

An account of fog over Chennai

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सार – जलवायविक दृष्टि से (1951 से 1980 के आँकड़ों के आधार पर) चेन्नै हवाई अड्डे पर कोहरा छाने की आवृत्ति 4.3 दिनों की है। परन्तु पिछले दशक में वैमानिक मौसम वैज्ञानिक प्रचालन पूर्वानुमानकर्ताओं ने प्रायः कोहरे वाले दिनों की इससे अधिक संख्या रिकार्ड की है। अतः 1981–2002 (वर्ष 1984 को छोड़कर, जिसके आँकड़े उपलब्ध नहीं) के दौरान चेन्नै हवाई अड्डे के मौसम वैज्ञानिक कार्यालय ने वर्तमान मौसम प्रेक्षणों के आधार पर कोहरे वाले दिनों की आवृत्ति का विवेचनात्मक रूप से विप्लेषण किया है। इस अध्ययन में कोहरे के छाने की वार्षिक बारम्बारता में 21.5 दिनों की बढ़ोतरी देखी गई है। चेन्नै हवाई अड्डे पर कोहरे के छाने का सबसे अनुकूल समय जनवरी और उसके बाद फरवरी और मार्च देखा गया है। कोहरा प्रायः 0000–0200 यू. टी. सी. के दौरान छाता हुआ देखा गया है जबकि कई बार 2200–2400 यू. टी. सी. के दौरान अधिक संख्या में देखा गया है। कोहरा छाने की सबसे सामान्य अवधि 60–120 मिनटों तक की है। हालाँकि इस अवधि के 540–570 मिनटों से अधिक भी बढ़ जाने की संभावना है। 1990 के दौरान निम्न स्तर (धरातल) में रात के समय के प्रतिलोमन की आवृत्ति चिंताजनक रूप से बढ़ी है तथा 2000 से प्रतिलोमन लगभग दिन प्रतिदिन की घटना है। तीव्र गति से हो रहे शहरीकरण, यातायात वाहनों और औद्योगिक उन्नति वायुमंडलीय प्रदूषण में बढ़ोतरी का कारण हो सकते हैं जिससे रात्रि के समय स्थायित्व स्थितियों के साथ ही साथ कोहरे की बारम्बारता में वृद्धि हुई है। उनके मामलों में दृष्यता शून्य तक रिकार्ड की गई है और अनेक कारणों का विप्लेषण भी किया गया है। उच्च सापेक्षिक आर्द्रता और प्रदूषण के उच्च सांद्रण के साथ मिलकर 1200 यू. टी. सी. पर निष्प्रभावी अथवा पूर्णतया अस्थायी स्तरण के कारण कोहरा 2200 यू. टी. सी. और उसके बाद से छाना आरम्भ हो जाता है तथा 0000 यू. टी. सी. पर रात्रि के समय में होने वाले धरातलीय प्रतिलोमन समताप रेखा कोहरे को बनाए रखते हैं। यद्यपि एक बार जब कोहरा छा जाता है तो निम्न स्तरीय प्रतिलोमन कोहरे को बनाए रखता है फिर भी केवल प्रतिलोमन ही कोहरे के छाने की पर्याप्त वजह नहीं है।

ABSTRACT. Climatologically (based on 1951-1980) the annual fog frequency of Chennai airport is 4.3 days. But, the operational aviation meteorological forecasters often experienced more number of foggy days during the past decade. Hence the fog frequency has been critically analysed based on current weather observations made by aerodrome meteorological office, Chennai during 1981-2002 (barring 1984 for which data is not readily available). It has been found that the annual frequency based on the present study has shot up to 21.5 days. The most favourable period for fog over Chennai airport has been identified as January followed by February and March. The formation of fog has been mostly observed during 0000-0200 UTC although in good number of cases it was during 2200-2400 UTC. The most common duration of fog is 60-120 minutes albeit duration as high as 540-570 minutes are also probable. The low level (surface) nocturnal inversion frequency has alarmingly increased during 1990s and the inversion is almost a day-to-day phenomenon during 2000s. Rapid urbanisation, vehicular traffic and industrial growth could be the cause for the increased atmospheric pollution which has increased the nocturnal stability conditions as well the fog frequency. Visibility as low as zero had been recorded on a number of cases and their causes have been analysed. Neutral or absolutely unstable stratification at 1200 UTC coupled with high relative humidity and high concentration of pollution cause the fog to form from 2200 UTC onwards and the nocturnal surface inversion / isotherm at 0000 UTC maintains the fog. Though the low level inversion maintains the fog once it is formed already, inversion alone is not a sufficient condition for the formation of fog.

Key words – Low level inversion, Fog, Chennai airport, Pollution, Surface isotherm.

1. Introduction

In India, fog is considered as an important weather phenomenon during winter as it very badly affects the

transportation industry especially the aviation sector. In association with dense fog, the visibility is reduced to as low as 50 m and at times visibility drops to practically zero. Visibility plays an important role in aviation, as a pilot

TABLE 1

Monthly frequency of fog over Meenambakkam, Chennai, 1981-2002 (except 1984)

Month	January	February	March	April	September	October	November	December
Frequency	160	142	58	1	1	5	31	33

TABLE 2

Mean monthly frequency and probability of fog over Meenambakkam, Chennai, 1981-2002 (except 1984)

Month	January	February	March	October	November	December
Mean frequency	7.6	6.8	2.8	0.2	1.5	16
Probability	0.24	0.24	0.09	0.01	0.05	0.05

wants to know how far he will be able to see the landmarks, targets, obstructions, beacons etc. The poor visibility condition not only prevents the aircraft operation such as landing or take-off but also has indirect impacts like monetary loss and inconvenience due to rescheduling of flights etc. Hence the clearance of an aircraft for its landing and take-off operations during late night and early hours depends on the obscuration of the atmosphere presumably by fog and mist. These two hydrometeors can be distinguished in terms of visibility [India Meteorological Department (IMD), 1974].

