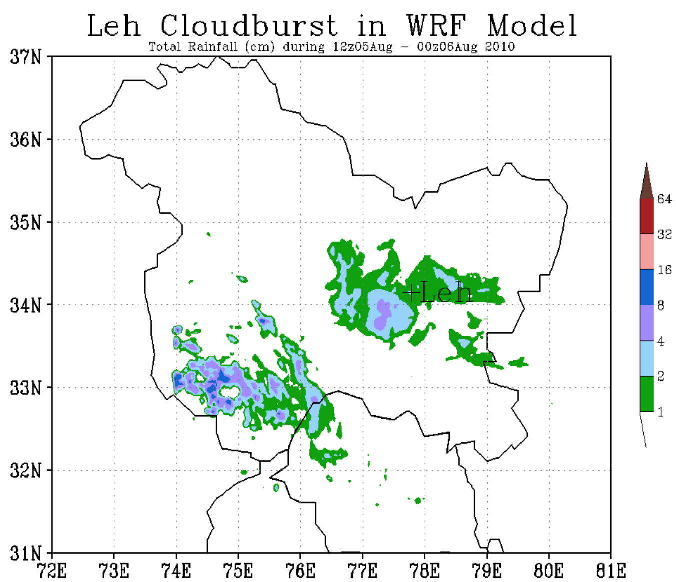
NCMRWF

NMRF/RR/10/2010

RESEARCH REPORT

Investigating the Leh 'Cloudburst'

Raghavendra Ashrit



October 2010

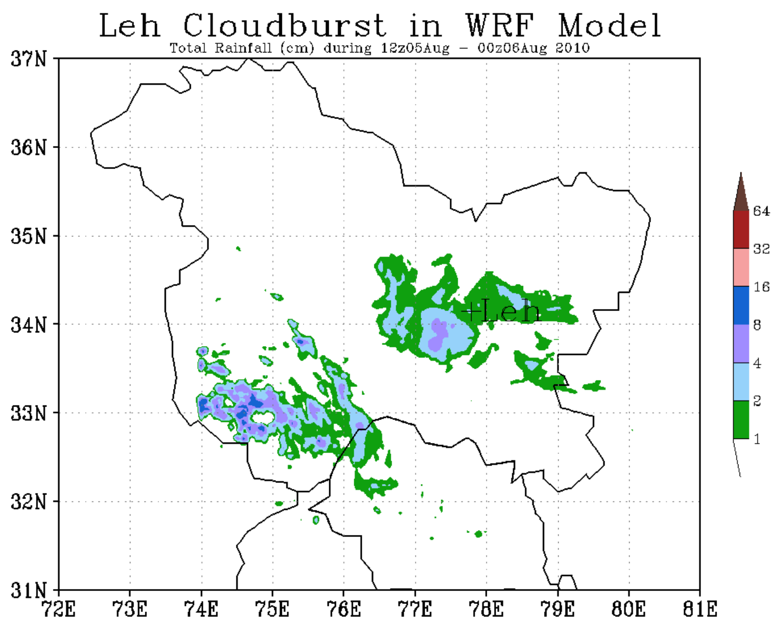
National Centre for Medium Range Weather Forecasting

Ministry of Earth Sciences

A-50, Sector 62, NOIDA – 201307, INDIA

Investigating the Leh 'Cloudburst'

Raghavendra Ashrit



National Centre for Medium Range Weather Forecasting

Ministry of Earth Science

A-50, Sector -62, NOIDA -201307, INDIA

Abstract

The August 6th 2010 Leh Cloudburst caused one of the worst case of flash flood in the Leh (Ladhak) leading to over 200 deaths and huge loss to normal life, civic amenities and infrastructure. In an earlier attempt Das *et al* (2006) simulated the 6th July 2003 cloudburst event that ravaged the Shillagarh in Himachal Pradesh and demonstrated the capability of the high resolution numerical models (3Km) in simulating cloudburst like systems. This forms the motivation for a detailed investigation into the Leh cloudburst event.

High resolution nested WRF model (9 and 3km) is used to simulate the Leh cloudburst event. The results from the 3Km WRF experiment show peak intensity between 1500-1800 UTC as indicated by the Tropical Rainfall Measuring Mission (TRMM) satellite based precipitation estimates. The model simulated highest rainfall amounts exceed 4 cm in three hours. In close agreement with TRMM estimates, the model simulation shows very little rainfall south of Leh region between 0300-0900UTC. The simulation features the isolated nature and rapid intensification typical of a cloudburst.

To further understand the evolution and intensification of the cloudburst in the model, vertical cross section of the cloudburst is constructed to study the thermodynamic characteristics. The cross-section analysis suggests that the cloudburst evolved in a deep humid layer of flow from the northwest of the Leh capped by relatively cold and dry flow from the east and southeast. This capping seems to inhibit the release of instability. The instability trigger seem to have come from the cloud cluster that moved from Nepal

1. Introduction

On 6th August, 2010 a cloud burst was reported near Leh in Jammu and Kashmir around 0130–0200 hours IST as per the India Meteorological Department report (IMD, 2010). The National Disaster Management (NDM) cell under the Ministry of Home Affairs (MHA) note in their situation report dated 6th August 2010 that this cloudburst hit the Leh region at around 0100-0200 hrs after torrential rains in the intervening night of 5-6 August, 2010. The report also notes that this cloudburst triggered flash floods in Choglumsar and Pathar Sahib villages and the surrounding areas of Leh township. The NDM flood situation report gives full details on the extent of disaster and recovery in the subsequent days. As of 25th Aug 2010 the total number of casualties reached 196 (including six foreigners) and the normalcy in basic civic amenities, like water supply, electricity, communication, health, transport, aviation and tourism was restored only by end of August.

According to the India Meteorological Department (IMD) a cloudburst features very heavy rainfall over a localized area at a very high rate of the order of 100mm per hour featuring strong winds and lightning. It is a remarkably localized phenomenon affecting an area not exceeding 20–30 km**2. A cloudburst occurs during monsoon season over the regions dominated by orography like Himalayan region, northeastern states and the Western Ghats. They are likely to occur when monsoon clouds associated with low-pressure area travel northward from the Bay of Bengal across the Ganges plains onto the Himalayas and 'burst' in heavy downpours (75–100mm per hour). The associated convective cloud can extend up to a height of 15 km above the ground. It represents cumulonimbus convection in conditions of marked moist thermodynamic instability and deep, rapid dynamic lifting by steep orography. Cloudburst events over remote and unpopulated hilly areas often go unnoticed until casualties are reported by the media.

