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Study of winter fog over Indian subcontinent : Climatological perspectives

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सार – कुहरा एक स्थानीय परिघटना है जिससे वायु में पानी की छोटी–छोटी बूंदों के टंगे रहने के कारण क्षैतिज दृश्यता 1000 मी. से भी कम हो जाती है। वस्तुतः कुहरा भी एक प्रकार से स्तही स्तर का मेघ है। यह परिघटना हमारी दैनिक गतिविधियों को प्रभावित करती है क्योंकि इसका हमारे जीवन, जन स्वास्थ्य, सड़क सुरक्षा और आर्थिक समृद्धि पर असर होता है। संवेदनशील सामाजिक आवश्यकताओं में भी इसकी जानकारी आवश्यक होती है। भारत में विकिरण और अभिवहन कुहरे का छाना आम घटना है जो उत्तर भारत में शरद ऋतु में अक्सर होता है। इस शोध पत्र में दैनिक घंटावार सिनॉप्टिक सतह आंकड़ों का उपयोग करके भारतीय उपमहाद्वीप (0° उ.–35° उ. तथा 60° पू.–100° पू.) में शरद ऋतु के दौरान 0300 यू.टी.सी. पर 1000 मी. से कम दृश्यता वाले दिनों के औसत की स्थानीक परिवर्तिता के परिणाम को दर्शाया गया है। इससे भारत के कुछ चुनिंदा आई. सी. ए. ओ. स्टोशनों पर सर्दी के महीनों (दिसम्बर 2010–फरवरी 2011) में आधे–आधे घंटे पर लिए गए मेटार प्रेक्षणों के आधार पर कुहरे की घटनाओं का विश्लेषण भी प्रस्तुत किया गया है।

कुहरा वाले दिनों की औसत संख्या में माहवार स्थानिक परिवर्तता से पता चला है कि भारतीय गांगेय क्षेत्रों में दिसम्बर के दौरान 7 से 10 दिनों तक और जनवरी के दौरान 8 से अधिक दिनों में 1000 मी. से कम दूरी की दृश्यता रही। पश्चिम बंगाल का दक्षिणी गांगेय क्षेत्र फरवरी में कुहरे के प्रति अति संवेदनशील रहता है। ऋतु के अनुसार कुहरे में भिन्नता से पता चलता है कि भारतीय गांगेय क्षेत्रों में औसतन 6.5 दिनों से अधिक में कुहरे का जोर रहता है। कर्नाटक के दक्षिण अंदरूनी भाग में कुहरे वाले दिनों की घटनाएँ तथा समुद्र तटीय कर्नाटक में कुहरे वाले दिनों की घटनाएँ औसतन 6.5 दिनों की होती हैं। इस ऋतु के दौरान उत्तर भारत में औसतन 2.5 दिनों में घने कुहरे का जोर रहता है जबकि पश्चिम बंगाल का गांगेय क्षेत्र, पश्चिमी राजस्थान और पूर्वी राजस्थान के समीपवर्ती भाग और पर्वी उत्तर प्रदेश में औसतन 3.5 दिनों का कुहरा होता है। शीत ऋतु के दौरान उत्तरी भारत में औसतन 3 दिनों तक घना कुहरा छाया रहता है। कुछ चुनिंदा आई. सी. ए. ओ. स्टेशनों के निश्चित समय श्रृंखला के वायु तापमान, ओसांक तापमान, ओसांक अवदाब, दृश्यता, पवन एवं उसके परिमाण के कटिबंधीय तथा रेखांशीय अवयवों का विश्लेशण करने से पता चला है कि जब धीमी गति की पवने अहमदाबाद में दक्षिण–पूर्व की तरफ, अमृतसर में उत्तर से उत्तर–पश्चिम की तरफ, नई दिल्ली में उत्तर से उत्तर–पूर्व की तरफ, कोलकाता एवं गुवाहाटी में पश्चिम से दक्षिण–पश्चिम की तरफ चलती हैं तो दृश्यता 1000 मी. के नीचे आ जाती है और इस स्थिति में ओसांक अवदाब 3° सेल्सियस के नीचे आ जाता है। भारतीय उपमहाद्वीप के वर्ष 1971–2010 तक की दीर्घअवधि में 1000 मी. से कम की दृश्यता वाली स्थितियों का विश्लेषण करने से पता चला है कि भारतीय गांगेय क्षेत्र में औसत पवन गति 0.6 मी./से. वायु का तापमान दिसम्बर से फरवरी के दौरान 0300 यू.टी.सी. पर 9° से. से 15° से. की सीमा मे रहा। सापेक्षिक आर्द्रता की वर्ष 1971–2010 की दीर्घअवधि में किए गए विश्लेषण से पता चला है कि भारतीय गांगेय मैदानी क्षेत्र में दिसम्बर–फरवरी में 0300 यू.टी.सी. पर सापेक्षिक आर्द्रता की कमी 72% से 84% तक रही।

ABSTRACT. Fog is localized phenomenon where horizontal visibility is reduced to less than 1000 m due to suspension of very small water droplets in the air. In fact Fog is cloud at surface level. This phenomenon matters to us in our daily activities due to its effect on life, public health, road safety, and economic prosperity. Its knowledge is essential to meet critical societal needs. In India, radiation and advection fog are most common which occur mostly over north India in winter. This study presents results of spatial variability of average number of days having visibility less than 1000 m at 0300 UTC during winter season over Indian subcontinent (0° N-35° N and 60° E-100° E) using synoptic hour daily surface data. Analysis of Fog events based on half hourly METAR observations for winter months (December 2010-February 2011) at selected ICAO stations of India is also presented.

