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Analysis and forecasting of fog over Bangalore airport

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सार — बंगलूर हवाईअड्डे के ऊपर कोहरे का अध्ययन किया गया है। कोहरे वाले दिन से पहले की रात की विभिन्न अनुकूल परिस्थितियों का इसमें अध्ययन किया गया है। विभिन्न तकनीकों का प्रयोग करते हुए कोहरे का पूर्वानुमान लगाने के प्रयत्न किए गए हैं। भौतिक सिद्धांतों और सांख्यिकी, दोनों के लिए संश्लिष्ट प्रणाली एक नई वस्तुनिष्ठ प्रणाली है जो बेहतर तकनीक उपलब्ध कराती है। तुलना के लिए विभिन्न विधियों की पारिशुद्धता का आकलन किया गया है। विश्लेषण का सबसे महत्वपूर्ण परिणाम यह है कि कोहरे की अवधि और तीव्रता की आवृत्ति में 80 के दशक से 90 के दशक तक क्रमिक वृद्धि हुई है। अन्य परिस्थितियाँ सामान्य रहने पर इस वृद्धि

ABSTRACT. The fog over Bangalore airport has been analysed. The different favourable conditions on the previous night of the fog day has been studied. Attempts have been made to forecast the fog using different techniques. The Composite method is a new objective method which provides a better technique both in terms of physical principles and statistics. The accuracy of different methods have been calculated for the purpose of comparison. The most important result of the analysis is that the frequency of duration and intensity of fog have gradually increased from the decade of 80s to the decade of 90s which may be due to the increase in pollution of air, other factors remaining unchanged.

Key words - Fog, Onset, Duration, Intensity, Dispersal, Forecast, Persistence, Correlation, Synoptic, Composite.

1. Introduction

Fog is one of the important hazards to aviation activities. Fog over Bangalore airport has been studied using 10 years' data. Fog occurrences at Bangalore airport are generally of radiation type. The height of Bangalore airport is approximately 900 m and there lies a lake adjacent to the runway both stretching in the east-west direction. Also, Bangalore is one of the industrial cities of India with many sources of pollution. The local breeze at Bangalore airport is generally easterly in winter months. Sreenivasaih (1944) studied the frequencies of fog, mist and haze at Bangalore Central Observatory.

2. Data

The study has been carried out on the data of four months in November, December, January and February over a period of 10 years from 1983-84 to 1992-93. The developed techniques have been applied to the data of 1993-94 for determining the accuracy of the techniques. The weather parameters used for this purpose include : (1) cloud coverage, (2) wind speed, (3) relative humidity, (4) dry bulb temperature (DB), wet bulb temperature (WB) and dew point (DP); (all at 1730 IST and 2330 IST) (5) visibility at 0830 IST etc. recorded at the Meteorological Office, Bangalore airport.

3. Analysis and results

3.1. *Occurrence of fog*

3.1.1. *Frequency distribution of fog*

The analysis showed that fog occurred on 194 occasions in 10 years' period with an average of 19.4 events per year. The most striking result is that the average number of fog days per year increased from 15.83 during 1983-89 to 24.75 during 1990-1993. The frequency of fog was maximum during the month of January followed by December, November and February.

Mist occurred on 216 occasions with an average 21.6 events per year. The frequency of mist was maximum in January like that of fog followed by December, February and November. In January, frequency of fog was more than

TABLE 1

Frequency distribution of fog and mist

Month	Fog	Mist	Fog/Mist
November	42	47	89
December	46	54	100
January	84	66	150
February	22	49	71
Total	194	216	410
Average per year	19.4	21.6	41.0
Average per year for 6 years period (1983-84 to 1988-89)	15.83	23.17	39
Average per year for 4 years period (1989-90 to 1992-93)	24.75	19.25	44

TABLE 2

Frequency distribution of time of onset of fog (IST)

Time of onset/month	0001 0030	0031 0100	0101 0130	0131 0200	0201 0230	0231 0300	0301 0330	0331 0400	0401 0430	0431 0500	0501 0530	0531 0600	0601 0630	0631 0700	0701 0730	0731 0800	0801 0830	0831 0900
November	0	1	1	0	1	1	3	3	2	3	4	5	14	3	1	0	0	0
December	0	0	0	1	0	1	2	3	3	6	3	1	9	13	4	0	0	0
January	0	0	0	0	3	0	5	6	8	7	7	7	16	10	6	8	1	0
February	0	0	0	0	0	0	1	0	1	2	0	3	2	5	4	3	1	0
Total	0	1	1	1	4	2	11	12	14	18	14	16	41	31	15	11	2	0

that of mist and it was just opposite for other months. In February, frequency of mist was more than double that of fog. The total number of days of fog and mist was 410 with an average of 41 days per year. The maximum occurred in January followed by December, November and February. The average frequency of fog and/or mist also showed an increase from 39 per year (1983-89) to 44 per year (1990-93). These results may be attributed to the increase in pollutants due to industrialisation and emission from automobiles etc.,.other factors remaining constant.