The IMD report (IMD, 2010) following the Leh cloudburst, based on the satellite imagery suggests that a convective system developed in the easterly current associated with monsoon conditions over the region. The convective cloud band extending from southeast to northwest developed over Nepal and adjoining India in the afternoon of 5th August. It gradually intensified and moved west-northwestward towards Jammu & Kashmir. An intense convective cloud cluster developed to the east of Leh by 2130 hours IST of 5th August which resulted in a cloudburst event between 0130-0200 IST of 6th Aug 2010. However, analysis based on the Tropical Rainfall Measuring Mission (TRMM) products gives a slightly different picture about the location and time of the event. Figure 1 shows the TRMM multi-satellite precipitation analysis (3B42_V6). The 3 hourly accumulated rainfall estimate shows peak rainfall intensity between 1500 to 1800 UTC. Prior to the event there was almost no rain near Leh (indicated by star). The 3 hour accumulated rainfall between 1500-1800 UTC exceeds 4 cm south of Leh. Figure 2 shows the rainfall estimates from the TRMM intermediate IR product (3B41RT). This product indicates significant rainfall activity along with high amounts in the region after 0900UTC. The IR product however suggests some agreement with the IMD reports of rainfall over the Leh region after 1800 UTC.

2. Aim of the study

The NCMRWF operational forecast based on the 0000UTC of 5th August 2010 suggested isolated rainfall activity near the Leh region (Figure 3). These forecasts are based on the WRF (WRF-ARW) model with horizontal resolution of 27 Km (for details please see http://www.ncmrwf.gov.in ; Ashrit and Saji Mohandas 2010). The model prediction suggests peak rainfall activity to the south of the Leh region which in principle agrees with the TRMM rainfall valid at 1800 UTC. Although the model predicted rainfall amounts and the location do not completely agree with the TRMM products, the predicted timing of the event at 1800 UTC seems encouraging. Using a numerical model of horizontal grid spacing of 27 Km, it would be unrealistic to expect a very accurate prediction of the cloud scale systems. Cloudbursts belong to meso-gamma scale (2-20Km) as defined by Orlanski (1975). In an earlier attempt Das *et al* (2006) simulated the 6^{th} July 2003 cloudburst event that ravaged the Shillagarh in Himachal Pradesh and demonstrated the capability of the high resolution numerical models (3Km) in simulating cloudburst like systems. This forms the motivation for a detailed investigation into the Leh cloudburst event.

3. Experimental Design

The high resolution experiments using a nested domain of 3 and 9 Km grids, along with the T254L64 global model analysis fields (in place of forecast fields) is carried out to simulate the Leh cloudburst event. The domain and model configuration are briefly summarized in Figure 4 and Table 1. As per the United States Geological Survey (USGS) land use classification, the Leh region features the land use categories 22 (Mixed tundra) and 23 (Bare ground tundra) and is located at an altitude of 3513 m above the sea level. The original 30s USGS data (land use and elevation) are gridded on to the WRF model grids at 3 & 9 Km resolution. The model is initialized using the 0000UTC analysis from the T254L64 model. The lateral boundary conditions are updated at 6 hr interval using the T254L64 analysis fields. The 27 Km operational domain provides the boundary conditions for the nested domains. The model features non-hydrostatic configuration and non-interactive nesting. Table 1 lists the model specifications in brief. For parameterization of convection, the Kain-Fritsch (new Eta) scheme is used (Kain and Fritsch 1990 and 1993). As with the original KF scheme, it utilizes a simple cloud model with moist updrafts and downdrafts, including the effects of detainment, entrainment, and relatively simple microphysics.

4. Results

4.1 Tropospheric Circulation

The circulation and relative humidity in the lower (850 hPa), middle (550 hPa) and upper (400 hPa) troposphere are shown in Figure 5 (a-f)for

0600 UTC (left panels) and 1200 UTC (right panels) of 5th August 2010 based on the T254L64 analysis. The 850 hPa flow is typical of active monsoon condition with high humidity in the lower troposphere. The winds in the lower troposphere are prominently south easterlies from the Bay of Bengal all along the Himalayas. Circulation in the lower troposphere clearly indicates large scale moisture transport towards northwest India. Circulation at 550 hPa shows moisture incursion towards the western Himalayas. This is prominent west of 85 E at 0600 and 1200 UTC. At 400 hPa the streamlines indicate easterlies all over the Himalayas. Other dominant feature is an upper level anticyclone in the western part of Jammu & Kashmir. Over the Leh region and neighborhood the upper level winds are easterlies. The flow from over the Himalayas can be considered by and large dry and cold compared to the warm and humid flow pattern in the lower levels. The conditions clearly suggest a situation in which warm and humid air from the monsoon flow is capped under cold and dry flow aloft. These synoptic conditions form the background for the mesoscale model experiments. The analysis based on the T254L64 analysis suggests conditions favorable for development of instability particularly over mountains. The results from the WRF model are discussed in the next section.

4.2Precipitation

The WRF model experiments carried out are similar to the operational runs with only difference being (a) the use of nested domains for resolving the high resolution features of the local topography and (b) the use of the analysis instead of the forecast boundary conditions. As can be seen from Figure 4 the location of the Leh region in the valley, surrounding topography and the local land use characteristics resolved only at 9 Km which further shows improvement at 3 Km resolution. The 3 hour accumulated rainfall as simulated in the 9 Km domain are shown in Figure 6. The impact of enhanced spatial resolution is prominent in Figure 6 (9 Km) when compared to Figure 3 (27 Km). Peak rainfall intensity is captured to the south of Leh region at 1500 and 1800UTC. Similarly the results from the 3 Km domain (Figure 7) also indicate peak intensity between 1500-1800 UTC. In both the domains, the peak rainfall amounts exceed 4 cm in three hours. The simulations show very little rainfall south of the Leh region between 0300-0900 UTC. This feature is similar to what is observed in the TRMM rainfall estimates (Figure 1). The WRF model simulation features the isolated nature and rapid intensification typical of a cloudburst.

4.3Vertical Structure

The evolution and intensification of the cloudburst in the model is discussed briefly in this section. For this purpose vertical cross section of the cloudburst is constructed to study the thermodynamic characteristics. The Figure 8a shows maximum reflectivity (max_dbz) and winds at 600 hPa at 1200 UTC. High reflectivity (>40 dbz) indicates deep convection. The cross sections are constructed about the line indicated by A and B. The vertical cross section of reflectivity from the hydrometeors is shown as shaded (>20 dbz) in Figure 8b,c and d. In the Figure 8b the tangential wind normal to the cross section AB is shown in contours. The magnitudes <0 (>0) suggest north-westerlies (south-easterlies). The north-westerlies extend from near surface (11 m/s) up to 200 hPa (13 m/s) mainly over regions of high reflectivity. Strong south-easterlies seem to form an envelope around the flow from north-west. Figure 8c shows the cross-section of relative humidity. The regions of high reflectivity feature higher relative humidity (~80% or more). In the Figure 8d cross-section of vertical velocity contours is presented along with reflectivity. Positive contours (updrafts) are in the interval of 50 cm/s and negative contours (downdrafts) are in the interval of 20 cm/s. Strong updrafts (>400 cm/s) indicating deep convection are located in the middle (area of highest reflectivity). The updrafts are surrounded by downdrafts from the anvil. The downdrafts exceed 80 cm/s.

