MAUSAM, 52, 4 (October 2001), 717-726

551.5 : 504

Visibility over Indian airports during winter season

U. S. DE, G. S. PRAKASA RAO

and

A. K. JASWAL

Meteorological Office, Pune-411 005, India

(*Received 21 August 2000, Modified 16 May 2001*)

सार - हवाई अड्डों पर हवाई जहाज़ों के उड़ने और उतरने के समय दृश्यता की भूमिका महत्वपूर्ण होती है। 1969 के आगे के वर्षों के देश के 25 स्थानों के शीतकालीन दैनिक दृश्यता आंकड़ों (2100,0000,0300 और 0600 यू.टी.सी पर) की जाँच की गई है। इसके साथ-साथ उसी समय रिकार्ड किए गए शुष्क बल्ब तापमान और सापेक्षिक आर्द्रता की भी जाँच की गई है। प्रत्येक नगर के आँकड़ा-समूहों के साथ रैखीय उपनति समाश्रयण का तालमेल बैठाया गया है। इनके महत्व की 99 प्रतिशत आश्वस्तता स्तर तक जाँच की गई है।

हाल की के वर्षों में, नगरों की वायु-गुणवत्ता में आई कमी के कारण, विशेषकर सुबह के समय प्रायः अस्पष्ट दृश्यता (2000 मीटर से अधिक) वाले दिनों की संख्या में बढ़ोतरी का पता चला है। इसी स्थिति के कई दिनों तक निरतंर बने रहने का भी पता चला है।

इन परिणामों से अधिकाँश स्थानों पर दृश्यता में कमी की प्रवृति का पता चला है। दृश्यता प्रायः 0300 यू.टी.सी. पर कम होती है और वायु की सीमांत परत में मिलावट तथा प्रक्षोभ के कारण दृश्यता और कम हो जाती है।

ABSTRACT. Visibility plays a key role at the time of landing and take off operations at airports. The daily visibility data from 1969 onwards for 25 stations in the country (at 2100, 0000, 0300 and 0600 UTC) are examined for the winter period. Side by side the dry bulb temperatures and the relative humidity recorded at the same time are also examined. Linear trend regressions have been fitted on the data sets for each of the cities. The significance is tested at 99% level of confidence.

In recent years, degradation of air quality in the cities has often been suggested as the cause for the increase in the number of poor visibility days (< 2000 meters) particularly in the morning hours. Continuous persistence of this phenomenon for a number of days has also been reported.

The results show that there are decreasing trends in visibility at most of the stations. At 0300 UTC the visibility is generally low and increased afterwards due to mixing and turbulence in the boundary layer.

Key words – Trends, Visibility, Percentage frequencies, Air temperature, Relative humidity.

1. Introduction

Visibility plays a crucial role in all forms of transport and in particular aviation. The poor visibility conditions not only prevent aircraft operations such as landing or take off during that period but also have indirect effects on the economy of operations and passenger inconvenience. Visibility is a measure of transparency of the atmosphere in a horizontal direction at the earth's surface. It refers to the greatest distance at which a black object of a specified size can be seen and recognised against the horizon by an observer with normal sight. Factors, which reduce visibility at the earth's surface and aloft include fog, cloud, precipitation, dust storm, sandstorm and various air

TABLE 1

Decennial growth of population in India and number of motor vehicles registered (Source : Statistical Abstract India 1998)

Year	Population (crore)	Percentage variation	Urban population (%)	Total vehicles (lakhs)
1950-51	36.1088	13.31	17.3	3.063
1960-61	43.9234	21.51	18.0	6.645
1970-71	54.8160	24.80	19.9	18.653
1980-81	68.3329	24.66	23.3	51.814
1990-91	84.6303	23.85	25.7	213.742
1991-92	86.4426*	#	#	235.074
1992-93	87.7389*	#	#	255.053
1993-94	89.0607*	#	#	276.599
1994-95	90.4138*	#	#	302.947
1995-96	94.0039*	#	#	335.575

* - Estimated mid-year population, # - Data not available, 1 Crore = 100 lakh

pollutants. Smoke from industrial and domestic fires can become a problem if an inversion is present.

Poor visibility in the winter months over Mumbai airport is not generally due to moist phenomena like mist or fog but is caused by smoke or particulate matter (Mukherjee *et al.*, 1980, Padmanabhamurty, 1984). Visibility is closely correlated to the concentration of suspended particulate matter and is inversely proportional to the concentration of pollutants at Mumbai airport (Chandiramani *et al.*, 1975). Increasing trend in the daily minimum temperature over Mumbai airport for the period 1952-58 and 1964-72 was attributed to increased urbanisation (Pradhan *et al.*, 1976). Sinha Ray *et al.* (1997) has found steep increasing trend in minimum temperature compared to that of maximum temperature where urbanisation took place during last 40-50 years. Studies of extreme temperature events over the Indian region showed that the frequency of number of days with minimum temperature $\leq 10^{\circ}$ C during winter months shows decreasing trend over north Indian stations (Rao *et al.*, 2000). Also Green and Battan (1967) have attributed a strong positive correlation of worsening visibility with population increase which is primarily a result of increased automobile emissions. The statistics for India are presented in Table 1. The table shows that there is a tremendous increase in the number of vehicles. In the quarter century between 1970 to 1995, the number of vehicles increased 17 times for a population increase of about 7.5 times.

