

Utilisation of 'Aerostat' Doppler Weather Radar in nowcasting of convective phenomena

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सार – ऐरोस्टेट सिस्टम, भारतीय वायु सेना द्वारा अपनाया गया वायु रक्षा रेडार संजाल का एक भाग है। मौसम विज्ञान से संबंधित अनेक उपकरणों का इस सिस्टम के साथ जोड़ा गया है जिसमें डॉप्लर मौसम रेडार भी शामिल है। धरातल पर लगे डी. डब्ल्यू. आर. की अधिकतम दूरी 300 एन. एम. की है जबकि स्कैन मोड पर प्रायः यह 150 एन. एम. का उपयोग करता है। स्कैन मोड के बिंब आधे घंटे के अंतराल में उपलब्ध कराए जाते हैं जिनका उपयोग भारतीय वायुसेना के विभिन्न बेसों पर गर्ज के साथ तूफानों का तात्कालिक पूर्वानुमान अत्यंत प्रभावी ढंग से देने के लिए किया जाता है। इस शोध पत्र में वर्ष 2008 में मानसून ऋतु से पूर्व और दक्षिणी पश्चिमी मानसून ऋतु के दौरान कुछ अध्ययनों की सहायता से उत्तरी पश्चिमी भारत में गर्ज के साथ तूफानों/आँधियों के अद्यतन पूर्वानुमान के लिए डी. डब्ल्यू. आर. बिंबों के उपयोग के बारे में विवेचन किया गया है। इसके अलावा 24–36 घंटे पहले क्षेत्र में संभावित संवहनी क्रिया के संकेत/निर्देश प्राप्त करने के लिए प्रचालनात्मक मेसोस्केल एन. डब्ल्यू. पी. निदर्श के द्वारा व्युत्पन्न किए गए उत्पादों का विवेचन किया गया है। अतः एन. डब्ल्यू. पी. निदर्श से लघु अवधि मौसम पूर्वानुमान का उपयोग वास्तविक समय में डी. डब्ल्यू. आर. बिंबों का ध्यानपूर्वक मॉनीटरन करते हुए पहले से ही संकेत देने के लिए किया जा सकता है। यह पाया है कि एयर फील्ड के आसपास विशेष मौसम प्रतिघ्वनियों में हलचल का ट्रेक रखने के लिए डी. डब्ल्यू. आर. एक अच्छा माध्यम है जो सटीक चेतावनियों/परामर्शियों को प्रयाप्त समय रहते जारी करने के लिए अत्यंत उपयोगी सिद्ध होगा। मेसोस्केल एन. डब्ल्यू. पी. मॉडल कम से कम 24–36 घंटे पहले संभावित संवहनी क्रिया के विश्वसनीय संकेत देने में सक्षम है। दोनों सूचनाओं के समाकलन से संवहनी क्रिया के स्थान और समय विशेष के पूर्वानुमान की विश्वसनीयता और सटीकता में काफी वृद्धि हो सकती है।

ABSTRACT. 'Aerostat' system is a part of the air defence radar network, adopted by the Indian Air Force. Many meteorological instruments have been integrated with this system, including Doppler Weather Radar (DWR). The ground-based DWR has a maximum range of 300 NM, however, it generally uses 150 NM range on scan mode. The scan mode images are provided at half an hour interval, which are being utilised very effectively for nowcasting of thunderstorms at various IAF bases. In the present study, utilisation of DWR images for nowcasting of thunderstorms / dust storms is discussed over NW India with the help of a few case studies during pre-monsoon and SW monsoon seasons of 2008. Further, products generated through operational meso-scale NWP model runs have been studied in order to obtain indications / guidance for expected convective activity over the area at least 24-36 hours in advance. Thus, short-range weather forecasts through NWP models can be used as an advance indication for careful monitoring of DWR images in near real time. It has been found that the DWR is a very good tool to track the movement of significant weather echoes around the airfields, which can be very helpful in issuing appropriate warnings / advisories with sufficient lead time. Meso-scale NWP models are capable of generating reliable indications for expected convective activity at least 24-36 hours in advance. The integration of both the inputs can increase the accuracy and reliability of location and time specific prediction of convective activity.

Key words – Aerostat, Radar meteorology, Nowcasting, Thunderstorms.

1. Introduction

One of the major developments immediately after World War II was introduction of Radar in Meteorology. Initially being used mainly for observational purposes, its utility increased rapidly with passage of time. The

scientific community world wide discovered many ways to utilise various products generated through conventional Radars for weather prediction. The introduction of Doppler Weather Radars revolutionised the field of meteorology by adding many more applications to its newly formed sub-division, called 'Radar Meteorology'.

With the introduction of advanced aircraft for both, commercial and military, Aviation Meteorology has taken a giant leap. This advancement in aviation industry has imposed much more stringent and accurate requirement of weather prediction, especially for military aviation. 'Aerostat' system is also a part of aviation and an important part of the air defence radar network, adopted by the Indian Air Force in the recent past. The major component of this system resides in a specially-designed Helium filled balloon, which can be raised to a certain height to improve the aerial coverage of the Air Defence Radar (Aerostat System). Due to its floating capability, its operation is extremely sensitive to adverse weather conditions. Thus, it is essential that imminence of bad weather be detected and tracked continuously to enable timely action and prevent damage to the system. In view of this, the system is provided with ground-based Doppler Weather Radar (DWR), Wind Profiler, Thunderstorm Sensor, Lightning Location Protection System, Automatic Weather System (AWS) and On-board Met Sensors for accurate forecasting of weather at site. These facilities can also be used by airfields for normal operations (Harish Kumar, 2007).