The Student's 't' test was applied to test the significance of change in average frequency from the decade of 80s to the decade of 90s. It showed that there was a significant increase in the mean frequency of fog at 0.01% level of significance, whereas there was no significant change in the mean frequency of mist, fog/mist even at 0.1% level of confidence with one tailed test. The monthwise frequency distribution is shown in Table 1. The frequency of occurrence of fog per month from 1931-60 data to the present study of 1983-94 gives for November 1.6 to 4.2 days, for December from 3 to 4.6 days, for January from 3 to 8.4 days and for February 0.4 to 2.2 days. As such it may be noted that the frequency of occurrence of fog over Bangalore has considerably increased from 1931-60 with the present study of 1983-94.

The calculation of 5 days average showed that the frequency of fog was maximum during second half of January, with 52 out of total 84 over the period of 10 years. The results are shown in Table 2.

3.1.2. *Onset time of fog*

The frequency of onset of fog was maximum between 0601 to 0630 IST (Indian Standard Time) for the month of November and January, between 0631 and 0700 IST in December and February. However, the maximum number of fog occurred around or just after the sunrise which was in well agreement with physical principles. Just after the sunrise the turbulence mixing of the air in the shattered layer slightly increases helping in the formation of fog. The detailed data are shown in Fig. 1. However, for the period of four months, the frequency was maximum, *i.e.*, 41 between 0601 and 0630. During the months of November and December there was no onset of fog after 0730 IST. During January and February there was no onset of fog after 0830 and only once between 0801 and 0830 during these 2 months. Fog invariably does not occur after 0730 IST and before 0300 IST.

3.1.3. *Intensity of fog*

Intensity of fog can be measured in terms of the minimum visibility associated with it. In this regard the visibility in the fog days of 0530 and 0830 IST has been studied. It is found that the visibility was less than or equal to 95 (Code 95 corresponds to slight mist/dust haze) at 0830 hr IST on 113 occasions (58.2%) out of 194 fog days. Also, the fre-

