layer and freezing level during 1-31 December 2009 at Ayanagar, New Delhi

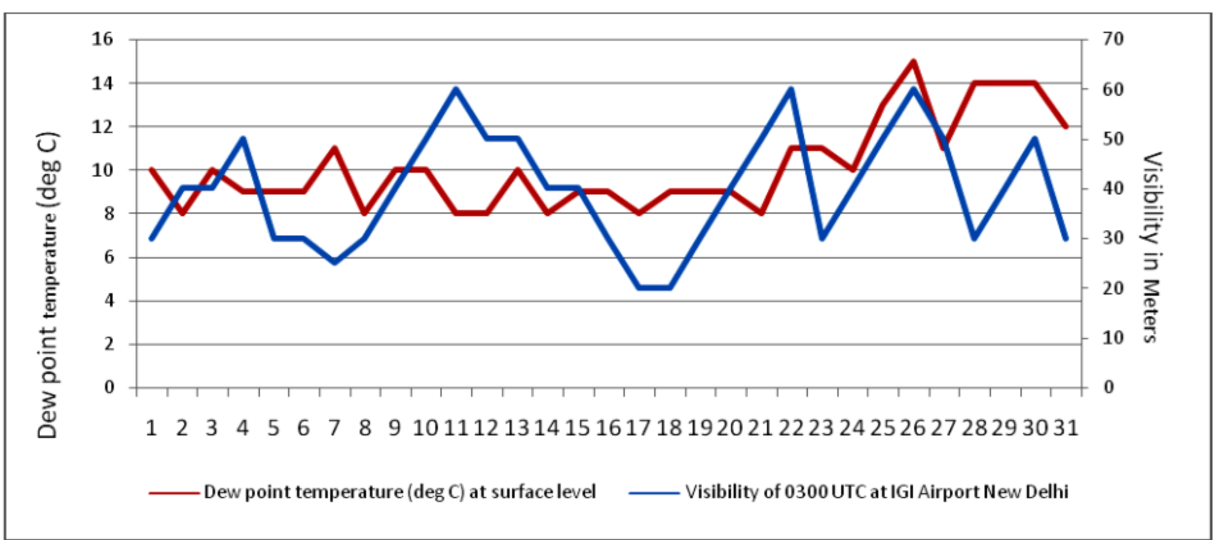


Fig. 4. Dew point temperatures (°C) at 0000 UTC at Ayanagar and visibility at 0300 UTC at IGI Airport, New Delhi during 1-31 January 2009

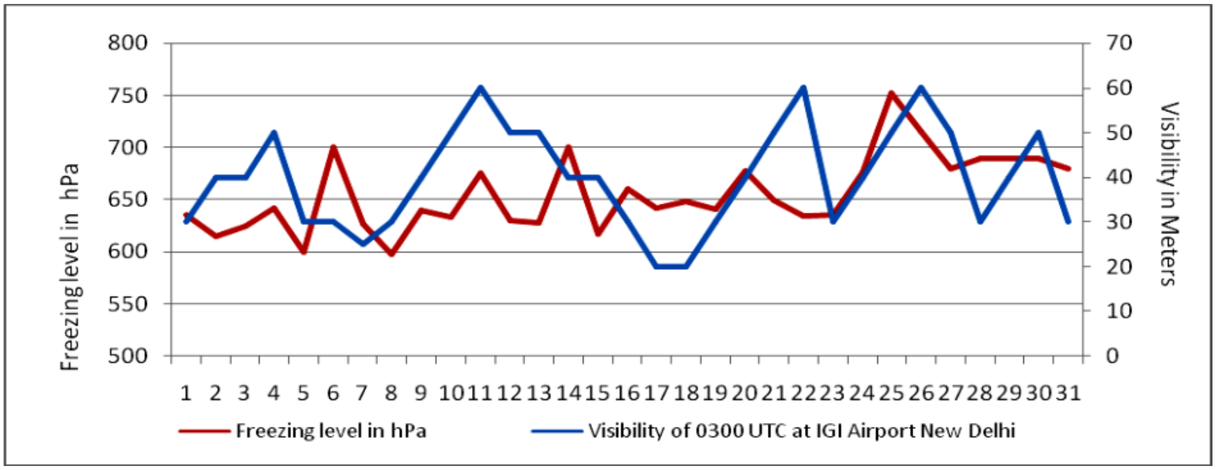


Fig. 5. Freezing level at 0000 UTC at Ayanagar and visibility at 0300 UTC at IGI airport, Delhi during 1-31 January 2009

