MAUSAM, **57**, 2 (April 2006), 271-290

551.575.1

Radiation fog over north India during winter from 1989-2004

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(*Received 27 March 2003, Modified 16 May 2005*)

सार – इस शोध-पत्र में तेरह हवाई अड्डों के वर्तमान मौसम संबंधी आँकडों का उपयोग करते हुए उत्तरी भारत में विकिरण युक्त कोहरे का अध्ययन किया गया है। हाल ही के वर्षों में भारत के उत्तरी भागों में कोहरे की उत्पत्ति में बहुत अधिक वृद्धि पायी गई है। चूँकि इंदिरा गाँधी अन्तरराष्ट्रीय (आई. जी. आई.) हवाई अड्डे की वर्ष 1997–1998, 1998–1999, 1999–2000, 2000–2001, 2001–2002, 2002–2003 और 2003–2004 के दौरान कुल 900 उड़ानों के मार्ग बदले गए। इसलिए इस हवाई अड्डे के वैमानिकी प्रचालनों पर पड़े कोहरे के प्रतिकूल प्रभाव का अध्ययन किया गया है। इंदिरा गाँधी हवाई अड्डे पर कैट–I, कैट–II और कैट–III प्रचालनों के लिए विमानों को उतारने में सहायक अत्यधिक सक्षम उपकरण प्रणाली आई. एल. एस. उपलब्ध कराई गई है। इस शोध–पत्र में गत पन्द्रह वर्षों के स्कोपोग्राफों परिकलित कम दृश्यता वाले प्रचालनों के लिए आवश्यक रनवे की दृश्य रेंजों आर. वी. आर. की उपयोगिता पर विचार–विमर्श किया गया है। उपग्रह द्वारा कोहरे पर किए गए प्रेक्षणों का धरातलीय प्रेक्षणों के साथ सही तालमेल पाया गया है। उपग्रह से प्राप्त हुए चित्र इस बात का प्रमाण हैं कि वर्ष 1998–1999 के दौरान उत्तरी भारत में अत्यधिक सघन कोहरा अरब सागर में बने प्रचंड चक्रवात से अत्यधिक मात्रा में आर्द्रता के प्रवाह के कारण बना था। इस शोध-पत्र में इंदिरा गाँधी हवाई अड्डा, लखनऊ हवाई अड्डा, वाराणसी हवाई अड्डा और अमृतसर हवाई अड्डा पर कोहरे के दौरान अधिकतम तापमान और सापेक्षिक आर्द्रता की विसंगतियों के मध्य संबंध का पता लगाने का भी प्रयास किया गया है।

ABSTRACT. Radiation fog over north India has been studied using current weather data of thirteen airports. There has been a tremendous increase in the fog formation over northern parts of India in recent years. An attempt has been made to study the adverse impact of fog on aeronautical operations at Indira Gandhi International (I.G.I.) airport as total number of flights diverted during 1997-98, 1998-99, 1999-2000, 2000-01, 2001-02, 2002-03 and 2003-04 were about 900. I.G.I. airport is provided with a very efficient Instrument Landing System (ILS) for Cat-I, Cat-II and Cat-III operations. The utility of Runway Visual Ranges (RVRs) required for low visibility operations, calculated from skopographs, for the last fifteen years, has been discussed. Satellite observations on fog have been found to be in fair agreement with the surface observations. Most catastrophic fog formations, which occurred over north India during 1998-99, were found to be due to the enormous amount moisture flow from a severe cyclone formed in the Arabian Sea as evidenced in satellite imagery. An attempt has also been made to establish a relation of maximum temperature and Relative Humidity anomaly with the duration of fog at I.G.I. airport, Lucknow airport, Varanasi airport and Amritsar airport.

Key words – RVR, Instrument landing system (ILS), Aircraft diversion, Low visibility procedure, Operation categories, Maximum temperature anomaly, Relative humidity anomaly, ITCZ, Atmospheric stability.

1. Introduction

Fog over North India is a menance to aeronautical operations during winter Season. This weather phenomenon has been very alarming to aviation services due to poor horizontal visibility caused by large suspended particles laden with moisture over the airfields. During the winters of 1997-98, 1998-99, 1999-2000, 2000-01, 2001-02, 2002-03 and 2003-04 aeronautical activities at most of the airports in north India were severely paralysed in most parts of the day and night. Around 900 aircrafts were diverted to various airfields only from I.G.I. airport New Delhi. Seeing the inconvenience of passengers and great financial loss to the national and international airlines. Government of India decided to procure a very sophisticated electronic system called Instrument landing System (ILS) from Airport Systems International Inc. (AS II), U.S.A. at I.G. airport for safe landing during poor visibility conditions Under ILS operation, a pilot requires Runway Visual Range (RVR) for landing and take off. A busy airport like I.G.I. airport New Delhi has been presently provided with two types of transmissometers *viz*., Automatic Visual Range Assessor (AVRA MK-I) and Flamingo, a modified version ol Skopograph, which provide RVR values in meters, round - the - clock, to ensure safe landing of

TABLE 1(a)

Significant diversions of aircraft due to fog at I.G.I. airport New Delhi from November 1997 – February 2004

S. No.	Date	Duration of fog Hrs : Min	Number of diversions	S. No.	Date	Duration of fog Hrs : Min	Number of diversions	S. No.	Date	Duration of fog Hrs : Min	Number of diversions
1	27 Nov 1997	13:00	6	42	12 Feb 2000	07:51	1	83	07 Jan 2003	24:00	1
2	24 Dec 1997	13:00	10	43	01 Jan 2001	07:00	2	84	10 Jan 2003	18:51	18
3	26 Dec 1997	16:00	6	44	02 Jan 2001	14:05	8	85	11 Jan 2003	16:51	3
4	30 Dec 1997	09:00	19	45	03 Jan 2001	07:00	11	86	12 Jan 2003	15:30	4
5	07 Jan 1998	16:30	29	46	07 Jan 2001	09:30	1	87	13 Jan 2003	13:30	4
6	09 Jan 1998	17:00	9	47	08 Jan 2001	17:00	15	88	14 Jan 2003	14:40	2
7	03 Feb 1998	07:00	5	48	09 Jan 2001	16:25	7	89	15 Jan 2003	17:25	4
8	25 Feb 1998	13:39	4	49	10 Jan 2001	15:50	1	90	16 Jan 2003	19:30	23
9	15 Dec 1998	13:30	8	50	12 Jan 2001	18:30	1	91	17 Jan 2003	17:30	20
10	16 Dec 1998	17:30	23	51	15 Jan 2001	16:00	15	92	18 Jan 2003	24:00	1
11	17 Dec 1998	18:00	12	52	16 Jan 2001	14:19	3	93	19 Jan 2003	19:45	14
12	18 Dec 1998	22:30	7	53	17 Jan 2001	16:20	1	94	20 Jan 2003	19:22	11
13	20 Dec 1998	15:00	9	54	19 Jan 2001	12:30	3	95	21 Jan 2003	14:20	3
14	22 Dec 1998	18:30	19	55	23 Jan 2001	05:30	3	96	29 Jan 2003	19:20	1
15	23 Dec 1998	19:00	5	56	12 Dec 2001	15:30	13	97	30 Jan 2003	05:21	4
16	24 Dec 1998	24:00	8	57	15 Dec 2001	12:30	4	98	01 Feb 2003	06:39	2
17	25 Dec 1998	12:51	4	58	16 Dec 2001	15:00	2	99	03 Feb 2003	05:30	2
18	26 Dec 1998	15:51	4	59	17 Dec 2001	07:50	6	100	18 Dec 2003	07:09	7
19	27 Dec 1998	17:30	5	60	20 Dec 2001	05:30	2	101	19 Dec 2003	18:20	15
20	31 Dec 1998	17:51	12	61	28 Dec 2001	19:30	24	102	22 Dec 2003	20:00	27
21	07 Jan 1999	21:00	4	62	29 Dec 2001	07:39	8	103	24 Dec 2003	24:00	6
22	12 Jan 1999	16:21	10	63	30 Dec 2001	15:00	1	104	25 Dec 2003	15:00	22
23	18 Jan 1999	15:30	5	64	31 Dec 2001	15:00	1	105	26 Dec 2003	18:09	2
24	21 Jan 1999	13:00	4	65	01 Jan 2002	15:30	6	106	29 Dec 2003	03:50	2
25	25 Jan 1999	09:09	4	66	02 Jan 2002	18:00	2	107	30 Dec 2003	18:30	8
26	27 Dec 1999	14:00	10	67	04 Jan 2002	16:30	3	108	31 Dec 2003	20:45	2
27	28 Dec 1999	18:00	4	68	05 Jan 2002	10:40	1	109	02 Jan 2004	19:00	5
28	29 Dec 1999	16:00	5	69	07 Jan 2002	10:55	1	110	03 Jan 2004	10:00	23
29	30 Dec 1999	14:30	6	70	08 Jan 2002	11:06	4	111	04 Jan 2004	12:00	1
30	31 Dec 1999	17:00	4	71	09 Jan 2002	13:45	16	112	06 Jan 2004	20:00	1
31	01 Jan 2000	18:39	11	72	17 Jan 2002	15:40	2	113	07 Jan 2004	12:51	17
32	02 Jan 2000	19:30	19	73	27 Jan 2002	02:30	3	114	13 Jan 2004	12:51	3
33	03 Jan 2000	16:21	5	74	28 Jan 2002	10:50	2	115	14 Jan 2004	18:21	9
34	04 Jan 2000	17:00	1	75	13 Jan 2002	09:30	6	116	15 Jan 2004	11:20	22
35	05 Jan 2000	16:30	4	76	26 Jan 2002	00:00	19	117	16 Jan 2004	14:22	2
36	06 Jan 2000	16:30	8	77	27 Jan 2002	02:50	4	118	20 Jan 2004	03:00	2
37	13 Jan 2000	10:00	3	78	01 Jan 2003	15:21	1	119	23 Jan 2004	06:00	9
38	23 Jan 2000	11:00	2	79	02 Jan 2003	21:39	7	120	24 Jan 2004	10:11	5
39	07 Feb 2000	12:09	4	80	03 Jan 2003	11:00	2	121	26 Jan 2004	05:51	1
40	08 Feb 2000	17:30	6	81	05 Jan 2003	17:30	3	122	12 Feb 2004	09:00	10
41	11 Feb 2000	06:30	5	82	06 Jan 2003	18:12	15	123	22 Feb 2004	04:15	9

TABLE 1 (b)