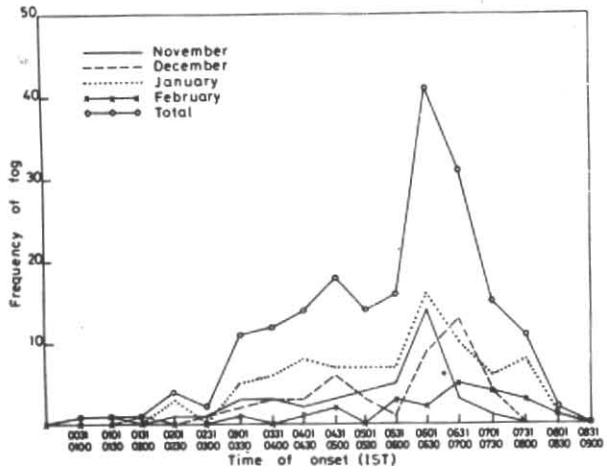


Fig. 1. Onset of fog

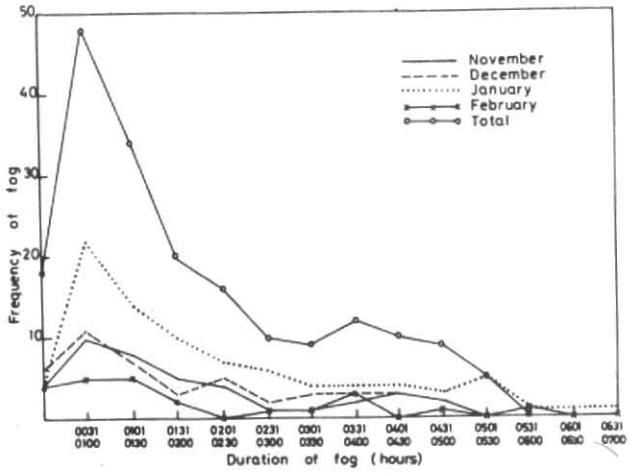


Fig. 2. Duration of fog

quency was maximum in January (61 and 71.4%) followed by December (20 or 43.5%); February (18 or 81.8%) and November (14 or 33.3%). The mean frequency of fog days, when visibility reduced to 95 or less, increased from 7.5 per year to 17 per year and this difference in mean was statistically significant at 0.01% level of significance according to one tailed Student's 't' test. The visibility of less than or equal to 93 at 0830 IST occurred maximum number of times in January (24 or 28.6%) followed by December (8 or 17.4%), February (3 or 13.6%) and November (2 or 4.8%).

3.1.4. *Duration of fog*

It was found that most of the fog occurred with a duration of 31 to 60 minutes. The detailed data are shown in Fig. 2. On examination of individual daily data, the extreme values of duration of fog for different months during the 10-year period is given below :

Month	*Date*	*Year*	*Duration*	
			Hr	Min
Jan	11	1993	06	50
Dec	16	1990	06	25
Nov	10	1988	06	00
Feb	18	1990	04	40

It showed that fogs with maximum duration occurred towards decade of 90s. Considering the frequency of fog with a duration more than three hours it was found that frequency was maximum 21 (25%) in January followed by December, November and February. Also it showed that there was increase in mean frequency per year for the fogs with duration more than three hours from decade of 80s to decade of 90s for the four months period as a whole and also for individual months except December.

3.1.5. *Time of dispersal of fog*

Fig. 3 gives the time of dispersal of fog during different months- November, December, January and February. Maximum number of fogs 53 out of 194 fogs dispersed between 0801 and 0830 hr IST. Next 37 fogs dispersed between 0701 and 0730 hr IST followed by 33 occasions between 0730 and 0800 hr IST. In general, the following is the percentage of dispersal of fogs during different months by 0830 and 0900 hr IST:

Month	*By 0830 IST*	*By 0900 IST*
Nov	93%	100%
Dec	87%	91%
Jan	74%	87%
Feb	77%	90%

The above table shows that there is a late dispersal of fog during the months of January compared to other months.

3.2. *Forecasting of fog*

Various methods have been tried for objective forecasting of fog such as: (1) Persistence method, (2) Synoptic method, (3) Statistical method, (4) Tayler's method and (5) Composite method.

3.2.1. *Persistence method*

Persistence forecasts (*i.e.* repeat what happened during the last 24 hours) in the tropics have good chance of success in the mid seasons. During the transition from one season to another, when one quasi-steady pattern of mean meridional circulation and standing waves is changing into another, persistence forecast have slightly less chance of success (Asnani 1993). The results of the method of persistence are

TABLE 3

Results of different methods for 10 years period 1983-84 to 1992- 93

Methods	November					December				
	FF	FR	FA	Error (%)	F Exp (%)	FF	FR	FA	Error (%)	F Exp (%)
Persistence (F)	38	11	42	20	26	48	11	46	23.2	23.9
Persistence (F+M)	84	22	42	28.3	52.4	101	25	46	31.3	54.3
Synoptic	115	30	42	33.4	71.4	193	37	46	53.2	80.4
Statistical	69	18	42	22	43	131	31	46	37	67.4
Composite	104	32	42	28.3	76.2	112	35	46	28.4	76.1

TABLE 3 (Contd.)

Methods	January					February				
	FF	FR	FA	Error (%)	F Exp (%)	FF	FR	FA	Error (%)	F Exp (%)
Persistence (F)	80	38	84	28	45	24	2	22	15	9
Persistence (F+M)	148	57	84	38.1	67.9	76	6	22	30.4	27.3
Synoptic	213	75	84	47.4	89.3	158	17	22	51.6	77.3
Statistical	149	65	84	33	77	71	14	22	22	64
Composite (C)	137	63	84	30.6	75	127	17	22	40.6	77.3
Composite (C')	156	64	84	36.1	76.2					

FF - Fog forecast, FR - Fog forecast realised, FA - Fog actual, F- Fog, M- Mist,
F Exp — Fog explained = Number of fog forecast realised/Number of fog actual = FR/FA