The most destructive and important aviation weather hazard during pre-monsoon season over NW India is formation of convective clouds, causing thunderstorm, dust storm or hail storm. The major challenge a weather forecaster faces during the operational flying activity is how accurately he can predict the weather for the next 2 to 3 hours. The conventional methods do not aid much in nowcasting. With the introduction of aerostat system and associated DWR, the neighbouring airfields can use its products (especially, horizontal scans of reflectivity, which are available at every 30 minutes or even less) to monitor approach and intensity of convective weather continuously in nowcasting mode. Operational meso-scale NWP models can provide vital guidance regarding expected convective weather at least 24-36 hours in advance, thus, providing short range weather forecasting capability. By adding both the methods, time and location specific forecasts of such weather phenomena can be effectively enhanced.

In the present study, utilisation of DWR images for nowcasting of thunderstorms / dust storms is discussed over NW India with the help of a few case studies during pre-monsoon and SW monsoon seasons of 2008. Further, products generated through operational meso-scale NWP model runs have been studied in order to obtain indications / guidance for expected convective activity over the area at least 24-36 hours in advance. Thus, short-range weather forecasts through NWP models can be used as an advance indication for careful monitoring of DWR images in near real time.

2. Aerostat system and associated meteorological equipment

2.1. Operating limitations due to weather

Due to the floating capability of the Aerostat Radar, its operation is extremely sensitive to adverse weather conditions. Some of such meteorological conditions are :

(i) *Wind speeds* - Operational upto 65 kt at any height; survival upto 90 kt on ground; launch & recovery 40 kt (If wind speed exceeds 90 kt, the balloon has to be deflated on ground). The balloon can be redeployed only after the wind speed comes down to less than 40 kt without gust and not expected to increase again.

(ii) *Gusting* - Less than 5 kt gusting, while inflating the balloon with helium (Inflation takes place preferably during night time. It takes approximately 6 to 8 hours to inflate the balloon completely. This is done once only, after which leakage, if any, is blocked and the balloon is filled).

(iii) *Turbulence* - During lowering or hoisting, maximum spectrum width (which is a measure of turbulence) should be less than 4.9 m/sec (13 ft/sec).

(iv) *Lightning* - Lightning strikes will cause damage to the aerostat systems. System can survive with lightning with less than 1,00,000 amp (Adequate protection given to the system from lightning by conducting the lightning discharge to the ground through the tether).

(v) *Thunderstorm* - Thunderstorm is invariably associated with severe turbulence, high gusting wind speeds, wind shear, updrafts and downdrafts, microburst, lightning and very heavy rain. These pose major threat to the operation of the aerostat system. Thunderstorm should not be within 20 NM for its safe operation.

(vi) *Dust devils* - Cause damage to the moored aerostat.

(vii) *Precipitation* - Accumulation of precipitation of any form on the upper surface of the aerostat hull and fins can overcome the free lift safety margin very rapidly, thereby hampering effective operations of the system.

2.2. Weather instruments associated with aerostat

In view of the meteorological limitations, it is mandatory that imminence of bad weather be detected and tracked continuously to enable timely action and prevent damage to the system. In order to have smooth and

efficient operations, the aerostat has been installed with the following associated weather instruments:

- (i) Automatic Weather Station (AWS) and Onboard Met Sensors.
- (ii) Wind Profiler.
- (iii) Thunderstorm Sensor and Electric Field Mill.
- (iv) Doppler Weather Radar (DWR).

3. Doppler weather radar : Specifications and working principle

The DWR associated with the aerostat system is a Rockwell Collins ground-based DWR, which is marketed by Advance Design Corporation. The ground-based DWR has a maximum range of 300 NM, however, it generally uses 150 NM range on scan mode. On RHI mode, it can give the cloud heights up to a distance of 75 NM; beyond which, it catches the weather echoes, only when the cloud height exceeds 40,000'. The scan mode images are provided at half an hour interval, which are being utilised very effectively for nowcasting of thunderstorms at various IAF bases.

3.1. Modes of operation

The radar has three modes of operation, which include Weather (Precipitation) detection, Weather plus Turbulence detection and Turbulence only. The various modes in DWR are as follows :

- (i) *Weather (Wx) mode* - The weather (Wx) mode is a weather (Precipitation) detection mode only. Detectable weather will be displayed in one of five colours (light green, dark green, yellow, red and maroon) as designated by the user in their system configuration. Table 1 shows various colour schemes used by DWR display.
- (ii) *Weather plus turbulence (Wx + T) mode* - The Wx + T mode is the weather plus turbulence display mode. Any precipitation targets, which are within 50 NM maximum range of this mode, will be displayed. If the precipitation contains severe weather with turbulence, the turbulent area will be displayed by the colour magenta.
- (iii) *Turbulence (T) mode* - The T mode is a turbulence detection mode only. Only areas showing detectable turbulence will be displayed for ranges up to 50 NM only. Detected turbulence will consist of precipitation areas where Spectrum Width (square root of the variance of velocity) in the range of 5 m/sec (14.6 ft/sec) to 12 m/ sec (39 ft/sec) is detected. Turbulent area will be displayed by the colour magenta.

