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ORIGINAL PAPER

An investigation on the dynamic and scale interactive processes for estimating the predictability of cloudburst over elevated orography

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Abstract The cloudburst is defined as a heavy downpour at a very high rainfall rate over small spatio-temporal scale. The Indian states of Uttarakhand (30°15′N; 79°15′E) and Himachal Pradesh (32°29′N; 75°10′E) are prone to cloudburst due to its geographical setup. The large-scale monsoon flow along with elevated orography makes cloudburst phenomena frequent a well as severe over the regions. However, cloudburst and the heavy rainfall events occasionally, become difficult to distinguish. The present study attempts to identify the processes associated with cloudburst over elevated orography and compare it with one of the most debated event of 2013 which was reported as heavy rainfall but, not a cloudburst by Indian Meteorological Department (IMD). The temporal variations of rainfall and cloud-top pressure (CTP) are considered to identify the genesis of the event. The vertical developments of the system along with large-scale circulation pattern are estimated in the present study. The result of the study reveals that the mid-tropospheric dry entrainment, low-level temperature inversion and cloud height clearly distinguish the "cloudburst" and "heavy rainfall" events and confirms that the system of 2013 was indeed a heavy rainfall event and not a cloudburst.

Keywords Cloudburst · Dynamics · Scale interaction · Monsoon · Uttarakhand · Himachal Pradesh

1 Introduction

A cloudburst is characterized by a very heavy rainfall over a small localized area at a very high rainfall rate of order of 100 mm per hour along with strong winds and lightning (Srivastava and Bhardwaj 2014). The affected area does not exceed 20–30 square km. The

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western Himalayan region experiences the cloudburst during summer monsoon season due to strong monsoon circulation as well as the interaction of monsoon circulation with mid-latitude westerly system. The cloudburst is also likely to occur when monsoon clouds associated with low-pressure area travel northward from Bay of Bengal across the Ganges plain toward the Himalayas and bursts in heavy downpours. The elevated orography of the area also plays a significant role in intensifying the system. The orography enhances the convection, and associated convective cloud extends up to a height of 15 km above the ground level. It represents cumulonimbus convection condition with marked moist thermodynamic instability and deep, rapid dynamic lifting through elevated orography. The cloudburst occurs over remote, and unpopulated hilly areas often remain unnoticed; however, the casualties are reported by different media. The cloudburst event belongs to meso-gamma scale (2–20 km) (Orlanski 1975). This phenomenon is one of the least understood mesoscale systems. The mesoscale processes are known to be influenced by surface elevation, moisture, snow cover, temperature, vegetation and surface roughness which are categorized into two sub-divisions: (1) systems that are forced by instability which are in motion (example; squall line, mesoscale convective system) and (2) systems that are induced by terrain heights (example; mountain or valley circulation). Paegle et al. (1990) recommended that the terrain-influenced circulation is intrinsically more predictable than the synoptically induced flows, which are susceptible to the initialization problem in the numerical models. In complex terrain region, the mesoscale predictability may be enhanced because of deterministic connections between synoptic-scale flows and the underlying topography (Mann and Kuo 1998). Challenges in forecasting the cloud-scale phenomenon like cloudburst are based on several factors like interaction between terrain and synoptic-scale circulation, latent heating or cooling and uncertainties in cloud microphysics. Shukla et al. (2014) have tried to improve satellite image-based nowcasting capability of models by coupling a clustering technique into a spatio-temporal auto-regression method. Studies on the mechanism of orographic rainfall have been carried out by Bougeault et al. (2001). The analysis of cloudburst over Leh (34°10′N; 77°40′E) shows varieties of synoptic features (Ashrit 2010). The study shows that low-level warm and moist air are capped under cold and dry air aloft. The capping seems to inhibit the release of instability upstream of the foothills. The instability released over the small foothills as the potentially unstable flow is orographically lifted to the saturation level. Socorro et al. (2010) show that the reason of severity of cloudburst is also associated with the convergence of moist air from the Arabian Sea at low level toward the desert land that enhances the buoyancy. The system, as approaches the Himalayan foothills, in the presence of desert soil over the region provides additional source of moisture. Cloudburst of 16 July 2003 has been simulated by Das et al. (2006). This study provides a conceptual model of cloudburst that consists of three stages of formation (Fig. 1). The model suggests that at the early stages of cloudburst, two convective cells are separated but drifted toward each other as a part of mean flow. At the mature stage, these two cells merge and intensify due to strong wind shear and intense vertical motion within the cells. The formation of anvil and heavy downpours along with southward movement of the cell is observed at this stage. At the dissipation stage, two cells are observed to merge to produce a large single cell that is drifted westward. The cloudburst then ceases its severity. The cloudburst is responsible for enormous damage to property and life through flash flood and land slide situations. Understanding the intricacies of the system is necessary for precise prediction of cloudburst with at least 6 h lead time. Rain gauges and radars are conventional tools used to monitor heavy rainfall events like cloudburst. Held (1982) evaluated radar observations of two same types of storms: First one is a half-hour-long hailstorm, and the other is a

