MAUSAM, **63**, 1 (January 2012), 89-112

551.575 : 551.509.325

Development of intensity based fog climatological information system (daily and hourly) at IGI airport, New Delhi for use in fog forecasting and aviation

RAJENDRA KUMAR JENAMANI

India Meteorological Department, New Delhi – 110 037, India

(*Received 29 October 2010, Modified 16 August 2011*)

e mail : rjenamani@hotmail.com

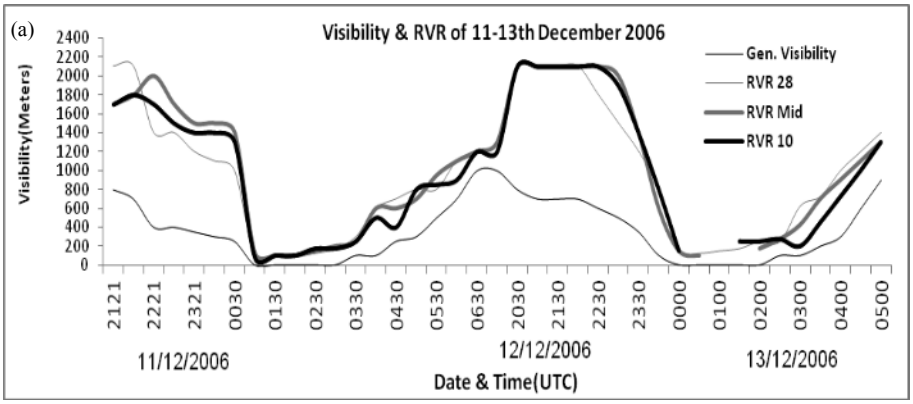
सार – इस शोध पत्र का मुख्य उद्देश्य इंदिरा गाँधी अंर्तराष्ट्रीय (आई.जी.आई) हवाई अडड़ा, नई दिल्ली पर कुहरे की भिन्न भिन्न सघनताओं की घटनाओं का सूक्ष्म जलवायविक रूप से अध्ययन करना है। इसमें वर्ष 1981–2005 तक की अवधि में घंटेवार दृश्यता के आँकड़ों का उपयोग करते हुए 1 दिसंबर से 31 जनवरी तक की चरमशीत ऋतु के 62 दिनों की घटना के समरूपी कुल घंटो की संख्या और उनकी तारीखवार जलवायविक संभावनाएँ शामिल हैं। उनकी दैनिक भिन्नताओं को समझने के लिए समरूपी आँकडों का उपयोग करते हुए दोनों महीनों के लिए घंटेवार जलवायु के संबंध में अलग–अलग विचार किया गया है। विमानन के लिए कुहरे की अवधि और सघनता दोनो ही सबसे अधिक और संकटपूर्ण स्थिति में सही तारीखों और समय के साथ अतिसंवेदनशील अवधियों का पता लगाने के लिए आकलित किए गए हैं। जिस समय कुहरे से संबंद्ध उड़ान की दिशा परिवर्तन का जोखिम सबसे अधिक होता है उस अवधि का पता लगाने के लिए संचयी कुहरे की घटनाओं के समरूपी 10 दिनों के और 3 घंटो के जलवायविक तत्वों का आकलन किया गया है। उनकी परिवर्तनशीलता को बेहतर ढंग से समझने के लिए दो महीनों की अवधि की सभी तारीखों की घटनाओं में एक विशेष प्रकार के कुहरे की घटनाओं के चरम घंटों की तारीखें भी प्रलेखित की गई हैं। इन जलवायु विषयक सूचनाओं का उपयोग बहुत से वायु परिवहनों को उड़ान प्रचालन की योजना बनाने और कुहरे के विस्तार की यांत्रिकी को सुव्यवस्थित करने की कार्यवाही हेतु किया जा सकता है। अन्ततः दिसंबर और जनवरी के सभी 62 दिनों के लिए प्रथम पंक्ति में घंटों में और प्रथम कॉलम में तारीखों सहित तथा कुहरे की इन घटनाओं की तारीख और घंटेवार जलवायविक स्थितियों की संभावनाओं को बताते हुए प्रत्येक दिन के सभी 24 घंटों के लिए इन जलवायविक आँकड़ों पर आधारित विभिन्न सघनताओं वाले कुहरे की संभाव्य मैट्रिक्स को प्रस्तुत किया गया है। जिसका उपयोग विभिन्न प्रकार की सघनता वाले कुहरे का पूर्वानुमान लगाने के लिए जलवायु के उपकरण के रूप में और संभावित जलवायु की अवधि के लिए इंदिरा गाँधी अंर्तराष्ट्रीय हवाई अडडे पर किया जा सकता है।

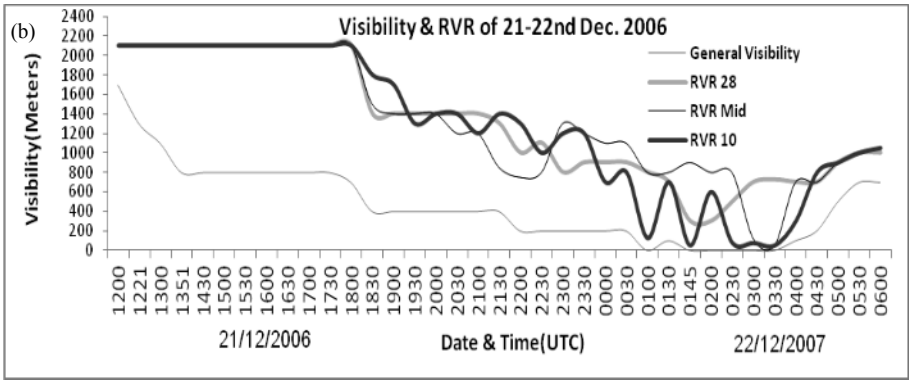
ABSTRACT. The main objective of the present paper is to make a microclimatological study of occurrence of fog of different intensities at Indira Gandhi International (IGI) airport, New Delhi which includes their date-wise climatological probabilities and their corresponding total number of hours of occurrence for 62-days of peak winter from 1st December to 31st January by using hourly visibility data for the period of 1981-2005. Their hourly climatology has been discussed separately for both months using same data for understanding their diurnal variations. Both the computations have been done to find most vulnerable periods with exact dates and timings when both duration and intensity of the fog are very high and hazardous for aviation. Corresponding 10-days and 3-hourly climatology of cumulative fog occurrences are computed to identify a period when fog related flight diversion risk is highest. For better understanding of their variability, dates of extreme hours of occurrences of a particular fog type amongst occurrences of all dates for the period during both months have also been documented. These climatological informations can be used by various airlines for planning flight operation and action for establishment of fog dissipation mechanism. Finally, fog probability matrices of various intensities based on these climatological data have been presented with dates in first column and hours in the first row for all 62 days of December and January and for all 24 hours of each day giving date and hour wise climatological probability of their occurrences which can be used at IGI as climatological tool for forecasting of fog of various intensity and expected climatological period.

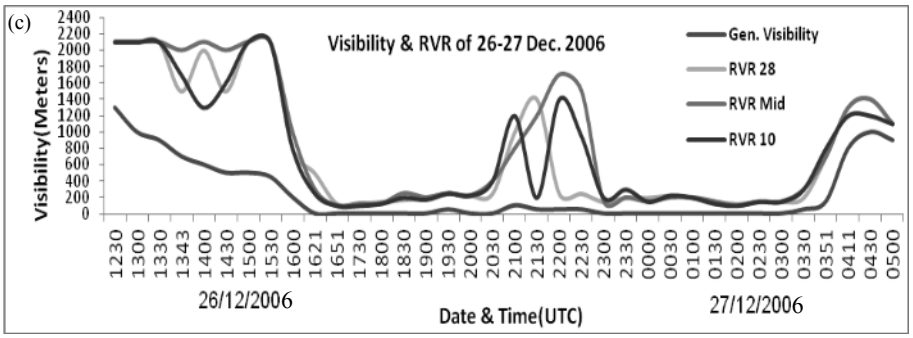
Key word – Fog, Probability, Diurnal variation, Extremes, Vulnerable period.

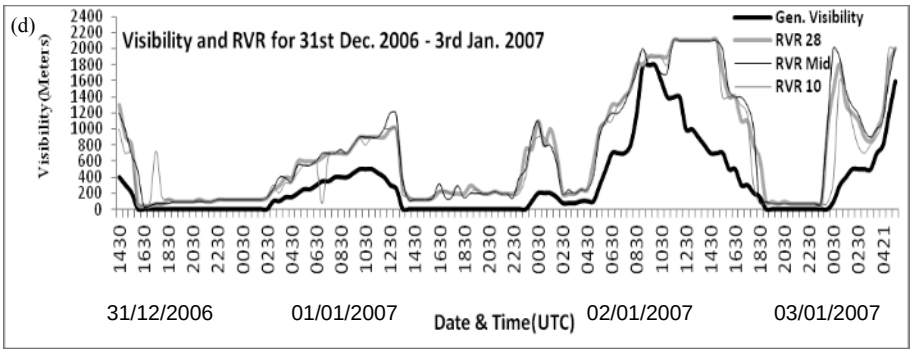
1. Introduction

Fog is an aviation hazard. The vulnerability to fog at Indira Gandhi International (IGI) airport, New Delhi is high due to very dense fog formation during each winter. With total number flight operations at IGI increased significantly from 527 in November 2005 to 675 in Dec 2006 and then to nearly 850 in 2010, there has been









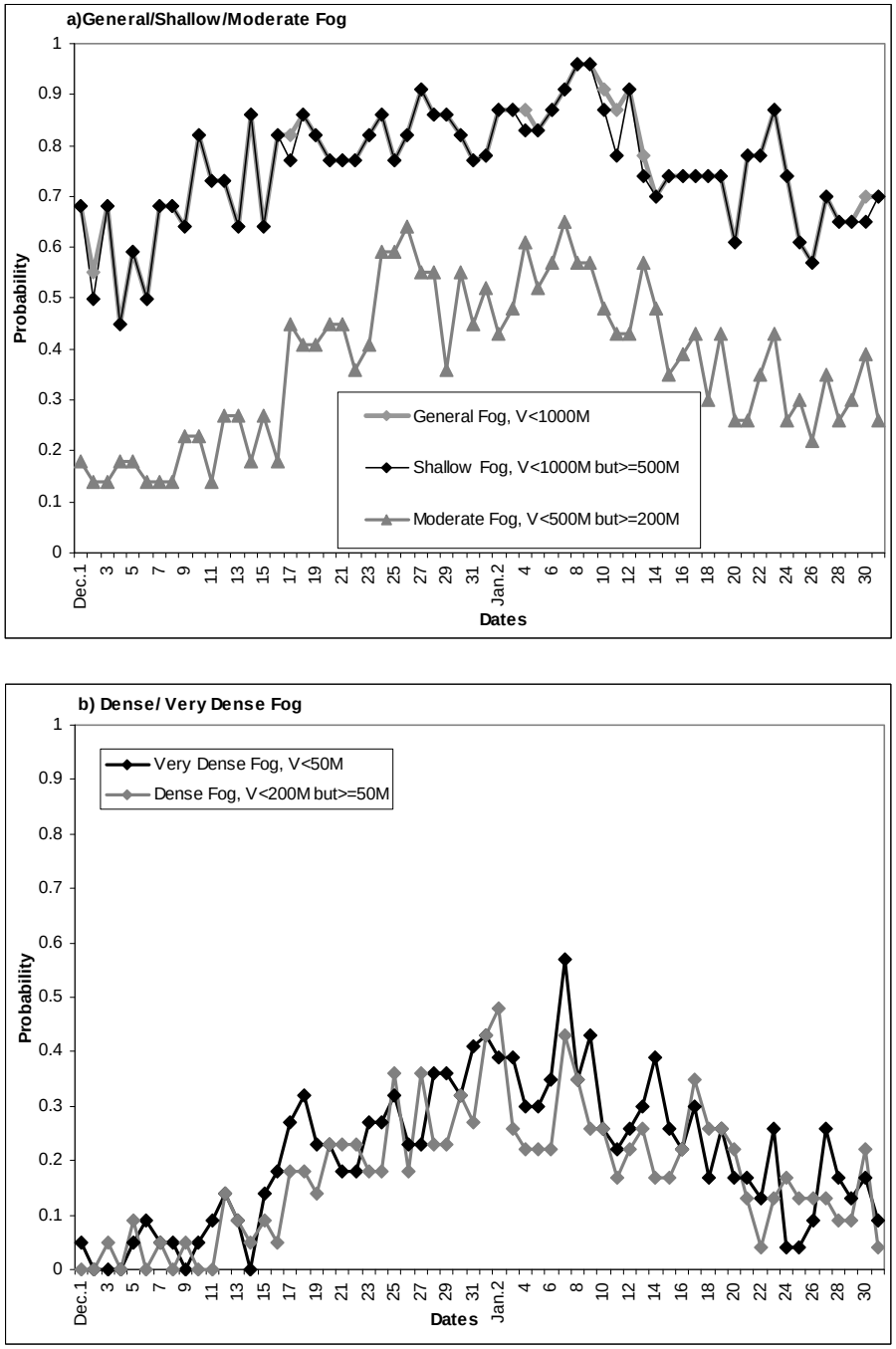
Figs. 1(a-d). Temporal variation of general visibility & RVR values during dense fog spell of IGI Airport recently during Dec & Jan

