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Poor visibility during winter over Santacruz airport—Its causes and forecast

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सार—सांताक्रुज हवाई अड्डे पर शीत ऋतु के दौरान प्रातःकाल की आरंभिक अवधि में दृश्यता काफी तेजी से घटती जा रही है जिसके कारण वायुयानों का यातायात अनेक बार लगभग एक घंटे तक पूर्ण रूप से रुक जाता है। इस शोध पत्र में, दृश्यता की कमी के लिए उत्तरदायी घटकों का विश्लेषण किया गया है। जैसे रात्रि का प्रबल प्रतिलोमन (निम्न स्तर), निचले वायुमंडल में प्रदूषण, मंद पवन आदि। औद्योगिक तथा घरेलू प्रदूषण के साथ-साथ रात्रि के निम्न स्तरीय प्रतिलोमन भी दृश्यता को कम करते हैं। एक बार 1800 से 2000 यू टी सी तथा दूसरी बार 0200 व 0300 यू टी सी के बीच दृश्यता में कमी पाई गई है। इस शोध पत्र में अगले 2 से 3 घंटों के लिए दृश्यता के पूर्वानुमान के लिए एक वस्तुनिष्ठ पद्धति विकसित की गई है।

ABSTRACT. There is rapid decrease in visibility during early morning hours in winter season over Santacruz airport. The deterioration at times prevents aircraft operation in toto for about 1 hour or so. The causes of reduction in visibility, *viz.*, strong nocturnal inversion (low level), pollution in the lower atmosphere, light wind etc have been analysed in this paper. It was observed that industrial and domestic pollution together with strong low level nocturnal inversion causes poor visibility. Visibility attains double minima-one between 1800 and 2000 UTC and the other between 0200 and 0300 UTC. An objective method to forecast visibility in the next 2 to 3 hours has been developed in this paper.

Key words — Visibility, Objective method, Fanning, Inversion, Stack height, Pollution.

1. Introduction

Visibility plays an important role in aviation meteorology. The poor visibility condition not only prevents the aircraft operations such as landing or taking-off during that period but also has indirect effects like monetary loss and delay in further scheduling of air navigation. Thiruvengadathan and Rao (1977) analysed the frequency of poor visibility during the winter period of 1974-75. Chandiramani *et al.* (1975) studied the causes of a specific ever low poor visibility of 50 m on 4 April 1974. Pradhan *et al.* (1976) tried to establish relation between poor visibility and inversion. In this paper an attempt has been made to analyse the cause(s) of poor visibility and to develop an objective method to forecast visibility so that TAF/TREND forecast can be given well in advance about the poor visibility to cause for effective airline operation.

2. Data used

METAR/SPECI report from the current weather registers of winter period (November-March) of 1987-1993 were taken. Since the visibility of more than 3000 m is not of much crucial importance for aviators, the present study is restricted to visibility less than 3000 m only. Low level wind and temperature and surface parameters were taken from 0000 UTC TEMP for the period January 1989 to March 1993.

3. Discussion

3.1. *Visibility peaks*—The average value of visibility during winter months between 1600 and 0400 UTC is shown in Fig. 1. It is observed that visibility gradually deteriorates from 1700 UTC and it attains double minima. The first minima is observed between 1800 and 2000 UTC at the order of 1600 m during November, 1200 m during December and February, 1500 m during January. The second minima is obtained between 0200 and 0330 UTC ordinarily and the value is normally around 800 m but in specific cases visibility was as low as 400 m.

3.2. *Poor visibility* — Table 1 indicates the number of days in which the visibility was in the class interval stated therein, extracted from the half-hourly METAR/SPECI reports. In 65% of the cases the visibility was less than 800 m. In 81% cases visibility was less than 1000 m. The causes of poor visibility are discussed in the following paragraphs.