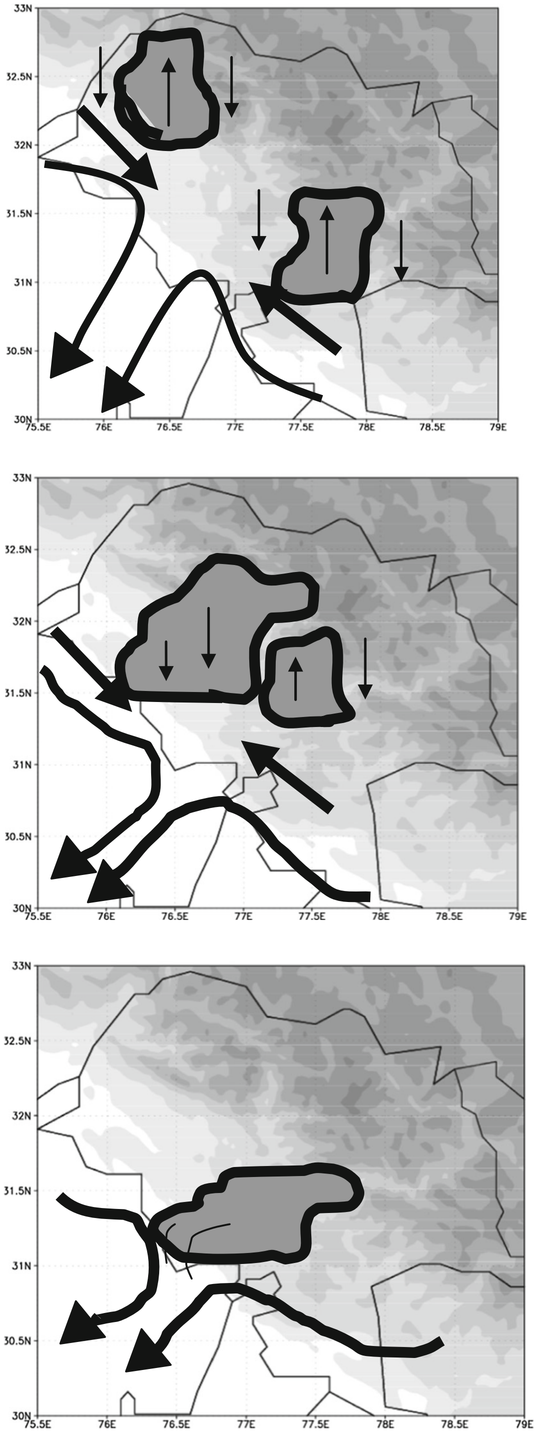

Fig. 1 Stages of cloudburst formation (courtesy: Das et al. 2006)

cloudburst event consisting of two episodes of very heavy rainfall, 174 mm/h over 20 min and 55.2 mm/h over 30 min. Both storms had similar radar signatures making it difficult to identify the cloudburst. The study shows that sometimes RADAR is not very useful to detect cloudburst phenomena. Kullu (31°88′N; 77°15′E), a state of Himachal Pradesh, India experienced a flash flood due to cloudburst on 21 July 2001 at 1:30 P.M. which affected the villages of Siund, Saran, Shesher and Thachan (Sharma, 2006). This cloudburst in the upper reaches of Sainj valley caused flash flood in two nallahs, namely Sainj and Jeeba and caused extensive damage to the habitation settled on either side of the main Sainj Nallah affecting nearly 40 families. Heavy downpour accompanied with cloudburst killed eight persons and left several others homeless in the Devpuri area, Chamoli district of Uttarakhand Himalaya, India on the night of 12 July 2007 (Naithani et al. 2011). Asi Ganga, a tributary of Bhagirathi river located upstream of Uttarkashi township, witnessed a massive flash flood on the night of 3 August 2012 due to cloudburst that occurred at the Pandrasu ridge that serves as a water divider between Yamuna and Bhagirathi rivers. On 13 September 2012, the Okhimath (30°30′N; 79°05′E) region in Rudraprayag district, Uttarakhand was revisited by cloudburst induced landslides which killed 66 people and damaged land and property. On that day, Okhimath Tehshil received 212.5 mm of rainfall (Rana et al. 2012).

The present study considers two cloudburst events over Himachal Pradesh and four over Uttarakhand. The cloudbursts are studied through diagnostic analysis of large-scale wind field, rainfall, cloud-top pressure (CTP) and temperature at vertical levels. The purpose of the present study is to identify the processes associated with cloudburst over elevated orography and then compare it with one of the most debated cloudburst event of 2013, reported as heavy rainfall by Indian Meteorological Department (IMD). The investigation reveals that the cloud-top pressure as well as low-level temperature inversion plays a significant role to precisely distinguish a "cloudburst" event from "heavy rainfall" event.

2 Data and methodology

The selected areas in the present study are Uttarakhand (28°–31°N; 77°–81°E) and Himachal Pradesh (30°–34°N; 75°–80°E). The domain of interest is a data-sparse region in the western Himalayas where only satellite observations are available to identify the cloudburst events. The data for the study are taken from Tropical Rainfall Measuring Mission (TRMM), Microwave Imager (TMI) and Precipitation Radar (PR) which is a 128-element active phase array system operating at 13.8 GHz, and Visible and Infrared Radiometer System (VRS). The TRMM also carries the Cloud and Earth's Radiant Energy System (CERES) and the Lightning Imaging System (LIS). The PR is most useful for the three precipitation sensors on TRMM. In the present analyses, the horizontal resolution of PR is taken to be 4.3 km; vertical resolution is 250 m, swath width is 215 km and sensitivity <0.7 mm/h (Kummerow et al. 1998). The data of 3-hourly rainfall (mm/h) is collected from TRMM (3B42 V7) (http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=TRMM_3-Hourly) (Liu et al. 2012). Though rainfall amount has been underestimated by TRMM, time and spatial location has been depicted quite rightly. The 3-hourly data of cloud ice mixing ratio (CIMR), cloud liquid mixing ratio (CLMR) zonal and meridional wind, vertical velocity, relative humidity cloud-top pressure (CTP) and cloud-top temperature (CTT) are collected from Modern Era Retrospective-Analysis for

Research and Applications (MERRA) (Rienecker et al. 2011). The MERRA is a NASA reanalysis for the satellite era using a major new version (V5) of the Goddard Earth Observing System (GEOS) which is data assimilation System (DAS). MERRA provides the above data at spatial resolution of 0.5 $\times$ 0.625 and temporal resolution of 3 h from 1980 present. Each of the date of cloudburst mentioned here are taken from several studies and reports. The 3-hourly TRMM rainfall rate (in mm/h) and CTP are plotted to detect the time of cloudbursts. To understand the development of the system, preceding day of the cloudburst has also been taken into consideration. The changes in vertical profile of the system with time have been estimated for Himachal Pradesh and Uttarakhand. The variability in CTP before the event has been evaluated. The data below 600 hPa were not available during the analysis; thus, full vertical profile could not be explored. Only the data of temperature (in K) were available. Hence, instead of analyzing the vertical profile, the thermal inversion from surface to different level has been estimated. The temperature (in K) inversion at 850 and 500 hPa with respect to 925 hPa pressure levels provides very significant results which has been considered in this study during the event and with a lead time of 3, 6 and 9 h.

3 Results and discussion

Six cases of cloudbursts are selected to identify the differences between cloudburst and heavy rainfall events by examining the vertical profile of CTP (hPa), CTT (K), ice-water content, wind and relative humidity. Among the six events, two events were reported over Himachal Pradesh (HP) (32°29′N; 75°10′E) and rest of the four over Uttarakhand (30°15′N; 79°15′E). The temporal variation of rainfall rate (mm/h) and CTP helps to detect the initiation time of the cloudburst. The present study thus analyzes five cloudburst events and compares them with the heavy rainfall events. The cloud-top pressure (CTP) signifies the height of the cloud. Low cloud-top pressure represents high convective cloud-top height, whereas high CTP represents relatively low cloud-top height. The time of the cloudburst is taken when the higher rainfall rate is associated with minimum CTP. The comprehensive analysis of different cases of the cloudbursts reported over Himachal Pradesh and Uttarakhand has been carried out.