The monthly spatial variability of average number of days with fog having visibility less than 1000 m indicates presence of fog over Indo-Gangetic plains on an average of 7 to 10 days during December and more than 8 days during January. South Gangetic West Bengal is susceptible to fog during February. Seasonal variation of fog shows that there is prominence of fog over Indo-Gangetic plains on an average of more than 6.5 days. Significant incidences of foggy days occur over South Interior Karnataka and Coastal Karnataka has incidence of foggy days on an average of 6.5 days. North India is susceptible to dense fog on average of 2.5 days during the season while Gangetic West Bengal, West Rajasthan

and adjoining parts of east Rajasthan and East Uttar Pradesh have occurrence of fog on an average of 3.5 days. Thick fog occurs on an average of 3 days over northern India during the winter season. Analysis of time series of air temperature, dew point temperature, dew point depression, visibility, zonal and meridional components of wind and its magnitude at selected ICAO stations indicate that visibility reduces to below 1000 m while light winds are southeasterly at Ahmedabad, northerly to northwesterly at Amritsar, northerly to northeasterly at New Delhi, westerly to southwesterly at Kolkata, Guwahati and dew point depression is below 3 °C during such conditions. Long period 1971-2010 analysis of visibility conditions less than 1000 m over Indian subcontinent shows Indo-Gangetic plains region to have average wind speed to be 0.6 m/s, air temperature in the range 9 °C to 15 °C during December-February at 0300 UTC. Long period 1971- 2010 analysis of relative humidity shows Indo-Genetic plains region to have relative humidity in the range 72% to 84% at 0300 UTC during December-February.

Key words – Visibility, Fog, ICAO, METAR.

1. Introduction

Fog is localized phenomenon that matters to us in our daily activities due to its effect on life, public health, roadways and airways safety, and economic prosperity. Its knowledge is essential to meet critical societal needs. For years together the scientific community all over the world has shown keen interest in better understanding of fog (Bendix *et al*., 1994; Cho *et al*., 2000; Friedlein, 2004; George, 1940; LaDochy, 2005; Westcott, 2004; Taylor, 1917). In India, Radiation and Advection fog types are common during winter. The advection fog occurs in the forward sector whereas the radiation fog occurs mainly in the rear sector of a synoptic scale weather system known as "Western Disturbances" that affect India during winter. Radiation fog usually occurs at late night when the earth radiates long wave terrestrial radiation and the air close to the ground gets heated, rises and is cooled by adiabatic expansion, causing saturation conditions and fog. The radiation fog gets dissipated after sunrise when the day warms up. Studies on fog in India indicate much concern and interest on this subject (Basu, 1957; Natrajan and Banerji, 1959; Kundu, 1957; Tenpe, 1967; Gupta, 1987; Tulsidas and Mohapatra, 1998; Sreenivasaiah, 1944; Elsworth, 1945; George, 1948; Chakravortty, 1948; Rangarajan, 1952). Recent studies on fog in India over aerodromes during last decade have highlighted considerable socio-economic concern due to alarming increase in fog and pollution and persistence of fog during winter over Indo-Gangetic plains (Jenamani, 2007; Suresh *et al*., 2007; Bhowmik *et al*., 2004; Singh *et al*., 2006; Singh *et al*., 2007; Suresh and Mohapatra, 2008; Singh, 2011).

Favourable conditions for radiation fog formation are (*i*) clear or light clouded sky, (*ii*) calm or light surface wind and (*iii*) air with initially high dew point temperature. Visibility parameter is an indirect indicator of fog and fog occurs whenever visibility drops to less than 1000 m over Indian Subcontinent (0° N - 35° N and 60° E-100° E). In this study synoptic hour daily surface data for the period 1971-2000 are utilized for studying spatial variability of fog days having visibility less than 1000 m at 0300 UTC. Analysis of fog events based on half hourly Meteorological Report (METAR) observations at selected ICAO stations of India is also presented.

2. Data and methodology

The present study utilizes quality checked synoptic hour daily surface data of meteorological parameter visibility for 507 surface observatories over India obtained from National Data Centre (NDC), India Meteorological Department (IMD), Pune for the period 1971-2010. Events with occurrence in visibility less than 1000 m were selected and average fog days was computed for the winter months (December-February) for the period 1971-2010. The analysis of spatial variability of fog days is given in section 3.

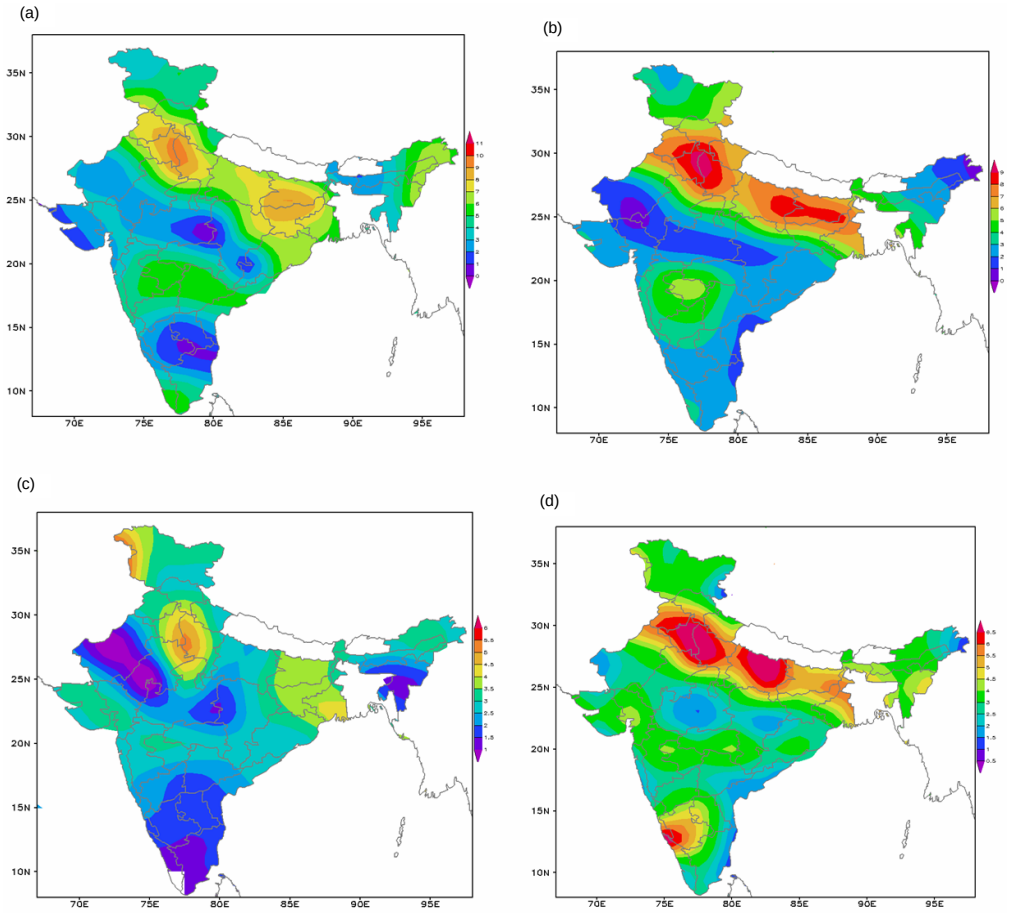
Half hourly METAR observations at selected ICAO stations of India were used to derive monthly half hourly averages of air temperature, dew point temperature, and dew point depression, and visibility, zonal and meridional components of wind. These averages are presented and analyzed to find initial conditions during occurrence of fog.