Years & month	No of diversions	No of days of fog (duration >12 hours)	No of hours of fog	Mean (hours)
Dec 1997	35	03	38	12.66
Dec 1998	104	11	194.2	17.65
Dec 1999	99	05	79.5	15.9
Dec 2000	-	-	-	-
Dec 2001	61	23	204.4	8.88
Dec 2002	23	22	124.5	5.65
Dec 2003	91	22	260	11.81
Jan 1997	-	-	-	-
Jan 1998	38	02	37.5	18.75
Jan 1999	27	05	74	114.8
Jan 2000	55	08	127	15.87
Jan 2001	76	25	271.8	10.872
Jan 2002	40	27	225.8	8.36
Jan 2003	141	29	431.2	14.86
Jan 2004	100	28	253.33	9.04
Feb 1997	-	-	-	-
Feb 1998	09	02	20.7	10.35
Feb 1999	-	-	-	-
Feb 2000	16	04	44	11.00
Feb 2001	-	10	30.1	3.01
Feb 2002	-	19	67.2	3.53
Feb 2003	-	15	59.5	3.96
Feb 2004	19	19	63.75	3.35
Dec 1997 – Feb 1998	82	07	92.2	13.17
Dec 1998 – Feb 1999	151	17	287.1	16.88
Dec 1999 – Feb 2000	100	17	249	14.64
Dec 2000 – Feb 2001	76	14	178.3	12.73
Dec 2001 – Feb 2002	107	20	284.4	12.42
Dec 2002 – Feb 2003	168	24	382.6	15.94
Dec 2003 – Feb 2004	210	24	289.3	12.05

flights. Flamingo has been manufactured by IMPULSPHYSIK, Germany whereas AVRA is an indigenous transmissometer system, In the present paper, RVR values calculated from Skopograph, previous version of Flamingo, have been used to study inter-annual variation in the thickness of fog lying in various categories of ILS operations. Government of India planned to provide aviation services under ILS Cat-II / Cat-IIIA operations at I.G.I. airport from the winter season of 2000-01. To meet this requirement, India Met. Department installed and commissioned Flamingo, a dual base transmissometer on 11 December 2000 and calculated RVR values from this equipment were utilized in flight control safety service and flight management until the system became operational in 2001. The cases of the formation of synoptic scale fog over north India are found to increase during the last several years, which disrupted normal life, surface transport and aeronautical services. With the launch of geo-stationary weather satellites, frequency and coverage of space data in the visible channel has increased tremendously enabling the study of wide spread fog over north India. Very High Resolution Radiometer (VHRR) imageries of INSAT-1D in the visible and IR Channels have been used for identification of horizontal spread of fog and to obtain knowledge about the flow of moisture from Arabian Sea and western disturbances coming from Iran, Afghanistan and Pakistan, which is one of the vital factors in the formation of widespread radiation fog. Jagadish Singh *et al*. 1979, 1983 and Singh & Kant 1999 have done extensive studies on fog using satellite data. Some more studies such as Gupta 1987, Thulsidas and Mahapatra 1995 have also been made on local fog formations mostly over aerodromes.

2. Source of data

Current weather reports of I.G.I. airport, Lucknow airport, Amritsar airport and Varanasi airport have been used for the period of fifteen years (1989-2004) to find out the durations of fog from November to February each season. VHRR imageries in the Visible channel (0.55μ – 0.75μ) from Indian National Satellites of first and second generation obtained from Satellite Meteorology Division, DGM's Office, Lodi Road have been used to study the widespread nature of the radiation fog. Meteorological maps corresponding to surface and upper atmosphere prepared at Met. Office Safdarjung, New Delhi have been used to study the atmospheric stability near the ground and the source of moisture during the period of fog formation. Data regarding the diversion of aircrafts was obtained from National Airports Division (NAD), Airport Authority of India (AAI), New Air Traffic Services (ATS) building New Delhi.

3. Observational features

3.1. *Diversion of aircrafts*

Table 1(a-b) gives significant diversions of aircraft due to fog at I.G.I. airport, New Delhi from November 1997 to February 2004. It is seen from the table that on 7th January 1998, I.G.I. airport New Delhi was subjected to

TABLE 2 (a)

Duration (hours) of Runway Visual Range (RVR) during fog at I.G.I. airport New Delhi under various categories of ILS

Years	Months	Duration of RVR (hours)		
		Cat-I RVR < 2 km ≥ 550m	Cat-II RVR < 550m ≥ 350m	Cat-III RVR < 350m
2003-2004	November	42.7	00	00
	December	72.8	07	53
	January	157	09.9	75.6
	February	54.5	01.5	13
2002-2003	November	76.2	00	00
	December	181.7	01.9	10.2
	January	266	10.3	111
	February	76.2	00.7	06.5
2001-2002	November	62.1	00	00
	December	172.5	06.5	36
	January	140.8	05.8	52
	February	98	02	05
2000-2001	November	73.5	00.5	00.4
	December	102.5	00	00
	January	117	04.9	80.4
	February	56.6	02.4	00
1999-2000	November	22.5	00	00
	December	214.9	01	45.3
	January	160.9	08.5	83
	February	62.8	02.6	25.7
1998-1999	November	122.6	02.5	01.5
	December	229	08.5	148
	January	168.4	10	80.2
	February	142.3	04.5	20
1997-1998	November	123.1	00.5	07.5
	December	205.4	06	38
	January	129.4	00.5	20.5
	February	53.5	01	13
1996-1997	November	40.2	00	00
	December	151.7	02	01.5
	January	236.6	01	17.5
	February	53.9	00.5	05
1995-1996	November	50.3	00	00
	December	112.6	00	00.5
	January	143.7	01	14
	February	82.9	01	14.5
1994-1995	November	104.2	00	00
	December	133.9	01.5	00
	January	147.9	03	19
	February	78.7	01.5	12.3
1993-1994	November	43.1	00	00
	December	187.5	02.5	01
	January	156.5	04.5	24.2
	February	61.9	01.5	04.5
1992-1993	November	50	00.5	03
	December	97.2	00	00
	January	50.8	01.5	02
	February	77.7	04.5	09.5
1991-1992	November	34.7	00	00
	December	121.1	03.5	25
	January	59.7	01.5	13.8
	February	13.5	03.5	03
1990-1991	November	79	00	04
	December	189.8	00	05
	January	256.9	03	06.7
	February	87.5	00.5	05
1989-1990	November	09.1	00	00
	December	115	01.5	36
	January	53.5	04	46
	February	39.9	01.5	14.5

TABLE 2 (b)

I.G.I. Airport : Season wise Runway Visual Range (RVR) in hours
Category – 1

Fog	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04
Nov	9.1	79	35	50	43	104	50	40	123	123	23	74	62	76	43
Dec	115	190	121	97	187	134	113	152	205	229	215	103	173	182	73
Jan	53.5	257	60	51	157	148	144	237	129	168	161	102	141	266	157
Feb	39.9	88	14	78	62	79	83	54	54	142	63	57	98	76	55
Mean	54.4	153	57	69	112	116	97	121	128	166	115	84	118	150	82
Sum	218	613	229	276	449	465	389	482	511	662	461	335	473	600	327

Average (15 years) : 432.66 (Hours) St. Dev. (15 years) : 56.26 (Hours)

TABLE 2 (c)

Season wise Runway Visual Range (RVR) in hours
Category – 11

Fog	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04
Nov	00	00	00	0.5	00	00	00	00	0.5	2.5	00	0.5	00	00	00
Dec	1.5	00	3.5	00	2.5	1.5	00	2	6	8.5	1	00	6.5	1.85	7
Jan	4	3	1.5	1.5	4.5	3	1	1.5	0.5	10	8.5	4.9	5.8	10.3	9.9
Feb	1.5	0.5	3.5	4.5	1.5	1.5	1	0.5	1	4.5	2.6	2.4	2	0.65	1.5
Mean	1.8	0.9	2.1	1.6	2.1	1.5	0.5	1	2	6.4	3.0	1.9	3.6	3.2	4.6
Sum	7	3.5	8.5	6.5	8.5	6	2	4	8	25.5	12.1	7.7	14.3	12.8	18.4

Average (15 years) : 9.65 (Hours) St. Dev. (15 years) : 9.65 (Hours)

TABLE 2 (d)

Season wise Runway Visual Range (RVR) in hours
Category – III

Fog	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04
Nov	00	4	00	3	00	00	00	00	7.5	1.5	00	0.36	00	00	00
Dec	36	5	25	00	1	00	0.5	1.5	38	148	45.3	00	35.9	10.1	86
Jan	46	6.65	13.7	2	24.1	19	13	11.5	20.5	80.2	83	80.4	52	139	75.6
Feb	14.5	5	3	9.5	4.5	12.2	13.5	5	13	20	251	00	5	6.5	13
Mean	24.1	5.16	10.4	3.62	7.41	7.81	6.75	4.5	19.7	62.4	95	20.2	23.2	38.7	43.6
Sum	96.5	20.6	41.7	14.5	29.6	31.2	27	18	79	250	379	80.8	93	155	175

Average (15 years) : 99.37 (Hours) St. Dev. (15 years) : 28.98 (Hours)

TABLE 2(e)

(Monthly Inter-annual variability of RVR) in hours

Years	Cat-I : Range = < 2 km ≥ 550m						
	RVR (Hours) Nov	RVR (Hours) Dec	RVR (Hours) Jan	RVR (Hours) Feb	Nov-Dec Range	Dec-Jan Range	Jan-Feb Range
1989-90	9.1	115	53.5	39.9	-105.9	61.5	13.6
1990-91	79	189.8	256.9	87.5	-110.8	-67.1	169.4
1991-92	34.7	121.1	59.7	13.5	-86.4	61.4	46.2
1992-93	50	97.2	50.8	77.7	-47.2	46.4	-26.9
1993-94	43.1	187.5	156.5	61.9	-144.4	31	94.6
1994-95	104.2	133.9	147.9	78.7	-29.7	-14	69.2
1995-96	50.3	112.6	143.7	82.9	-62.3	-31.1	60.8
1996-97	40.2	151.7	236.6	53.9	-111.5	-84.9	182.7
1997-98	123.1	205.4	129.4	53.5	-82.3	76	75.9
1998-99	122.6	229	168.4	142.3	-106.4	60.6	26.1
1999-00	22.5	214.9	160.9	62.8	-192.4	54	98.1
2000-01	73.5	102.5	117	56.6	-29	-14.5	60.4
2001-02	62.1	172.5	140	98	-110.4	32.5	42
2002-03	76.2	181.7	266	76.2	-105.5	-84.3	189.8
2003-04	42.7	72.8	157	54.5	-30.1	-84.2	102.5
Standard deviation		48.30	66.49				
Average		152.51	149.62				
Coefficient of variation		31.67	44.44				

TABLE 2(f)

Monthly Inter-annual variability of RVR (hours)