The temporal variation of TRMM rainfall rate (mm/h) during 15–16 July 2003 shows two peaks (Fig. 2a). A sudden increase in rainfall at 21Z on 15 July 2003 followed by an abrupt decrease indicates a heavy downpour. The second peak has been observed at about 12Z of 16 July. The magnitude of rainfall rate of first event (0.85 mm/h) is observed to be higher than the second event (0.6 mm/h). The variation in CTP and CTT is observed to be similar (Fig. 2b). The minimum CTP at 21Z on 15 July shows higher cloud heights. Thus, 15 July at 21Z may be considered to have a cloudburst event. The changes in vertical profile of CIMR, CLMR and vertical velocity are estimated (Fig. 2c). The cloud ice mixing ratio is observed to be more than 9 gm/kg which shows higher ice content at 500–400 hPa pressure level at the time of the cloudburst. A small amount of liquid water content has been observed during the second event, whereas no such liquid phase has been observed during the first event. The negative vertical velocity depicts a downdraft which has been observed during the first event. Southwesterly flow has been observed at the mid-troposphere (600–400 hPa). The prevalence of relative humidity at the time of cloudburst may help to transport moisture by the southwesterly flow (Fig. 2d). The relative humidity implies the extent of saturation rather than moisture content. The vertical shear in

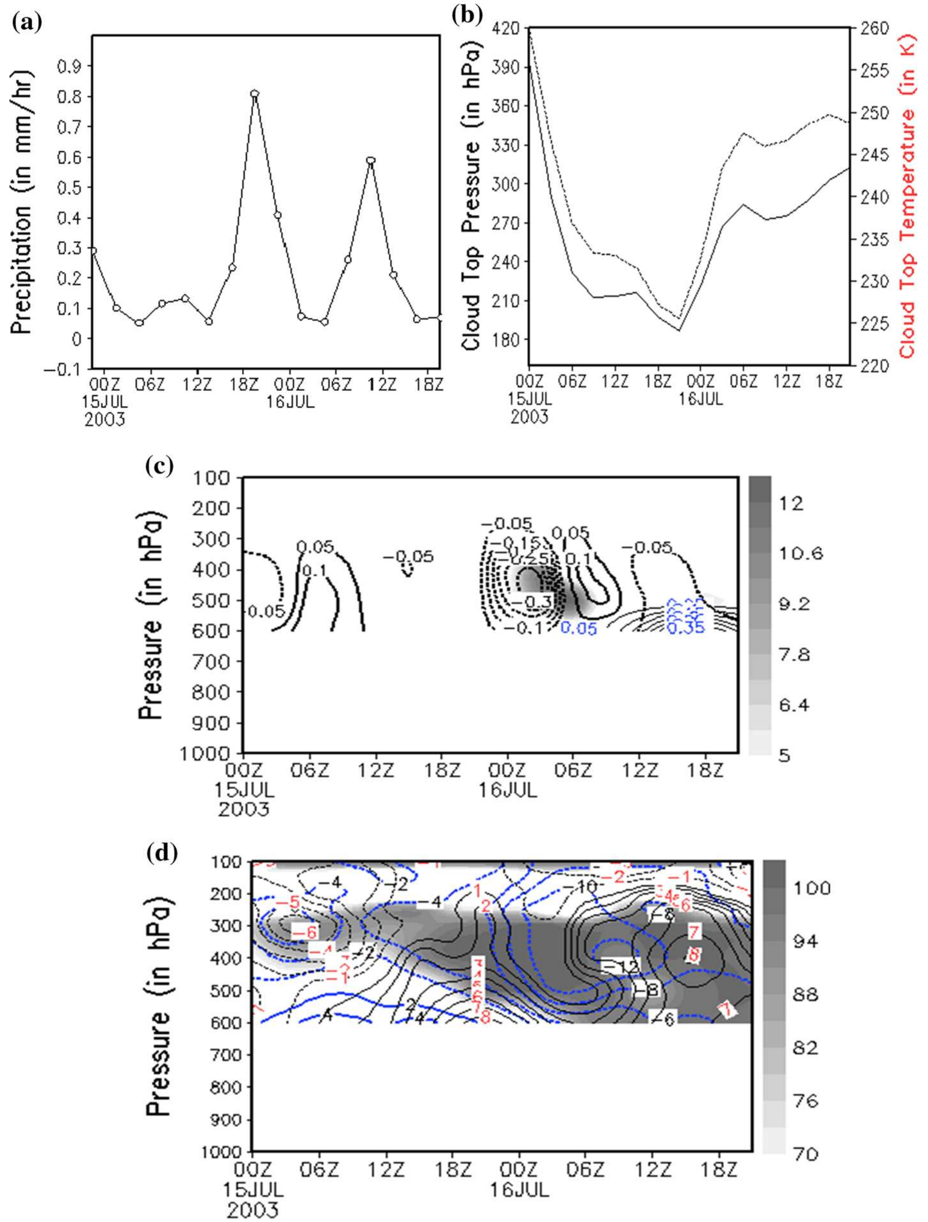

Fig. 2 Temporal variation of **a** precipitation along with **b** cloud-top pressure (*solid line*) and cloud-top temperature (*dotted line*) **c** cloud ice mixing ratio (*gray shaded*) and cloud liquid mixing ratio (*contour* with *blue label*) (vertical profile) and vertical velocity (in *bold contour*) **d** relative humidity along (*shaded*) with zonal (*blue contour*) and meridional wind (*black contour*) (vertical profile) on 15–16 July 2003 over Himachal Pradesh

meridional wind is observed to develop at 06Z that propagated up to 400 hPa level at 3–4 h prior to the cloudburst event which depicts that an upper level shear might have brought severity in the event.