3. Results and discussion

The spatial variability of average number of days with fog (having horizontal visibility less than 1000 m) is presented here. Month-wise (December, January and February) and seasonal patterns of spatial variability are studied.

3.1. *December*

Average number of fog days is noted over the Gangetic plain of North India covering meteorological sub-divisions of Punjab, Haryana and West Uttar Pradesh show average number of fog days in the range 7 to 10 days [Fig. 1(a)]. It is found that parts of Bihar, Jharkhand and adjoining Gangetic West Bengal have on average 5 to 9 days of occurrence of fog. Areas covering Meghalaya and Assam show variation of 2 to 3 days. Prominence of fog is seen over rest of India on average 4 days while peninsular India, comprising parts of South Interior



Figs. 1(a-d). Average number of days with fog having visibility < 1000 m for the period 1971-2000 (a) December, (b) January, (c) February and (d) Season

Karnataka, Telangana and Tamil Nadu, is covered with fog on an average of 2 days. It can be attributed to passage of western disturbances over northern latitude of India and movement of low pressure waves westwards over peninsular India.

3.2. *January*

It is noted from Fig. 1(b) that the Indo-Gangetic plains show variation of number of fog days in the range of 5 to more than 8 days, whereas the state of Maharashtra with adjoining meteorological subdivisions *viz*., North Interior Karnataka and Rayalaseema show incidence of fog on average 4 days. Peninsular India shows incidence of fog days on an average of 3 days with visibility less than 1000 m.

3.3. *February*

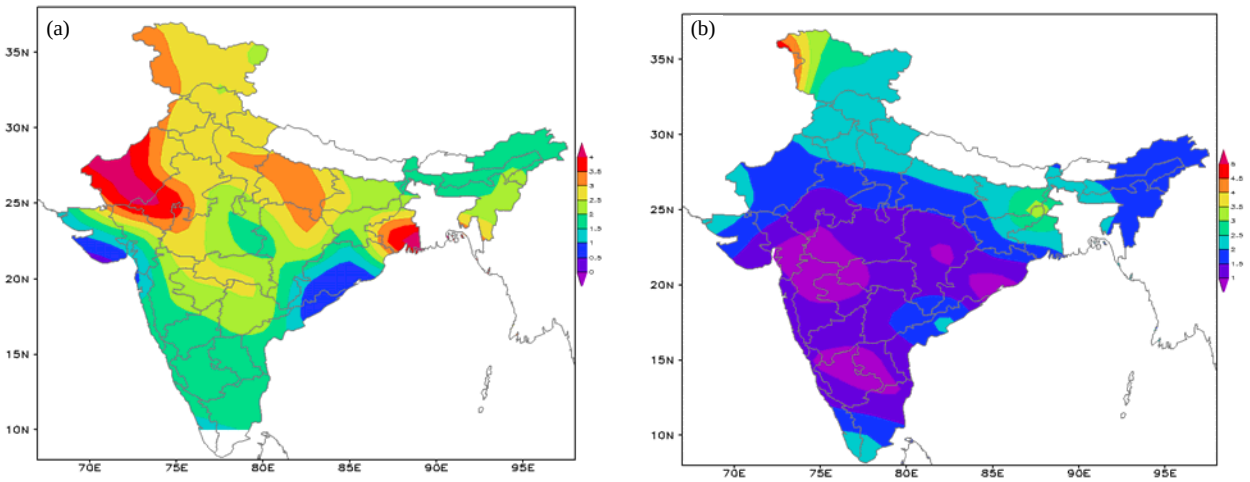
February month shows maximum number of fog days over Indo-Gangetic plains. Fig. 1(c) shows that the area covering Haryana, West Uttar Pradesh and adjoining part of Rajasthan have 4 to 5.5 days of average number of fog. The south Gangetic West Bengal is susceptible to fog on an average 4 days. It is observed that states of Meghalaya, Tripura, Manipur, Nagaland and areas of Rajasthan and peninsular India is having fog on average of 1 to 2 days during this month.

3.4. *Winter Season (December-February)*

From Fig. 1(d), it is clear that the Indo-Gangetic plains are more susceptible to fog incidence. On the average fog occurs for 4.5 to 6.5 days over the areas of South Interior Karnataka, Coastal Karnataka indicating presence of fog.