increase in fog related congestion and diversion. Like any other earlier fog season, IGI also experienced many severe spells of dense fog in 2006-2007 which hampered the landing and takeoff severely. Until 2006, the only RW-28 at the airport was having capability of CAT III-ILS. Figs. 1(a-d) show the details of trend in general visibility and 3 RVR values (Touch down, Mid and End RVR) recorded from respective automatic instruments installed at the main RWY 28-10 at 30 minutes intervals for first four dense fog spells that paralyzed the airport during the season. These figures indicate that there were visibility related problems involved in flight operations at IGI due to such sudden deterioration and improvement because of fog occurrences of various intensities. While Fig. 1(a) shows the first dense fog (reducing visibility below 200m) spell that IGI experienced was during 11-13 December with 4 hours during 0030-0430 UTC of 12th morning and 5 hours during 2330-0430 UTC of 12th night-13th morning, the most severe and most prolonged fog spell of the season was during 1130 UTC of 31 December, 2006 and continued till 0800 UTC of 2 January, 2007 as indicated in Fig. 1(d). It also caused the Authority to close the airport for traffic for many hours during both the nights of 31st and 1st due to RVR falling below of its minimum operational value of 150 meter. The general visibility in Fig. 2(d) shows airport was covered under fog uninterruptedly for 45.5 hours during the spell. By the time the sky opens up for operation, air traffic at IGI returning back to normalcy took prolonged period because it was necessary to clear huge backlog and waited passengers. In view of high duration dense fog affecting the aircraft operations season after season at IGI, Meteorological office was requested by the airport operator, airlines etc, from fog season of 2005 to provide various climatological information pertaining to occurrence of fog of various intensities pertaining to various CAT-ILS ranges and their forecasts for implementing an effective fog mitigation plans. But, there was no such accurate Intensity based fog micro-climatological information available with Met Office at IGI airport. In studies of Friedlein (2004) and Slemmer (2004), such information is already available for Peoria International Airport**,** Illinois and Salt Lake City International Airport, Utah respectively which are located at USA and severely affected by dense fog frequently. Event based fog climatology also have been developed by Tardif and Rasmussen (2007) in the New York City Region where events are characterized according to frequency, duration, intensity etc.

In the present paper, complete fog climatological information which includes date-wise and hourly climatology of occurrence of fog of different intensities for peak winter months of December and January of each winter for IGI airport have been discussed. For this, hourly data at IGI airport for the main winter months of December and January for the 25-years period of 1981-2005 has been considered. Computations have been done to identify timing and dates when both duration and intensity of the fog are very high and hazardous for aviation. Corresponding 10-days and 3-hourly climatology of cumulative fog occurrences are computed to identify a period when fog related flight diversion risk is highest. In order to understand their inter-seasonal variation better, characteristics of past extreme foggy days at various visibility ranges observed during the study period are also tabulated. Finally, a fog forecasting matrix based on these climatological data has been presented with dates in first column and hours in the first row for finding climatological probability of occurrences of fog of different intensities on given date (1st Dec - 31st Jan) and hour (0000 UTC - 2300 UTC).

2. Data and methodology

The hourly visibility data for 25-years and 24-years periods for January and December from 1981 to 2005 and from 1981 to 2004 respectively of IGI airport was collected from the current weather register archived in Regional Meteorological Center, New Delhi. Fog has been classified into following five categories based on visibility criteria : *General Fog* : visibility <1000 meters; *Shallow Fog or Light Fog* : visibility <1000 meters but ≥500; *Moderate Fog* : visibility <500 meters but ≥ 200; *Dense Fog* : visibility <200 meters but ≥50; *Very Dense Fog* : visibility <50 meters. In the period of study, visibility data of December months in 1992 and 1995 and January months of 1995 and 1996 was missing. For finding climatological probability of occurrence of fog for a particular day at a particular intensity, occurrence and non-occurrence of that fog corresponding to that day have been considered from each year covering the period of the study. Hence for finding of probability of occurrence of fog of any types on 1st December, it considers 24-hours visibility data of the date 1st December of 1981, 1st December of 1982 etc. till 1st December of 2004. If respective fog has been found to be prevailed at least once in any observation hours of any particular date, then that date has been considered as one occurrence day and all such days in the study period are added to arrive at the total occurrences of that category of fog. We presented it in probability for its suitable use in forecasting. Climatological probability of a date to have fog has been calculated by dividing number of days having fog on a particular date to total number of days having data on that date. Similarly climatological hours of occurrences of each category of fog for all the 62-days from 1st December to 31st January for IGI airport has been determined by finding total hours of occurrence of a particular category for corresponding days in the month for all the year



Figs. 2(a&b). Climatological probability of a date to have fog

together followed by division with total number years for which dates have been considered. It is then suitable converted to percentage of hours of the day having a particular fog for making it better informative. For determination of hourly climatology or diurnal variations of fog of different intensities in December (January), occurrences of fog at each hour of each data of the month have been considered. Corresponding 10-days and 3-hourly climatology of cumulative fog occurrences are computed by cumulatively adding their averages. It may be noted that UTC timing is behind of 5.5 hours to Indian Standard Time (IST) and hence difference parts of its day

in UTC timing which we have discussed here has been defined as morning from 0000 UTC till 0600 UTC, mid-day/noon from 0600 UTC till 0900 UTC, etc.

One of the main objectives of the classifications of fog into various categories based on general visibility in the present study is to make an approximate estimate on number of hours of use of various CAT ILS categories on day to day by doing micro-climatological analysis of general visibility which is available for very longer period instead of RVR data. When we compared general visibility data on day to day at real time with RVR data based upon which ICAO CAT-ILS conditions of flight landing/take off have been presently followed during fog period at IGI, it shows the various categories of fog classified in the present study based on various general visibility ranges are more or less observed to be in correspondences with various CAT-ILS based RVR ranges, *e.g*., moderate fog corresponds to CAT-I and CAT-II ILS while dense and very dense corresponds to CAT-III ILS.

3. Results

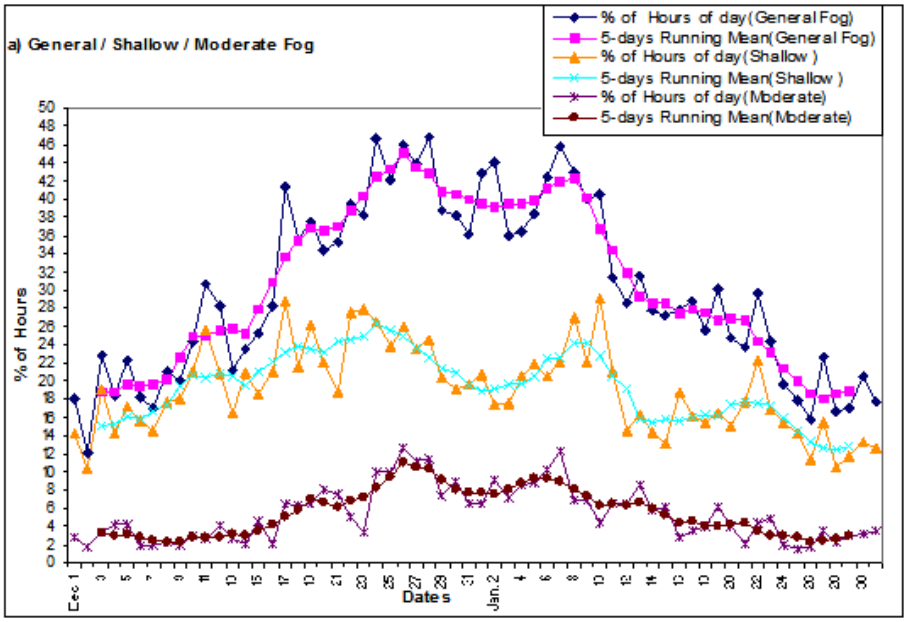
3.1. *Daily climatology*

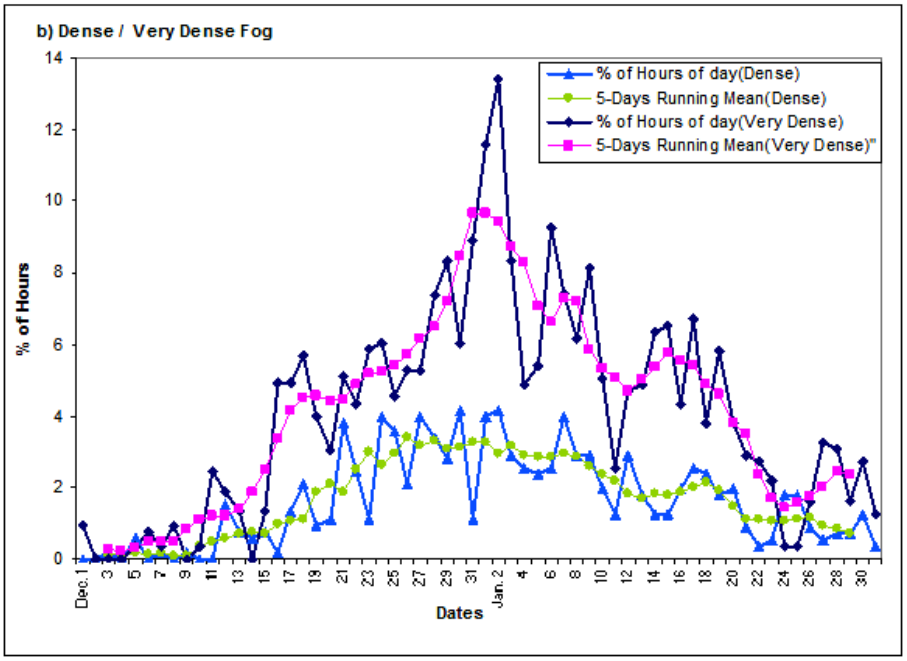
3.1.1. *Date-wise climatological probability having fog of different intensities*

Figs. 2(a&b) show date-wise climatological probability having fog of different intensities during Dec 1 to Jan 31. One can find number of occurrences of particular date having fog by multiplying the probability values with total number of years having data. General fog occurrences in Fig. 2(a) shows that its date-wise probability of occurrences vary between 0.5 to 0.97 with least chances of occurrences during 1-10 December and highest chances of 0.75 to 0.97 *i.e*., almost having 75-100% chance during 11 December – 31 January (*i.e*., almost all days for this period had reported fog for most of the years). The latter can be defined as the most vulnerable period of occurrences of fog over IGI airport. Shallow fog daily climatological probability occurrence in Fig. 2(a) also shows exactly the same variations as general fog. However, daily variation of moderate fog occurrences in Fig. 2(a) shows very high variation among different days with progress of the season. It is the least in the first 16 days with value of 0.2 which increased suddenly to 0.4 on 17 December and further increased to 0.6 on 24 December. Such high number of occurrences remains till 16 January and thus the most vulnerable period of this fog occurrence is 24 December-14 January when nearly 40-65% chance of a day to have been affected by moderate fog. In latter days, though date-wise number of occurrences or their probability have been decreased, values remained around 0.3 in the most of the dates of last 17 days of January which are higher than that of number of occurrences of December in its first 15 days. Daily variations of dense and very dense fog occurrences in Fig. 2(b) also show very high variation among different days with progress of the season. Their climatological number of occurrences or probability of occurrences were nearly 0 or negligible (below 0.15) till 17 December and during last 10 days of January. Probabilities of occurrences of fog of both intensities were nearly same and remained between 0.2 and 0.5 for the remaining dates. Also, the most vulnerable period for the occurrence of dense and very dense fog during 62 days of Dec and Jan is 25 Dec - 16 Jan for the IGI airport because of probability values reached to highest values of 0.4 to 0.6 during this period with day to day variation between 0.2 to 0.4.