On 21 July 2007 at 00Z, a heavy downpour over Himachal Pradesh has been observed with high rainfall rate of about 2.4 mm/h (Fig. 3a). The temporal variation in rainfall shows a strong solitary event on that day. The CTP and CTT show similar variation in this case also (Fig. 3b). Lowest CTP has been observed at 5 h prior to the cloudburst event, and subsequently, the CTP is observed to increase slightly but remained below 180 hPa which indicates the existence of cloud with high top height. At the time of rainfall, the CTP was

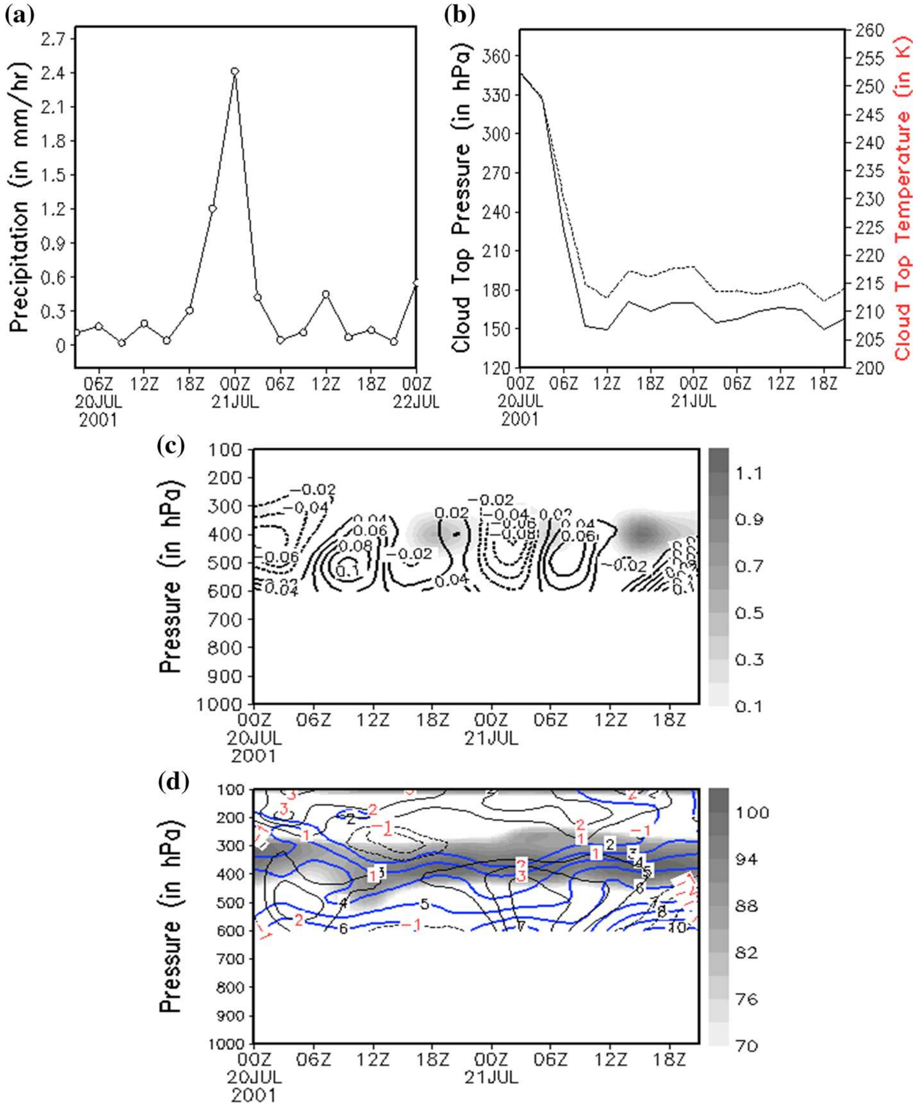

Fig. 3 Temporal variation of **a** precipitation along with **b** cloud-top pressure (*solid line*) and cloud-top temperature (*dotted line*) **c** cloud ice mixing ratio (*gray shaded*) and cloud liquid mixing ratio (*contour* with *blue label*) (vertical profile) and vertical velocity (in *bold contour*) **d** relative humidity along (*shaded*) with zonal (*blue contour*) and meridional wind (*black contour*) (vertical profile) on 20–21 July 2007 over Himachal Pradesh

observed to be below 180 hPa. Thus, the event on 21 July 2007 at 00Z may be considered as cloudburst event. The CIMR is observed to be below 1.1 g/kg which depicts low content of ice (Fig. 3c). At the time of sudden rain, the ice content was observed to be low which is associated with a downdraft having negative vertical velocity. Though the ice content was observed to be low, the presence of ice phase indicates it to be a severe system. The liquid water content at above 600 hPa pressure level is observed to be nil. Due to unavailability of the low-level data, the liquid water content could not be analyzed. Being a measure of saturation, high relative humidity at 300–400 hPa level represents a moist and near saturated layer (Fig. 3d). An easterly wind above 600 hPa is observed to prevail throughout the time of investigation. An upper level meridional shear has been observed at 3–4 h prior to the cloudburst event.

A sudden rainfall has been observed over Uttarakhand at 15Z on 6 July 2004 followed by a sharp increase in rainfall rate (in mm/h). The maximum rainfall rate is observed at 18Z on 6 July 2004 and subsequently a sharp decrease (Fig. 4a). The minimum CTP before the sudden rainfall has been observed to be around 180 hPa at 3–4 h prior to cloudburst (Fig. 4b). The CTP is observed to be minimum at 9Z of 7 July 2004, and the rainfall is observed to start increasing after 3–4 h. Thus, two cloudburst events have been observed. As the rainfall data are area averaged, so the area over which cloudbursts occur is not detectable. Two peaks in rainfall may or may not occur over the same region. Hence both events are considered as cloudburst on that particular day. The CIMR of about 1 g/kg depicts low ice content. Considering the two events as cloudburst, it is observed that second event has been associated with high ice content than first event whereas a week downdraft has been associated with first event at 300 hPa (Fig. 4c). A deep and saturated moist layer along with southwesterly wind is observed to prevail at 400 hPa level throughout the time of analysis (Fig. 4d). Northeasterly at around 100 hPa level may add upper level vertical shear to both the systems.

A sharp rise in rainfall rate at 9Z on 12 July 2007 can be attributed from the temporal variation in the rainfall rate (mm/h) followed by a decrease up to 6Z on 12 July 2007 (Fig. 5a). Subsequently, it was observed to rise again. The maximum rainfall rate before the first fall was observed to be about 1.3 mm/h at 18Z on 11 July and then attained the maximum at 18Z on 12 2007. Considering the CTP, these two rainfall rise may be considered as cloudburst events (Fig. 5b). It was observed that for the first event, the CTP was about 140 hPa and for the second event the CTP was about 130 hPa. Ice content was observed to be high at 21Z on 11 July 2007 and 00Z on 12 July 2007 at 400 hPa during the first event, and during the second event the ice content was high at around 18Z on 12 July at 500–600 hPa level. It was observed that during the first event the ice zone was linked with a downdraft which is not observed in the case of second event (Fig. 5c). The moist and saturated zone up to 300 hPa have been observed to be disturbed at 18Z on 11 July just prior to the first event. The decrease in relative humidity at 500–400 hPa pressure levels might be due to the mid-tropospheric entrainment. The enhancement in the relative humidity may be due to either decrease in temperature or moisture incursion. It was observed that the northerly has been replaced by southerly in the pressure levels 300–600 hPa (Fig. 5d). The upper level meridional shear is observed within 300 and 400 hPa pressure levels at the time of the first event. It is also observed that the westerly prevailed up to 300 hPa throughout the study period, while the easterly at 200–100 hPa might have generated zonal shear to the system.