Similar cross-section analysis for 1400 UTC and 1500 UTC are presented in Figure 9 and 10 respectively. At 1400 UTC (Figure 9) the cloudburst attains peak intensity as shown by high reflectivity (Figure9a).

The cross-section of the reflectivity and tangential wind (Figure 9b) shows development of south-easterlies close to the surface with overlapping flow from the north-west. The reflectivity features highest magnitudes close to the surface. High relative humidity (>80%) is spread all across the developing storm with concentration close to the ground (Figure 9c). The vertical velocity cross-section (Figure 9d) shows strong downdrafts close to the surface. Highest reflectivity close to the surface is a manifestation of the intense downdrafts and rainfall activity. The cross section of reflectivity features a minor but distinct discontinuity between 500 and 400 hPa which also seems to separate downdrafts below from the updrafts. At 1500 UTC (Figure 10) the cloudburst features reduced intensity. The system is also shifted towards west. The cross section also shows reduction in the horizontal extent of the storm. This can be inferred from weaker updrafts although the downdrafts continue to be strong close to the surface.

The time series of the Reflectivity (dBz), CINE (J/Kg) and CAPE (J/Kg) for the location of highest rainfall intensity in the model (34.15°N N/77.72°E) is shown in Figure 11. CAPE gives the accumulated buoyant energy from the LFC to the equilibrium level while CINE gives the accumulated negative buoyant energy from the parcel starting point to the LFC. The time series of reflectivity shows intense convective activity starting around 1200 UTC. The CAPE shows a peak value excess of 1000 J/Kg at 10 00UTC. Following the development of convection the CAPE drops drastically and the CINE shows peaking at 1200UTC.

5. Discussion

The large-scale tropospheric flow south of the western Himalayas discussed in section 4.1 and the cross-section analysis discussed in section 4.3, suggest that the cloudburst evolved in a deep humid layer of flow from the northwest of Leh region. The flow from the east and southeast is relatively cold and dry as can be understood from Figure 5 e,f. The high resolution experiments further confirm the capping of relatively warm humid flow (Figure 8b, 9b and 10b) from the northwest. This capping seems to inhibit the release of instability. This feature during the Leh cloudburst partly seem to follow the processes described in Socorro et al (2010), a study on the deep convection close to Western Himalayas over Pakistan. The case of deep convective system discussed in Socorro et al (2010) mainly features moist Arabian Sea low-level air traversing desert land, where surface flux of sensible heat enhances buoyancy. As the flow approaches the Himalayan foothills, the soil may provide an additional source of moisture if it was moistened by a previous precipitation event. Low-level and elevated layers of dry, warm, continental flow apparently cap the low-level moist flow, inhibiting the release of instability upstream of the foothills. The convection is released over the small foothills as the potentially unstable flow is orographically lifted to saturation. However in the case of Leh cloudburst, the flow from the west or northwest seems to be sufficiently moisture rich following intense convection and flooding in northeastern parts of Pakistan in late July and early August 2010. The instability trigger seem to have come from the cloud cluster that moved from Nepal region (IMD 2010).