3.1.2. *Date-wise climatological percentage of hours of the day having fog of different intensities*

Figs. 3 (a&b) show date-wise climatological percentage of hours of the day having fog of different intensities during 1 Dec to 31 Jan along with their 5-days running means. It shows that the occurrences of general fog hours in a day over IGI airport are nearly 20-25% of the total hours of the day in the first 10 days of December, *i.e*., 5-6 hours with steady increasing trend till start of January. The percentage of number of fog hours increased up to 40-45% (10-11 hours) of the day by 25 December from 20-25% (4-5 hours per day) found during 1-10 December. Continuing to same trend, it reached about 11-12 hours in a day by 10 January and then decreased steadily to 20% (4-5 hours) per day by January 31. Hence climatological study of number of hours to have fog reveals that 25 December - 10 January period is the most vulnerable period when percentage occurrence of fog remained higher with almost nearly 40-45% of the day, *i.e*., 11-12 hours. However, percentages of hours of the day having shallow fog from Fig. 3(a) indicate that its occurrence hours gradually increased from 15% on 1 Dec to 25% on 25 Dec followed by immediate decrease to 20% on 1 January which again increased to 25% on 9 January. It falls for most of the dates thereafter and reached 15% by the end of the January as it was in 1st week of December. Moderate fog occurrences in Fig. 3(a) reveals very less daily variation during the season. Nearly 3 % of the hours of the day during 1-15 Dec. have chance of moderate fog which increased up to highest value of 12 % during 25-27 December and then remained 8-10% till 8 January. Then, it falls gradually to 2-4% by the end of January. It is interesting to note from daily variations of number of hours of dense and very dense fog occurrences plotted in Fig. 3(b) that percentage of hours per day to have dense fog on any dates is very much less (less than half of it) compared to that of very dense fog occurrences

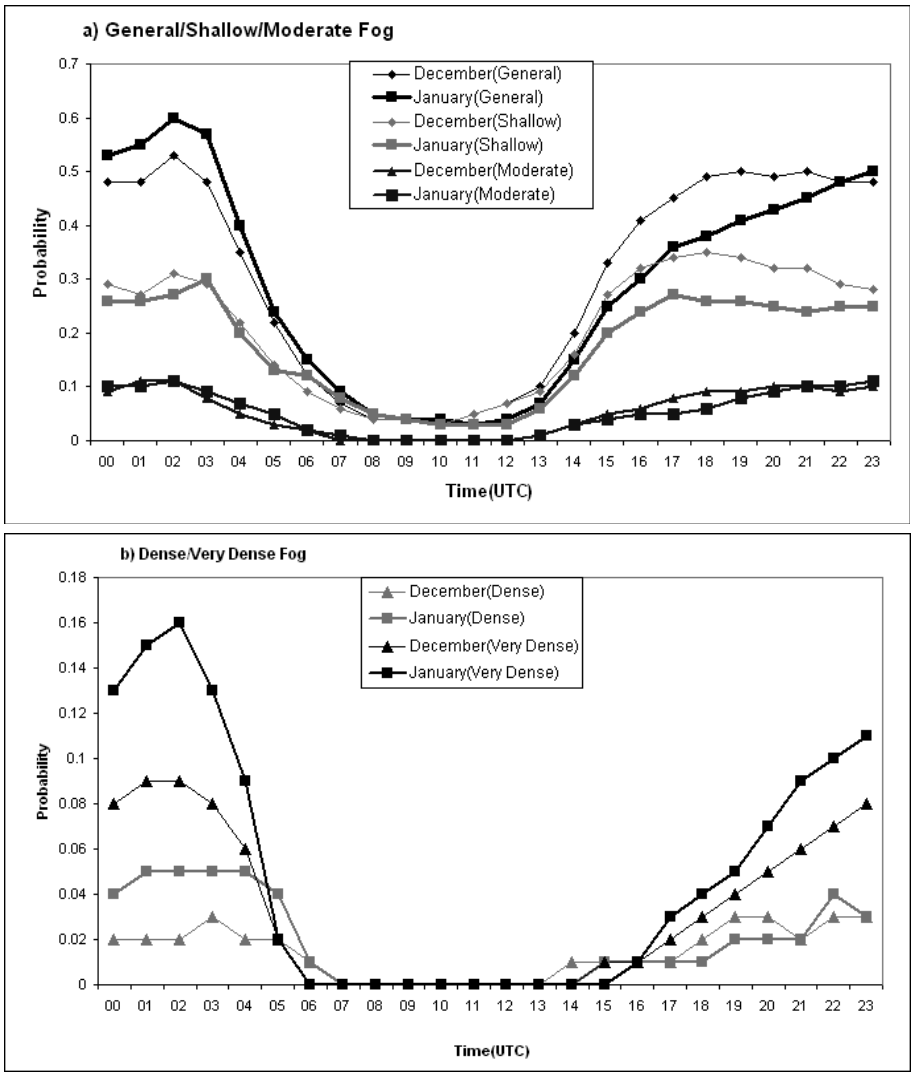




Figs. 3(a&b). Climatological % of hours of the date having fog

on the same date. Fig. 3(b) shows that hours of occurrences of dense fog is almost nil till 10 Dec which increased rapidly to 3-4% of hours of the day by 25 Dec and remained same till 8 January followed by gradual decrease to 1% by the end of January. But in case of very dense fog, even though its % of hours of occurrences also remained nearly 0 till 10 Dec., it increased at a first rate to 10-14% of hours (*i.e.*, 2.4 hours per day) of the day by 1-3 January which then gradually decreased to 2% by the end of January.

By considering percentage of fog hours variation on day to day of various intensity ranges from Fig. 3(a) and Fig. 3(b), one can note formation of 20% hours of a day for the period 1-10 December are general fog out of which 15% hours are of shallow fog which does not affect

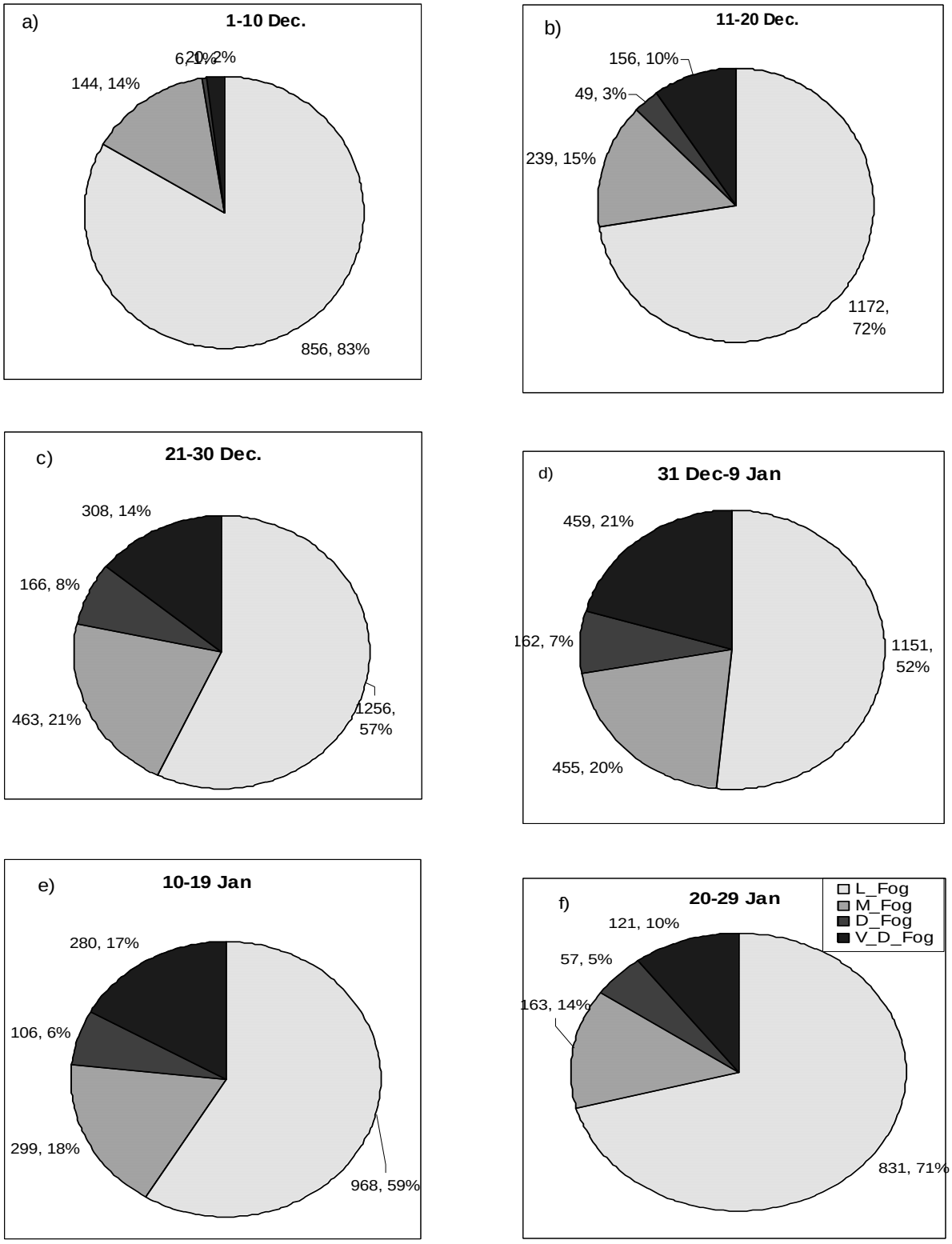


Figs. 4(a&b). Climatological probability of a particular hour having fog (diurnal variation)

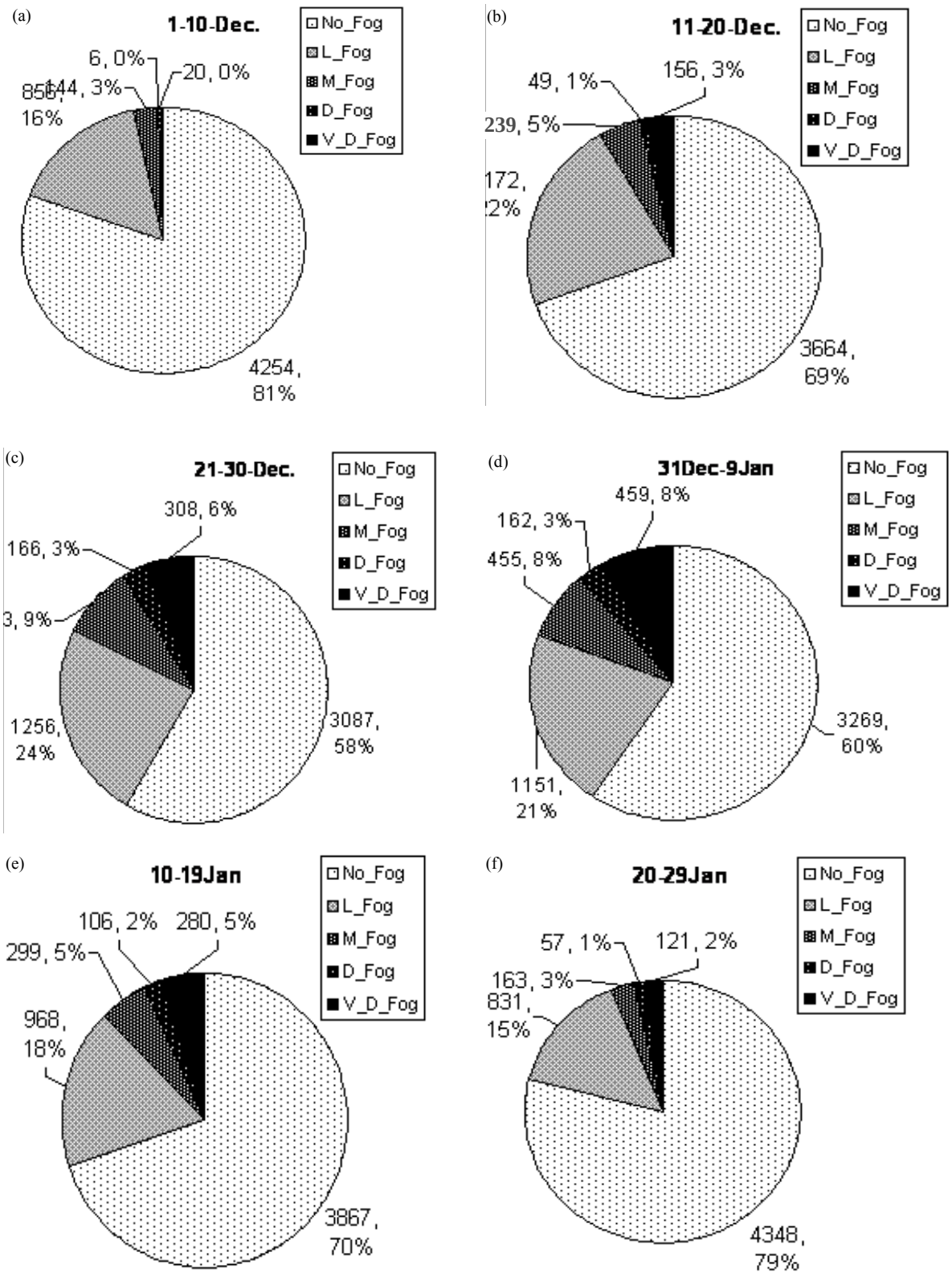
aviation, 3% hours are of moderate fog, 0.25% are of dense fog and remaining of 1.75% are of very dense fog. Since fog of moderate intensity or below can only affects aviations at IGI airport, so nearly 5% of the hours of a day during 1-10 December are of aviation hazardous fog. Similarly, one can note for subsequent dates from Fig. 3a and Fig. 3(b) about percentage of hours of the day affected by various types of fog. For the main vulnerable period of 25 Dec - 10 Jan [Figs. 3(a&b)], one can also note that out of roughly a total of 40-45% of hours of the day affected by fog, nearly 20-25% are shallow fog, 8-10% are moderate fog, 3% are dense and 5-8% are very dense fog.