Years	Cat-II : Range = < 550m ≥ 350m						
	RVR (Hours) Nov	RVR (Hours) Dec	RVR (Hours) Jan	RVR (Hours) Feb	Nov-Dec Range	Dec-Jan Range	Jan-Feb Range
1989-90	0	1.5	4	1.5	-1.5	-2.5	2.5
1990-91	0	0	3	0.5	0	-3	2.5
1991-92	0	3.5	1.5	3.5	-3.5	2	-2
1992-93	0.5	0	1.5	4.5	0.5	-1.5	-3
1993-94	0	2.5	4.5	1.5	-2.5	-2	3
1994-95	0	1.5	3	1.5	-1.5	-1.5	1.5
1995-96	0	0	1	1	0	-1	0
1996-97	0	2	1	0.5	-2	1	0.5
1997-98	0.5	6	0.5	1	-5.5	5.5	-0.5
1998-99	2.5	8.5	10	4.5	-6	-1.5	5.5
1999-00	0	1	8.5	2.6	-1	-7.5	5.9
2000-01	0.5	0	4.9	2.4	0.5	-4.9	2.5
2001-02	6.5	6.5	5.8	2	0	0.7	3.8
2002-03	0	1.9	10.3	0.7	-1.9	-8.4	9.6
2003-04	0	7	9.9	1.5	-7	-2.9	8.4
Standard deviation		2.85	3.52				
Average		2.79	4.63				
Coefficient of variation		102.19	76.18				

TABLE 2(g)

Monthly Inter-annual variability of RVR (hours)

Years	Cat-III : Range = < 350m						
	RVR (Hours) Nov	RVR (Hours) Dec	RVR (Hours) Jan	RVR (Hours) Feb	Nov-Dec Range	Dec-Jan Range	Jan-Feb Range
1989-90	0	36	46	14.5	-36	-10	31.5
1990-91	4	5	6.7	5	-1	-1.7	1.7
1991-92	0	25	13.8	3	-25	11.2	10.8
1992-93	3	0	2	9.5	3	-2	-7.5
1993-94	1	1	24.2	4.5	0	-23.2	19.7
1994-95	0	0	19	12.3	0	-19	6.7
1995-96	0	0.5	14	14.5	-0.5	-13.5	-0.5
1996-97	0	1.5	17.5	5	-1.5	-16	12.5
1997-98	7.5	38	20.5	13	-30.5	17.5	7.5
1998-99	1.5	148	80.2	20	-146.5	67.8	60.2
1999-00	0	45.3	83	25.7	-45.3	-37.7	57.3
2000-01	0.4	0	80.4	0	0.4	-80.4	80.4
2001-02	0	36	52	5	-36	-16	47
2002-03	0	10.2	111	6.5	-10.2	-100.8	104.5
2003-04	0	53	75.6	13	-53	-22.6	62.6
Standard deviation		38.65	34.78				
Average		26.63	43.06				
Coefficient of variation		145.14	80.78				

TABLE 3 (a)

Relation of the departure of Max. Temperature and Relative Humidity (R.H.) from normal with the duration of fog at I.G.I. airport New Delhi during the month of December

S. No.	Date	Maximum temp. dep. from normal (°C)	Minimum temp. dep. from normal (°C)	R.H (0300 UTC) dep. from normal (%)	Fog duration (hours)
1	29 Dec 1999	-03	-01	+21	16
2	16 Dec 1998	-02	00	+25	17.5
3	18 Dec 1998	-05	00	+23	22.5
4	19 Dec 1998	-07	00	+23	21
5	20 Dec 1998	-04	02	+09	15
6	23 Dec 1998	-04	02	+22	19
7	24 Dec 1998	-02	03	+19	24
8	25 Dec 1998	-08	02	+14	12.9
9	26 Dec 1998	-04	01	+19	15.9
10	27 Dec 1998	-03	01	+21	17.5
11	28 Dec 1998	-04	03	+18	19.4
12	29 Dec 1998	.04	00	+15	13.5
13	01 Dec 1997	-04	01	+31	13.5
14	02 Dec 1997	-04	02	+12	10.5
15	03 Dec 1997	-03	02	+13	12
16	04 Dec 1997	-03	03	+13	14
17	05 Dec 1997	-02	02	+15	14
18	11 Dec 1997	-05	04	+23	13
19	12 Dec 1997	-06	03	+25	17.4
20	13 Dec 1997	-06	03	+18	11.2
21	17 Dec 1997	-09	01	+10	11.5
22	18 Dec 1997	-05	04	+11	13.2
23	20 Dec 1997	-09	02	+06	11
24	23 Dec 1997	-07	-03	+22	17
25	24 Dec 1997	-05	-01	+22	13
26	25 Dec 1997	-06	03	+11	11.5
27	26 Dec 1997	-06	02	+08	16
28	27 Dec 1997	-07	00	+18	24
29	28 Dec 1997	-09	01	+18	17
30	30 Dec 1995	-02	04	+18	16
31	31 Dec 1995	-01	04	+18	18
32	01 Dec 1992	-03	04	+24	14.5
33	06 Dec 1992	-01	05	÷17	12
34	26 Dec 1991	-06	00	+22	14.5
35	10 Dec 1990	-01	03	+09	14
36	25 Dec 1989	-05	-01	+22	14.5
37	27 Dec 1989	-04	01	+21	10
38	29 Dec 1989	-01	01	+21	17.5
39	30 Dec 1989	-04	-01	+21	17.4
40	31 Dec 1989	-07	00	+18	12.2

TABLE 3 (b)

Relation of the departure of Max. Temperature and Relative Humidity (R.H.) from normal with the duration of fog at Lucknow airport during the month of December

S. No.	Date	Maximum temp. dep. from normal (°C)	Minimum temp. dep. from normal (°C)	R.H (0300 UTC) dep. from normal (%)	Fog duration (hours)
1	27 Dec 1998	-06	00	+07	14.7
2	28 Dec 1998	-07	-04	+17	24
3	29 Dec 1998	-11	-02	+17	17.5
4	30 Dec 1998	-07	-02	+17	21
5	31 Dec 1998	-02	-02	+14	13
6	24 Dec 1997	-05	00	+17	24
7	25 Dec 1997	-11	01	+12	12
8	27 Dec 1997	-07	-03	+17	11
9	14 Dec 1994	-01	00	+10	13.5
10	15 Dec 1994	-04	-01	+15	12
11	19 Dec 1994	-01	-02	+16	12
12	07 Dec 1993	-03	04	+11	10
13	18 Dec 1992	-01	00	+13	11.5
14	31 Dec 1992	-02	00	+17	14
15	24 Dec 1991	-02	06	+12	11

TABLE 3 (c)

Relation of the departure of Max. Temperature and Relative Humidity (R.H.) from normal with the duration of fog at Varanasi airport during the month of December

S. No.	Date	Maximum temp. dep. from normal (°C)	Minimum temp. dep. from normal (°C)	R.H (0300 UTC) dep. from normal (%)	Fog duration (hours)
1	19 Dec 1998	-01	00	+23	21.3
2	20 Dec 1998	-01	00	+28	21
3	21 Dec 1998	-03	-01	+25	15.5
4	22 Dec 1998	-01	01	+17	15.5
5	26 Dec 1998	-01	00	+22	16
6	27 Dec 1998	-07	00	+21	15
7	28 Dec 1998	-07	-03	+21	15.6
8	29 Dec 1998	-08	-01	÷20	13
9	30 Dec 1998	-06	-03	+26	24
10	31 Dec 1998	-10	-	+23	13
11	01 Dec 1997	-06	04	+30	12.5
12	17 Dec 1997	-04	03	+23	13.5
13	18 Dec 1997	-05	01	÷28	12.2
14	25 Dec 1997	-05	01	+12	10
15	26 Dec 1997	-08	-02	+27	19.7
16	27 Dec 1997	-12	-03	+21	13
17	27 Dec 1995	-06	04	+21	12.5
18	28 Dec 1995	-02	04	+26	11.5
19	29 Dec 1995	-02	04	+21	13
20	30 Dec 1995	-02	04	+21	11.8
21	31 Dec 1995	-03	04	+21	10.8
22	28 Dec 1989	-04	02	+26	14.6
23	29 Dec 1989	-09	-03	+21	12.9
24	30 Dec 1989	-06	-03	+26	16.01

TABLE 3 (d)

Relation of the departure of Max. Temperature and Relative Humidity (R.H.) from normal with the duration of fog at Amritsar airport during the month of December

S. No.	Date	Maximum temp. dep. from normal (°C)	Minimum temp. dep. from normal (°C)	R.H (0300 UTC) dep. from normal (%)	Fog duration (hours)
1	12 Dec 1998	-01	00	+07	24
2	13 Dec 1998	-05	01	+07	24
3	14 Dec 1998	-07	00	+07	24
4	15 Dec 1998	-07	-01	+07	16
5	16 Dec 1998	-04	-01	+07	20
6	17 Dec 1998	-03	-01	+06	24
7	18 Dec 1998	-06	-01	+06	24
8	19 Dec 1998	-10	01	+06	18.5
9	22 Dec 1998	-01	-01	+05	12
10	24 Dec 1998	-07	02	+05	21.5
11	25 Dec 1998	-08	01	+05	18
12	26 Dec 1998	-06	02	+05	20.5
13	27 Dec 1998	-07	03	+05	18
14	28 Dec 1998	-06	02	+05	24
15	29 Dec 1998	-09	00	+05	12
16	14 Dec 1997	-06	01	+10	11.5
17	23 Dec 1997	-07	01	+05	11.5
18	24 Dec 1997	-06	00	+05	11
19	21 Dec 1997	-07	02	+04	11
20	25 Dec 1989	-03	02	+05	10
21	29 Dec 1989	-03	-05	+05	10.5
22	30 Dec 1989	-01	-03	+05	11.5
23	31 Dec 1989	-02	-01	+05	14

more than 16-hours fog and 29 aircrafts were diverted to various airfields. On 16 December 1998, fog duration was more than 17-hours and 23 aircrafts were diverted. On 31 December 1998, duration of fog was around 18-hours and 12 aircrafts were diverted. On 12 January 1999, fog duration was more than 16-hours and 10 aircrafts were diverted. Similarly on 1 and 2 January 2000, 11 and 19 aircrafts were diverted respectively. Total number of aircrafts diverted due to fog during the winter of 1997-98 was 88, during 1998-99 the number increased to 151 and during 1999-2000 it came down to 100, during 2000-01 it again came down to 76 and thereafter the number increased to 107, 168 and 210 during 2001-02, 2002-03 and 2003-04 respectively. Thus total number of diversions during these seven years was about 900. Seeing the terrible diversions, cancellations and re-scheduling of the flights and consequent huge loss of money by airline operators, Government of India decided to install an efficient ILS equipment for helping the pilots in carrying out landing and take-off operations during poor visibility conditions. The total and mean duration of fog hours is given in Table 1(b).

