Occurrence of Winter Thunderstorm and Squall followed by Immediate Dense Fog at IGI airport –Monitoring and Forecasting Challenges

Suresh Ram
India Meteorological Department, MoES
Mausam Bhawan, Lodi Road, New Delhi
Email: sureshram265@gmail.com

ABSTRACT

Unique incident of Thunderstorm (TS)/squall immediately followed by dense fog occurred on 7-8th February, 2011 reducing the visibility to almost zero which severely affected the flight movement at Indira Gandhi International (IGI) airport New Delhi. The immediate formation of dense fog which was of radiation type and further during night/morning time could never be foreseen by forecaster even at nowcast time scale of 1-6 hours in advance. In the present study, data from the surface, upper air, satellite, DWR and airport meteorological instruments located at the ends of the three runways(RWY) have been critically analysed to detect and monitor the intensification and movement of both the events to find out their use in nowcasting. Study of upper air parameters shows the atmosphere was highly unstable by 1200UTC before the occurrence of TS with CAPE value reaching up to 548 J/Kg. The lapse rate 60C/Km while at 0000UTC when dense fog was at the peak the upper air pattern changed to stable atmosphere where the reversed lapse rate was observed. This study shows that use of DWR, satellite and the Integrated Aviation Weather Observing System (IAWOS) at IGI airport has an advantage over synoptic and NWP inputs for accurate nowcast of severe TS/ Squall to severe fog spell over the station reducing the ground visibility to zero.

Keywords: *Thunderstorm, Squall, Nowcasting, Fog, DWR, Satellite and Integrated Aviation Weather Observing System.*

1. Introduction

Normally IGI airport is affected by few cases of dense fog of radiation type during February when Western Disturbances (WDs) affect northern India with rain. Time of occurrence and intensity of likely weather phenomena which may affect aviation severely is still a challenging job for the forecasters. In one case, a severe thunderstorm occurred in the afternoon of 7th February 2011 between1400 and 1700 UTC causing rain and gusty winds which was followed by fog leading to zero visibility at the airport by 2130UTC. The occurrence of both these weather events were so rapidly followed by each other that the concerned forecaster while issuing accurate weather warning for thunder squall, could not predict the occurrence of very dense fog in time.

In winter season, WD is one of the main weather systems affecting north India. WD is an eastward moving upper air trough in the sub-tropical westerly which often manifested as cyclonic Circulation/ trough in the upper air charts or as closed lows on surface charts. These systems influence the weather over the country all through the year, even though the climatological frequency of WD is slightly higher during the winter season as compared to that during the other seasons and hence the chances of thunderstorm followed by fog is higher. In the month of February, IGI airport has been affected by few cases of dense fog. It has been observed that the dense fog in the month of February is of very short duration. These cases normally occur as radiation fog due to overnight rain caused by western disturbances. These rainfall events are also associated with squall, hail storm in view of transition from winter to summer season. The occurrence of fog over northern part of India and over Delhi has been studied by Bhushan (2003), Bhowmik et al. (2004) and Singh and Surya kant (2006) and Singh (2011) while comprehensive studies on climatological and forecasting aspects of fog occurrences over IGI Airport are available in Jenamani and Tyagi (2010a, 2010b, 2011). These studies have been done mostly for the month of December and January when prolonged and severe spells of fog normally occurs over the region. Thunderstorms can generally form and develop in

any geographic location, perhaps most frequently within areas located at mid-latitude when warm moist air collides with cooler air. Thunderstorms are responsible for the development and formation of many severe weather phenomena. The thunderstorms and the phenomena that occur along with them, pose great hazards to human life. Several methods are used to study thunderstorms. Generally, the thunderstorms require three conditions to form, availability of sufficient moisture, unstable atmosphere (air mass) and lifting mechanism like low level convergence.

The triggering mechanism of thunderstorm occurs when the region is affected by some synoptic low-pressure system. The thunderstorm and squall at different locations have been analyzed by many researchers mainly for pre-monsoon and monsoon season. The frequency distribution of thunderstorms and squall in different months in Indian region was carried out by Rao and Raman (1961) and recently a detailed climatological study has been carried out by Tyagi (2007). The statistical study of occurrence of thunder squall over Guwahati has been analysed by Kumar and Mohapatra (2006), over Patna by Laskar, (2009). Study of detailed climatological facts about squall over Delhi was carried out by Bhalotra (1954). Recently the climatological study of occurrence of thunderstorm and squall over Delhi (IGI airport) has been done by Jenamani et al. (2009). In the present study, we have analyzed various aspects of the thunderstorm with rain immediately followed by fog and its forecasting aspects as detected and forecasted using all new observing systems e.g. IAWOS, automatic weather station (AWS), DWR etc which have been operational during April 2010 under modernization of IMD phase-I and CWG -2010. The autographic records, synoptic three hourly observations on the day of occurrence and the previous day of squall and data from current weather instrument system (CWIS), DWR and satellite imageries have been analyzed for this purpose.

In the present study, attempt has been made to analyze the synoptic and meso-scale characteristics of both the events using data from satellite, DWR and all other conventional sources including weather data/RVR data. Various parameters have been critically analysed to find whether both the events could have been better predicted.

2. Data and Methodology

The synoptic situation on day of occurrence of thunderstorm has been discussed. The meteorological parameters associated with thunderstorm and fog from 1200UTC on 7thFebruary, 2011 to 1200UTC on next day has been considered. The data from IAWOS located at different runways (Figure 1), surface observation data and current weather observation of Airport Meteorological office, IMD, at IGI airport, New Delhi has also been discussed. The thermodynamical parameters and derived parameters influencing the thunderstorm over Delhi have been analysed. The radiosonde (RS/RW) data of Delhi at 0000 UTC and 1200 UTC on day of occurrence and on next day of thunderstorm has been considered to find out various thermodynamincal indices including Showalter index (SI), lifted index (LI), SWEAT index, K-index (KI), Total totals index (TTI), Convective available potential Energy (CAPE), Convective Inhibitions Energy (CINE), Temperature of Lifting Condensation Level (LCL), Pressure of LCL, Equilibrium level and Level of Free Convection (LFC) etc. The calculation of various indices has been taken/calculate from http://weather.uwyo.edu/upperair/indices.html and Ananthakrishnan & Yegnanarayanan (1949).

3. Description of the events on 7-8 February, 2011 over Delhi

3.1 Occurrence of Thunder storm/squall

The upper air chart of 0000UTC on 7th February, 2011 has been analysed, it has been observed that an active WD lay over central Pakistan and adjoining Punjab as upper air system. The surface and upper air winds were strong (15-40kt) & were southwesterly/southerly to the west of Delhi and southeasterly to the northeast of Delhi up to 4.5km a.s.l. An upper air westerly trough roughly runs along 65^{0}E and north of 28^{0}N and lay over 72^{0}E north of 24^{0}N by the evening of 7th February, 2011.

LOCATION OF RVR INSTRUMENTS

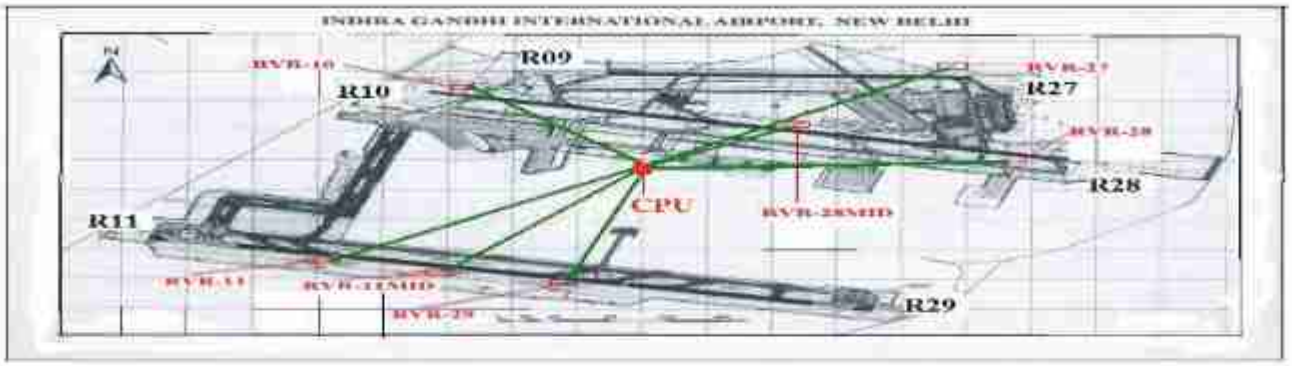

Figure 1: Location of aviation automatic weather stations (AWS) available on different runway at Indira Gandhi International airport, New Delhi.