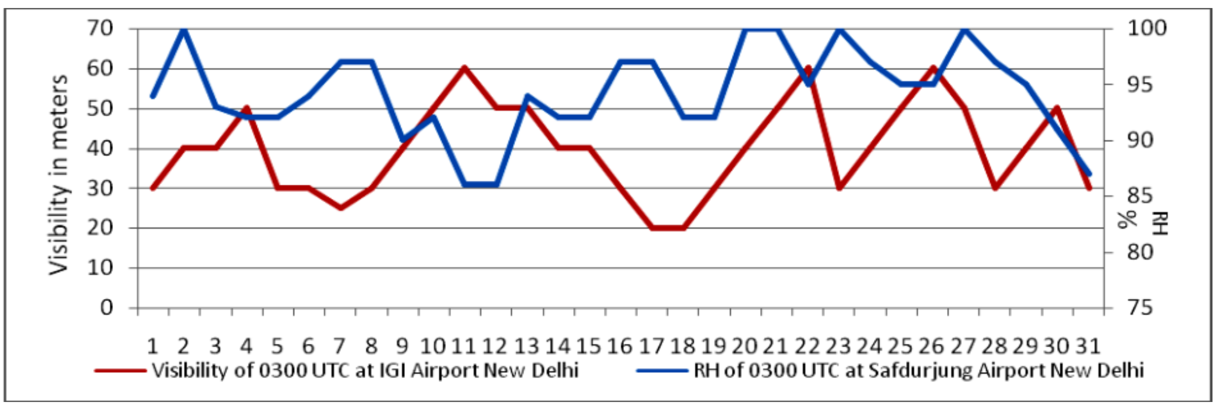


Fig. 6. Relative humidity (RH %) at 0300 UTC and visibility at 0300 UTC during 1-31 January 2009 at Safdarjung and IGI airport, New Delhi