3.2.1. *Low level inversion* — The clear sky or 1 or 2 octa cirrus type cloud that prevail during winter months permits nocturnal inversion. The surface inversion was seen up to 1.5 km above ground level. However, in most cases the inversion was concentrated up to 0.6 km only. Though the average rise in temperature between surface and 0.6 km was of the order of 3.5° C, rise of 9°C was not uncommon. Table 2 represents the frequency of occurrence of low level inversion. It can be seen that low level inversion (as observed at 0000 UTC) was more prominent on almost all days in winter months. The frequency and intensity is more in January than in other winter months. The association of inversion with visibility is shown in Table 3. It can be seen that in more than

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TABLE 1

Frequency distribution of visibility during winter period 1989-93

Period	Visibility (m) ≤600	601-800	≤800 (No. of days)	801-1000	1001-1200	Total
Jan 1989	7	9	16	3	1	20
Feb 1989	6	5	11	2	0	13
Mar 1989	7	5	12	2	0	14
Nov 1989	2	7	9	0	0	9
Dec 1989	2	2	4	3	1	8
Jan 1990	2	12	14	3	0	17
Feb 1990	2	5	7	1	1	9
Mar 1990	4	7	11	3	0	14
Nov 1990	2	0	2	1	3	6
Dec 1990	0	3	3	1	1	5
Jan 1991	5	12	17	6	0	23
Feb 1991	5	8	13	3	1	17
Mar 1991	4	9	13	3	5	21
Nov 1991	0	3	3	0	4	7
Dec 1991	3	8	11	2	8	21
Jan 1992	7	9	16	4	3	23
Feb 1992	1	7	8	4	1	13
Mar 1992	0	2	2	3	5	10
Nov 1992	0	0	0	0	2	2
Dec 1992	0	2	2	1	4	7
Jan 1993	2	3	5	1	8	14
Feb 1993	4	4	8	1	4	13
Mar 1993	1	4	5	1	4	10
Total	66	126	192	48	56	296

85% of cases, poor visibility was associated with inversion only.

3.2.2. *Industrial pollution* — There are about 120 approved layouts and 200 medium/large scale units producing steel, chemical, plastic articles, in addition to more than 8000 small scale units located in Andheri, Marol, Sakinaka, Jogeshwari, Kurla areas which form north and eastern side of Santacruz airport (Indian Express, Bombay edition 31 August 1992). The thick concentration of industries considerably reduces the visibility when smoke and other particulate matter emitted by the industrial chimneys were slowly drifted by the prevailing wind near the surface boundary layer towards Santacruz airport. In addition to these, the domestic fires (out of charcoal, wood, kerosene, etc) lit by the hutment dwellers for food preparation and for warmth during night also liberate smoke and pollution. These pollution (industrial and domestic) cause suspended particles in the lower atmosphere as well as form a dense smog (smoke and fog) with the exploitation of humidity prevailing during night time. In view

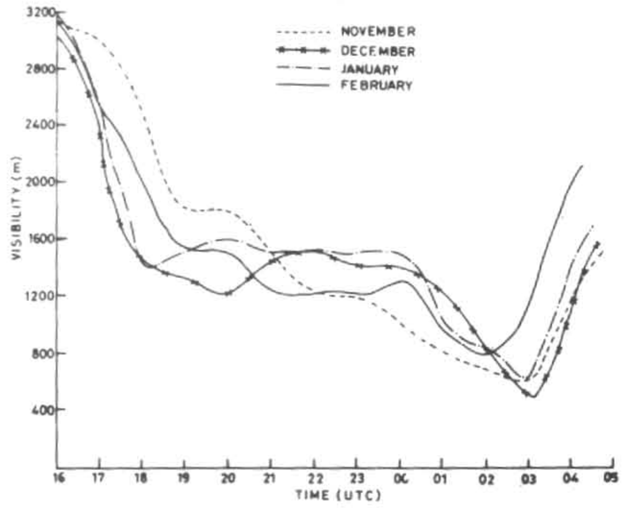

Fig. 1. Deterioration of visibility with time (November to February)

of these smoke and stable layer caused out of nocturnal inversion, the visibility is reduced to a minimum of 600 m in the early hours.

3.2.3. *Humidity* — Variation of visibility with Dew-point Depression (DD) is tabulated in Table 4. Ordinarily Relative Humidity (RH) of 85% and more, causing fog, reduces visibilty to less than 1000 m. But in respect of Santacruz airport poor visibility, say, less than 800 m, is caused by RH less than 70% (mostly less than 55%) in 70% cases. On the contrary, only in less than 11% cases when the RH was more than 80%, visibility was less than 1200 m. As such, it can be concluded that it is not the high RH that reduces visibility but it is the smoke that settles down in stable layer. Table 5 shows the relationship between the visibility and RH under "no inversion" category. Under this category, it is found that in more than 75% of cases the RH was less than 70%. Hence it is concluded that high RH is not the only factor that reduces visibility.