Fig. 3. Dispersal of fog

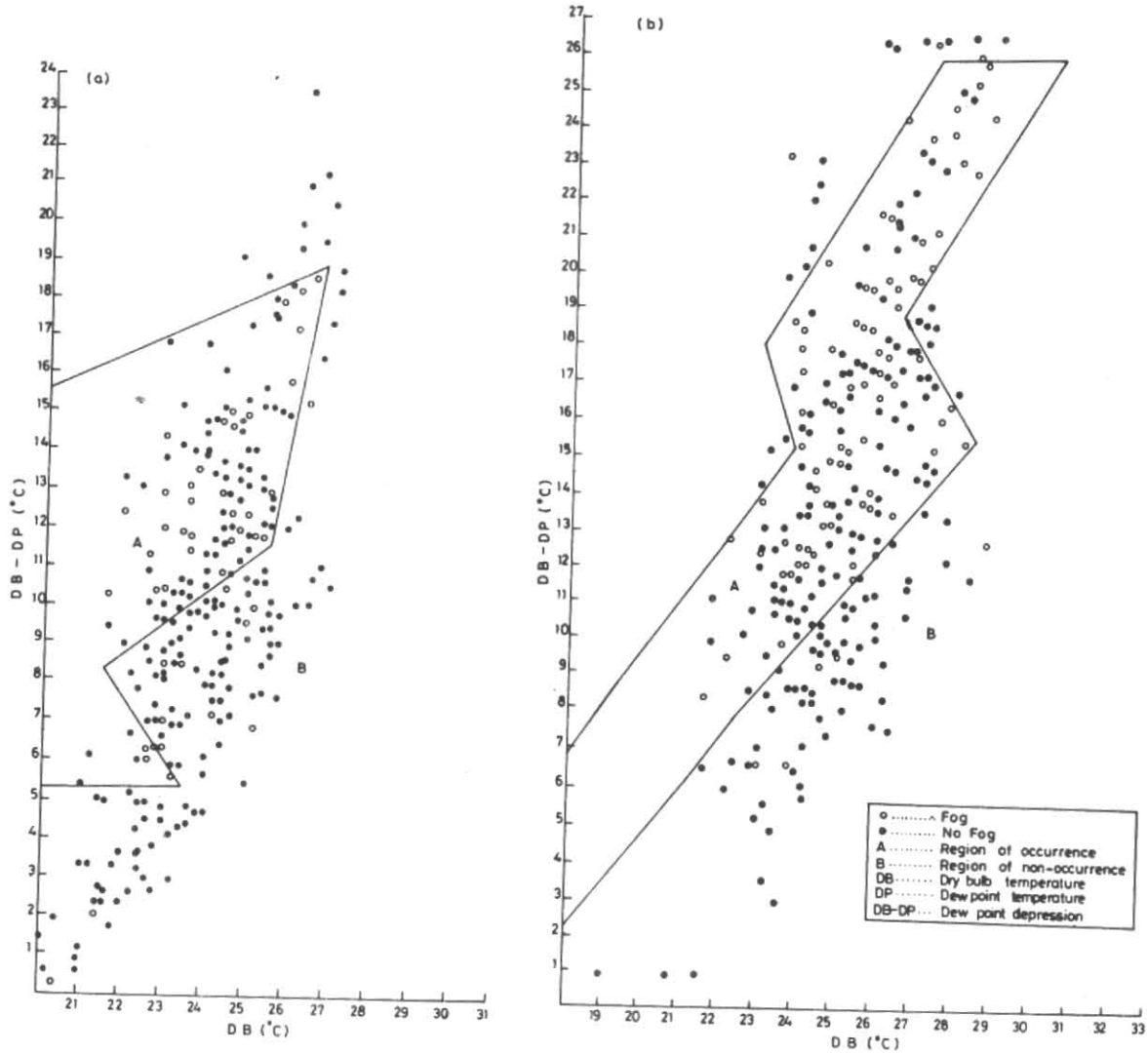
shown in Tables (3) & (4). It shows that accuracy of this method is maximum for the month of February followed by November, December and January. But the percentage of fog explained is highest for January followed by December, November and February. Hence the persistence method is more suitable for the month of January which has also the maximum frequency of occurrence of fog. This method cannot be used for the forecast of the first day of fog in the season.