The temporal variation in rainfall rate shows random variation resulting in high peak at 18Z on 13 September 2012. A sharp rise in rainfall at 18Z followed by shape decrease depicts a heavy downpour over Uttarakhand (Fig. 6a). The CTP also shows minimum

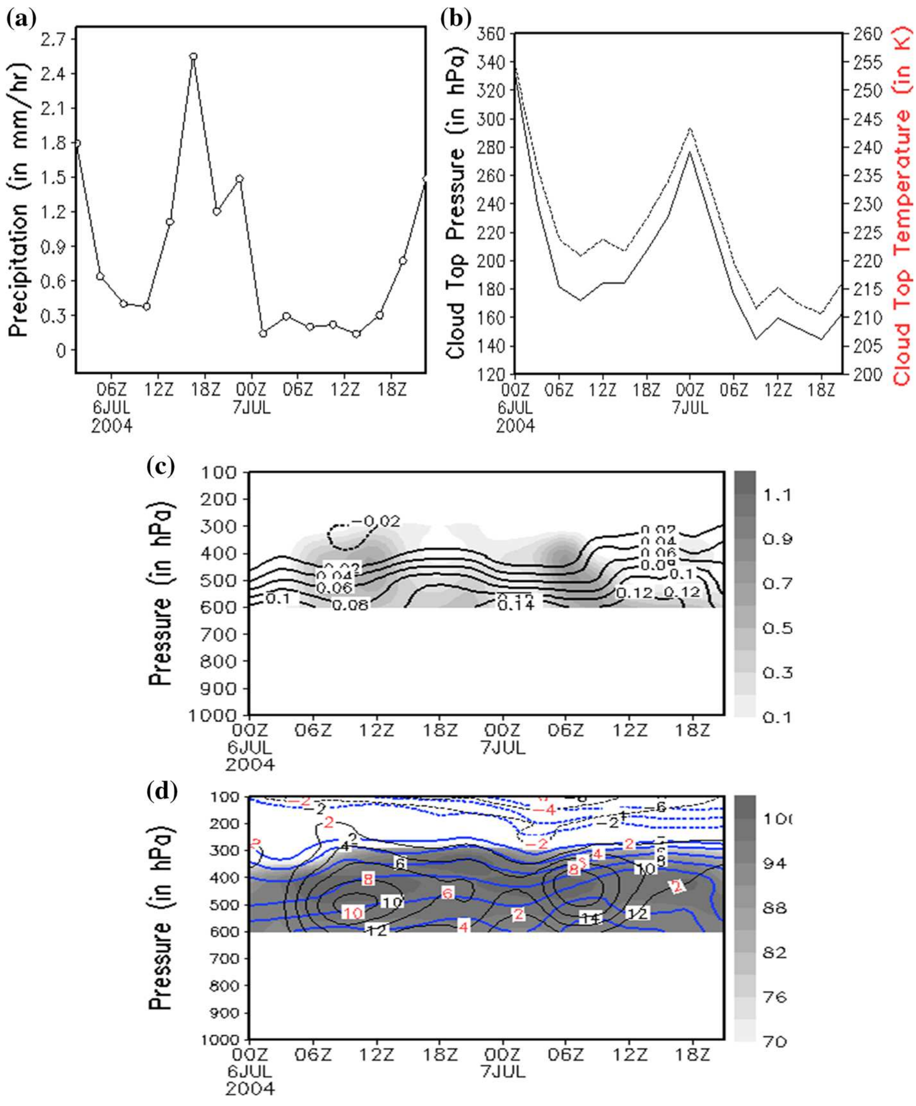

Fig. 4 Temporal variation of **a** precipitation along with **b** cloud-top pressure (*solid line*) and cloud top temperature (*dotted line*) **c** cloud ice mixing ratio (*gray shaded*) and cloud liquid mixing ratio (*contour* with *blue label*) (vertical profile) and vertical velocity (in *bold contour*) **d** relative humidity along (*shaded*) with zonal (*blue contour*) and meridional wind (*black contour*) (vertical profile) on 6–7 July 2004 over Uttarakhand

($\sim$120 hPa) at that time which depicts the presence of high cloud (Fig. 6b). Ice content was observed to be quite high on that day at 400 hPa. The updraft was observed to initiate at 06Z on 12 September and the downdraft started at about 03Z on 13th September (Fig. 6c). Intense downdraft zone has also been observed at 18Z on 13 September 2012. It was observed that the northerly was replaced by the southerly at the time of the cloudburst (Fig. 6d). The easterly was observed to prevail above 600 hPa throughout the study period.