3.2.4. *Wind* — Between 1600 and 2200 UTC, the surface wind was mostly variable between north-northeasterly and easterly with a maximum speed of 3 kt. During this period, the smoke liberated from domestic and industrial sources (which are thickly concentrated in the northern and eastern quadrant of Santacruz airport) is drifted towards the airport. The pollutants moving at a very low speed cause a minima between 1800 and 2000 UTC. Between 2200 and 0300 UTC, the wind was mostly calm. During this period the stagnated pollutants under the influence of strong nocturnal inversion unable to mix up and disperse, behave as suspended particulate matter by exploiting high humidity prevailing at that time. Vertical mixing is hampered by stable layers caused out of inversion. The

TABLE 2

Frequency of low level nocturnal inversion during winter period 1989-92

Period	Inversion (°C)								
	0.0	≤1.0	1.1-2.0	2.1-3.0	3.1-4.0 (No. of days)	4.1-5.0	5.1-6.0	>6	Maximum (°C)
Dec 1989	1	3	5	6	3	5	2	2	7.8
Jan 1990	0	0	0	3	3	4	7	13	12.0
Feb 1990	0	6	4	3	2	2	0	5	7.8
Mar 1990	1	4	4	5	4	4	0	0	5.0
Nov 1990	0	2	6	3	3	5	3	0	6.0
Dec 1990	1	5	6	6	3	3	2	0	5.6
Jan 1991	1	2	1	7	4	5	4	3	9.2
Feb 1991	0	3	7	2	4	3	3	2	8.1
Mar 1991	3	5	5	5	2	4	1	0	6.0
Nov 1991	1	7	3	5	2	2	1	2	7.8
Dec 1991	1	4	3	4	4	3	5	2	6.4
Jan 1992	1	1	1	4	4	4	5	9	9.0
Feb 1992	1	4	4	5	2	2	0	2	8.8
Mar 1992	0	4	4	6	4	4	2	2	7.4

sun rises, normally, at 0145 UTC during January and February. The dawn and oblique sun rays cause eddy circulation at lower level, thereby the suspended particles spread very near to the surface. This causes minimum visibility between 0200 and 0330 UTC. The improvement can be noticed only after the inversion is destroyed by further insolation, ground heating and/or wind shifts/ changes. Fig. 2 shows the topography and concentration of industries around Santacruz airport.

Stable layers and calm or light winds are conducive to concentration of pollutants at or near the source of contamination. Temperature inversions are particularly suited to the formation of palls of smoke and industrial haze. Since the air is warmer overhead in an inversion, the pollutants are soon at a temperature equal to that of the surrounding air. Therefore, they do not rise further. Cooling by radiation at night from the top of a smoke layer induces subsidence and concentration of pollution increase at and below the top of inversion.

3.3. *Stack height* — The level (height) where pollution enters the atmosphere can be characterised by the "stack height". The marked effects of inversion are clearly seen, emphasising that it is desirable to ensure that the effective stack height is above the local surface inversion in order to minimize ground level concentration, otherwise, "fanning" will occur within the inversion layer causing reduction in visibility. Fanning permits no dispersion. In respect of Santacruz airport, the stack height of industrial sources is not more than 100 m in north and eastern quadrant of airport. Hence the domestic and industrial pollution may be limited to a height of not more than 150 m (just some height above stack height), which is well within the stable layer of normal height of 600 m. This is the reason for poor visibility during winter though RH was less.

4. Verification

In about 10 instances, spot verification was done at the runway 27 end point (where skopograph is installed) in the early hours to ascertain the actual cause of poor visibility and to verify the worthiness of skopograph reading. It was seen from there that up to about 15 m of height above ground level, there was thick smoke. The airport building (roughly 35 m height) and the trees in southern sector could not be clearly seen. The tower portion of airport building (west direction) and top 1 or 2 branches of trees of roughly 20 m height (south direction) could only be seen faintly. The skopograph responded promptly when its focussing mirror was obscured or blocked partially. During the same period visibility as observed by tower assistant was obtained by walkie-talkie and it was found that the eye estimation was on the higher side by 500 m or so. Considering the height of the industrial chimneys, the stack height is not more than 100 m in the north and eastern sector of airport. But the average depth of inversion is 600 m (though inversion up to 1500 m is also not uncommon). Hence the industrial and domestic pollution might have travelled at a depth of around 100 m (most probably <35 m) towards runway 27 and suffered fanning within the inversion layer causing no dispersion of pollution.