TABLE 1

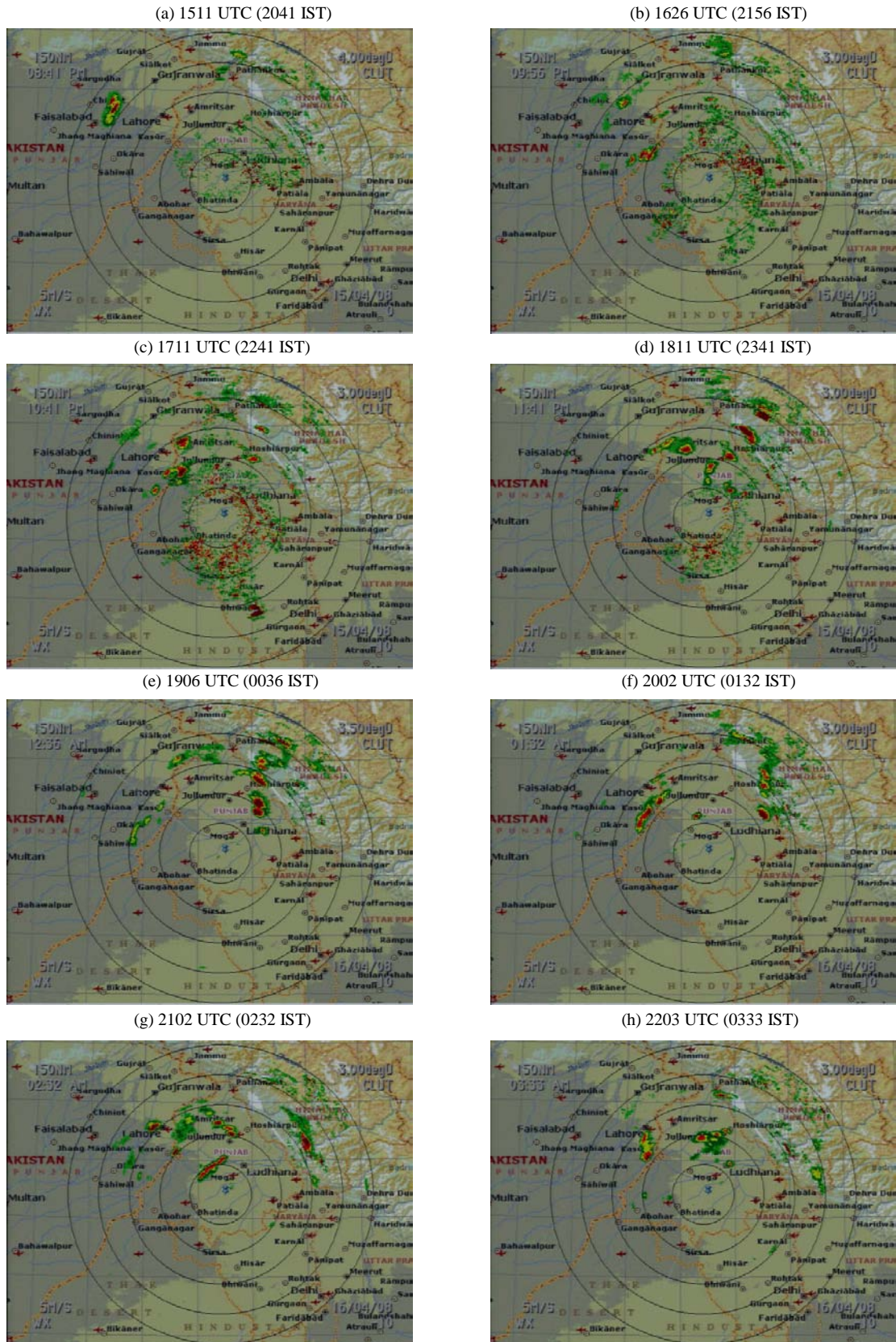
DWR display colour scheme

Z level gain at CAL	Reflectivity (dBZ)	Rainfall rate (mm/h)	Displayed colour
	10	< 0.316	
Z ₁	20	0.316 – 1.33	Light Green
Z ₂	30	1.33 – 12.58	Dark Green
Z ₃	40	12.58 – 25.84	Yellow
Z ₄	45		
Z ₅	50	25.84 – 53.06	Red
Z ₆	60	53.06 – 109.0	Maroon
Measure of Turbulence	(Spectrum Width)	5-12 m/sec	Magenta

3.2. Products generated through DWR

The following meteorological products can be generated by the DWR :

- (i) *Standard meteorological products* - Plan Position Indicator (PPI), Range Height Indicator (RHI), Maximum Display, Constant Altitude PPI (CAPPI), Pseudo CAPPI, Echo Top and Echo Base.
- (ii) *Extended meteorological products* - Velocity Azimuth Display, Volume Velocity Processing, Uniform Wind Technique, Vertically Integrated Liquid and Reflectivity, Spectrum at Maximum Velocity (Spectrum Width), Storm Relative Velocity, Severe Weather Analysis Display, Pseudo CAPPI and Echo Top Height.
- (iii) *Hydrological products* - Surface Rainfall Intensity, Precipitation Accumulation, Surface N-hourly Rainfall, Rainfall Intensity Histogram and Point Rainfall Total.
- (iv) *Wind shear detection products* - Radial, Azimuth, Elevation, Radial Azimuth, Radial Elevation, Horizontal and Vertical Shears.
- (v) *Warning and forecasting products* - Warning, Hail Warning, Storm tracking and rain tracking.
- (vi) *Phenomena detection products* - Severe Weather Indicator, Microburst Detection, Gust Front Detection, Meso-Cyclone Detection, Storm Structure Analysis and Dust Storm Detection.
- (vii) *Aviation products* - Layer turbulence.
- (viii) *Raw data pre-processing* - Bright Band, Attenuation, Beam Blockage and Velocity Data Corrections.