(*i*) *Seasonal susceptibility of dense fog*

Dense fog is localized phenomenon where during day light observations objects are not visible at 50 meters and at 100 meters during night observations due to suspension of water droplets in the air. Average number of days with dense fog is presented in Fig. 2(a). Fig. 2(a)



Figs. 2(a&b). Average number of days with (a) dense fog having visibility code 90 (During day observations, objects not visible at 50 m and at 100 m during night observations (b) thick fog having visibility code 91 (During day observations, objects visible at 50 m but not at 200 m and at 330 m during night observations

shows that the North India is susceptible to dense fog on average number of 2.5 days. The meteorological subdivisions, *viz*., West Rajasthan and adjoining parts of east Rajasthan, East Uttar Pradesh and Gangetic West Bengal are also susceptible to dense fog on average number of 3.5 days.

(*ii*) *Seasonal susceptibility of thick fog*

Thick fog is localized phenomenon where during day light observations objects are visible at 50 meters but not at 200 meters and at 330 meters during night observations due to suspension of water droplets in the air. Fig. 2(b) presents the pattern of thick fog incidence over India. It is noticed that thick fog is on average number of 3 days over North India covering and extending towards east, covering the region of Gangetic West Bengal. The central parts of India and south peninsula and northeast India have on a average 2 days of occurrence of thick fog. However, thick fog does not occur over parts comprising adjoining areas of Madhya Pradesh, Madhya Maharashtra, Vidharba, Marathwada and adjoining east Gujarat and areas of South Interior Karnataka and adjoining Telangana.

3.5. *Relationship of fog and meteorological parameters*

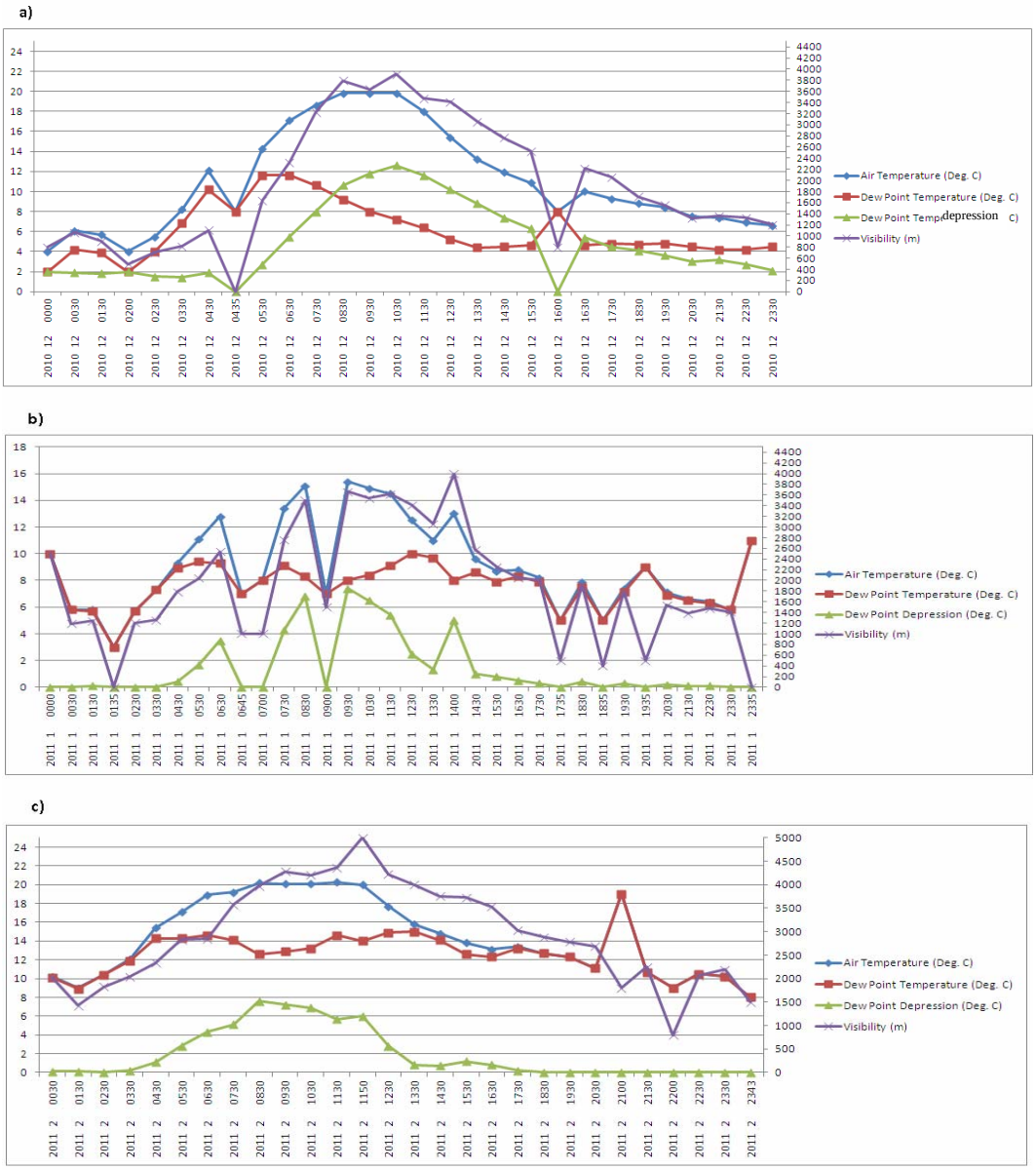
Fog has been analyzed in relation to different meteorological parameters using half hourly METAR observations at selected International Civil Aviation Organization (ICAO) station Amritsar of India. Month-wise analysis of fog events for other ICAO stations namely Ahmedabad, New Delhi, Kolkata, Guwahati has also been broadly summarized. In this context analysis of time series of different meteorological parameters such as dew point temperature, dew point depression and zonal and meridional components of wind is presented.

