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On the persistence of fog over northern parts of India

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सार – शीतकाल में दिसंबर के अंत और जनवरी के आरंभ के दौरान की अवधि में, लगभग पंद्रह दिनों का एक ऐसा दौर आता है जब भारत के उत्तरी राज्यों के मैदानी भागों में हर वर्ष प्रायः नियमित रूप से कोहरा छाया रहता है। इस शोध–पत्र में लेखकों ने कोहरे के, विशेषकर इस क्षेत्र में निरंतर छाए रहने के कारणों का पता लगाने का प्रयास किया है। यहाँ इसका कारण बड़े पैमाने पर परिसंचरण माना गया है। यह डायग्नॉस इसे पूर्वानुमान का माध्यम बनाने के लिए है और वी.आई.एस. और जलवाष्प धाराओं तथा व्यूत्पन्न पवनों के उपग्रह से प्रेक्षित मेघ चित्रों के आधार पर यह अध्ययन किया गया है।

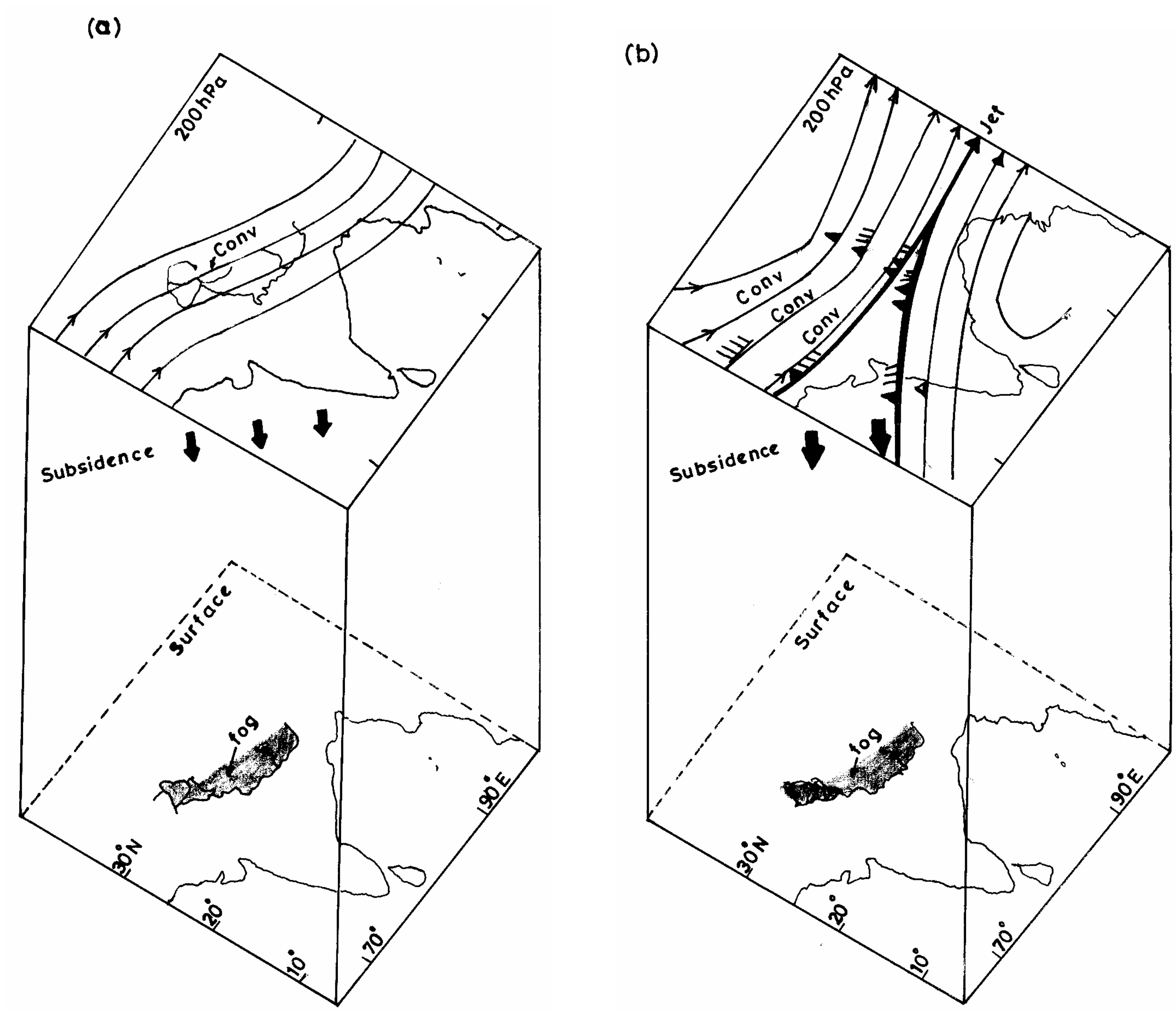
ABSTRACT. In winter there is a spell of about a fortnight, during end of December and beginning of January when persistent fog over plains of northern states of India occurs every year almost regularly . In this paper authors have tried to find the reasons of persistence of this fog particularly over this area. The reason envisaged here is in the large scale circulation . This diagnosis is for making it a forecasting tool and the study is based on satellite observed cloud imagery received in the VIS and water vapour channels and the derived winds.