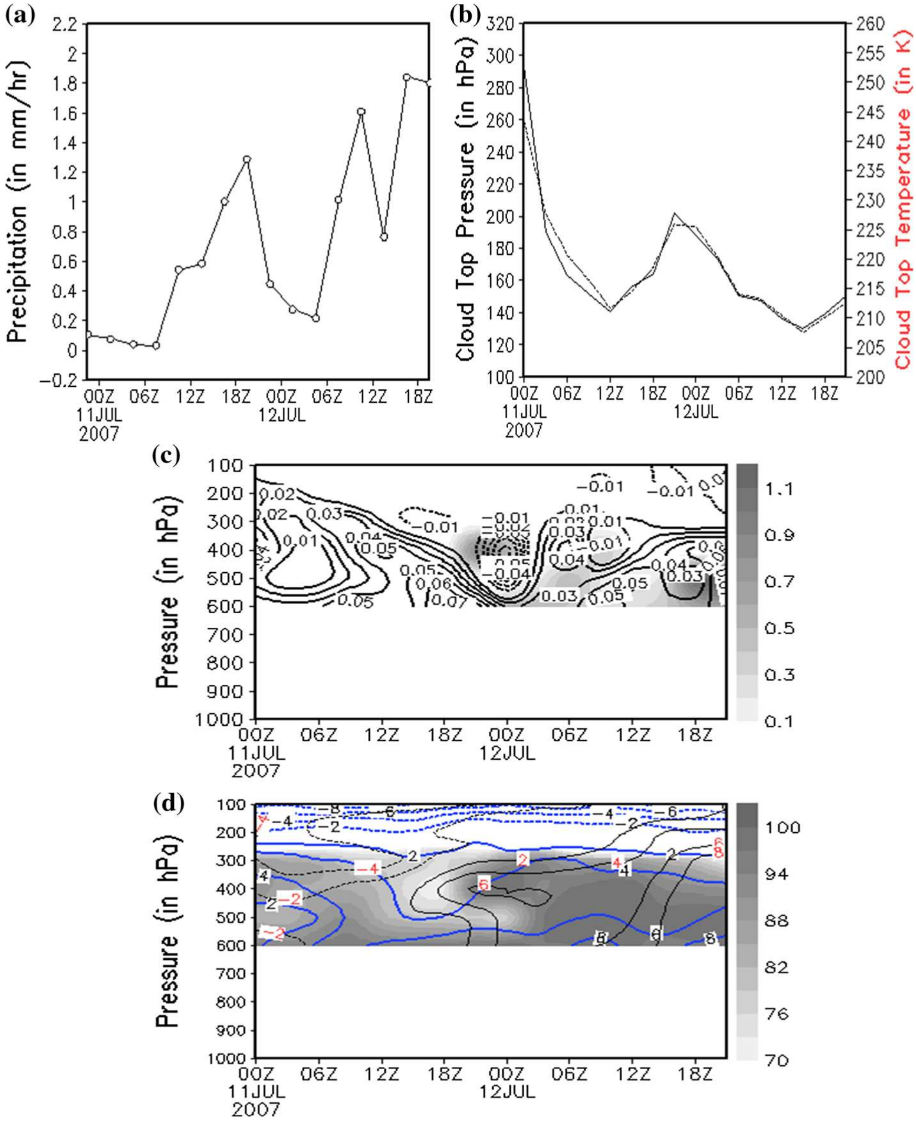

Fig. 5 Temporal variation of **a** precipitation along with **b** cloud-top pressure (*solid line*) and cloud-top temperature (*dotted line*) **c** cloud ice mixing ratio (*gray shaded*) and cloud liquid mixing ratio (*contour* with *blue label*) (vertical profile) and vertical velocity (in *bold contour*) **d** relative humidity along (*shaded*) with zonal (*blue contour*) and meridional wind (*black contour*) (vertical profile) on 11–12 July 2007 over Uttarakhand

The pattern of rainfall rate during 13–20 June 2013 shows gradual increasing trend, and the trend is observed to sustain for following 2 days (Fig. 7a). The minimum CTP has been observed at 00Z on 17 June 2013 at around 200 hPa (Fig. 7b). The ice content at 500 hPa was observed to be high at the time of initiation of the downdraft at 15Z on 14 June 2013 (Fig. 7c). The ice content is also found to be high on 19 July 2013 but no downdraft zone has been observed. The high relative humidity at the time of downdraft may depict high

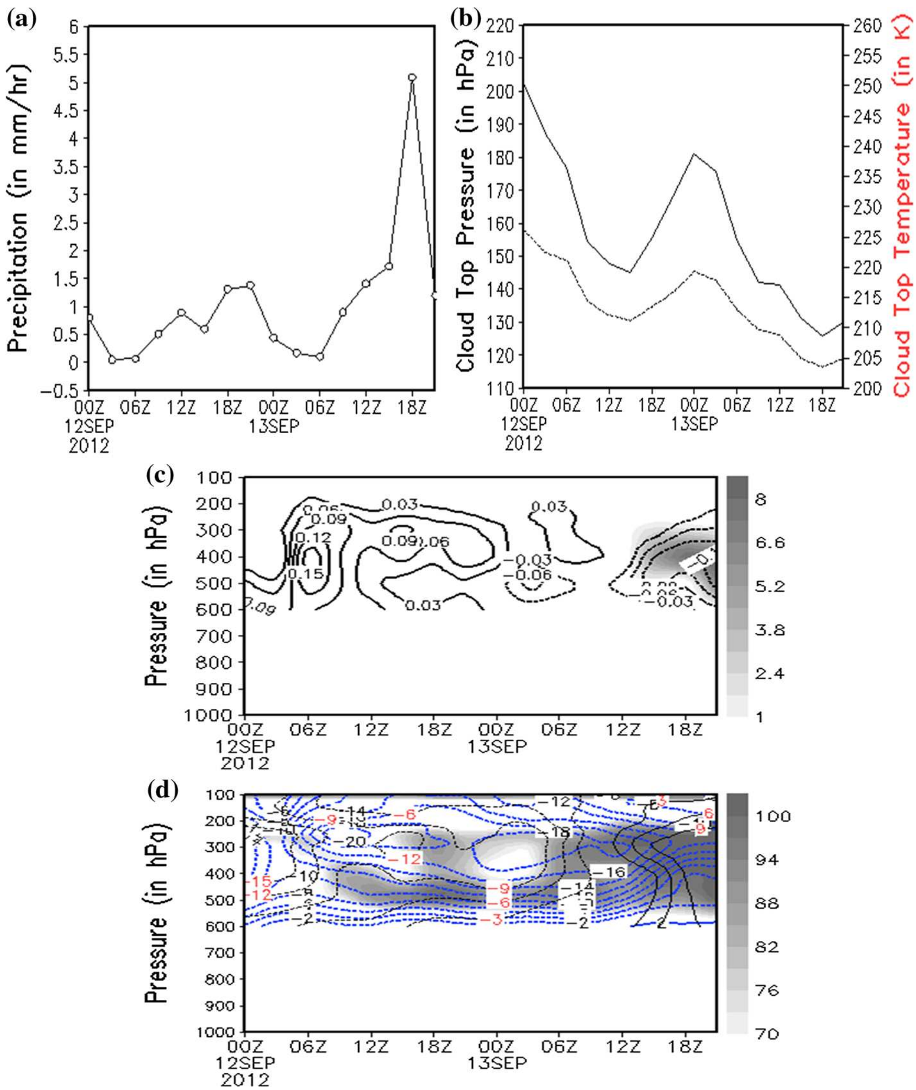

Fig. 6 Temporal variation of **a** precipitation along with **b** cloud-top pressure (*solid line*) and cloud-top temperature (*dotted line*) **c** cloud ice mixing ratio (*gray shaded*) and cloud liquid mixing ratio (*contour* with *blue label*) (vertical profile) and vertical velocity (in *bold contour*) **d** relative humidity along (*shaded*) with zonal (*blue contour*) and meridional wind (*black contour*) (vertical profile) on 12–13 September 2012 over Uttarakhand

saturation at that time. The relative humidity was observed to be high up to 300 hPa till 17 June 2013 which further increased. Southwesterly wind was observed to prevail above 600 hPa level during the entire study period (Fig. 7d).