2. Data and methodology

The vagaries of data collection make visibility studies difficult. Visibility measurements are traditionally made by estimating the maximum distance at which an object can be visually perceived. This may vary among observers. Visibility markers, which are generally mountains or other natural features of the terrain, are used to estimate visibility. These estimates depend on the general characteristics of the marker, its surroundings and the quality and illumination of the sight path, the eye and the brain (Malm *et al.*, 1980). In the present study the three hourly visibility values (surface synoptic observations) for airports and two city stations (Pune and Srinagar) over a period of 21 to 31 years from 1969 to 1999 are examined for 2100, 0000, 0300 and 0600 UTC. However, for two airports *i.e.* Bangalore and Varanasi, 2100 UTC observations started late and being available for a period of less than 10 years are not considered. For a surface observatory station the visibility is recorded at each synoptic hour and reported in the abridged code (90 to 99). The number of days with visibility less than 2000 meters (visibility code ≤ 94) are taken into consideration for the winter season (Dec-Jan-Feb). At the Indian airports, "Runway Visual Range" (RVR) observations are reported when the general visibility falls below 2000 meters as a national practice and hence the threshold value is kept as 2000 meters. As the temperature and relative humidity play a significant role in determining the visibility at a place, the trends in dry bulb temperature and relative humidity for the corresponding period are also studied. The linear trend analysis was carried out for these three parameters *i.e.*, visibility, dry bulb temperature and relative humidity. The increasing (+) and decreasing (-) trends are presented in Table 2 indicating the data period. The '*' sign indicates that they are significant at 99% level of confidence. The correlation and regression co-efficients are presented in Tables 3 & 4.

TABLE 2

Increasing (+) / decreasing (-) trends of winter season percentage frequencies of horizontal visibility < 2000 meters, mean air temperature and mean relative humidity at 2100, 0000, 0300 and 0600 UTC. '*' indicates trends are significant at 99% level

S. No.	Station	Period	Visibility				Air temperature				Relative humidity			
			2100	0000	0300	0600	2100	0000	0300	0600	2100	0000	0300	0600
1.	Amritsar (A)	1969-97	+*	+*	+*	+*	-	+	+	-	+*	+*	+	+*
2.	New Delhi (A)	1969-97	+*	+*	+*	+*	+	+*	+*	+	+*	+*	+*	+*
3.	Patna (A)	1969-98	+*	+*	+*	+*	-	+	-	-*	+*	+*	+*	+*
4.	Varanasi (A)	1969-98	#	+*	+*	+*	#	+	-	+	#	+	+*	+*
5.	Allahabad (A)	1969-98	+	+*	+*	+*	-	+*	-	-	+	+	+	+*
6.	Lucknow (A)	1969-96	+	+*	+*	+*	+	+*	+	+	+	+	+*	+*
7.	Agartala (A)	1969-94	+	+*	+*	+	-	+*	-	-	+*	+	+*	+*
8.	Bangalore (A)	1969-97	#	+*	+*	+	#	+	+	+	#	-	+	-
9.	Guwahati (A)	1969-94	+	+*	+*	+	-	+	+	-	+*	-	+	+*
10.	Jammu (A)	1970-90	+	+	+*	+	+	+	+	+	+	+*	+*	+*
11.	Jaipur (A)	1969-97	+	+	+*	+	+	+*	+	+	+*	+*	+*	+*
12.	Ahmedabad (A)	1969-93	-	+	+*	+	+	+	+	+	+	+*	+	+
13.	Bhopal (A)	1969-96	-	+	+*	+	-	+	+	+	+	+*	+	+
14.	Aurangabad (A)	1969-97	0	+	+*	+	-	+	+	-	+*	+*	+*	+*
15.	Mumbai (A)	1969-97	+	+	+	+*	+	+	+	+	-	+	+*	+
16.	Srinagar	1969-85	+	+	+	+	+	+	+	-	+	+	-	+
17.	Mohanbari (A)	1969-94	+	-	+	+	+	+	+	+	-	+	-*	-
18.	Nagpur (A)	1969-96	+	+	+	+	-	+	+	+	+	+	+	+
19.	Bhubaneshwar (A)	1969-95	0	+	+	+	+	-	-	+	+	+	+	+
20.	Visakhapatnam (A)	1969-96	+	+	+	+	+	-	-	+	-	+*	+*	-
21.	Chennai (A)	1969-96	0	-	+	+	+	+	+*	+	+	+	+	+
22.	Pune	1969-99	0	+	-	-	-	+	-	+	+*	+*	+*	+
23.	Kolkata (A)	1969-95	-	-	-	+	+	+	+*	+	+	-	+	+
24.	Thiruvananthapuram (A)	1969-96	+	-	-	0	+*	+	-	+*	+	+	+*	+
25.	Hyderabad (A)	1969-96	-	-*	-*	+	+	+	+*	+	+	+	-	+