Key words – Persistent, Widespread fog, Jet axis, Synoptic situation; Trough, Ridge, Divergence, Convergence, Vorticity, Cyclonic shears, Cloud imagery.

1. Introduction

Widespread fog formation in the forenoon over northern states, of India namely Punjab, Haryana, Uttar Pradesh and Bihar is nearly periodic each year during last week of December and first week of January since 1997. Such occurrences of persistent widespread fog since 1997 are rare events during past decades. The size of fog area and its persistence over a fortnight attract the attention of weather forecaster, particularly aviation forecaster. Fog area can be watched daily in INSAT VIS cloud imagery received between 0300 & 0600 UTC. Authors in this study have attempted to find why the fog persists so long. In other words, what kind of synoptic situation in the circulation pattern gives rise to persistence of fog. It was taken for granted that all other conditions for fog formation were present during short duration fog (of one or two days) and during (persistent) fog of a fortnight. It was noted that the circulation pattern change in the upper air was responsible for fog persistence. Firstly, in the upper (near 200 hPa) air circulation, arrival of baroclinic wave in westerlies with trough axis along about 90° E Long. and ridge with axis along about 65° E Long. (laterally covering above mentioned states) was seen to be a feature responsible for formation of persistent (in time) fog. Second type of upper air flow pattern which overlies fog region was that the upper horizontal cyclonic shears in the wave shaped system created the upper level convergence in its left entrance sector. Either (or both together) of the synoptic situations provided lower level divergence for fog formation. The horizontal cyclonic shears were present to the north of jet axis running to the south of fog covered states. The jet winds were created either by the confluence of extra tropical westerly flow (having invariably trough along 80° E with N-S winds on its west flank and westerly winds to the north of subtropical high over Bay of Bengal or by the increase in temperature gradients . These two pattern are shown schematically in Fig. 1.

Many studies have been made on fog formation. Basu (1952) and Basu (1957) , Natrajan & Banerji (1959), Kundu (1957), Tenpe (1967) , Gupta (1987), Tulsidas & Mohapatra (1998) and other have worked on local fog formation mostly over aerodromes. They were of the opinion that fog formation takes place in association with



Figs. 1(a&b). Schematic view of methodology given in para 2. Shaded area (on surface) shows fog. Streamlines show trough axis near 95° E Long. and ridge axis along 65° E at 200 hPa level in Fig. (a) and upper cyclonic wind shears in association with jet in Fig. (b)

western disturbance having some circulation characteristics close to surface. Presence of a feature such as anticyclone over the adjoining sea have been found useful in supply of necessary moisture. Some other authors, Brown and Roach (1976), Brown (1980), Zdunkowski and Nielsen (1969), Fisher and Caplam (1963), Roach *et al.* (1976) have worked on prediction of fog numerically taking into account the physical processes responsible for radiational cooling and condensation of fog droplets. Taylor (1917) gave the general conditions of humidity and winds etc which are known and used as thumb rules for fog formation.

During the occurrences of fog taken up here, it was observed that the duration was abnormally high, minimum temperatures were appreciably above normal and maximum temperatures appreciably below normal. This resulted in abnormal and unbearable cold conditions throughout north India. Occurrence of this phenomenon forced India Met. Department to revise the criterion for cold wave conditions.

In this paper, authors have attempted to diagnose the synoptic situations responsible for the occurrence of persistent and widespread fog so that it could be utilized profitably for forecasting.

2. Methodology

As mentioned above, a fog spell of about fortnight during last week of December and following January occurs about every year over the northern states of India namely eastern parts of Punjab, northeast Pakistan, north parts of Rajasthan, Haryana, Uttar Pradesh adjoining plains of Madhya Pradesh and northern parts of Bihar. In this study authors analysed the fog situation during four winter seasons *i.e*. 26 December 1999 - 09 January 2000, 30 December 2000 - 06 January 2001, 24 December 2001-05 January 2002 and 26 December 2002 - 25 January 2003. The first three cases of fog given here had mostly the configuration shown in the Fig. 1 (a). In the fourth case [Fig. 1 (b)], on several days, the upper air cyclonic horizontal shears created lower layer divergence. This means that in the first type of synoptic situation (*i.e*. ridge – trough couplet) the portion of the upper level wave which provided convergence in the upper air covered fog areas of Punjab, Haryana, Uttar Pradesh and Bihar. It is also seen that such waves remained quasi stationary during the fog period. This stationarity is mainly due to large scale circulation features *i.e*. cut off lows in middle latitudes. The upper convergence affected lower level subsidence and consequently helped formation of inversion layer in the lower atmosphere. This inversion helped formation of fog and inhibited any ascending motion higher to inversion layer and prevented development of any cloud. During end of December and beginning of January, the lower layer of air in contact with the ground is cooler, perhaps coolest, and if aided by the above mentioned persistent inversion, can produce persistent fog. It is in fact seen that fog over the northern states of India existed with lower layer inversions supported by the upper air convergence. The required amount of moisture is present in the lower atmosphere due to evapotranspiration from the green fields, evaporation from rivers, dams, lakes and water irrigated fields. Advection of water vapour from the equatorial area in the higher atmosphere [as seen in the water vapour imagery, Fig. 5 (b)] also brings moisture. This upper layer moisture will also reach the lower levels of the atmosphere by the subsidence in the forward part of the upper level ridge. So all these factors were responsible for gathering the required amount of moisture in the fog layer. Higher than surrounding temperature at the inversion level will quantitatively justify this suggestion.