Figs. 1(a-h). DWR Images from Barnala on 15-16 April 2008

The radar images obtained from the DWR at Barnala do not present any legends for colours representing dBZ levels. The interpretation is carried out based on the colour assignment as given in Table 1. Most of these images are on PPI mode, with range of 150 NM (with each ring of 30 NM). In case of approach of bad weather near the radar site, the range is reduced to 75 NM (with each ring of 15 NM). The range and some other specifications of the image are printed on the top right corner of each image for ready reference. Occasionally, radar images are also provided on RHI mode to depict vertical extent of a particular echo. However, these controls are available with the radar controller only and meteorological users do not exercise such changes in scope or mode. The background of the radar image at normal mode (*i.e.*, at 150 NM range) depicts the geographical locations of major towns and airfields, which can not be changed.

4. Methodology

For the present study, continuous (mostly half-hourly) Radar images obtained from the DWR located at Barnala (Punjab) have been studied during pre-monsoon and SW Monsoon seasons of 2008. Based on the observed weather, a few cases were selected, when fairly widespread Thunderstorm (T'ST) / Dust Storm (D'ST) / Thundershowers (T'SH) affected almost all the bases located over plains of NW India. The movement of echoes was compared with the approach and actual time of occurrence of adverse weather spells over various IAF bases. One such case (on 15-16 April 2008) is being presented in this paper, when fairly widespread T'ST / T'SH with strong surface winds affected Punjab and Haryana.

Subsequently, the NWP products generated through operational meso-scale NWP model at the Air Force Centre for Numerical Weather Prediction (AFCNWP), based on 1200 UTC GFS (Global Forecast System) initial conditions of the previous day, were studied and location & time specific forecasts were compared with the actual time and location of adverse weather spells. Apart from predicted rainfall, profiles of vertical velocity, relative humidity, simulated radar reflectivity and wind speed at various heights were used as signatures associated with convective activity [(Arora and Nandi, 2007) and (Arora *et al.*, 2008)] For the purpose of this study, the model chosen was MM5 (Version 3.7.2), with two double-nested domains with horizontal resolutions of 27 & 9 km. Keeping other physics similar for both the domains, Cumulus Parameterisation scheme was switched off for inner domain [Arora and Srivastava, 2008 (Technical Report No. AFCNWP / TR / 01 / 2008)]. The model was integrated for 36 hours (*i.e.*, till 0000 UTC of next-to-next day). Post-processing was carried out through GrADS

(Grid Analysis and Display System) visualisation package (GrADS Documentation available on internet).

4.1. Case study : 15-16 April 2008

4.1.1. Observed weather

Fairly widespread convective activity was observed over Punjab, Haryana and adjoining NW Rajasthan during 15-16 April 2008. The activity largely commenced as Towering Cumulus (TCu) and Cumulonimbus (Cb) development during evening hours of 15 April 2008 and continued as Thunderstorm (T'ST) / Thundershowers (T'SH) till morning hours of 16 April 2008 (precipitation amounts being very less). The observed weather, time of commencement and cessation of activity, total rainfall till 0000 UTC / 16 April 2008 and occurrence of strong surface winds over various IAF bases are presented in the table given below :