3.2. *Hour-wise climatology or diurnal variations*

Figs. 4(a&b) show hourly climatology or diurnal variation of fog occurrences of different intensities in probability (total number of occurrences in the hour/total number of days having data in that hours) for December and January months. Variation of general fog occurrences in Fig. 4(a) during the day shows the highest occurrence probability of 0.4-0.6 at the start between 0000 UTC-0400 UTC, *i.e.*, early morning/morning and again towards the end at 1700-2300 UTC, *i.e.*, mid-night with least of 0.07-0.2 between 0700 UTC - 1300 UTC. In other words, the most favorable time of its occurrence is 1700-0400 UTC. However, interestingly comparison of diurnal variation between both the months from both the curves show that chances of fog occurrences between evening and mid-night are higher in December than January while from mid-night till next afternoon of 0700 UTC, its chances of occurrences are higher in January than December. In other word evening visibility is poorer in December compared to January while night/morning visibility is poorer in



Figs. 5(a-f). Climatological progress/variations in actual hours and % hours of fog of different intensities from 10-dates cumulative (Symbols-L_Fog - Shallow or light fog, M_Fog - Moderate fog, D_Fog - Dense fog, V_D Fog-Very Dense Fog)



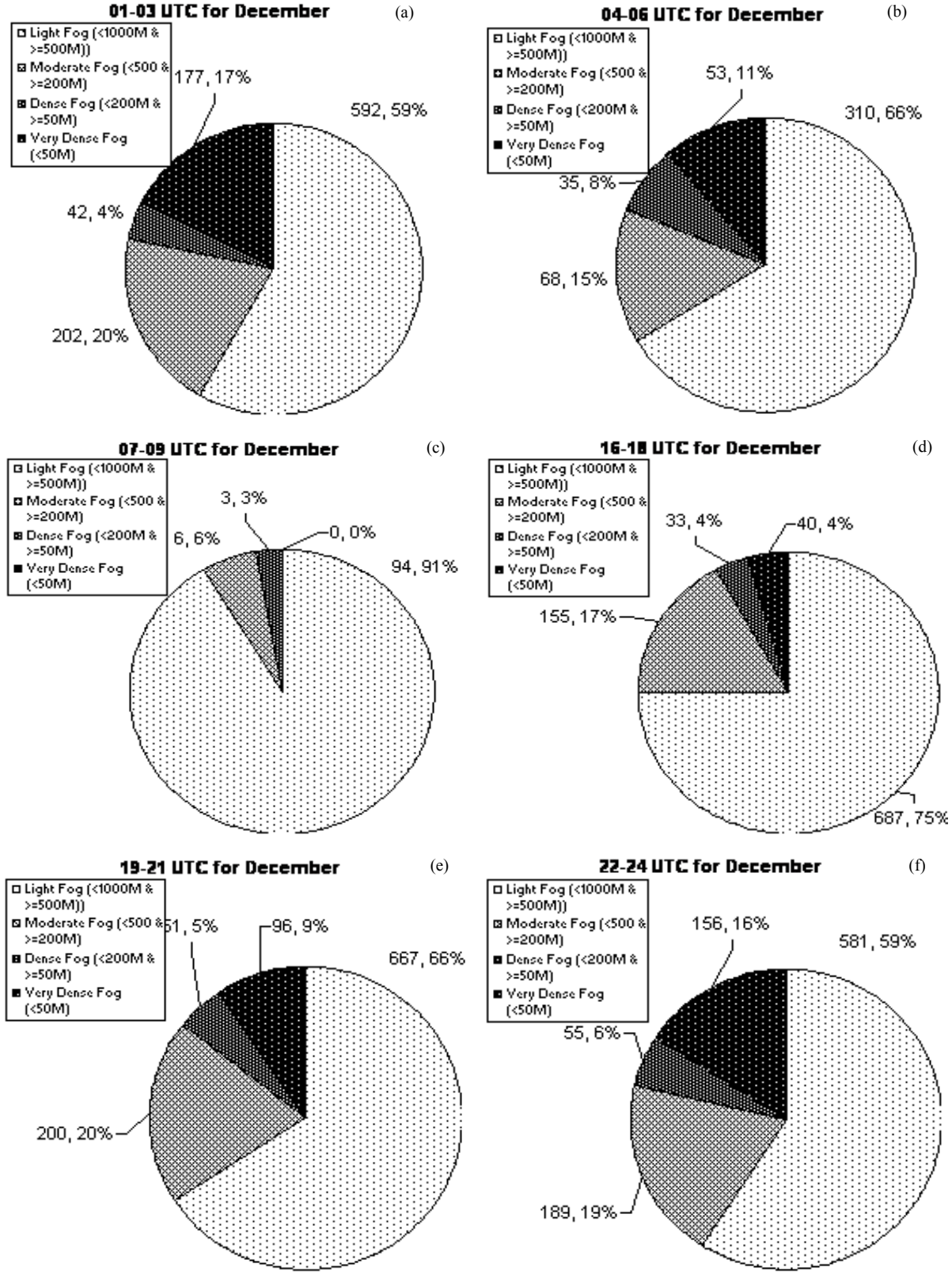
Figs. 6(a-f). Climatological progress/variation in actual hours and % of calendar total hours computed for fog of various intensities and no fog hours from 10 dates cumulative

January compared to December. It is also confirmed from visibility data averaged in meters for respective hours by considering their dates for all years for respective months separately. Diurnal variation of shallow fog occurrences in Fig. 4(a) also shows more or less similar variation though their values decreased nearly 0.2 for all hours except between 0700 UTC - 1300 UTC. But the diurnal variation of fog of next higher intensity range, *i.e.*, moderate fog in Fig. 4(a) shows significant reduction in their occurrences at all hours of the day compared to shallow fog with complete absence of such fog occurrences during period of afternoon to evening between 0700 UTC-1300 UTC with highest value of 0.1 occurring from mid-night till morning. It may also further be noted from Fig. 4(a) that diurnal variation of moderate fog in December is almost same as that of January. The diurnal variation of dense fog occurrences in Fig. 4(b) shows further significant reduction in their occurrences at all hours of the day compared to fog of other intensities discussed before with complete absence of such fog occurrences found during 0600 UTC-1300 UTC and highest value of 0.02-0.04 occurring at mid-night till morning.

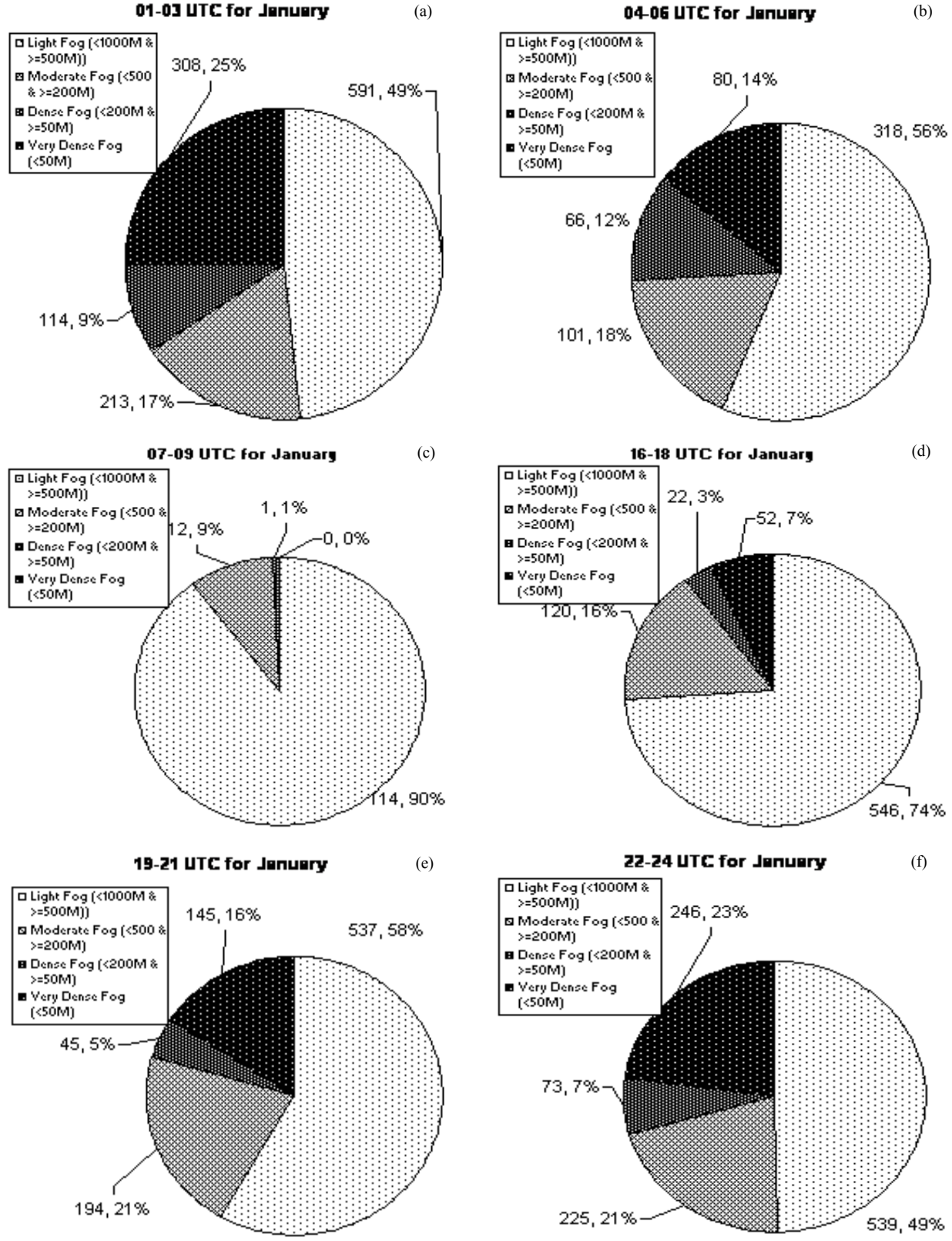
3.3. *Climatological progress/variations of fog occurrences in 10-days and 3-hourly time steps and their impact on aviation*

To understand and to make a better graphical presentation of climatological informations about how fog of different intensities started increasing their relative frequencies over the Airport with advance of the winter and *vice-versa* during its withdrawal stage, occurrences of total fog hours for each intensities of fog and their percentage share in the total fog hours of all intensities occurred at the airport are computed on 10 days basis starting from 1 Dec. Then these percentage values along with total number of occurrences are presented in pie diagrams in Figs. 5(a-f) for 1-10 Dec, 11-20 Dec, 21-30 Dec, 31 Dec - 9 Jan, 10-19 Jan and 20-29 Jan. It is interesting to note the gradual increase of percentage of occurrences of fog of higher intensities (moderate, dense and very dense) from 1-10 Dec till 21-30 Dec. [Figs. 5(a-c)] as their frequencies have been increased from 14%, 1% and 2% in 1-10 Dec to 15%, 3% and 10% in 11-20 Dec and then to 21%, 8% and 14% in 21-30 Dec respectively. It is coincided with significant decrease in shallow fog frequency from 83% to 72% and then to 57% in the corresponding 10-days intervals. It may be noted that the same trend continued till 31 Dec - 9 Jan in respect of very dense fog as its percentage of occurrences increased further to 21% while shallow fog decreased to 52% [Figs. 5(c&d)]. However in case of moderate and dense fog, the frequencies have showed a marginal decrease to 20% and 7% respectively in 31 Dec - 9 Jan. Thereafter, percentage frequencies of occurrence of all higher intensities fog (moderate, dense and very dense) [Figs. 5(e&f)] have decreased gradually till 20-29 Jan and reached 18%, 6% and 17% in 10-19 Jan and 14%, 5% and 10% in 20-29 Jan respectively. When compare among percentage of occurrences of fog of different intensities plotted at 10 days intervals from Figs. 5(a-d), it is interesting to note how percentage share of fog of higher intensities(marked in deep shading in pie diagrams) increased its areas from start of the season till 31 Dec - 9 Jan with proportional decrease of shallow fog (marked in light shading in pie diagrams) during the same period which then followed by reversal of their trends for subsequent periods as shown in Figs. 5(e-f) *i.e.*, till end of January. Hence the most vulnerable period when highest frequency of very dense fog occurred is 31 Dec - 9 Jan followed by 10-19 Jan, 21-30 Dec and 20-29 Jan respectively. The least vulnerable period is first ten dates *i.e.*, 1-10 December.

