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Research Article

DISASTROUS SQUALLS AT DELHI

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ABSTRACT
Squalls are one of the greatest aviation hazards and worst disasters causing immense loss of human life and huge damage to urban and rural properties. In this paper statistical analysis of 10 years (1996-2005) squall data of Indira Gandhi International (I.G.I.) and Safdarjung airports has been analyzed and showed that about 324 squalls lashed Delhi city out of which 184 squalls were recorded at I.G.I. Airport and 140 at Safdarjung Airport. Considering both the airports separately, the maximum number of squalls (27) occurred at I.G.I. Airport in 1997 and minimum number (05) in 2003 at Safderjung Airport. Delhi experienced maximum number of squalls (46) in 1997 and minimum (16) in 1998. A case study of squall line observed on 10th April 2012 Delhi and neighboring areas with the help of Delhi Doppler Weather Radar (DWR) data also presented. It is seen that maximum turbulence zone is just behind the gust front line which is possibly the probable direction of squall movement.

Key Words: *Squalls, DWR, Strong Winds*

INTRODUCTION

Squalls is a strong wind which last very short duration of time (about a minute) and associated with severe weather or rain. World Meteorological Organisation (WMO) defined in a squall, the wind must increase at least 8 m/s and must attain a top speed of at least 11 m/s, lasting at least one minute in duration. Very strong winds in squalls damage electric and telephone poles disrupting power supply and telephone services. They cause great damage to building structures, aircraft hangars and also aircrafts parked on the open fields. Many trees are uprooted and horticulture crops badly damaged. In rural areas roof tops of a large number of dwelling houses are blown away. Sometimes it is seen that train services are disrupted by uprooted trees on the tracks and also due to snapped off overhead wires. Roads are also blocked for hours due to fallen trees disrupting traffic. On many occasions they develop large horizontal shears near the airports causing great threat at the time of landings and take offs as the aircrafts get drifted away from the runway. As per the India Meteorological Department (IMD) criteria, squalls with surface wind (in gusts) upto 80 kmph are termed as “Moderate” and greater than 80 kmph termed “Severe”. Squalls with speed greater than 100 kmph may be termed “Very Severe” due to their appreciably more damaging effects.

Squall lines are strong indicators of potential severe weather (Wong and Yip 2006) which can cause injuries, loss of lives and property damage and areas of extreme instability and severe turbulence. They are narrow bands or lines of squally thunderstorms that brings heavy rain strong winds and lightning. The environment in which this squall line developed was characterized by strong shear, particularly in low levels, and small CAPE. Low level mesoscale vortices like squall lines are quasi-linear convective systems having unidirectional shear magnitude is 20 m s^{-1} or greater over a 0–2.5- or 0–5-km above ground layer (Weisman and Trapp, 2003). The evolution and characteristics of the squall line can be analyzed with the help of Doppler Weather Radar echoes. There is a distinct linear structure to squall lines and not necessarily propagate or translate in a direction perpendicular to their length. Most of the 2 Dimensional higher studies of squall lines are initialized in a horizontally homogeneous manner such as warm bubble convergent circulation or cold pool (Hane 1973, Moncrieff and Miller 1976 Thorpe et al., 1982, Hane et al., 1987; Nicholls 1987; Nicholls and Weissbluth 1988, Nicholls et al., 1988, Rotunno et al., 1988, Lafore and Moncrieff 1989, Tripoli and Cotton 1989a, b, Schmidt and Cotton 1990). Th**ese** studies are important to understand the internal cloud scale dynamics and convective heating effects and the cloud scale influence of squall line propagation. For Indian scenario a lot of work regarding the statistical study of squall events at various stations of India is already been done by various authors (Alvi and Punjabi, 1966, Alvi, 1967, Banerjee, et al , 1983, Bhalotra, 1954, 1957, Bhattacharya and Basu, 1983, Dekate and Bajay, 1966, Ramakrishnan, 1953, 1957, Ramakrishnan and Gopinath, 1954, Ramakrishnan and Ganapathiraman, 1953, Ramamurthy, 1962, Saxena and Natrajan, 1966, Sharma, 1966, Soundararajan, 1961, Soundararajan and Raghavan, 1962, Subba Reddy, 1985).

MATERIALS AND METHODS

The squalls data used for IGI and Safdarjung airports have been taken from IMD. Newly installed Doppler Weather Radar (DWR) of Delhi data is utilized for the rainfall episode of surrounding areas of Delhi on 12th April 2012.

RESULTS AND DISCUSSIONS

The 10 years 324 squall data of IGI and Safdarjung airports are given in Table 1. Safdarjung Airports which is located in the central part of Delhi city had comparatively less number of squalls than I.G.I. Airport except in the years 2000 and 2002 when both the airports experienced equal number of squalls (20 and 18 respectively). The number of squalls at Safdarjung Airport was remarkably low (05) in 2003, the cause of which is still a matter of investigation.

There were 53 Severe/Very Severe (combined) squalls observed at Delhi during the period under study, out of which 40squalls were observed at I.G.I. Airport and 13 at Safdarjung Airport. Maximum number of severe/very severe squalls (07) was observed in 1997 and 2001 at I.G.I. Airport but the severity was comparatively of very high order in 1997 when on 6th and 16th June peak wind velocities in the squalls were recorded as 139 kmph and 119 kmph respectively with corresponding temperature falls as –19.7 °C and –12.3 °C. Similarly in a squall of 2001, 120 kmph wind was recorded on 4th June with associated temperature fall of 8.4 ºC. The year 2005 witnessed three very severe squalls on 27th April and 5th June(two squalls) with peak wind velocities 138 kmph, 112 kmph and 110 kmph with associated temperature falls of 12 °C, 9.6 ºC and 8.4 ºC respectively. In 1996 also, four squalls of very severe intensity with speed exceeding 100 kmph lashed I.G.I. Airport with appreciable fall in temperatures. Very severe squalls affecting Delhi airfields are given in Table-2.

Observational Features

Table 3: Inter –annual distribution of squalls over I.G.I. and Safderjung Airports, in increasing order of their intensities, has been given. Percentage of occasions in different ranges of speed has been calculated. Maximum percentage of occasions is associated with peak velocity of squalls having less than 60 kmph.

Table 4: Maximum number of occasions (157) is associated with squall velocity less than 60 kmph and minimum occasions (11) pertain to peak velocity ranging between 90 -99 kmph.

Table 5: Month-wise inter-annual distribution of squalls over I.G.I. Airport has been given. Maximum frequency of squalls (5.7) is associated with June whereas frequency in the month of May is 5.5 which are slightly less than that in June. Annual frequency is found to be 18.4.