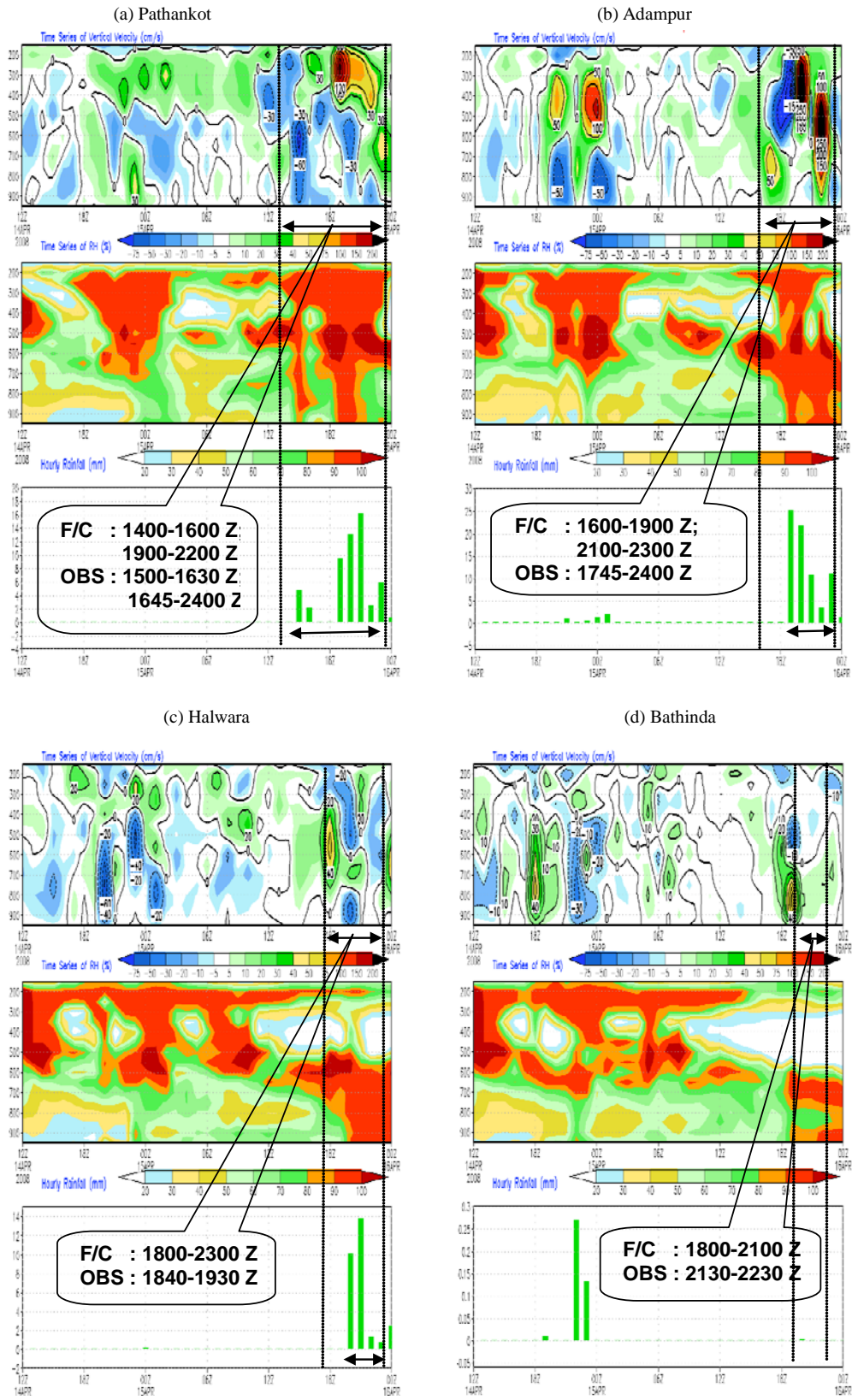
S. No.	Station	Observed weather	Duration (UTC)	Total rainfall (mm)	Strong sur winds Dir / Speed	Time (UTC)
1.	Pathankot	T'ST / T'SH	1500-1630; 1645-0045	2.8	320 / 45 kt	1950
2.	Adampur	T'ST / T'SH	1745-2400	1.4	090 / 50 kt	1835
3.	Halwara	T'ST	1840-1930	Nil	050 / 22 kt	1845
4.	Bathinda	T'ST / T'SH	2130-2230	Trace	340 / 28 kt	1830
5.	Ambala	T'ST / T'SH	1845-2100	Trace	-	-
6.	Sirsa	TCu / Cb	-	Nil	-	-
7.	Suratgarh	TCu / Cb	-	Nil	-	-

4.1.2. Analysis of DWR imageries

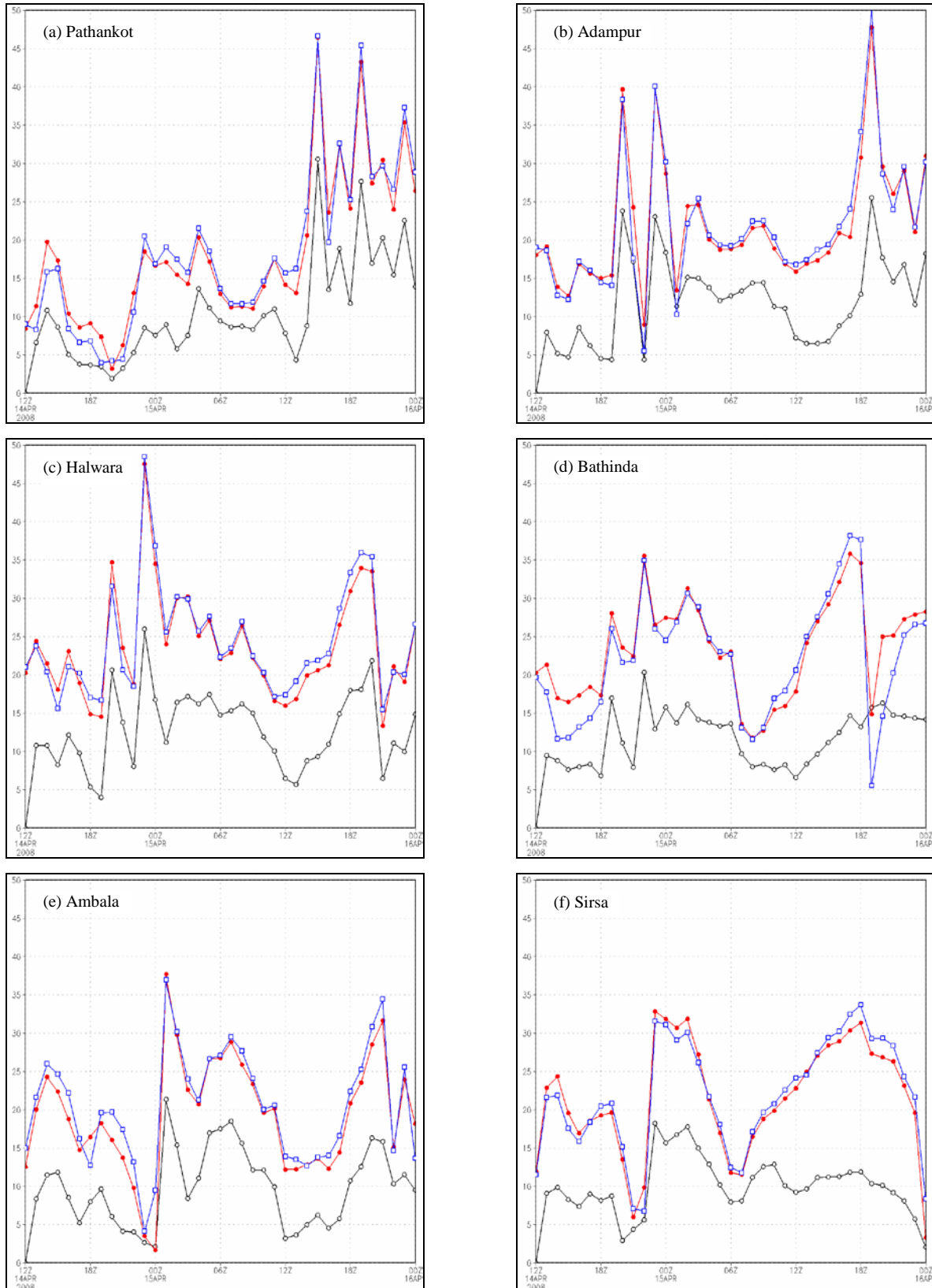
At 1411 UTC, Radar image showed an echo over Pakistan, about 20 NM SE of Sargodha. This echo moved slightly eastwards at 1511 UTC. At 1626 UTC, another echo was seen along the International border, about 60-70 NM west of Barnala. Between 1711 & 1811 UTC, 2-3 significant echoes were observed moving towards northeast, affecting weather over Pathankot, Amritsar and Adampur. By 1906 UTC, a significant echo was observed between 50-60 NM to the northeast of Barnala. Between 1906 & 2203 UTC, fresh echoes formed and moved towards northeast, affecting weather over Pathankot, Adampur, Halwara and Bathinda. Some of these images are presented in Figs. 1(a-h).