- Data for the synoptic hour less than 10 years, 0 – No trend

3. Discussions

The general trends of decreasing visibility are noticed over most of the stations. Twenty one out of the twenty five stations have rising slopes indicating that number of days with visibility less than 2000 meters are increasing. These trends are significant for fourteen stations, nine stations, six stations and three stations at 0300, 0000, 0600 and 2100 UTC respectively, thus indicating that number of days with poor visibility are maximum at 0300 UTC. The slopes are negative for four stations (*i.e.*, Pune, Kolkata,

TABLE 3

Correlation and regression coefficients of horizontal visibility <2000 meters, mean air temperature and mean relative humidity during winter season. '*' means trends are significant at 99% level

S. No.	Station	2100 UTC						0000 UTC					
		Visibility		Air temp.		Humidity		Visibility		Air temp.		Humidity	
		Reg.	Corr.	Reg.	Corr.	Reg.	Corr.	Reg.	Corr.	Reg.	Corr.	Reg.	Corr.
1.	Amritsar (A)	0.205	0.569*	-0.011	-0.132	0.430	0.618*	1.208	0.681*	0.012	0.132	0.146	0.546*
2.	New Delhi (A)	0.398	0.683*	0.008	0.093	0.333	0.506*	2.961	0.819*	0.079	0.637*	0.207	0.478*
3.	Patna (A)	0.242	0.587*	-0.031	-0.367	0.361	0.559*	1.914	0.895*	0.031	0.361	0.251	0.667*
4.	Varanasi (A)	#	#	#	#	#	#	2.761	0.794*	0.054	0.461	0.311	0.419
5.	Allahabad (A)	0.332	0.408	-0.039	-0.335	0.323	0.478	1.459	0.700*	0.062	0.485*	0.286	0.420
6.	Lucknow (A)	0.075	0.271	0.014	0.182	0.275	0.388	2.070	0.737*	0.060	0.588*	0.121	0.286
7.	Agartala (A)	0.003	0.061	-0.033	-0.322	0.503	0.796*	0.766	0.638*	0.078	0.707*	0.019	0.049
8.	Bangalore (A)	#	#	#	#	#	#	0.255	0.612*	0.023	0.281	-0.010	-0.031
9.	Guwahati (A)	0.020	0.164	-0.025	-0.267	0.242	0.512*	1.865	0.761*	0.041	0.425	-0.035	-0.231
10.	Jammu (A)	0.231	0.556	0.018	0.110	0.435	0.335	0.229	0.349	0.045	0.370	0.539	0.629*
11.	Jaipur (A)	0.022	0.230	0.007	0.071	0.311	0.577*	0.061	0.382	0.057	0.545*	0.344	0.594*
12.	Ahmedabad (A)	-0.010	-0.205	0.001	0.008	0.279	0.293	0.001	0.020	0.034	0.261	0.527	0.504*
13.	Bhopal (A)	-0.011	-0.226	-0.005	-0.038	0.199	0.304	0.063	0.308	0.017	0.173	0.365	0.478*
14.	Aurangabad (A)	0.000	0.000	-0.001	-0.014	0.398	0.591*	0.042	0.406	0.026	0.160	0.841	0.727*
15.	Mumbai (A)	0.008	0.316	0.026	0.415	-0.005	-0.016	0.123	0.117	0.014	0.169	0.126	0.399
16.	Srinagar	0.040	0.086	0.026	0.105	0.022	0.017	0.182	0.231	0.029	0.174	0.064	0.240
17.	Mohanbari (A)	0.052	0.358	0.006	0.053	-0.004	-0.009	-0.143	-0.124	0.005	0.058	0.003	0.038
18.	Nagpur (A)	0.008	0.240	-0.006	-0.049	0.062	0.108	0.002	0.033	0.035	0.304	0.127	0.189
19.	Bhubaneshwar (A)	0.000	0.000	0.014	0.127	0.109	0.235	0.064	0.110	-0.005	-0.032	0.093	0.286
20.	Visakhapatnam (A)	0.008	0.302	0.015	0.201	-0.114	-0.213	0.094	0.196	-0.010	-0.076	0.222	0.498*
21.	Chennai (A)	0.000	0.000	0.024	0.371	0.071	0.142	-0.050	-0.242	0.024	0.297	0.073	0.388
22.	Pune	0.000	0.000	-0.013	-0.181	0.197	0.465*	0.050	0.399	0.084	0.305	0.912	0.517*
23.	Kolkata (A)	-0.003	-0.054	0.008	0.079	0.168	0.424	-0.668	-0.296	0.060	0.461	-0.028	-0.145
24.	Thiruvananthapuram(A)	0.001	0.036	0.038	0.584*	0.023	0.060	-0.008	-0.223	0.019	0.296	0.072	0.244
25.	Hyderabad (A)	-0.001	-0.040	0.019	0.209	0.140	0.262	-0.051	-0.446*	0.049	0.356	0.130	0.342

- Data for the synoptic hour less than 10 years

Thiruvananthapuram and Hyderabad) implying an increase in the visibility and this increase is significant for Hyderabad. Plots of the poor visibility with trend line (significant at 99%) for 15 individual stations are shown in Fig. 1 and for temperature and relative humidity in Fig. 2.

