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Radiation fog viewed by INSAT – 1 D and Kalpana Geo - Stationary satellite

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सार – इस षोध - पत्र में इनसैट-1 डी के अति उच्च विभेदन रेडियोमीटर (वी.एच.आर.आर.) के दृष्य चित्रों और भू–स्थिर कल्पना उपग्रह का उपयोग करते हुए उत्तर भारत के सघन, लंबी अवधि के और सिनाप्टिक पैमाने के कोहरे का अध्ययन किया गया है। उपग्रहों के चित्रों में देखी गई कोहरे की सघनता, उसका विस्तार क्षेत्र और अभिलक्षण भू–आधारित सतही मौसम विज्ञान प्रेक्षणों के अनुरूप पाए गए हैं। इसमें इंदिरा गांधी अंतरराष्ट्रीय हवाई अड्डा, नई दिल्ली, अमौसी हवाई अड्डा, लखनऊ, बाबतपुर हवाई अड्डा, वाराणसी और राजासांसी हवाई अड्डा, अमृतसर की अधिकतम तापमान और सापेक्षिक आर्द्रता संबंधी विसंगतियों का उपयोग करते हुए असामान्य लंबी अवधि के कोहरे के बनने की स्थितियों को प्रस्तुत किया गया है। दिल्ली के वायुमंडल के निचले भाग में अति उच्च कोटि की वायुमंडलीय स्थिरता देखी गई है जिससे सघन और लम्बी अवधि के कोहरे के बनने की अनुकूल स्थितियाँ बनी हैं। इसमें डिफेंस मौसम विज्ञान उपग्रह कार्यक्रम (डी.एम.एस.पी.) उपग्रह में निहित विषेष संवेदी सूक्ष्म तरंग/चित्र (एस.एस.एम./आई.) के 19, 37 और 85 गीगाहर्टज वाले आवृत्ति चैनलों का उपयोग करते हुए बसिस्ट इत्यादि अध्ययन (1998) के आधार पर प्राप्त किए गए आर्द्रता सूचकांक और कोहरे की अवधि के मध्य पाए गए संबंध का अध्ययन किया गया है।

ABSTRACT. The intense, long-spell and synoptic scale fog over north India has been studied using Very High Resolution Radiometer (V.H.R.R.) visible imageries of INSAT-1D and Kalpana Geo-Stationary satellites. The intensity, coverage and characteristics of fog seen in satellite imageries are found to be in conformity with the ground –based surface meteorological observations. The unusually long spell fog formations have been explained using maximum temperature and relative humidity anomalies of I.G.I Airport, New Delhi, Amousi Airport, Lucknow, Babatpur Airport, Varanasi and Rajasansi Airport, Amritsar. Atmospheric stability of very high order was seen in the lower part of the atmosphere at Delhi creating favourable condition for the formation of intense and long-spell fog. The relation between Wetness Index derived based on Basist study (1998) using 19, 37 and 85 GHz frequency channels of Special Sensor Microwave/Imager (SSM/I) onboard Defense Meteorological Satellite Programme (DMSP) satellite and fog duration were studied.

Key words – Special sensor, Microwave/Imager, Wetness Index, ITCZ, Equatorial trough.

1. Introduction

Fog is an aviation hazard. There are occasions when it adversely affects the road and rail services also. It causes diversions of aircrafts and delays in take off due to poor horizontal visibility. In recent years, despite sophisticated Instrument Landing System Cat. III (ILS Cat.III) installed at I.G.I Airport, New Delhi, many aircrafts were devoid of landing at the airport and diverted to various airfields causing great inconvenience to passengers and loss of revenue to airlines. During the last four winter seasons (2000-2003), about 450 aircrafts were diverted to alternate aerodromes incurring huge financial loss to national & international airlines. Out of 450 diversions, 141 diversions were made in Januray 2003 only, 7 aircrafts on 2nd January, 15 on 6th January, 18 on 10th January, 23 on 16th January, 20 on 17th January, 14 on 19th January, and 11 on 20th January etc (Singh and Kant 2006). Space meteorology can play major role in mitigating the menance caused due to poor visibility. Guiding air traffic managers at regular intervals on real time basis using latest satellite imagery the exorbitant financial loss and inconvenience to passengers can be minimized. Keeping this in view, satellite imageries have been used to study the occurrence of wide spread fog in north India during the recent past in conjunction with ground – based and upper air meteorological observations. The results are described in the following sections.

2. Observational features

2.1. *Role of maximum temperature and relative humidity anomalies in long spell fog formation*

The basic criteria of fog formation is the presence of high relative humidity of air and its cooling either by radiation loss of the ground or by advection of cold air