Second type of synoptic situation was the cyclonic shears of upper air wave–shaped flow pattern, having trough around 80° E longitude and ridges on either side, with its convergence - providing-sector *i.e*. left entrance overlying fog region [Fig. 1(b), Fig. 5(c)]. which in turn provided lower level divergence helping to form fog in the atmospheric layer close to surface. The horizontal cyclonic shears were created to the north by the wave shaped jet axis, running just to the south of Gangetic plains. The jet and strong winds were created either by the confluence of westerly flow of extra tropics and of westerly winds to the north of subtropical high, which shifts or spreads over land northward of Bay of Bengal or by any other effect responsible for bringing the subtropical jet axis to run just south of fog region.

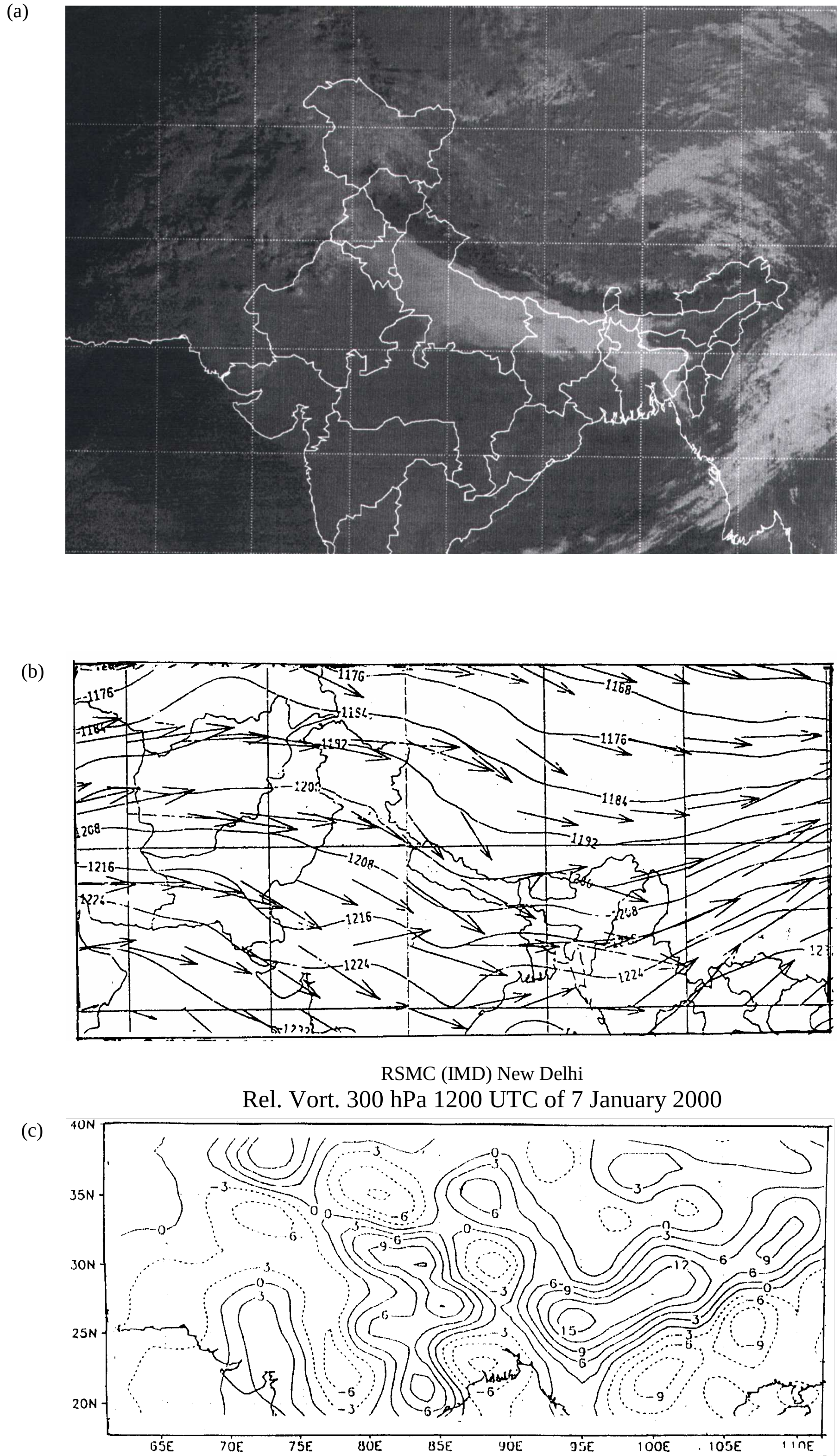
3. Data and analysis

Cloud Motion Vectors (CMVs) as available on Internet from Co-operative Institute for Meteorological Satellite Studies(CIMSS), were utilized for seeing the upper air ridge and trough pattern over the northern parts of India. Water vapour in the middle and the upper layer was inferred from the water vapour imageries received from the METEOSAT-5. The upper wind analyses made at IMD and at NCMRWF New Delhi were also utilized for seeing the upper air circulation. The isotherm and contour analyses of the required layer were also viewed in the charts prepared at NHAC, IMD, New Delhi.

In the following paragraphs, fog extension, position of upper air ridge and trough in the large scale circulation have been described for the periods: 26 December 1999 - 09 January 2000, 30 December 2000-06 January 2001, 24 December 2001 - 05 January 2002 and 26 December 2002 - 25 January 2003.