Table 1. Thermodynamical indices on day of occurrence of thunderstorm with rain on 7thFebruary, 2011 immediately followed by very dense fog on 8thFebruary, 2011over IGI airport New Delhi.

Stability indeces	07.02.2011		08.02.2011	
	0000Z	1200Z	0000Z	1200Z
Showalter index(SI)	-0.5	-3.2	5.8	10.9
Lifted index	-0.1	-3.4	-0.2	2.1
K index	16.7	29.1	-17.9	-47.1
SWEAT index	341	312	63	40
Total totals index	52	55	43	16
Convective Available Potential energy(CAPE)	15	548	4.7	0
Convective Inhibition Energy(CINE)	-352	-40	-101	0
Bulk Richardson Number	0.2	6.5	0.1	0
Equilibrum Level	453	307	478	--
Level of Free Convection	562	716	799	--
Press. (hPa) of the Lifted Condensation Level	815	818	885	805
Temp. (K) of the Lifted Condensation Level	281	282	282	277

This shows that under the influence of above system strong moisture incursion took place over the region and atmosphere was favourable for development of thunderstorm activity due to the interaction of northerly/northwesterly cold dry and southwesterly/southerly warm moist air. The system was rapidly moving northeasterly which has given thunderstorm and squall with rain over Delhi. The thermodynamical indices have been analyzed and are given in Table 1. The SI is simplest measure of stability, if SI is positive it shows that the lifted parcel is colder than its new environment and thus atmosphere is stable. The SI & LI were negative and TTI was more than 50, and high sweat index was favoring for TS activity since morning on 7th February, 2011. Though the KI value was not favouring for TS activity, the high value of CAPE favors the formation of thunderstorm very quickly. CAPE was 15 J/Kg & 548 J/Kg at 0000 UTC & 1200 UTC on 7th February, 2011 and favours TS activity towards evening/night. On 6thFebruary, 2011, the CAPE value was 0 J/Kg and 348 J/Kg at 0000UTC and1200UTC respectively and on 8th February, 2011; it was 5 J/Kg and 0 J/Kg respectively. However, the CINE was -352 J/Kg & -40 J/Kg at 0000UTC & at 1200UTC on 7th February, 2011 and -101 J/Kg & 0 J/Kg at 0000UTC & at 1200UTC on 8th February, 2011 which was also strongly favorable for development of TS towards evening/night of 7thFebruary, 2011.

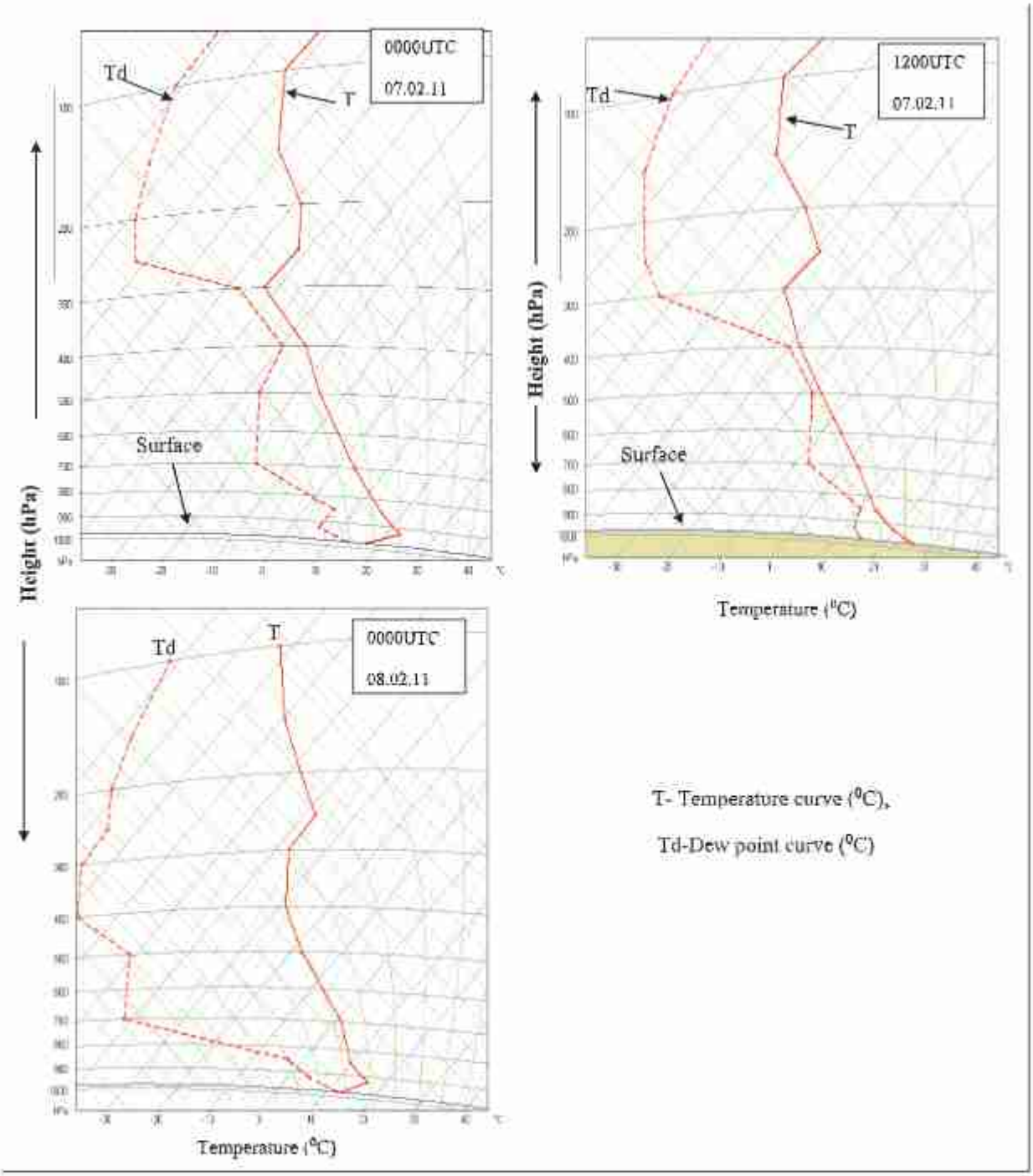

Figure 2: Tephigram associated with thunderstorm and fog over New Delhi on 07-08th February, 2011.

The Tephigram of 0000UTC and 1200UTC on day of occurrence of thunderstorm/squall has been shown in Figure 2. This shows that the atmosphere was unstable and was favorable for development of thunder activity. The surface observations recorded from 1200UTC on 7th February, 2011 to 1200UTC on 8th February, 2011 have been shown in Table 2. This shows that minimum and maximum temperature on 7th February, 2011 was 8^0C & 4^0C above normal respectively and relative humidity was 16% above normal at 1200UTC on 7th February, 2011. Surface wind was 3-4 knots from southwest direction till 2100UTC and then becomes northwesterly 2-4 knot. The wind speed slightly increased from 0600UTC on 8th February, 2011 which has favored lifting of fog on 8th February, 2011.

The thunderstorm started at 1420UTC and rain accompanied at 1505UTC and rain stopped at

Table 2. Surface observation on day of occurrence of thunderstorm on 7thFebruary, 2011(1200UTC) and immediately followed by very dense fog 8thFebruary,2011(1200UTC) over IGI airport New Delhi.

Date	Time (UTC)	Temp (°C)	DP (°C)	RH (%)	MSLP (mb)	Min. Temp (°C)	Max. Temp (°C)	Surface Wind (Knot)	Rainfall (mm)
07.02.2011	1200	24.8	16.0	58(42)	1007.3	16.2(8.0)	27.2(23.0)	230/03	Nil
	1500	20.6	14.8	69	1008.9			320/04	Nil
	1800	16.2	15.5	96	1010.6			230/03	10.4
	2100	15.0	14.6	98	1011.0			230/03	Nil
08.02.2011	0000	13.6	13.6	100	1011.5			250/03	Nil
	0300	12.4	12.4	100(77)	1013.0	12.2(8.0)	27.2(23.0)	230/03	Nil
	0600	16.6	14.1	85	1013.6			320/02	Nil
	0900	22.6	9.3	43	1010.8			320/04	Nil
	1200	20.4	10.0	51(42)	1010.3	12.2(8.0)	23.7(23.0)	320/08	Nil

Value in the parenthesis is the normal value.