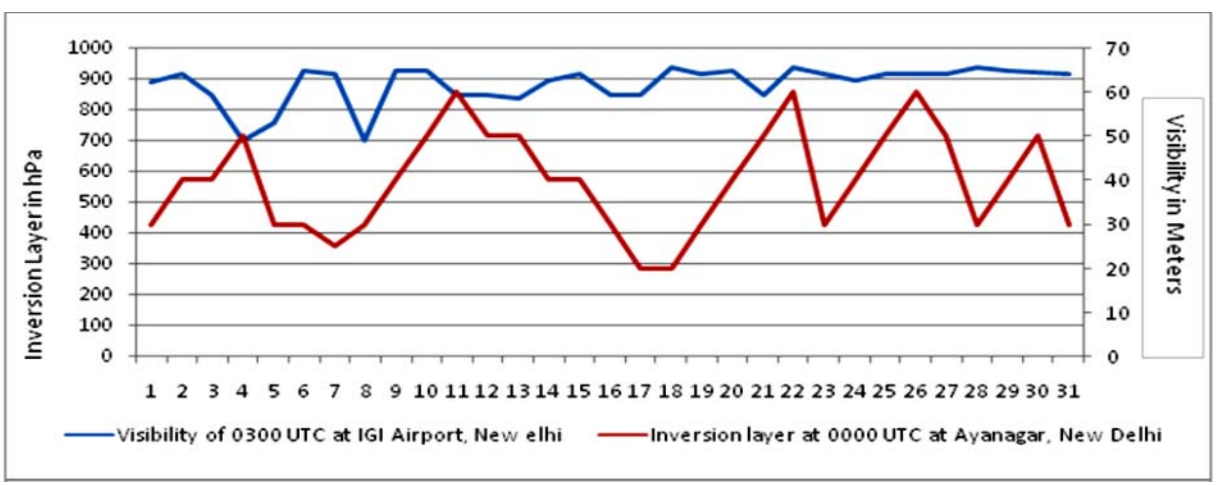


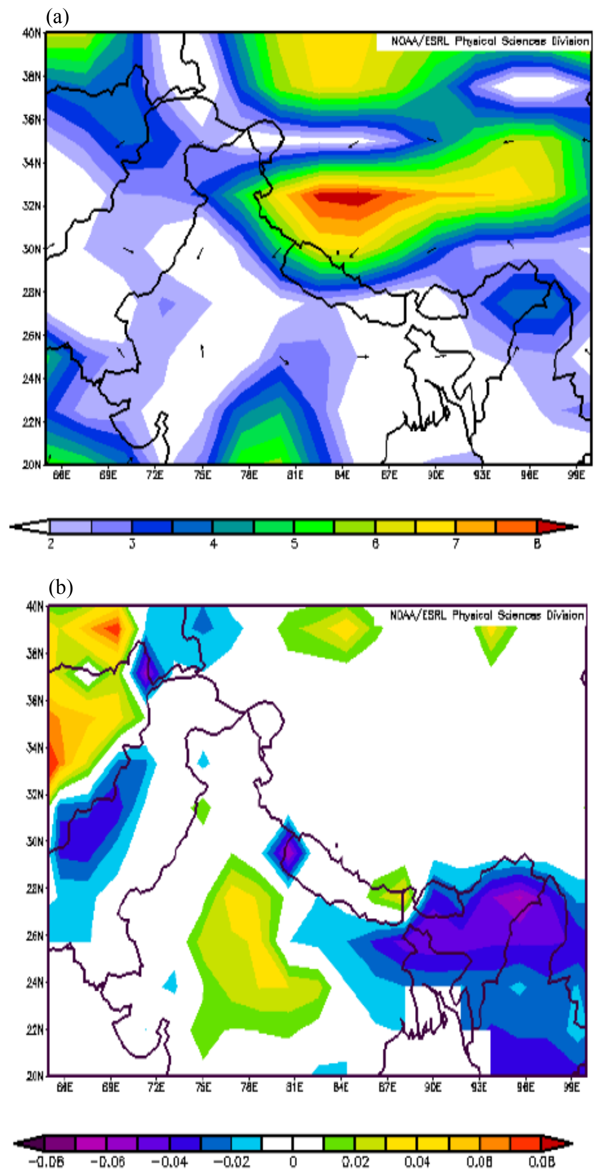
Fig. 7. Inversion layer at 0000 UTC and visibility at 0300 UTC during 1-31 January 2009 at Ayanagar and IGI airport, New Delhi

3. Fog over Delhi in December 2009 and January 2010

3.1. *Dynamic aspects*

(a) *December 2009* : During the month there were no significant western disturbances passing over northwest India. This was the main factor that kept the moisture level low over northwest India and remaining parts of northern plains. The lower level winds were also strong, *i.e.*, more than 5.0 kts over the region throughout the month except 2-3 days towards the end of the month. Minimum temperature was more than 6.0° C on most of the days during the month. On 26 & 30 December observed minimum temperature was between 5.2 & 5.3° C (Fig. 2). However, fog can also occur even at higher minimum temperature on some occasions when other parameters are favourable. Sometimes moisture incursion takes place over northern plains due to southwesterly winds from north Arabian Sea or wind confluence occurs over central India. These enhance the relative humidity, but due to absent of these synoptic features relative humidity remained below 80 % or less for most of the days in December 2009 (Fig. 2). Near surface inversion layer also contribute for formation of fog up to some extent as inversion helps to evaporate cool water droplets near the surface and enhanced stability of surface layer. Inversion was not observed for most of the days. Fog was not observed for most of the days of the month. However, shallow fog was observed in morning hours on 18, 30 and 31 December where the visibility reached less than 200m in dense fog for ½, 1, and 2 hours respectively. Inversion layer over Delhi remained below 900 hPa level on most of the days. Only on one or two days when it was on slight higher side (Fig. 3). Soil moisture contents were very less, which adversely affected enhancing the relative humidity in lower levels. Most of the dynamic conditions were therefore not favourable for formation of fog over northern plains. Therefore, no fog was observed on most of the days during the month of December 2009.

(b) *January 2010* : Dew point temperature during 1-22 January fluctuated between 8.0 & 10.0° C. Thereafter, it increased upto 15.0° C on the morning of 26 January, which triggered the fog conditions in the morning hours of same day and visibility slashed down less than 50M for some hours. In (Fig. 4) it is clearly shown that on most of occasions when dew point temperatures rose, visibility came down due to incursion of moisture in lower troposphere. No significant relation has been found between freezing level and visibility (Fig. 5). However, on many occasions when freezing level came down to 600 hPa, visibility remained higher side, *i.e.*, more than 200m. Inversion layer in lower levels was conducive to create the radiation fog over Delhi region. It remained on the higher side (Fig. 3) for many days of the month *i.e.*, upto 850 hPa or around it.