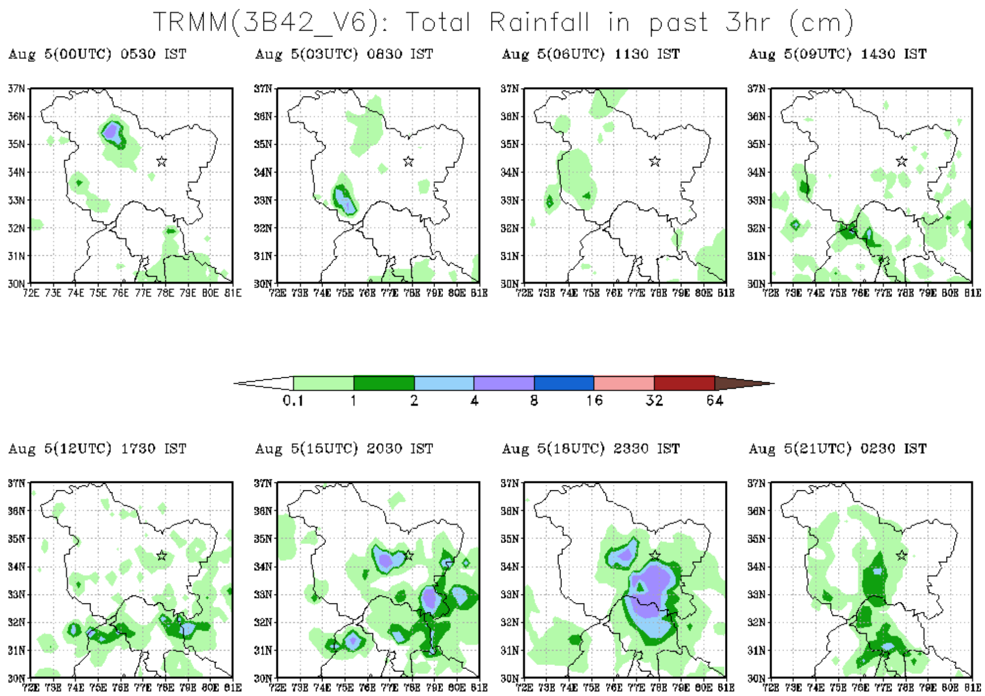


Figure 1. Accumulated 3h rainfall on 5th Aug 2010 as per TRMM product 3B42RT

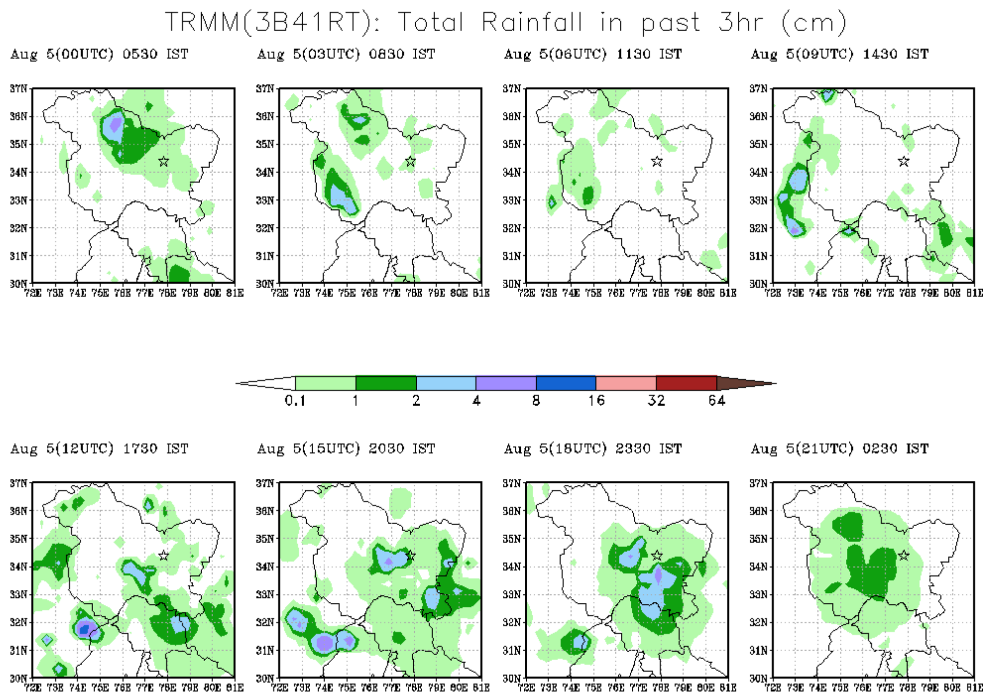


Figure 2. Accumulated 3h rainfall on 5th Aug 2010 as per TRMM product 3B41RT

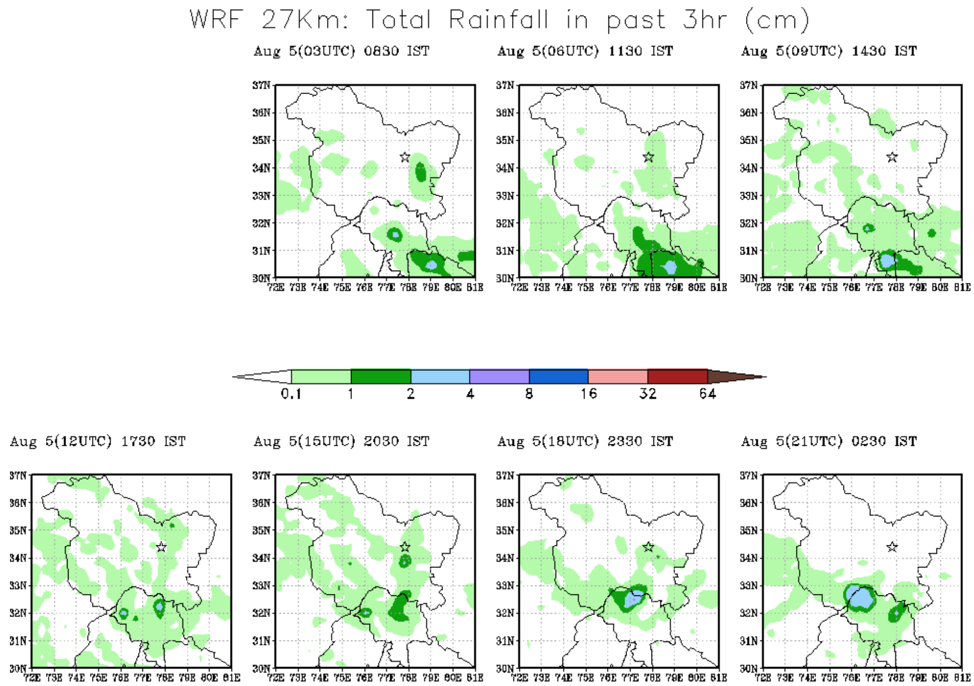


Figure 3. Accumulated 3h rainfall on 5th Aug 2010 in the operational WRF model.

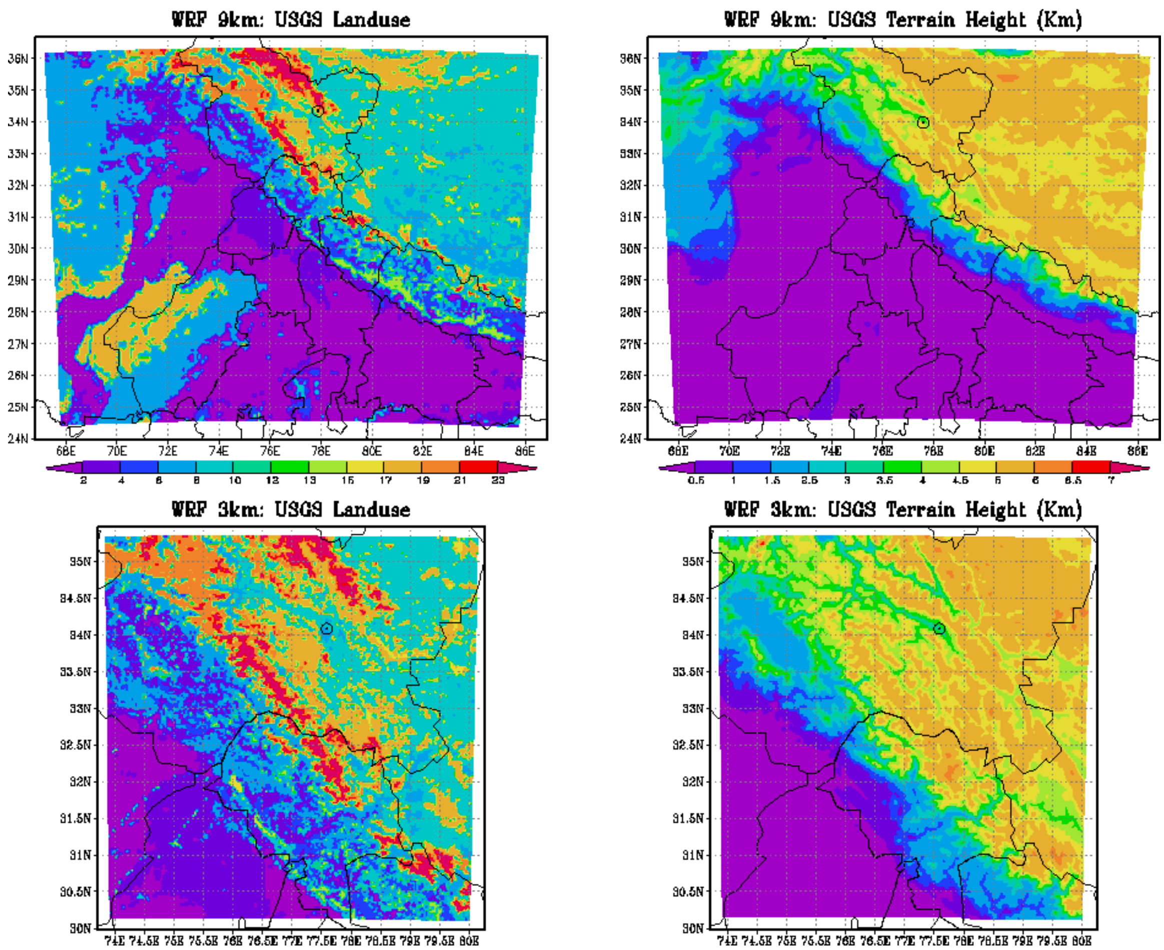


Figure 4. High resolution WRF model domains showing the USGS 9Km (top) and 3 Km (bottom) land use (left) and terrain height.