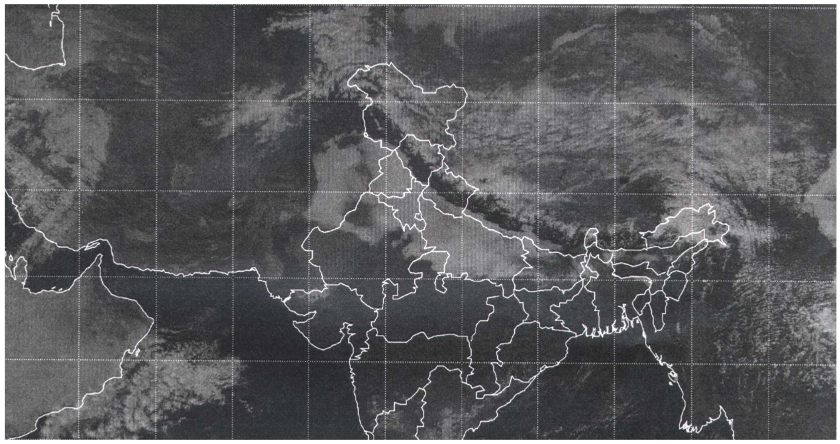
3.1. *Fog spell from 26 December, 1999 – 09 January, 2000*

From INSAT VIS cloud imagery it can be seen that widespread fog started forming over southeast parts of Uttar Pradesh on 26 December 1999 (*ref* 0600 UTC INSAT VIS cloud imagery). There was no fog over the concerned northern states of India before 26 December. By 28 December east Haryana, northwest and east parts of Uttar Pradesh and northeast parts of Bihar were also covered by the fog (0500 UTC INSAT visible cloud imagery). Fog areas and locations of upper air ridge and trough have been given date wise in Table 1. In fact Fig. 2(a) shows fog cover (in milky white shade) on 7 January, 2000 as seen in INSAT-1D VIS cloud imagery. Position of ridge and trough at 200 hPa level and wind vectors (length of arrow proportional to wind speed) of the same day can be seen in Fig. 2(b). Relative vorticity pattern (in lieu of divergence pattern which could be obtained only for the fourth spell of fog), is shown in Fig. 2(c). Regions of positive vorticity (full lines) or weak negative vorticity (dashed lines) are the regions where upper level convergence produced subsidence down to create persistent inversion above fog layer. Relative vorticity of the order of –3 to 9×10^{-5} /sec are covering fog area in Fig. 2 (c). More than half area is under positive vorticity & rest under with weaker negative vorticity.

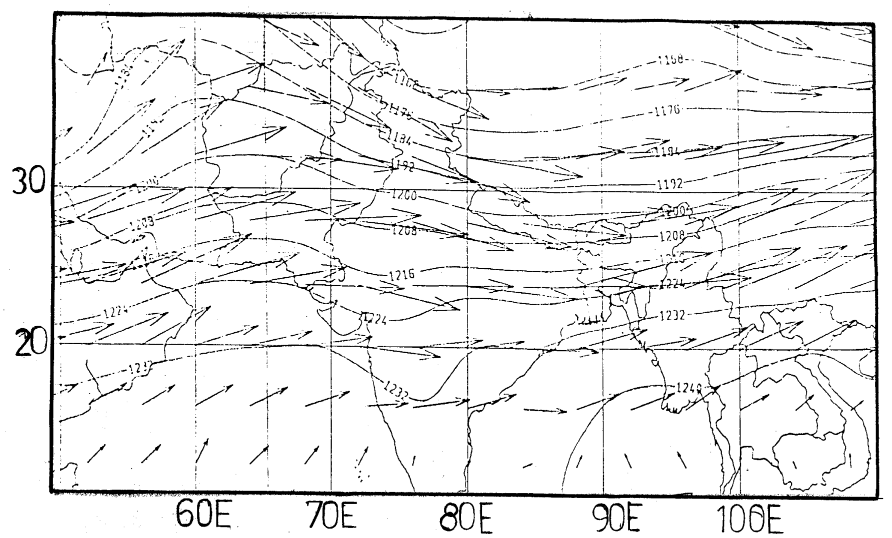


Figs. 2(a-c). (a) INSAT 1D cloud imagery (0600 UTC/7 January 2000) showing fog, (b) Thick lines are contours in gpm. Arrows are wind vectors. Ridge and trough are at 65° E and 85° E respectively on 7 January 2000 and (c) Positive (full line) or weak negative (dashed line) vorticity × 10/sec covering fog area of Fig. 2(a)