Table 6: Month-wise inter-annual distribution of squalls over Safdarjung Airport has been given. Maximum frequency of squalls (3.9) is associated with the month of June whereas frequency in the month of May (3.3) is slightly less than that in June. Annual frequency is 14.0. This can also be conceived physically that I.G.I. Airport is situated in a comparatively open area than Safdarjung Airport. Because of their locations, squalls face comparatively more frictional force at Safdarjung Airport due to dense, high rise buildings around it, whereas squalls at I.G.I Airport have stronger wind speeds and high frequency of their occurrence.

Table 7: Squalls were generally associated with fall in temperature out of 324 squalls, 310 squalls (95.7 %) are associated with temperature falls ranging between 0 to 6 $^{\circ}$C (35 % between 0 to 2 $^{\circ}$C, 28 %

between 2.1 to 4 °C and 17 % between 4.1 to 6 °C) There were two severe / very severe squalls which lashed Delhi on 6 and 12 June, 1997 with temperature falls of 19.7 °C and 16.8 °C respectively. But such squalls were very rare i.e. only 0.6 %.

Table 8: Diurnal variation of squall over Delhi has been given. It is seen that squalls over Delhi generally occurs in the afternoon. About 68 % squalls were seen to occur between 12 to 21 hours I.S.T.

Table 9: Extreme values of meteorological parameters such as wind speed, temperature drop, pressure rise and the amount of sudden change in speed which are associated with squalls have been given.

Table 10: Variation of pressure and temperature associated with squalls over Delhi has been given. In about 88.5 % cases squalls have been seen to register rise in pressure and fall in temperature.

Table 11: Monthly distribution of pressure rise associated with squalls has been given. In about 34 % cases rise of pressure is equal to and less than 0.5 hPa. About 62 % cases pressure rise in squalls lies in the range 0 to 2 hPa.

Table 1: Number of Squalls in Delhi

Year	I.G.I. Airport	Safdarjung Airport	Total
2005	18	14	32
2004	23	17	40
2003	21	05	26
2002	18	18	36
2001	19	13	32
2000	20	20	40
1999	20	17	37
1998	09	07	16
1997	27	19	46
1996	09	10	19
Total	184	140	324

Table 2: Very Severe Squalls in Delhi Airfields (1996-2005)

S.No.	Airfield	Date	Time of Commencement (I.S.T.)	Peak velocity (kmph)	Change in Temperature (ºC)
1	IGI Airport	27.4.05	1741	138	-12.3
2	-do-	05.6.05	1521	112	-09.6
3	-do-	05.6.05	1550	110	-08.4
4	-do-	09.4.04	1530	118	-09.3
5	-do-	26.5.04	0100	108	-00.3
6	-do-	24.5.02	2151	113	+01.0
7	-do-	27.5.02	2125	107	+01.5
8	-do-	04.6.01	1322	120	-08.4
9	-do-	13.6.98	1505	102	-05.9
10	-do-	06.6.97	1900	139	-19.7
11	-do-	16.6.97	2220	119	-12.3
12	-do-	24.4.96	1838	106	-05.8
13	-do-	30.4.96	1915	111	-06.6
14	-do-	01.5.96	2302	111	-05.0
15	-do-	28.5.96	2112	115	-10.8
16	Safdarjung Airport	17.6.05	1549	102	-03.4
17	-do-	30.4.96	1936	110	-03.0

Table 3: Inter –annual distribution of squalls over I.G.I and Safdarjung Airports, in increasing order of their intensity (maximum wind speed)

S.N	Year	Squall speed (kmph)	I.G.I. airport No. of occasions (1)	Safderjung airport No. of occasions (2)	Total (1+2)	Total squalls in the year	Percentage occasions
1	2005	<60	6	6	12	32	37.5
		60-69	2	4	6		18.8
		70-79	5	1	6		18.8
		80-89	1	1	2		06.3
		90-99	1	1	2		06.3
		≥100	3	1	4		12.5
		Total	**18**	**14**	**32**		
2	2004	<60	8	11	19	40	47.5
		60-69	5	3	8		20.0
		70-79	4	3	7		17.5
		80-89	3	0	3		07.5
		90-99	1	0	1		02.5
		≥100	2	0	2		05.0
		Total	**23**	**17**	**40**		
3	2003	<60	11	4	15	26	57.7
		60-69	6	1	7		26.9
		70-79	2	0	2		07.7
		80-89	1	0	1		03.9
		90-99	1	0	1		03.9
		≥100	0	0	0		00.0
		Total	**21**	**5**	**26**		
4	2002	<60	5	15	20		55.6
		60-69	6	1	7		19.4
		70-79	3	1	4		11.1
		80-89	2	0	2		05.6
		90-99	0	1	1		02.8
		≥100	2	0	2		05.6
		Total	**18**	**18**	**36**		
5	2001	<60	3	8	11	32	34.4
		60-69	3	4	7		21.9
		70-79	6	1	7		21.9
		80-89	3	0	3		09.4
		90-99	3	0	3		09.4
		≥100	1	0	1		03.1
		Total	**19**	**13**	**32**		
6	2000	<60	10	16	26	40	65.0
		60-69	5	2	7		17.5
		70-79	2	1	3		07.5
		80-89	3	1	4		10.0
		90-99	0	0	0		00.0

		≥100	0	0	0		00.0
		Total	**20**	**20**	**40**		
7	1999	<60	8	14	22	37	59.5
		60-69	8	1	9		24.3
		70-79	2	1	3		08.1
		80-89	2	1	3		08.1
		90-99	0	0	0		00.0
		≥100	0	0	0		00.0
		Total	**20**	**17**	**37**		
8	1998	<60	4	4	8	16	50.0
		60-69	0	0	0		00.0
		70-79	3	1	4		25.0
		80-89	1	2	3		18.8
		90-99	0	0	0		00.0
		≥100	1	0	1		06.3
		Total	**9**	**7**	**16**		
9	1997	<60	10	9	19	46	41.3
		60-69	2	5	7		15.2
		70-79	8	4	12		26.1
		80-89	5	0	5		10.9
		90-99	0	1	1		02.2
		≥100	2	0	2		04.4
		Total	**27**	**19**	**46**		
10	1996	<60	0	5	5		26.3
		60-69	1	2	3		15.8
		70-79	3	1	4		21.1
		80-89	0	0	0		00.0
		90-99	1	1	2		10.5
		≥100	4	1	5		26.3
		Total	**9**	**10**	**19**		

Table 4: Inter –annual distribution of squalls over Delhi in increasing order of their intensity (maximum wind speed)

S.N.	Year	Squalls speed in kmph					
		<60	60-69	70-79	80-89	90-99	≥100
1	2005	12	06	06	02	02	04
2	2004	19	08	07	03	01	02
3	2003	15	07	02	01	01	00
4	2002	20	07	04	02	01	02
5	2001	11	07	07	03	03	01
6	2000	26	07	03	04	00	00
7	1999	22	09	03	03	00	00
8	1998	08	00	04	03	00	01
9	1997	19	07	12	05	01	02
10	1996	05	03	04	00	02	05
	Total	**157**	**61**	**52**	**26**	**11**	**17**
Net total during 10 years							**324**