The atmospheric conditions favourable for the formation of fog/mist are (i) presence of high RH near the earth's surface so that only little cooling is required to reach the dew point (ii) cloudless or partly cloudy sky condition which permits strong radiative cooling (iii) light surface wind (speed in the range 2 to 8 knots) for gentle mixing of cooled air (iv) inversion layer (layer wherein the temperature increases with height) which inhibits vertical mixing of particulate matters thereby the condensed particles stagnate [Her Majesty Stationery Office (HMSO), 1960; Critchfield, 1987; World Meteorological Organisation (WMO), 1978]. These conditions are often observed during late night and early morning hours in the months December – February and observed rarely during September – November and March – April over Chennai, known as Madras earlier, in southern peninsular India. The atmospheric conditions during winter and alarming increase of low level inversion frequency and air pollution over Chennai which are conducive for the formation of fog and mist have been studied by Suresh (1998, 2000, 2002, 2003).

As the knowledge of weather over the terminal aerodrome helps the aviators to plan and re-schedule their operations to attain optimal economic benefits, TAF

comprising of expected wind, visibility and weather is a mandatory requirement for smooth conduct of air line operations. Though visibility can be affected by the atmospheric obscuration factors like precipitation, fog and mist, only fog is considered in this paper as it reduces the visibility to less than or equal to 1000 m which is quite detrimental to aircraft operations. Hence an attempt has been made to prepare a statistical summary of incidence of fog and visibility over Chennai airport at Meenambakkam which can be used as a tool for the forecaster to issue TAF and help the aviators to know about the favourable period of occurrence, duration of fog and expected visibility etc.

2. Data

Climatologically Meenambakkam airport in Chennai has its fog frequency as 1.5 days each for the months of January and February, and 0.5 days for the month of December besides a very little frequency of 0.1 to 0.3 days during March and September – November totaling 4.3 days per annum (IMD, 1999). This frequency is based on 1951-80 data. However, Gupta and Jayanthi (1991), based on 1931-60 data, have documented that fog over Chennai was of radiation type and has a low frequency of 1 day in a month during winter totaling to 3 days in a year. Hence in order to work out the latest frequency of fog over Chennai, current weather observations comprising of routine aviation meteorological reports (METAR) at 30 minutes interval, special meteorological reports (SPECI) as and when the conditions warrant to issue such reports for the period September – March, 1981-2002 (except for 1984 during which period the data is not readily available) have been collected from AMO, Chennai. The upper air data of the boundary layer has been collected from the RS/RW station, Chennai for the study period wherever needed.

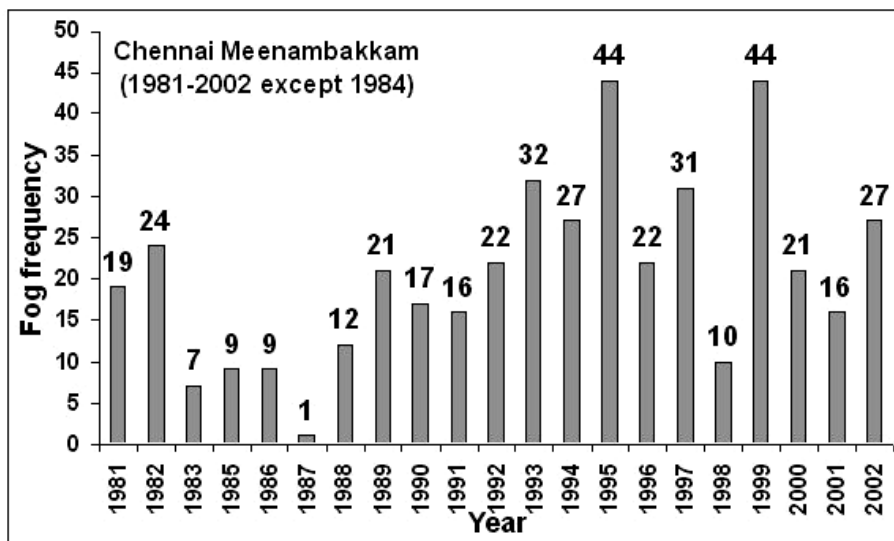


Fig. 1. Annual frequency of fog over Meenambakkam, Chennai during 1981-2002 (barring 1984)

It is interesting to note that the other class I meteorological observatory located at Nungambakkam in Chennai had hardly 0.7 days of fog per annum with maximum frequency of 0.2 days each during January and February in comparison to 4.3 days over Chennai airport at Meenambakkam (IMD, 1999). These two observatories are separated by about 20 km. Nungambakkam is away from the coast by about 4 km and represents an urban area while Meenambakkam is away from the coast by more than 14 km and represents rural area. The two different air mass conditions contribute significantly to the fog frequency over Chennai. Since Nungambakkam observatory does not have half hourly current weather observations and the frequency of fog is of more concern to aviation industry, the study is restricted to Meenambakkam only.