(a)



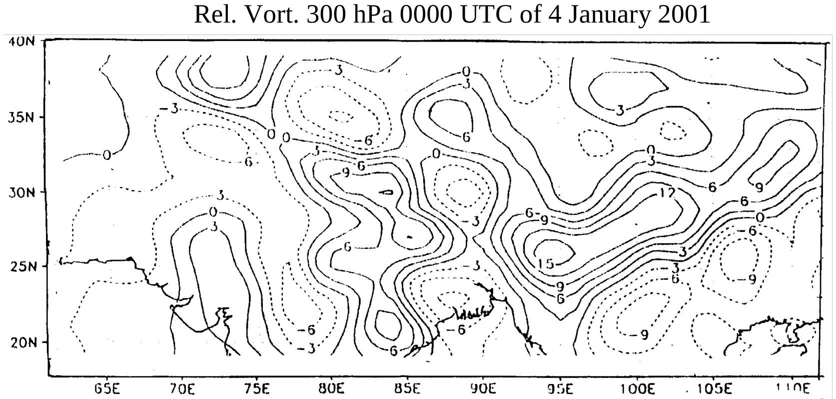
(b)



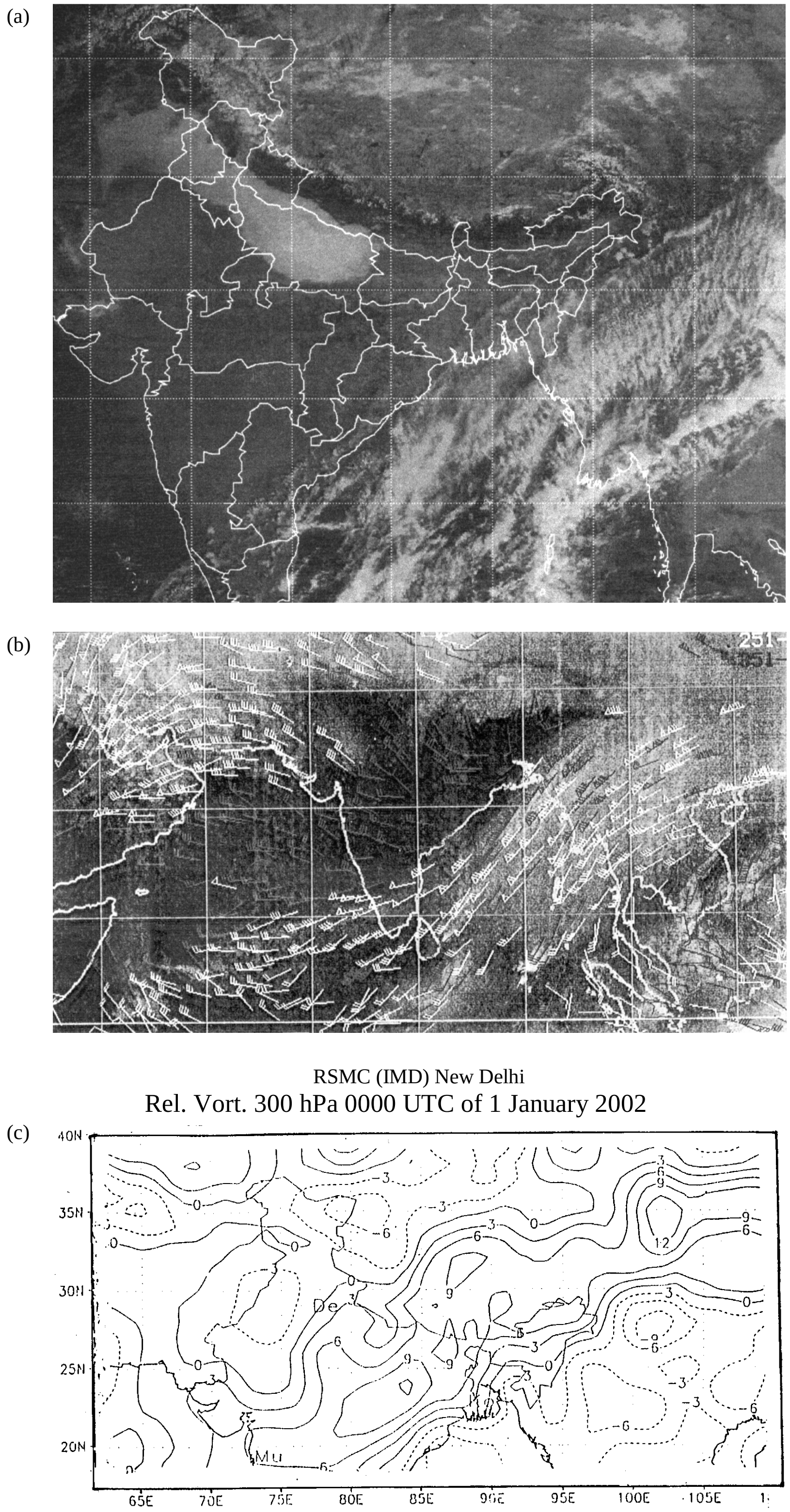
RSMC (IMD) New Delhi

Rel. Vort. 300 hPa 0000 UTC of 4 January 2001

(c)



Figc. 3(a-c). (a) INSAT 1D cloud imagery (0600 UTC/4 January 2001) showing fog, (b) Thick lines are contours in gpm. Arrows are wind vectors. Ridge and trough are at 65° E and 85° E respectively on 4 January 2001 and (c) Positive (full line) or weak negative (dashed line) vorticity $\times 10^{-5}$/sec covering fog area of Fig. 3(a)



Figs. 4(a-c). (a) INSAT 1D cloud imagery (0600 UTC/1 January 2002) showing fog, (b) Wind vectors of mid & upper troposphere intercepted from CIMSS. Ridge & Trough area at 65° E and 85° E respectively on 1 January 2000 and (c) Positive (full lines) or weak negative vorticity (dashed line) $\times 10^{-5}$/sec covering fog area of Fig. 4(a)

From above it can be seen that whenever there was fog over northern states of India during morning hours, rear part of trough was overlying [Fig 2(b)]. This was in conformity with methodology given in para 2 above (Fig. 1).

3.2. *Fog spell from 2 - 6 January 2001*

Fig. 3(a) shows the fog cover in the INSAT VIS imagery at 0300 UTC of 4 January 2001. On the same day, position of upper atmospheric ridge and trough can be seen in Fig. 3(b) showing contour analysis and wind vectors. Length of vectors is proportional to wind speed. Fig. 3(c) displays the relative vorticity pattern at 200 hPa level. It can be seen that half fog region, of Fig. 3(a), is overlain by the positive vorticity of the order of 3×10^{-5}/sec area (full isolines) or weak negative vorticity (dashed isolines) of lower or same magnitude, which are associated with upper air convergence, which in turn provides subsidence downward.