(*i*) *Amritsar*

Time series of air temperature, dew point temperature, dew point depression, and visibility at station Amritsar during December 2010 is depicted in Fig. 3(a). It is seen that visibility is below 1000 m from 0000 UTC reducing sharply to 0 m at 0435 UTC. The corresponding dew point temperature is less than 10 °C for this period and dew point depression not crossing 2 °C for this period. Time series of winds as depicted in Fig. 4 indicate westerly to northwesterly winds with magnitude 1.5 m/s during this period. Visibility has dropped to less than 1000 m at 1600 UTC when sharp decrease in dew point depression is noticed. During January 2011, there is shift in pattern where we observe sharp decrease in visibility at 0135 UTC. Time series in Fig. 3(b) suggests a sharp fall in dew point depression from 1430 UTC up to 2335 UTC and during early morning hours up to 0430 UTC. However dew point temperature is below 10 °C during this month. Zonal and meridional components of winds during above period indicate light westerly winds with magnitude up to 1.0 m/s. The temporal pattern of visibility during February 2011 as depicted in Fig. 3(c) shows that visibility is reduced to less than 1000 m indicating light westerly winds during that time.

Month-wise analysis of fog events for other ICAO stations namely Ahmedabad, New Delhi, Kolkata, Guwahati is given below.

During December 2010, over station Ahmedabad winds are light (magnitude 2.0 m/s) and southeasterly at



Figs. 3(a-c). Time series of air temperature (ºC), dew point temperature (ºC), dew point depression (ºC) and visibility (m) at ICAO station Amritsar (VIAR) during (a) December 2010, (b) January 2011 and (c) February 2011

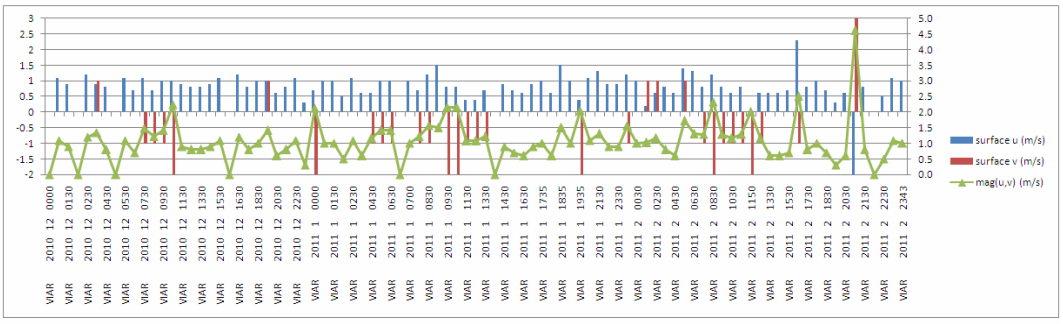
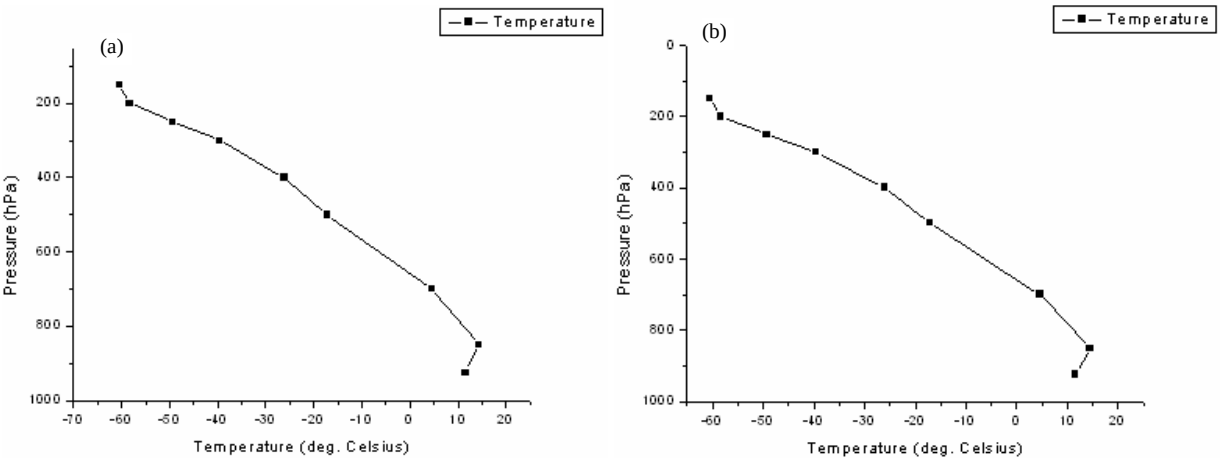
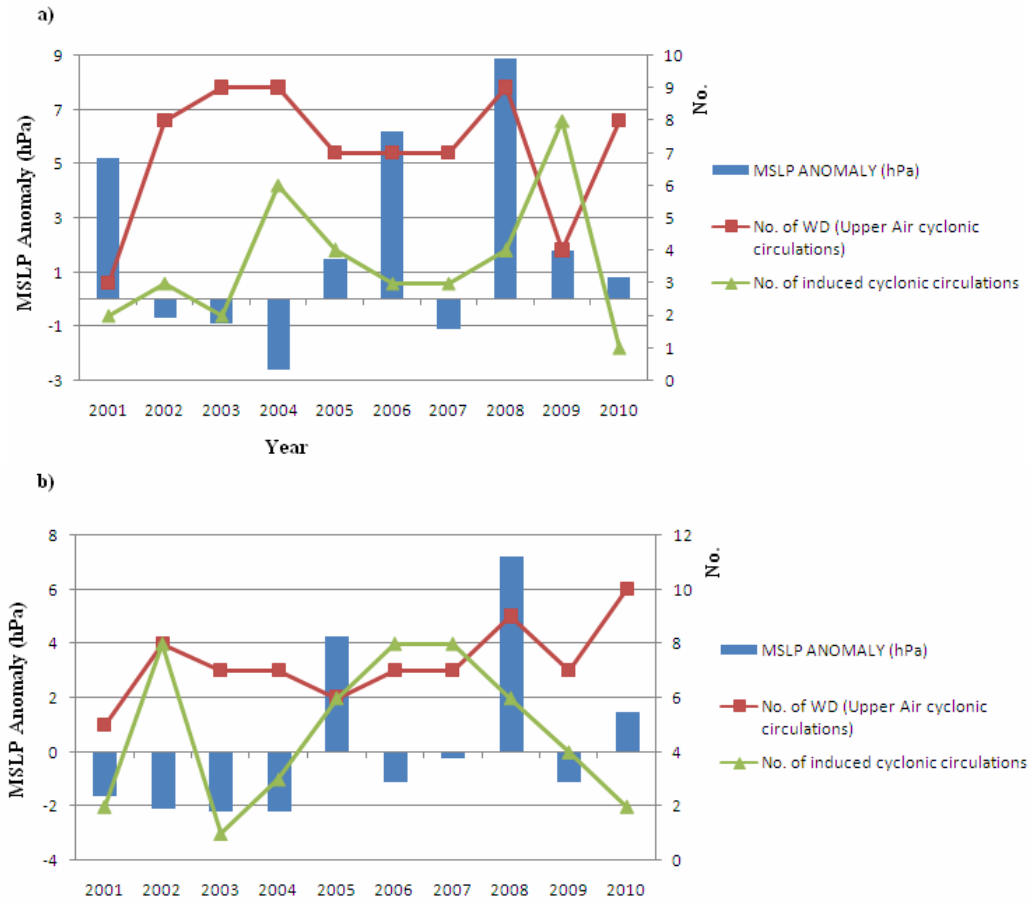