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Table 5: Month-wise Inter –annual distribution of squalls over Delhi (I.G.I. airport)

S.N.	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	2005	0	0	1	2	4	8	0	0	0	0	3	0	18
2	2004	0	0	1	4	5	9	4	0	0	1	0	0	23
3	2003	0	0	0	0	6	9	1	4	1	0	0	0	21
4	2002	0	1	0	3	4	6	2	0	1	0	0	0	18
5	2001	0	0	1	5	9	3	0	1	1	0	0	0	19
6	2000	2	0	0	2	1	8	3	1	2	0	0	0	20
7	1999	0	0	1	1	6	5	3	2	2	0	0	0	20
8	1998	0	0	0	1	1	4	2	0	0	1	0	0	09
9	1997	0	0	0	4	13	5	1	0	2	2	0	0	27
10	1996	0	0	0	2	6	0	2	0	0	0	0	0	09
Total		2	1	4	24	55	57	17	8	9	4	3	0	184
Frequency (Monthly)		0.2	0.1	0.4	2.4	5.5	5.7	1.7	0.8	0.9	0.4	0.3	0	18.4
Annual frequency = 18.4														

Table 6: Month-wise Inter –annual distribution of squalls over Delhi (Safdarjung airport)

S.N.	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	2005	0	1	1	2	2	6	1	0	0	0	1	0	14
2	2004	0	0	0	5	5	4	0	0	0	3	0	0	17
3	2003	0	1	0	0	2	2	0	0	0	0	0	0	05
4	2002	0	0	0	2	5	6	3	1	0	1	0	0	18
5	2001	0	0	0	4	1	2	0	0	2	0	0	0	13
6	2000	2	0	1	2	1	8	3	1	2	0	0	0	20
7	1999	0	0	1	0	4	2	5	3	2	0	0	0	17
8	1998	0	1	1	0	1	3	0	0	0	1	0	0	07
9	1997	0	0	1	5	5	5	0	1	0	2	0	0	19
10	1996	0	0	0	4	3	1	2	0	0	0	0	0	10
Total		2	3	5	24	33	39	14	6	6	7	1	0	140
Frequency (Monthly)		0.2	0.3	0.5	2.4	3.3	3.9	1.4	0.6	0.6	0.7	0.1	0.0	14
Annual frequency = 14.0														

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Table 7: Temperature change associated with squalls over Delhi

Month	**Temperature fall in °C**									
	0.0-2.0	**2.1-4.0**	**4.1-6.0**	**6.1-8.0**	**8.1-10.0**	**10.1-12.0**	**12.1-14.0**	**14.1-16.0**	**>16**	**Total**
Jan	2	1	1	-	-	-	-	-	-	4
Feb	2	1	-	-	-	-	-	-	-	3
Mar	2	3	4	-	-	-	-	-	-	9
Apr	18	13	6	4	2	1	1	-	-	45
May	31	26	20	10	5	2	3	-	-	97
Jun	24	22	16	7	4	4	2	-	2	81
Jul	10	12	6	3	-	1	-	-	-	32
Aug	7	4	-	3	1	-	-	-	-	15
Sep	7	4	-	-	-	-	-	-	-	11
Oct	5	1	2	-	1	2	-	-	-	11
Nov	2	-	-	-	-	-	-	-	-	2
Dec	-	-	-	-	-	-	-	-	-	-
Total	110	87	55	27	13	10	06	-	02	310
%	35.5	28.1	17.7	8.7	4.2	3.2	1.9	-	0.6	

Table 8: Diurnal variations of squalls over Delhi

Month	**HOURS (I.S.T)**								
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24	Total
Jan	-	-	-	-	2	2	-	-	4
Feb	-	1	2	-	-	-	1	-	4
Mar	1	1	-	-	-	5	3	-	10
Apr	7	-	-	2	1	13	17	7	47
May	8	4	4	2	12	14	29	19	92
Jun	4	9	2	4	21	29	20	4	93
Jul	-	-	1	1	8	14	3	5	32
Aug	1	2	-	-	3	3	4	-	13
Sep	1	1	1	-	3	2	3	3	14
Oct	1	-	-	2	-	3	5	-	11
Nov	1	-	2	-	-	1	-	-	4
Dec	-	-	-	-	-	-	-	-	-
Total	24	18	12	11	50	86	85	38	324

Table 9: Some extreme values of Meteorological parameters which occurred during the squalls in the period 1996-2005

Parameters	Maximum value	Date and time (IST)	Direction of squall
Wind speed (kmph)	139	6-6-1997 (1900)	Westerly
Temperature drop (ºC)	19.7	6-6-1997 (1900)	Westerly
Pressure rise (hPa)	7.4	6-6-2005 (2008)	Southwesterly
Change in speed (V_{max}-V_{BC}) [kmph]	128	27-4-2005 (1741)	Westerly

Where, V_{max} = Maximum wind speed during squall
V_{BC} = Wind speed before commencement of squall

Table 10: Variation of pressure and temperature associated with squalls over Delhi

S.N.	Pressure	Temperature	Total no. of occasions	Percentage frequency
1	Rise	Fall	284	88.5
2	Rise	Rise	13	04.0
3	Fall	Fall	15	04.7
4	Fall	Rise	0	00.0
5	No Change	Fall	4	01.2
6	No Change	Rise	0	00.0
7	Rise	No Change	4	01.2
8	Fall	No Change	1	00.3
9	No Change	No Change	0	00.0
Total =321				

Table 11: Monthly distribution of pressure changes associated with squalls over Delhi

Month	**Pressure rise in hPa**								
	≤0.5	06-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	>6.0	Total no. of observations
Jan	1	-	2	1	-	-	-	-	4
Feb	1	-	1	1	-	-	-	-	3
Mar	5	1	-	4	-	-	-	-	10
Apr	12	14	15	3	2	-	-	-	46
May	28	13	26	10	4	3	-	-	84
Jun	30	20	22	9	3	3	-	1	88
Jul	12	13	5	-	-	-	-	-	30
Aug	6	3	2	1	-	-	-	-	12
Sep	5	4	3	-	-	-	-	-	12
Oct	1	3	5	1	-	-	-	-	10
Nov	3	1	-	-	-	-	-	-	4
Dec	-	-	-	-	-	-	-	-	-
Total	104	72	81	30	9	6	-	1	303

