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A method for forecasting visibility at Hindon

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सार - इस समय दृश्यता पूर्वानुमान का दृष्टिकोण सिनाप्टिक और पूर्वानुमानकर्ता के मौसम पूर्वानुमान के व्यक्तिगत अनुभवों पर आधारित है। शीत ऋतु के दिसम्बर के महीनों में दृश्यता बहुत अस्पष्ट होती है। वायुयान चालकों को निश्चित अवधि में निश्चित स्थान पर निश्चित मात्रात्मक मान के अनुसार दृश्यता पूर्वानुमान की आवश्यकता होती है। अतः इस अध्ययन में दिल्ली के निकट हिंडन नामक स्थान पर दिसम्बर माह में दृश्यता पूर्वानुमान के लिए मात्रात्मक रूप में अनुकूल निदर्श को विकसित करने का प्रयास किया गया है।

दृश्यता पूर्वानुमान की विकासात्मक प्रक्रिया में स्वसमाश्रयण, बहु समाश्रयण, जलवायु विज्ञान और स्थायित्व जैसी विभिन्न पद्वतियों को अपनाया गया है। दिसम्बर माह के सात वर्षों के आँकड़ों (1984-1990) का उपयोग करते हुए निदर्शों का विकास किया गया है। इस निदर्श का मूल्यांकन 1994-95 के हाल ही के वर्षों के प्राप्त स्वतंत्र ऑकड़ों के सेटों के साथ किया गया है इसमें यह पाया गया है कि बहु समाश्रयण और स्व-समाश्रयण पद्वतियों की तुलना में जलवायु विज्ञान की स्थायित्व पद्वति बेहतर परिणामों को उपलब्ध कराती है इस निदर्श की विकसित स्थिति में स्वतंत्र आँकड़ा सेटों के साथ इसकी अधिकतम 70 प्रतिशत की सकारात्मक क्षमता का पता चलता है।

ABSTRACT. At present the approach to forecasting visibility is synoptic and personal experience of the weather forecaster. The month of December typically a winter month, is associated with poor visibility. Aviators require visibility forecast in terms of a definite quantitative value at a specific place in specific time frame. Therefore, in this study an attempt is made to develop a suitable model for forecasting visibility in December at a place Hindon near Delhi in a quantitative manner.

In the development process of forecasting visibility, different approaches such as auto-regression, multiple regression, climatology and persistence have been attempted. The models are developed using seven years (1984-90) data of December. The model is evaluated with the independent data sets from the recent years 1994-95. It is found that climatology-persistence method provides better results as compared to the multiple regression and auto-regression methods. The developed model provided positive skill scores as high as 70% on development as well as independent data sets.

Key words — Visibility, Climatology, Forecasting methods, Skill scores.

1. Introduction

Horizontal visibility is a very important weather element in aviation. It is equally important in road, rail and sea transportation, and also in many defence and civil operations. On a regular basis, there is demand from a flight planner who requires forecast of the visibility condition at an aerodrome of departure and landing at a pre-determined time. To forecast visibility at a pre-determined time, one must have the knowledge and information about the occurrence/non-occurrence of weather phenomenon such as fog/mist, precipitation, dust storm *etc*., their intensity as well as the output of pollutants by various industries or other human activities such as house hold smoke, dust or smoke due to agriculture and other industrial operations. Thus, the forecasting of visibility at a location is very complex and difficult problem and requires information on many variates.

Hindon and neighborhood are affected by poor visibility in winter months (December-February). The poor visibility has some diurnal element into it. Apart from the effects produced by synoptic systems in the form of clouds, rain, drizzle, fog and mist, the changes in the thermal stability and wind conditions in the

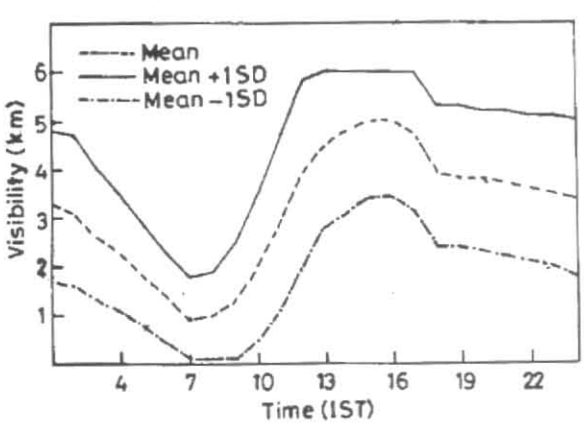


Fig. 1. Hourly values of mean and standard deviation of visibility for December at Hindon