TABLE 1

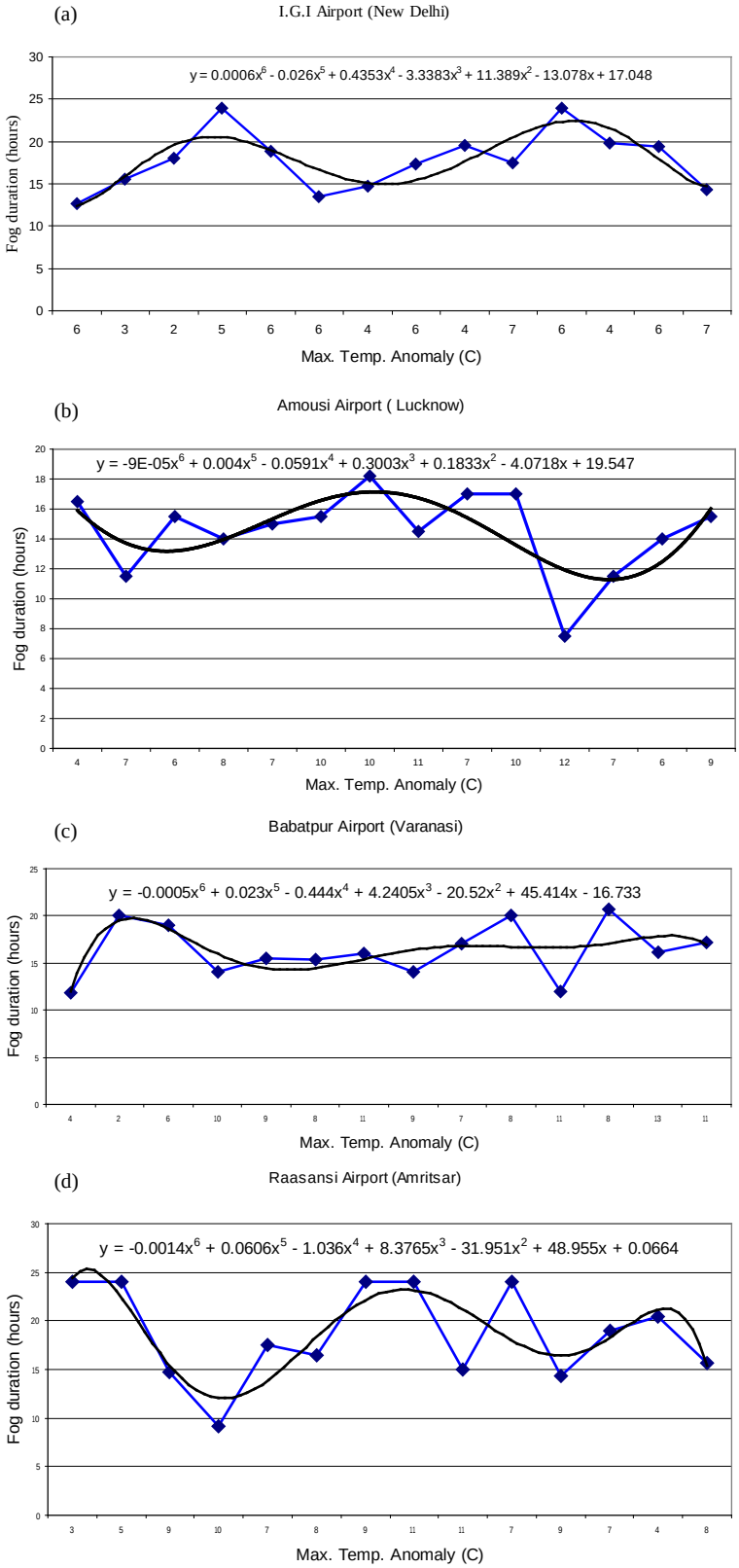
Relation of fog duration with maximum temperature and relative humidity (R.H.) anomalies

S. No.	Date	I.G.I. Airport, New Delhi			Amousi Airport,Lucknow			Babatpur Airport, Varanasi			Rajasansi Airport, Amritsar		
		Fog duration (Hours)	Max. temp. anomaly (°C)	R.H anomaly at 0300 UTC (%)	Fog duration (Hours)	Max. temp. anomaly (°C)	R.H anomaly at 0300 UTC (%)	Fog duration (Hours)	Max. temp. anomaly (°C)	R.H anomaly at 0300 UTC (%)	Fog duration (Hours)	Max. temp. anomaly (°C)	R.H anomaly at 0300 UTC (%)
1	11 Jan 2001	12.7	-06	+19	16.5	-04	+15	11.8	-04	+18	24	-03	+03
2	01 Jan 2002	15.5	-03	+20	11.5	-07	+09	20	-02	+20	24	-05	+03
3	02 Jan 2002	18	-02	+20	15.5	-06	+14	19	-06	+23	14.8	-09	+03
4	07 Jan 2003	24	-05	+19	14	-08	+09	14	-10	+20	9.1	-10	+03
5	10 Jan 2003	18.9	-06	+19	15	-07	+14	15.5	-09	+23	17.5	-07	+03
6	13 Jan 2003	13.5	-06	+19	15.5	-10	+15	15.3	-08	+23	16.5	-08	+03
7	14 Jan 2003	14.7	-04	+16	18.2	-10	+15	16	-11	+23	24	-09	+03
8	15 Jan 2003	17.4	-06	+19	14.5	-11	+15	14	-09	+20	24	-11	+03
9	16 Jan 2003	19.5	-04	+19	17	-07	+16	17	-07	+06	15	-11	+03
10	17 Jan 2003	17.5	-07	+19	17	-10	+11	20	-08	+23	24	-07	+03
11	18 Jan 2003	24	-06	+19	7.5	-12	+11	12	-11	+17	14.3	-09	+03
12	19 Jan 2003	19.8	-04	+19	11.5	-07	+11	20.7	-08	+23	19	-07	+03
13	20 Jan 2003	19.4	-06	+19	14	-06	+16	16.2	-13	+23	20.5	-04	+03
14	21 Jan 2003	14.3	-07	+20	15.5	-09	+17	17.2	-11	+25	15.7	-08	+04