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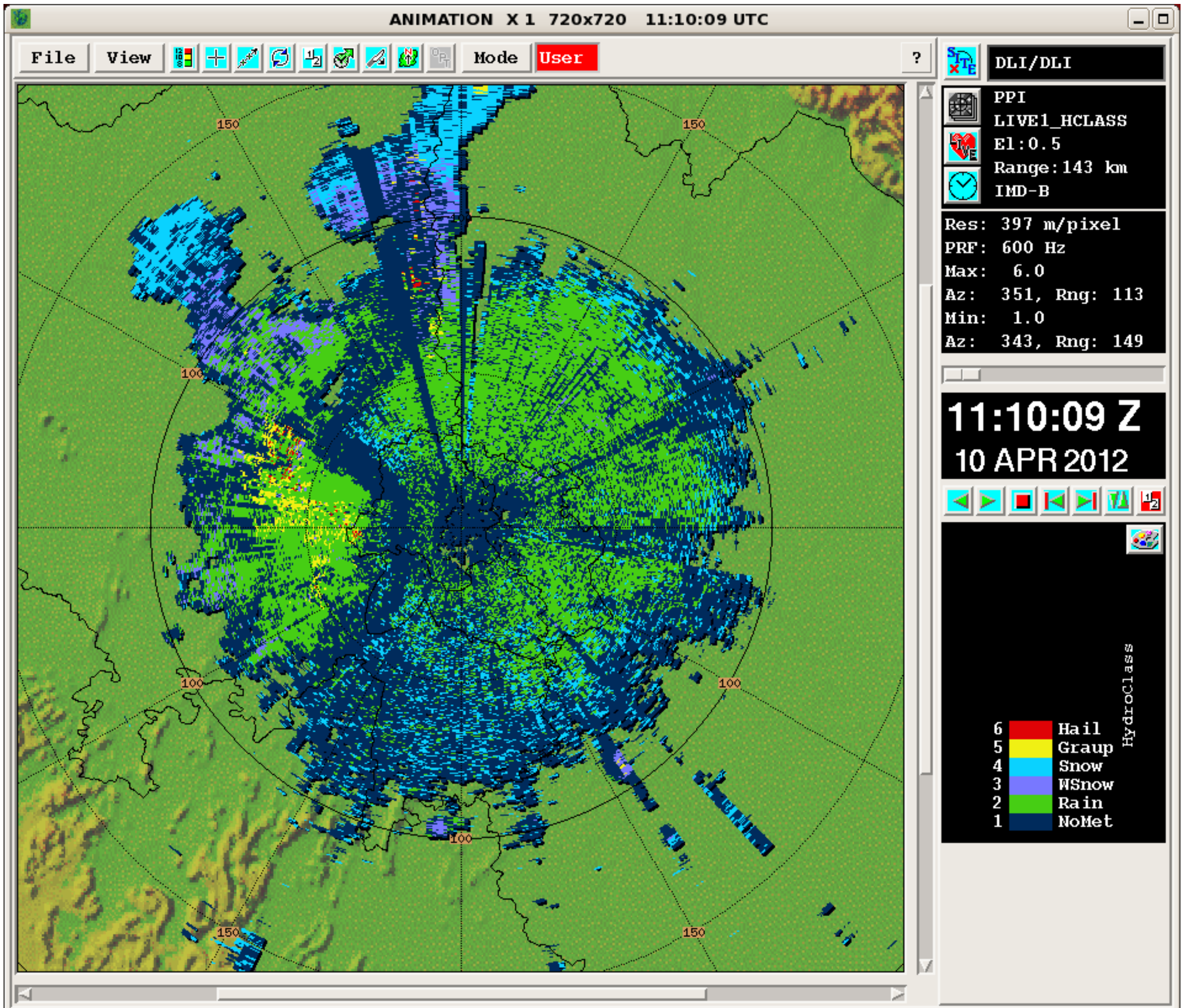

Figure 1: HydroClass 10th April 2012 (Dark blue line represents the gust front)

Case study of squall line observed by DWR:

Figure 1 shows the hydrometeor distribution surrounded Delhi area and dark line shows the structure of gust front in which perpendicular movement will be the possible movement of squall lines. Figure 2 shows the reflectivity pattern Delhi and surrounded area which covers moderate to intense convection (> 65 db signal strength) and Figure (3 to 6) represents the sequence of velocity spectrum. These will represents the turbulent observed in surrounded areas of Delhi (> 4 m/sec). Figure 7 represents the observed rainfall over the area; this distribution is based on the Marshal Palmer rule (Marshall and Palmer, 1948). The observed rainfall amount of Delhi and NCR region was more that 12.00 mm.

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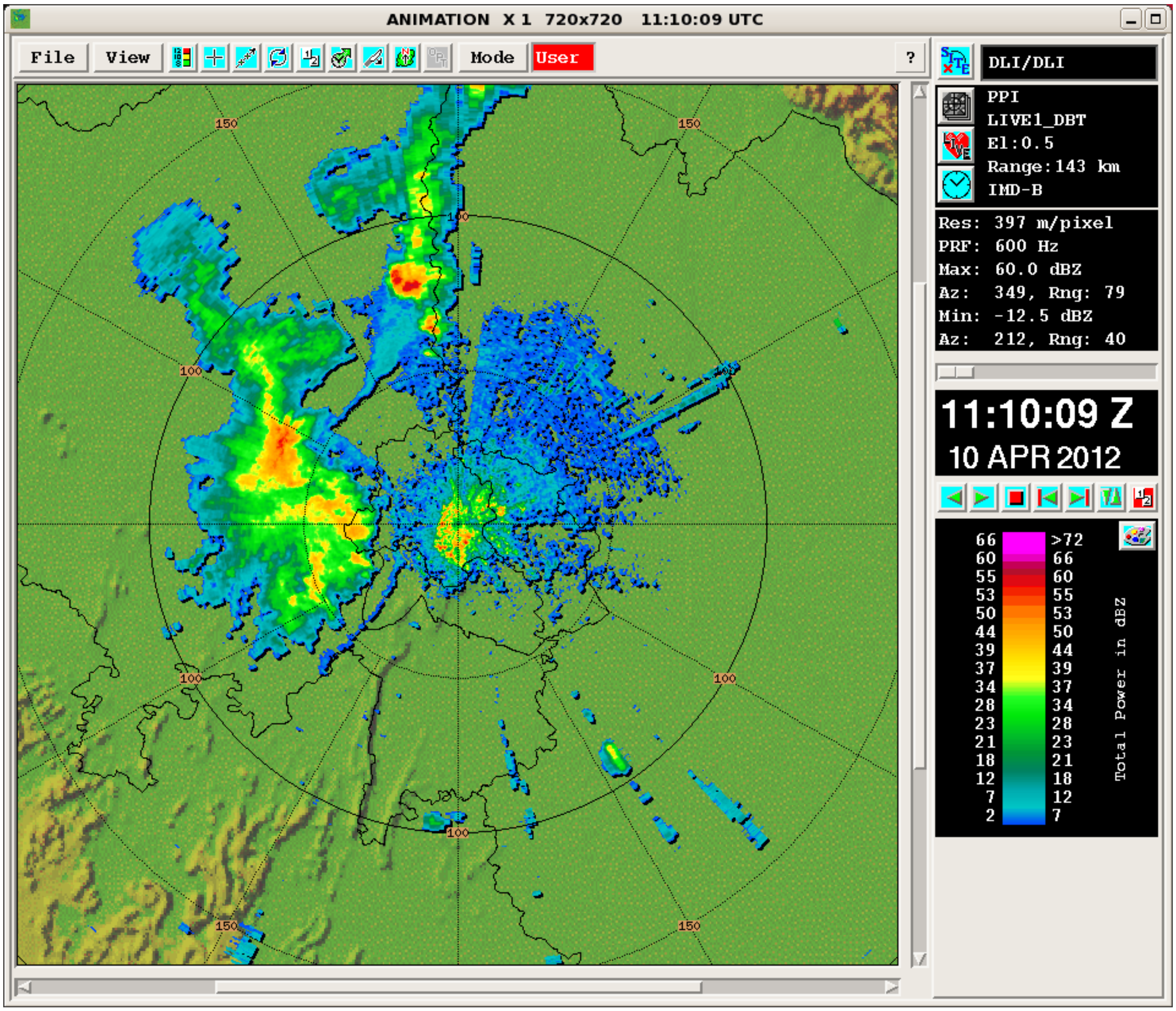