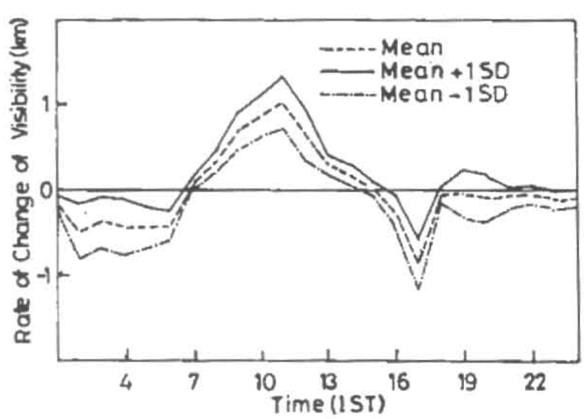


Fig. 2. Hourly values of mean and standard deviation of rate of change of visibility for December at Hindon

boundary layer also affect the visibility considerably. At present, most of the approaches to forecasting visibility are synoptic coupled with some sort of personal experience of the weather forecaster. However, with modern advancement and sophisticated technological developments, there is a need for accurate and quantitative forecast of visibility at each hour from any given initial time for a further period of 12 to 24 hours for better operational planning. Since December month is a typical winter month of poor visibility conditions, it is proposed to study and develop a method for forecasting visibility in December at Hindon a place near Delhi.

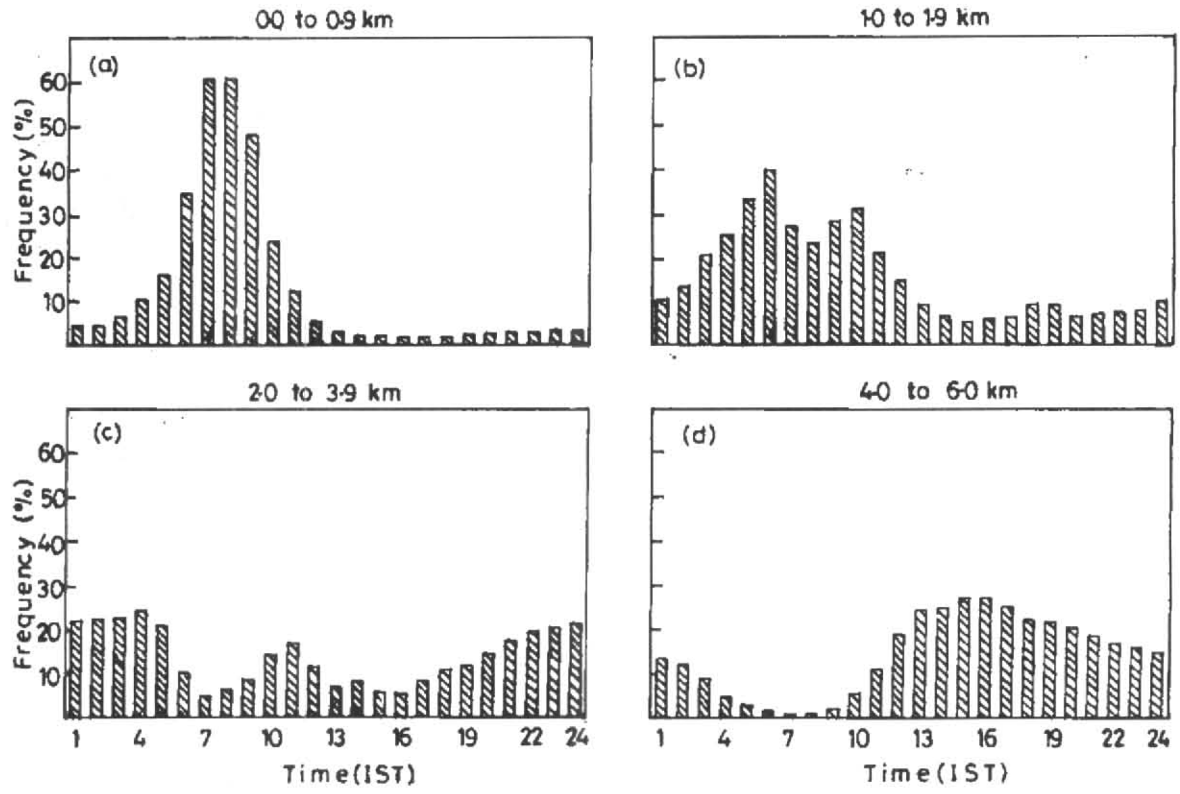
Survey of the literature, particularly pertaining to studies of visibility over Indian region such as Chandiramani *et al*,(1975), Bajpai (1980), Mukherjee *et al.*, (1980), Suresh (1994) *etc.* bring out that most of the methods to forecast visibility are subjective in nature and do not fulfil the specific requirement of the aviators for a quantitative forecast.