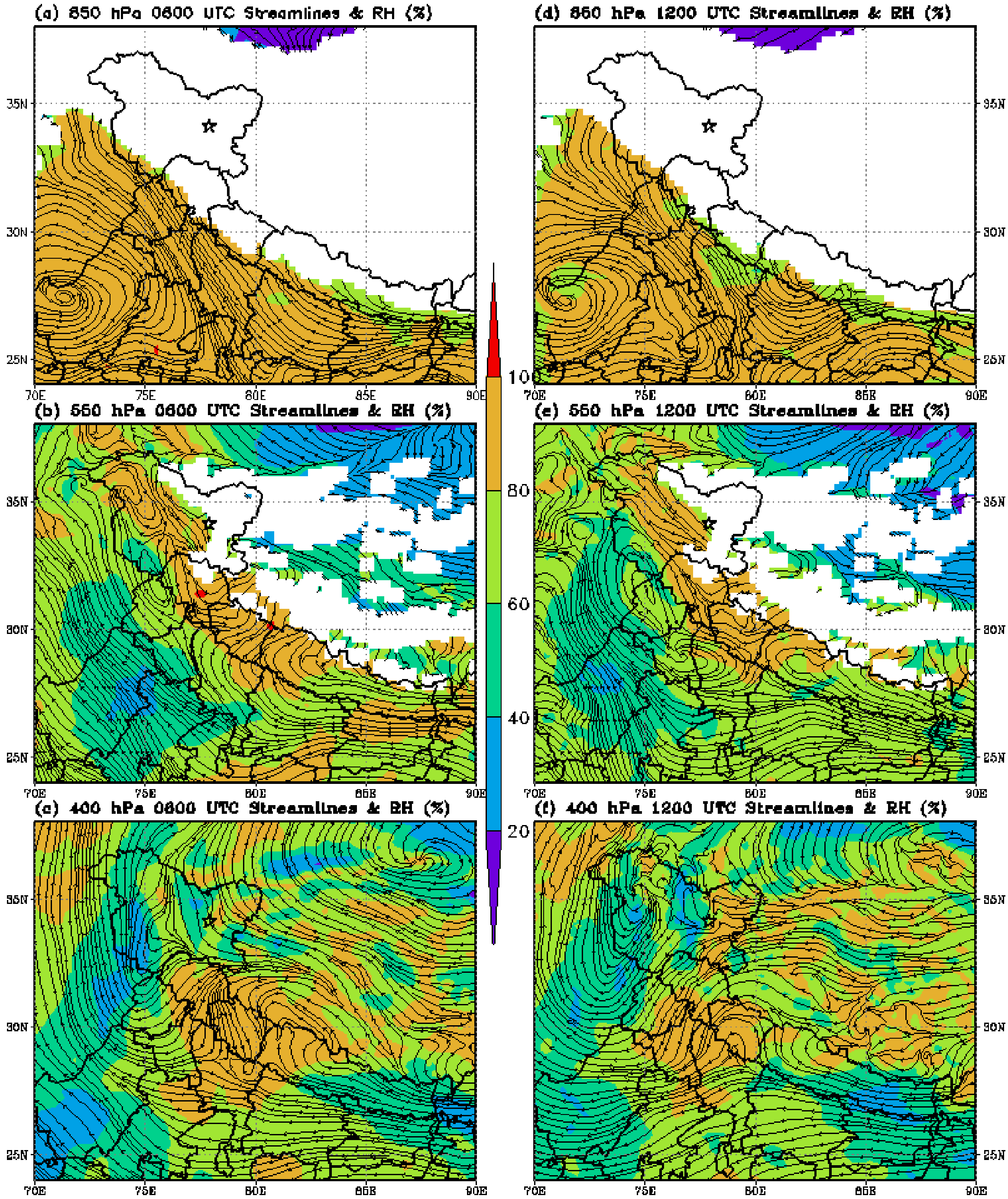


Figure 5 Synoptic features shown by the streamlines and Relative Humidity at 850, 550 and 400 hPa (a,b and c respectively) at 0600UTC of 5th Aug 2010. Panels on the right (d, e and f) are same as a,b and c respectively but for 1200UTC of 5th Aug 2010.

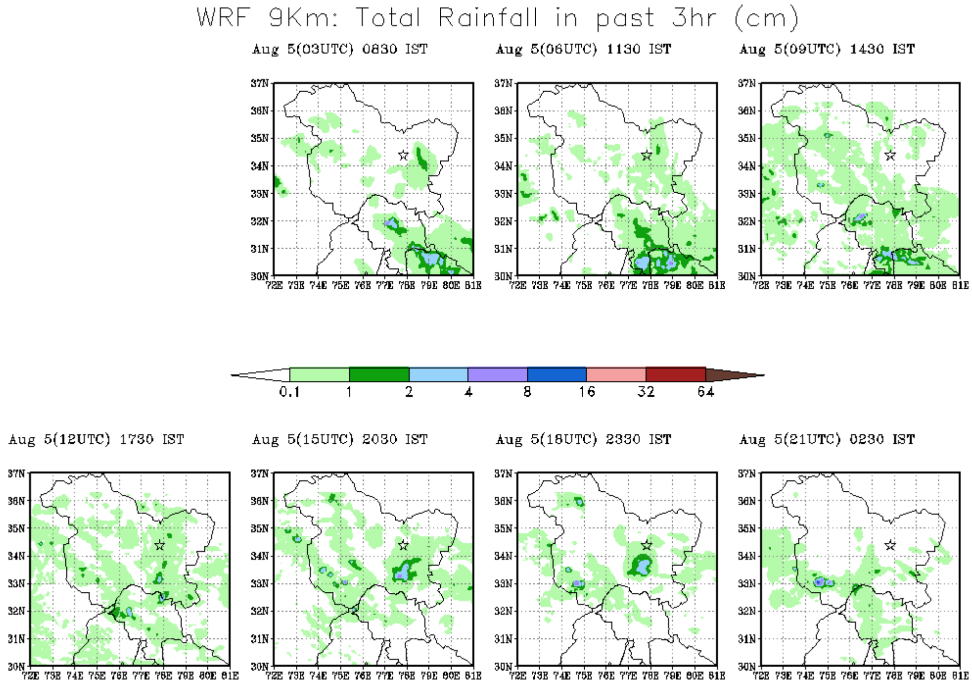


Figure 6 Accumulated 3h rainfall on 5th Aug 2010 in the 9 Km WRF model.