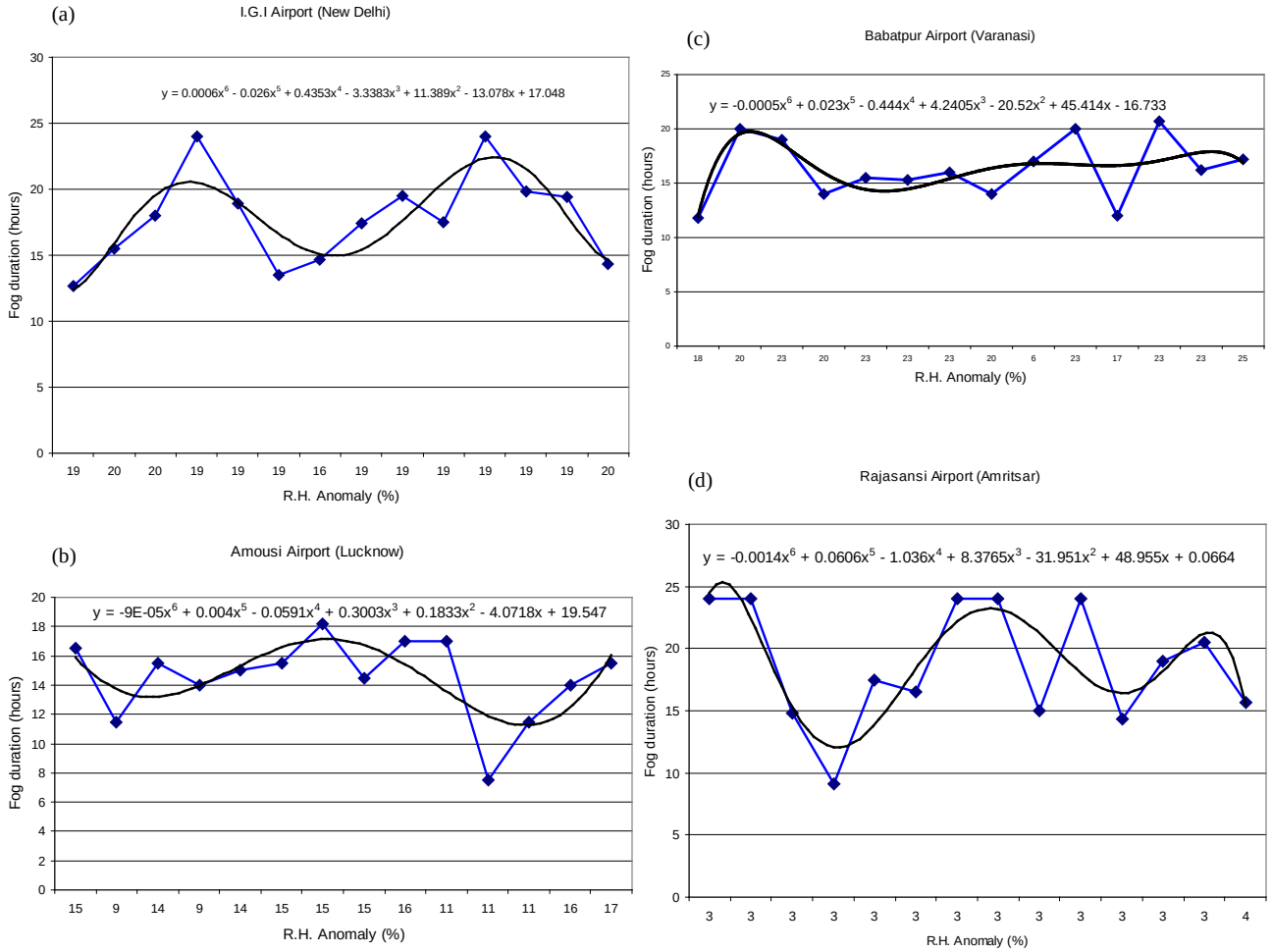
from the neighbouring areas so that air above the ground get saturated to the level of droplet formation. In Table 1, the maximum temperature and humidity anomalies of four airports *viz.*, I.G.I. Airport, New Delhi, Amousi Airport, Lucknow, Babatpur Airport, Varanasi, Rajasansi Airport, Amritsar have been presented. The anomalies data is taken from India Meteorological Department, New Delhi and these are the departures from normal values, which are daily recorded at respective airports. These airports have round-the-clock surveillance on weather and therefore have been chosen to represent north-west India in the study of widespread fog. Fourteen cases of widespread fog reported by these airports indicate that the day time temperatures were much below normal and the relative humidity at 0830 hrs (IST) were also appreciably above normal. The long durations of fog (Table 1) indicate that there were practically no insolations over north-west India for long durations during January 2003. The frequency of western disturbances to the west and north of the country was so high that the advection of cold air over higher latitudes created severe cold wave conditions over northern parts of the country. Consequently, maximum temperatures that were much below normal kept the air saturated for most part of the day causing most favourable conditions for the sustainance of the fog. Maximum temperatures at Amousi Airport were mostly 10° C to 12° C below normal during the period from 13 to 18 January 2003. Babatpur Airport had maximum temperature 11° C below normal on 14th, 18th and 21st January 2003 and 13° C, which is remarkably below normal on 20th January. Similarly Rajasansi Airport had maximum temperature 10° C below normal on 7th January and 11° C below normal on 15th and 16th January. The relation between fog duration and max. temperature & R.H anomalies for the four airports is given in Figs. 1 (a-d) and Figs. 2 (a-d) respectively.

2.2. *Atmospheric stability and fog*

During the month of December and January over north India, the temperature inversion usually occurs near the ground due to radiation cooling of the earth surface, which favours the formation of fog. Even if layer above the ground is isothermal or lapse rate is slightly negative, fog forms, but it does not last long due to strong insolation after sunrise. But for the sustenance of fog for longer period, atmosphere above the ground requires very high degree of stability and therefore lapse rates should be highly negative so that the suspended droplets in the fog may settle down above the ground reducing the horizontal



Figs. 1(a-d). Relation between fog duration & max. temperature anomaly for (a) I.G.I. Airport, New Delhi, (b) Amousi Airport, Lucknow, (c) Babatpur Airport, Varanasi and (d) Rajasansi airport, Amritsar



Figs. 2(a-d). Relation between fog duration and R.H. anomaly for (a) I.G.I. Airport, New Delhi, (b) Amousi Airport, Lucknow, (c) Babatpur Airport, Varanasi and (d) Rajasansi Airport, Amritsar

TABLE 2

Stability in lower atmosphere at I.G.I Airport, New Delhi during fog

S. No.	Date	Surface temperature (°C)	Warmest layer above ground		Lapse rate of temperature (°C/km)	Thickness of warm layer above ground (km)	Fog duration (Hours)
			Height (km)	Temperature (°C)			
1	02 Jan 2003	8.0	0.42	10.1	-5.0	0.42	21.7
2	06 Jan 2003	7.0	1.50	13.1	-4.1	3.14	18.2
3	10 Jan 2003	5.5	0.76	11.1	-7.4	1.52	18.9
4	11 Jan 2003	5.5	0.98	11.6	-6.2	1.55	16.9
5	12 Jan 2003	6.8	0.92	10.5	-4.0	1.66	15.5
6	13 Jan 2003	6.0	0.55	11.6	-10.2	1.79	13.5
7	14 Jan 2003	7.0	0.85	18.2	-13.2	2.04	14.7
8	15 Jan 2003	4.5	0.90	13.3	-9.8	2.42	17.4
9	16 Jan 2003	5.0	1.25	14.0	-7.2	3.13	19.5
10	17 Jan 2003	6.5	0.82	13.8	-8.9	2.87	17.5
11	18 Jan 2003	8.0	1.06	16.1	-7.6	1.89	24.4
12	19 Jan 2003	6.5	1.12	16.2	-8.7	3.16	19.8
13	20 Jan 2003	6.0	1.25	14.9	-7.1	2.17	19.4
14	21 Jan 2003	5.0	0.81	16.7	-14.4	3.12	14.3