3. Methodology

The collected METAR and SPECI have been statistically analysed to work out the monthly frequency of fog, frequencies of critical visibility in the ranges that are of operationally important for aviation point of view, time of commencement and cessation of foggy weather, duration of fog etc.

3.1. Frequency of fog over Chennai

The month-wise frequency of fog have been worked out for the period 1981-2002 barring 1984 based on current weather observation data recorded by the AMO, Chennai at Meenambakkam and furnished in Table 1.

Occurrence of fog during winter (January – February) is quite significant though the chances are not ruled out during March, November and December. Out of a total of 431 incidences of fog spread over 21 years, only one occurrence had been reported during April (in 1997) and September (in 1992). Hence the occurrence of fog during April and September has been considered insignificant. On an average the annual fog frequency works out to be 20.5 days which is substantially high when it is compared to those during 1931-1960 (3 days) and 1951-1980 (4.3 days). The median frequency is 21 days. The total number of occurrences of fog over Chennai airport in a 11 year period from 1981-1992 (barring 1984) is 157 whereas for a ten year period from 1993 to 2002 the total occurrences were as high as 274. This suggests that there appears to be an increasing trend in fog over Chennai during the last decade. The annual frequency of fog have been plotted and shown as Fig. 1. It may be interesting to note that fog was observed just one day only during 1987 and that was observed during the month of December. High incidence of fog have been occurring from 1993 with the maximum occurrence of 44 days during 1995 and 1999 albeit clear cut trend could not established in view of high oscillation in the annual frequency that has been observed during 1998 with 10 days and 16 days during 2001. The probable cause for just a single occurrence during 1987 and high incidence during 1995 and 1999 have been further analysed and presented in section 4. The monthly frequency has been further analysed critically. The probability of fog during various months have been worked out and tabulated in Table 2. For the computation of probability all days of respective months, for the 21

TABLE 3

Month-wise break up of fog frequency over Chennai airport during 1981-2002 (barring 1984)

Year	Fog frequency over Chennai airport								Total
	Jan	Feb	Mar	Apr	Sep	Oct	Nov	Dec	
1981	9	3	4	0	0	1	0	2	19
1982	15	6	2	0	0	0	0	1	24
1983	3	0	0	0	0	1	1	2	7
1985	3	4	0	0	0	0	0	2	9
1986	3	0	4	0	0	0	1	1	9
1987	0	0	0	0	0	0	0	1	1
1988	6	6	0	0	0	0	0	0	12
1989	5	14	0	0	0	0	0	2	21
1990	9	1	0	0	0	0	5	2	17
1991	9	1	0	0	0	0	2	4	16
1992	5	9	6	0	1	1	0	0	22
1993	16	3	4	0	0	1	2	6	32
1994	12	12	2	0	0	0	0	1	27
1995	13	13	11	0	0	0	6	1	44
1996	8	6	4	0	0	0	4	0	22
1997	10	13	1	1	0	1	1	4	31
1998	3	3	1	0	0	0	3	0	10
1999	12	19	8	0	0	0	3	2	44
2000	10	5	6	0	0	0	0	0	21
2001	3	13	0	0	0	0	0	0	16
2002	6	11	5	0	0	0	3	2	27
Total	160	142	58	1	1	5	31	33	431

TABLE 4

Frequencies of minimum visibility over Chennai airport during fog, 1981-2002 (barring 1984)

Month	Visibility (m) during fog days							Total
	≤ 50	51-100	101-200	201-300	301-500	501-800	801-1000	
January	16	10	10	7	31	39	47	160
February	11	9	3	2	20	44	53	142
March	4	2	1	6	7	18	20	58
April	0	0	0	0	0	0	1	1
September	0	0	0	0	1	0	0	1
October	0	0	1	0	0	3	1	5
November	2	3	3	0	5	5	13	31
December	2	0	0	2	2	12	15	33
Total	35	24	18	17	66	121	150	431