This fog spell occurred mainly in association with type of flow shown in Fig. 1(a). The upper air ridge was located on the various days along meridian between 50° E to 70° E and trough was along meridian between 70° E to 95° E.

From 2 January to 4 January the fog covered northeast Pakistan, north Rajasthan, west Uttar Pradesh and Haryana. Fog remained from 2 January to 6 January.

3.3. *Fog spell from 28 December 2001 - 05 January 2002*

There was no fog over the northern states of India upto 27 December 2001. On 28 December widespread fog occurred over Punjab and Haryana and by 29 and 30 December it spread on either sides covering northeast Pakistan and northern parts of west Uttar Pradesh plains. By 31 December it extended to east Uttar Pradesh. On 1st and 2nd January the fog spread was similar to 31 December. On 3rd January fog was patchy as it covered only northeast Pakistan, west Punjab, northwest Uttar Pradesh plains and north Bihar. There was no fog 4 January onward. First half of this spell occurred in association with type of flow shown in Fig. 1(b). Where as the second half was associated with type of upper air flow shown in Fig. 1 (a) when the upper air ridge was seen along meridian between 60° E to 70° E and trough was seen along meridian between 80° E to 90° E.

The fog cover, location of upper air ridge & trough and the relative vorticity pattern on 1 January, 2002 are shown in Figs. 4 (a-c) respectively. Positive relative vorticity of magnitude 3×10^{-5} /sec is covering nearly entire fog area. It is obvious from Fig. 4(b) that on 1 January the upper air circulation had largely the features of type of flow shown in Fig. 1 (b).

During the spell fog covered many days northeast Pakistan, Punjab, Haryana, north Uttar Pradesh and north Bihar.