1522UTC and thunderstorm stopped at 1650UTC and 10.4 mm moderate rainfall has been recorded over IGI airport New Delhi. The upper air winds become westerly/northwesterly by the 1800UTC and by 2100UTC the lower level winds become north of north westerly as it brought cold air to reduce the temperatures which was favorable for fog formation in next early morning of 8th February, 2011. The rapid fall of temperature from 1500UTC to 1800UTC has been observed due to change of wind to north westerly from south westerly which played a crucial role for immediate formation of fog. The dense fog started at 2100UTC on 7th February, 2011 and continued till 0530UTC on 8th February, 2011.

The meteorological parameters during the occurrence of thunderstorm/squall recorded by IAWOS at different RWY has been shown in Figure 3 (a-d). This shows that QNH started rising rapidly from 1450UTC and reached to maximum at 1526UTC and then starts falling gradually up to 1544UTC over the all the RWY. The temperature started falling at 1457UTC, initially it falls slowly then rapid fall was observed up to 1517UTC and then it started increasing gradually over all the RWY. Figure 3c shows that RH was 50% since 1200UTC and increased gradually till 1408UTC over all the runway after that a little dip was observed and then increased over RWY 29 at 1412UTC though there was very little change over other RWY. The RH increased sharply from 70 to 100% at 1500UTC over all the RWY because of thunder with rain occurred at 1505UTC and then it continued to 100% till 0600UTC on 8th February, 2011 due to dense fog. Figure 3d shows that dew point over different RWY. This shows that dew point started increasing over RWY 29 at 1417UTC & reached maximum at 1510UTC and then reduced sharply. The dew point over RWY 11 & RWY 27 was showing no sharp increase. The visibility, RVR and surface wind, during the occurrence of thunderstorm/squall followed by fog, recorded by IAWOS at different RWY has been shown in Figure 4 (a-c). This show that visibility reduces to 900m over RWY 29 at 1414UTC and then improved gradually and visibility over another runway could not fall. The occurrence of TS was reported at 1420UTC by current weather observer, this shows that visibility reduces due to downdraft occurred earlier and away to the station. It also shows that visibility starts reducing over all the runway at 1458UTC and it reaches to 0640m at 1515UTC due to heavy thunder shower but RVR was not affected. The visibility improved rapidly afterwards over all runways. Visibility fluctuated between 2500m to 10km over all the runways up to 1630UTC and thereafter it reduces. Visibility started falling over all the RWY after 1900UTC. It started setting to zero after 2100UTC. The dense fog occurred between 2100 to 0445UTC. Wind speed between 1200UTC on 7th February, 2011 and 0600UTC on 8th February, 2011 has been shown in Figure 4c. This shows that surface wind was calm over all runway before thunderstorm and then wind increased first over runway11 and followed by other runway. After attaining the speed of 9knot at

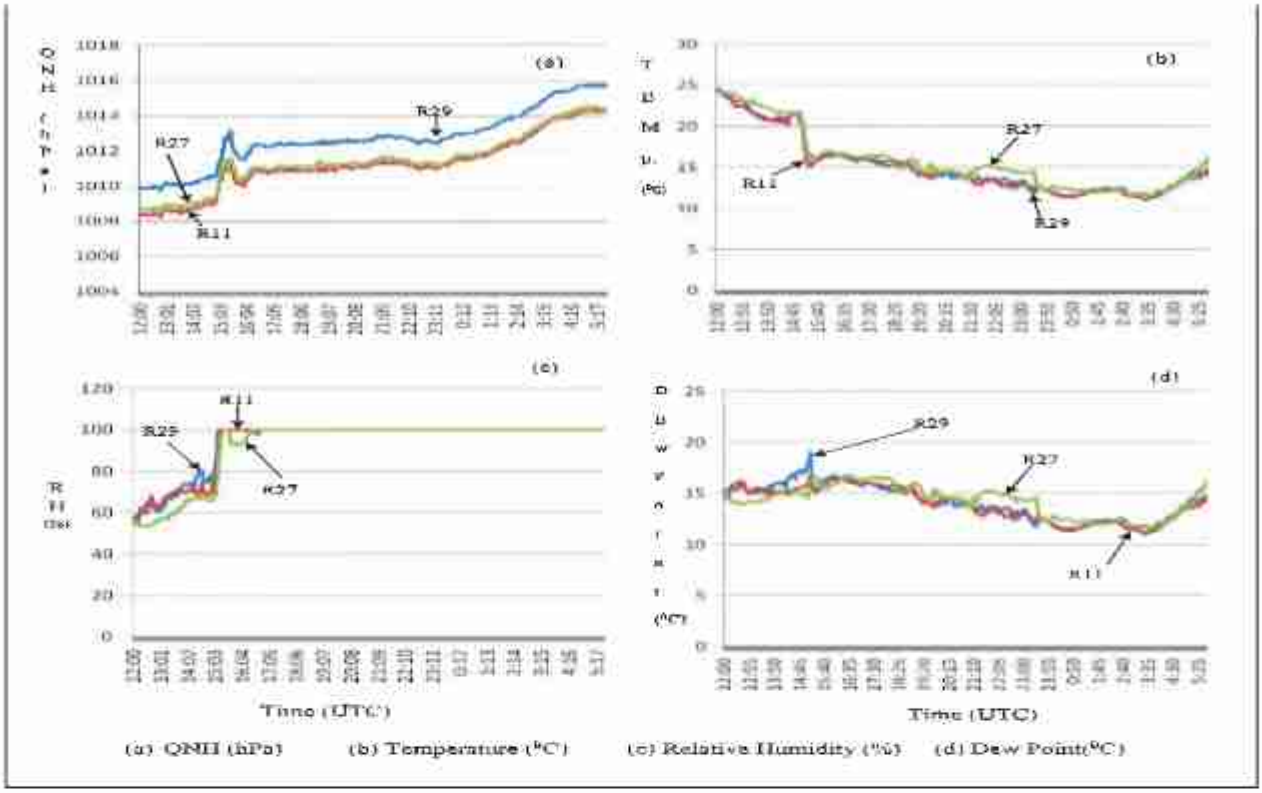

Figure 3 (a to d): Variation of QNH, Temperature, Relative humidity and Dew point on 7-8 February, 2011 during thunderstorm and followed by fog recorded by Integrated Weather Observing System over different runway at over IGI airport New Delhi.