TABLE 4

Correlation and regression coefficients of horizontal visibility <2000 meters, mean air temperature and mean relative humidity during winter season. '*' means trends are significant at 99% level

S. No.	Station	0300 UTC						0600 UTC					
		Visibility		Air temp		Humidity		Visibility		Air temp		Humidity	
		Reg.	Corr.	Reg.	Corr.	Reg.	Corr.	Reg.	Corr.	Reg.	Corr.	Reg.	Corr.
1.	Amritsar (A)	1.496	0.733*	0.015	0.184	0.101	0.345	0.743	0.640*	-0.010	-0.136	0.415	0.604*
2.	New Delhi (A)	2.477	0.813*	0.048	0.492*	0.287	0.556*	1.439	0.744*	0.002	0.030	0.351	0.532*
3.	Patna (A)	2.127	0.863*	-0.010	-0.144	0.302	0.544*	0.704	0.739*	-0.037	-0.438*	0.390	0.596*
4.	Varanasi (A)	2.316	0.762*	-0.024	-0.276	0.380	0.551*	0.283	0.548*	0.003	0.033	0.531	0.588*
5.	Allahabad (A)	1.002	0.565*	-0.004	-0.039	0.248	0.396	0.818	0.640*	-0.024	-0.215	0.481	0.612*
6.	Lucknow (A)	2.054	0.794*	0.026	0.380	0.310	0.525*	0.524	0.555*	0.003	0.042	0.338	0.484*
7.	Agartala (A)	0.553	0.633*	-0.009	-0.130	0.374	0.746*	0.061	0.412	-0.024	-0.268	0.509	0.812*
8.	Bangalore (A)	0.329	0.679*	0.003	0.046	0.100	0.240	0.014	0.338	0.008	0.129	-0.015	-0.022
9.	Guwahati (A)	0.568	0.692	0.014	0.200	0.095	0.367	0.008	0.061	-0.022	-0.236	0.269	0.608*
10.	Jammu (A)	0.781	0.627*	0.017	0.156	0.513	0.594*	0.186	0.330	0.017	0.144	0.519	0.518*
11.	Jaipur (A)	0.832	0.780*	0.055	0.309	0.375	0.590*	0.059	0.321	0.012	0.139	0.323	0.550*
12.	Ahmedabad (A)	0.489	0.543*	0.043	0.369	0.394	0.420	0.010	0.105	0.009	0.149	0.281	0.302
13.	Bhopal (A)	0.214	0.505*	0.018	0.213	0.301	0.383	0.065	0.429	0.008	0.072	0.231	0.322
14.	Aurangabad (A)	1.555	0.674*	0.006	0.064	0.597	0.673*	0.006	0.248	-0.006	-0.058	0.435	0.599*
15.	Mumbai (A)	0.869	0.423	0.002	0.022	0.281	0.638*	0.198	0.558*	0.021	0.344	0.069	0.177
16.	Srinagar	0.142	0.105	0.046	0.308	-0.087	-0.227	0.003	0.004	-0.001	-0.007	0.126	0.112
17.	Mohanbari (A)	0.137	0.338	0.027	0.360	-0.166	-0.546*	0.008	0.120	0.014	0.134	-0.118	-0.324
18.	Nagpur (A)	0.025	0.046	0.008	0.086	0.204	0.251	0.002	0.024	0.003	0.023	0.053	0.085
19.	Bhubaneshwar (A)	0.293	0.414	-0.007	-0.085	0.081	0.158	0.008	0.094	0.029	0.296	0.059	0.113
20.	Visakhapatnam (A)	0.123	0.275	-0.008	-0.097	0.254	0.568*	0.030	0.333	0.007	0.104	-0.013	-0.029
21.	Chennai (A)	0.023	0.119	0.042	0.519*	0.017	0.061	0.009	0.258	0.026	0.396	0.029	0.061
22.	Pune	-0.039	-0.069	-0.010	-0.089	0.560	0.785*	-0.001	-0.061	0.012	0.140	0.176	0.322
23.	Kolkata (A)	-0.179	-0.106	0.037	0.528*	0.081	0.268	0.016	0.087	0.023	0.240	0.198	0.503
24.	Thiruvananthapuram (A)	-0.011	-0.202	-0.004	-0.062	0.182	0.444*	0.000	0.000	0.039	0.623*	0.020	0.048
25.	Hyderabad (A)	-0.503	-0.631*	0.073	0.572*	-0.084	-0.193	0.001	0.036	0.009	0.102	0.160	0.271

- Data for the synoptic hour less than 10 years

Considering the winter season of 90 days duration (Dec-Feb), cases of poor visibility during the season for individual stations are discussed below:

(*i*) *Amritsar* : The number of days with poor visibility (< 2000 meters) which were only two in seventies rose to forty-five days in the early eighties and increased further to seventy two days in the nineties. The range in the variations in dry bulb temperature at 0300 UTC is between 6 to 8° C and in the relative humidity 85 to 90 %. The trends are increasing for both the parameters.