Figs. 8(a&b). (a) Vector wind anomaly at 925 hPa level and (b) Soil moisture 0-10 cm during 1-31 December 2009 based on re-analysis data of NCEP/NCAR

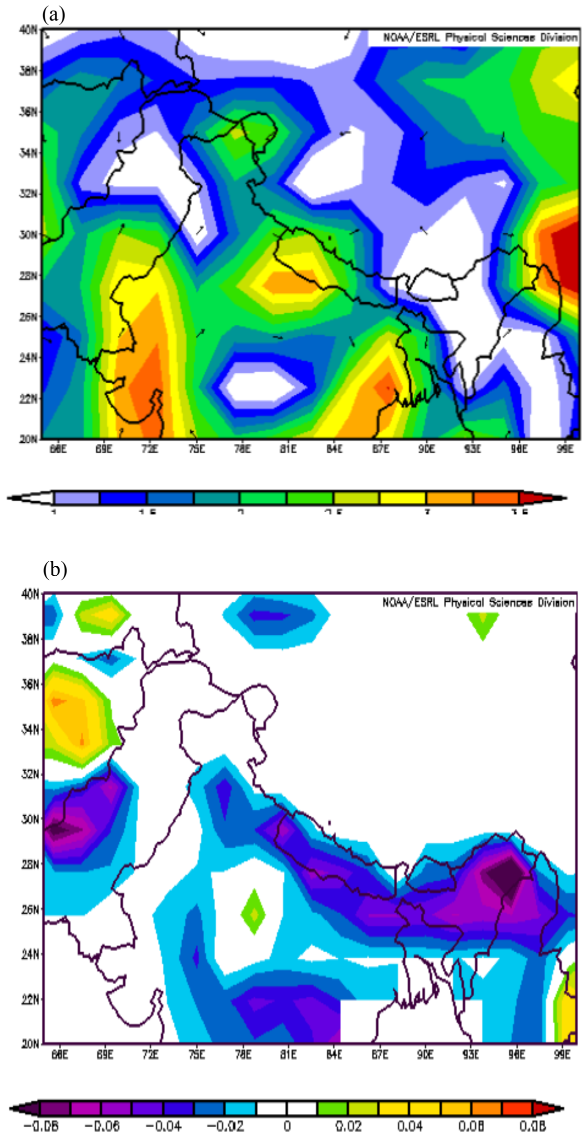
Relative humidity at 0300 UTC was more than 90% on all days, except on 11 & 12 and 31 January when it was 85%, 85% and 87%. It is clear from (Fig. 6) that relative humidity played an important role in formation of fog as well as its sustainability. Relative humidity is the prime factor to cause the fog conditions in addition to speed of surface winds, backing or veering of wind, minimum temperature, dew point depression and inversion layers in lower levels. Inversion layer and visibility have good coloration as shown in Fig. 7, it protect the moisture to evaporate and help in persistency of fog for a long time. Jenamani (2007) has also studied of maximum temperature during the month of January at IGI Airport, New Delhi and found that the maximum temperature varied between 20.6 & 21.5° C during 1969-88, while later it followed a significant decreasing trend, with maximum temperature falling to a record lowest value of 18.9° C in 2005 from 21.7° C recorded in 1988-90, *i.e*., a total fall of nearly 3° C in 15 years, with fall of 0.2° C/year. A relation was developed by Roy Bhowmik *et al*., (2004) among surface wind, minimum temperature, dew point depression and relative humidity to forecast the fog over Delhi is in agreement with past studies. Correlation coefficients have been calculated between inversion layer in lower levels & visibility, dew point & visibility, freezing level & visibility and relative humidity & visibility, it is found 0.47, 0.21, 0.26 and -0.18 respectively.

3.2. *Synoptic aspects*

During December-January Delhi and northern plains is mainly affected by (*i*) western disturbances, (*ii*) fog, (*iii*) some area of northwest India occasionally experience frost, (*iv*) western Himalayan region experience snowfall along with rain, (*v*) strong surface winds etc. Synoptic aspects of formation and persistence of fog are described in following paragraphs for December 2009-January 2010.

(a) *December 2009* : During the month 5 western disturbances affected western Himalaya region leading to rain/snowfall over western Himalayan region. However, only one western disturbance during the last week of the month caused isolated light rainfall over the adjoining northern plains of western Himalayan region. The minimum temperatures were appreciably to markedly above normal over many parts of north and central India during many days of the month. Rainfall over northern India was deficient or scanty which showed that most of the western disturbances passed through northern India without causing sufficient rainfall. Rainfall distribution was deficient or scanty in most of the sub-divisions of northwest India.