4.1.3. Analysis of NWP products

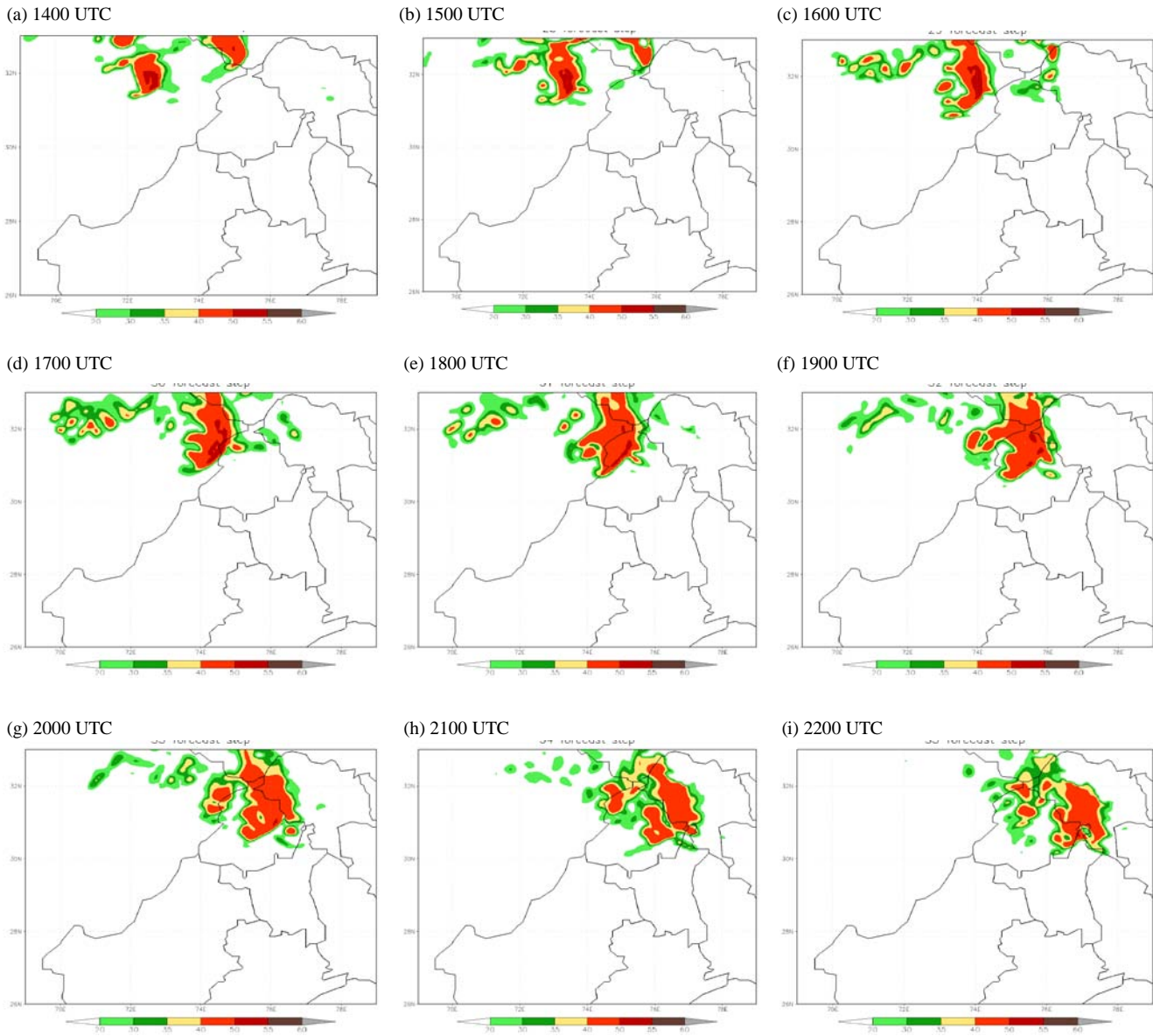
In order to capture signatures of significant convective activity (and hence associated T'ST / D'ST), some of the most important and basic products are vertical profiles of vertical velocity and relative humidity, forecast rainfall (which is not essential, as convective activity may not always be associated with precipitation) and wind speeds at lower levels. Based on the 1200 UTC GFS initial conditions of 14 April 2008, the analysis of