Fig. 4. Time series of zonal and meridional components of wind and its magnitude at ICAO station Amritsar (VIAR) during December 2010, January and February 2011



Figs. 5(a&b). Upper air temperature profile of station Patiala (a) 17 January, 2011 and (b) 25 February, 2011



Figs. 6(a&b). Number of western disturbances and induced systems affecting India and MSLP anomaly over Caspian Sea (region bounded by Lat. 41° N/Long. 50° E- Lat. 45° N /Long. 60° E) during last decade (a) January and (b) February

early morning hours favoring drop in visibility and occurrence of fog under stable boundary layer with temperature inversion above the ground surface. In these events the observed dew point temperature is 13 ºC and

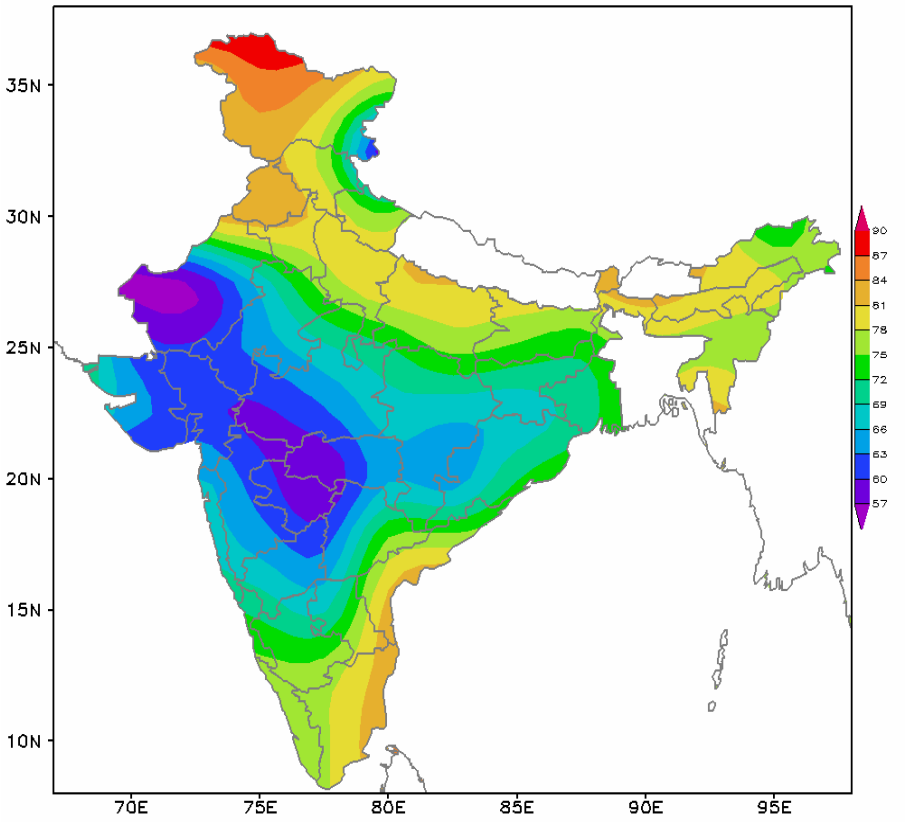


Fig. 7. Spatial variability of relative humidity (%) at 0300 UTC during winter season (December-February) for the period 1971-2010

dew point depression is 3 ºC. For station New Delhi, visibility drops in the range 400 m to 600 m from 0000 UTC up to 2330 UTC. Corresponding observed dew point depression is below 3 ºC and observed winds are northeasterly light winds with magnitude 1.0 m/s increasing 2.0 m/s. In case of Kolkata, visibility is not reduced below 1000 m even though observed dew point depression is below 3 ºC during early morning and late night hours. Winds are light westerly with magnitude 2.5 m/s and dew point depression is below 14 ºC. For station Guwahati, there is sharp fall in visibility (200 m) at 0305 UTC with 2.5 m/s westerly light winds.

During January 2011, over Ahmedabad, visibility is reduced to less than 1000 m at 0330 UTC under influence of 3.0 m/s southeasterly light winds. In case of New Delhi, observed dew point depression is below 9 ºC and light northerly winds with magnitude 1.0 m/s during early morning hours and light northwesterly winds during evening hours (1730 UTC onwards). For station Kolkata, visibility is reduced to 1000 m from 0120 UTC to 0220 UTC when dew point temperature is below 12 ºC and dew point depression is below 3 ºC and surface winds are westerly to southwesterly light winds with magnitude 2.0 m/s. For Guwahati visibility varies between 920 m at 0100 UTC to 400 m at 0305 UTC during early morning hours and observed dew point temperature is below 14 ºC and dew point depression is 0 ºC. It may be due to occurrence of cold air advection.