TABLE 3

Visibility vs inversion
(December 1989-March 1993)

Visibility (m)	No. of days of	
	Inversion	No inversion
300	1	0
400	8	0
500	7	0
600	25	3
700	14	4
800	72	10
900	3	0
1000	33	5
1100	1	0
1200	45	9
Total	209	31

TABLE 4

Visibility vs Humidity
(December 1989-March 1993)

Surface relative humidity (%)	Visibility (m)			Total
	<600	601-800	801-1200	
	(No. of days)			
> 90	1	1	3	5
80-90	0	12	10	22
70-80	4	19	37	60
< 70	39	68	46	153
Total	44	100	96	240

5. The Objective method

Since visibility is much influenced by humidity, precipitation, thunderstorm, duststorm, etc., an attempt has been made to develop a mathematical prediction equation to forecast visibility 2 or 3 hours ahead. As the chance of thunderstorm, duststorm, precipitation during winter over Santacruz is almost nil, the prediction equation has been developed by utilising surface humidity, low level inversion parameters which have some correlation with the visibility. The data have been fed to the PC/ AT computer and all possible combination of simple and partial correlation coefficients have been obtained using Lotus package language. Retaining only those variables whose individual correlation coefficients are more significant than the automatic correlation coefficients, the objective method has been developed. The method as defined by Panofsky and Brier (1958) has been used here.

The prediction equation is given by

$$X_n - \bar{X}_n = \sum_i b_i \, (X_i - \bar{X}_i) \quad (1)$$

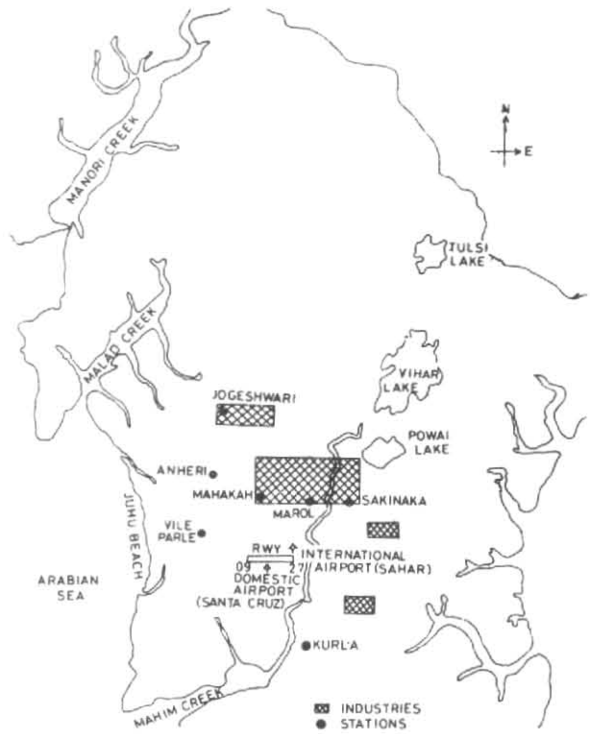

Fig. 2. Concentration of industries surrounding Bombay airport

TABLE 5

Visibility vs relative humidity (under no inversion condition)
(December 1989-March 1993)

Visibility (m)	Relative humidity (%)					Total
	40-50	51-60	61-70	71-80	81-90	
< 600	1	0	2	0	0	3
601-800	2	2	5	3	2	14
801-1000	0	1	3	1	0	5
1001-1200	1	3	3	0	2	9
Total	4	6	13	4	4	31

where, $i = 1, 2, 3, \ldots\ldots (n-1)$

X_n is the predictand (here visibility between 0200 and 0400 UTC)

X_1 — Surface wind speed (0000 UTC),

X_2 — Surface dry bulb temp. (0000 UTC),

X_3 — Surface dew point temp. (0000 UTC),

X_4 — Temp. at 150 m−Temp. at surface (0000 UTC).