3.2. *Instrument Landing System (ILS) and Runway Visual Range (RVR)*

ILS at any airport provides a pilot with the guidance regarding landing and take-off along the surface of the runway in low visibility. This guidance must be of very high integrity to ensure that landing have very high degree of success. It plays very important role under poor visibility and low cloud ceiling conditions. The system consists of ground and aircraft based electronic equipments, which provide approach path information to the pilot. One of the stringent requirements under ILS operation is the availability of RVR from 50m to 2 km at I.G.I. Airport; there are three RVR measuring instruments located at Touchdown Zone (TDZ), Mid-point (MID) and Stop-End (END), As soon as RVR goes below 800m, Low Visibility Procedure (LVP) is introduced by the Air Traffic Controller (ATC) of National Airports Division, Airports Authority of India (AAI) and takes various pre-defined actions to ensure the sale operation of aircraft during period of reduced visibility or low cloud base. ILS Category-I (Cat-I) is precision approach with RVR of not less than 500m. ILS (Cat-II) is precision approach with RVR not less than 350m. Category-III_A (Cat-III_A) is a precision instrument approach and landing with RVR not less 200m. Category-III_B (Cat-III_B) is a precision instrument approach and landing with RVR Less than 200m hut not less than 50m. Category-III_C (Cat-III_C) has no RVR limitations. Table 2 (a) shows various ILS categories in which aeronautical operations were ideally to be carried out during periods mentioned against different months for the last 15 years depending upon RVR values. Analysis of Table 2(a) shows that on the average, during low visibility conditions, the airport remains about 80% period under Cat-I operation, about 2% period under Cat-II operation and 18% period under Cat-III operation. There were six seasons when Cat-I operational period lay between 92 and 96% with maximum during 1990-91. There were four seasons in which Cat-I operational period was between 68 and 80% with minimum being during 1989-90. The maximum period in which the Airport remained under Cat-II operation was 25-hours during 1998-99. However, the average period of Cat-II operation per season is only 10-hours. During the season 1989-90, the Airport was subjected to very thick fog on many days and therefore, the period of Cat-III operation was about 99-hours. After this for about seven years, the thickness of fog was not so much and thus the period of Cat-III operation remained on the average about 30-hours per season. From the season 1997-98, the thickness and duration of fog started increasing and attained peak during 1998-99 and further during the last two seasons

TABLE 4 (a)

Relation of the departure of Max. Temperature and Relative Humidity (R.H.) from normal with the duration of fog at I.G.I. airport New Delhi during the month of January

S. No.	Date	Maximum temp. dep. from normal (°C)	Minimum temp. dep. from normal (°C)	R.H (0300 UTC) dep. from normal (%)	Fog duration (hours)
1	03 Jan 2000	-05	02	+20	16.4
2	04 Jan 2000	-03	00	+20	17
3	05 Jan 2000	-03	01	+20	16.5
4	06 Jan 2000	-02	00	+19	16.5
5	07 Jan 2000	-06	-01	+19	18.5
6	10 Jan 2000	-05	06	+03	13.5
7	07 Jan 1999	-04	06	+14	21
8	08 Jan 1999	-07	02	+19	12.5
9	11 Jan 1999	-05	04	+03	11.2
10	12 Jan 1999	-04	03	+19	16.5
11	13 Jan 1999	-06	03	+13	12
12	18 Jan 1999	-05	00	+19	15.5
13	19 Jan 1999	-06	02	+16	16.5
14	20 Jan 1999	-05	02	+19	13.5
15	30 Jan 1999	-06	00	+20	12
16	31 Jan 1999	-06	00	+19	11.5
17	08 Jan 1998	-02	04	+19	19
18	09 Jan 1998	-04	02	+19	17
19	22 Jan 1998	-03	-02	+03	10.7
20	23 Jan 1998	-03	-01	+06	11.9
21	20 Jan 1997	-06	02	+11	13
22	21 Jan 1997	-05	01	+17	14.5
23	22 Jan 1997	-03	-01	+20	12.5
24	23 Jan 1997	-04	-01	+11	9.5
25	10 Jan 1995	-05	02	+19	18
26	13 Jan 1995	-04	02	+08	12
27	16 Jan 1995	-03	04	+12	15
28	13 Jan 1994	-04	08	+19	18.2
29	14 Jan 1994	-04	07	+19	12.5
30	15 Jan 1994	-04	06	+19	11.5
31	07 Jan 1993	-04	04	+14	15
32	08 Jan 1993	-06	02	+19	12
33	04 Jan 1991	-04	-02	+11	10
34	06 Jan 1991	-03	00	+08	13.5
35	09 Jan 1991	-02	01	+16	12
36	16 Jan 1991	-03	00	+03	10
37	01 Jan 1990	-08	-02	+11	12.5
38	02 Jan 1990	-05	-01	+20	19.5
39	03 Jan 1990	-06	00	+20	20.2
40	04 Jan 1990	-04	00	+20	13.5

TABLE 4 (b)

Relation of the departure of Max. temperature and Relative Humidity (R.H.) from normal with the duration of fog at Lucknow airport during the month of January

S. No.	Date	Maximum temp. dep. from normal (°C)	Minimum temp. dep. from normal (°C)	R.H (0300 UTC) dep. from normal (%)	Fog duration (hours)
1	01 Jan 2000	-05	0 1	+14	19
2	02 Jan 2000	-07	01	+14	17.5
3	03 Jan 2000	-07	00	+09	15.5
4	04 Jan 2000	-07	-01	+09	17.5
5	05 Jan 2000	-04	-04	+14	18.5
6	06 Jan 2000	-10	-01	+14	12.7
7	07 Jan 2000	-04	-03	+14	20.5
8	08 Jan 2000	-08	-03	+14	16.3
9	01 Jan 1999	-02	-02	+14	13
10	11 Jan 1999	-05	-02	+10	12.4
11	12 Jan 1999	-05	-03	+10	13.8
12	14 Jan 1999	-03	00	+10	13.5
13	15 Jan 1999	-07	-04	+15	11.5
14	16 Jan 1999	-09	-04	+11	14.7
15	18 Jan 1999	-09	-03	+11	13.5
16	20 Jan 1999	-06	-05	+11	17.5
17	21 Jan 1999	-09	-03	+12	13.5
18	31 Jan 1999	-04	-04	+26	10
19	01 Jan 1998	-05	-02	+14	14.5
20	02 Jan 1998	-08	-03	+14	22.5
21	03 Jan 1998	-09	-04	+09	11.5
22	05 Jan 1998	-06	-01	+14	22.2
23	06 Jan 1998	-05	-03	+14	21
24	07 Jan 1998	-05	-01	+14	24
25	08 Jan 1998	-11	-01	+14	24
26	09 Jan 1998	-09	00	+14	19
27	11 Jan 1998	-01	-01	+15	20.7
28	12 Jan 1998	-03	-01	+15	10
29	13 Jan 1995	-06	03	+10	15
30	14 Jan 1995	-07	-04	+15	19.5
31	03 Jan 1990	-05	-06	+14	13
32	04 Jan 1990	-03	-05	+14	10.5
33	12 Jan 1990	-02	-01	+15	13.5
34	13 Jan 1990	-01	-02	+15	10

TABLE 4 (c)

Relation of the departure of Max. temperature and Relative Humidity (R.H.) from normal with the duration of fog at Varansi airport during the month of January

S. No.	Date	Maximum temp. dep. from normal (°C)	Minimum temp. dep. from normal (°C)	R.H (0300 UTC) dep. from normal (%)	Fog duration (hours)
1	01 Jan 2000	-09	02	+20	14.2
2	02 Jan 2000	-06	01	+18	13
3	03 Jan 2000	-06	-02	+18	17.9
4	04 Jan 2000	-09	00	+20	16
5	05 Jan 2000	-08	-04	+23	18.7
6	06 Jan 2000	-07	-02	+18	10
7	07 Jan 2000	-06	-05	+20	19.2
8	08 Jan 2000	-09	-04	+18	15.5
9	09 Jan 2000	-04	-01	+20	11
10	01 Jan 1999	-03	-03	+17	11
11	02 Jan 1999	-01	-02	+02	10.5
12	03 Jan 1999	-01	00	+18	24
13	12 Jan 1999	-04	-02	+18	10.4
14	13 Jan 1999	-02	-03	+17	10
15	15 Jan 1999	-06	-02	+17	10
16	16 Jan 1999	-09	-01	+13	10
17	18 Jan 1999	-11	-03	+18	14.5
18	20 Jan 1999	-12	-02	+17	13.5
19	21 Jan 1999	-06	-02	+25	13.5
20	25 Jan 1999	-01	03	+22	20.1
21	26 Jan 1999	-02	01	+25	22.5
22	27 Jan 1999	-05	-01	+26	24
23	28 Jan 1999	-07	-02	+16	11
24	29 Jan 1999	-03	-	+21	16.1
25	30 Jan 1999	-01	-02	+26	11
26	31 Jan 1999	-01	-02	+26	24
27	05 Jan 1998	-02	-01	+03	14
28	08 Jan 1998	-03	00	+03	12.5
29	06 Jan 1997	-01	-01	+18	13
30	08 Jan 1997	-01	-01	+18	11
31	21 Jan 1997	-07	01	+20	12
32	09 Jan 1995	-07	-	+18	12
33	10 Jan 1995	-07	05	+18	10
34	13 Jan 1995	-07	-04	+23	16.2
35	14 Jan 1995	-06	-03	+18	18
36	15 Jan 1995	-07	-02	+18	12.5
37	20 Jan 1994	-01	-02	+13	11
38	09 Jan 1993	-02	07	+18	10.5
39	09 Jan 1991	-08	00	+18	16
40	10 Jan 1991	-03	-01	+23	11
41	02 Jan 1990	-03	-06	+18	12.4
42	03 Jan 1990	-10	-07	+24	14.2
43	12 Jan 1990	-01	01	+18	10.7
44	13 Jan 1990	-02	-02	+23	11.6

TABLE 4 (d)

Relation of the departure of Max. temperature and Relative Humidity (R.H.) from normal with the duration of fog at Amritsar airport during the month of January

S. No.	Date	Maximum temp. dep. from normal (°C)	Minimum temp. dep. from normal (°C)	R.H (0300 UTC) dep. from normal (%)	Fog duration (hours)
1	05 Jan 2000	-06	00	+03	15
2	06 Jan 2000	-09	01	+03	15.5
3	07 Jan 2000	-09	-01	+03	24
4	08 Jan 2000	-09	01	+03	19.5
5	10 Jan 1999	-02	01	+03	24
6	11 Jan 1999	-08	03	+03	13.5
7	13 Jan 1999	-04	-01	+03	16.5
8	14 Jan 1999	-05	01	+03	16.5
9	15 Jan 1999	-04	01	+03	15.5
10	19 Jan 1999	-05	02	+03	10.3
11	12 Jan 1994	-01	07	+03	14
12	17 Jan 1994	-05	-02	+03	10
13	01 Jan 1990	-06	00	+03	12
14	02 Jan 1990	-04	-04	+03	17
15	03 Jan 1990	-03	-01	+03	21
16	07 Jan 1990	-07	01	+03	12

decreasing trend is noticed. It was observed that during the 1997-98, 1998-99, 1999-2000 and 2000-2001 winter seasons, the Airport remained under Cat-III operation for 79-hours, 250-hours, 154-hours and 81-hours respectively. Due to lack of suitable ILS equipment, Air Traffic Control could not properly handle the landing and take-off of aircrafts during poor visibility conditions, thereby causing a large number of diversions. The sudden increase in Cat-III periods also indicated that thickness and durations of fog had increased during the above mentioned four years, which can be broadly attributed to the increase in condensation nuclei embedded in polluted air and the favourable synoptic situations. The average durations (in hours) in which ILS Cat-I, Cat-II and Cat-III operations were carried out respectively for 15 winter seasons are given in Tables 2(b-d) along with standard deviations. The standard deviation, average and coefficient of variation values for RVR (Cat-I, Cat-II & Cat-III) are given in Tables 2(e-g). The standard deviation values for Cat-I and Cat-III are more in comparison to the Cat-II. This shows that the horizontal spreading of the data around the mean is more in Cat-I and Cat-III in all the fifteen years. Similarly the coefficient of variation in Cat-I and Cat-IIII are more in comparison to Cat-I, which shows that the ratio of standard deviation and mean are closer in Cat-II and Cat-III.