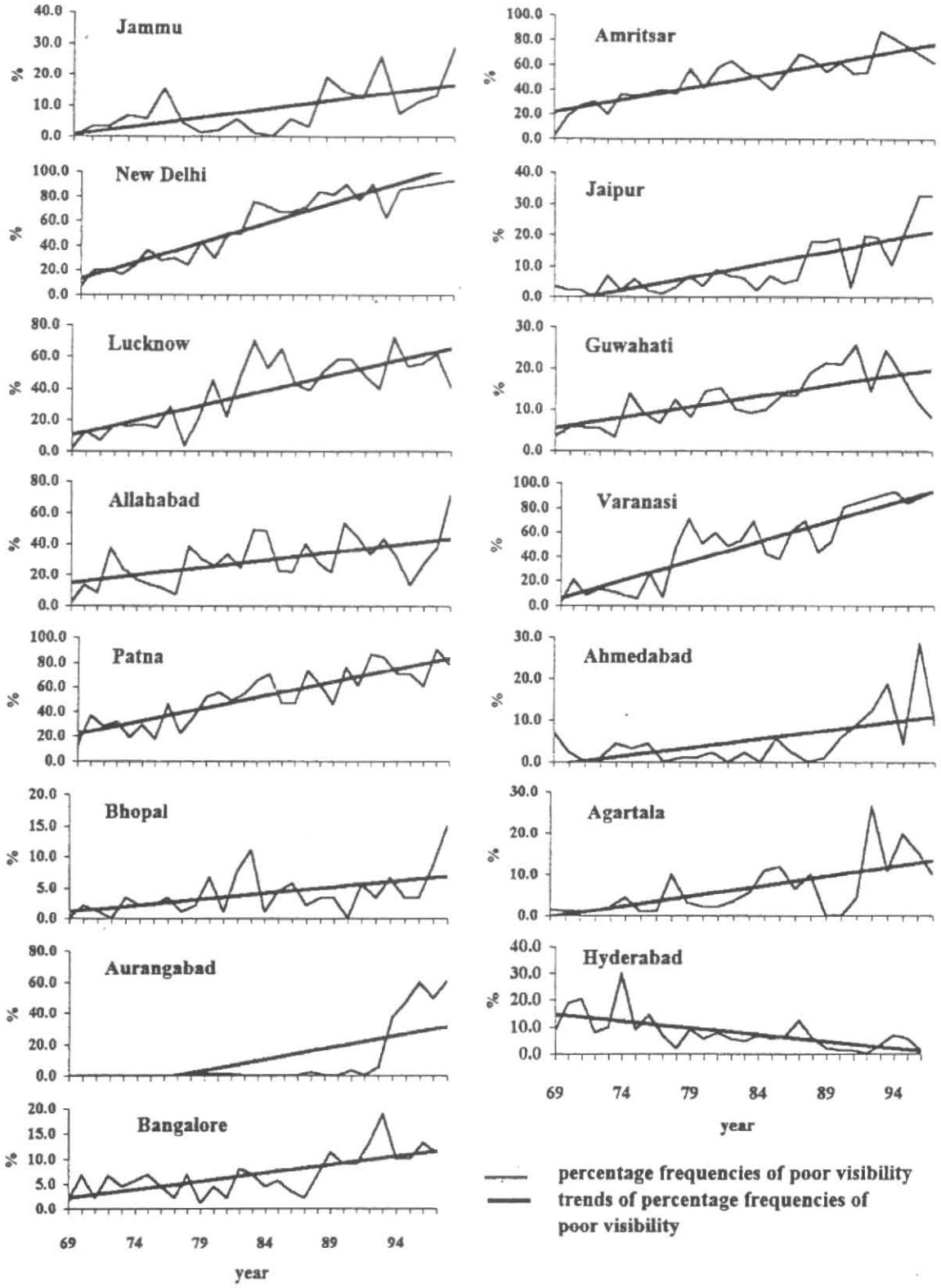

Fig. 1. Percentage frequencies of number of days with horizontal visibility < 2000 m at 0300 UTC during winter season with significant trends at 99% level