3.2.2. *Modified Tayler's method (Prediction diagram method)*

Tayler (1917) devised a method to forecast fog on the basis of the dew point depression or difference in dry bulb and wet bulb temperature for calm and clear nights. He prepared the diagram by plotting the dew point depression as ordinates and the air temperature as the ascissa. After plotting the different values of dew point depression for different cases of air temperature, a dividing line can be drawn which will indicate the probability of fog. Fog being influenced by local factors these prediction diagrams should be modified. Hence the Tayler's diagram have been modified for Bangalore airport and are shown in Figs. (4 & 5). The data of 1730 and 2330 hr IST have been plotted to find the suitable diagram for prediction of fog in the next day morning. It is found that these diagrams give better results for the air temperatures recorded at 2330 IST of previous night. These diagrams are applied to the data of 1993-94 and the results are shown in Table 4. If the plotted point for a particular pair of values of the dew point depression and dry bulb temperature lies in the region marked as 'A', there is possibility of occurrence of fog. If it lies in the region 'B', there is possibility of non-occurrence of fog.

3.2.3. *Synoptic method*

The favourable conditions for the formation of radiation fog are: (1) clear sky, (2) light wind and (3) high relative



Figs. 4(a & b). Prediction diagrams based on 1730 IST observation for (a) December and (b) January

humidity. Hence the sky with scattered (4 octa or less) cloud condition with wind speed less than or equal to 6 kt and relative humidity with threshold values have been considered. These conditions are applied to the observations of 1730 and 2330 IST of previous day, and it is found that the forecasts based on 2330 IST observations are more accurate.

The results and accuracy of this method show that the values of RH are greater than 71%, 71%, 61% and (56-90%) for November, December, January and February respectively. This method applied to the data of 2330 IST explained 71.4%, 80.4%, 89.3% and 77.3% of fogs with errors of 33.4, 53.2, 47.4 and 51.6% for the months of November, December, January and February respectively over the period of 10 years.

3.2.4. *Statistical method*

In this method the simple correlation co-efficients (CC) were calculated between frequency of fog and frequency of cloud coverage (C), relative humidity (H), wind speed (W) all at 2330 IST respectively for the four months. Then a threshold value was found out by adding the correlation co-efficients, *i.e.*, (C+H+W)CC. It was assumed that if the synoptic condition at 2330 IST yields the value of correlation co-efficient greater than the threshold value, then the fog could occur in the next day early morning. The threshold values are greater than 1.5, 1.03, 1.61, 1.56 for November, December, January and February respectively. It explained 43, 64.7, 77 and 64 percent of fogs with the errors of 22, 37,

TABLE 4 (a)
Verification of forecasting techniques
November 1993

Methods	FF	FR	MR	FA	MA	Error (%) (F) =	Error (%) (F+M)=	F Exp %	M Exp %	F+M Exp %
Persistence (F)	07	03	02	07	06	27.6 (8)	34.5 (10)	42.86	33.3	38.5
Persistence (F+M)	12	05	04	07	06	31.0 (9)	24.1 (7)	71.4	66.7	69.2
Synoptic	13	06	02	07	06	27.6 (8)	34.5 (10)	85.7	33.3	61.5
Prediction diagram 1730 IST	13	06	04	07	06	27.6 (8)	20.7 (6)	85.7	66.7	76.9
Prediction diagram 2330 IST	13	07	01	07	06	20.7 (6)	34.5 (10)	100	16.7	61.5
Composite (A)	14	06	05	07	06	31.0 (9)	17.2 (5)	85.7	83.3	84.6

TABLE 4 (b)
December 1993

Methods	FF	FR	MR	FA	MA	Error (%) (F) =	Error (%) (F+M)=	F Exp %	M Exp %	F+M Exp %
Persistence (F)	08	04	03	08	08	25.8 (8)	29.0 (9)	50.0	37.6	43.7
Persistence (F+M)	17	08	05	08	08	29.0 (9)	22.6 (7)	100	62.5	81.3
Synoptic	18	08	05	08	08	32.3 (10)	25.8 (8)	100	62.5	81.3
Prediction diagram 1730 IST	07	04	02	08	08	22.6 (7)	35.5 (11)	50.0	25.0	37.5
Prediction diagram 2330 IST	18	08	05	08	08	32.3 (10)	25.8 (8)	100	62.5	81.3
Composite (B)	13	07	03	08	08	22.6 (7)	29.0 (9)	87.5	37.5	62.5

MR - Mist forecast realised, MA - Mist actual
M Exp — Mist explained-Number of mist forecast realised/Number of mist actual = MR/MA