TABLE 3

Relation of wetness index with fog

S.No.	Year (Week No)	I.G.I Airport, New Delhi		Amousi Airport, Lucknow		Babatpur Airport, Varanasi		Rajasansi Airport, Amritsar	
		Wetness index (01-40)	Average fog duration per week (Hours)	Wetness index	Average fog duration per week (Hours)	Wetness index (01-40)	Average fog duration per week (Hours)	Wetness index (01-40)	Average fog duration per week (Hours)
1	1989 (49)	3.18	5.4	2.73	4.0	3.75	1.3	4.30	2.1
2	1989 (50)	3.54	7.3	4.19	2.3	4.40	1.9	6.74	3.8
3	1989 (51)	2.86	8.6	4.27	3.5	4.65	1.9	6.67	2.3
4	1989 (52)	7.55	12.1	7.19	6.8	8.98	6.8	10.07	10.1
5	1990 (01)	6.31	11.7	5.97	7.1	5.67	6.4	7.65	9.6
6	1990 (02)	2.96	8.0	4.25	6.3	4.10	6.5	6.44	3.3
7	1990 (03)	2.92	7.0	3.74	5.5	4.31	3.0	3.29	0.5
8	1990 (04)	2.60	4.2	2.94	0.0	3.77	0.0	3.84	3.1
9	1990 (05)	1.71	2.8	2.04	0.0	2.30	0.0	3.00	0.0
10	1992 (01)	6.10	2.0	5.78	9.8	7.02	4.1	6.42	3.0
11	1992 (02)	4.23	9.6	-	4.6	6.50	3.0	7.27	3.8
12	1992 (03)	4.30	6.7	5.26	7.2	5.33	4.0	5.43	2.6
13	1992 (04)	2.76	5.8	5.62	9.2	5.37	5.5	4.80	1.5
14	1992 (05)	7.49	3.6	6.28	2.8	6.98	6.5	10.56	3.8
15	1992 (49)	4.15	6.5	6.70	4.6	5.60	0.0	6.98	3.5
16	1992 (50)	2.88	6.2	4.78	5.7	-	0.7	6.95	2.6
17	1992 (51)	3.30	8.1	5.39	8.7	4.47	3.7	6.59	3.7
18	1992 (52)	3.70	4.4	5.70	7.6	4.94	5.2	5.84	3.5
19	1993 (01)	5.63	7.5	6.14	6.2	4.48	7.1	5.56	4.3
20	1993 (02)	5.14	3.6	4.50	2.1	5.72	5.8	4.53	4.0
21	1993 (03)	5.61	4.0	4.11	4.2	4.67	3.7	4.65	4.2
22	1993 (04)	3.52	8.0	3.91	4.7	3.67	0.0	3.89	0.5
23	1993 (05)	4.24	6.0	4.32	3.9	4.01	3.6	4.00	2.0
24	1993 (49)	4.49	10.0	6.54	4.2	6.67	0.8	5.52	0.0
25	1993 (50)	-	9.6	-	4.5	-	0.0	-	1.8
26	1993 (51)	4.52	12.7	5.51	3.5	6.30	0.0	7.70	3.3
27	1993 (52)	5.38	14.8	5.32	3.8	5.69	2.5	7.05	2.5
28	1994 (01)	5.90	11.0	5.48	4.4	5.80	1.0	6.06	1.5
29	1994 (02)	9.32	11.1	6.21	7.6	5.80	4.6	8.47	6.2
30	1994 (03)	9.18	9.0	8.97	7.1	9.27	5.2	9.70	7.2
31	1994 (04)	5.25	2.7	5.93	2.0	5.53	2.0	6.51	0.0
32	1994 (05)	3.99	3.5	5.70	0.0	7.08	3.3	4.16	0.0
33	1994 (49)	5.95	8.6	7.73	8.3	8.42	5.9	6.67	2.3
34	1994 (50)	2.93	0.0	4.88	4.5	6.96	5.8	6.28	3.5
35	1994 (51)	4.24	6.2	4.26	3.2	6.41	5.4	7.00	2.8
36	1994 (52)	4.24	4.2	4.66	4.8	6.40	2.5	7.35	2.3
37	1995 (01)	5.18	9.4	4.30	4.9	6.08	5.9	7.77	1.3
38	1995 (02)	14.7	11.3	11.8	9.4	10.58	10.3	8.82	4.5
39	1995 (03)	10.16	8.6	7.60	6.0	7.02	3.6	10.06	1.0
40	1995 (04)	6.37	3.6	5.77	0.0	6.11	1.3	6.25	0.0
41	1995 (05)	5.41	8.3	4.21	1.5	5.75	8.7	5.56	2.8
42	1995 (49)	4.04	3.5	4.15	0.0	6.93	7.6	5.05	3.0
43	1995 (50)	3.89	2.7	4.22	0.0	6.68	0.5	5.25	1.5
44	1995 (51)	4.72	5.0	3.79	0.0	6.08	3.6	5.98	0.0
45	1995 (52)	5.40	13.2	5.73	2.5	10.57	6.7	6.51	5.2
46	1996 (01)	6.26	10.8	7.65	1.6	8.29	0.0	6.46	2.2
47	1996 (02)	5.15	14.1	6.06	3.8	7.55	0.0	6.06	2.5
48	1996 (03)	6.36	6.1	12.05	5.7	6.72	3.8	8.50	1.2
49	1996 (04)	4.05	1.7	7.03	0.0	5.16	2.1	5.59	3.0
50	1996 (05)	4.32	8.6	4.65	2.5	3.21	7.0	3.84	1.6
51	1996 (49)	3.24	3.7	5.80	0.0	6.42	3.0	4.38	0.0
52	1996 (50)	2.84	4.0	5.57	0.0	5.89	2.1	6.05	1.6
53	1996 (51)	4.64	6.0	5.40	2.7	5.80	4.3	7.67	2.5
54	1996 (52)	5.33	3.9	5.13	4.0	4.79	7.9	7.47	3.9

TABLE 3 (*Contd*.)