In Figs. 6(a-f), we have included hours of no fog occurrences and hours of occurrences of fog of different intensities from total calendar hours for whole period 1981-2005. From Figs. 6(a-c), it is quite interesting to note about gradual decrease of % of no fog occurrences hours at the airport while % of different fog occurrences have been in increasing mode from 1-10 Dec till 21-30 Dec. This is followed by their respective values in % of shares at the airport remaining nearly same during 31 Dec - 9 Jan [Fig. 6(d)]. Afterwards, % of occurrences of different fog frequencies has decreased [Figs. 6(e&f)]. If these corresponding % of various fog hours from total calendar hours from Figs. 6(a-f) corresponding to different aviation applicable CAT systems at IGI are considered as per Table 1, then on an average, % of very dense fog hours corresponding to CAT-IIIB and CAT-IIIC very dense fog hours which affect IGI Airport are 3%, 6%, 8%, 5% and 2% of total calendar hours for 11-20 Dec, 21-30 Dec, 31 Dec - 9 Jan, 10-19 Jan and 20-29 Jan periods respectively with 0% in 1-10 Dec. In other words, during such corresponding % of hours out of total calendar hours during respective period of the season, the air traffic at the airport gets severely affected because of lack of capability in most of the flights to land in CAT-IIIB and the IGI airport has not acquired the CAT-IIIC-ILS facilities for operation at RVR <50. Similarly, one can find the variation of other corresponding % of hours of fog of other intensity in Figs. 6(a-f) for corresponding period to understand the use of other CAT-ILS *e.g.*, CAT-I, CAT-II etc. For example, their respective values for the period 31 Dec - 9 Jan when the airport is most vulnerable in Fig. 6(d) show 40% as fog hours and 60% as no fog hours. Out of 40% of fog hours in the respective period, it has 21% as shallow fog hours when no CAT ILS is necessary except to be remaining alert as any time the fog may intensify bringing down visibility below 500 m, 8%



Figs. 7(a-f). Climatological progress/variation of fog in actual hours and % of occurrence of different intensities from 3-hourly cumulative of the day for the month of December



Figs. 8(a-f). Climatological progress/variation of fog in actual hours and % of occurrence of different intensities from 3-hourly cumulative of the day for the month of January

TABLE 1

Dates having very high number of hours (>15 hours) of general fog

Dates when visibility <1000 M December (1981-2004)						Dates when visibility <1000 M January (1981-2005)					
Year	Date	No. of Hours	Year	Date	No. of Hours	Year	Date	No. of Hours	Year	Date	No. of Hours
1997	27	24	2001	30	18	1998	7	24	2002	9	18
1997	28	24	2002	12	18	1998	8	24	2002	18	18
1998	16	24	2003	26	18	2000	2	24	2003	1	18
1998	19	24	2004	21	18	2000	4	24	2003	5	18
1999	31	24	2004	28	18	2000	5	24	2003	11	18
2001	28	24	1985	21	17	2002	1	24	1983	24	17
2003	27	24	1986	7	17	2003	7	24	1985	1	17
1998	18	23	1987	20	17	2003	18	24	1986	8	17
1998	24	23	1987	25	17	2000	1	23	1986	9	17
1999	27	23	1987	26	17	2000	9	23	1988	5	17
1999	29	23	1987	30	17	2002	4	23	1991	5	17
2002	26	23	1993	25	17	2000	10	22	1994	1	17
2003	24	23	1997	12	17	2003	2	22	1994	3	17
1996	20	22	1997	23	17	2004	2	22	1994	8	17
1999	28	22	1998	26	17	1990	3	21	1997	6	17
2003	30	22	1999	24	17	1997	21	21	1997	27	17
1986	8	21	1999	26	17	1999	7	21	1999	1	17
1998	17	21	2001	12	17	2002	2	21	1999	12	17
1998	23	21	2002	25	17	2003	15	21	2001	8	17
1998	30	21	2003	21	17	2003	16	21	2001	17	17
2003	22	21	2003	28	17	2005	2	21	2002	5	17
2003	31	21	2004	24	17	1987	11	20	2002	8	17
2004	22	21	1983	15	16	1990	2	20	2003	9	17
1997	26	20	1986	23	16	1994	13	20	1982	9	16
1998	20	20	1986	25	16	2000	7	20	1982	27	16
1998	22	20	1987	16	16	2000	8	20	1986	7	16
1998	28	20	1987	21	16	2002	6	20	1991	6	16
1998	29	20	1987	31	16	2003	10	20	1994	7	16
2001	29	20	1988	22	16	2003	19	20	1997	1	16
1989	29	19	1989	25	16	2003	20	20	1997	15	16
1993	28	19	1990	4	16	2004	6	20	1999	2	16
1994	5	19	1990	17	16	1994	19	19	1999	18	16
1996	3	19	1993	24	16	2000	3	19	1999	20	16
2002	24	19	1993	29	16	2001	12	19	2001	9	16
2004	11	19	1994	1	16	2001	15	19	2001	18	16
1988	24	18	1998	15	16	2002	17	19	2002	3	16
1989	30	18	2000	16	16	2003	6	19	2002	7	16
1996	21	18	2000	27	16	2003	17	19			
1996	22	18	2001	15	16	2004	14	19			
1998	11	18	2001	25	16	1985	6	18			
1998	12	18	2001	27	16	1986	10	18			
1998	21	18	2001	31	16	1987	19	18			
1998	27	18	2002	17	16	1994	20	18			
1998	31	18	2002	20	16	1998	9	18			
1999	25	18	2003	25	16	1999	3	18			
1999	30	18				1999	19	18			
2001	16	18				2000	6	18			

TABLE 2

Dates having very high number of hours (>12 hours) of moderate to very dense fog when visibility <500 M (1981-2005)

December			January		
Year	Date	No. of Hours	Year	Date	No. of Hours
2001	28	20	2000	2	20
1997	27	19	2000	1	19
1999	29	19	2002	1	19
1999	31	19	2003	16	18
1998	18	18	2004	2	18
2003	24	18	1990	2	17
1998	16	17	2003	19	17
1998	17	17	2004	6	17
1999	28	17	1990	3	16
1998	22	16	2000	3	16
1998	27	16	2000	7	16
1998	28	16	2001	12	16
1998	31	16	2002	2	16
2002	26	16	2003	2	16
1988	24	15	2003	10	16
1996	21	15	2003	17	16
1997	28	15	2003	20	16
1998	23	15	2005	2	16
2001	29	15	1998	7	15
2002	25	15	1998	8	15
2003	21	15	2000	5	15
1987	26	14	2002	9	15
1989	29	14	2003	15	15
1998	15	14	2004	14	15
1998	19	14	1985	6	14
1998	21	14	1986	8	14
1999	27	14	1987	11	14
1999	30	14	1987	19	14
1989	30	13	2000	4	14
1993	29	13	2000	6	14
1997	23	13	2001	15	14
1998	26	13	2001	17	14
1998	30	13	2002	4	14
2001	30	13	2003	1	14
2003	30	13	2003	6	14
			2003	18	14
			1994	3	13
			1997	15	13
			1999	1	13
			2001	9	13
			2002	3	13
			2002	5	13
			2003	5	13
			2003	11	13

TABLE 3

Dates having very high number of hours (>9 hours) of dense fog to very dense fog when visibility <200M (1981- 2005)

December			January		
Year	Date	No. of Hours < 200m	Year	Date	No. of Hours < 200m
1998	18	17	2003	16	15
2001	28	17	2004	6	15
1998	27	16	1990	3	14
1999	31	16	2000	3	14
1998	16	15	2003	19	14
1998	17	15	2004	14	14
1998	22	15	1985	6	13
1998	31	15	1999	1	13
2003	24	15	2001	17	13
1998	23	14	2003	10	13
1988	24	13	2003	20	13
1989	29	13	2005	2	13
1999	28	13	2000	4	12
2003	21	13	2002	1	12
1997	27	12	2002	2	12
1998	28	12	2003	17	12
1999	29	12	1987	19	11
2002	26	12	2000	5	11
1998	30	11	2000	6	11
1999	30	11	2000	7	11
2001	29	11	2001	9	11
1998	21	10	2003	1	11
	January		2004	2	11
2000	2	18	1998	8	10
2000	1	16	2001	8	10
1990	2	15			

TABLE 4

Dates having very high number of hours (>6 hours) of very dense fog when visibility < 50M (1981- 2005)

December			January		
Year	Date	No. of Hours	Year	Date	No. of Hours Vis. < 50M
1998	27	15	2003	16	14
1999	31	15	1985	6	13
1998	16	14	2004	6	13
1998	22	14	2004	14	13
1998	31	14	1999	1	12
1998	17	13	1987	19	11
1998	18	13	2000	3	11
1998	23	12	2000	6	11
1998	30	11	2003	17	11
1989	29	10	2003	19	11
1998	28	10	2003	20	11
2001	28	10	1998	8	10
1991	26	9	2000	4	10
1997	11	9	2002	1	10
1998	21	9	2002	2	10
2003	21	9	2003	1	9
1999	30	8	2003	10	9
1989	25	7	2005	2	9
1997	23	7	1994	15	8
1998	26	7	1997	22	8
1999	28	7	2003	15	8
1999	29	7	2003	18	8
2003	24	7	1987	14	7
	January		1990	1	7
2000	2	17	1998	7	7
2000	1	15	1999	18	7
1990	2	14	2000	5	7
1990	3	14	2001	17	7

as moderate fog hours which requires CAT-I & II ILS, 3% as dense fog hours which requires CAT-IIIA & IIIB ILS and 8% as very dense fog hours of CAT-IIIB and CAT-III C ILS. In the absence of any method to find the important of making available of other various additional modern fog mitigation system at IGI, such important intensity based fog climatological informations can be used by air lines and airport operator of IGI to understand that there is high economical and time benefits, if they update ILS landing facilities of the RWY to further higher CAT ILSs *i.e.*, CAT-IIIC ILS and those of the aircrafts and trainings of pilots using them.

Figs. 7 and 8 show cumulative 3-hourly progress of fog occurrences on a day in % of total occurrences from 0000 UTC to 2300 UTC for December and January separately. Cumulative 3-hours percentage of fog occasions of those periods particularly during afternoon times, which had no significant contribution, is not

TABLE 5

Probability of occurrence of general fog (Visibility < 1000 M) at a particular hour of a day in the month of December