In February 2011, it is noticed for Ahmedabad that visibility does not drop below 1000 m. For station New Delhi, it is observed that visibility reduced to below 1000 m from 0000 UTC up to 0451 UTC and again reaches 1000 m at 2330 UTC when observed dew point depression reduces to below 4 ºC under influence of 2.0 m/s light northeasterly winds and observed dew point temperature 12 ºC. For Kolkata sharp fall in visibility is noticed around 2100 UTC when dew point depression is 1ºC under influence of light northeasterly winds (magnitude 1.0 m/s) and observed average dew point temperature below 17 ºC.

To investigate if low level inversion is formed during calm winter nights during fog, upper air temperature profile of different ICAO stations was studied. The data of upper air temperature profile for Amritsar during January 2011 and February 2011 was not available. Therefore,

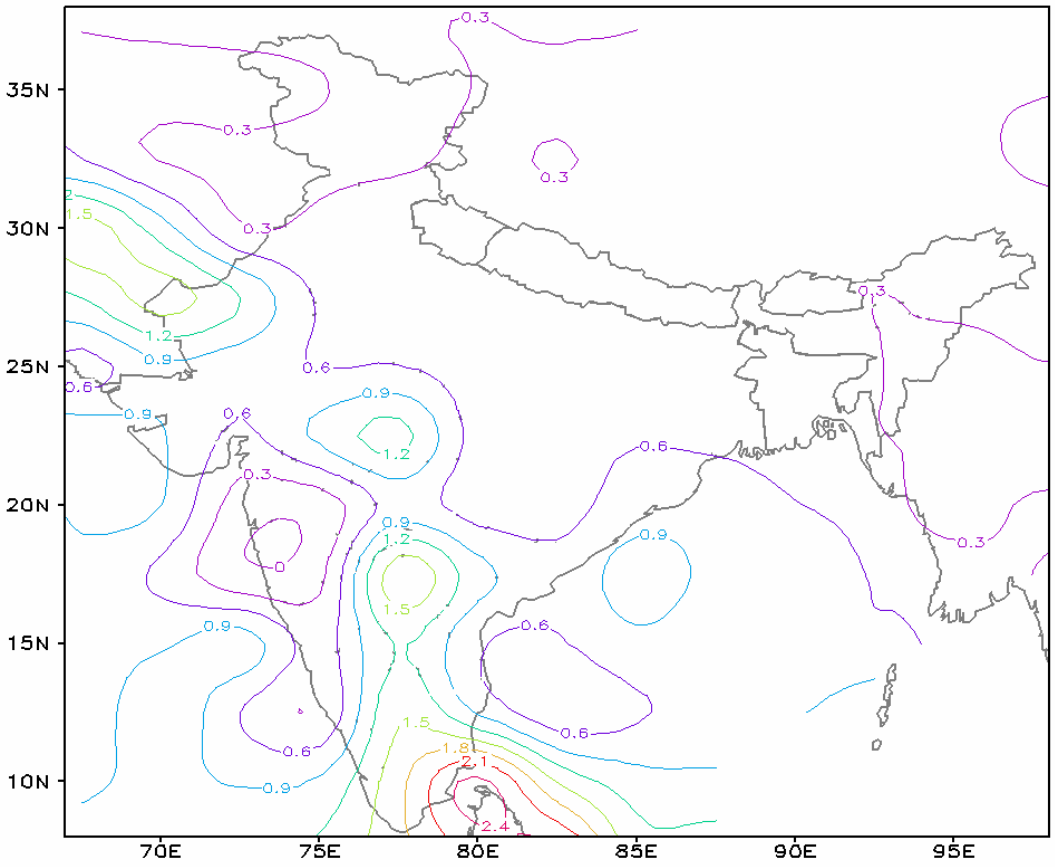


Fig. 8. Spatial variability of average wind speed (m/s) having visibility conditions less than 1000 m for the period 1971-2010 during winter season at 0300 UTC

upper air temperature profile data for station Patiala which is having a real distance of 206 km from Amritsar was considered for two dates 17 January, 2011 and 25 February, 2011 at 0200 UTC when visibility reduced to less than 1000 m for Amritsar as depicted in Figs. 5(a&b). It is observed that low level inversions are commonly formed during calm winter nights as a result of radiative cooling of the surface. In the presence of low winds turbulence carries heat aloft and limits surface cooling. However in the presence of inversion vertical motion occurring is less which impedes turbulence and allows cooling of surface layer thereby strengthening inversion and fog formation. This inversion may sometimes trap air near surface and allow pollutants to build up. On such occasions a stable boundary layer is formed. This was observed for different ICAO stations suggesting a temp increase with altitude in a stable boundary layer.

3.6. *Spatial variability of relative humidity*

Fig. 7 depicts the spatial variability of relative humidity at 0300 UTC during winter season (December-February) for the period 1971-2010. It is seen that over the Indo-Gangetic plain relative humidity in the range 72% to 84% prevails at 0300 UTC. Jammu and Kashmir has relative humidity above 84%. Other areas have R.H. less than 70% and the lowest R.H. is over part of West Rajasthan.

3.7. Spatial variability of average wind speed (m/s)

Fig. 8 depicts the spatial variability of average wind speed (m/s) at 0300 UTC under visibility conditions less than 1000 m for the period during winter season. It is seen that the average wind speed varies in the range 0.3 m/s-2.1 m/s over the Indian subcontinent. Significantly the Indo-Gangetic plain shows very low average wind speed of 0.6 m/s. Parts of Jammu and Kashmir have average wind speed less than 0.3 m/s. For other regions, the wind speed varies between 0.9 m/s and 2.1 m/s.