Figs. 2(a-d). Vertical profiles of vertical motion and relative humidity over IAF stations on 15-16 April 2008



Figs. 3(a-f). Time series of forecast wind speeds at stations at 10 m (Black line), 950 hPa (Red line) and 925 hPa (Blue line) levels

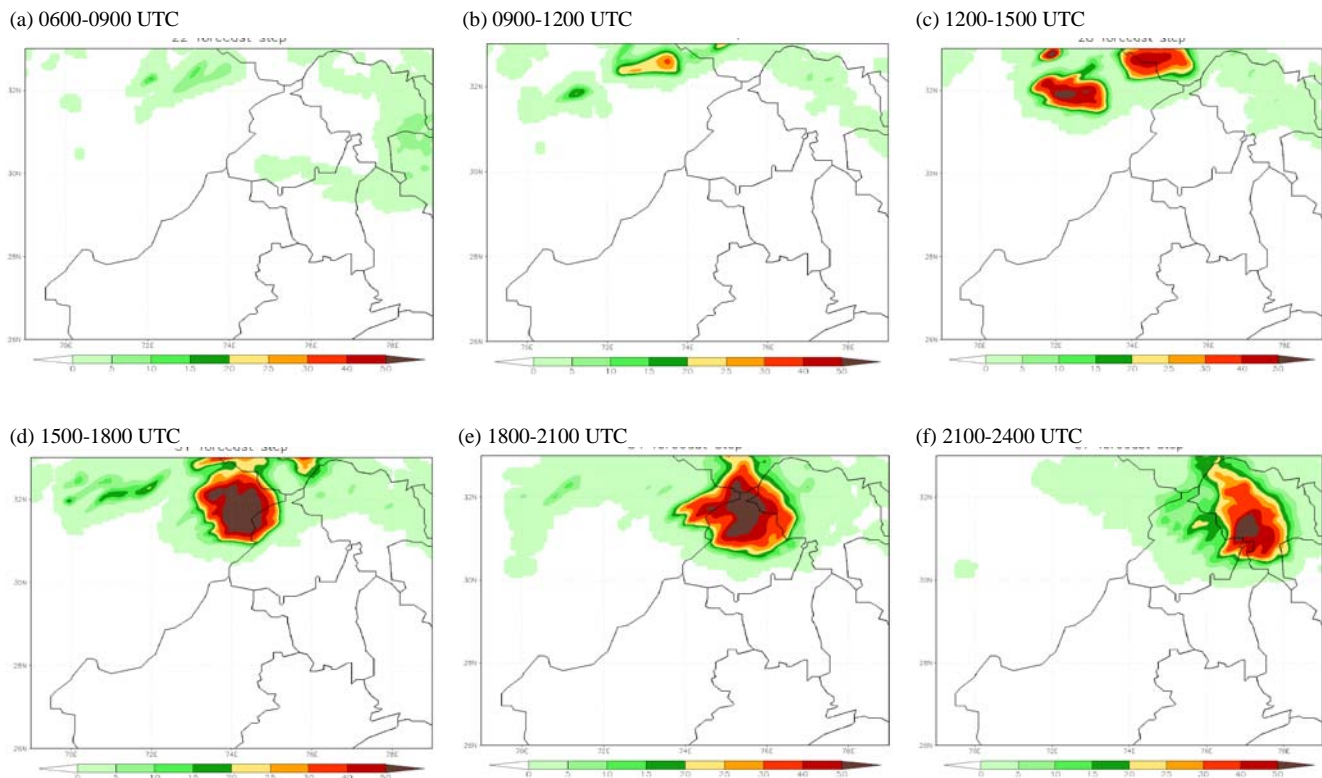


Figs. 4(a-i). Simulated Composite Reflectivity (in dBZ)

forecast patterns of these parameters depicted following features :

(i) *Vertical profiles of vertical velocity and relative humidity* - Vertical profiles of vertical velocity and relative humidity, along with time series of hourly rainfall over various stations (all parameters are obtained through NWP model forecasts) are presented in Figs. 2(a-d). Based on the analysis, respective predictions with time frames are given in the table given below and compared with the observed weather and time of occurrence :