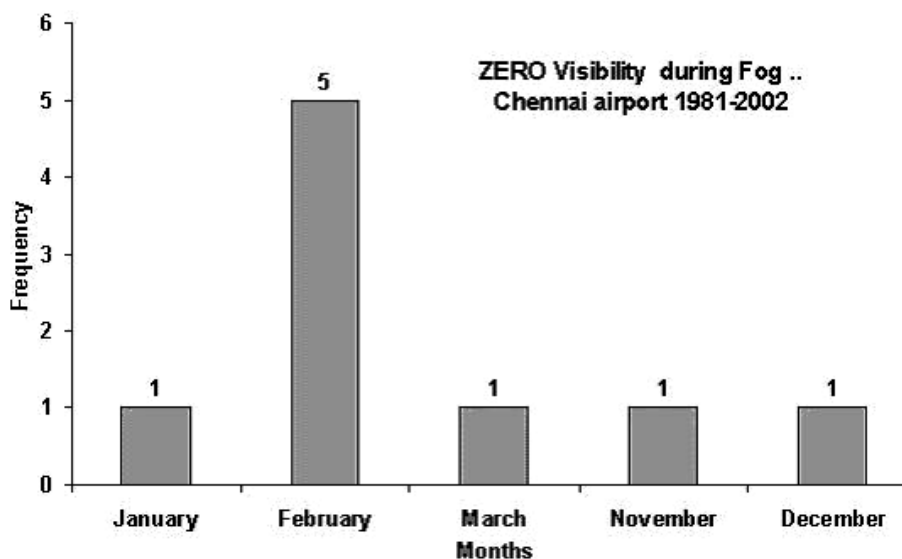


Fig. 2. Frequencies of fog associated with zero visibility

year period, have been taken into account. For the purpose of terminal aerodrome forecast (TAF), the probability should be either equal to or more than 0.3 but less than 0.5 as per the guidelines in vogue. Though the maximum probability of fog over Chennai airport on any given month itself is 0.24, the forecaster may consult this Table just as a tool and issue his TAF by according weightage to other favourable mechanisms for the fog formation such as prevalence of stability, availability of moisture and by monitoring other surface meteorological parameters etc. Hence it is considered that the probability thus computed may help the aviation forecaster to issue TAF with probability for some change groups.

The fog frequency in each month has been tabulated for the years 1981-2002. The months in which the fog frequency is maximum during a year have been highlighted in the Table 3. Out of 21 years, there were twelve years in which the maximum occurrence was observed during January, in eleven years the frequency maximum was observed during February (of course in 4 years, *viz.*, 1988, 1994, 1995 and 1998, maximum frequency was observed during January and February as well), in one year the maximum occurrence was during March, in one year the lone occurrence was during December (1987) and in the year 1998 the maximum occurrence of fog was noticed during November also whose frequency was same as that observed during January and February. Based on total number of occurrence in any given month and going by the modal value, it is observed that the most favourable month for

fog over Chennai airport is January followed by February. Nonetheless, it is seen that maximum occurrence in a calendar year is quite possible in March, November and December as well. The atmospheric conditions for the maximum occurrence of fog have been discussed in section 4.

3.2. Minimum visibility during fog days

As fog is associated with visibility less than or equal to 1000 m, the frequencies of minimum visibility that were estimated during fog days have been analysed as this information is very crucial for aircraft operation. The results are summarized in Table 4. In as much as 34.8 % of fog days, the minimum visibility was in the range 800-1000 m and in 28.1% cases the visibility was in the range 500-800 m. In about 15.3% cases the visibility was between 301 and 500m and the visibility was less than or equal to 300 m in 21.8% cases of fog days. Out of 35 cases of visibility less than or equal to 50m, zero visibility was reported in nine cases. Fig. 2 shows the frequencies of fog associated with zero visibility in various months during the study period. Out of nine cases, five cases (three during 2002 and two during 1982) were observed during February itself.

3.2.1. Cases of zero visibility

As mentioned earlier, zero visibility in association with fog was recorded on nine occasions during 1981-2002. The break up figures are three cases during 2001,

TABLE 5
Time of onset/formation of fog over Chennai airport, 1981-2004 (barring 1984)

Time of onset of fog (UTC)	Jan	Feb	Mar	Apr	Sep	Oct	Nov	Dec	Total
1800-2000	2	1	0	0	0	1	1	0	5
2000-2200	10	5	2	0	0	1	2	0	20
2200-2400	43	21	11	0	0	1	7	5	88
0000-0200	99	113	45	1	1	2	21	27	309
0200-0400	6	2	0	0	0	0	0	1	9
Total	160	142	58	1	1	5	31	33	431

two cases during 1981 and one each during 1990, 1999, 2000 and 2002. Of these nine cases the maximum frequency of five was recorded in the month of February followed by one each in the months of January, March, November and December. The probable cause(s) for nine zero visibility cases were examined. All the nine cases the zero visibility were recorded during the late night and early morning hours. Out of nine cases, atmospheric stability conditions could not be estimated in two cases as there was no RS ascent during those period. In six of the remaining seven cases, the 1200 UTC lapse rate was more than Dry Adiabatic Lapse Rate (DALR) in the atmospheric boundary extending from the surface to a few hundred metres a.g.l. Alarming high concentration of SO₂, NO_x, PM₁₀ and SPM pollutants, exceeding the permissible limits of National Ambient Air Quality Standards, were observed in places like T. Nagar (8 km North of airport), Kilpauk (12 km NNE of airport) and Manali (30 km NE of airport) during winter, 1997 - 2003 (Jayanthi and Krishnamoorthy, 2006). These pollutants might have been advected with the prevailing northerly to eastnortheasterly winds during evening and early night hours towards Meenambakkam airport. The RH prevailing during late night and early morning hours were in excess of 85% and in some cases it was observed well above 94%. Hence the pollutants exploiting the available excess humidity might have resulted in fog between 1800 and 2300 UTC under the prevalence of surface inversion/isotherm due to radiational cooling and thermal energy absorption and scattering by these pollutants on all those days. The 0000 UTC RS/RW data indicated that absolute stability was prevailing in the lowest atmosphere on all the cases. In six cases surface inversion was observed and in one case surface isothermal layer extended up to 80m. As the inversion and isotherm do not permit vigorous vertical mixing of the condensed nuclei in the boundary layer with the atmosphere, the maintenance of fog can be attributed to the stable lower atmosphere during the early hours till inversion / isotherm is destroyed.