Date	Time in UTC																						
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	.4	.3	.4	.3	.2	.1										.2	.3	.3	.3	.3	.3	.2	.3	.3
2	.3	.3	.3	.2											.1	.1	.2	.2	.2	.2	.2	.2	.2	.3
3	.3	.3	.3	.3	.2		.1	.1	.1							.1	.4	.3	.4	**.5**	**.5**	**.5**	.4	**.5**
4	.4	.4	.3	.3	.3	.1										.2	.2	.2	.3	.4	.4	.3	.3	.3
5	.3	.3	.3	.3	.2			.1						.1	.1	.2	.4	.4	**.5**	**.5**	.4	**.5**	.4	**.5**
6	.4	.4	.4	.3	.1											.2	.3	.3	.3	.3	.4	.4	.3	.3
7	.3	.3	.4	.3	.1					.1				.1	.2	.2	.3	.3	.2	.2	.2	.2	.2	.3
8	.3	.4	.4	.4	.2	.1								.1	.1	.3	.3	.3	.4	.4	.4	.3	.3	.4
9	.4	**.5**	**.5**	**.5**	.2									.1	.2	.1	.3	.4	.3	.2	.3	.3	.2	.3
10	.3	.4	**.5**	.3	.2	.1									.1	.3	.3	**.5**	.4	.4	**.5**	**.5**	**.5**	**.5**
11	**.5**	**.5**	**.7**	**.5**	.4	.2	.1					.1	.1	.1	.2	.2	.3	.4	.4	**.5**	**.5**	**.5**	**.5**	**.5**
12	.4	**.5**	**.5**	.4	.4	.2	.2							.1	.1	.3	.4	.4	**.5**	.4	**.5**	**.5**	**.5**	**.5**
13	**.5**	.4	**.5**	.4	.3	.3											.2	.4	.4	.3	.3	.4	.4	.4
14	.4	.3	.4	.3	.1	.1									.1	.2	.4	**.5**	**.5**	**.5**	**.5**	**.5**	**.5**	**.5**
15	.4	.4	**.5**	.4	.2	.2									.3	.4	.4	.4	**.5**	**.5**	.4	.4	.3	.3
16	.3	.3	**.5**	**.5**	.3	.2	.1	.1	.1						.1	.3	.4	**.5**	.4	**.5**	**.5**	**.5**	**.5**	**.5**
17	**.5**	**.5**	**.6**	**.6**	.4	.2	.2	.1							.2	**.5**	**.7**	**.7**	**.8**	**.8**	**.7**	**.8**	**.7**	**.6**
18	**.6**	**.6**	**.7**	**.6**	**.5**	.3	.1					.1	.1	.1	.2	.3	**.5**	**.5**	**.5**	**.5**	**.5**	**.6**	**.5**	**.5**
19	**.5**	**.6**	**.7**	**.6**	.4	.4	.1							.1	.3	**.5**	**.5**	**.6**	**.6**	**.6**	**.5**	**.5**	**.5**	**.5**
20	**.6**	**.6**	**.6**	**.6**	**.5**	.2	.1	.1		.1			.1	.1	.2	**.5**	**.5**	**.5**	**.5**	**.5**	**.5**	**.5**	**.5**	**.5**
21	**.5**	**.5**	**.5**	**.5**	.4	.2	.2						.1	.1	.3	**.5**	**.5**	**.5**	**.5**	**.6**	**.6**	**.6**	**.5**	**.6**
22	**.6**	**.6**	**.6**	**.5**	.3	.3	.2	.1	.1	.1	.1	.1	.1	.2	.3	**.6**	**.6**	**.5**	**.7**	**.7**	**.6**	**.5**	**.5**	**.5**
23	**.6**	**.5**	**.5**	**.6**	.4	.3	.2					.1	.1	.1	.4	.4	**.5**	**.5**	**.7**	**.7**	**.6**	**.6**	**.6**	**.6**
24	**.7**	**.7**	**.7**	**.7**	**.5**	**.5**	.3	.2	.1	.1		.1	.1	.2	.3	**.6**	**.6**	**.7**	**.8**	**.8**	**.7**	**.6**	**.6**	**.5**
25	**.5**	**.5**	**.5**	**.6**	**.5**	**.5**	.2	.1						.2	.4	**.5**	**.6**	**.6**	**.7**	**.7**	**.7**	**.7**	**.7**	**.7**
26	**.7**	**.7**	**.8**	**.6**	**.6**	.4	.2	.1		.1	.1	.1	.1	.1	.3	**.6**	**.6**	**.6**	**.7**	**.7**	**.6**	**.7**	**.7**	**.7**
27	**.7**	**.7**	**.7**	**.6**	**.5**	.4	.3	.1	.1	.1	.1	.1	.1	.2	.3	.4	**.5**	**.6**	**.7**	**.7**	**.6**	**.6**	**.6**	**.6**
28	**.7**	**.7**	**.8**	**.8**	**.6**	.3	.3	.2	.1	.1	.1	.1	.3	.3	.4	.4	**.5**	**.5**	**.6**	**.6**	**.6**	**.7**	**.7**	**.7**
29	**.6**	**.7**	**.7**	**.6**	**.6**	.3	.2	.1	.1	.1	.1	.1	.1	.2	.4	.4	.4	**.5**	**.5**	**.5**	**.6**	**.5**	**.5**	**.5**
30	**.5**	**.5**	**.6**	**.6**	**.5**	.4	.2	.1	.1	.1	.1	.1	.1	.2	.3	.4	**.5**	**.6**	**.6**	**.6**	**.6**	**.5**	**.5**	**.5**
31	**.5**	**.5**	**.5**	**.5**	**.5**	.3	.2	.1	.1		.1	.1	.1	.1	.3	.3	.4	**.5**	**.5**	**.5**	**.6**	**.6**	**.6**	**.6**

included in graphical presentation of Figs. 7 and 8. It is also interesting to note that vulnerability of very dense fog gradually increased from night to morning in Fig. 8(d) for 1600-1800 UTC to Fig. 8(f) for 1900-2100 UTC followed by Fig. 7(a) for 0100-0300 UTC and decreased there after in Fig. 7(b) for 0400-0600 UTC. As per Figs. 7(a-f), the highest % of very dense fog (16-17%) and moderate fog (19-20%) occurred during 2200-0300 UTC and 1900-0300 UTC with 6 and 9 hours prolonged period respectively while dense fog (8%) occurred at 0400-0600

TABLE 6

Probability of occurrence of moderate to very dense fog (Visibility <500M)at a particular hour of a day in the month of December

Date	Time in UTC																
	00	01	02	03	04	05	06	14	15	16	17	18	19	20	21	22	23
1		.1										.1	.1	.1	.1		.1
2	.1															.1	.1
3												.1	.1	.1	.1	.1	.1
4	.1	.1	.1									.1	.1	.1	.1	.1	.1
5	.1	.1	.1	.1								.1	.1	.1	.1	.1	.1
6	.1	.1	.1	.1													
7															.1	.1	.1
8	.1	.1	.1	.1													
9			.1														
10			.1	.1	.1	.1										.1	.1
11	.1	.1	.1	.1	.1	.1						.1	.1	.1	.1	.1	.1
12	.1	.2	.2	.1									.1	.1	.1	.2	.2
13	.2	.2	.2	.1	.1											.1	.1
14		.1	.1		.1	.1	.1			.1							.1
15	.1	.1	.1	.1	.2	.2	.1			.2	.2		.2	.2	.2	.1	.1
16	.1	.1	.1	.1	.1	.1	.1		.1	.1	.1		.1	.1	.1	.1	.1
17	.2	.2	.2	.2	.2	.1	.1				.1	.2	.2	.2	.2	.2	.2
18	.3	.3	.3	.3	.2					.1	.1	.2	.2	.2	.2	.3	.3
19	.2	.3	.3	.3	.2	.1			.2	.3	.3	.1	.2	.2	.1	.2	.3
20	.3	**.4**	**.4**	**.4**	.2	.1		.1	.1	.1	.1	.1	.1	.2	.1	.2	.3
21	.3	.3	.3	.2	.1	.1					.1	.3	.3	.3	**.4**	.3	.3
22	.3	**.4**	**.4**	.3	.3	.2	.1	.1	.2	.2	.2	.1	.1	.1	.1	.1	.1
23	.1	.2	.3	.1	.2	.1		.1	.1	.1	.1	.1	.1	.2	.2	.3	.3
24	.3	.3	**.4**	.3								.3	**.5**	**.4**	.2	**.4**	**.4**
25	**.4**	**.4**	**.4**	**.4**								.2	.2	.3	**.4**	**.5**	**.5**
26	**.5**	**.4**	**.4**	**.4**	.2	.1			.1	.2	.2	.3	.3	**.5**	**.5**	.3	**.4**
27	**.4**	.3	**.5**	.3	.2	.1		.1	.1	.1	.3	.3	**.4**	**.4**	**.5**	**.4**	.3
28	.3	**.4**	**.4**	.3	.3	.2	.1	.2	.3	.2	.3	.3	.3	**.5**	**.4**	**.4**	**.4**
29	**.4**	**.5**	**.5**	**.4**	.2	.2			.1	.2	.2	.2	.2	.3	.3	.3	.3
30	.3	.3	.3	**.4**	.2	.1		.1	.1	.3	.3	.3	.3	**.4**	**.4**	.3	**.4**
31	**.4**	**.4**	.3	.2	.2	.2		.1	.1	.1	.1	.2	.2	.3	.3	**.4**	.3

UTC and shallow fog (91%) occurred at 0700-0900 UTC in December. In case of January, Figs. 8(a-f) show the highest % of both very dense fog (23-25%) and moderate fog (21%) occurred during 2200-0300 UTC and 1900-2400 UTC, a 6 hour prolonged period while dense fog (12%) occurred for 0400-0600 UTC and shallow fog (90%) occurred at 0700-0900 UTC. It is interesting to note from comparison of 3-hourly cumulative % of occurrences of fog of various intensities between December and January that both months have a common

TABLE 7

Probability of occurrence of dense fog (visibility <200 M) at a particular hour of a day in the month of December																				Probability of occurrence of very dense fog (visibility <50 M) at a particular hour of a day in the month of December																			
Date/ Time (UTC)	00	01	02	03	04	05	06	15	16	17	18	19	20	21	22	23	Date/ Time (UTC)	00	01	02	03	04	05	15	16	17	18	19	20	21	22	23
1																	1															
2																	2															
3																	3															
4																	4															
5																.1	5															
6	.1																6	.1														
7																	7															
8																	8															
9																	9															
10																	10															
11	.1	.1	.1	.1													11	.1	.1	.1	.1											
12			.1	.1	.1	.1							.1	.1	.1	.1	12					.1										
13	.1			.1	.1												13				.1	.1										
14																	14															
15														.1	.1	.1	15															.1
16	.1	.1	.1	.1	.1	.1								.1	.1	.1	16	.1	.1	.1	.1	.1	.1							.1	.1	.1
17	.1	.1	.1	.1	.1	.1					.1	.1	.1	.1	.1	.1	17	.1	.1	.1	.1	.1					.1	.1	.1		.1	.1
18	.2	.1	.1	.1	.1	.1	.1					.1	.1	.1	.2	.1	18	**.2**	.1	.1	.1	.1	.1							.1	.1	.1
19	.2	.2	.2	.2	.2	.1										.1	19	**.2**	**.2**	**.2**	.1	.1										
20	.1	.2	.1	.1										.1	.1	.1	20	.1	.1	.1	.1											.1
21	.1	.2	.1	.1						.1	.2	.2	.2	.2	.2	.2	21	.1	.1	.1	.1							.1	.1	.1	.1	.1
22	.2	.2	.2	.2	.1							.1	.1	.1	.1	.1	22	.1	.1	**.2**	.1	.1										
23	.1	.1	.1	.1	.1	.1					.1	.1	.1	.2	.2	.2	23		.1	.1	.1	.1					.1	.1	.1	**.2**	**.2**	**.2**
24	.2	.2	.2	.2	.1	.2		.1	.2	.2	.1	.1	.1		.1	.1	24	**.2**	**.2**	**.2**	.1	.1			.1						.1	.1
25	.2	.2	.2	.1	.1							.1	.1	.1	.2	**.3**	25	.1	.1	.1	.1								.1	.1	.1	**.2**
26	.2	.2	.2	.1	.1	.1						.1	.1	.1	.1	.2	26	**.2**	**.2**	**.2**	.1	.1							.1	.1	.1	.1
27	.1	.1	.2	.2	.1				.1	.1	.1	.2	.2	.2	.2	.2	27	.1	.1								.1	.1	.1	**.2**	.1	.1
28	.2	.2	.2	.2	.1	.1				.1	.1	.1	.2	.2	**.3**	**.3**	28	.1	.1	**.2**	**.2**	.1				.1		.1	.1	.1	**.2**	**.2**
29	**.3**	**.3**	**.3**	**.3**	.2	.1					.1	.1	.2	.2	.2	.2	29	**.2**	**.3**	**.3**	**.2**	**.2**	.1						.1	**.2**	.1	**.2**
30	**.3**	.2	.2	.2	.1						.2	.2	.2	.2	.2	.2	30	**.3**	**.2**	**.2**	.1	.1								.1	.1	
31	.2	.1	.2	.2	.2	.1		.1	.1	.1	.1	.1	.1	.2	**.3**	**.3**	31	.1	.1	.1	**.2**	**.2**		.1		.1	.1	.1	.1	.1	**.2**	**.3**

vulnerable time of most intense fog, *i.e.*, very dense fog, occurring at 2200-0300 UTC, a late night/morning event covering 16-17% and 23-25% of the total fog time respectively in both months that demand provision of CAT-III ILS at IGI to avoid maximum chance of aircrafts diversion/cancellation.