S. No.	Station	Observed Weather	Observed Time (UTC)	Forecast Time (UTC)
1.	Pathankot	T'ST / T'SH	1500-1630	1400-1600
			1645-0045	1900-2200
2.	Adampur	T'ST / T'SH	1745-2400	1600-1900
				2100-2300
3.	Halwara	T'ST	1840-1930	1800-2300
4.	Bathinda	T'ST / T'SH	2130-2230	1800-2100
5.	Ambala	T'ST / T'SH	1845-2100	2100-2400
6.	Sirsa	No Significant Weather		-
7.	Suratgarh	No Significant Weather		-



Figs. 5(a-f). Forecast past 3-hourly rainfall patterns on 15-16 April 2008

(ii) *Wind speeds in lower levels* - Time series of wind speeds at 10 m height and at 950 & 925 hPa levels were obtained from the model outputs for individual stations. Time series for few stations are presented in Figs. 3(a-f). A comparison of predicted wind speeds at various levels with observed strongest surface wind for all stations is presented in the table given below :

S. No.	Station	Strongest surface wind		Forecast winds at 10 m		Forecast winds at 950 hPa		Forecast winds at 925 hPa	
		Speed (kt)	Time (UTC)	Speed (kt)	Time (UTC)	Speed (kt)	Time (UTC)	Speed (kt)	Time (UTC)
1.	Pathankot	25	1800	30	1500	47	1500	17	1500
		45	1950	28	1900	43	1900	45	1900
				23	2300	35	2300	37	2300
		50	1835	25	1900	48	1900	50	1900
2.	Adampur	48	2120	17	2200	29	2200	30	2200
3.	Halwara	22	1845	22	2000	34	1900	36	1900
4.	Bathinda	28	1830	16	2000	36	1700	38	1700
		25	2130						
5.	Ambala	-	-	16	2000	31	2100	35	2100
6.	Sirsa	-	-	No clear pattern		31	1800	34	1800
7.	Suratgarh	-	-	No clear pattern		32	1600	33	1600

(iii) *Simulated composite reflectivity* - Simulated Composite Reflectivity charts have been presented in Figs. 4(a-i). Patterns indicated presence of significant echo over Pakistan at 1400 UTC, which moved eastwards with time. After 1500 UTC, this echo entered Punjab; and covered entire northern Punjab by 1900 UTC. Between 2000 & 2200 UTC, it was seen over northern parts of Haryana. On comparison, these were found to be matching closely with the actual radar echoes. However, there was significant difference in the intensity and aerial coverage of echoes, as forecast reflectivity of echoes was much more intense and covered much larger area compared to the actual ones.

(iv) *Forecast rainfall pattern* - Convective activity is not always associated with precipitation, especially during Pre-Monsoon season. However, forecast rainfall through meso-scale NWP models certainly indicates possibility of convection. Figs. 5(a-f) contains forecast 3-hourly rainfall (*i.e.*, rainfall during past three hours) patterns. Forecasts at 1200 & 1500 UTC indicate significant rainfall over Pakistan, which moved eastwards during the period. The predicted rainfall belt approached Punjab by 1800 UTC and persisted over almost entire Punjab (except some parts of south Punjab) by 2100 UTC. By 2400 UTC, this belt

moved further eastwards over Himachal Pradesh (HP). Actual rainfall amounts (24 hours) over all the stations were very less, which were predicted as very high over Pathankot and Adampur. However, the actual time of commencement of convective activity was well within the predicted time frame.

5. Inferences

From the analysis of Radar Imageries and NWP products for both the cases, the following inferences can be drawn :

(i) Radar images from Barnala gave very reliable indication about the approach of significant weather well in advance. Continuous monitoring of these images can significantly enhance accuracy and lead time for issuing relevant meteorological warnings / advisories, and in turn, improved flight safety.

(ii) Meso-scale NWP models can be successfully utilised in capturing signatures of convective activity within reasonable spatial and temporal limits. The indications / guidance provided by these models can be used as a precursor for monitoring phase of Radar imageries cautiously.

(iii) Vertical profiles of vertical motion and relative humidity for a point location indicate possible time frame of expected convective activity. Forecast wind speeds in lower levels give good indication for expected intensity of convective activity. Associated precipitation can also be predicted well, atleast over the area, along with possibility of reasonable time lag or positional error. Predicted rainfall amounts may not always be reliable in terms of space and time. As an example, significant rainfall occurring over a particular location may be predicted as 'NIL' or very less rainfall in location specific forecast. However, such significant rainfall might be predicted over the immediate neighbourhood during the same time frame.

6. Conclusion

Doppler Weather Radar can be further exploited by relaying its data / information to other neighbouring

airfields for safe conduct of flying operations. It is a very good tool to track the movement of significant weather echoes around the airfields, which can be very helpful in issuing appropriate warnings / advisories with sufficient lead time. Meso-scale NWP models are capable of generating reliable indications for expected convective activity atleast 24-36 hours in advance. Short-range weather forecasts through NWP models can be used as an advance indication for careful monitoring of DWR images in near real time. The integration of both the inputs can increase the accuracy and reliability of location and time specific prediction of convective activity.

One of the known facts about radar echoes is that these are sensitive to the seasons. Intensity of radar echoes associated with convective activity during pre-monsoon season over NW India generally remains much less compared to the convective activity during SW monsoon. The reason behind this may be presence of much higher amount of moisture in the atmosphere during SW monsoon season. As a future plan, authors are planning to examine several cases of convective phenomena during pre-monsoon and SW monsoon seasons of 2009 and 2010 in order to provide quantitative findings and differences between characteristics of echoes during the two seasons.

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