3.3. Time of formation / onset of fog

The time of onset/formation of fog in various months during the study period has been worked out from the current weather data and the results are summarized in Table 5. The most preferred time for the formation of fog, based on the modal frequencies, is between 0000 and 0200 UTC which is quite understandable as in this period only the sun's oblique rays just penetrate through the stable layer in the lower atmosphere and churns the low level pollutants that are trapped in the stable layer. About 71.7% cases, fog was first reported only during this period. However, in about 20.4% cases, fog was first observed between 2200 and 2400 UTC which suggests that the pollutants are well trapped in the stable lower atmosphere to form hydrometeors even before the small churning mechanism arisen out of Sun's twilight/insolation takes place to mix those pollutants for the formation of fog.

3.4. Duration of fog

The duration of fog, *i.e.*, the time from the formation to the cessation of fog reported in METAR and SPECI, as the case may be, have been computed and presented in Table 6. The mean duration is 121 minutes. The modal class is 61-90 minutes. In order to calculate the median, the 'less than' ogive and 'more than' ogive curves have been plotted in Fig. 3 to find out the point of intersection of these ogive curves. The median thus obtained was 98 minutes which is agreeing with the calculation based on formula for the median (98.5 minutes). Hence it can be concluded that most commonly expected duration of fog, once it is established, could be between 60 and 120 minutes. It is interesting to note that the fog once formed, lasted upto 240 minutes in about 91% of the cases. However, fog observed at 2110 UTC on 13th and that formed at 1810 UTC on 19th lasted for 570 minutes each.

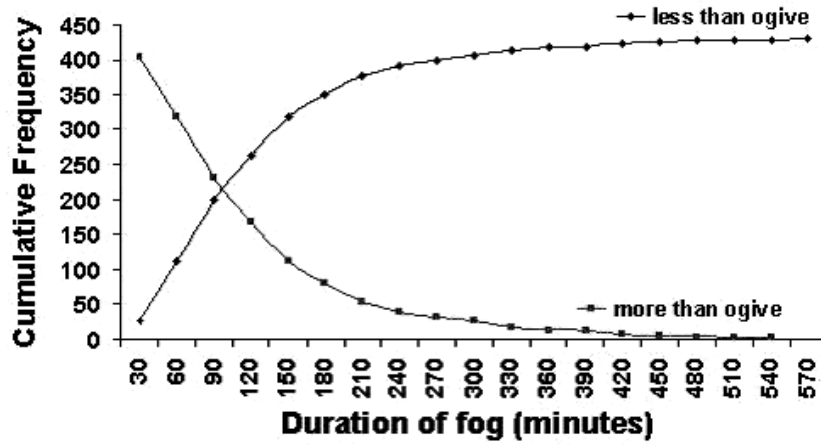


Fig. 3. Ogive curves for duration of fog over Chennai airport during 1981-2002 (barring 1984)

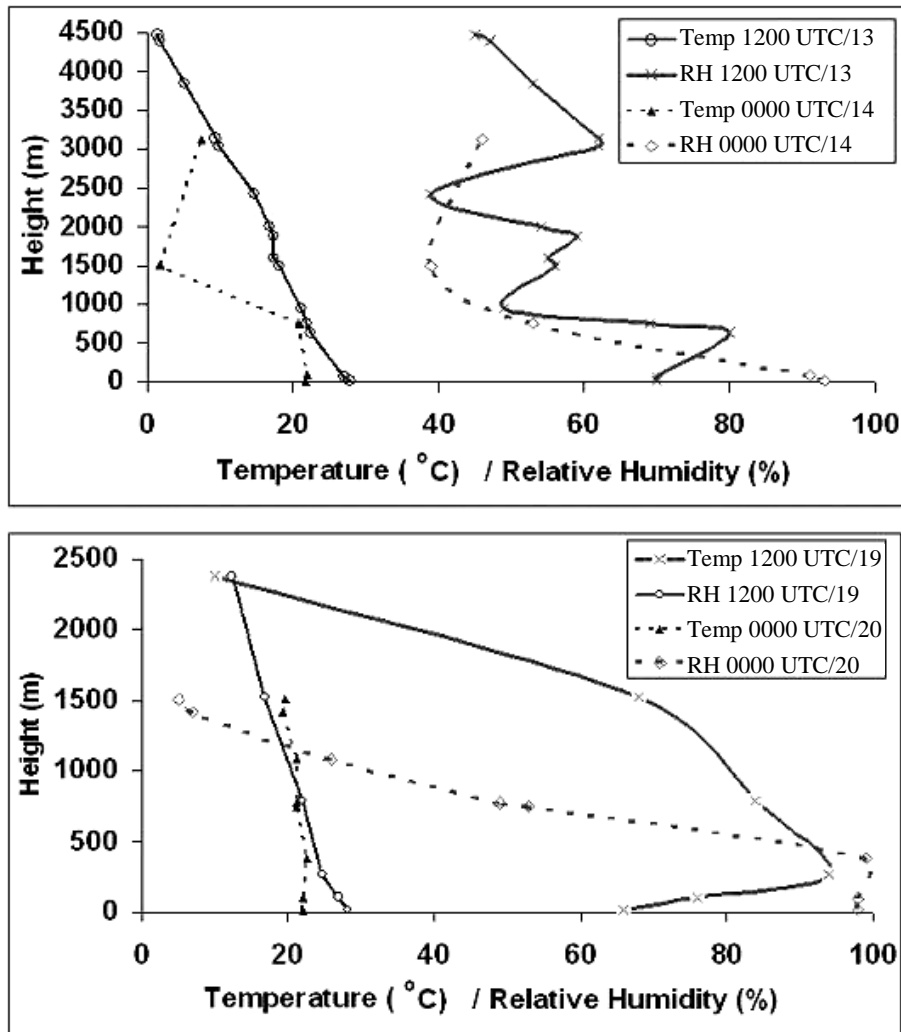


Fig. 4. Vertical profile of temperature and relative humidity on 13th, 14th, 19th and 20th January 2000 over Chennai