TABLE 5(a)

Round the clock and days of continuous fog at I.G.I. airport (New Delhi)

Years	Airport fog duration (hours)	Round the clock (24 hours) fog	Days of continuous fog (duration > 12 hours)	Total number of days (duration > 12 hours)
Dec 1989	219.56	-	03	05
Jan 1989	-	-	-	-
Dec 1990	163	-	-	01
Jan 1990	223.58	-	04	04
Dec 1991	121.91	-	-	01
Jan 1991	144.5	-	-	04
Dec 1992	142.91	-	01	02
Jan 1992	78.38	-	-	-
Dec 1993	262.21	-	-	-
Jan 1993	81.48	-	02	02
Dec 1994	96.81	-	-	-
Jan 1994	184	-	03	13
Dec1995	153.11	-	02	02
Jan 1995	217.75	-	-	03
Dec 1996	98.85	-	-	-
Jan 1996	157.91	-	-	-
Dec 1997	303.15	01	15	17
Jan 1997	67.45	-	04	04
Dec 1998	328.4	01	10	11
Jan 1998	108.45	-	04	04
Dec 1999	202	-	01	01
Jan 1999	169.76	-	04	07
Dec 2000	85	-	-	01
Jan 2000	240.3	-	05	06
Dec-2001	204.3	-	02	06
Jan 2001	271.8	-	11	13
Dec 2002	124.51		02	03
Jan 2002	225.8		03	08
Dec 2003	260	01	08	11
Jan 2003	431.23	02	17	22
Jan 2004	253.3	-	04	12

TABLE 5(b)

Round the clock and days of continuous fog at Lucknow airport

Years	Airport fog duration (hours)	Round the clock (24 hours) fog	Days of continuous fog (duration > 12 hours)	Total number of days (duration > 12 hours)
Dec 1989	77	-	-	-
Jan 1989	-	-	-	-
Dec 1990	29.66	-	-	-
Jan 1990	108	-	93	04
Dec 1991	64.08	-	-	01
Jan 1991	18.08	-	-	-
Dec 1992	147.5	-	-	02
Jan 1992	108.5	-	-	-
Dec 1993	65	-	01	01
Jan 1993	73	-	-	-
Dec 1994	89.91	-	02	03
Jan 1994	103.66	-	-	-
Dec1995	10	-	-	-
Jan 1995	87.5	-	02	02
Dec 1996	21.5	-	-	-
Jan 1996	60.23	-	-	-
Dec 1997	137.65	01	02	03
Jan 1997	67.08	-	-	-
Dec 1998	227.38	01	05	05
Jan 1998	246.21	01	08	10
Dec 1999	148.16	-	-	-
Jan 1999	241.83	-	04	10
Dec 2000	80	-	-	03
Jan 2000	175.41	-	08	08
Dec-2001	246.51		04	11
Jan 2001	144.78		02	04
Dec 2002	111.36		01	04
Jan 2002	121		01	03
Dec 2003	166.4		02	06
Jan 2003	292.18		08	13
Jan 2004	244.55	-	07	09

TABLE 5(c)

Round the clock and days of continuous fog at Varanasi airport

Years	Airport fog duration (hours)	Round the clock (24 hours) fog	Days of continuous fog (duration > 12 hours)	Total number of days (duration > 12 hours)
Dec 1989	67.91	-	03	03
Jan 1989	-	-	-	-
Dec 1990	30.91	-	-	-
Jan 1990	92	-	03	04
Dec 1991	71	-	-	-
Jan 1991	79.5	-	02	02
Dec 1992	75.5	-	-	-
Jan 1992	90.5	-	-	-
Dec 1993	08.5	-	-	-
Jan 1993	81.68	-	01	01
Dec 1994	113.75	-	-	-
Jan 1994	75.88	-	01	01
Dec1995	138.66	-	05	05
Jan 1995	122.51	-	04	05
Dec 1996	82.3	-	-	-
Jan 1996	34.93	-	-	-
Dec 1997	141.5	-	03	06
Jan 1997	175.55	-	-	03
Dec 1998	312.23	01	09	10
Jan 1998	201	-	-	02
Dec 1999	235.95	-	-	-
Jan 1999	186.77	03	14	17
Dec 2000	74.33	-	-	01
Jan 2000	178.38	-	09	09
Dec-2001	285.25	01	10	12
Jan 2001	95.43		-	02
Dec 2002	199.88		03	06
Jan 2002	138.88		01	02
Dec 2003	161.55	-	03	06
Jan 2003	351		13	17
Jan 2004	296.9		8	12

TABLE 5(d)

Round the clock and days of continuous fog at Amritsar airport

Years	Airport fog duration (hours)	Round the clock (24 hours) fog	Days of continuous fog (duration > 12 hours)	Total number of days (duration > 12 hours)
Dec 1989	125.25	-	-	04
Jan 1989	-	-	-	-
Dec 1990	14	-	-	-
Jan 1990	97	-	03	04
Dec 1991	60.5	-	-	-
Jan 1991	25.5	-	-	-
Dec 1992	65	-	-	-
Jan 1992	37	-	-	-
Dec 1993	45.5	-	-	-
Jan 1993	50.25	-	-	-
Dec 1994	30.5	-	-	-
Jan 1994	49.5	-	-	02
Dec1995	15	-	-	-
Jan 1995	41.5	-	-	-
Dec 1996	39	-	-	-
Jan 1996	28	-	03	04
Dec 1997	113.5	-	-	04
Jan 1997	106.5	-	-	-
Dec 1998	388	06	13	15
Jan 1998	44	-	-	-
Dec 1999	155.08	-	-	-
Jan 1999	179.16	01	03	06
Dec 2000	50.15	-	-	-
Jan 2000	152.75	01	04	06
Dec-2001	109.25	03	03	04
Jan 2001	225.83	02	08	12
Dec 2002	71.25	-	-	01
Jan 2002	134.41	01	03	04
Dec 2003	146.10	01	01	04
Jan 2003	428.1	06	16	20
Jan 2004	131	01	02	03

TABLE 6 (a)

Duration of fog (hours) at I.G.I. airport, New Delhi

S. No.	Years	November (Hours)	December (Hours)	January (Hours)	February (Hours)	Total (Hours)
1	1989-90	10.4	220	223.6	79.5	533.1
2	1990-91	61	163	144.5	42.5	411
3	1991-92	20	122	78.4	26.5	246.9
4	1992-93	96.2	143	81.5	98.5	419.2
5	1993-94	90.2	262	184	82.7	619.1
6	1994-95	0	96.8	217.8	113	427.2
7	1995-96	0	153	158	127	438.4
8	1996-97	0	98.9	288.4	67.5	454.8
9	1997-98	144.5	303	196.2	109	752.4
10	1998-99	87	328	275.5	170	860.7
11	1999-00	0	202	240.3	86	528.3
12	2000-01	42.7	85	271.8	30.2	429.7
13	2001-02	5	204	225.8	67.2	502.3
14	2002-03	13.6	126	431.2	59.5	629.8
15	2003-04	7.5	260	253.6	63.8	584.9
Total		578.1	2767	3271	1222	7838
Average		38.54	184	218	81.5	522.5

TABLE 6 (b)

Duration of fog (hours) at Lucknow airport

S. No.	Years	November (Hours)	December (Hours)	January (Hours)	February (Hours)	Total (Hours)
1	1989-90	0	77	108	3.5	188.5
2	1990-91	0	29.7	18.1	0	47.8
3	1991-92	0	64.1	108	21.1	193.2
4	1992-93	2	147.5	73	20.5	243
5	1993-94	2.5	65	103.7	8.5	179.7
6	1994-95	15.5	90	87.5	8	201
7	1995-96	0	10	60.2	18.7	88.9
8	1996-97	11.5	21.5	67.1	0	100.1
9	1997-98	56.5	136.7	246.2	14.5	453.9
10	1998-99	17.2	227.4	241.8	28.9	515.3
11	1999-00	12.5	148.2	175	34.3	370
12	2000-01	22.5	80	144.7	0	247.2
13	2001-02	14.75	246.5	121	6	388.25
14	2002-03	0	111.4	292.2	21.8	425.4
15	2003-04	0	166.4	244.5	21.7	432.6
Total		154.95	1621.4	2091	207.5	4074.85
Average		10.33	108.09	139.42	13.83	271.65

TABLE 6 (c)

Duration of fog (hours) at Varanasi airport

S. No.	Years	November (Hours)	December (Hours)	January (Hours)	February (Hours)	Total (Hours)
1	1989-90	0.8	67.9	92	7.1	167
2	1990-91	3.2	30.9	79.5	9.5	123
3	1991-92	9	71	90.5	10	180
4	1992-93	8.5	75.5	81.6	40.7	206
5	1993-94	23	8.5	75.9	67.5	174
6	1994-95	35.5	113.7	122.5	81.2	352
7	1995-96	27.7	138.7	35	53	254
8	1996-97	33.5	82.3	175.5	17.2	308
9	1997-98	69.5	141.5	201	32.1	444
10	1998-99	27.7	312.2	186.7	72.9	599
11	1999-00	20	236	178.4	27.7	462
12	2000-01	37.2	74.4	95.5	8.9	215
13	2001-02	76.3	285.2	138.9	21.4	521
14	2002-03	13.2	199.9	351	31.9	595
15	2003-04	13.5	161.5	296.9	23.4	495
Total		398.6	1999.2	2200.9	504.5	5095
Average		26.57	133.28	146.73	33.63	339.67

TABLE 6 (d)

Duration of fog (hours) at Amritsar airport

S. No.	Years	November (Hours)	December (Hours)	January (Hours)	February (Hours)	Total (Hours)
1	1989-90	0	125.3	97	28.5	250.8
2	1990-91	4	14	25.5	0	43.5
3	1991-92	2.5	60.5	37	14	114
4	1992-93	34.6	65	50.3	43	192.9
5	1993-94	7.5	45.5	49.5	3	105.5
6	1994-95	10	30.5	41.5	14.3	96.3
7	1995-96	16.5	15	28	21.5	81
8	1996-97	0	39	106.5	11	156.5
9	1997-98	2.5	113.5	44	13	173
10	1998-99	1.5	388	179.2	34	602.7
11	1999-00	3.5	155.1	152.7	25.7	337
12	2000-01	24.2	50.2	225.8	7	307.2
13	2001-02	4	109.3	134.4	4.1	251.8
14	2002-03	7	71.2	428.1	24.6	530.9
15	2003-04	7.1	146.1	131	16	300.2
Total		124.9	1428.2	1730.5	259.7	3543.3
Average		8.33	95.21	115.37	17.31	236.22

3.3. *Maximum temperature and relative humidity anomaly and duration of fog*

Instances of occurrence of fog over North India during winter months are quite common. During these months fog generally occurs in the late hours of nights and early mornings usually after the passage of western disturbances when the sky is practically clear and calm conditions prevail. In normal cases fog lasts for four to five hours. When the fog durations exceed 10 hours, the supply of moisture and external cooling of air other than radiation cooling over the ground surface play key role in their sustenance. Tables 3 & 4 shows that daytime cooling and increase in relative humidity at 0300 UTC are most important parameters for the occurrence of widespread and long duration fog.