Fog conditions were observed in morning hours over the plains of north India during a few days of the month. Maximum horizontal vector winds anomaly were confined over some parts of western Himalayan region, central and peninsular India [Fig. 8(a)]. Soil moisture is one of the factor, which contributes to enhance the relative humidity in lower levels [Fig. 8(b)] over parts of northwest India and northeastern states.



Figs. 9(a&b). (a) Vector wind anomaly at 925 hPa level and (c) Soil moisture 0-10 cm during January 1-31, 2010 based on re-analysis data of NCEP/NCAR

(b) *January 2010* : During the month 4 western disturbances affected western Himalayan region on 2-3, 20, 23 and on 27 January. These caused scattered rain/snow in Jammu & Kashmir & Himachal Pradesh and isolated rainfall in Punjab during 2nd and 3rd week. An easterly wave moved across peninsular India during 9-13 of this month. Under its influence of this easterly wave a trough developed which extended from north Maharashtra coast to Kerala coast on 12 which caused isolated rainfall over Maharashtra, Madhya Pradesh and Uttar Pradesh. It enhanced the moisture over Indo-Gangetic plains. Rainfall

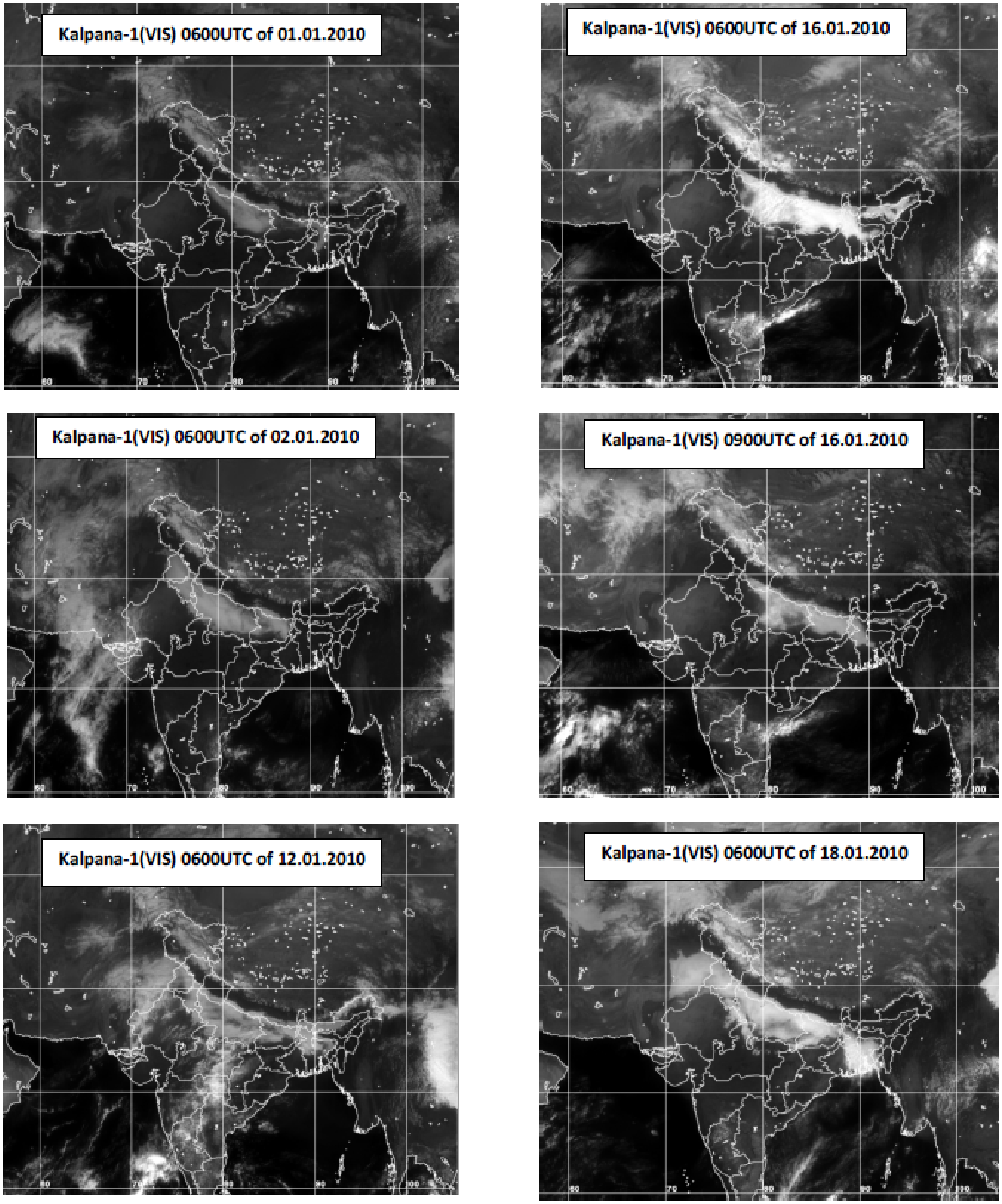


Fig. 10. Kalpana-1 (VIS) Satellite imageries at 0600 & 0900 UTC showing fog cover area and its thickness over a particular area

during the month of January, entire north, northeast and central India was received scanty rainfall and no rainfall over Arunachal Pradesh. Southern peninsular India was received excess rainfall except over Tamilnadu where it was deficient and over Lakshadweep received normal rainfall. Thus considerable moisture was advected toward Gangetic plains as a result of this weather pattern over peninsular India and central India.

Cold wave conditions prevailed over parts of northwest India on 1, 16, 23 and 24 January over parts of Indo-Gangetic plains on 7, 8, 11, 22 & 26 and some parts of central and adjoining east India on 3, 6, 7, 8, 16, 21-24 and 26 January. Cold day conditions were also observed for many days over Uttar Pradesh and Bihar, few days over Punjab and Haryana and very few days over north Rajasthan and Assam. Delhi experienced 9 days of cold day conditions when the maximum temperature remained 16.0° C or less. The average maximum temperature of January 2010 was 19.03° C at Delhi, which is 20.8° C below normal. The minimum temperature during the month was above normal for 21 days, below normal for 3 days and normal for 7 days. Fog/shallow fog conditions prevailed over Punjab, Haryana and Uttar Pradesh for many days of the first week. Also fog conditions prevailed over most parts of Indo-Gangetic plains during second week and dense fog conditions over most parts of Indo-Gangetic plains during the second fortnight