In Europe and USA at some locations, with facilities to monitor continuously the concentration of pollutants, reliable actual and forecast of surface and lower tropospheric wind, temperature and moisture fields in time and space, has resulted in the development of models which provide forecast of the visibility conditions in time and space. In India, other than current weather observations of the visibility, the other data such as regular measurement of air quality and pollutant concentration are not available and hence to tackle the problem of visibility forecast, one has to heavily depend on the synoptic and historical data. One such location where the necessity of developing a methodology to predict visibility quantitatively for operational requirements is a location 15 km to the northeast of Delhi that is considered in this study. In its vicinity, there are industrial units of Mohan Nagar, Sahibabad and extensive residential colonies such as Shahdara *etc.* and the location is situated close to the rivers Yamuna and Hindon. Therefore, an attempt is made to develop a suitable quantitative method for forecasting visibility at the selected site in December at each hour for next 24 hours.

2. Data and analysis procedure

In India, visibility is estimated in steps of 50m upto 500m, in steps of 100m upto 5 km and in steps of 1 km above 5 km (India Meteorological Department, 1994). At some of the modern airports, when the visibility reduces below 2 km, it may be measured by means of well-known sophisticated instrument such as Skopograph *etc.*, while at other observatories where this facility is not available, the visibility is estimated by an observer by making use of run-way markers or other objects whose distances from the point of observation are well known. In practice, the pre-determined distance of stationary objects such as buildings, water-tanks, towers, sheds *etc.*, in the vicinity of the observation point are used to measure horizontal visibility. At Hindon the selected place of present study, instrument such as Skopograph is not available and hence the observations are estimated and the same data are utilised in the development and testing of forecast models.

The place of study has a reasonably long series of surface meteorological data consisting of surface wind, drybulb and dewpoint temperatures, visibility, maximum/minimum temperature, clouds, rainfall *etc.* The data used for development of forecast models are hourly current weather observations as well as synoptic observations for the month of December for the period



Figs. 3 (a-d). Frequency distribution (%) of visibility at each hour in the horizontal range: (a) 0.0 to 0.9 km, (b) 1.0 to 1.9 km, (c) 2.0 to 3.9 km and (d) 4.0 to 6.0 km

1984-90. In addition, radiosonde data of Delhi at 0000 and 1200 UTC are also utilised. The developed model is tested with independent data sets of December for the recent years of 1994 and 1995.

3. Characteristic features of visibility at Hindon

As a first step in the development of a quantitative method, a study on the characteristic features of climatology of visibility at Hindon have been carried out. For this purpose, the development as well as independent data sets are utilised. Average hourly visibility during the month of December along with ± 1 standard deviation is given in Fig. 1. From this figure, it is observed that the lowest visibility on daily basis occurs between 0700 to 0800 hrs (IST) and highest between 1500 to 1600 hrs (IST). The average hourly rate of change of visibility along with ± 1 standard deviation is given in Fig 2. It is seen from this figure that the highest rate of change of visibility occurs at 1100 and 1700 hrs (IST), which is due to the rapid improvement and deterioration of visibility around these times. The distribution of visibility at each hour covering the ranges 0.0 to 0.9 km, 1.0 to 1.9 km, 2.0 to 3.9 km and 4.0 km & more are given in Figs. 3 (a-d). It is seen from Figs. 3 (a & b) that poor to very poor visibility conditions are encountered daily between 0500 and 1000 hrs (IST) but infrequently the poor visibility conditions could develop at any other time of the day also, which are mainly due to either intermittent/continuous precipitation or fog/mist presisting for longer duration in the day. Figs. 3 (c & d) indicate that even between 0500 and 1000 hrs (IST), there are a few days when the visibility could exceed 4.0 km. The best visibility conditions are observed between 1300 to 1700 hrs (IST) during the month of December.

As the visibility at a specific location depends upon other meteorological elements such as drybulb and dewpoint temperatures, relative humidity, cloud amount *etc.*, correlation study has been carried out to find the nature of their relationship with visibility.