TABLE 8

Probability of occurrence of general fog (visibility <1000 M) at a particular hour of a day in the month of January

	Time in UTC																							
Date	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	**.5**	**.6**	**.6**	**.6**	**.5**	.3	.3	.2	.2	.1	.1		.1	.2	.4	**.6**	**.6**	**.6**	**.5**	**.6**	**.6**	**.6**	**.7**	**.7**
2	**.7**	**.7**	**.7**	**.7**	**.6**	.4	.3	.3	.2	.1	.1	.1	.2	.3	.3	.4	**.6**	**.5**	**.5**	**.6**	**.6**	**.6**	**.6**	**.6**
3	**.7**	**.6**	**.7**	**.7**	**.5**	.3	.3	.2				.1	.1		.2	.4	.4	.4	**.5**	**.5**	.4	.4	**.5**	**.6**
4	**.6**	**.6**	**.7**	**.6**	.3	.1	.1	.1	.1	.1	.1	.1	.1	.2	.3	**.5**	**.5**	**.5**	**.5**	**.5**	**.5**	**.5**	**.6**	**.6**
5	**.7**	**.7**	**.7**	**.7**	.3	.3	.2							.2	.3	.3	**.5**	**.6**	**.6**	**.6**	**.6**	**.7**	**.7**	**.7**
6	**.6**	**.6**	**.7**	**.6**	**.6**	.4	.3	.2					.1	.1	.4	**.5**	**.6**	**.6**	**.6**	**.6**	**.6**	**.7**	**.8**	**.7**
7	**.8**	**.8**	**.9**	**.8**	**.6**	**.5**	.3	.1	.1	.1	.1	.2	.1	.1	.3	.4	.4	**.5**	**.6**	**.6**	**.6**	**.7**	**.7**	**.7**
8	**.7**	**.7**	**.8**	**.7**	**.5**	.4	.3	.2	.1	.1	.1			.2	.3	.4	**.5**	**.5**	**.5**	**.5**	**.6**	**.7**	**.8**	**.6**
9	**.7**	**.6**	**.7**	**.7**	**.5**	.4	.4	.2	.1	.1	.1	.1	.1	.1	.3	.3	.4	**.5**	**.5**	**.5**	**.5**	**.5**	**.6**	**.6**
10	**.7**	**.8**	**.8**	**.7**	**.6**	.3	.3	.1	.1					.1	.2	.3	**.5**	**.6**	**.5**	**.6**	**.6**	**.6**	**.7**	**.6**
11	**.7**	**.7**	**.7**	**.7**	.4	.3	.1							.1	.1	.3	.4	.4	.4	.4	.4	**.5**	**.5**	**.6**
12	**.6**	**.6**	**.6**	**.6**	.3	.2	.1							.1	.1	.2	.3	.3	.3	.4	**.5**	**.6**	**.5**	**.6**
13	**.7**	**.7**	**.7**	**.7**	**.5**	.1	.1	.1								.2	.2	**.5**	.4	**.5**	**.5**	**.6**	**.6**	**.5**
14	**.5**	**.5**	**.6**	**.6**	**.5**	.4	.1	.1							.1	.3	.3	.3	.3	.4	.4	.3	.4	.4
15	.4	.4	.4	.4	.4	.2	.2	.1	.1	.1		.1			.1	.2	.2	.3	.4	**.5**	**.5**	**.5**	.4	**.5**
16	**.5**	**.5**	**.6**	**.5**	.3	.2	.1	.1	.1	.1				.1	.1	.2	.4	.4	.4	.3	.4	.4	.3	.4
17	.4	**.5**	**.5**	**.5**	.3	.2	.3	.1							.3	.2	.3	.4	.4	**.5**	**.5**	**.5**	**.6**	**.5**
18	**.6**	**.6**	**.6**	**.5**	.4	.2	.2	.1							.1	.2	.3	.2	.3	.3	.3	.3	.3	.3
19	.3	.4	**.5**	.4	.3	.3	.2	.1	.1					.1	.2	.4	.4	**.5**	**.5**	**.5**	**.5**	.4	.4	**.5**
20	**.5**	**.5**	**.5**	**.5**	.3	.2	.1	.1							.1	.3	.3	.3	.4	.4	.3	.3	.3	.3
21	.3	.3	**.5**	**.5**	.3	.1	.1								.2	.1	.1	.3	.3	.4	.4	.4	.4	**.5**
22	**.5**	**.6**	**.7**	**.6**	.4	.3	.1								.1	.2	.3	.4	**.5**	.4	.4	.4	**.5**	**.6**
23	**.6**	**.7**	**.7**	**.7**	**.5**	.2											.1	.1	.2	.3	.3	.4	.4	**.5**
24	**.6**	**.6**	**.6**	**.5**	.3	.1										.1			.1	.2	.3	.3	.4	**.5**
25	.4	.4	.4	**.5**	.2	.1											.1	.2	.2	.2	.3	.4	.4	.3
26	.3	.3	.4	.3	.3	.1	.1												.2	.3	.3	.3	.3	.4
27	.4	**.5**	**.6**	**.6**	.4	.2	.1	.1								.2	.2	.3	.2	.2	.3	.3	.4	.4
28	.4	**.5**	**.6**	**.5**	.3	.2										.1	.1	.1	.1	.1	.1	.1	.2	.3
29	.3	.3	.4	.3	.2											.1	.2	.2	.2	.3	.3	.3	.3	.3
30	.4	.4	**.5**	**.6**	.3	.1											.2	.3	.3	.3	.3	.3	.3	**.5**
31	.4	.4	.4	.4	.3	.2												.1	.3	.3	.3	.4	.3	.3

3.4. *Extreme dates of fog occurrences of different intensities*

Month wise dates of very high total number of fog hours of fog occurrences in a day, exceeding a select threshold value for different categories (General, moderate to very dense, dense to very dense and very dense fog) during the study period is shown in Tables 1-4. Different threshold values are fixed for filtering these extreme dates in the period of study for different categories of fogs and these dates in case of general fog, moderate to very dense fog, dense to very dense fog and very dense fog are those

TABLE 9

Probability of occurrence of moderate to very dense fog (visibility <500 M) at a particular hour of a day (January)

Date	Time (UTC)																	
	00	01	02	03	04	05	06	13	14	15	16	17	18	19	20	21	22	23
1	.3	**.4**	**.4**	.3	.3	.2	.1	.1	.1	.1	.1	.2	.3	**.4**	**.4**	**.4**	**.5**	**.5**
2	**.5**	**.5**	**.4**	**.4**	**.4**	.3	.2	.1	.2	.3	.3	.3	.3	**.4**	**.4**	**.4**	**.4**	**.4**
3	**.4**	**.4**	**.4**	**.4**	.3	.2	.1			.1	.1	.2	.2	.3	.3	.3	.3	.3
4	.3	**.4**	**.4**	.3	.2					.1	.1	.2	.2	.3	.3	.3	.3	.3
5	**.4**	.3	.3	.2	.2	.1					.1	.1	.1	.3	**.4**	**.4**	**.5**	**.4**
6	**.4**	**.4**	**.5**	**.5**	.3	.2			.1	.1	.2	.3	.3	.3	.3	**.4**	**.4**	**.4**
7	**.5**	**.5**	**.7**	**.5**	.3	.2		.1	.1	.1	.2	.3	.3	.3	.3	.3	**.4**	**.4**
8	**.4**	**.4**	**.5**	.3	.3	.2				.1	.1	.1	.1	.1	.2	.3	.3	.3
9	**.4**	**.4**	**.5**	**.4**	.3	.3	.1				.1	.1	.2	.2	.3	.3	.3	.3
10	.3	**.4**	.3	.3	.3	.2				.1			.1	.1	.1	.1	.1	.3
11	.3	.3	.3	.2	.1	.1				.1	.1	.1	.1	.1	.1	.1	.2	.3
12	.3	.3	.3	.3	.2						.1	.2	.2	.2	.3	.3	.3	.3
13	.3	.3	**.4**	.3	.2	.1						.1	.3	.3	.3	.3	.3	.3
14	.3	.3	.3	.3	.2	.2							.1	.1	.2	.3	.3	.3
15	.3	.3	.3	.3	.3	.1					.1	.1	.2	.2	.2	.2	.2	.2
16	.3	.2	.3	.2	.1	.1								.1	.2	.2	.1	.2
17	.3	.3	.3	.3	.2	.2	.1				.1	.1	.1	.1	.2	.2	.3	.3
18	.3	.3	.3	.3	.1	.1							.1	.1	.1	.2	.2	.2
19	.2	.2	.3	.3	.2	.1	.1			.1	.1	.2	.2	.3	.3	.3	.2	.2
20	.2	.3	.3	.2	.2	.2				.1			.1	.1	.1	.1	.1	.1
21	.1	.2	.2	.1	.2									.1			.1	.1
22	.1	.2	.2	.2	.2	.1									.1	.1	.2	.3
23	.2	.3	**.4**	.3	.2												.2	.2
24	.1	.2	.3	.2	.1													
25		.1	.1	.1	.1											.1	.2	.1
26	.2	.2	.2	.1	.1													.1
27	.1	.2	.2	.2	.1										.1	.2	.3	.3
28	.3	.3	.3	.3	.2												.1	.1
29	.1	.2	.2	.1												.2	.2	.2
30	.2	.3	.3	.3	.2	.1									.1	.1	.1	.1
31	.1	.2	.2	.1	.1											.1	.1	.1

dates which have recorded more than 15 hours, more than 12 hours, more than 9 hours and more than 6 hours of fog at respective intensity in the day. Table 1 shows that 7 dates of December of the years 1997 (27^{th}, 28^{th}), 1998 (16^{th}, 19^{th}), 1999 (31^{st}), 2001 (28^{th}) and 2003 (27^{th}) and 8 dates of January in the year 1998 (7^{th}, 8^{th}), 2000 (2^{nd}, 4^{th}, 5^{th}), 2002 (1^{st}), 2003 (7^{th},18^{th}) had highest number of total general fog hours *i.e.*, 24 hours over the airport. One may

TABLE 10

Probability of occurrence of dense fog (visibility <200 M) at a particular hour of a day in the month of January																				Probability of occurrence of very dense fog (visibility <50 M) at a particular hour of a day in the month of January															
Date/ Time (UTC)	00	01	02	03	04	05	06	14	15	16	17	18	19	20	21	22	23	Date/ Time (UTC)	00	01	02	03	04	05	16	17	18	19	20	21	22	23
1	**.3**	**.3**	**.3**	**.3**	.2	.2					.1	.2	**.3**	**.3**	**.3**	**.4**	**.4**	1	**.2**	**.3**	**.3**	**.2**	.1			.1	.1	**.2**	**.3**	**.2**	**.3**	**.3**
2	**.4**	**.3**	**.3**	**.3**	**.3**	**.3**	.1	.1	.2	.2	.2	.2	**.3**	**.3**	.2	.2	**.3**	2	**.3**	**.3**	**.3**	**.3**	**.3**	.1	.1	.1	.1	**.2**	**.2**	**.2**	**.2**	**.2**
3	**.3**	**.3**	**.3**	**.3**	.2					.1	.1	.1	.1	.1	.1	.2	**.3**	3	**.3**	**.3**	**.2**	**.2**	.1					.1	.1	.1	**.2**	**.3**
4	**.3**	.2	**.3**	**.3**	.2									.1	.1	.1	.1	4	**.2**	.1	**.3**	.1								.1	.1	.1
5	.2	.2	.2	.2	.1								.1	.1	.2	**.3**	.2	5	.1	**.2**	**.2**	.1	.1							.1	**.2**	**.2**
6	**.3**	**.3**	**.4**	**.3**	**.3**	.1					.1	.2	.1	.2	.2	.2	.2	6	**.3**	**.3**	**.2**	**.2**	**.3**			.1	.1	.1	.1	.1	.1	**.2**
7	.2	**.3**	**.4**	**.4**	.2							.1	.1	.2	**.3**	**.3**	**.3**	7	**.2**	**.2**	**.3**	**.2**							.1	.1	**.3**	**.3**
8	**.3**	**.3**	**.3**	**.3**	.2	.1							.1	.1	.2	.1	.1	8	**.3**	**.3**	**.3**	**.2**	**.2**							.1	.1		
9	.2	.2	**.3**	**.3**	**.3**	.1	.1					.1	.1	.2	.2	**.3**	**.3**	9	.1	**.2**	**.2**	**.3**	**.3**	.1						.1	**.2**	**.2**	**.2**
10	**.3**	.2	.2	.2	.2									.1	.1	.1		10	**.2**	**.2**	**.2**	**.2**								.1	.1		
11	.1	.1	.1	.1										.1	.1	.1	.1	11	.1		.1									.1	.1		
12	.1	**.3**	.2	.2	.1							.1	.1	.2	.2	.2	.1	12	.1	.1	.1	.1	.1					.1	.1	.1	.1	.1
13	.2	.2	.2	.1										.1	.2	.2	.2	13	.1	.1	.1								.1	**.2**	**.2**	**.2**
14	.3	.2	.2	.2	.2	.1								.1	.1	.2	.2	14	**.3**	**.2**	**.2**	**.2**	.1						.1	.1	.1	.1
15	.2	.2	.2	.2	.1	.1						.1	.1	.2	.2	.1	.1	15	**.2**	**.2**	**.2**	**.2**	.1					.1	.1	**.2**	.1	.1
16	.2	.2	.2	.1	.1	.1							.1	.1	.1	.1	.2	16	.1	.1	.1	.1								.1	.1	**.2**
17	.2	**.3**	.2	.2	.2	.1					.1	.1	.1	.1	.1	**.3**	.2	17	**.2**	**.2**	**.2**	.1	.1						.1	.1	.1	**.2**
18	**.3**	**.3**	.2	.1									.1	.1	.1	.1	.2	18	**.2**	**.2**	.1							.1	.1	.1	.1	.1
19	.1	.1	.2	.1	.1	.1				.1	.1	.1	.1	.1	.1	.2	.2	19	.1	.1	**.2**	.1	.1			.1	.1	.1	.1	.1	.1	.1
20	.2	.2	.2	.2	.1								.1	.1	.1	.1	.1	20	.1	.1	.1	.1							.1	.1	.1	.1
21		.1	.1	.1	.1											.1	.1	21		.1	.1	.1									.1	.1
22	.1	.1	.1	.1	.1													22	.1	.1	.1	.1	.1									
23	.1	.1	.2	.1	.1													23	.1	.1	**.2**	.1										
24			.2	.1	.1													24														
25		.1	.1	.1	.1												.1	25														
26	.1	.1	.1	.1	.1													26		.1	.1	.1										
27		.2	.1	.1	.1											.1	.2	27		.1	.1	.1	.1									**.2**
28	.2	.2	.2	.2	.1													28	**.2**	**.2**	**.2**	**.2**										
29		.1	.1													.1	.1	29													.1	.1
30	.1	.1	.2	.2	.1									.1				30	.1	.1	.1	**.2**	.1									
31	.1	.1	.1		.1													31			.1		.1									