3.3.1. *I.G.I. Airport New Delhi*

Eighty significant cases of long duration fog (more than 10 hours) are given in Table 3 (a) Table 4(a). which are associated with negative maximum temperature anomaly and positive relative humidity anomaly of various magnitudes during the month of December and January respectively from 1989-2000. Due to negative maximum temperature anomaly during daytime, air above the ground remains saturated for long period causing continuous formation and sustenance of fog. Two most significant fog formations were observed on 27 December 1997 and 24 December 1998 when fog persisted for 24 hours continuously when maximum temperature anomaly were -7° C & -2° C and departure of relative humidity from normal were +18% & +19% respectively. It must be also mentioned that persistence of fog during the day itself acts to reduce the maximum temperature, as the sun is kept obscured by the fog. Therefore under persistent fog conditions maximum temperature is reduced which then does not allow thermal turbulence to set in and hence the fog persists.

3.3.2. *Lucknow, Varanasi and Amritsar airports*

Departures of maximum temperature and relative humidity from normal with the duration of fog for the month of December with regard to Lucknow, Varanasi and Amritsar Airports have been given in Tables 3 (b-d) respectively. Similarly maximum temperature and relative humidity anomalies with the duration of fog for the month or January for the corresponding airports have been given in Tables 4(b-d) respectively. The remarkable feature at Lucknow Airport was that round the clock fog was observed on 28 December 1998 and 24 December 1997 when the maximum temperature anomalies were -7° C and -5° C respectively and the departures of relative humidity from normal were +17% each. Varanasi Airport reported 24-hour fog on 30 December 1998 when the maximum temperature anomaly was -6° C and the departure of relative humidity from normal was +26%. Similarly, Amritsar Airport had 6 occasions *viz*., 12 December 1998, 13 December 1998, 14 December 1998, 17 December 1998, 18 December 1998 and 28 December 1998 when fog was very thick and persisted round the clock with significant negative maximum temperature anomalies and positive R.H. anomalies.

The month of January during 1998-99 was equally severe for the formation of fog as compared to the month of December. Lucknow had two occasions, 7th & 8th January 1998 when the fog persisted round the clock with positive relative humidity anomaly of 14% [Table 4 (b)]. Varanasi had three occasions, 3rd, 27th & 31st January

TABLE 7

Catastrophic fog sequence over north India

	Duration of fog (hours)			
	I.G.I. airport New Delhi	Lucknow airport	Varansi airport	Amritsar airport
16 Dec 1998	17.5	03	14	20
17 Dec 1998	18	13.5	15.5	24
18 Dec 1998	22.5	11	00	24.0
19 Dec 1998	21	12.5	21.3	18.5
21 Dec 1998	14.5	09.5	15.5	07.5
22 Dec 1998	18.5	11.5	15.5	12
23 Dec 1998	19	115	06	24
24 Dec 1998	24	06.5	06.5	21.5
25 Dec 1998	12.8	12	06	18
26 Dec 1998	15.8	05.5	16	20.5
27 Dec 1998	17.5	14.6	15	18
28 Dec 1998	19.3	24	15.6	24
29 Dec 1998	13.5	17.5	13	12
30 Dec 1998	15.5	21	24	06.5
31 Dec 1998	17.8	16.6	13	09.5
01 Jan 1999	16.5	13	11	14
02 Jan 1999	14	18.6	10.5	09
03 Jan 1999	14	15.5	24	03.5
04 Jan 1999	06.4	12	06.4	00
16 Jan 1999	06.7	14.7	09.5	04.5
17 Jan 1999	08.5	09	07	06
18 Jan 1999	15.5	13.5	14.5	09.4
19 Jan 1999	16.5	08	08.5	10.3
20 Jan 1999	13.5	17.5	13.5	06.5
21 Jan 1999	13	13.5	13.5	01.5

TABLE 8(a)

Extent of stability at 0000 UTC in lower troposphere at I.G.I. airport, New Delhi during fog

S. No.	Date	Surface temp (°C)	Temp at 900 hPa (°C)	Temp at 850 hPa (°C)	Temp at 800 hPa (°C)	Temp at 750 hPa (°C)	Temp at 700 hPa (°C)	Lapse rate (°C/km)	Duration of fog hours	Temp difference between 750 hPa & surface
1	15 Dec 1998	08.2	18.2	17.2	14.4	10.0	07.4	-09.4	13.5	+1.8
2	16 Dec 1998	08.0	16.6	15.0	13.0	11.0	06.8	-08.3	17.5	+3.0
3	17 Dec 1998	09.4	17.0	16.2	13.2	10.2	06.8	-07.4	18	+0.8
4	18 Dec 1998	09.2	15.8	13.8	13.0	11.8	08.4	-10.6	22.5	+2.6
5	19 Dec 1998	06.0	14.6	14.0	13.4	13.0	09.2	-16.4	21	+7.0
6	20 Dec 1998	07.8	15.4	16.0	14.2	12.0	09.0	-05.5	15	+4.2
7	21 Dec 1998	13.0	16.4	12.2	08.2	09.2	04.8	-09.1	14.5	-3.8
8	23 Dec 1998	09.8	13.3	10.2	10.2	07.2	04.2	-05.3	19	-2.6
9	24 Dec 1998	09.6	12.4	12.0	10.4	07.2	02.8	-02.7	24	-2.4
10	25 Dec 1998	08.0	15.4	13.0	10.6	08.2	05.4	-09.0	12.9	+0.2
11	26 Dec 1998	07.6	15.0	12.0	09.6	09.6	07.4	-07.1	15.9	+2.0
12	27 Dec 1998	08.4	10.0	15.4	15.0	13.0	10.0	-04.6	17.5	+4.6
13	28 Dec 1998	08.0	14.8	14.8	12.4	10.8	08.2	-08.4	19.4	+2.8
14	29 Dec 1998	06.0	14.8	12.6	12.6	09.6	05.8	-18.2	13.5	+3.6
15	30 Dec 1998	10.0	14.2	11.4	09.2	07.0	02.4	-11.7	15.5	-3.0
16	31 Dec 1998	08.0	13.8	13.0	10.0	06.2	02.6	-13.9	17.9	-1.8
17	01 Jan 1999	07.8	14.2	12.0	09.0	06.8	04.0	-09.8	16.5	-1.0
18	02 Jan 1999	08.6	14.0	15.2	14.4	13.0	10.8	-09.2	14	+4.4
19	03 Jan 1999	09.4	14.0	11.0	11.0	08.0	04.8	-08.4	14.2	-1.4
20	18 Jan 1999	09.0	13.8	12.8	11.2	07.8	04.0	-04.6	15.5	-1.2
21	19 Jan 1999	09.6	12.2	13.5	12.4	07.4	03.4	-02.5	16.5	-2.2
22	20 Jan 1999	08.2	14.0	14.6	11.4	08.0	04.2	-04.2	13.5	-0.2
23	21 Jan 1999	11.0	18.0	15.0	11.0	06.0	01.0	-10.0	13.0	-5.0
24	22 Jan 1999	11.0	16.2	13.2	09.6	04.5	00.7	-11.7	11.5	-6.5

TABLE 8(b)

Extent of stability at 1200 UTC in lower troposphere at I.G.I. airport, New Delhi during fog

S. No.	Date	Surface temp (°C)	Temp at 900 hPa (°C)	Temp at 850 hPa (°C)	Temp at 800 hPa (°C)	Temp at 750 hPa (°C)	Temp at 700 hPa (°C)	Lapse rate (°C/km)	Duration of fog hours
1	15 Dec 1998	17.8	19.2	18.0	15.0	11.8	8.0	-1.37	13.5
2	16 Dec 1998	19.0	17.0	14.8	12.8	10.2	6.2		17.5
3	17 Dec 1998	15.4	17.0	16.2	13.2	10.0	6.8	-1.07	18
4	18 Dec 1998	13.0	15.2	13.6	13.6	11.8	8.6	-0.56	22.5
5	19 Dec 1998	15.0	16.0	15.4	15.8	14.0	11.4	-0.4	21
6	20 Dec 1998	16.6	16.6	15.2	13.2	10.2	7.0		15
7	21 Dec 1998	19.0	14.8	12.4	11.0	9.0	4.4		14.5
8	23 Dec 1998	15.6	14.6	12.2	9.4	6.4	2.8		19
9	24 Dec 1998	12.0	14.8	12.2	9.8	5.2	0.8	-1.1	24
10	25 Dec 1998	15.0	14.2	13.0	11.8	11.8	8.2		12.9
11	26 Dec 1998	15.4	15.4	14.0	12.8	11.2	8.0		15.9
12	27 Dec 1998	15.0	16.2	15.8	12.8	12.0	11.6	-1.1	17.5
13	28 Dec 1998	14.0	15.4	13.6	12.6	10.0	8.0	-0.7	19.4
14	29 Dec 1998	19.6	15.8	13.4	12.4	10.0	7.0		13.5
15	30 Dec 1998	19.4	13.8	10.6	8.2	6.2	1.8		15.5
16	31 Dec 1998	16.4	14.6	11.8	8.6	6.2	3.4		17.9
17	01 Jan 1999	15.4	15.2	13.8	12.6	10.6	8.0		16.5
18	02 Jan 1999	18.2	16.0	12.6	11.8	10.8	10.0		14
19	03 Jan 1999	16.2	14.8	12.2	12.6	9.4	6.0		14.2
20	18 Jan 1999	12.4	14.2	12.4	10.2	7.8	4.6	-0.9	15.5
21	19 Jan 1999	14.4	16.0	14.6	12.4	9.0	4.2	-1.0	16.5
22	20 Jan 1999	16.2	17.4	14.2	10.4	6.2	2.0	-1.3	13.5
23	21 Jan 1999	18.4	16.8	12.8	8.8	4.8	0.2		13.0
24	22 Jan 1999	22.0	17.8	15.2	10.6	5.8	0.0		11.5