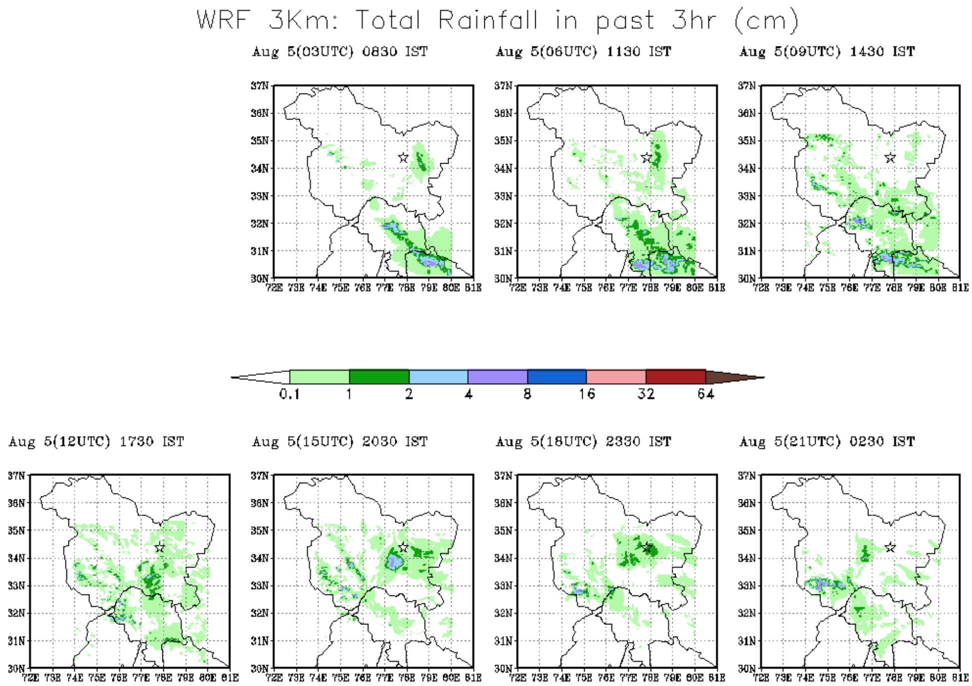


Figure 7 Accumulated 3h rainfall on 5th Aug 2010 in the 3 Km WRF model.

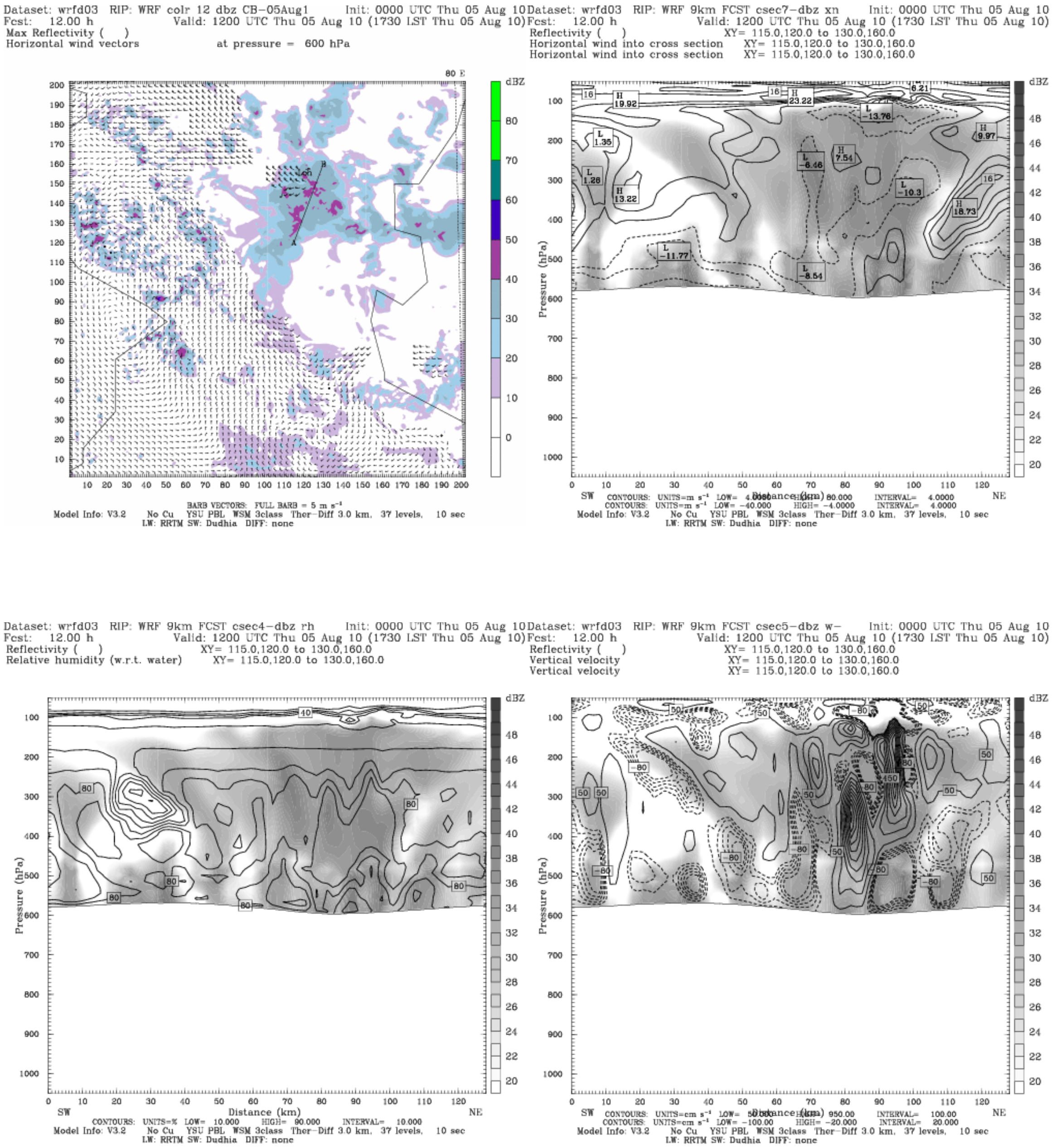


Figure 8 (a) Winds at 600 hPa and Max reflectivity (dbz) at 1200UTC in the WRF model simulation. (b) Tangential wind (Vt) perpendicular to the cross-section AB (c) Relative Humidity (%) and (c) Vertical velocity. Shaded area in b,c and d indicate reflectivity from the hydrometeoros > 20 dbz