Figure 2: Reflectivity on 10th April 2012 (Area of convection approached towards Delhi.

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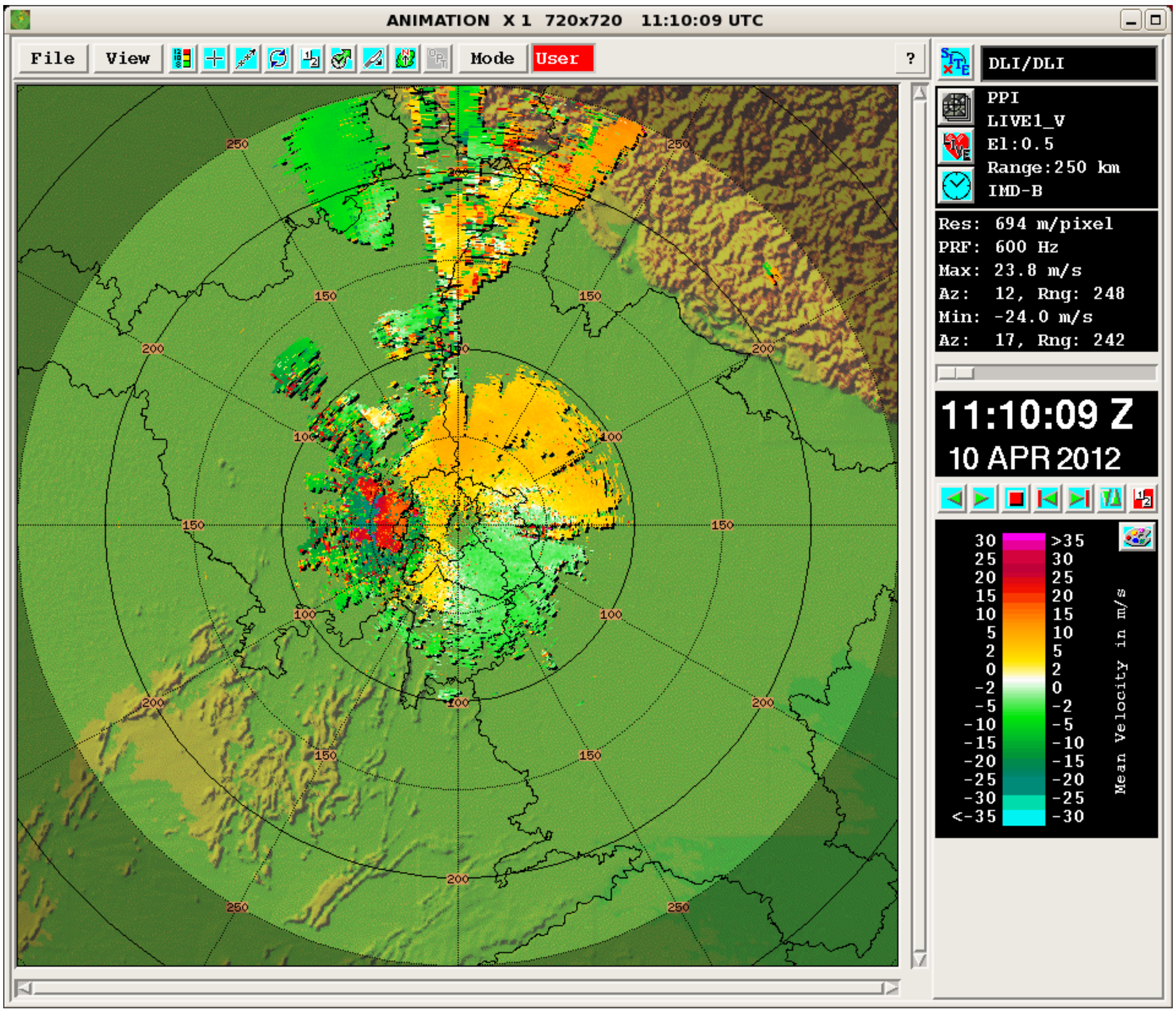

Figure 3: Velocity 10th April 2012 (Sequence 1) [Area of turbulence moves towards Delhi]