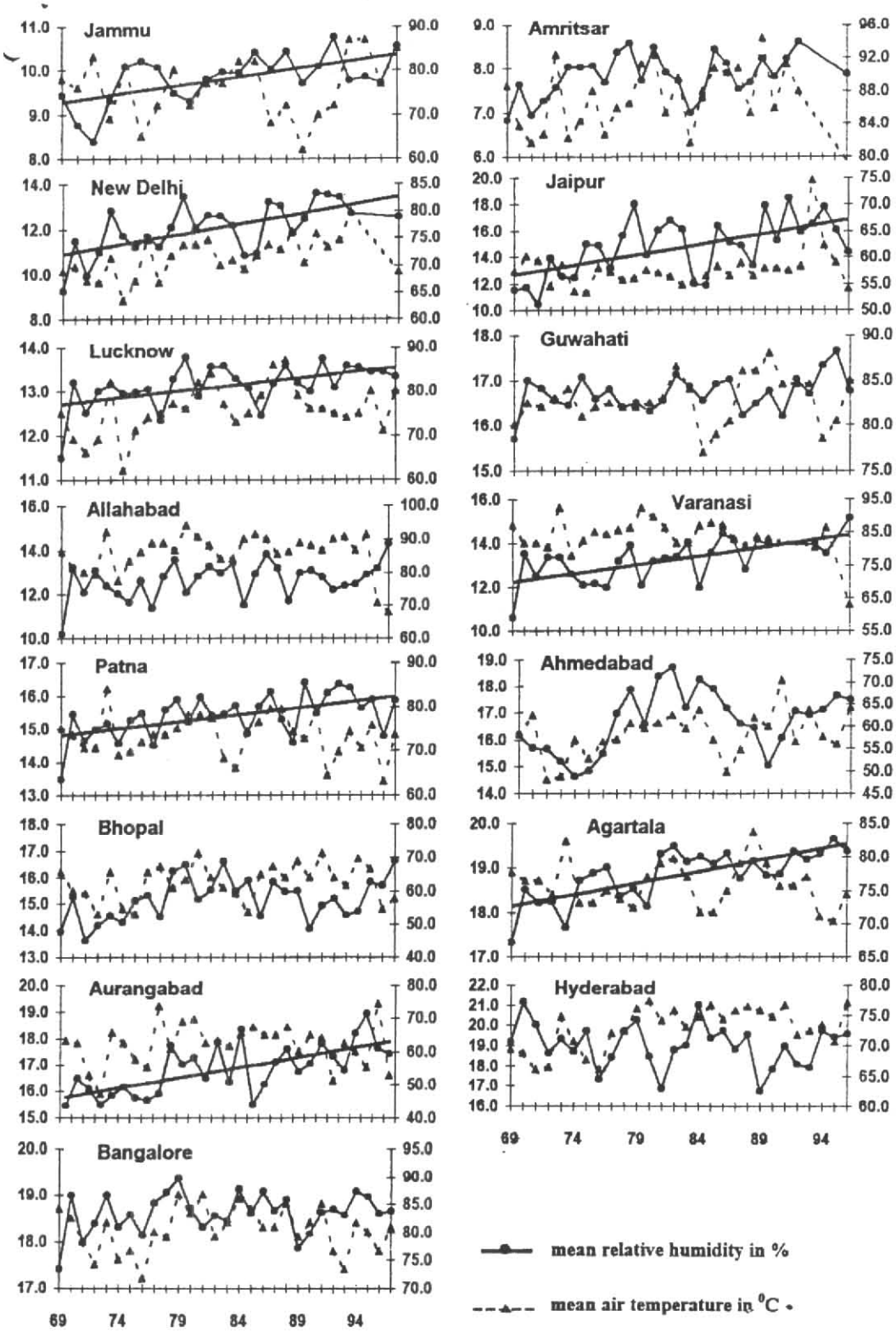

Fig. 2. Winter season mean air temperature and relative humidity at 0300 UTC. Trend lines are drawn for mean relative humidity significant at 99% level for 8 selected stations the left hand y-axes indicate temperatures and the right hand ones indicate RH

(*ii*) *New Delhi* : Singh *et al.* (1999) have studied the visibility trend for New Delhi airport for the period 1964-98 and found an increasing trend in the frequency of poor visibility occasions. The number of poor visibility days increased gradually from six to forty five between 1970 and 1980 and later increased steeply to about seventy two days in nineties. The range in the variations in the dry bulb temperature is between 9 and 12° C and in the relative humidity 65 to 80%. These two parameters show significant positive trends.

(*iii*) *Varanasi* : In early seventies, the number of days with poor visibility were nine per season increasing to forty five days in eighties and further rose to seventy two days in nineties. Temperatures varied between 13 to 15° C with decreasing trend and relative humidity between 60 to 80% with significant positive trend.

(*iv*) *Patna* : The number of days with poor visibility increased from twelve in early seventies to forty five in eighties and further increased to seventy to eighty days in late nineties. The dry bulb temperature varied between 13 to 16° C with negative trend and relative humidity between 65 to 85% with positive trend.

(*v*) *Aurangabad* : The visibility was very good till 1990 (*i.e.*, only two poor visibility days per season). A sudden increase was noticed with about fifty four days of poor visibility per season in the late nineties. The temperatures are between 16 to 18° C with positive trend and variations in relative humidity are between 45 to 65 % with significant positive trend.

(*vi*) Lucknow and Allahabad indicate continuous increase in the number of poor visibility days *i.e.*, from nine in early seventies to twenty seven in eighties and sixty three days in late nineties. The temperature range is between 11 to 13° C. The variations in relative humidity are between 60 to 80% with an increasing trend.

(*vii*) Jammu, Jaipur, Guwahati, Ahmedabad, Bhopal, Agartala and Bangalore also show significant decreasing trend in the visibility. However, the number of days with poor visibility are between eighteen to twenty seven out of ninety days *i.e.*, 20 to 30% of the season. The temperature variations are between 11 to 19° C for all the stations except Jammu where the range is 8 to 11°C. Relative humidity varied between 40 to 70 %.