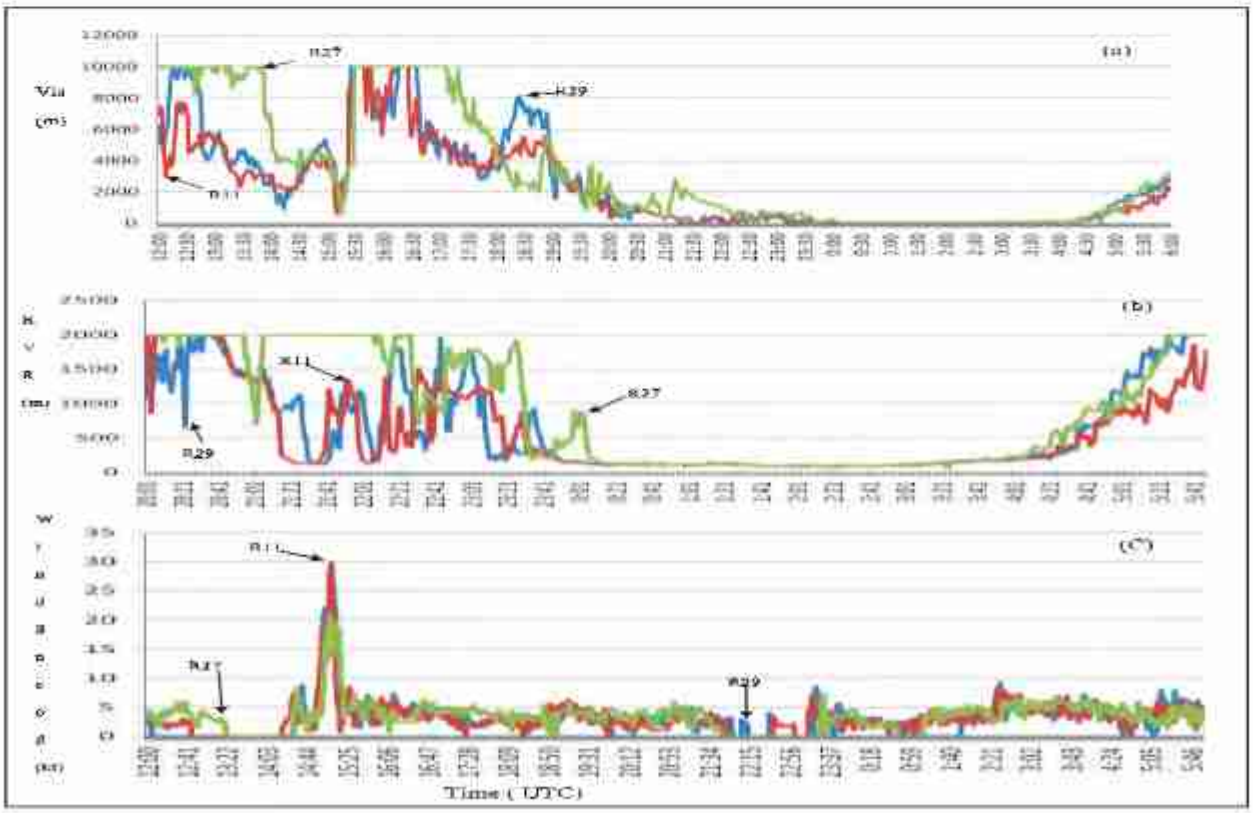

Figure 4: Variation of (a) visibility (b) RVR and (c) wind speed during thunderstorm followed by fog on 7- 8th February, 2011 recorded by aviation AWS over different runway at IGI airport New Delhi.

1434UTC over all runways it came down to 2knot after 15minutes. Surface wind became strong after1454UTC over all runways, maximum wind reported was 21knot over RWY27 at 1507UTC, 30knot over RWY11 at 1509UTC and 27knot over RWY29 at 1510UTC. The gustiness of surface wind was 30knot observed but it could not fulfill the criteria of squall and it was not well-defined squall.

Current weather observation has been given in Table 3. This shows that the sky was covered by total 5octa cloud, 2octa low and 3octa medium cloud since morning on 7th February, 2011 and cloud started increasing from 0900UTC and up to 1300UTC sky was covered by 7octa clouds including one octa CB cloud and thunderstorm started at 1420 UTC and was overcast at 1500UTC. The thunderstorm with rain started 1508UTC and 10.4mm rainfall was recorded. Surface wind increased from 3kt to 18kt with maximum gust of 28kt and cloud at 1508UTC when system hit the station. It started reducing from 1700UTC and there was only 2octa cloud at 2000UTC. The thunderstorm activity was part of large-scale rain occurring over northwest India due to western disturbances. The rain occurred in all parts of northwest India. The Maximum rain occurred in Jammu and Kashmir followed by Himanchal Pradesh and Uttarakhand.

3.2 Occurrence of dense fog

The rain occurred during 1505 to1522 UTC was 10.4mm and sky clear was after 1930 UTC and visibility reduced to 900m due shallow fog at 2100UTC just one and half hours after clearing the sky and after two hours, dense fog was observed whereas the cloud reduced to 3octa since 1730UTC. The visibility distribution over Delhi from Meteo France Synergie system and its neighborhood at 0000UTC and at 0300UTC has been shown in Figure 5. This shows that only Delhi is affected by dense fog whereas the surrounding of Delhi has reported visibility 2 to 4 km though the rain occurred in all parts of northwest India.

The current weather observations of different parameters have been shown in Table 3 and in Figure 6. This shows that fog starts setting after 2030UTC on 7th February, 2011 reducing visibility rapidly to below 1000m. At 2130UTC, very dense fog was set reducing visibility below 50metre and sky was obscured and persisted till 0400UTC on 8th February, 2011. Visibility started improving after 0430UTC and at 0500UTC it was 500m in shallow fog and visibility further improved to 1500m in mist by 0600UTC. The fog occurred was of radiation type which was caused by cooling of the ground by outgoing radiation. The condition was favourable for formation of fog as rain has provided sufficient moisture in the atmosphere; sky was almost clear by 2000UTC on 7th February, 2011 and northwesterly light wind has also supported the formation of fog by mixing and cooling of air in lower levels. The variation of visibility, runway visibility (RVR) and surface wind over different RWY during the fog period has been shown in Figure 4. This shows that visibility and RVR started reducing after 2030UTC at RWY 29-11. The moisture was available in abundance hence less cooling was required for formation of fog and this shows the gradual drop in surface temperature.

4. Detection and Monitoring

4.1 Thunderstorm/squall

The satellite imageries (IR) from 1200UTC to 1700UTC on 7th February, 2011 are shown in Figure 7. This shows that at 1200UTC northwest/west and southeast/south of the Delhi was covered by low and medium clouds. The clouds were moving towards northeast direction. The satellite imageries at 1300UTC show that cloud development and movement from northwest/west was more and faster. The clouds initially started covering Delhi from northwest/west direction at 1400UTC and giving thundershower over Delhi covering it completely by 1500UTC. After 1500UTC it started opening from northwest/west direction and at1600UTC northeast/eastern part only was covered by low and medium cloud and at 1700UTC Delhi was clear.

The product Max (z) of DWR from 1202 UTC to 1602UTC on 7th February, 2011 has been shown in Figure 8. This shows that about two to four octa cloud mass with embedded small CB cells lay 70km away in northwest (NW) and west direction

Table 3. Variation of meteorological parameter reported on current weather during thunderstorm/squall on 7th February, 2011 and fog 08thFebruary, 2011 over IGI airport New Delhi.

Time (UTC	Visibility (M)	Weather	Wind (Knot)	Temerature (°C)	Dew Point (°C)	QNH (hPa)	Sky Condition (Amount of cloud in octa)
1200	5000	Haze	230/05	24.6	14.7	1008.5	SC(2),AC(5), (6)
1230	5000	Haze	200/04	24.2	14.8	1008.5	SC(2),AC(4), (5)
1300	4500	Haze	210/03	23.4	14.7	1008.8	SC(2),AC(4), (5)
1330	4000	Haze	00000	22.8	14.7	1008.8	SC(2),CB(1),AC(5), (7)
1400	3500	Haze	00000	22.2	14.8	1008.8	SC(2),CB(1),AC(5), (7)
1421	2200	TS	00000	21.8	15.4	1008.9	SC(2),CB(1),AC(5), (7)
1500	3000	TS	330/03	21.5	14.8	1009.1	SC(3),CB(1),AC(6), (7)
1508	800	HVY TSRA	300/18G28	18.1	16.3	1010.7	SC(3),CB(1),AS(8), (8)
1522	1500	FBL TSRA	240/07	16.5	16.5	1011.2	SC(3),CB(1),AS(8), (8)
1551	3000	TS	160/05	16.5	15.4	1010.1	SC(3),CB(1),AS(6), (7)
1630	3500	TS	250/04	16.6	16.6	1010.8	SC(3),CB(1),AS(6), (7)
1700	4000	TS	260/05	16.4	16.4	1010.6	SC(2),CB(1),AC(3),(4)
1730	3500	BR	230/03	16.4	16.4	1010.8	SC(2),CB(1),AS(3), (3)
1751	3000	BR	240/03	16.4	16.4	1010.7	SC(2),CB(1),AS(3), (3)
1830	2500	BR	240/03	15.8	15.8	1010.8	SC(1),CB(1),AS(3), (3)
1900	2500	BR	310/04	15.9	15.9	1010.9	SC(1),CB(1),AS(3), (3)
1930	2200	BR	270/04	14.9	14.9	1010.9	SC(1),CB(1),AS(3), (3)
2000	1500	BR	260/03	14.6	14.6	1010.9	AS(2), (2)
2030	1000	BR	240/03	14.6	14.6	1010.9	AS(2), (2)
2100	0900	MIFG	240/04	14.2	14.2	1011.0	AS(2), (2)
2110	0600	MIFG	270/05	13.5	13.5	1011.1	AS(2), (2)
2130	Below 50	V.Dense FG	330/05	13.5	13.5	1011.2	AS(2), (2)
2200	Below 50	V.Dense FG	00000	13.5	13.5	1011.2	AS(2), (2)
2230	0100	Dense FG	00000	13.5	13.5	1011.0	AS(2), (2)
2300	0300	FG	00000	12.9	12.9	1011.0	AS(2), (2)
2330	Below 50	V.Dense FG	00000	12.4	12.4	1011.0	AS(2), (2)
0000	Below 50	V.Dense FG	250/03	12.3	12.3	1011.3	Sky obscured
0030	Below 50	V.Dense FG	240/03	12.0	12.0	1011.3	Sky obscured
0100	Below 50	V.Dense FG	00000	11.6	11.6	1011.6	Sky obscured
0130	Below 50	V.Dense FG	200/04	11.9	11.9	1012.0	Sky obscured
0200	Below 50	V.Dense FG	200/04	12.3	12.3	1012.2	Sky obscured
0230	Below 50	V.Dense FG	220/04	12.1	12.1	1012.3	Sky obscured
0300	Below 50	V.Dense FG	260/06	12.2	12.0	1013.0	Sky obscured
0330	00 50	V.Dense FG	250/05	12.2	12.0	1013.5	Sky obscured
0400	0050	V.Dense FG	240/06	12.7	12.0	1013.8	Sky obscured
0430	0150	Dense FG	240/04	12.8	12.2	1014.0	Sky obscured
0452	0500	FG	250/04	13.6	12.8	1014.0	AC(3) ,(3)
0510	0700	MIFG	280/05	13.8	13.2	1014.0	AC(3) ,(3)
0530	1200	BR	300/05	14.7	13.5	1014.2	AC(3) ,(3)
0600	1500	BR	290/05	16.4	14.2	1014.2	AC(3) ,(3)