TABLE 1

Correlation coefficient between visibility, cloud cover and surface wind

Time (IST)	Correlation coefficient				
	Cloud	Surface wind Zonal-component		Surface wind Meridional-component	
		(+)	(-)	(+)	(-)
0100	-0.23	0.04	-0.53	0.01	-0.05
0200	-0.18	0.00	-0.62	-0.06	-0.06
0300	-0.16	0.09	-0.67	0.04	-0.04
0400	-0.12	0.22	-0.44	0.11	0.04
0500	-0.11	0.37	-0.42	0.28	-0.14
0600	-0.08	0.45	-0.39	0.53	-0.03
0700	0.01	0.59	-0.38	0.50	-0.11
0800	-0.02	0.53	-0.34	0.55	-0.35
0900	-0.07	0.63	-0.52	0.50	-0.37
1000	-0.10	0.63	-0.06	0.33	-0.44
1100	-0.17	0.57	-0.45	0.29	-0.45
1200	-0.26	0.55	-0.25	0.46	-0.39
1300	-0.40	0.45	-0.11	0.41	0.32
1400	-0.38	0.42	-0.22	0.39	-0.32
1500	-0.42	0.37	-0.06	0.21	-0.27
1600	-0.40	0.32	0.34	0.10	-0.16
1700	-0.26	0.34	0.42	0.14	-0.00
1800	-0.16	0.10	-0.25	-0.00	0.31
1900	-0.16	0.04	-0.33	-0.02	0.06
2000	-0.23	0.02	-0.20	-0.04	-0.03
2100	-0.27	-0.03	-0.15	-0.07	-0.00
2200	-0.27	0.01	-0.22	-0.04	0.00
2300	-0.28	0.01	-0.53	-0.09	0.02
2400	-0.25	0.01	-0.39	0.02	-0.08

In order to study the effect of clouds, visibility at each hour is correlated with total amount of clouds reported at that hour and it is found that visibility has a negative correlation with clouds as indicated in Table 1. Examination of the plotted current weather sheets of the station indicate that with the presence of clouds the visibility does deteriorate, though not necessarily. Further, the frequency of deterioration of visibility is higher when the clouds approach the station rather than when they recede. The increase in cloudiness results in decrease of solar radiation which decreases the heating of the surface and layer of air in immediate contact with it. Thus, the diurnal process of improvement in visibility may be slowed. Further, if the moisture increases in the layer close to ground during the presence of clouds, haze/mist may be formed and it takes a longer time to dissolve or

TABLE 2

Correlation coefficient between visibility, temperature and humidity

Time	Drybulb Temperature	Dewpoint Temperature	Relative Humidity
0230	0.04	-0.04	-0.32
0530	0.24	-0.34	-0.44
0830	0.44	-0.54	-0.43
1130	0.33	-0.43	-0.41
1430	0.39	-0.42	-0.51
1730	0.16	-0.26	-0.24
2030	0.06	-0.16	-0.35
2330	0.05	-0.25	-0.49

disperse. The change in the stability conditions close to the ground during the presence of clouds would also play an important role in the variation of the visibility.