(*viii*) The number of poor visibility days are increasing in Mumbai, Srinagar, Mohanbari, Nagpur, Bhubaneshwar, Visakhapatnam and Chennai but the trends are not significant.

(*ix*) The trend in respect of Hyderabad is entirely opposite and significant. The number of poor visibility days were between eighteen to twenty seven up to late seventies. The number gradually decreased to less than nine days in late nineties. The air temperatures are of the order of 18 to 21° C with significant increasing trend and relative humidity between 60 to 75 % with a negative trend. The Hyderabad observatory was shifted from old airport building to present RS/RW building (located at a distance of 1.5 km) in February 1971. This may not be the reason for good visibility days since the period considered for the study is from 1969. The mean air temperature more than 19°C at 0300 UTC after 1980 may not be conducive for the inversion to take place. The improving trend in visibility at Hyderabad in-spite of rapid urbanization is difficult to explain and needs to be watched and studied further.

(*x*) Pune, Kolkata and Thiruvananthapuram airports also show an increasing trend in visibility but not significant. The marshy lands, which were around Kolkata airport earlier, are being converted and the change in topography may be a cause for improved visibility.

It is seen from the above, that relative humidity varied between 40 to 80% in most of the stations and suggests that the poor visibility is not generally due to the moist phenomena like mist or fog but due to suspended particulate matter and smoke from factory chimneys and domestic fires. At the north Indian stations *viz.*, Amritsar, New Delhi, Varanasi, Patna, Lucknow and Allahabad (with a mean temperature of 6 to 15° C and relative humidity between 60 to 80% at 0300 UTC) the visibility deteriorated significantly with poor visibility days increasing to 70 to 80% in the winter season.

The visibility has deteriorated in west, central and NE Indian stations like Jaipur, Ahmedabad, Aurangabad, Bhopal, Guwahati and Agartala (with a mean temperature of 11 to 19° C and relative humidity between 40 to 70 %) and poor visibility days are increased from 20 to 60% per season. Regional and synoptic scale meteorological conditions provide the final trigger that cause poor