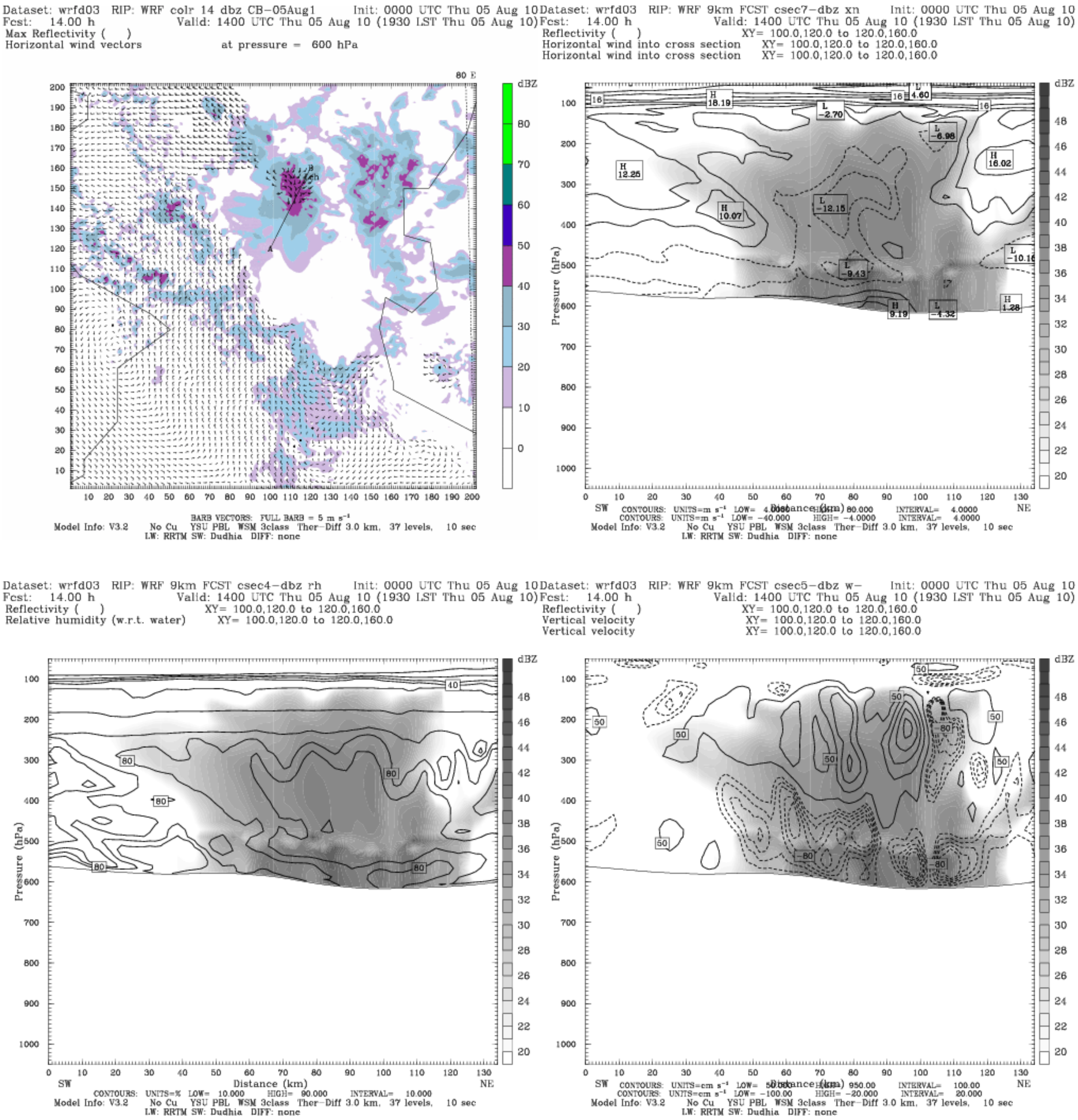


Figure 9 (a) Winds at 600 hPa and Max reflectivity (dbz) at 1400UTC in the WRF model simulation. (b) Tangential wind (Vt) perpendicular to the cross-section AB (c) Relative Humidity (%) and (c) Vertical velocity. Shaded area in b,c and d indicate reflectivity from the hydrometeoros > 20 dbz

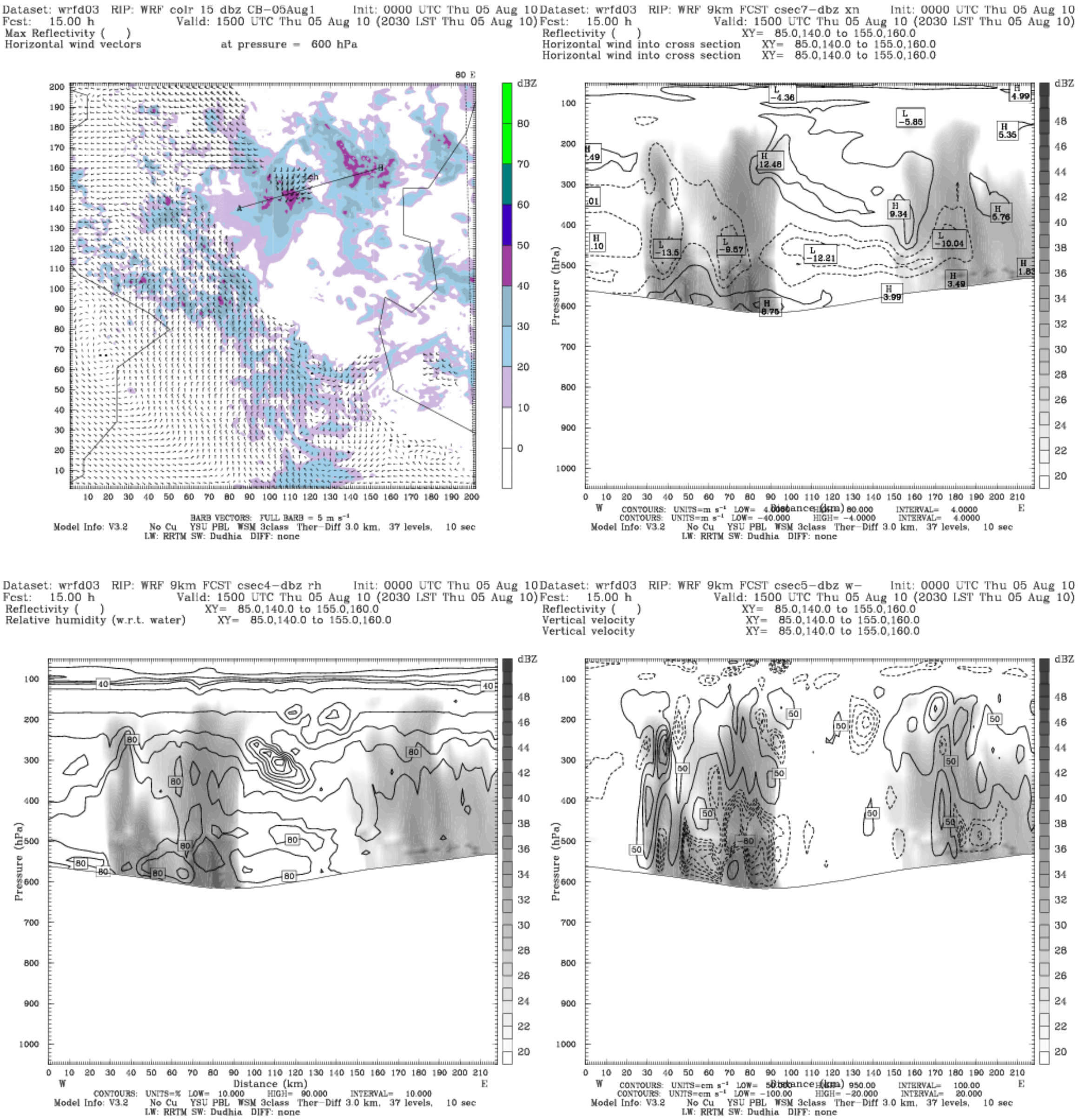


Figure 10 (a) Winds at 600 hPa and Max reflectivity (dbz) at 1500UTC in the WRF model simulation. (b) Tangential wind (Vt) perpendicular to the cross-section AB (c) Relative Humidity (%) and (c) Vertical velocity. Shaded area in b,c and d indicate reflectivity from the hydrometeoros > 20 dbz