3.8. *Spatial variability of air temperature (°C)*

Fig. 9 presents spatial variability of air temperature at 0300 UTC having visibility conditions less than 1000 m for the period 1971-2010 during winter season. It is

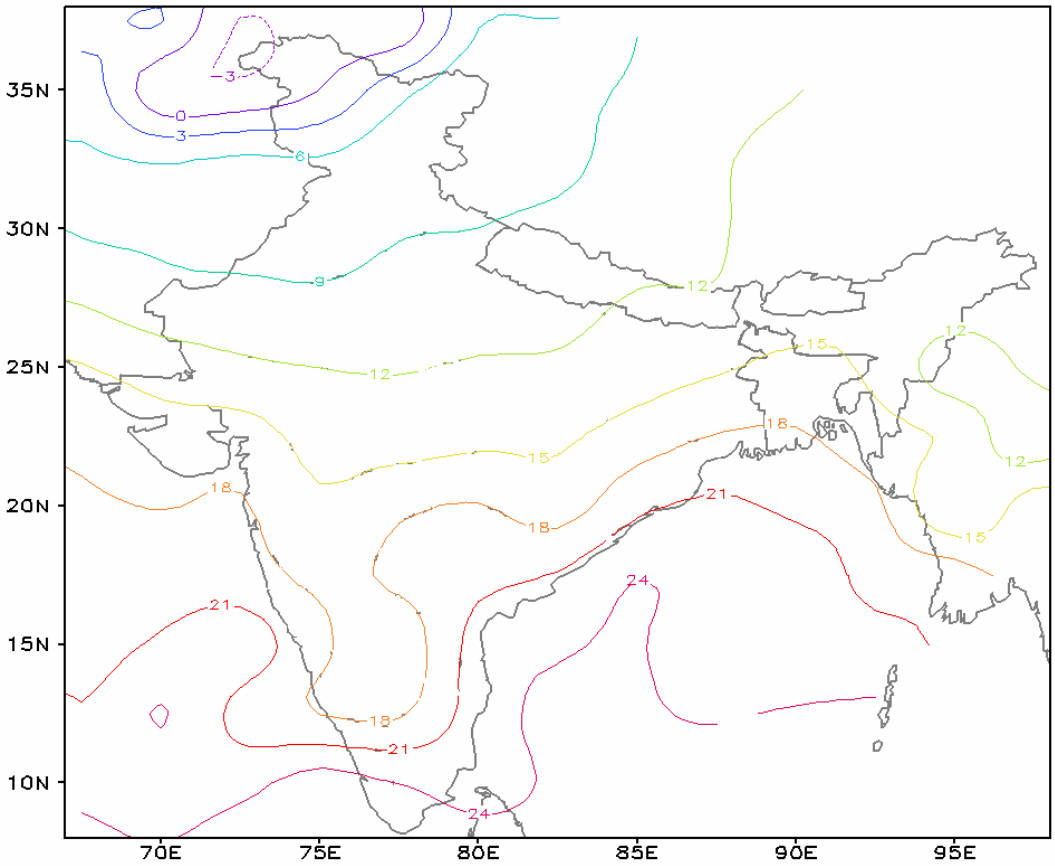


Fig. 9. Spatial variability of air temperature (°C) having visibility conditions less than 1000 m for the period 1971-2010 during winter season at 0300 UTC

significantly observed that air temperature increases gradually from north to south. It is less than 6 °C over east Jammu and Kashmir and greater than 21 °C over tip of peninsular India. Over Indo-Gangetic plains air temperature varies in the range 9 °C to 15 °C. Over Central India it varies from 12 °C to 15 °C.

3.9. *Behaviour of induced systems and western disturbances in decade*

Figs. 6(a&b) represents the relation between the number of western disturbances and induced systems affecting India and MSLP anomaly over Caspian Sea and Aral Sea for January and February in the decade 2001-2010. It is seen that number of western disturbances and number of induced systems show a positive correlation during January and February of the last decade with exception that of January 2009 and February 2003 where MSLP positive anomaly is seen during January 2009 with reduced number of western disturbances and increased western disturbances during February 2003 with negative MSLP anomaly. This is due to presence of Col conditions in wind field at 850 hPa and 700 hPa over northern region of India.

4. Conclusions

Broadly following conclusions can be inferred from this study.

(*i*) The inter-seasonal spatial variability of average number of days with fog having visibility less than 1000 m indicates presence of fog over Indo-Gangetic plain on an average of 7 to 10 days during December, in the range of 5 to more than 8 days during January. During February South Gangetic West Bengal is susceptible to fog. Seasonal variation of fog shows that there is prominence of fog over Indo-Gangetic plain on an average of more than 6.5 days. Significantly South Interior Karnataka and Coastal Karnataka has incidence of foggy days on an average of 6.5 days.

(*ii*) North India is susceptible to dense fog on average of 2.5 days during the season while Gangetic West Bengal,

West Rajasthan and adjoining parts of east Rajasthan and East Uttar Pradesh has occurrence of fog on an average 3.5 days. Thick fog occurs on an average 3 days over north India during the season.

(*iii*) Analysis of time series of air temperature, dew point temperature, dew point depression, visibility, zonal and meridional components of wind and its magnitude at selected ICAO stations indicate that visibility reduces to below 1000 m when light winds are southeasterly at Ahmedabad, northerly to northwesterly at Amritsar, northerly to northeasterly at New Delhi, westerly to southwesterly at Kolkata and Guwahati and dew point depression is below 3 °C during such conditions.

(*iv*) Long period 1971-2010 analysis of visibility conditions less than 1000 m over Indian subcontinent shows Indo-Gangetic plains region to have average wind speed to be 0.6 m/s, air temperature at 0300 UTC in the range 9 °C to 15 °C during December-February at 0300 UTC.

(*v*) Long period 1971-2010 analysis of relative humidity shows Indo-Gangetic plains region to have relative humidity in the range 72% to 84% at 0300 UTC during December-February.

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