similarly note dates of other days of occurrences of such fog conditions during both months when total general fog hours remained more than 15 hours which are also dates having very high number of general fog hours. In total, there are 92 days in December and 84 days in January when fog have been occurred for more than 15 hours of the day. But in case of occurrence of hours of those fogs which reduced the visibility to below 500m, *i.e.*, moderate

to very dense fog in Table 2, the ever highest hours of remaining of such fog conditions uninterruptedly for the study period was 20 hours on 28 Dec 2001 and 2 Jan, 2000. Then dates of subsequent number of high hours of fog in decreasing order up to 13 hours of occurrences have also been listed in the same table. In total, there are also 35 days in December and 44 days in January during the period of study when moderate to very dense fog have been occurred for more than or equal to 13 hours in a day. It may be noted that these dates include dates when ever highest general fog hours were also observed. However, in case of occurrences of further high intense fog, *i.e*., dense to very dense fog, Table 3 shows the ever highest hours of remaining of such fog uninterruptedly for December were 17 hours on 18 Dec 1998 and 28 Dec, 2001 and for January they were 18 hours on 2 Jan, 2000. The dates of subsequent number of hours in decreasing order up to 10 hours of occurrences have also been listed in the same table. In total, there are 22 days in December and 28 days in January when dense to very dense fog have been occurred for 10 hours or more in a day. It may be noted that dates of occurrences of these high hours of dense to very dense fog in January is nothing but the same dates when also very high general fog/moderate to very dense fog hours were recorded as per their list in Tables 1 & 2. But, both dates are not matching in case of the month of December in some cases if one compares their dates of highest occurrences in Tables 1-2. Finally, Table 4 shows some extreme dates having very high hours of very dense fog occurrences at the airport during which dates, airport must be closed for the traffic when such intense fog conditions prevailed. It shows the ever highest hours of remaining of such fog uninterruptedly for December was 15 hours on 27 Dec 1998 and 31 Dec, 1991 and for January, it was 17 hours on 2 Jan, 2000. Then dates of next higher number of hours in decreasing order up to 7 hours of occurrences have also been listed in the same table. In total, there are 23 days in December and 32 days in January when very dense fog have been occurred for 7 hours or more in a day. None of these dates were found in ever highest hours of occurrences of any other types of fog in Tables 1-3 as discussed before which indicate that dates of general, moderate to very dense fog and dense to very dense fog days which had fog hours of more than 15, 12, 9 hours of respective fog hours had not intensified into any extreme dates of very dense fog cases having more than 6 such hours of fog.

3.5. *Probability matrices of occurrences of fog of various intensities (dates vis-à-vis hours) based on climatology and their use in forecasting*

Probability matrices of occurrences of fog of various intensities (dates *vis-à-vis* hours) have been presented in Tables 5-7 and Tables 8-10 for the months of December and January respectively. Probability values which are ≥ 0.5 in case of general fog in Table 5 and 8, ≥0.4 in case fog of moderate or higher in Table 6 and 10, ≥0.3 in case dense fog or higher and ≥0.2 in case of very dense fog in Tables 7 and 10 have been presented by bold figures for understanding their relative importance while using them for giving forecast time of occurrences of fog of various intensities during Dec and Jan months. In all of these tables, it may also be noted that probability values of those fogs which are less than 0.1 have been shown as blank.

It is very interesting to note from probability of general fog occurrences in Table 5 for December that number of hours having probability 0.5 (*i.e*., climatologically 50% chances the hour of that date will have fog reducing visibility at the airport to below 1000m) gradual increases from start of December till end. If one considers value of ≥.1 then Table 5 looks like a matrices of "V" shaped with all timings of dates falling mid part of its upper half having values <0.1 which is assumed as 0 (here after all 0 values are left as vacant) covering 06 to 1200 UTC hours of the day. However, the characteristics of the probability matrices computed for January in Table 8 is just opposite to December with matrix represented in the Table 5 looking like a reversed V shaped with mid part of its lower half having 0 values for dates and timings which falls 0600 to 1200 UTC. Hence both matrices have been followed a truly natural variation as in Dec, the fog started by gradual spreading for more hours with the progress of the days in that month which is followed by a peak period at the end of it continuing up to first week of January and there onwards, gradual diminishing upto the end of the peak winter at the end of January. One can note nature's symmetries in the intensifications/spreading of fog in Dec and *vice versa* in January from both tables. One can also combine both the tables to note that Dec 16 till Jan 14 when fog probability occurrences at night/early morning are more than 0.6 which is the most vulnerable period of fog occurrences. Tables 6 and 9 are also looked like V and reversed V types respectively with more number of no occurrences, *i.e*., 0 values observed longer period during the day. One can also note advance of the season with increasing of fog probability of occurrences with time in Dec. Tables 6 and 9 also show the highest probability values in the range of 0.4-0.5 (*i.e*., 40-50%) which have been observed between Dec 24 to Jan 9, the most vulnerable period of fog occurrences of such intensity. Probability matrices of dense to very dense fog occurrences in the left side of Tables 7 and 10 shows that such fog do not occur till 15 Dec and its occurance probability continues till end of January with a magnitude of 0.2 or more. One can further note from Tables 7 and 10 that such high intense fog occurrences with moderate probabilities of 0.3-0.4 are

observed during January 1-9 only (Table 10). In the case of very dense fog, *i.e*., the most intense fog, interesting features of occurrences probability matrices in the right side of the Tables 7 and 10 is that, the probability values have been gradually reduced both in magnitude and area as number of rows and columns occupied by them are lowest compared to the probability matrices of other intensity fog. Both tables also show that the highest probability of occurrence of very dense fog is limited to 0.3 (*i.e*., 30%) which have been observed only between January 1-9 for a very brief period.

Since there is no objective method available till now for forecasting of fog in much advance, the present climatological study of fog serves as useful tool for various airlines operating to Delhi across the world for finding a better winter flight scheduled to minimize flight diversion/cancellation and thereby minimize high losses during these two months. Weather forecasters at the airport can also use these vital informations for forecasting of occurrence of fog on day to day basis.

4. Conclusions

Followings are important climatological findings of date-wise and hour wise occurrences of fog of various intensities at IGI airport which can be used by aviation met. forecasters for issuing its forecast, by various airlines operating to Delhi across the world for suitable winter flight re-scheduling and by airport authority for making necessary arrangement for implementation of all CAT ILS landing systems and passenger mitigation plan during winter:

(*i*) Occurrences of date-wise probability of general fog, moderate fog, dense fog and very dense fog show that they vary between 0.5 to 0.97, 0.2 to 0.6, 0 to 0.5 and 0 to 0.5 respectively during the peak winter period of 1 Dec - 31 Jan with their most vulnerable period being Dec 11-Jan 31, 24 Dec - 16 Jan, 25 Dec - 16 Jan and 25 Dec - 16 Jan during which the probabilities reach more than 0.75, 0.5, 0.4 and 0.4 respectively. Once sets in, fog in general category remains for 4-5 hours per day until 10 Dec, increased to 10-11 hours on 25 Dec and remained same till 10 January. It then decreases steadily to 4-5 hours which remained for same hours till end of study period. It shows 25 December-10 January is the most vulnerable period when fog remained almost nearly 40 to 45% of the day, *i.e*., nearly 10-11 hours. Similarly, numbers of hours in the dates (in %) having fog of other higher intensities are computed and corresponding most vulnerable periods are identified.

(*ii*) Diurnal variation of general fog occurrences in both months show that there is a very high probability of such fog occurrences of 0.4 to 0.6 between 1700 UTC - 0400 UTC, *i.e*., mid-night till morning with least values of 0.07 to 0.2 between 0700 UTC - 1300 UTC, *i.e*., afternoon/ evening. However, interestingly comparison of diurnal variation between both the months show that chances of fog occurrences between 1200 UTC till 2200 UTC are higher in December than January and *vice-versa* thereafter till 0700 UTC. In other word evening visibility is poorer in December compared to January while late night/morning visibility is poorer in January compared to December. Similar diurnal variations with reduced probabilities have been observed for fog of other intensities except in case of very dense fog occurrences. In latter case, which affects aviation severely, diurnal variation shows the occurrence of its probability at night/morning in January is nearly double to that of December for whole period.

(*iii*) Percentage share of fog of different intensities in 10-days cumulative from 1-10 Dec till January end show % share of fog of higher intensities increase till 31 Dec - 9 Jan with decrease of shallow fog during the same period followed by just opposite trend in respective fog occurrences till end of January. The most vulnerable period when highest frequency of dense and very dense fog occurred is 31 Dec - 9 Jan (28%) followed by 10-19 Jan (23%), 21-30 Dec (22%) and 20-29 Jan (15%). The least venerable period is 1-10 Dec (3%).

(*iv*) When numbers of no fog hours are included for finding % of hours in 10 days cumulative, the result show similar variation with 31 Dec - 9 Jan period as the most vulnerable period of 40% of total calendar hours of fog and 60% of it are of no fog hours. Out of 40% fog hours, 21% is of shallow fog, 8% of timing is of moderate fog, 3% of timing is of dense fog and 8% of timing is of very dense fog occurrences. Respective values corresponding to fog of various intensities and no fog hours have also been computed in % of total calendar hours for remaining periods of peak winters of 1-10 Dec 11-20 Dec etc.

(*v*) Computation of 3-hourly cumulative % of occurrences in the days of intense fog occurrences (dense to very dense fog) confirms 2200-0300 UTC as the most vulnerable period with 21-22% and 30-34% for December and January months respectively out of which 16-17% and 23-25% of the total fog time for December and January months respectively constitute very dense fog.

(*vi*) Analysis of dates having extremely higher number of fog hours of various intensities in the study period show one or more dates having occurrences of very high number of hours of fog corresponding to general fog, moderate to very dense fog, dense to very dense fog and very dense fog as 24, 20, 18 and 17 respectively. There

are 92, 35, 22, and 23 (84, 44, 28 and 32) fog dates in December (January) having more than 15, 12, 9 and 6 hours of general, moderate to very dense, dense to very dense and very dense fog intensities respectively. Information on these extreme occurrences can be used to understand the potential impact of fog at IGI and hence also to find the proper mitigation polices by various stake holders including airlines and airport operators for their strict implementations for reducing their effect in case of reoccurrences.

(*vii*) Forecasting matrices of fog of different intensities for both months have been followed a true natural variation. In Dec, the fog hours increased gradually with the progress of the month and reached a peak period in the first week of January followed by gradual diminishing till the end of January. In other words, it is interesting to note from present study that fog season with respect to various intensity of fog conditions at IGI Airport during peak winter month of 62-days covering Dec and Jan always follow very systematic life cycle like that of monsoon season which preceded by a onset phase, intensification period and then cessation period and hence of less chaotic if seasonal predictions of these characters are attempted which are presently demanded by users for carrying out advance effective fog mitigation measures.

(*viii*) Critical analysis of fog's life cycle at various visibility intensity ranges during peak winter month of 62-days covering Dec and Jan show that the most vulnerable periods of general fog occurrences as Dec 16 till Jan 14, moderate to very dense fog as Dec 24 till Jan 9, dense to very dense fog as January 1-9 and very dense fog also as January 1-9 when respective fog continue for longer durations at night/early morning with probability of occurrences values reaching as high as 0.6 (60%), 0.4-.5 (*i.e*., 40-50%), 0.3-0.4 (*i.e*., 30-40%) and 0.3 (*i.e*., 30%) respectively.

Acknowledgement

This work is undertaken at Meteorological Office of IGI airport, Palam, New Delhi under the special project of "Micro-climatological characteristics of Fog at IGI airport". I express my sincere thanks to Mrs Bharati Jha, Mr. Ravinder Singh, both Senior Observers and Mr. Ashok Kumar, Scientific Assistance, of Met. Office of IGI airport, Palam, New Delhi for their help in tracing the old "Current Weather register", feeding all data into the computer in proper format and then helping in analysis. I also express my sincere thanks to the anonymous reviewer for his valuable suggestions which have helped immensely to improve both presentation and scientific aspects of the present paper.

References

Friedlein, M. T., 2004, "Dense fog climatology Chicago O'Hare International Airport July 1996-April 2002", *Bulletin of the American Meteorological Society*, **85**, 4, 515-517.

Slemmer, J., 2004, "Study of dense fog at the salt lake city international airport and its impacts to aviation, National Weather Service (NWS)", Western region technical attachment, No. 04-01, Center Weather Service Unit (CWUS), Salt Lake City, Utah(www.wrh.noaa.gov/wrh/04TAs/0401/SLCFog.htm).

Tardif, R., Rasmussen R. M., 2007, **"**Event-Based Climatology and Typology of Fog in the New York City Region", *J. of Applied Metero. and Climatol*., **46**, 4, 1141-1168.