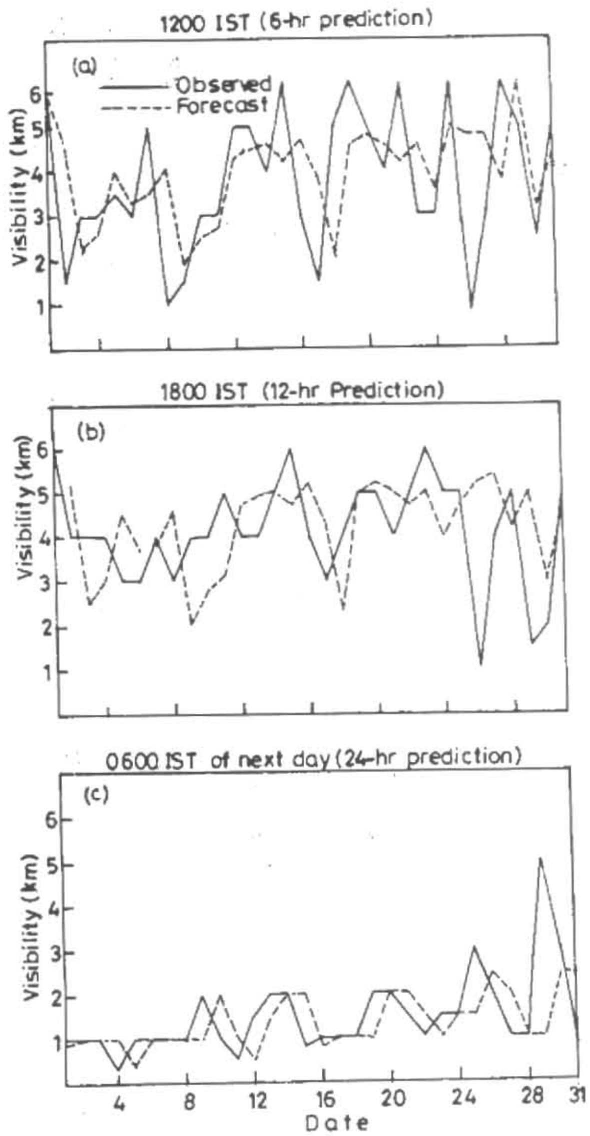
To understand the relationship between surface wind and visibility, the surface wind at each hour has been resolved into zonal (u) and meridional (v) components and correlation coefficients with visibility are calculated. Relationship of visibility with direction of wind, irrespective of the speed, for six ranges (from 0 to 6 km in steps of 1 km) has also been investigated by polar diagram. The study of relationship of surface wind with visibility does not bring out any systematic relationship between these two parameters except that with northerly and easterly surface wind, the likelihood of reduced visibility condition is more frequent. During the month of December at Hindon, the surface wind is predominantly from westerly-northwesterly (W-NW) direction and changes to easterly-southeasterly (E-SE) at the approach of a synoptic system from the west. The E-SE wind at the surface or in the boundary layer is known to be associated with warm and moist air, which may also carry with it low or medium clouds which inturn affect the visibility. The visibility of 4 km or less is seen to be associated with all directions of surface wind. Further, stronger wind speeds of the order of 8-10 kts or more are usually not associated with poor visibility except when it is raining. The visibility is rather poor during calm or very light and variable surface wind conditions.

The relationship between visibility and relative humidity, drybulb and dewpoint temperatures are also examined and the results of correlation study are given in Table 2. The visibility has a negative correlation with relative humidity and dewpoint temperature and a positive correlation with drybulb temperature. It is thus inferred that a combination of clouds, increased moisture, light surface wind and temperature inversion close to the ground lead to poor visibility conditions.