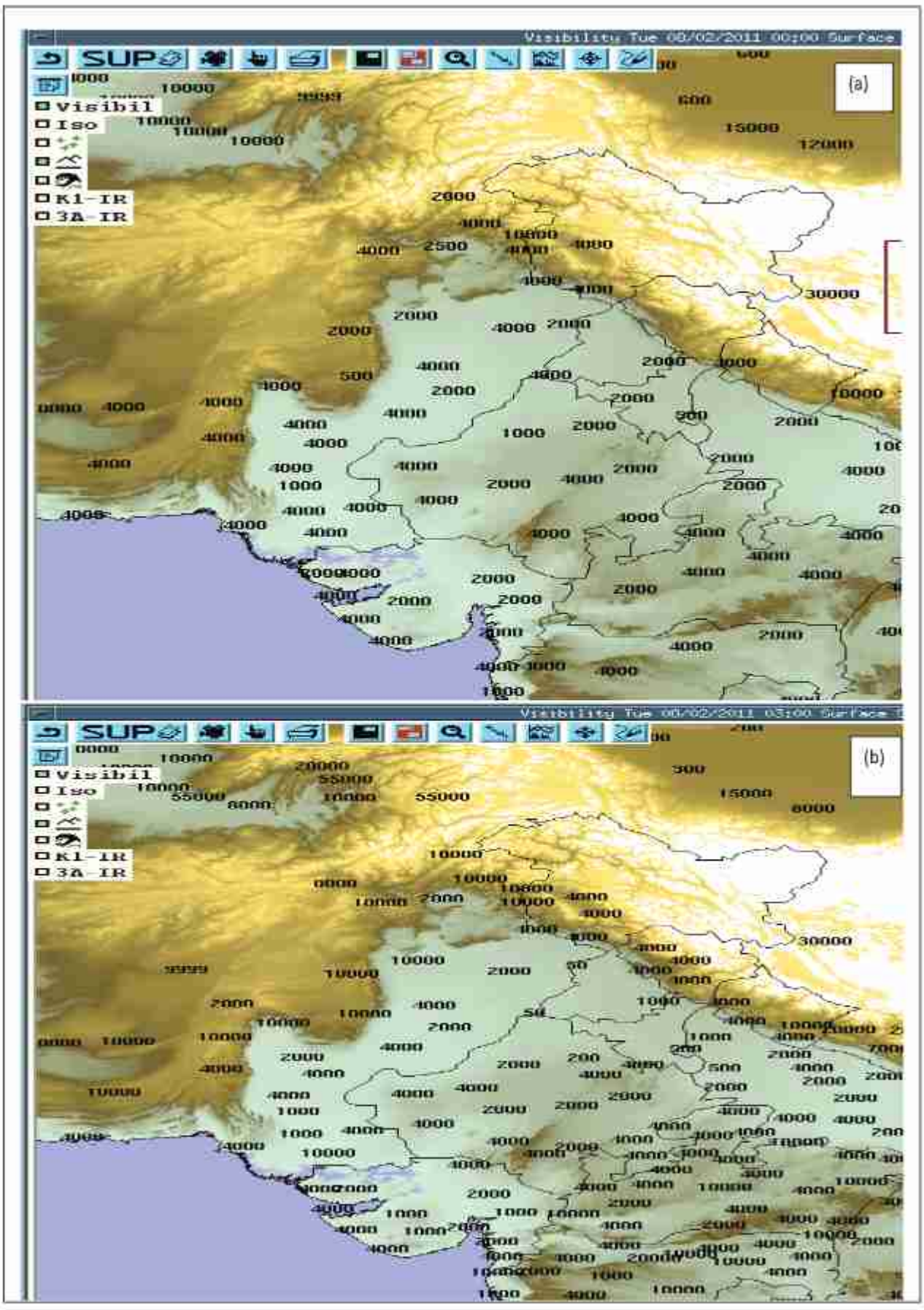

Figure 5: Visibility of north west India at (a) 0000UTC & (b) 0300UTC on 8th February, 2011 affected by dense fog over IGI airport New Delhi.