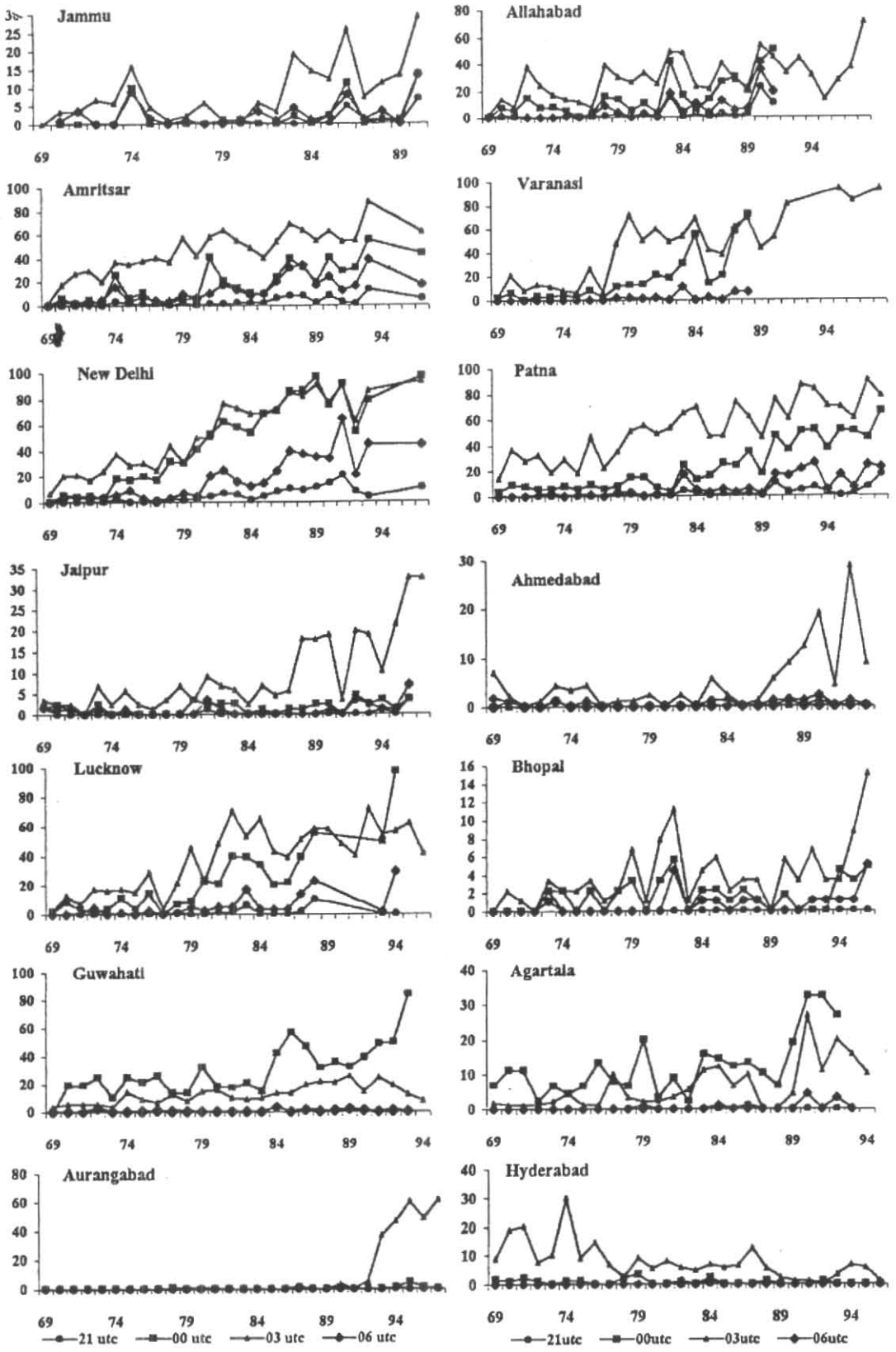

Fig. 3. Diurnal variation of percentage frequencies of poor visibility at 2100, 0000, 0300 and 0600 UTC during winter season. y-axes indicate percentage of occurrences of visibility below 2000 meters

visibility. Changing weather patterns can substantially alter the transparency of the atmosphere. Pollutants trapped in the stagnant air of a temperature inversion under high pressure may often produce obstruction to visibility continuously. The introduction of instability quickly disposes the pollutants. However, these are not discussed in detail as it is beyond the scope of the present study.

4. Diurnal variation of visibility

The diurnal variation of visibility at 2100, 0000, 0300, 0600 UTC during winter season over 14 different airport stations are shown in Fig. 3, with abscissa representing the year and the ordinate the percentage frequency of number of days with poor visibility.

More or less, all stations show similar features with maximum number of days of poor visibility occurring at 0300 UTC followed by 0000, 0600 and 2100 UTC. The study suggests that the visibility deteriorates from 2100 UTC to 0300 UTC and improves after that.

5. Conclusions

(*i*) Most of the north Indian airport stations show significant increasing trend in poor visibility days in the winter season. On ninety percent of the occasions, the visibility is below 2000 meters accounting for poor visibility almost everyday. Stations in south India show only 20 to 30% days with poor visibility while at some of them, like Hyderabad, trend is decreasing *i.e.*, visibility is becoming better. The airline authorities have to take note of these climatological trends.

(*ii*) The visibility is the lowest at 0300 UTC and shows improvement after that, indicating role of mixing and surface eddies after the sunrise.

(*iii*) Increasing trend in the relative humidity and increased presence of aerosol particulate matters in the atmosphere are the most likely causes of poor visibility over north Indian stations.

(*iv*) Rapid urbanisation and increased number of automobiles in the major cites appear to be the causes of increased aerosols in the city. However, stagnation of airflow and heat island effects need to be examined more closely to assess their role in this respect quantitatively.

Acknowledgements

The authors are thankful to Mrs. Sheeja Kurian for typing the manuscript.

References

Chandiramani, W.G., Pradhan, S. K., Gurundham, G., Kishan, Daya and Manral, N.S., 1975, "A case study of poor visibility over Bombay airport", *Indian J. Met. Hydrol. & Geophys.*, **26**, 208-210.

Green, C.R. and Battan, L.J., 1967, "A study of visibility *versus* population growth in Arizona", *J. Ariz. Acad. Sci.*, **4**, 226-228.

Malm, W.C., Leiker, K.K. and Molenar, J.V., 1980, "Human perception of visibility", *J. Air Pollut. Control Assoc.*, **30**, 122-131.

Mukherjee, A.K., Daniel, C.E.J. and Sethumadhavan, K., 1980, "Deterioration of Visibility at Bombay airport due to atmospheric pollutants", *Mausam*, **31**, 2, 287- 290.

Padmanabhamurty, B., 1984, "Some aspects of the urban climates of India", World Climate Programme, Proceedings of the Technical Conference on Urban Climatology and its Application with special regards to Tropical areas, Mexico, 26-30 November, 1984, WMO-652, 136-165.

Pradhan, S., Kishan, Daya and Manral, N., 1976, "The effects of Urbanisation and Industrial Development on Air Temperature at Bombay airport", *Indian J. Met. Hydrol. & Geophys.*, **27**, 187-190.

Rao, G.S.P., Jaswal, A.K. and De, U.S., 2000, "Extreme temperature events over the Indian sub-continent", Proceedings of TROPMET-2000, 1-4 February, 2000, Cochin.

Singh, R.D., Singh, Dhanna and Dube, R.K., 1999, "Climatology and Trend of Visibility at I.G.I. airport, New Delhi and their use in forecasting", Proceedings of National Symposium, TROPMET-99, 16-19 February, 1999, Chennai.

Sinha Ray, K.C., Mukhopadhyay, R.K. and Chowdhury, S.K., 1997, "Trends in maximum, minimum temperatures and sea level pressure over India", Presented at INTROMET, New Delhi.