TABLE 6

Percentage of occurrence of forecast visibility within specified error limit (December 1989-March 1992)

Visibility (m)	Error score					
	≤ 0.1	≤ 0.2	≤ 0.3	≤ 0.4	≤ 0.5	> 0.5
300- 600	0	0	2.1	21.7	50.0	100.0
700	0	50.0	100.0	100.0	100.0	100.0
800	67.1	97.6	100.0	100.0	100.0	100.0
900	100.0	100.0	100.0	100.0	100.0	100.0
1000	21.9	86.1	100.0	100.0	100.0	100.0
1100	0	100.0	100.0	100.0	100.0	100.0
1200	0	5.6	74.1	100.0	100.0	100.0
Overall 300-1200	29.2	53.3	74.6	85.0	90.4	100.0

TABLE 7

Verification of objective method during November 1992-March 1993

Visibility (m)	No. of days in which forecast was within the error score						
	≤ 0.1	0.1 to 0.2	0.2 to 0.3	0.3 to 0.4	0.4 to 0.5	> 0.5	Total
300	—	—	—	—	—	1	1
400	—	—	—	—	—	3	3
500	—	—	—	—	—	1	1
600	—	—	—	1	1	—	2
800	8	5	—	—	—	—	13
1000	4	—	—	—	—	—	4
1200	—	—	17	5	—	—	22
Total	12	5	17	6	1	5	46

X_1, X_2, X_3, X_4 are the predictors.

The 'bar' (—) denotes the average (mean).

The constants $b_1, b_2, b_3, \ldots \ldots b_{n-1}$ are obtained by solving :

$$\sum_{i=1}^{n-1} b_i \overline{x_j x_i} = \overline{x_j x_n} \quad (2)$$

where, $j = 1, 2, 3, \ldots \ldots \ldots (n-1)$

where, x_is are departures from the respective mean $x_i = X_i - \overline{X_i}$

The prediction equation thus obtained is :

$$X_n - 865 = 11.51\,(X_1 - 0.975) + 12.51\,(X_2 - 21.11) + 14.41\,(X_3 - 14.14) - 2.72\,(X_4 - 1.55).$$

The inversion parameter was also considered for the full depth but the forecast was differing considerably from the actual value. Perhaps, this may be due to very small correlation coefficient (0.0306 for the present study) with visibility as found out by earlier by Pradhan *et al.* (1976). Hence, inversion has been considered up to 150 m here which has a good association with other parameters and considering 'stack height' aspects discussed earlier.

For the purpose of verification of the above method, the 'error score' has been defined as :

Error score = | Forecast − Observed | / (Observed)

The average error score for the total period has been worked out as 0.246. The average absolute error was 186 m and the standard deviation was 227 m. The method performed quite well in forecasting visibility in the range 700 to 1000 m. Table 6 shows the percentage occurrence of visibility forecast in the specified error limit (score). The method, however, could not forecast visibility less than 600 m within error score of 0.3, *i.e.*, within a deviation up to 180 m. But the variation is very much within the standard deviation and average absolute error. In fact, in two cases when the actual visibility was 300, 400 m, the forecast was about 700 m which is a significant difference. However, on analysing the meteorological parameters that prevailed on those 2 days, it was found that with similar trend of meteorological elements (analogy) in some earlier days the visibility was 800 m or so. As such the reason for such poor visibility could not be explained either by the present method or by persistence (analogy). But for the above, this method could forecast reasonably well.

The equation developed was subjected to verification for the winter period 1992-93, an independent period. From Table 7 it is seen that within the limits of 10%, 20%, 30% (corresponding to error score 0.1, 0.2, 0.3), forecast was done in 26, 37, 74% cases respectively. In specific case, the modal visibility of 800 m was forecast within 10, 20% error limits in 62, 100% cases respectively.

Freeman (1962) developed a graphical method of objective forecast to forecast visibility over London airport. Inspite of repetitive application of corrective measures to select 'best' predictors, his method could not give correct forecast in 22% cases and the number of errors were signicantly on the higher side. In the present method, improvement is possible provided data in friction layer up to 150 m height (the height that is just above the stack height) is made available in 0000 UTC TEMP in every 20/25 m height. This will help in exactly calculating the inverse lapse rate, which decides the stability of the atmosphere and pollution movement, in turn.

6. Conclusions

(i) Visibility attains double minima during winter—one between 1800 and 2000 UTC of the order 1200 m and the other between 0200 and 0330 UTC of the order 800 m (as low as 400 m was also not uncommon).

(ii) The poor visibility is due to dense smoke in the stable layer of inversion and calm/very light wind, but not due to high humidity as normally expected.

(iii) The objective method to forecast visibility can be improved if data is made available at every height step of 20/25 m in the 0000 TEMP message, as the stability factor governs the movement (mixing/dispersal/fanning etc) of pollution which causes reduction in visibility.

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