S.No.	Year (Week No)	I.G.I Airport, New Delhi		Amousi Airport, Lucknow		Babatpur Airport, Varanasi		Rajasansi Airport, Amritsar	
		Wetness index (01-40)	Average fog duration per week (Hours)	Wetness index	Average fog duration per week (Hours)	Wetness index (01-40)	Average fog duration per week (Hours)	Wetness index (01-40)	Average fog duration per week (Hours)
55	1997 (01)	6.01	10.9	5.63	6.5	5.47	8.8	7.57	8.5
56	1997 (02)	5.32	12.6	4.66	0.0	5.25	11.5	5.23	2.6
57	1997 (03)	6.12	9.2	7.10	5.1	6.99	6.9	7.62	7.7
58	1997 (04)	4.14	7.5	4.74	3.1	5.58	5.0	7.68	3.3
59	1997 (05)	5.22	5.5	4.36	0.5	5.57	3.7	6.23	3.3
60	1997 (49)	8.83	9.1	12.46	4.3	10.20	2.6	10.01	2.5
61	1997 (50)	17.58	10.0	2.11	6.6	13.75	4.6	9.51	6.2
62	1997 (51)	11.98	7.0	15.49	8.1	11.81	10.0	8.32	5.0
63	1997 (52)	7.99	10.2	11.64	7.7	9.93	8.6	7.11	9.0
64	1998 (01)	5.91	6.7	9.26	18.4	8.45	12.6	6.19	6.3
65	1998 (02)	5.02	8.3	7.55	10.8	7.00	6.6	4.81	4.2
66	1998 (03)	4.11	11.7	6.45	3.2	6.43	2.3	4.81	1.0
67	1998 (04)	3.87	6.4	4.82	3.7	5.58	3.4	4.48	0.5
68	1998 (05)	4.06	5.3	8.24	2.0	6.16	4.4	3.91	2.8
69	1998 (49)	4.77	1.1	6.08	6.2	6.99	7.4	7.37	2.5
70	1998 (50)	6.23	10.5	6.76	4.2	7.39	10.5	7.54	2.2
71	1998 (51)	7.23	24.7	7.02	11.4	6.79	11.1	8.06	2.9
72	1998 (52)	7.00	16.0	6.98	16.7	6.62	13.2	6.71	2.6
73	1999 (01)	6.16	11.0	6.22	9.3	6.12	8.5	5.28	2.2
74	1999 (02)	8.93	12.8	9.93	9.4	6.56	5.6	8.34	3.1
75	1999 (03)	6.33	12.8	7.95	12.9	5.75	9.8	5.52	2.4
76	1999 (04)	5.84	4.1	5.71	2.6	5.91	1.8	5.96	2.4
77	1999 (05)	5.61	5.6	5.26	3.9	5.20	4.1	5.74	2.3
78	1999 (49)	4.99	5.7	7.52	2.1	7.99	3.8	7.97	2.5
79	1999 (50)	4.92	7.3	7.32	5.8	7.34	2.7	6.54	2.2
80	1999 (51)	4.54	7.4	5.84	9.8	6.37	8.6	6.90	4.2
81	1999 (52)	6.22	13.6	5.95	11.1	6.79	15.7	5.94	10.6
82	2000 (01)	6.89	17.5	5.97	19.7	6.22	16.8	5.64	17.3
83	2000 (02)	6.20	7.9	5.87	6.7	5.88	5.9	6.09	7.2
84	2000 (03)	3.73	5.5	3.42	2.0	5.16	2.2	6.13	0.0
85	2000 (04)	6.33	12.7	4.21	1.2	5.45	3.1	5.12	1.5
86	2000 (05)	4.39	4.5	3.27	3.0	4.77	4.0	4.29	3.7
87	2000 (49)	2.89	0.0	3.84	0.0	5.88	1.0	5.50	1.3
88	2000 (50)	3.73	5.0	3.76	12.0	5.30	2.8	6.45	2.7
89	2000 (51)	4.61	5.6	4.77	5.3	5.58	5.1	6.83	5.0
90	2000 (52)	5.18	7.6	5.15	7.2	5.47	5.2	5.76	4.7
91	2001 (01)	10.47	7.1	6.14	7.35	6.11	5.6	6.80	6.1
92	2001 (02)	6.76	17.9	5.08	9.1	5.52	4.4	4.88	13.0
93	2001 (03)	5.87	12.5	4.48	5.4	4.94	3.0	4.75	10.5
94	2001 (04)	3.75	4.0	3.02	3.0	3.82	3.0	3.08	1.5
95	2001 (05)	2.78	4.1	2.26	0.0	3.36	1.0	2.26	0.0
96	2001 (49)	3.42	3.3	4.64	10.0	6.64	3.8	6.29	0.0
97	2001 (50)	4.09	10.6	5.80	15.0	7.16	16.1	6.19	6.5
98	2001 (51)	4.60	6.0	5.22	9.2	6.02	12.5	6.13	1.0
99	2001 (52)	5.61	11.6	5.25	11.1	6.04	5.5	6.65	13.4
100	2002 (01)	5.95	13.6	4.32	9.0	5.58	11.1	6.02	12.9
101	2002 (02)	4.89	8.6	4.46	7.0	6.06	4.4	3.19	4.3
102	2002 (03)	7.11	10.0	6.10	7.0	6.01	3.4	3.88	3.5
103	2002 (04)	4.80	4.2	4.47	0.0	5.69	3.0	2.27	3.0
104	2002 (05)	3.73	2.8	4.65	0.0	4.77	2.1	2.40	1.0
105	2002 (49)	3.33	2.4	4.69	0.0	6.00	3.1	5.27	2.3
106	2002 (50)	3.81	4.0	4.41	10.5	5.88	5.6	6.62	2.9
107	2002 (51)	4.91	6.3	5.49	7.4	5.53	8.6	6.09	3.2
108	2002 (52)	6.51	8.6	6.16	6.0	5.55	9.5	5.85	7.1
109	2003 (01)	9.19	17.2	10.27	8.1	7.24	6.5	5.91	16.8
110	2003 (02)	6.11	17.9	7.03	13.0	5.28	12.5	5.02	15.5
111	2003 (03)	6.13	17.6	7.15	15.1	5.42	16.8	5.09	19.8
112	2003 (04)	4.47	9.5	5.34	15.5	5.86	10.5	3.54	10.1
113	2003 (05)	5.66	9.1	7.32	3.0	5.37	4.1	4.46	4.3