of the month. Horizontal vector wind maximum anomaly confined over Uttar Pradesh, southwest Rajasthan, Gujarat and east coast [Fig. 9(a)]. Soil moisture anomaly was observed negative over Indo-Gangetic plains and northeastern states [Fig. 9(b)]. It is inferred that there was no significant relation with fog and soil moisture. However, the ground surface moisture as a result of persistent fog itself enhances the moisture in lower atmosphere leading to enhance in relative humidity and finally contributes to formation and sustainable fog upto some extent.

Satellite imageries indicate widespread fog over Uttar Pradesh and Sub-Himalayan West Bengal & Sikkim on 1 January. It spread over Haryana, Punjab and Bihar on 2 January. It covered whole Indo-Gangetic plains and Assam on 12 January. A north-south trough developed and extended from east Uttar Pradesh to Kerala coast, it causes moisture incursion over northern parts of the country mainly over Uttar Pradesh and Bihar. The moisture incursion contributed in development of dense fog condition over Uttar Pradesh, Bihar and Assam, on 16th it became very dense and persisted whole day. The situation on 18th became more severe when this fog spread over entire northern plains in the west upto Pakistan and in east upto Bangladesh, it shown in satellite imageries [Fig. 10].

4. Conclusion

Wind speed and direction in lower levels, relative humidity, movement of effective western disturbances or westerly trough in middle troposphere levels, vertical wind, soil moisture, dew point depression and minimum temperature are the key parameters for formation of fog over northern plains. Many authors developed the relation within these parameters to forecast the fog. Besides these parameters its persistence also one cause of the fog for next day, as some time this merge with next day fog. Atmospheric cooling must be observed regularly. Dense fog contributes to develop the cold day conditions and as a result average day temperature for the month of January 2010 which reduces upto 19.03° C. Satellite imageries is a very good tool to observed the fog, fog area and intensity. It should be taken into consideration during forecast of fog. An initiative has been taken by IMD to use numerical model for predicting the fog over northern plains.

Acknowledgement

Author is thankful to Director General of Meteorology for encouragement to study the fog conditions over Delhi and northern plains during December 2009 and January 2010. Author is also thankful to Shri H. B. S. Negi, AM and Shri Satish Chandra, SA who are working in NHAC, DGM's Office, New Delhi for helping in tabulating the different type of data, designing of graph & figures and typing the manuscript of the paper.

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