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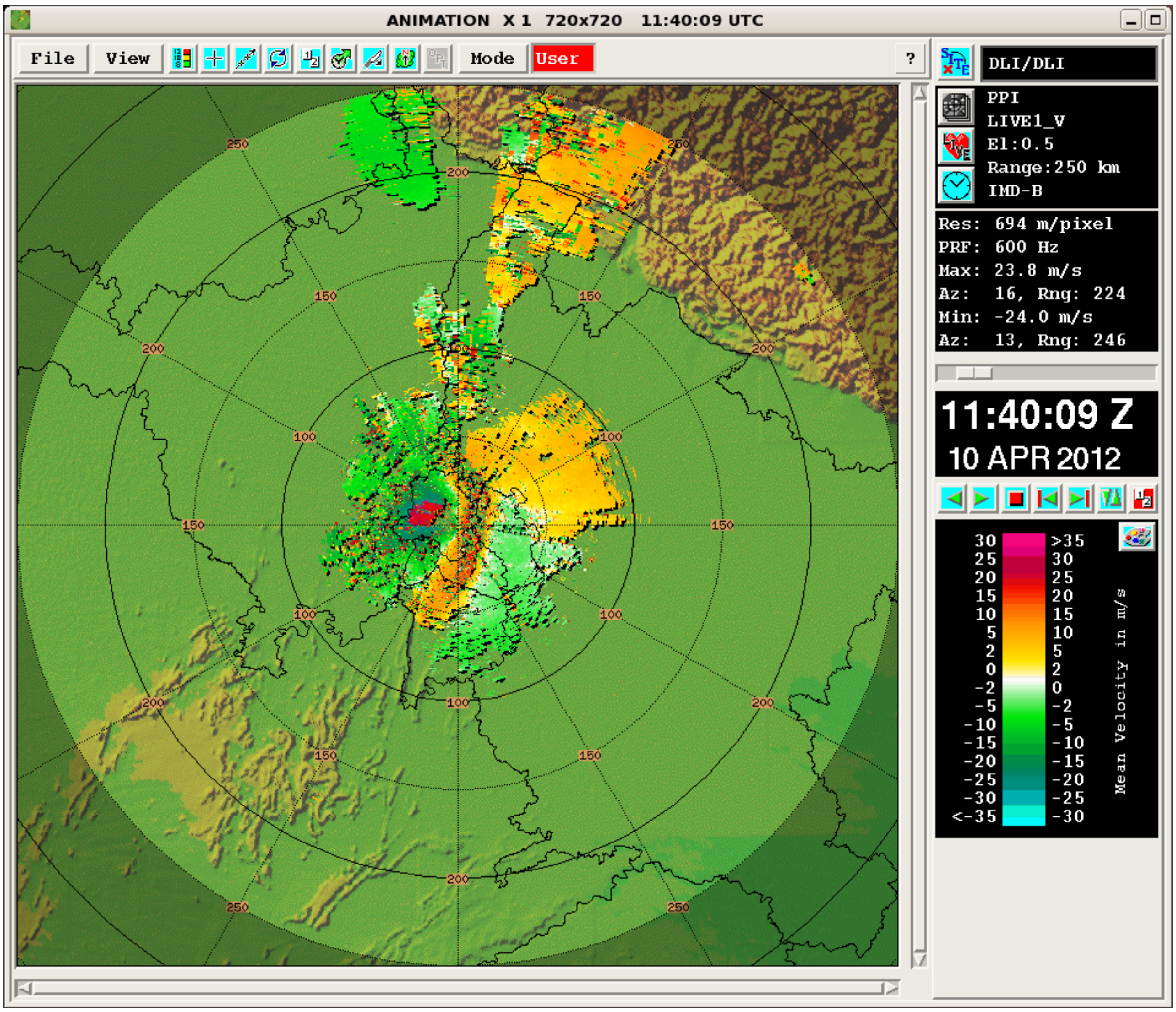

Figure 4: Velocity 10th April 2012 (Sequence 2)

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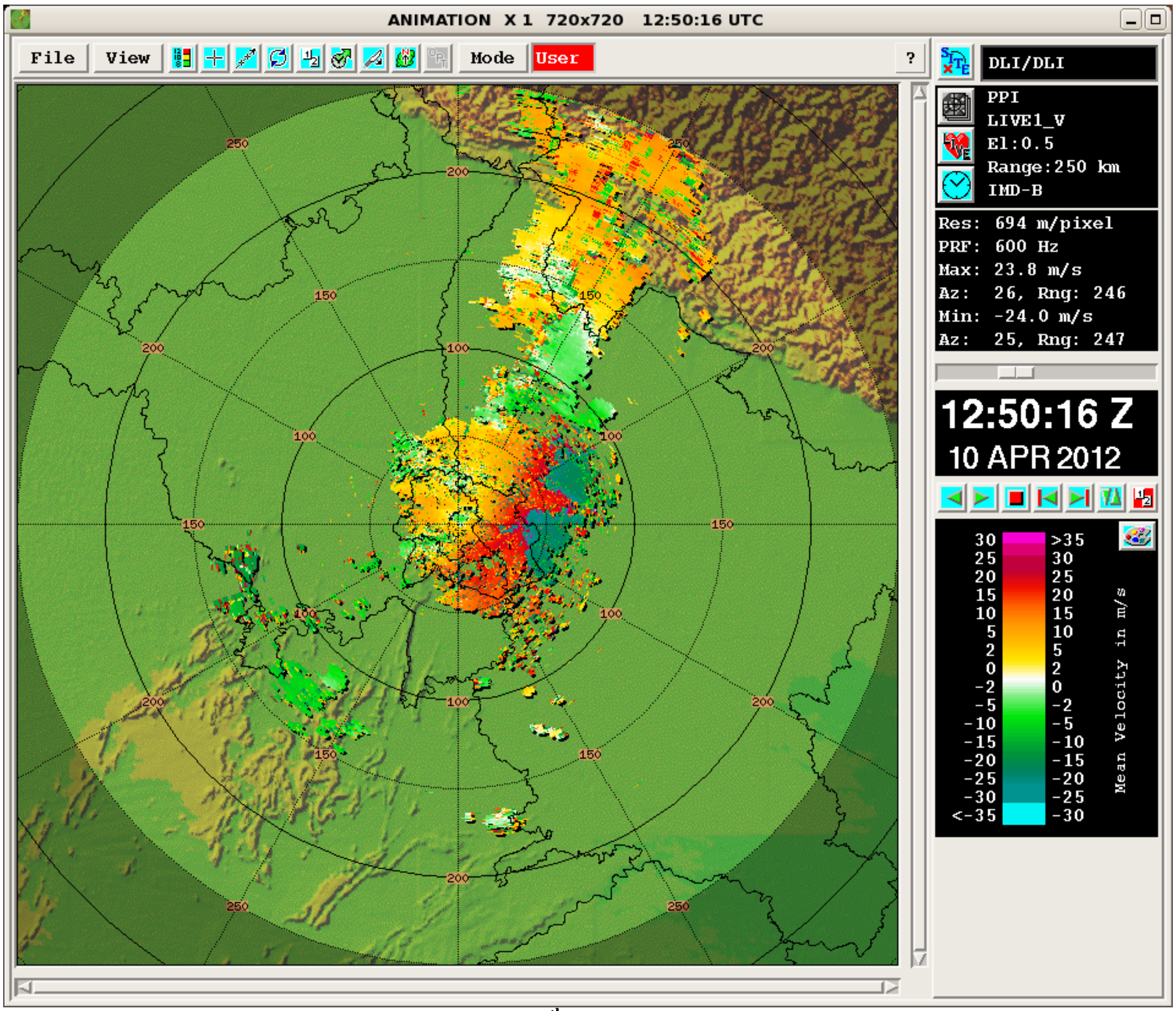

Figure 5: Velocity 10th April 2012 (Sequence 3)