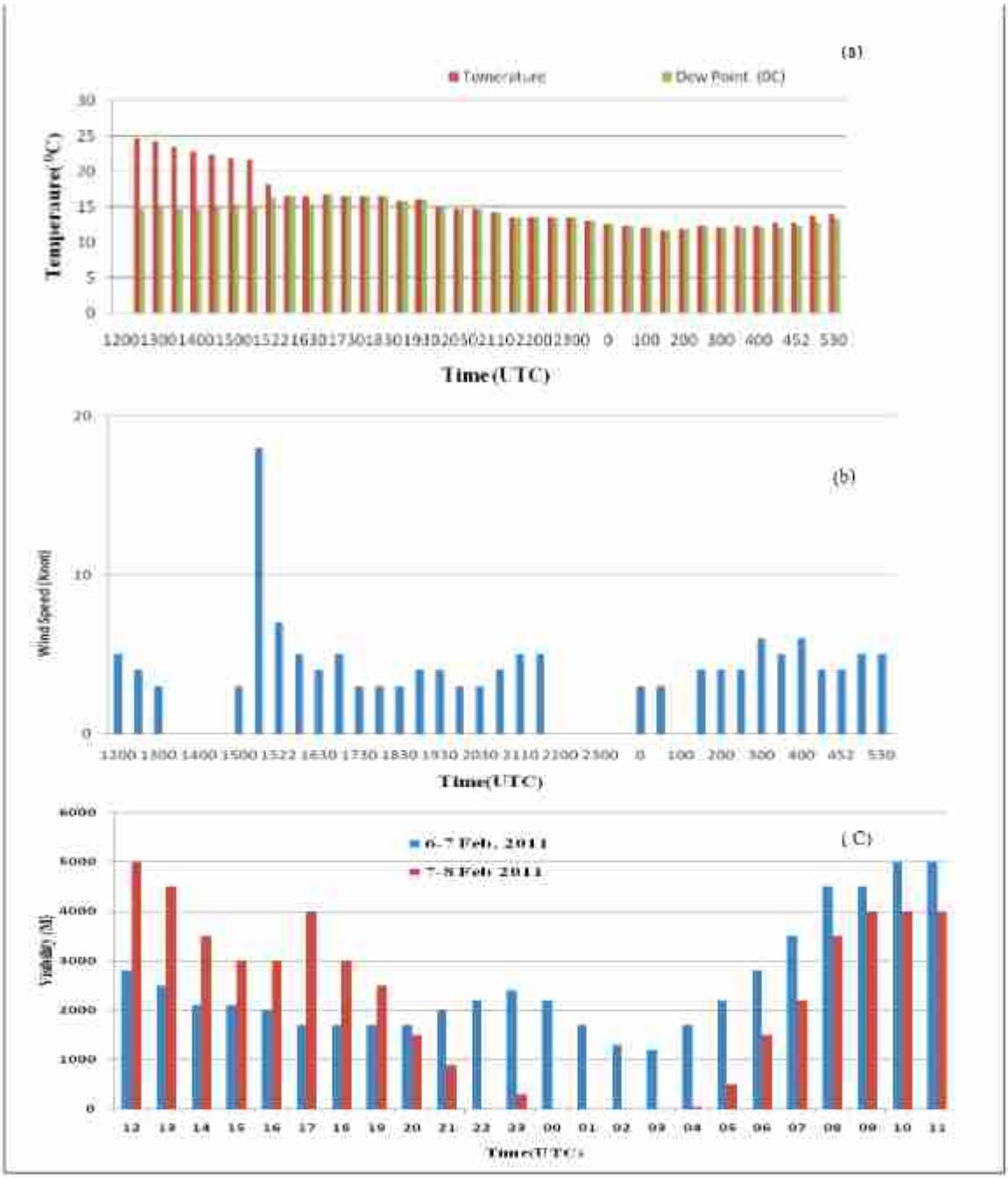

Figure 6: Variation of meteorological parameters (a) Temperature & dew point (b) Wind speed and (c) Visibility during thunderstorm/ squall & dense fog on 7-8 February, 2011.

at 1202UTC. It has been observed that the two convective cells were present in NW direction with 8km of vertical height of core of highest reflectivity of 44-48dBZ and other cell was observed in west (W) direction with 7km height of core of highest reflectivity of 40-44 dBZ. These cells were intensifying and moving in northeast (NE) direction. At the 1232UTC, the cells in NW direction were about 60km away from IGI airport with 9km of vertical height and of reflectivity of 48-52dBZ other cell was about 40km in west direction with 8km of vertical height and of reflectivity of 44-48dBZ. Also two small cells of reflectivity of 36-40 dBZ developed in NW and west direction about 100-140 km away from the IGI airport New Delhi. The cells in NW direction moved further NE wards and merged & organized in the shape of parenthesis and lay 60km away in north of northwest direction at 1302 UTC, the cell in west direction moved faster and approached to NW of Delhi though it was of low intensity but the cells behind this were of high intensity. The Max(z)

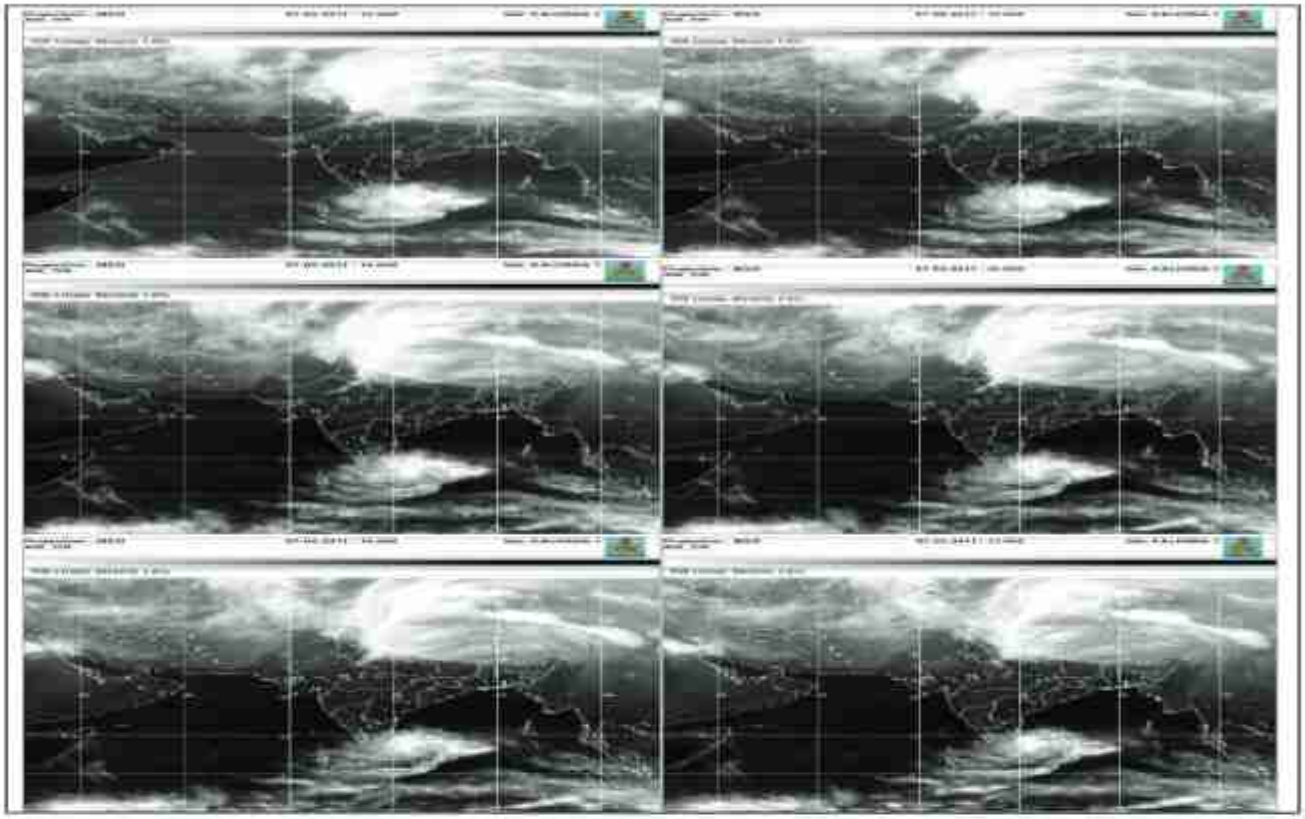

Figure 7: IR Satellite imageries showing cloud mass over Delhi and neighborhood from 1200UTC to 1700UTC on 7th February, 2011.