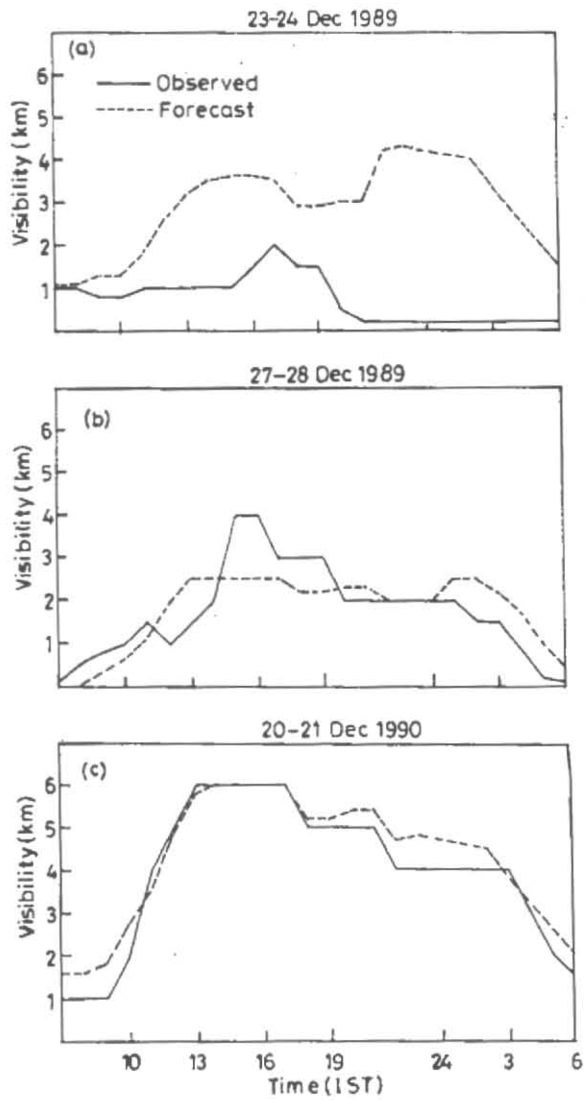
4. Computational method

There is a need to predict visibility at the specific location and in a time frame of twelve to twenty four hours in advance commencing at any time of the day, say from 0700 hrs (IST) in the morning. It is also essential that the method should be flexible so that the forecast can be updated at any time. The visibility is reduced due to weather phenomenon such as fog/mist/haze and rain/drizzle. In order to solve this complex problem, initially two different approaches such as multiple regression and auto-regression following Draper and Smith (1981) are attempted to evolve appropriate prediction equations (a set of 24 equations) for each hour. The set of equations for each hour are developed and tested with the developmental as well as the independent data sets. It is found on comparison with the realised values that the forecasts had large deviations and the forecasts are not satisfactory beyond six hours from the initial time. It is also found while screening of predictors in the regression method that, though surface observations from the neighboring stations are used as predictors, their contribution towards explaining the daily variance of the visibility is small. It is thus felt that local parameters of the location contribute more significantly in the day-to-day variability of the visibility than advection features. Hence, another approach based on climatology and persistence is attempted. This method is simple and provides satisfactory results over a forecast timescale of up to a day in advance. The detailed formulation of the method is given below.

The climatology of visibility at the place of study shows a vary stable diurnal cycle in winter months. Further, this region is affected by 4-5 synoptic disturbances known as western disturbances per month and remain under the influence of these disturbances for 10-12 days in a month. Therefore, it was felt that a combination of climatology and persistence may be a better guide to forecast visibility as compared to regression methods. In order to reduce existing large variance in visibility, The visibility observations exceeding 6 km are treated as 6 km only. This cut off limit of 6 km does not affect the operational value of visibility to the aviator. Based on seven years (1984-90) data set, average rate of change of visibility at each hour are used to produce 24-hour visibility forecast. Starting with visibility at any given hour, and using the average rate of



Figs. 4 (a-c). Observed (—) and forecast (...) of visibility [unit in km] in December, 1990 for (a) 1200 IST (6-hr prediction), (b) 1800 IST (12-hr prediction) and (c) 0600 IST of next day (24-hr prediction)



Figs. 5 (a-c). Observed (—) and 24-hr forecast (...) of visibility [unit in km] (from 0700 IST to 0600 IST of next day) for (a) 23-24 December 1989, (b) 27-28 December 1989 and (c) 20-21 December 1990

change, the visibility forecast can be produced upto 24-hours in advance as given in equation below:

$$V_T = V_0 + \left(\frac{\Delta V}{\Delta T}\right)_1 + \left(\frac{\Delta V}{\Delta T}\right)_2 + ... + \left(\frac{\Delta V}{\Delta T}\right)_T \qquad (1)$$

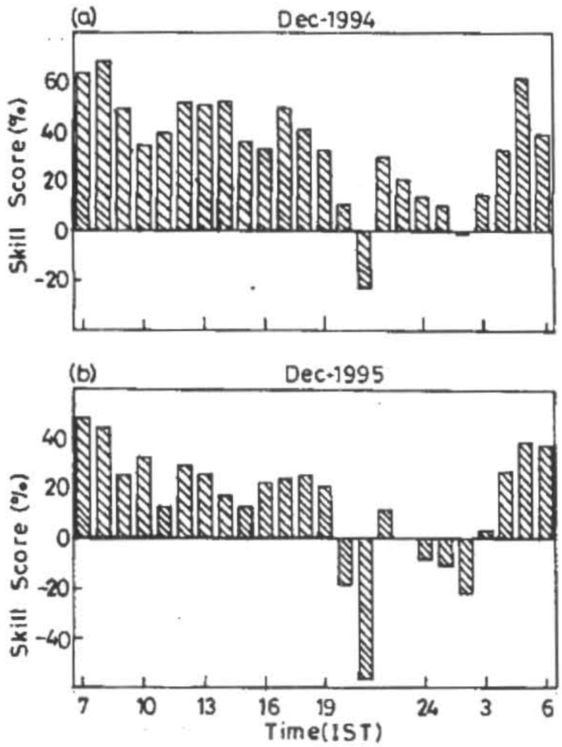
where V_T = Visibility at any time

V_0 = Visibility at the initial time

T = Time upto which the forecast visibility is required and

$\frac{(\Delta V)}{(\Delta T)}$ = Climatological rate of change of visibility.

This forecast on comparison with the realised value is found to further improve, if forecast at certain hours are multiplied by a weightage factor. The weightage factor is based on the actual visibility from 1200 to 1800 hrs (IST) of the previous day was developed on the basis of auto correlation studies of visibility. Since the weightage factor is based upon the previous day visibility,



Figs. 6 (a&b). Distribution of skill scores (%) at each hour with the independent data sets for (a) December 1994 and (b) December 1995

persistence has a definite role and hence the method is called climatology-persistence method. This weightage factor is used to improve the forecast between 1000-2100 hrs (IST).