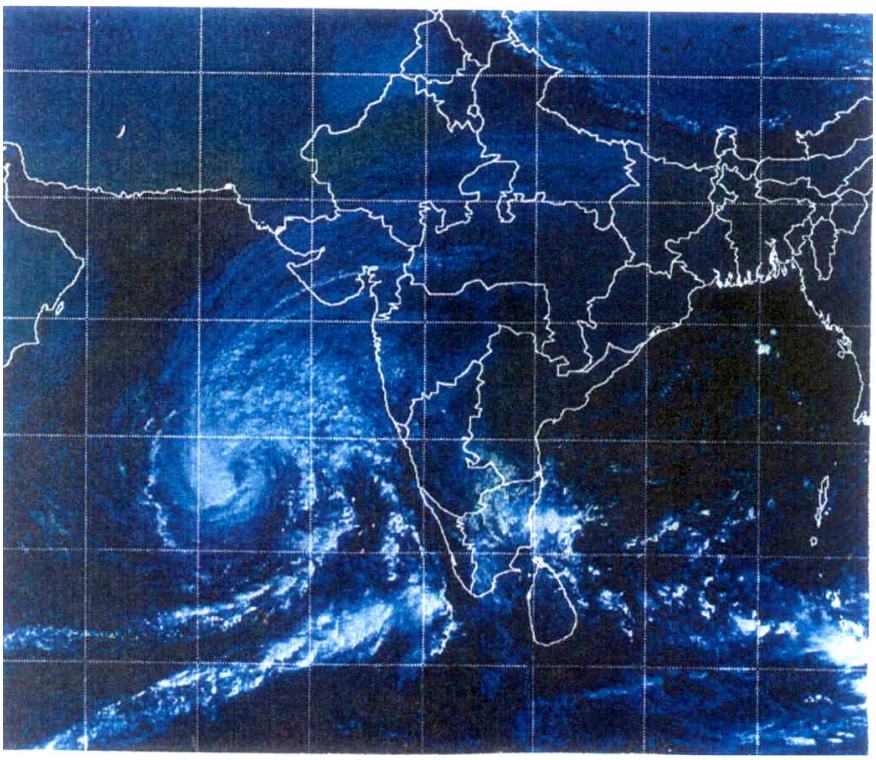


Fig. 1(a). A visible INSAT-1D satellite imagery at 0500 UTC on 14 December 1998 showing cyclonic storm in Arabian Sea advecting enormous amount of moisture over north India

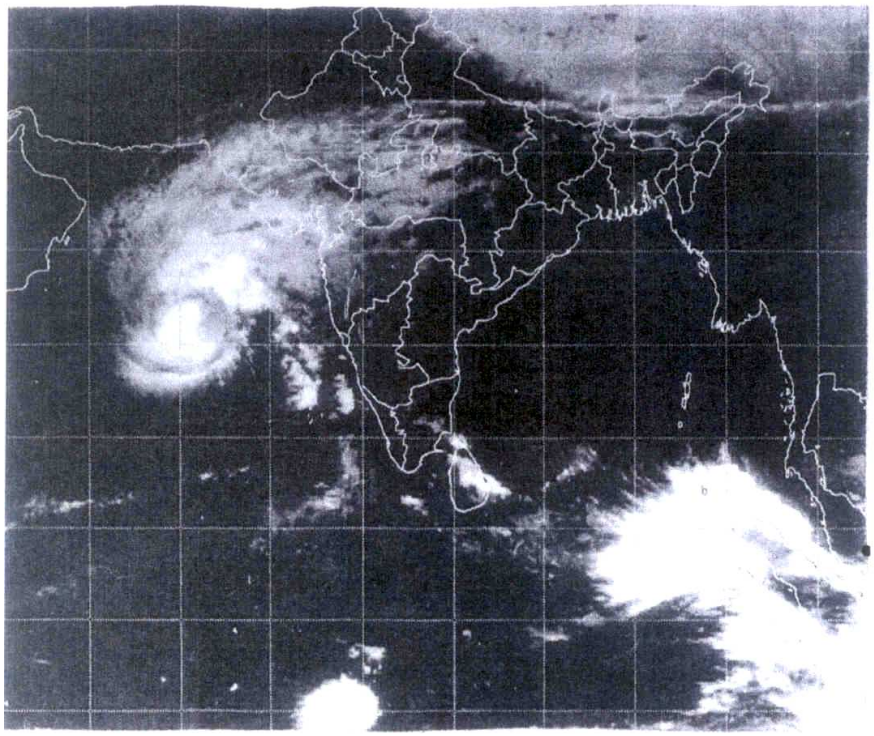
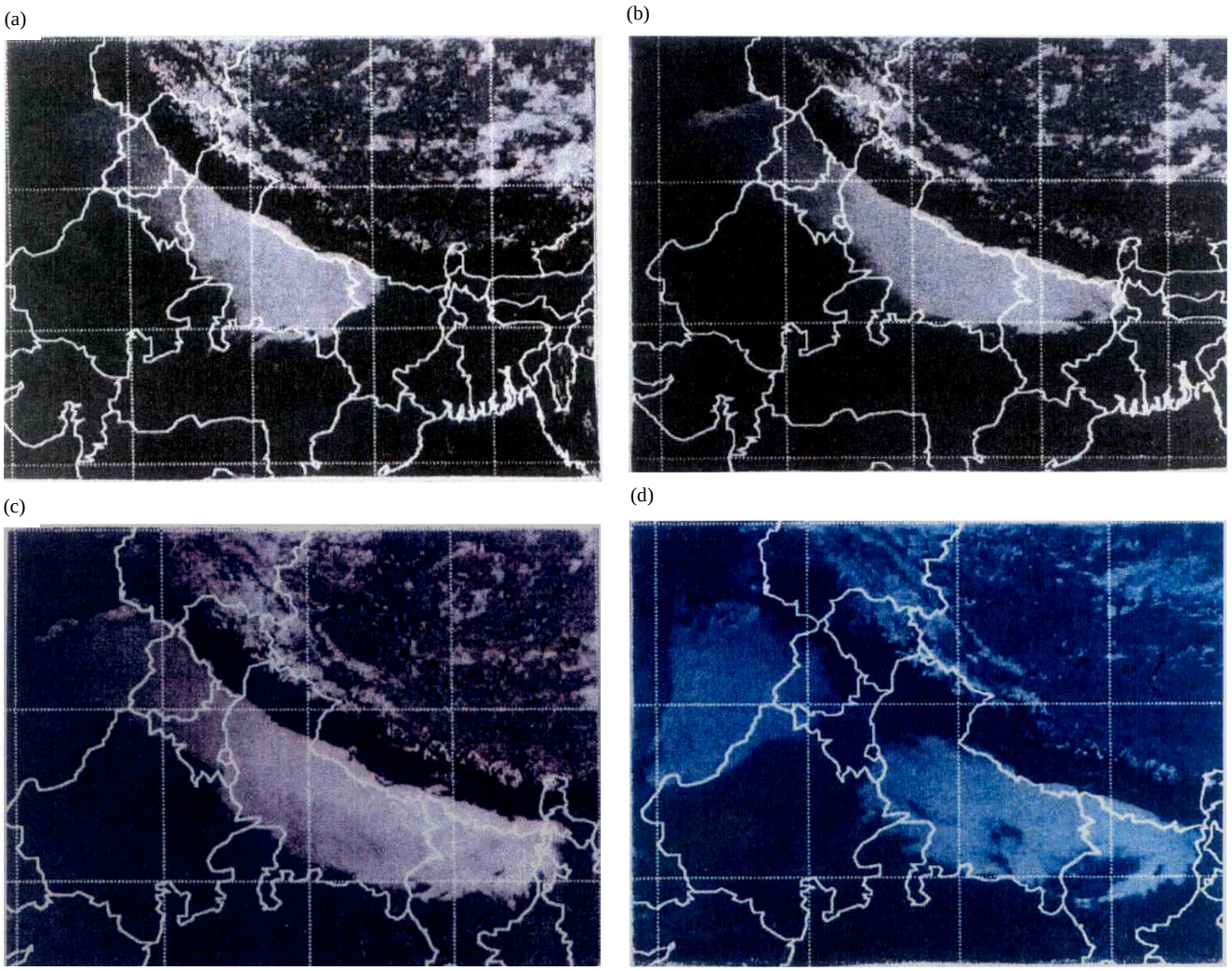


Fig. 1(b). INSAT-1D satellite imagery in IR Channel received at 0300 UTC on 15 December 1998 showing a cyclonic storm transporting tremendous amount of moisture over north India



Figs. 2(a-d). INSAT-1D viewed radiation fog over North India and adjoining Pakistan received in visible channel at (a) 0300 UTC on 26 December 1998, (b) 0300 UTC on 27 December 1998, (c) 0300 UTC on 28 December 1998 and (d) 0500 UTC on 29 December 1998

1999 when the fog occurred for 24-hours with positive relative humidity anomalies of 18% & 26% respectively [Table 4(c)]. Contrary to the above Amritsar witnessed round the clock fog on 7th January 2000 & 10th January 1999 with lower positive R.H. anomalies of 3% each [Table 4 (d)].

The information retrieved from Tables 3 (a-d) and Tables 4 (a-d) for round the clock and the total number of foggy days in fifteen years of study is updated in Tables 5 (a-d). The meteorological conditions are more favourable where the round the clock event is observed. Various studies (De *et al.* 2001 ; Bhushan *et al.* 2003) have been brought out to explain the persistency of the fog. They explained that subsidence from upper layers to the atmosphere over fog area are in the presence of cyclonic shears to the north of the sub-tropical wave (trough around 80° E Longitude), jet axis just passed through the fog region. The degradation of air quality in the cities has been often suggested as the cause of the increase of the number of poor visibility days.

3.4. *Inter-annual variations of fog over north India*

The current weather data of Delhi, Lucknow, Varanasi and Amritsar airports for the period November 1989 to February 2004 have been studied to find out inter-annual variations of fog over north India. These airports, which represent North India, keep round the clock watch over adverse weather phenomena and have recorded Met. visibility enabling the calculation of the duration of fog on day to day basis. Tables 6(a-d) is the presentation of

seasonal variation of fog for fifteen winter seasons. The figures show that the highest value of fog duration was observed during the winter season of l998-99 at all the airports. I.G.I. airport observed total fog of duration approx 7838 hours, Amritsar 3543 hours. Varanasi 5095 hours and Lucknow 4075 hours. The reason for drastic increase in the duration of fog at I.G.I. airport in the winter season of the last seven years may he attributed to the huge building construction works undertaken in Dwarka area adjacent to the Airport which is very big project in Delhi under which lakhs of buildings have been constructed. The civil works might have provided a lot of hygroscopic nuclei particularly cement and dust particles under the influence of favourable wind flow, which is one of the factors responsible for the formation of thick fog. Fog durations at all the airports during corresponding winter months are found to increase from 1989 to 1999 and thereafter slowly decrease. One of the most striking features was that major parts of north India witnessed minimum fog during the winter season of 1990-91 such as Lucknow 48 hours, Varanasi 123 hours and Amritsar 43 hours. However, I.G.I. airport witnessed minimum fog (247 hours) during 1991-92.