The present investigation reveals that each of the events was found to be different in some respect; however, the circulation pattern depicts some common features among the events. The feature which are observed to be significant in differentiating the cloudburst and heavy rainfall events are the low-level flow from oceanic region, mid-tropospheric dry

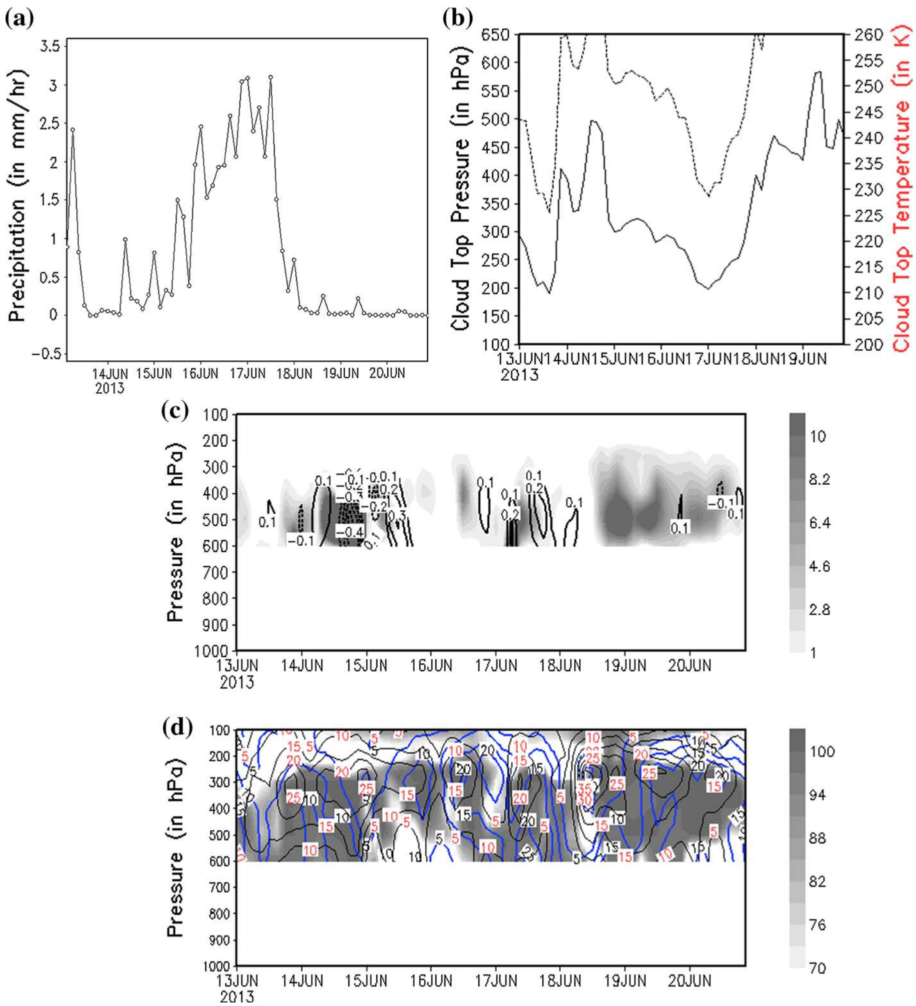

Fig. 7 Temporal variation of **a** precipitation along with **b** cloud-top pressure (*solid line*) and cloud-top temperature (*dotted line*) **c** cloud ice mixing ratio (*gray shaded*) and cloud liquid mixing ratio (*contour* with *blue label*) (vertical profile) and vertical velocity (in *bold contour*) **d** relative humidity along (*shaded*) with zonal (*blue contour*) and meridional wind (*black contour*) (vertical profile) on 13–20 June 2013 over Uttarakhand

wind entrainment and weak upper level flow. Brown and Zhang (1997) observed that dry conditions in the mid-troposphere within the rainy periods limit the vertical development of convection above the boundary layer and controls the cloud height. The variability in CTP before the event has been estimated (Fig. 8). The figure shows that the events which have been reported as cloudburst exhibit random variability. The result further shows that the cloudbursts over HP manifests less variability that can attribute from inter-quartile range (IQR) of CTP for 16.7.2003 (16.79) and 22.7.2001 (8.33), while the variability in IQR of CTP during cloudburst over Uttarakhand has been observed to be 30.46, 79.8, 22.28 and 61.91 on 12.7.2007, 03.08.2012, 13.09.2012 and 14.07.2013, respectively. It has been observed that a low-level thin thermal inversion also helps in intense convective

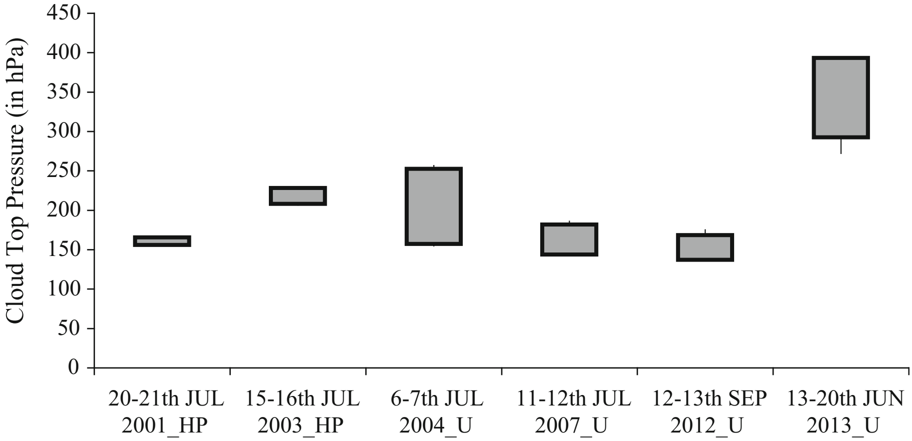

Fig. 8 Variability in cloud-top pressure before the time of the event in six cases over Himachal Pradesh and Uttarakhand