TABLE 6
Duration of fog over Chennai airport during 1981-2002 (barring 1984)

Duration (min)	Frequency	Duration (min)	Frequency	Duration (min)	Frequency
0-30	26	211-240	14	421-450	2
31-60	85	241-270	8	451-480	1
61-90	89	271-300	6	481-510	2
91-120	62	301-330	9	511-540	0
121-150	57	331-360	3	541-570	2
151-180	31	361-390	1		
181-210	28	391-420	5	Total	431

The cause for the longest duration of fog have been analysed and presented below.

3.4.1. Fog on 13th/14th January 2000

On 13th at 1200 UTC, a lapse rate of about 10.5° C/km was prevailing from surface to 78 m and lapse rate of 8° C/km was seen from 78 to 641 m. A 10% rise in relative humidity, from 70 to 80 %, was noticed between 78 and 641 m. Vertical profiles of temperature and relative humidity at 1200 UTC on 13th are shown in Fig. 4. Northeasterly wind of 6 to 8 knots was observed from surface to 641 m. The neutrally stratified lowest atmosphere and advection of pollutant from northeast exploiting humidity could have caused the fog to form around 2100 UTC. The maintenance of fog was done by the shallow inversion in the surface layer upto 83 m, with relative humidity of 93% at surface and 91% at 83m and northeasterly wind of 4 to 6 kts at 0000 UTC on 14th (Fig. 4). The pollutant level was very high on 14th morning over Chennai as the local people used to burn all waste and unwanted materials on this day called 'Bhogi' as a religious belief and hence the duration of fog was quite high.

3.4.2. Fog on 19th January 2000

For the fog on 19th January 2000, the 1200 UTC RS/RW observations showed a lapse rate of 13.6° C/km from surface to 265 m. The surface and upper wind in these layers were northeasterly 8 to 10 kts. Humidity inversion of 76 % at surface to 94 % at 265 m was also noticed. Atop these layers, absolute stability and dryness (drop of RH from 94% to 10% in the layer 265 to 2378m) were prevailing. The pollutants from northeast might have been well mixed and dispersed in the boundary layer from surface to 265 m under the instability conditions prevailing from 1200 UTC. This favoured formation of fog at 1810 UTC. Isothermal layer was seen from surface to 96 m at 0000 UTC on 20th and a capping (elevated)

TABLE 7

Comparison of fog frequencies during January – March with frequencies of surface/low level stable atmosphere over Chennai

January - March	Fog frequency	Frequencies of low level stability, January - March		
		Isotherm	Inversion	Total
1987	0	9	53	62
1995	37	7	46	53
1998	7	8	54	62
1999	39	9	56	65
2000	21	17	53	70

inversion was noticed atop upto 380 m. At the surface as well as at 96 m, the RH was 98 % and it was 99% at 380 m. Vertical profile of temperature and relative humidity have been depicted in Fig. 4. Wind was practically calm at surface and it was northwesterly 4 to 5 kts atop upto 380 m. Hence the maintenance of fog for longer duration could be possible under these absolutely stable atmospheric conditions.

4. Discussion

The frequency of fog is more during January – March as evidenced from Table 3. In order to find out the linkage between the frequencies of fog and concentration of pollution, atmospheric pollution data have been collected from the available records of Tamilnadu Pollution Control Board (TNPCB). Fortunately we could collect pollution data for the years 1987 with nil frequency of fog and 1999 with maximum frequency during January – March. In addition, pollution data for the years 1995, 1998, 2000 and 2001 were also collected from TNPCB. Since the atmospheric stability caused by low level inversion is believed to be one of the important factor for the formation of fog, low level Radio Sonde data for these

TABLE 8

Comparison of peak emission of pollution during January – February over Chennai

Name of the pollutant	NAAQS norms ($\mu\text{g} / \text{m}^3$)	Peak emission ($\mu\text{g} / \text{m}^3$) during		
		1984 - 1988	1995 - 1999	2000 - 2001
SPM	500	336.6	556.0	1091.0
NO _x	120	23.0	42.96	84.9
SO ₂	120	56.7	14.2	45.8

periods were collected from Meteorological Office, Chennai. The fog frequencies during January – March have been compared with low level isotherm and inversion frequencies and shown in Table 7.