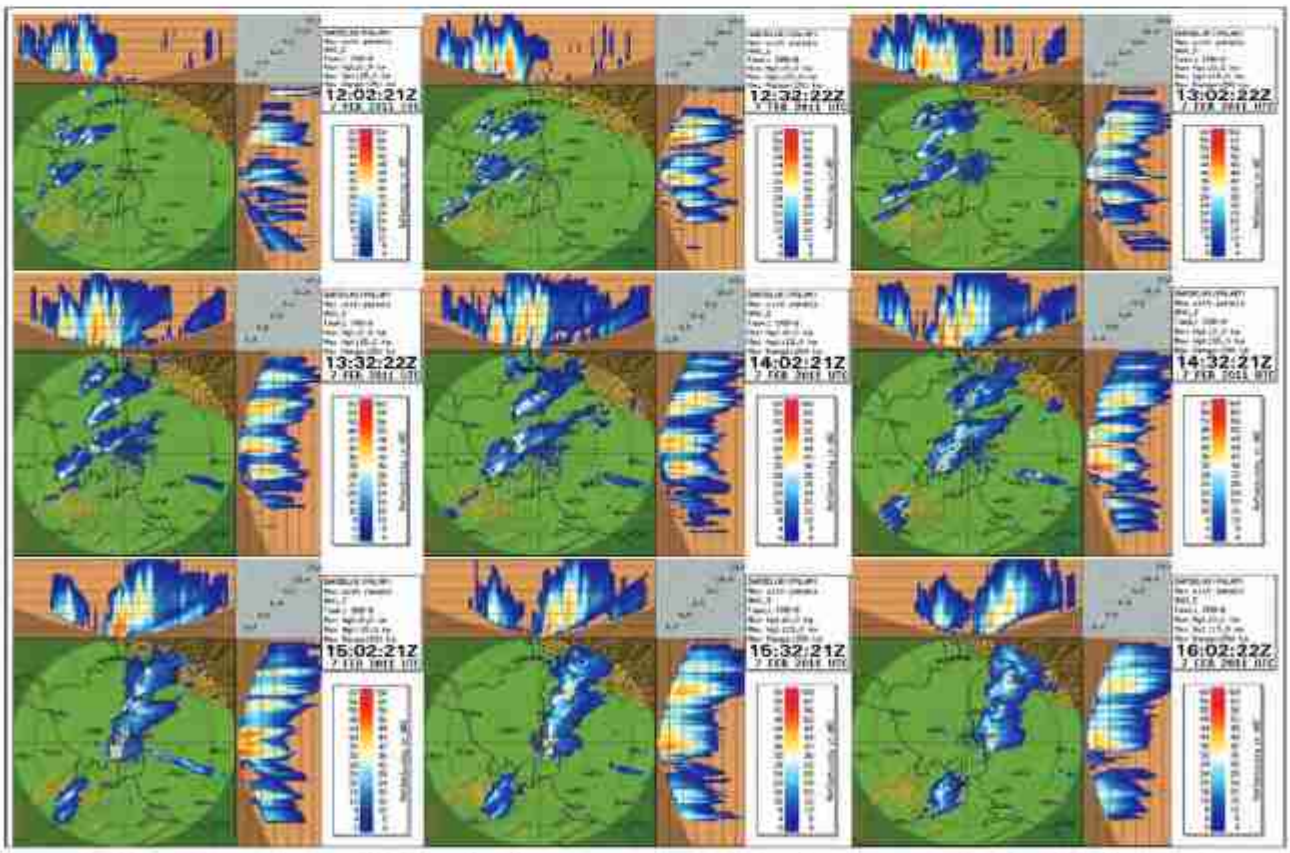

Figure 8: Max (z) product of DWR showing movement of cloud mass associated with thunderstorm on 7th February, 2011 over IGI airport New Delhi.

product of DWR picture at 1332UTC shows that the cloud mass of low intensity of CB cell was about 180-200km away in NW direction moved in NE direction and organized and the cell in shape of parenthesis has more intensified & further moved towards NE wards and lay centered at 50km away in north of north west direction. The cells approaching to NW of Delhi were organised and approached Delhi from NW. These cells were stretched in the form of straight line covering from Delhi to Pilani in Rajasthan. The cell near Pilani was stronger it was of reflectivity of 52-56dBZ of 7km of vertical height and might have given hailstorm over the region. All the three cloud masses were parallel and moving towards NE. The DWR picture at 1402UTC shows that the cloud mass of low intensity was about 200km away in NW direction moved in northward and weakened thereafter and the cell in shape of parenthesis has weakened and moved away towards north of northeast wards and lay centered at 60km away in north of Delhi. The cells in NW of Delhi have approached over Delhi from NW. It was of 11km vertical height of core of highest reflectivity of 48-52dBZ some more cells were generated in the west of Delhi at about 40km. The cell near Pilani was weakened though its reflectivity was 44-48dBZ. Delhi was severely affected by thunderstorm activity from NW to SW side at 1452UTC. The vertical height of core of highest reflectivity was 52-56dBZ of 9km. The Delhi and neighborhood was covered by CB cell at 1502UTC and the whole cloud mass was oriented from NE to SW extending from Dehradun, to Alwar through Karnal & Delhi. Though it was of 48-52dBZ of highest reflectivity with core height of 4-6km, this cell has given weather over Delhi. TS over Delhi started from 1420UTC to 1650UTC and accompanied with rain from 1505UTC to 1522UTC giving 10.4mm rainfall over Delhi. The movement of CB cells was very fast towards NE direction and the sky was started clearing from west side of Delhi by 1502UTC. The Delhi was cleared from CB cloud by 1602UTC and the cloud mass was lay over Uttarakhand and west UP covering Dehradun, Roorkee, Muzaffarnagar, Meerut and Ghaziabad though it was of low intensity. The variation of wind speed during thunder with rain and thunderstorm/squall and then immediately followed by dense fog between 1200UTC on 7thFebruary, 2011 and 0600UTC on 8th February, 2011 has been shown in Figure 4c. This shows that surface wind was calm over all runway just before occurrence of thunderstorm. The wind started increasing initially over runway11 and followed by other runway. After attaining the speed of 9knot at 1434UTC over all runways it came down to 2knot after 15minutes and it was the first spell of downdraft. Surface wind became strong after1454UTC over all runway and the maximum wind reported was 21knot over RWY27 at 1507UTC, 30knot over RWY11 at 1509UTC and 27knot over RWY29 at 1510UTC which matches with DWR picture and it was also confirms that the CB cell initially affected Delhi from NW direction (RWY-11) and it was severe.

4.2 Dense fog

The satellite picture (Visible) from 0300UTC to 0530UTC on 8th February, 2011 has been shown in Figure 9. This shows that at 0300UTC fog had formed over southwest Punjab and adjoining Pakistan, Rajasthan, over Delhi and adjoining parts of Haryana. The fog formed over west Rajasthan and adjoining Pakistan at 0430UTC can also be observed from the satellite imageries. The fog in night can only be detected through MODIS imageries (NOAA). The MODIS imageries at 2129UTC on 7th February, 2011 have been shown in Figure 10. This shows a dense fog patch over north Rajasthan and adjoining Haryana and scattered fog over some parts of Punjab, Himanchal Pradesh and Uttarakhand. There is no trace of dense fog over Delhi at 2129UTC and the dense fog over Delhi has formed after 2130UTC on 7th February, 2011. The satellite (Figure 7) imageries (IR) do not provide any help to detect fog. The satellite imageries (visible) can help to detect the fog in day time only. The fog formation and detection over IGI airport has been monitored continuously through current weather observation. This shows that after the spell of heavy thunderstorm/squall with rain, visibility started increasing and it was reported as 4000m at 1700UTC on 7th February, 2011 and then visibility started falling continuously and reducing to 1000m in mist at 2030UTC. It further reduced to 900m at 2100UTC and then to 600m at 2110UTC