development (Zhu 2003). Thus, to identify the presence of thermal inversion, the difference in temperature (in K) between different levels has been computed and observed that the temperature inversion between 925 and 850 hPa as well as 500 hPa clearly distinguish the cloudburst and heavy rainfall events. The temperature difference has been computed for four times (Lag 0, Lag 3, Lag 6 and Lag 9). Lag 0 defines the time of the event (termed as Lag_0), Lag 3 represents the time 3 h before the event (termed as Lag_3), lag 6 represents the time 6 h before the event (termed as Lag_6) and lag 9 represents the time 9 h before the event (termed as Lag_9). The temperature inversion at low level (925–850 hPa) shows a positive value which indicates the presence of an inversion (Fig. 9a). A decrease in temperature difference between 925 and 850 hPa from lag 3 to lag 0 has been observed, whereas an increase has been observed from lag 9 to lag 6 for all cases reported to be the cloudburst events except in heavy rainfall event (Fig. 9a). It has also been observed that the magnitude of temperature differences is high in lag 6, lag 3 and lag 0 situations during the cloudburst events. However, the temperature difference between 925 and 500 hPa level shows either an increase or remains constant since 9–3 h before the cloudburst event, while in case of heavy rainfall event the temperature difference between 925 and 500 hPa level shows to decrease (Fig. 9b).

4 Conclusions

The present investigation is carried out for six heavy rainfall events; two occurred over Himachal Pradesh and four over Uttarakhand to identify the processes that aids in differentiating the cloudburst and heavy rainfall events and to estimate the predictability of cloudburst over the elevated regions of India. The states of Himachal Pradesh and Uttarakhand both are known to be prone to cloudbursts. The monsoon circulation combined with orographic features lead to such devastating weather over the region. In the year 2013, a severe weather accompanied with a large amount of rainfall over a small location was reported over Uttarakhand. The event was termed as “cloudburst,” while the Indian meteorological Department reported it as “heavy rainfall” event. This controversy

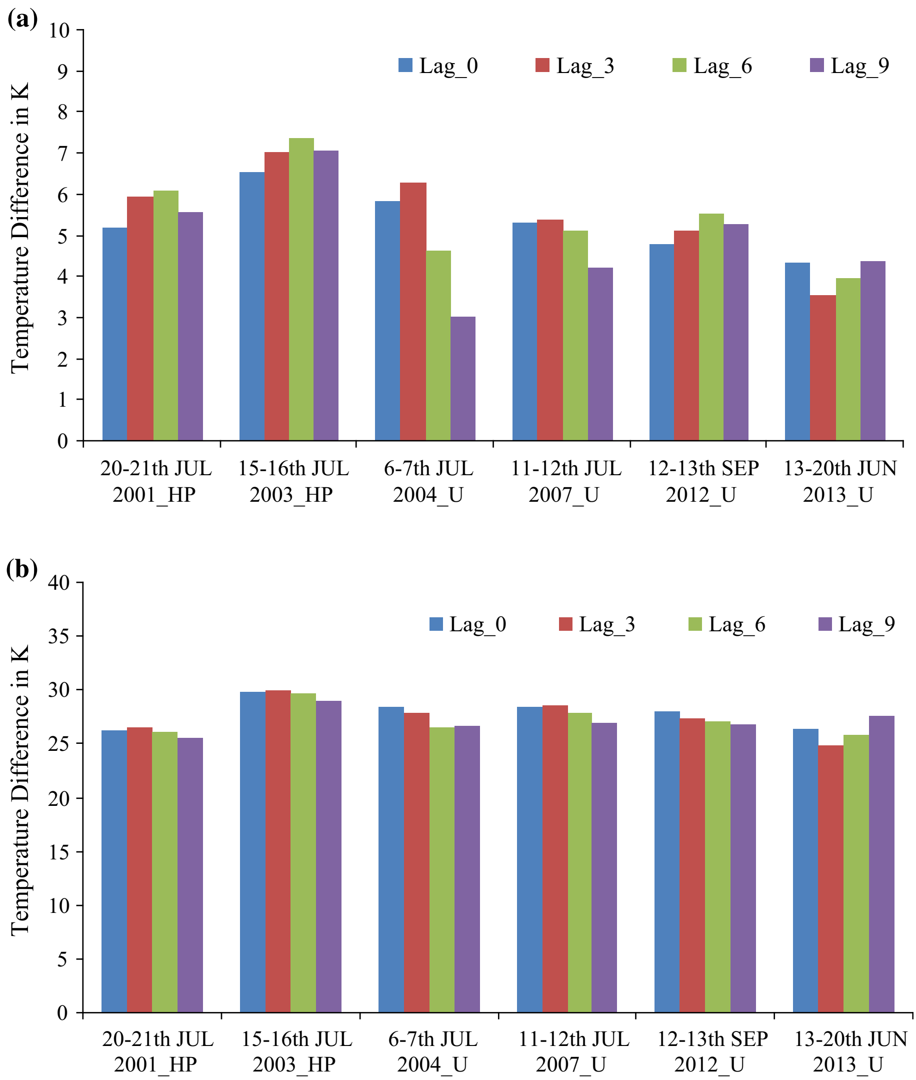

Fig. 9 Temperature difference between **a** 925 and 850 hPa, **b** 925 and 500 hPa for six cases. Lag_0 defines the time of event, Lag_3 represents 3 h before event, Lag_6 represents 6 h before event and Lag_9 represents 9 h before event

motivated to take up the study for identifying precisely the difference between cloudburst and heavy rainfall. The time series analysis of rain rate (mm/h) and CTP (hPa) aided to identify the time of the event and subsequently the difference between cloudburst and heavy rainfall has been evaluated through the vertical with profile, relative humidity and ice-water content. All the cases except the debated event of June 2013 show the presence of ice phase associated with a downdraft zone. The difference in the magnitude of ice content has also been observed. The vertical shear in meridional wind has been observed in most of the cases. The limitation is observed in estimating variation in the low levels. The investigation is thus carried out with observation from 600 hPa levels. The CTP has been observed to be quite low on the days of cloudbursts. Several studies differed the phenomenon of 14 June 2013 as cloudburst. The India Meteorological Department (IMD) reported this event as a heavy rainfall event. The significant difference in this event is observed in CTP which is 200 hPa. In case of cloudburst, on the other hand, the CTP varies between 100 and 150 hPa. This indicates that the height of cloud may be a significant parameter in identifying cloudburst. Thermal inversion at low level may be a key controlling factor for cloudburst. The presence of moisture and low-level inversion results in "Heavy rainfall" over Uttarakhand. At the same time the magnitude of thermal inversion was higher for cloudburst. From the analysis, it is observed that low-level temperature inversion as well as cloud-top pressure clearly distinguishes "Cloudburst" and "Heavy Rainfall" events.

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