4.1. Fog vis-à-vis low level inversion

Though the surface (low level) inversion was observed on as many as 53 days and the surface isothermal layer on 9 days during 1987, the fog frequency was practically zero during January – March, 1987. However, for almost same low level stability conditions, the fog frequency was as high as 37 and 39 during 1995 and 1999 respectively and frequencies for the other years were relatively significant than that was observed during 1987. Inversion strength ($\partial T_v / \partial z$) has been worked based on Arya (1988) and Sorbjan (1989) and found that the inversion strength during 1987, a 'no fog' year, was as high as 15.2°K/km in January and 16°K/km during in March 1987 which are quite comparable and even little higher than those observed during 1999 a high frequency fog year. However, during 1998 and 2000 (the years that are in lose proximity with 1999 having maximum fog frequency) the maximum fog frequency during January – March was 7 and 21 respectively albeit the maximum inversion strength was 12.8°K/km only. It is interesting to note that all foggy days had nocturnal low level inversion/isotherm but not all days with nocturnal inversion/isotherm resulted in fog. Hence it leads to believe that the low level inversion could be a necessary and need not a sufficient pre-requisite condition for the formation of fog. On a critical analysis it has been found that there had been no appreciable change in the humidity during the years under consideration.

4.2. Atmospheric pollution over Chennai

The concentration of aerosols and atmospheric pollutants over which the condensation took place for the formation of fog have been analysed. The alarming increase in atmospheric pollutants over different pockets

of Chennai during the years 1997-2003 in comparison to those prevailed during 1980s and early 1990s has been analysed by Jayanthi and Krishnamoorthy (2006). According to them, there has been a 400% increase in the number of vehicles, especially two wheelers and cars from 1985 to 1995 and a 60% increase during 2002 in comparison to 1995. It has also been documented by them that as many as 250 vehicles per day were added to the city by way of new registration alone during 2002. They have documented also that there was a three fold increase in the number of small scale industries in and around Chennai during 1990-2001. The increase in number of industries and vehicular movement due to rapid urbanization that had taken place during the last 10 to 15 years had contributed significantly to alarming increase in pollutants such as suspended particulate matters (SPM), and respirable SPM (PM_{10}), SO₂, NO_x. Table 8 shows the peak 8 hours emission of pollution during winter (January – February) compared with National Ambient Air Quality Standards (NAAQS) on some of the pollutants. It can be seen that the SPM is alarmingly high during 2000-2001 and it was above the NAAQS norms during 1995-1999 as well. The high concentration of pollution in the lower atmosphere coupled with prevailing stable atmospheric condition might have caused increased fog frequencies from 1993 as highlighted in Table 3.

4.3. Fog vis-à-vis pollution

The low frequency of fog during 1987 despite the high inversion strength perhaps can be attributed to lack of pollutants in the boundary layer to act as nuclei for the formation of fog. On the contrary, the pollution level was very high during 1995 and 1999. The high inversion strength that prevailed during these years did not permit vigorous vertical mixing and dispersion of condensed pollution nuclei. Hence the pollutants might have been 'trapped' in the stable atmospheric boundary layer. The prevalence of high humidity during late night and early hours might have condensed over these trapped pollutants which in turn might have formed as fog. This may perhaps explain the reason for the increased fog frequency during

TABLE 9

Frequencies of surface inversion/isotherm over Chennai during December – March

Month	1970-1974	1984-1988	1995-1998	1999-2000	2002-2003
December	5.6	NA	NA	NA	28.0
January	8.4	9.6	23.7	28.0	26.0
February	8.1	9.3	15.1	15.0	20.0
March	6.8	NA	NA	24.5	25.8

Source : 1970-1975 (IMD, 1983);
 1984-1988 (Suresh, 1998 & Suresh *et al.*, 1998);
 1995-1998 & 2002-2003 (Suresh, 2003)

those years. However, in view of the uncertainty in the day-to-day vehicular movement and associated release of pollutants, fog formation might have varied on day-to-day basis on all those inversion days. Moreover, due to strict implementation of pollution control measures by the Pollution Control Board especially since 2000, the concentration of pollutants are being controlled during the current years lest fog could be a daily phenomenon over Chennai.

4.4. Forecasting aspects of fog

The low level inversion frequency was very low during 1970s (IMD, 1983) and has increased considerably during 1980s (Suresh, 1998; Suresh *et al.*, 1998) and then further increased alarmingly during late 1990s (Suresh 2000 and 2003). Table 9 summarises the nocturnal stable atmospheric conditions arisen out of low level isotherm/inversion over Chennai. The low level inversion/isotherm indicates that the nocturnal atmospheric stability was almost a day-to-day phenomenon during January during the last decade. There is a substantial increase in nocturnal low level stability during March as seen from 1999 onwards. This perhaps could be the cause for increased fog frequency during March during the recent years as the low level inversion/isotherm maintains the fog.

There is an increase in the concentration of pollutants over Chennai (Suresh, 2003; Jayanthi and Krishnamoorthy, 2006). There are a number of days on which fog was not formed even though low level inversion was present. Though there is no one-to-one relationship with formation of fog and low level inversion at 0000 UTC, the low level inversion maintains the fog if it is already formed. The increase in pollution

concentration and low level inversion frequency together have contributed significantly to the formation of fog over Chennai especially during winter months wherein high amount of humidity prevails. The formation of fog is of serious concern to the aviation forecaster as he has to issue TAF and trend forecast more accurately as otherwise a large number of flight operations would be hampered either due to diversion or holding up of aircrafts in air resulting in monetary loss to air line agencies besides inconvenience to public. Knowledge of favourable mechanism and time of formation of fog and its duration over any specific month with an idea about the deteriorating visibility may help the forecaster to issue TAF and trend forecast more effectively.