5. Results and discussion

The climatology-persistence method has been found to provide much better results as compared to multiple regression and auto-regression methods. Therefore, the results of the climatology-persistence model with both developmental as well as independent data sets are presented and discussed. The possible reasons for large deviation in the forecast in certain cases are also examined and explained.

5.1. *Performance of the model with developmental data*

The model to forecast visibility is developed using the data for month of December for the period 1984-90. Using eqn. (1), forecasts are generated for the next 24 hours, starting from 0700 hrs (IST), though it could be started at any time. The observed and forecast values of visibility for 6, 12 and 24-hr projections, namely at 1200, 1800 hrs (IST) of the same day and 0600 hrs (IST) of the next day on all 31 days for one year of the developmental data set (December 1990) are given in Figs. 4 (a-c). It is noticed that at time large deviations are noticed particularly around 1100-1200 and 1700-1800 hrs (IST). This could possibly be due to the fact that these periods happen to be close to the points of inflection and the rate of change of visibility is highest as is evident from Fig. 2. The deviation of the forecast on some of the days is also due to occurrence of fog/smoke haze or precipitation continuing throughout the day and not captured adequately by the model. The 24-hr forecasts along with observed values for randomly selected three days (23-24 December 1989, 27-28 December 1989, 20-21 December 1990) were generated by the model and are given in Figs. 5 (a-c). The forecasts are produced as follows. To the observed visibility at 0600 hrs (IST) of the day, the average hourly rate of change of visibility as given in Fig. 2 is applied to produce a 24-hour forecast. This 24-hour forecast is further multiplied by a weightage factor. The weightage façtor is applied to the forecast visibility between 1000 to 2100 hrs (IST). The weightage factor algorithm is based on the actual visibility from 1200 to 1800 hrs (IST) of the previous day as stated earlier. 23-24 December 1989 was a day when the visibility was extremely poor (mostly less then 1 km) throughout the day mainly due to persistent fog and the model could not reproduce the conditions very well. 27-28 December 1989 was a day when the visibility was poor throughout the day but due to persistent mist/smoke haze and the model is able to reproduce it reasonably well. 20-21 December 1990 was a normal day in December and the forecast matches very well with the actual conditions. Thus examination of the forecasts with developmental data set indicated that the model is able to generate reasonably good forecasts.

5.2. *Performance with independent data*

The model is also tested with independent data sets of December 1994 and 1995. The visibility forecasts produced by the model alongwith the observed values of visibility for 6, 12 and 24-hr projections, namely at 1200, 1800 hrs (IST) of the same day and 0600 hrs (IST) of the next day for December 1994 and 1995 were compared (figures not presented). It is observed that a few times significant departures are noticed, particularly around 1100-1200 hrs (IST). This, as stated earlier could be due to rapid improvement and likely error at the point of inflection in measuring the rates. The other reasons are presistent fog throughout the day or precipitation. Thus, it is noticed that the model is able to reproduce the actual visibility conditions on independent data set also, but with a few exceptions. On examination of the data of days of

TABLE 3

Forecast error analysis of the dependent and independent cases with large deviation in prediction of visibility in the month of December (model - developed model; clim – climatology)

Year	Time	Date(s)	Forecast		Observed	Absolute error		RMSE		Skill Score % (SS)	Improvement in SS (%)
			model	clim		model	clim	model	clim		
					Developmental Data						
1990	1200	2	4.7	3.8	1.5	3.2	2.3	1.66	1.61	-6.31	11.53
		26	4.8	3.8	0.8	4.0	3.0				
1990	1400	2	6.0	4.8	2.0	4.0	2.8	2.05	1.74	-38.8	21.2
		8	5.7	4.8	1.5	4.2	3.3				
		18	2.8	4.8	6.0	3.2	1.2				
		23	6.0	4.8	1.5	4.5	3.3				
		26	6.0	4.8	1.0	5.0	3.8				
					Independent Data						
1994	2100	12	5.5	3.8	3.0	2.5	0.8	1.60	1.44	-23.46	+9.2
		18	4.0	3.8	1.0	3.0	2.8				
		22	4.8	3.8	2.0	2.8	1.8				
		30	5.3	3.8	3.0	2.3	0.8				
1995	2000	21	5.3	3.8	0.6	4.7	3.2	1.48	1.36	-18.4	+8.2

large deviation of forecasts, it was found that the model does not react fast enough under the following circumstances :

(a) Around 1100 and 1700 hrs (IST), when the rates of improvement or deterioration respectively are the fastest. These times happen to be the points of inflection in the visibility rates as noticed in Fig. 2.