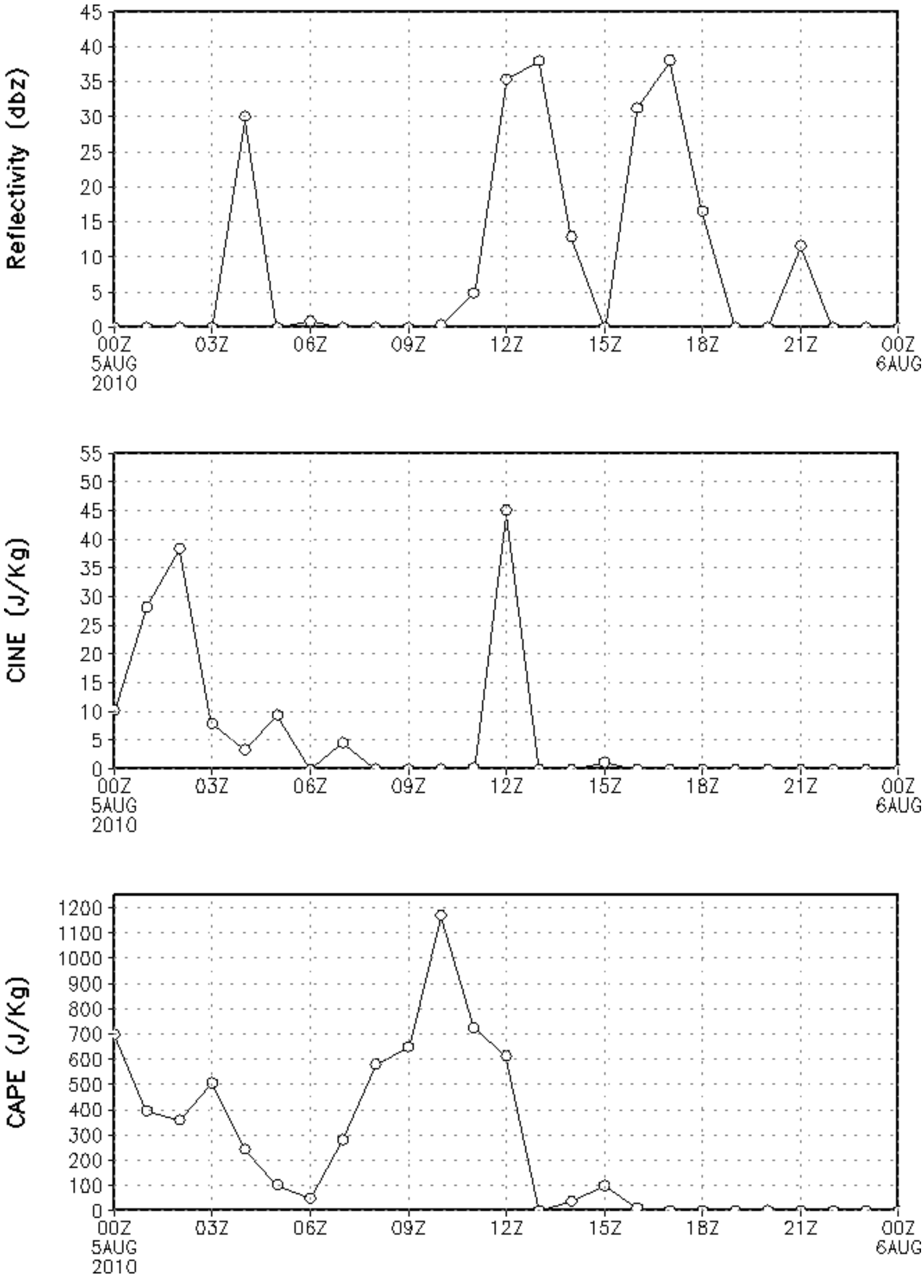


Figure 11. Time series of model simulated Reflectivity (dBz) from the hydrometeors, CINE (J/Kg) and CAPE (J/Kg) at 34.15°N N/77.72°E

Table 1 WRF Model Configuration Details

	WRF
Horizontal Resolution	27, 9 and 3 km.Arakawa-C Grid
Vertical Levels	38
Topography	USGS
Time Integration	Semi Implicit
Time Steps	120 s
Vertical Differencing	Arakawa's Energy Conserving Scheme
Time Filtering	Robert's Method
Horizontal Diffusion	2nd order over Quasi-pressure, surface, scale selective
Convection	Kain-Fritsch
PBL	YSU Scheme
Cloud Microphysics	WSM3-Class Simple Ice
Radiation	RRTM (LW) Dudhia (SW)
Gravity Wave Drag	No
Land Surface Processes	Thermal Diffusion

References

Das, S., Raghavendra Ashrit and M. W. Moncrieff 2006: Simulation of a Himalayan cloudburst event. J. Earth Syst. Sci., 115(3), 299-313.

IMD 2010: Cloudburst over Leh (Jammu & Kashmir)

Kain, J. S., and J. M. Fritsch, 1990: A one-dimensional entraining/ detraining plume model and its application in convective parameterization, J. Atmos. Sci., 47, 2784–2802.

Kain, J. S., and J. M. Fritsch, 1993: Convective parameterization for mesoscale models: The Kain-Fritcsh scheme, The representation of cumulus convection in numerical models, K. A. Emanuel and D.J. Raymond, Eds., Amer. Meteor. Soc., 246 pp.

NDM 2010: Southwest Monsoon-2010: Daily flood situation report. SITREP No-67/2010. (http://ndmindia.nic.in/flood-2010/floodsAug.htm)

Orlanski I 1975: A rational subdivision of scales of atmospheric precesses. Bull. Amer. Meteor. Soc., 56, 527-530.

Socorro Medina, Robert A. Houze, Jr., Anil Kumar and Dev Niyogi 2010: Summer monsoon convection in the Himalayan region: Terrain and land cover effects. Q. J. R. Meteorol. Soc. 136: 593–616,