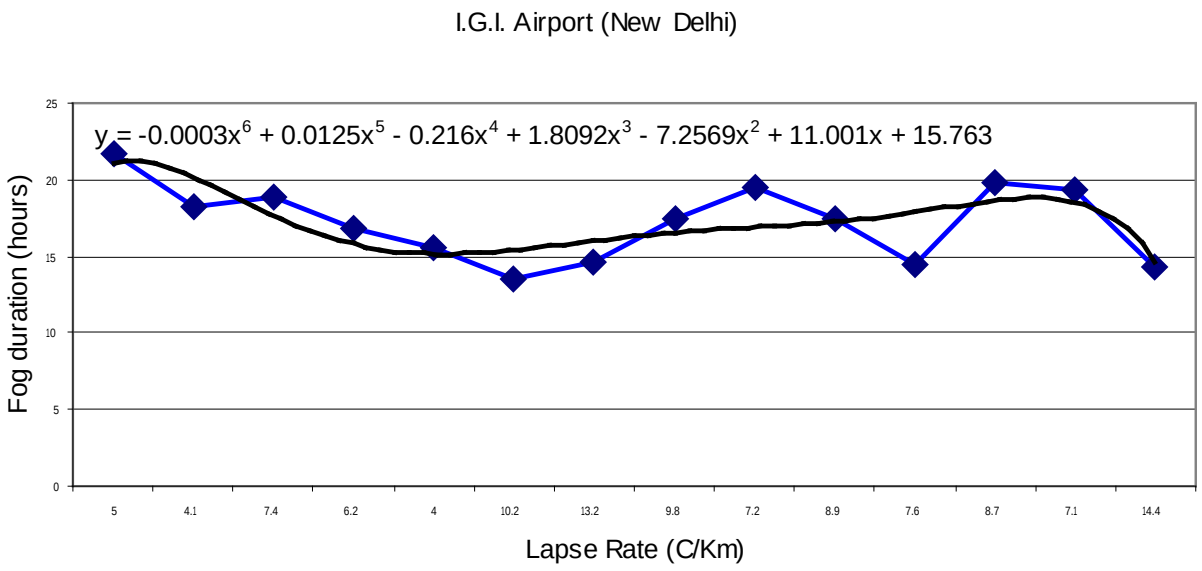


Fig. 3. Relation between fog duration and lapse rates for I.G.I. Airport, New Delhi

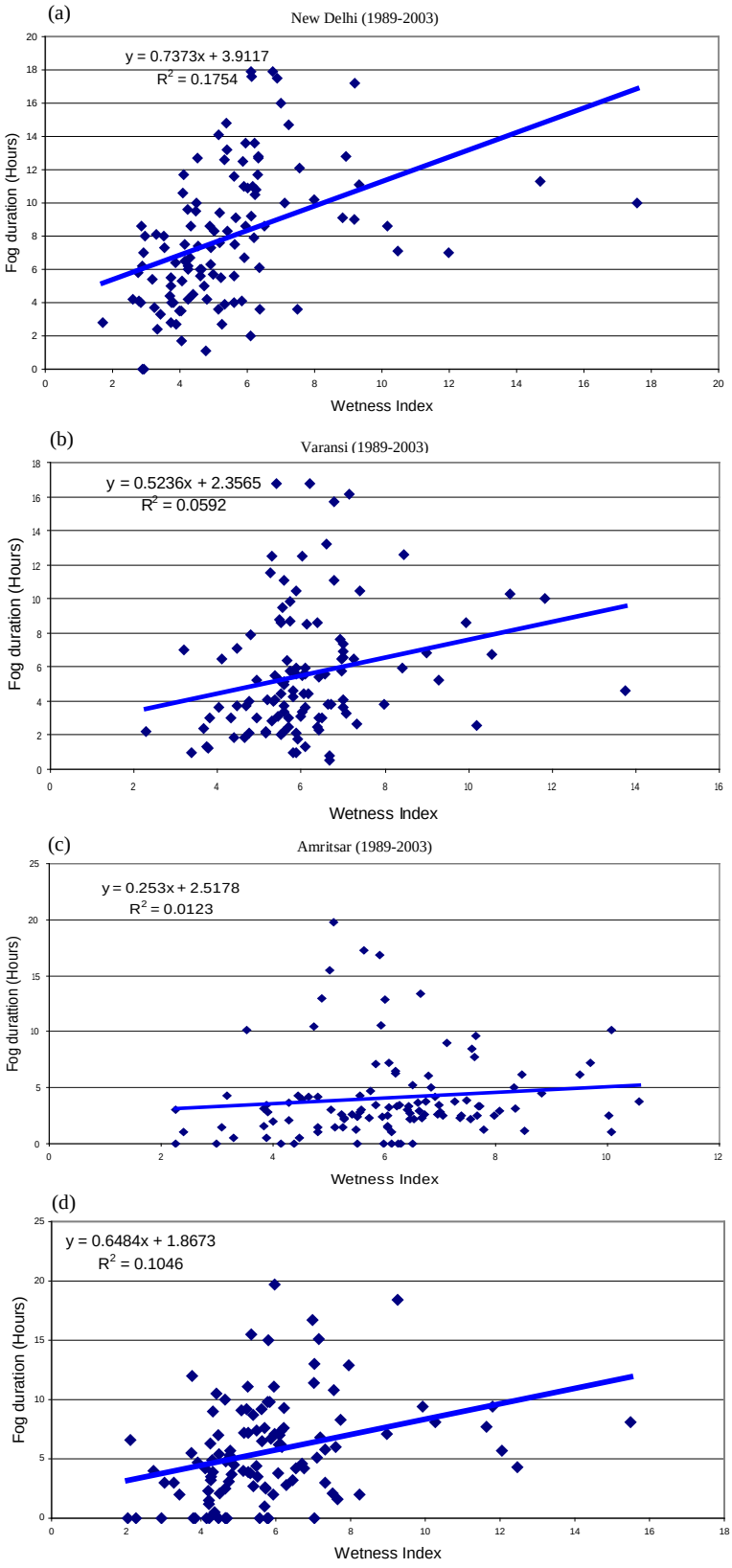
visibility to a few hundred meters. Such situation is shown in Table 2, where the lower part of the atmosphere were warmer as compared to the air above the ground surface, upto about 3 km above ground level on most of the occasions due to adiabatic heating (subsidence of air from the mid troposphere) giving rise to unusually long duration of fog. The most remarkable day was 18th January 2003 when the I.G.I. Airport had round-the-clock fog. Stability of the atmosphere was most significantly high on 14th and 21st January 2003 when lapse rates were –13.2° C/km and –14.4° C/km respectively. The relation between fog duration and lapse rates is given in Fig. 3.