3.4. *Fog spell from 25 December, 02 – 25 January, 2003*

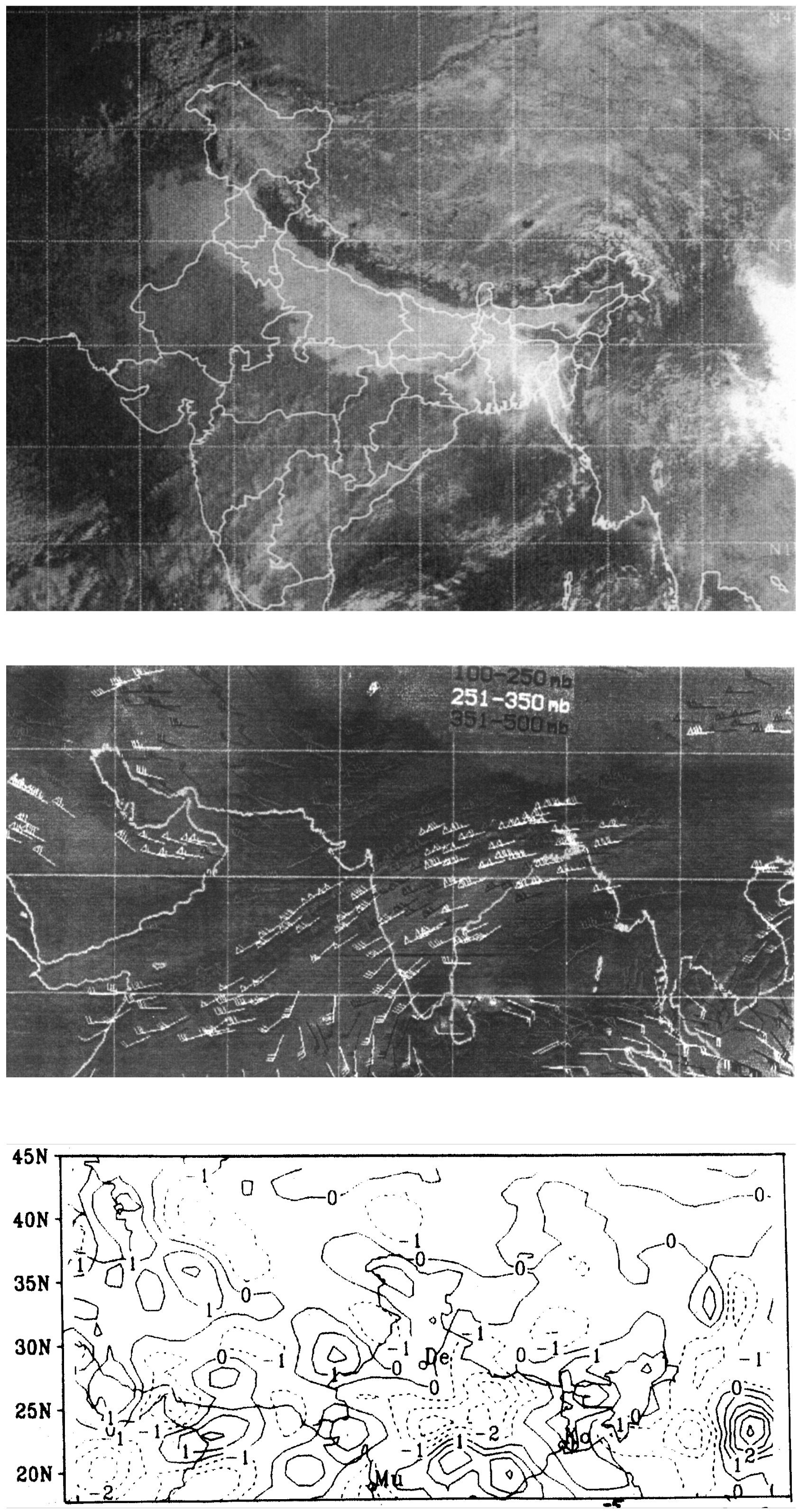
This was the longest fog spell studied here. Patchy fog had spread all over Uttar Pradesh , Bihar, north parts of Bengal and almost as a continuous sheet over west parts of Rajasthan on 25 December as seen in 25 December/0300 UTC VIS Metsat cloud imagery. Conditions were similar on 26 December and 27 December. On 28 December, practically no thick fog was seen over plains except just in the proximity of foothills of Western Himalayas. This fog had spread some hundred kilometer southwards on 29 December. On 30 December, widespread fog appeared over Uttar Pradesh & Bihar. But clouds prevailed on 31 December. Again patchy fog appeared on 1 January over Gangetic plains. So remained on 2 January 2003. But on 3 January it was again widespread over NW Pakistan, Punjab & Haryana. Although on 4 January it was widespread on west parts of Gangetic plains only ; on 5 January it had spread over entire Gangetic plains. This continued from 6 January to 9 January. On 10 January it was widespread over western parts of Gangetic plains but patchy over eastern parts. It was nearly similar on 11 January. By 12 January it covered entire Gangetic plains. And thus widespread fog continued from 12 to 21 January. On 22 January dense fog confined to north parts of Haryana but less dense remained on Punjab also. Fog diminished over Punjab by23 January and by 24 January fog confined to only northern parts of Gangetic plains. On 25 January, it confined to only eastern parts of Gangetic plains.

As seen in satellite imageries, there were two outstanding periods of widespread fog of this spell. One was from 4 to 9 January 2003 and other 12 to 21 January 2003. On 5 January 2003, the ridge and trough axes were around 65° E and 90° E respectively. From 6 to 9 January the fog region was under lying upper air region of horizontal cyclonic shears present in the north of wave shaped jet axis. On several occasions jet was formed by the confluence of extra tropical westerly flow and of westerly winds to the north of subtropical high over Bay of Bengal. A situation of this type present on 9 January can be seen in Fig. 5(b). The 200 hPa divergence field on 9 January given in Fig. 5(c) shows that the fog in Fig. 5 (a) on the day covered entire Gangetic plains as the region was overlain by upper air convergence.