Out of fifteen seasons under study, four seasons did not witness any fog in the month of November at I.G.I. airport and Lucknow airport whereas the fog was practically zero at Varanasi and Amritsar airport during the month of November 1989. In the month of November, maximum fog was observed at I.G.I. airport, Lucknow airport and Varanasi airport in 1997. The fog has local episode as well as widespread episodes.

Out of all the fifteen seasons under study in the month of December, maximum fog was observed during 1998-99 over north India as reflected in Tables 6 (a-d). Similarly Tables 6 (a-d) also indicate that maximum fog in the month of January was observed at I.G.I. airport in 1998, Lucknow airport in 1998, Varanasi airport in 1998 but Amritsar airport in 1999.

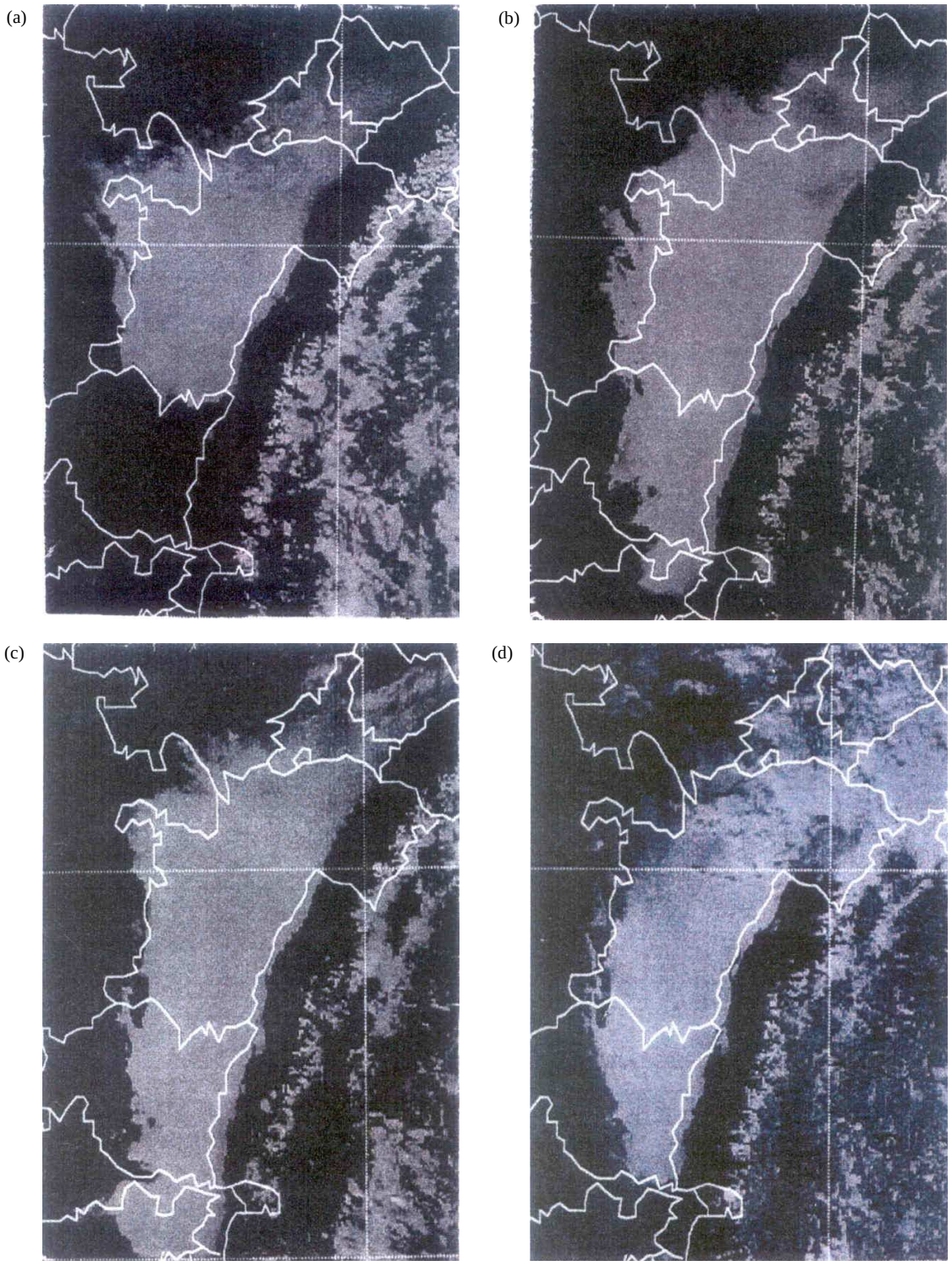
3.5. *Satellite study of fog*

Very few studies have been made on fog based on satellite data (Singh *et al*. 1979, 1983; Singh & Kant 1999). Geo-stationary satellites are the only platform from which synoptic scale long duration fog formation can be observed at frequent intervals. India Met. Department receives visible and infrared data from INSAT at three hourly intervals. Fog, which exists for longer duration of more than ten hours and cover larger areas of more than thousand square kilometres, may be clearly detected at hourly interval. Fog of 1998-99 was a catastrophic event over north India. Table 7 shows the duration of fog, which existed continuously over Delhi, Lucknow, Varanasi and Amritsar airports representing North India for a period of about three weeks from 16 December, 1998 to 4 January, 1999 and for about one week from 16 January, 1999 to 21 January, 1999. The persistence of fog over such long period could be attributed to the supply of moisture from a severe cyclone which formed in the second week of December in Arabian Sea and advected a lot of moisture over north India in middle and upper troposphere as shown in Figs. l(a&b). The low pressure system over northern parts of southeast Arabian Sea and neighborhood intensified into cyclonic storm which was located about 780 km southeast of Goa at 1730 hours IST of 13th December 1998. The system was situated about 750 km southwest of Goa at 0830 hours of 14th December and intensified into severe cyclonic storm in the evening of 14th December and was located about 750 km southwest of Veraval in the morning of 15th December. As usual, North India is a zone of subsidence during winter months, which caused enormous amount of moisture to settle down in the planetary boundary layer. ITCZ was also very active during this period due to the presence of the cyclone. It also helped in transporting sufficient moisture in the lower and middle troposphere over north India. The moist air after reaching sub-tropical zone subsided under Hadley circulation, thereby giving favourable fillip in the formation of fog.

The INSAT-1D VHRR pictures in the visible channel from 26-29 December 1998 covering a large area over north India have been given in Figs. 2(a-d). Flat textures and sharp edges in the imageries provide clear manifestation of radiation fog. The brightness variation in foggy patches is mainly due to difference in the thickness of fog as verified from the current weather data of various airports lying under the foggy areas. After more or less lull or a week, another spell of radiation fog again engulfed north India paralyzing aeronautical activities at the airports. Figs. 3(a-d) show visible imageries of INSAT-1D with a big coverage of widespread fog extending from Punjab to Assam and adjoining states. This spell also persisted up to the end of January 1999. The supply of moisture to this spell was also due to western disturbance in addition to the exiting one, which is clearly discernable in the visible picture of 20th January.

4. Impact of stability on fog in lower troposphere

Table 8(a) contains temperatures at various levels in the lower troposphere, lapse rates and duration of fog on the days of catastrophic fog during December 1998 and January 1999 at 0000 UTC. In general, all layers below 800 hPa levels are warmer than the ground but on eleven occasions *i.e.*, during 15 to 20 December 1998, 26 to 29 December 1998 and also on 2nd January 1999, all layers up to 750 hPa levels were warmer than the ground. In the



Figs. 3(a-d). INSAT-1D satellite imagery in visible channel received at 0300 UTC on (a) 14 January 1999 showing radiation fog over Uttar Pradesh, Haryana and adjoining Punjab (b) 16 January 1999 showing radiation fog over Punjab, Uttar Pradesh, Haryana, Bihar plains, Sub-Himalayan West Bengal and adjoining Bangladesh (c) 19 January 1999 showing radiation fog over Punjab, Uttar Pradesh, Haryana, Bihar plains, Sub-Himalayan West Bengal and adjoining Bangladesh and (d) 21 January 1999 showing Western Disturbance over Northwest India and adjoining Pakistan and also radiation fog over Bihar plains, Uttar Pradesh and adjoining area

latter situation I.G.I. airport experienced fog, duration ranging from 14 to 21 hours a day due to very high atmospheric stability in the lower troposphere. Thermal structures of various layers in the lower troposphere at 1200 UTC have been given in the Table 8(b) in conjunction with lapse rates and durations of fog. Temperature inversions were observed at about 50% of the occasions. Even on 18th and 19th December 1998, atmospheric layers were warmer than the ground surface up to 800 hPa (2.0 km) causing the persistence of fog for 22.5 and 21 hours respectively. On several days layers from surface to 850 hPa (1.5 km) were warmer. The exceptional depth of surface inversion persisting up to 850 hPa was in the event hours (1200 UTC) also suggest some abnormal processes taking place which help in the persistence of the fog. The data presented in the Table 8(a&b) clearly demonstrates the role played by high stability in the lower troposphere to inhibit thermal or wind induced turbulence which caused the fog conditions to persist 11 to 23 hours on different days during several days between 15 December 1998 to 22 January 1999. The persistence of high stability in the lower troposphere over Delhi during this period would require detailed study but point to the role of subsidence from say 500 hPa to 750 hPa.

5. Summary of observations

(*i*) Spatial coverage, frequency and duration of fog have increased considerably during the last seven years. With the result, a large number of diversions have taken place at I.G.I. airport New Delhi. Total number of Aircrafts diverted during the last seven winter season was about 900.

(*ii*) The periods of ILS Cat-III operation during the 1997-98, 1998-99, 1999-2000 & 2000-01 seasons increased enormously at I.G.I. airport New Delhi. The remarkable periods were 250 hours and 154 hours during 1998-99 and 1999-2000 seasons respectively The Airports Authority of India has recently procured a very sophisticated ILS to deal with the menance of long duration thick fog.

(*iii*) The days of negative maximum temperature anomaly and positive relative humidity anomaly have been found to be associated with long durations of fog with non-linear relation of higher order. Persistent fog during the day hours would not allow the maximum temperature to rise which in turn would inhibit thermally induced turbulence leading to persistence of fog conditions.

(*iv*) Out of 15 winter seasons from 1989 to 2004 the highest value of fog duration was observed during the winter season of 1998-99 over northwest India. I.G.I. airport New Delhi, Amritsar airport, Varanasi airport and Lucknow airport have total fog duration of 7838 hours, 3543 hours, 5095 hours and 4075 hours respectively.

(*v*) Atmospheric stability in lower troposphere during 1998-99 was unusually very high causing very thick and prolonged spell of fog. The causes for the high atmospheric stability in lower troposphere over north India during 1998-99 need to be explored further.

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