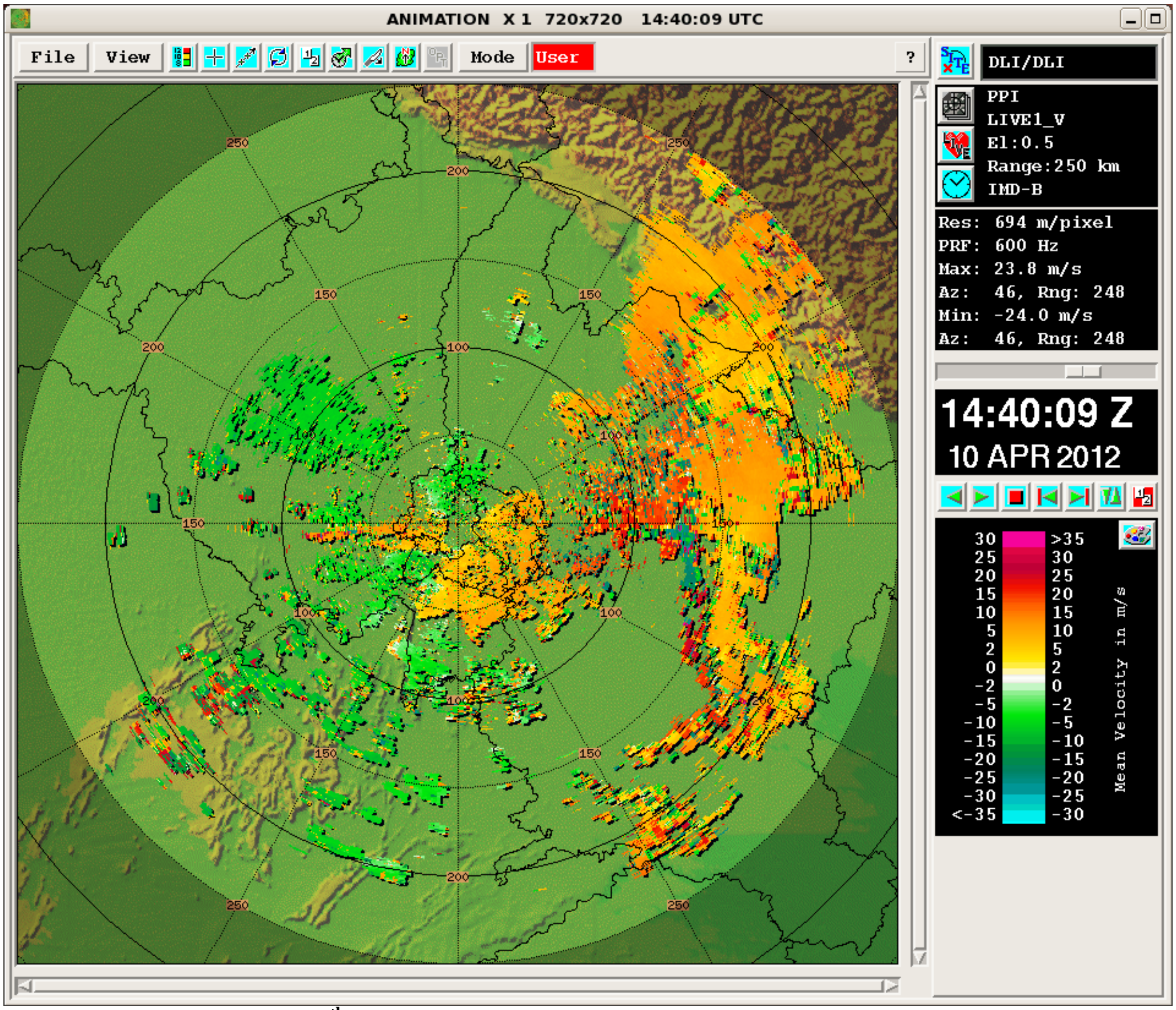

Figure 6: Velocity 10th April 2012 (Sequence 3) [Turbulent zone move away from Delhi]

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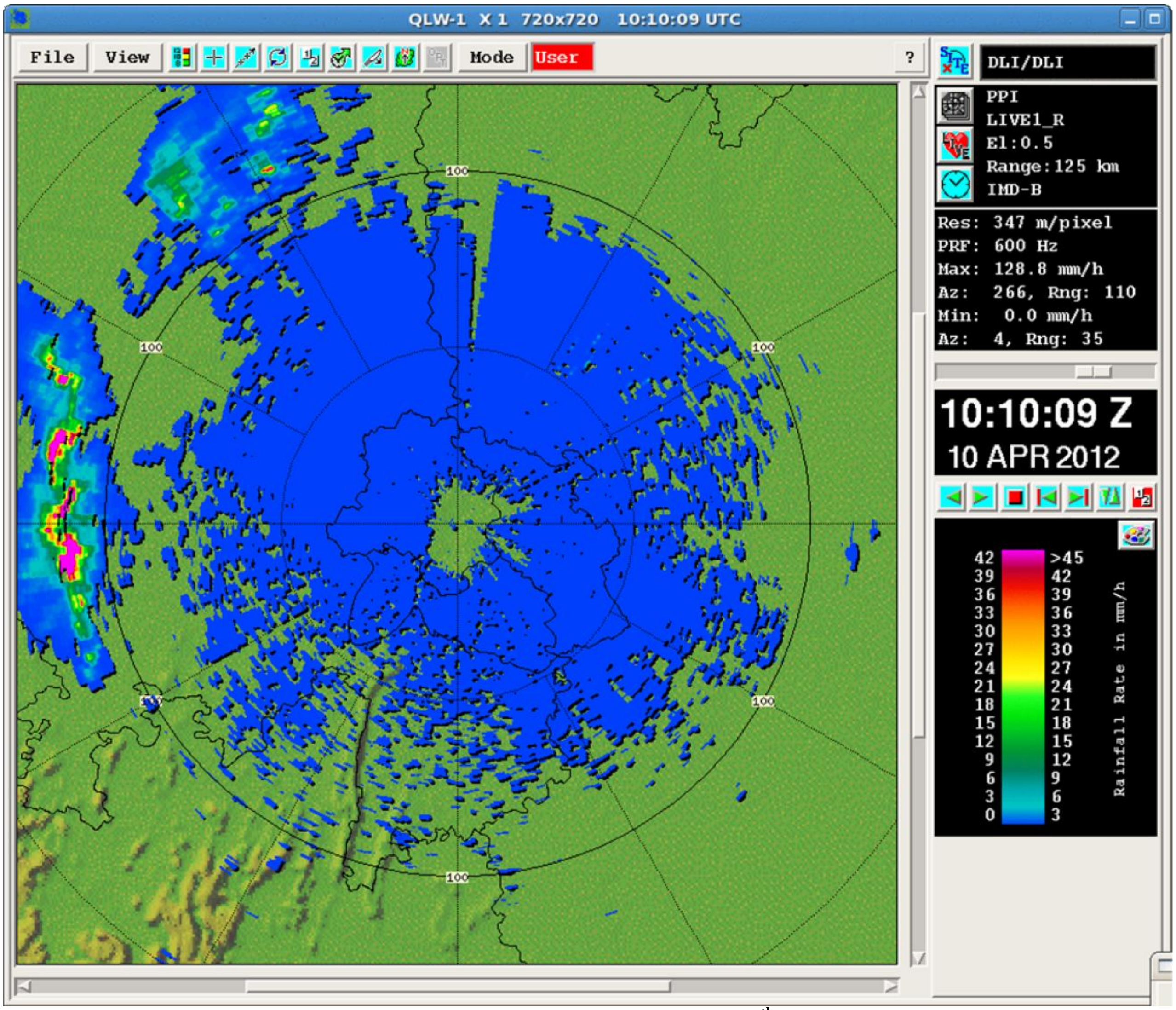