(a)

(b)

(c)



Figs. 5(a-c). (a) METSAT-1 cloud imagery (0300 UTC/9 January 2003) showing fog, (b) Wind vectors of mid & upper troposphere intercepted from CIMSS and (c) Negative (dashed lines) shows convergence 10^{-5}/sec covering fog area of Fig. 5(a)

TABLE 1

Date/Time	Area covered by fog	Position of ridge & trough in upper air wave (°E) and 4-day forecast position in brackets ( )	
		Ridge	Trough
26 Dec 1999	Southeast Uttar Pradesh	60 (55)	80 (90)
27 Dec 1999	Southeast Uttar Pradesh	60 (65)	90 (90)
28 Dec 1999	East Haryana, east Uttar Pradesh & east Bihar	65 (70)	95 (90)
29 Dec 1999	Haryana, east parts of Uttar Pradesh & Bihar adjoining Jharkhand	65 (65)	100 (100)
30 Dec 1999	Northeast parts of east Uttar Pradesh, Bihar adjoining Jharkhand & SHWB	60 (60)	95 (95)
31 Dec 1999	Punjab, Haryana, Uttar Pradesh, Bihar adjoining Jharkhand & SHWB	60 (flat flow)	100
1 Jan 2000	Haryana, west Uttar Pradesh & Bihar	Upper cyclonic shears over the states in association with wave shaped jet	
2 Jan 2000	Haryana, Uttar Pradesh & Bihar	Upper cyclonic shears over the states in association with wave shaped jet 75	85
3 Jan 2000	Punjab, NE Rajasthan, Uttar Pradesh, Haryana, EC Pakistan, SHWB, Jharkhand & Bangladesh	75 (80)	85 (95)
4 Jan 2000	Punjab, Haryana, UP, Bihar, north Jharkhand SHWB, north Bangladesh	60 (65)	80 (95)
5 Jan 2000	EC Pakistan, Punjab, Haryana Uttar Pradesh, Bihar adjoining Jharkhand, SHWB & north Bangladesh	90 (70)	60 (95)
6 Jan 2000	NE Pakistan, Punjab, Haryana, Bihar, North Jharkhand, SHWB & North Bangladesh	65 (data not available)	83
7 Jan 2000	Haryana, Uttar Pradesh, Bihar, SHWB & north Bangladesh (ref Fig. 2.)	65 (data not available)	93
8 Jan 2000	North parts of Uttar Pradesh & west Bihar	65 (65)	95 (95)
9 Jan 2000	Low clouds	(flat flow)	

During the second period 12 to 21 January of widespread fog, the synoptic situations in the upper air were as follows. On 12 and 13 January the fog area had the same type of upper air flow as during 6 to 9 January. From 14 to 21 January the upper ridge and trough axes were around such (*i.e*. 65° E and 90° E) longitudes so that the fog area was overlain by the ahead part of upper trough. From 21 January onwards till end, the upper air ridge and trough were providing combined features of flow modeled in Figs. 1 (a&b).

During this spell, fog mostly covered northeast Pakistan, Punjab, north Rajasthan, Haryana, Uttar Pradesh, Bihar, Sub Himalayan West Bengal and north Bangladesh.

4. Forecasting of persistent widespread fog

These days forecasting of long waves in westerlies upto a week have been quite operational. At NCMRWF New Delhi a General Circulation Model is run to produce forecast positions of trough and ridge systems with other forecasts one to five days before. One such 4-day forecast of winds produced by NCMRWF during first spell of fog (*ref* para 3.1.) has been utilized (Table 1) here for locating positions of the ridge and trough. The 4-day forecast positions have been given in brackets ( ) in Table 1 against the day those are valid. It is seen that these forecast positions are matching the actual positions and hence also indicate possibility of persistent widespread fog over northern states of India during the particular spell. Fog actually occurred as seen in Fig. 2(a).

5. Discussion & conclusion

From the observations noted in para 3 above, it can be believed that widespread fog during the four spells over northern states persisted under the synoptic situation that could provide upper air convergence over the fog region during last week of December and next week or of January; either in association with a upper wave in westerlies with trough along about 90° E longitude and ridge near 65° E longitude thus creating subsidence from upper layer of atmosphere over fog area or in the presence of cyclonic shears to the north of subtropical wave (trough around 80° E longitude) shaped jet axis passing just to south of fog region. This is what was conjectured as theme of this study *i.e*. fog persists in the subsidence area under convergence region of the upper troposphere during winter climatological days of fog formation. Wide spread fog disappeared when either wave moved eastward such that the fog area fell under ahead of trough part of wave in the near 200 hPa flow, or when the upper cyclonic shears disappeared. It may be noted that widespread fog over northern states can persist only when upper air flow laterally covering fog area provided upper level convergence over fog area.

Acknowledgements

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