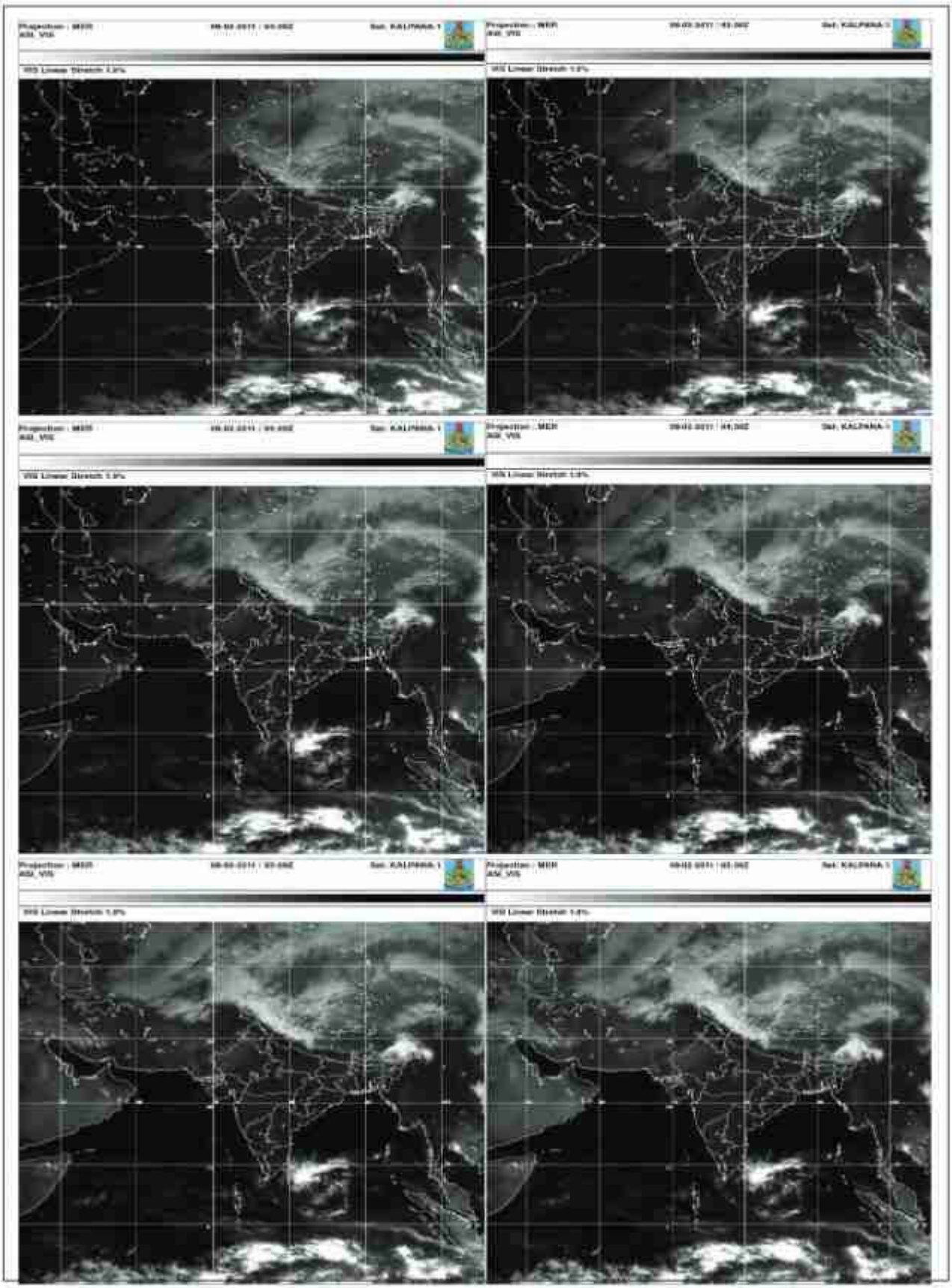

Figure 9: Visible Satellite imageries showing fog over Delhi and some part of Punjab from 0300UTC to 0530UTC on 8th February, 2011.

in shallow fog. The visibility suddenly reduced below 50m in very dense fog at 2130UTC and continued till 0300UTC on 8th February, 2011.

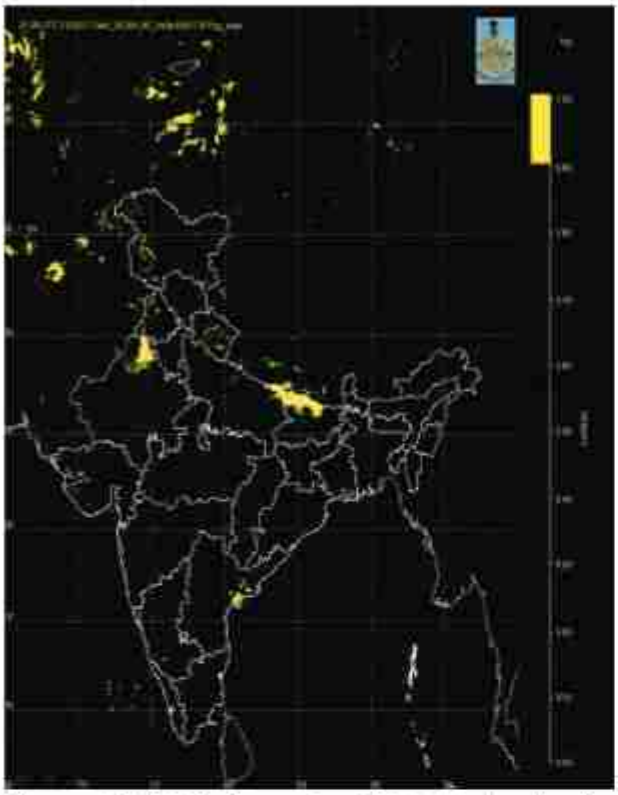

Figure 10: Modis imageries (NOAA) showing fog over NW India issued at 2129UTC on 7th February, 2011.

The sky was obscured in very dense fog during 000UTC to 0430UTC on 8th February, 2011. The visibility started improving after 0330UTC on 8th February, 2011, initially the rate of improvement was very slow but it improved very fast after 0452UTC and it was 1500 in mist at 0600UTC.

The Tephigram of 0000UTC on 7thFebruary, 2011 and 8th February, 2011 has been plotted and shown in Figure 2. This shows that temperature in boundary layer at 0000UTC on7th February, 2011 is 5 to 6°C more than that of 0000UTC on 8th February, 2011. This also shows the relative humidity in boundary layer at 0000UTC on 8th February, 2011 is higher than that of 0000UTC on 7th February, 2011. The inversion layer at 0000UTC on 7th February, 2011 is at lower height than 0000UTC on 8th February, 2011. The inversion near the surface in winter is a regular feature over North India that provides a stable atmosphere which is favourable for fog formation and its durability.

5. Real Time Forecasting and Nowcasting

The active WD was affecting the region and the real time forecast for thunderstorm/squall was issued by duty officer well in advance in Terminal Aerodrome Forecasts and in other aviation forecasts because of satellite pictures available for every 30 minutes and DWR pictures available for every 10 minutes. All these helped to monitor the movement and intensification of the system. The first aerodrome warning for thunderstorm and associated wind was issued at 1315UTC which was further extended at 1600UTC on 7th February, 2011. The current weather data had shown that the thunderstorm with rain and gusty wind occurred during 1420 to 1650UTC. Hence the TS event was correctly nowcasted. However, the forecast of occurrence of dense fog during following night at real time could neither be issued in 6-hourly regular fog forecasts with outlook valid for next 18-hours which were issued at 1200UTC & 1800UTC (Jenamani and Tyagi, 2011) nor in other aviation forecasts issued on 7th February, 2011. It was not anticipated that the system will move very fast and the sky will be almost clear and wind will become north westerly and light. There was no documented evidence available that in winter months when WD passes over station then within two hours there will be dense fog. However, it was nowcasted by duty officer and advice has been sent to air traffic control and watch supervisory office well in advance to adopt the low visibility procedure and to implement the category operations for smooth functioning. The amended fog forecast was issued at 2130UTC with visibility less than 50m in very dense fog with outlook for improvement after 0400UTC. The clear sky, fall of temperature, availability of moisture, light wind and the inversion in boundary layer favoured fog formation. As a result, the low-level moisture near the boundary layer condenses into tiny fog droplets causing the visibility reduction to zero over IGI airport.

The DWR, Satellite picture, integrated automatic weather observing system located at different runway, automatic weather stations, half hourly current weather observation, three hourly surface observations have helped the forecaster in monitoring and real time nowcasting of both the

severe weather events which occurred one after another.

6. Conclusions

In the present study, analysis of various meteorological features associated with the occurrence of a thunderstorm/squall at late evening which was immediately (after 2hours) followed by very dense fog formation in the following morning of 7-8th February, 2011 leads to the following: inferences:

(a) The thunderstorm at IGI airport New Delhi was part of large-scale rain occurrence mainly due to passing of a WD over the region as an upper air system in association with westerly trough.

(b) The cloud mass which caused TS/rain over Delhi along with WD moved very fast in the northeast direction has been confirmed from analysis of weather charts, satellite pictures at 30-minute gap, DWR pictures at 10-minute gap, current weather observations from eight integrated aviation AWS, etc.

(c) Fast movement of WD caused sudden clear skies and immediate fall in temperature due to changing of wind to northwesterly and further local radiation cooling. Such meteorological conditions became highly favorable for radiation fog formation reducing the visibility to zero for longer hours over the airfield as there was already an occurrence of overnight rain/TS over the airport making availability of moisture in abundance. Thus it is suggested that the forecaster on duty could monitor all observations minute by minute especially from DWR and satellite and then forecast the formation of dense fog if condition is favourable.

(d) Analysis of local features shows the stability index of TTI above 50, sweat index above 300, reflectivity above 44dBZ of DWR and negative value of Showalter index had favourd the thunderstorm occurrence.

(e) Study of upper air parameters showed the atmosphere to be highly unstable by 1200UTC before the occurrence of TS with CAPE value reaching upto 548 J/Kg and lapse rate 6^0C/Km while at 0000UTC when dense fog was at the peak the upper air pattern changed to stable atmosphere where the reversed lapse rate was observed.

(f) This study shows that use of DWR, satellite and the Integrated aviation weather observing system (IAWOS) at IGI airport has an advantage over synoptic and NWP inputs for accurate nowcasting of the kind of sudden development of severe weather events. In such a case the forecaster needs to monitor various developments meticulously through DWR, Satellite, and IAWOS. It is suggested that the forecaster should acquire prior knowledge of these systems.

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