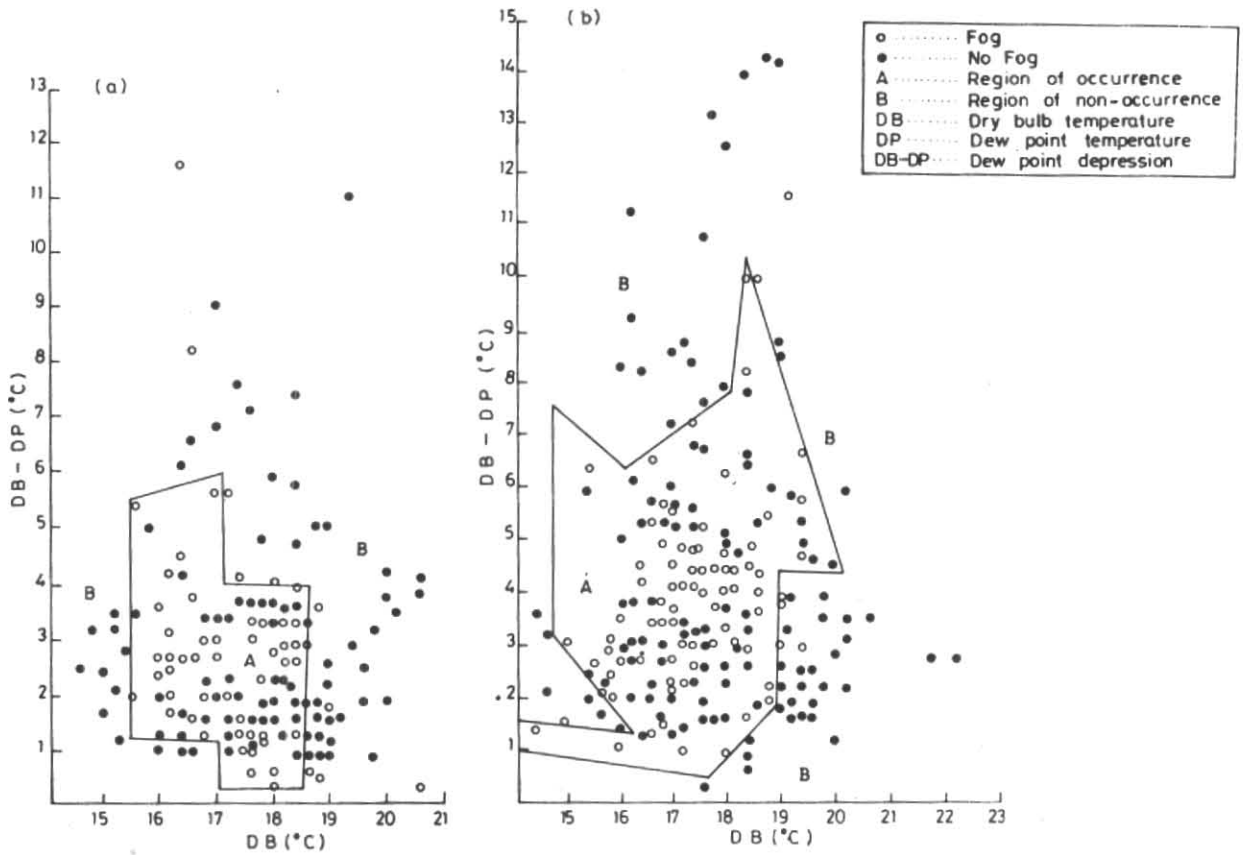
TABLE 4 (c)
January 1994

Methods	FF	FR	MR	FA	MA	Error (%) (F) =	Error (%) (F+M)=	F Exp %	M Exp %	F+M Exp %
Persistence (F)	12	03	05	12	11	58.1 (18)	61.3 (19)	25.0	45.5	34.8
Persistence (F+M)	22	08	09	12	11	58.1 (18)	35.5 (11)	66.7	81.8	73.9
Synoptic	27	12	09	12	11	48.4 (15)	25.8 (8)	100	81.8	91.3
Prediction diagram 1730 IST	16	09	06	12	11	32.3 (10)	29.0 (9)	75.0	54.5	65.2
Prediction diagram 2330 IST	18	10	07	12	11	35.5 (11)	25.8 (8)	83.3	63.6	73.9
Statistical	18	07	07	12	11	38.7 (12)	29.0 (9)	75.0	63.6	69.6
Composite (C)	13	07	05	12	11	35.5 (11)	38.7 (12)	58.3	45.4	52.2
Composite (C')	13	08	04	12	11	29.0 (9)	38.7 (12)	66.7	36.4	52.2