(b) Continuous fog or rain prevails throughout the day.

5.3. *Error analysis and skill score*

For the purpose of evaluating the sill of the developed method, mean absolute error (MAE) and root mean square error (RMSE) are calculated. It is found that the MAE varies between 0.25 and 1.5 km and RMSE between 0.26 and 1.9 km, in both the developmental as well as the independent data. The higher magnitude of errors are found particularly between 1000 hrs (IST) in the morning to 2300 hrs (IST) in the midnight, when the visibility is usually between 3.0 and 6.0 km. The RMSE of the forecasts generated using climatology is also estimated and the skill score at each hour is evaluated using the relation :

$$\text{Skill Score} = \left[1 - \frac{(\text{RMSE}_{\text{forecast}})^2}{(\text{RMSE}_{\text{climatology}})^2}\right] * 100\% \qquad (2)$$

The results of the skill score evaluation for the developmental data and the independent data sets indicate that the developed model exhibits skill over pure climatology, consistently both in the developmental as well as independent data sets except that between 1500-

0300 hrs (IST), especially in the year 1990 (for the developmental data) the model exhibits negative skill. The skill score in respect of independent data sets of December 1994 and 1995 are given in Figs. 6 (a &b) respectively and it indicates a few negative skill scores.

The investigation of the causes of the negative skill score in December 1990, 1994 and 1995 are carried out to and the reason fór the large value of RMSE of the model. The analysis of the individual forecasts indicated that the large values of error (forecast-realised) are found on those days when fog persists throughout the day and is associated with large cloud cover with or without precipitation. The results of the analysis are presented in Table 3, for the development as well as independent test data sets. The analysis is carried out for two randomly selected hours for December 1990, namely 1200 and 1400 hrs (IST). At 1200 hrs (IST), the skill score is –6.31. The RMSE at 1200 hrs (IST) has contribution of two large deviations that occurred on 2 and 26 December 1990. It is found from the hourly current weather observations that thick smoke haze persisted for a much longer duration with cloud cover on these two days.

In case if these two cases associated large errors are removed from the data sample used in both the model and climatology for this date, then the skill score becomes +11.53%, *i.e.* the RMSE of the model reduces. This analysis thus establishes that the model has a definite skill over that of climatology. Similarly forecast and realised values and the deviation are analysed on all days at 1400 hrs (IST). It is found that the model has large deviation on 5 days namely, 2, 8, 18, 23 and 26 December 1990 as indicated in Table 3. The cause of poor visibility and large deviation on 2, 8, 23 and 26 December 1990 are due to persistent thick smoke haze throughout the day. It is seen that the removal of the deviation from both the model and climatology yielded a positive skill score of 21.2%. It is also observed that the number of days of persistent fog/smoke haze throughout the day in December 1990 are higher than the rest of the years.

The error analysis of independent data sets also leads to similar results. The large deviation in the forecasts as observed in Table 3, are found to be due to fog/smoke haze and cloud cover persisting for a much longer duration during the day.

Thus, it is evident from the error analysis that the model shows definite and the positive skill in the forecasts. It is also evident that the model performed better than the climatology as it gives positive skill scores except at certain hours where the model did not perform well due to the reasons stated earlier. The performance with the independent data sets in 1994 and 1995 consistently yielded better results, except at 2100 hrs (IST) in both 1994 and 1995 and 2400-0200 hrs (IST) in 1995.

6. Conclusion

In This study, a method combining climatology and persistence is developed for forecasting visibility at each hour at Hindon. The developed model is tested with independent data sets. From this study, the following broad conclusions are drawn.

(*a*) In the month of December, the lowest visibility values are encountered between 0700-0800 hrs and the highest between 1500-1600 hrs IST

(*b*) The highest rate of change of visibility takes place around 1100 and 1700 hrs IST.

(*c*) It is found that the climatology-persistence method is able to produce reasonably accurate forecasts. This method yielded positive skill scores as high as 70%.

The rates of change of visibility at each hour would need to be updated at a suitable interval of time say every 5 years, depending upon the installation, shifting, relocations of the smoke/ pollutant producing units and other sources of smoke around the observation site. The model, though developed for the month of December, can be suitable modified to predict the visibility condition of other winter months and may be extended to other places.

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