The inversion/isotherm might have started during late night hours, say from 2100 UTC onwards. But, it may not be possible to ascertain the time at which the inversion has commenced from the 0000 UTC RS/RW data. More over the 0000 UTC RS/RW data would be locally available at the earliest by 0130 UTC only taking into account of RS flight time, the computation/coding timings and dissemination etc. Hence a forecaster may have a knowledge on inversion to issue his TAF/trend forecast only by 0130 UTC or so. But by then, fog might have been formed already as it may be recalled that in about 20% of cases the fog formed between 2200 and 0000 UTC and in more than 71% cases it was during 0000-0200 UTC. Hence it is highly desirable that during months of January – March the RS/RW ascents are released between 2200 and 2300 UTC which is well within the permissible norms of ± 2 hours of upper air observation timings so that the data is available to forecaster by 2300-0000 UTC. The availability of low level RS/RW data by 2300 – 0000 UTC may help the aviation forecaster to issue a precise TREND forecast on visibility and based on persistence of inversion during winter, fog forecast can be issued in TAF with probability.

5. Conclusions

The following conclusions have been drawn from this study.

(i) Fog frequency over Chennai airport has increased exponentially during the last decade, especially from 1993.

(ii) Low level inversion frequency has also increased alarmingly during late 1990s and continues to increase during 2000s also. Rapid urbanization and increased vehicular movement could be the cause for increased low level inversion frequency.

(iii) The air pollution level, especially the suspended particulate matter, SO₂ and NO_x have increased due to urbanization and industrial growth. Though the pollution level has been controlled to a major extent during the recent years, the concentration level is still above the national Ambient Air Quality standards.

(iv) Low level (surface) inversion/surface isotherm frequency causing the atmospheric stability is almost a day-to-day phenomenon in the months of December, January and March and the frequency is considerably high in February during the last decade.

(v) Neutrally stratified and/or absolutely unstable lower atmosphere at 1200 UTC during December – March cause the pollutants to condense and form fog during late night or early morning of the next day. The low level stable atmosphere (inversion/isotherm) maintains the fog till insolation punctures the stable atmosphere.

(vi) Though the low level inversion maintains the fog once it is formed already, inversion alone is not a sufficient condition for the formation of fog.

(vii) The mean annual fog frequency over Chennai airport is 21.5 days. The most favourable month for formation of fog over Chennai airport is January followed by February and March.

(viii) The most preferred time for onset of fog is 0000-0200 UTC followed by 2200-2400 UTC.

(ix) The average duration of fog is 60-120 minutes albeit duration as high as 540-570 minutes are also probable over Chennai airport.

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References

- Arya, S. P., 1988, "Introduction to Micrometeorology", Academic press, San Diego, p307.
- Critchfield, H. J., 1987, "General Climatology", 4th ed., Prentice Hall of India private Ltd., New Delhi, India, p453.
- Gupta, A. and Jayanthi, N., 1991, "Climatological aspects of Madras city", Pre-published Scientific Report No. 91/1, Regional Meteorological Centre, IMD, Chennai, p41 + figures.
- Her Majesty Stationery Office, 1960, "Handbook of aviation meteorology", HMSO, London, p404.
- India Meteorological Department, 1974, "Forecasting Manual - Part V - Aviation meteorology", prepared by N. S. Bhaskar Rao and V. Surya Rao, IMD, Pune, India, p130.
- India Meteorological Department, 1983, "Frequencies of stable layer in the planetary boundary layer over India", Vol I (p91) and II (p122), IMD, New Delhi.
- India Meteorological Department, 1999, "Climatological Tables of Observatories in India", 1951-1980, 5th ed., India Meteorological Department, New Delhi, 441-442.
- Jayanthi, V. and Krishnamoorthy, R., 2006, "Status of ambient air quality at selected sites at Chennai city", Proc. Brain storming session on Disaster Management, Sri Venkateswara University, Tirupati, 99-111.
- Sorbjan, Z., 1989, "Structure of the atmospheric boundary layer", Prentice Hall, Englewood Cliffs, New Jersey, p317.
- Suresh, R., 1998, "On some aspects of boundary layer over Madras airport", *Mausam*, **49**, 4, 528-530.
- Suresh, R., 2000, "A simple thermo dynamical model to estimate the rate of depletion of nocturnal low level inversion layer", *Mausam*, **51**, 1, 39-46.
- Suresh, R., 2002, "On the frequencies and rate of depletion of nocturnal surface and elevated inversion over Chennai", in : Advances in Atmospheric Chemistry, Proc. National Workshop on Atmospheric Chemistry (NWAC-99), 12-14 October 1999, ed. P. C. S. Devara and P. Ernest Raj, Indian Institute of Tropical Meteorology, Pune, ISBN 81-7525-355-X, 87-91.
- Suresh, R., 2003, "Air pollution – Physics and Meteorological aspects", *Environment Science & Engineering*, **1**, 3, 47-55.

Suresh, R., Suresh Chandra, K. and Sivagnanam, N., 1998, "On application of Hierarchical Linear Model for nowcasting visibility over Chennai airport", *Vayumandal*, **28**, 3&4, 79-88.

World Meteorological Organization, 1978, "Compendium of meteorology", Vol II, part 2, 'Aeronautical meteorology', prepared by B. J. Retallack, ed A. W. Nielsen, WMO No. 364, WMO, Geneva, Switzerland, p126.