Figure 7: Rainfall pattern in mm/hour on 10th April 2012

Concluding remarks: The statistical analysis of squall data analysis of 10 years IGI and Safdarjung shows total of 324 squalls in which 98 % squalls are associated with temperature falls ranging between 0 to 6 °C. A squall monitoring case study of squall lines over Delhi on 10th April 2012 shows that velocity scanning of DWR data have the turbulence potential which is indicator of heavy rainfall or bad weather.

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REFERENCES

Alvi SMA and Punjabi KL (1966). Diurnal and seasonal variations of squall in India. Indian Journal of Meteorology Geophysics17 (2) 206-216.

Alvi SMA (1967). Squalls over East Uttar Pradesh. Indian Journal of Meteorology Geophysics 18 (2) 233-246.

Banerjee AK Chowdhury A and Ganesan HR (1983). Some characteristic features of squall over India. Vayu Mandal 13 (1)110-119.

Bhalotra YPR (1954). Squalls at Delhi. Indian Journal of Meteorology Geophysics 5 (4) 315-328.

Bhalotra YPR (1957). Some features of squalls at Delhi. Indian Journal of Meteorology Geophysics 8 (2) 169-182.

Bhattacharya PK and Basu KK (1983). A study of variations of different meteorological elements associated with pre-monsoon thundersqualls at Calcutta, with special reference to unsaturated downdrafts. Vayu Mandal 13 (1) 96-100.

Dekate MV and Bajay KK (1966). A study of squalls at Santacruz observatory, Bombay. Indian Journal of Meteorology Geophysics 17 (2) 217-224.

Hane CE (1973). The squall line thunderstorm: Numerical experimentation. Journal of Atmospheric Science 30 (8) 1672-1690.

Hane CE, Kessinger CJ and Ray PS (1987). The Oklahama squall line of 19 May 1977. Part II: Mechanisms for the maintenance of region of strong convection. Journal of Atmospheric Science 44 **(**19) 2866-2883

Lafore JP and Moncrieff MW (1989). A numerical investigation of the organization and interaction of the convective and statiform regions of a tropical squall line. Journal of Atmospheric Science 46 (4) 521-544.

Moncrieff MW and Miller MJ (1976). The dynamics and simulation of tropical cumulonimbus and squall lines. Quarterly Journal of Royal Meteorological Society102 **(2**) 373-394.

Marshall JS and Palmer WM (1948). The distribution of raindrops with size. Journal of Meteorology 10 (1) 25-29

Nicholls ME (1987). A comparison of two dimensional numerical simulation of a tropical squall line. Monthly Weather Review. 115 **(**12**)** 3055-3077

Nicholls ME and Weissbluth (1988). A comparison of two dimensional and quasi three dimensional simulations of a tropical squall line. Monthly Weather Review. 116 **(12)** 2437-2452.

Nicholls ME Johnson RH and Cotton WR (1988). The sensitivity of two dimensional simulations of tropical squall lines to environmental profiles. Journal of Atmospheric Science 45 **(12**) 3625-3649.

Ramakrishnan KP (1953). The stronger squalls of Poona. Indian Journal of Meteorology Geophysics 4 (3) 243-248.

Ramakrishnan KP and Gopinath Rao B (1954). Some broad features of the occurrence of squalls in different parts of India. Indian Journal of Meteorology Geophysics 5 (4), 337-340.

Ramakrishnan KP (1957). Squalls at Cochin. Indian Journal of Meteorology Geophysics 8 (3) 289-295.

Ramakrishnan KP and Ganapathiraman (1953). Squalls in Madars Indian Journal of Meteorology Geophysics 13 (1) 103-105.

Ramamurthy K (1962). Squalls at Begumpet Indian Journal of Meteorology Geophysics 13 (4) 485-487.

Rotunno R, Klemp JB and Weisman (1988). A theory for strong long level squall line. Journal of Atmospheric Science 45 **(3**) 463-485.

Schmidt JM and Cotton WR (1990). Interactions between upper and lower tropospheric gravity waves on squall line structure and maintenance, Journal of Atmospheric Science, 47 (10) 1205-1222

Saxena SP and Natrajan R (1966). A study of squalls at Ahamdabad airfield Indian Journal of Meteorology Geophysics 17 (1) 71-76.

Sharma KK (1966). Squalls at Nagpur Indian Journal of Meteorology Geophysics17 (1) 77-82.

Soundararajan K. and Raghavan S (1962). Severe squalls at Madras Airport on 17 August 1961. Indian Journal of Meteorology Geophysics13 (4) 548-550.

Soundarajan K (1961). Squalls at Bangalore. Indian Journal of Meteorology Geophysics 2 (4) 583-589.

Subba Reddy RV (1985). A study of squalls at Madras airport. Mausam 36 (1), 91-96.

Thorpe AJ, Miller MJ and Moncrieff MW (1982). Two dimensional convection in non constant shear. A model of mid latitude squall lines. Quarterly Journal of Royal Meteorological Society108 **(4**) 739-762.

Tripoli GJ and Cotton WR (1989a). Numerical study of an observed orogenic mesoscale convective system Part I. Simulated genesis and comparison with observations. Monthly Weather Review 117 **(2)** 273-304.

Tripoli GJ and Cotton WR (1989b). Numerical study of an observed organic mesoscale convective system Part 2.Analysis of governing dynamics. Monthly Weather Review 117 **(2)** 305-328.

Wong Ka Yan and Yip Chi Lip (2006). Comparison of squall line positioning methods using radar data, knowledge based intelligent information and engineering systems, LNCS 4253 **(2**) 269-276.

Weisman Morris L Robert J Trapp (2003). Low-Level Mesovortices within Squall Lines and Bow Echoes. Part I: Overview and Dependence on Environmental Shear. Monthly Weather Review 131 **(**09) 2779–2803.