2.3. *Wetness index and fog*

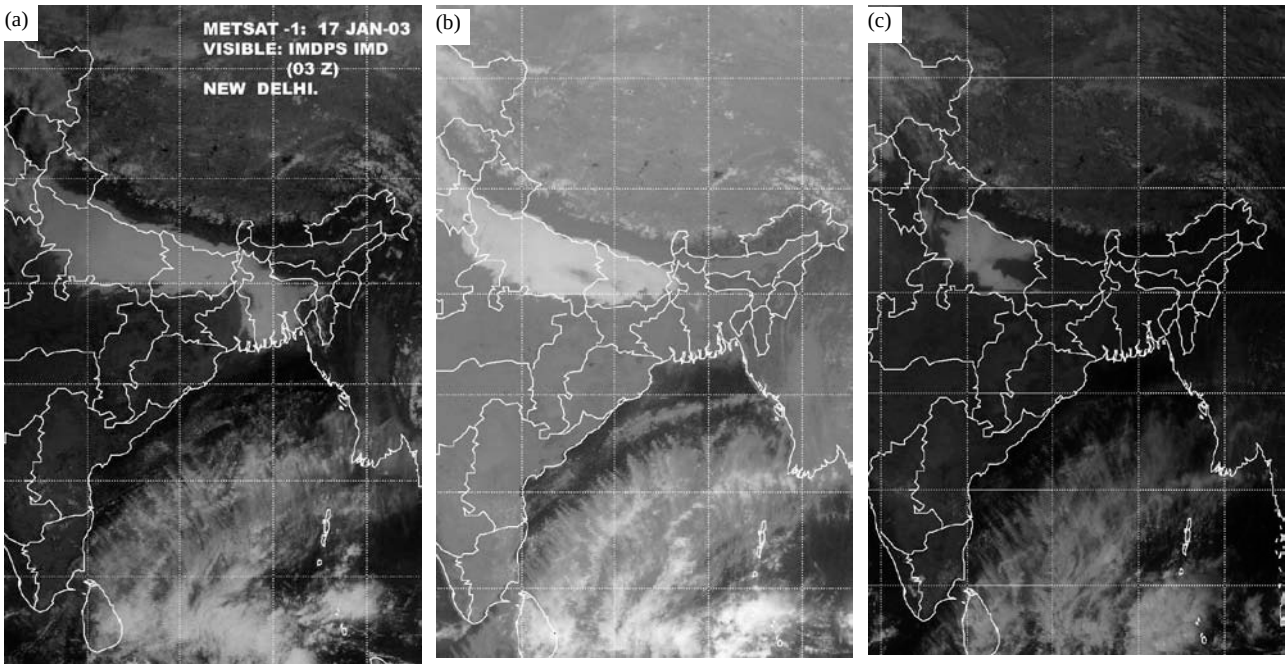
Table 3 present Wetness Index (W.I.) and average fog duration per day for I.G.I. Airport, Amousi Airport, Babatpur Airport and Rajasansi Airport for the period 1989 to 2003. Weekly surface W.I. is derived based on Basist approach (Basist *et al.* 1998) using 19, 37 and 85 GHz frequency channels of Special Sensor Microwave/Imager (SSM/I) onboard Defense Meteorological Satellite Programme (D.M.S.P.) satellite. The frequencies are primarily atmospheric window channels, which receive majority of their radiation from the surface. The relationships of brightness temperature at different frequencies are used to derive surface W.I. that is related to the amount of liquid water in SSM/I observations. The sources of moisture in foggy areas are two-fold. One from the atmosphere due to the passage of rain bearing weather systems and another from the land surface due to irrigation etc. W.I. represents land surface moisture and is positive at I.G.I. Airport where variation in fog duration is generally reflected in the change of W.I. in the same direction. Similarly, at Amousi Airport variation in fog duration is also broadly reflected in the change in W.I. at Babatpur Airport, W.I. gives positive signal in January and February but not in December. At Rajasansi Airport, W.I. behaviour with fog duration is found to be erratic. Observations, no doubt, indicate that moisture flux from the land surface contributes favourably in the formation and intensification of the fog but its impact on fog duration differs from place to place depending upon the effect of other parameters, which influence the development of fog. The relation between the fog duration and W.I. for the four airports is given in Figs. 4 (a-d).