TABLE 4 (d)
February 1994

Methods	FF	FR	MR	FA	MA	Error (%) (F)=	Error (%) (F+M)=	F Exp %	M Exp %	F+M Exp %
Persistence (F)	05	02	03	06	10	25.0 (7)	39.3 (11)	33.3	30.0	31.3
Persistence (F+M)	15	05	06	06	10	39.3 (11)	32.1 (9)	83.3	60.0	68.7
Synoptic	26	06	09	06	10	71.4 (20)	42.9 (12)	100	90.0	93.7
Prediction diagram 1730 IST	03	00	01	06	10	21.4 (6)	60.7 (17)	00	10.0	6.0
Prediction diagram 2330 IST	13	03	06	06	10	46.4 (13)	39.3 (11)	50.0	60.0	56.3
Statistical	20	05	07	06	10	57.1 (16)	42.9 (12)	83.3	70.0	75.0
Composite (D)	11	05	05	06	10	25.0 (07)	25.0 (07)	83.3	50.0	62.5

FR - Fog forecast realised, FA - Fog actual, F Exp - Fog explained



Figs. 5 (a & b). Prediction diagram based on 2330 IST observation for (a) December and (b) January

33 and 22 percent for the month of November, December, January and February respectively over ten years.

3.2.5. *Composite method*

Finding the threshold values of change in dry bulb and wet bulb temperatures alongwith the change in relative humidity, it may be possible to forecast fog. In addition, threshold value of dry bulb temperature is taken to consider specific heat and threshold value of wind speed is taken to take care of turbulence. This principle has been applied in composite method.

In this method, in addition to the threshold values of relative humidity (H), wind speed (W) and dry bulb (DB) and wet bulb (WB) temperatures at 2330 hr IST, also the threshold values of change in the dry bulb and wet bulb temperatures from 1730 IST to 2330 IST (ΔDB & ΔWB) and the changes in relative humidity from 1730 IST to 2330 IST (ΔH) are calculated. There are four different composite methods for four different months. Different parameters are found useful for different months. The results of the composite methods for four months over 10-year period and for the four months of 1993-94 are shown in Tables 3 and 4 respectively. These methods are devised with an objective of issuing atleast 75% correct fog forecast with minimum percentage of error when the forecast for both occurrence and non-occurrence of fog is considered. Composite methods A, B, C, C′ and D explain 76.2, 76.1, 75, 76.2 and 77.3 percent of fogs with the errors of 28.3, 28.4, 30.6, 36.1, and 40.6 percent respectively over ten years period.

4. Conclusions

The different methods have been applied to the four months *viz.*, November, December, January and February data of 1993-94 to find out the accuracy of the methods.

It is found that the composite method gives best results for different months followed by prediction diagram method applied to the data of 2330 IST.

The salient features of this study have emerged as follows:

(*i*) The frequency of fog, mist and fog/mist was maximum in January and that of haze was maximum in February. The frequency of fog decreased from January to December, November and February.

(*ii*) The average frequency of fog, fog/mist, fog/mist/haze increased from the decade of 80s to the decade of 90s. Student's 't' test showed a significant increase in mean frequency of fog from decade of 80s to the decade of 90s. Also duration and intensify of fog increased from decade of 80s to decade of 90s, being significant according to one tailed Student's 't' test.

(*iii*) The composite method is suitable for issue of forecast at 2330 IST for the fog on next day morning. Next to the composite method, prediction diagram method (2330 IST) is also suitable for forecast of fog.

(*iv*) Forecast can be issued at 1730 IST by the prediction diagram method for occurrence of fog on the next day morning. It gives suitable results for the month of November and January. However, these forecasts can be ammended at 2330 IST by composite methods or prediction diagram method after applying to the data of 2330 IST.

(*v*) While issuing the forecast at 0830 IST for the fog in the next day morning, the method of persistence may be used with the prevailing synoptic situation over the region. The method of persistence is more suitable for the month of December and January and when forecast is issued for fog/mist.

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References

Sreenivasaiah, B.N., 1944, "Fog, mist and haze at Bangalore", Tech. Note No. 12, India Met. Deptt.

Tayler, G.I., 1917, "The formation of fog and mist", *Quart. J. Roy. Meteor. Soc.*, **43**, 241-268.