3. Satellite – viewed fog

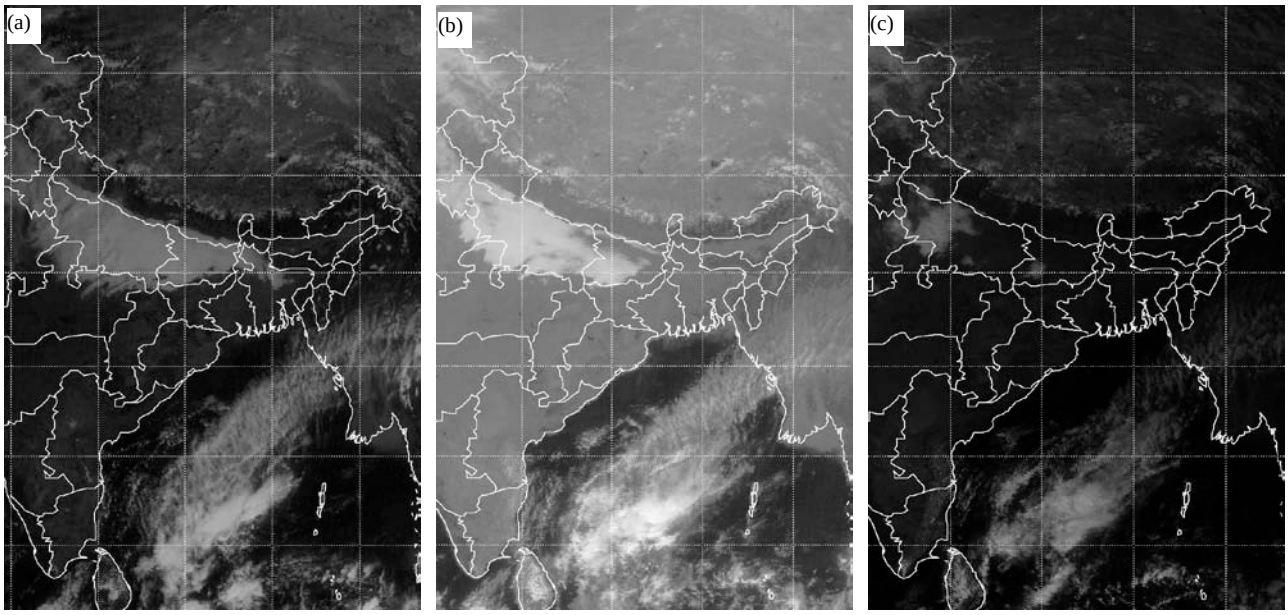
Very few studies have been made on fog based satellite data. (Singh *et al*. 1979, 1983; Singh and Kant, 1999, 2006; Bhushan *et al*., 2003). A widespread fog over north India and adjoining Pakistan recorded in visible channel of Kalpana Geo-Stationary Satellite at 11.30 hrs (IST) on January 17 18, 2003 is shown in Figs. 5&6. A Western Disturbance is seen to move across Iran, Pakistan, Afghanistan and from the horizontal visibility



Figs. 4(a-d). Relation between fog duration and wetness Index for (a) I.G.I. Airport, New Delhi, (b) Babatpur Airport, Varanasi, (c) Rajasansi airport, Amritsar and (d) Amousi Airport, Lucknow



Figs. 5(a-c). Widespread fog over North India and adjoining Pakistan seen in the visible imagery of Kalpana Geostationary Satellite at 0830, 1130 and 1430 hrs (IST) on 17 January, 2003. On this day following Airports reported long duration fog : (a) I.G.I. Airport, New Delhi : 17.5 hours, (b) Amousi Airport, Lucknow : 17 hours, (c) Babatpur Airport, Varanasi : 20 hours and (d) Rajasansi Airport, Amritsar : 24 hours



Figs. 6(a-c). Widespread fog over North India and adjoining Pakistan seen in the visible imagery of Kalpana Geostationary Satellite at 0830, 1130 and 1430 hrs (IST) on 18 January, 2003. On this day following Airports reported long duration fog : (a) I.G.I. Airport, New Delhi : 24 hours, (b) Amousi Airport, Lucknow : 7.5 hours, (c) Babatpur Airport, Varanasi : 12 hours and (d) Rajasansi Airport, Amritsar : 14.3 hours

extreme northern parts of India. Cold wave conditions prevailed over plains of north west India. The incursion of moisture over Uttar Pradesh, Bihar, and Punjab & Haryana in association with cold wave resulting into widespread fog over these areas is easily identifiable in the Kalpana satellite imagery due to its flat texture and sharp edges. The brightness variations in foggy patches are mainly due to thickness of fog, which was verified

data of various airports lying under the foggy areas. Inter Tropical Convergence Zone (ITCZ) near the equator is also seen to be active on the days of widespread fog in North India. In the active stage of ITCZ/Equatorial trough the vertical transport of huge amount of moist air which reaches up to sufficient height in the upper troposphere, transported horizontally on both sides of the equator and in turn, subsides over most parts of northwest India. This subsiding air caused increased stability of the atmosphere which is also reflected in the values of lapse rates. On many occasions when widespread fog is observed over north India, ITCZ/Equatorial Trough is seen to be active in satellite imageries with bands of towering convective clouds. This is one of the contributory factors in the widespread formation of fog.

4. Summary of observations

(*i*) The abnormally low values of maximum temperature and high relative humidity were found favourable for the formation of intense long duration fog.

(*ii*) The warming up of the lower part of the atmosphere up to a height of about 3 km and unusually high negative lapse rates were found to be associated with long-spell fog.

(*iii*) Wetness Index which represents skin soil moisture was seen to manifest positive signal towards the variation in fog duration on most of the occasions in 1998 over northwest India.

(*iv*) The polynomial term variations in the graphs showing the behaviour among fog duration, max. temperature & humidity anomalies and lapse rates indicate that the fog formation is a very complex process and can not be explained fully with the variation of one or two parameters. But this can definitely help to determine the probable extent of the fog duration by the variation in the max. temperature & humidity anomalies and the lapse rates.

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