Investigation of the Spatiotemporal Variability of Meteorological Parameters Associated with the Extreme Rainfall Events using Indian Geostationary Satellite Data

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Abstract
One of the most disastrous weather occurrences, an Extreme Rainfall Event (ERE), is described by exceptionally intense rainfall (more than 100 mm/hr.) over a limited area (20–30 sq km) over a brief period of time. ERE is also characterized by landslides, flash floods, debris flows, and unusually intense rainfall. The diverse topography, slope, aspect, and altitude of the North Western Himalayan (NWH) region make it particularly vulnerable to ERE. The primary objective of the current study is to examine the spatiotemporal variability of a number of meteorological variables associated with the extreme rainfall events that occurred over Katakholi Panchayet, Chhinka village, and Agarchatti region in Uttarakhand in August 2022. For the purpose of this analysis, a number of geophysical parameters acquired from the INSAT-3D geostationary satellite were used. The spatiotemporal analysis of the Outgoing Longwave Radiation (OLR) anomaly depicts that OLR drops over a wider region 4-5 hours prior to the occurrence of the events. Unlike the OLR anomaly, rainfall occurs over a small region for a brief period of time. It has also been noted that the Bay of Bengal acts as a source of moisture after the event, the convective system dissipated in the northeast direction. Although OLR decreases over a broader region, rainfall only occurs over a smaller area, which is also reflected by a smaller coefficient of determination value for all the events. The key finding of this study is the understanding of the spatial correlation between OLR and rainfall during extreme rainfall events.

Keywords ERE, Geophysical parameters, OLR anomaly.

Introduction

A severe, catastrophic weather phenomenon known as an Extreme Rainfall Event (ERE) or cloudburst is characterized as intense rainfall (more than 100mm/hour) over a condensed area (20–30 sq. km) in a limited period of time. The primary deciding factors for the occurrence of ERE over a region are location, altitude, and orography. The main effects of ERE, besides the intense rains, include landslides, debris flows, glacial lake outbursts, flash floods, etc. (Joshi and Kumar 2006). The Himalayas have a significant impact on the Indian Summer Monsoon (ISM). ERE is not unusual to occur over the Indian subcontinent. The North Western Himalayan foothills of the Himalayas experience quite a lot of ERE cases each year. A few examples are the cloudbursts at Leh (August 2010), Manali (July 2011), Rudraprayag (September 2012), and Kedarnath (June 2013)(Bharti et al. 2016; Rana et al. 2013). These ruinous events snatched hundreds of lives and caused huge destruction of transport systems, buildings, agricultural fields, etc. Geographical location, aspect, elevation, and intricacy of the orography make the northwest foothills of the Himalayas particularly vulnerable to cloudburst. The Northwest foothills of the Himalayas are orientated along the direction of the prevailing wind. The Himalayas serve as a barrier that enables the knock-on effect of moist air and subsequent upward movement. Additionally, it stops the transfer of heat from the wind coming from the Tibetan plateau. The low-lying plane of north India has been found to be more vulnerable to sensible heat flux from the surface than the area from the slope(Navale and Singh 2020). Another potential cause that promotes the occurrences of cloudbursts over the northwest foothills of the Himalayas is the diurnal variation of insolation. According to reports, the NWH region experiences the majority of its EREs and related flash floods in the early morning or late at night. ERE is triggered by the difference in insolation between the mountain and valley regions. Due to very low heat capacity, during the day, surface emission from the mountain region is greater than that from the valley region, resulting in a low-pressure area over the mountain's top and a high-pressure area over the valley. In contrast, the air over the mountain cools more quickly at night than it does above the valley, resulting in the formation of katabatic winds. Cloudburst occurs at night or in the early morning hours when the katabatic wind is at its lowest pressure, aiding in the buildup of the mesoscale convective system by means of the accumulation of water vapor. Rain gauges are sporadically scattered throughout the complicated terrain of the Himalayan foothills. There is no reliable cloud burst forecasting system because of the low coverage of rain gauges. Due to the region's geographical remoteness, a substantial number of cloud burst occurrences that occur over the Himalayan foothills are left unnoticed (Kumar et al. 2018). Geospatial technology serves as one of the most promising way-out for the identification of cloud bursts. Large synoptic coverage and high temporal resolution of the geostationary satellite provide accurate information about the cloud bursts. For the investigation of the meteorological variables that serve as indicators for extreme rainfall events in this work, we used several geophysical parameters from the Indian National Satellite System (INSAT 3D). Significant information on the origins of ERE over the NWH region is revealed by a thorough spatiotemporal analysis of numerous meteorological variables that symbolize ERE. On the basis of this study, we have also made an effort to figure out any noticeable variations in any meteorological parameter that might possibly work as an early warning sign of ERE and, as such, be relevant to the existing nowcasting system.

Materials and Methods

Study Area: The Himalayas, one of the largest mountains in the world, borders the Indian subcontinent from the Tibetan plateau. Based on the complexity of the terrain and the elevation, the Himalayas are subdivided into three major ranges:

- Outer range: It is also known as the Siwalik range, where the average elevation of the terrain lies between 900-1200 meters.
- Middle range: It is also known as the Lesser Himalayas, where the elevation varies between 3700-4500 meters**.**
- Greater Himalayan range: It is the most important range in the Himalayas, with the majority of the greatest peaks. The average altitude of this range varies between 6000-8800 meters. This range plays a significant role in preventing the heat

exchange between the Indian subcontinent and the Tibetan Plateau (Nandargi and Dhar 2011;Bharti, 2015).

This present study aims to analyze three ERE events over Uttarakhand, which happened over the Katakholi panchayet on 01.08.2022, Chhinka village on 09.08.2022 & Agarchatti region on 10.08.2022.

Table 1 Studied ERE sites over the Uttarakhand region.

Sl. No.	Location	Date	Latitude (degree north)	Longitude (degree east)	Elevation (meter)
1.	Katakholi panchayat	01.08.2022	30.1472	78.7747	1694
2.	Chhinka village	09.08.2022	30.3058	79.1305	1107
3.	Agarchatti	10.08.2022	30.0161	79.3091	1399

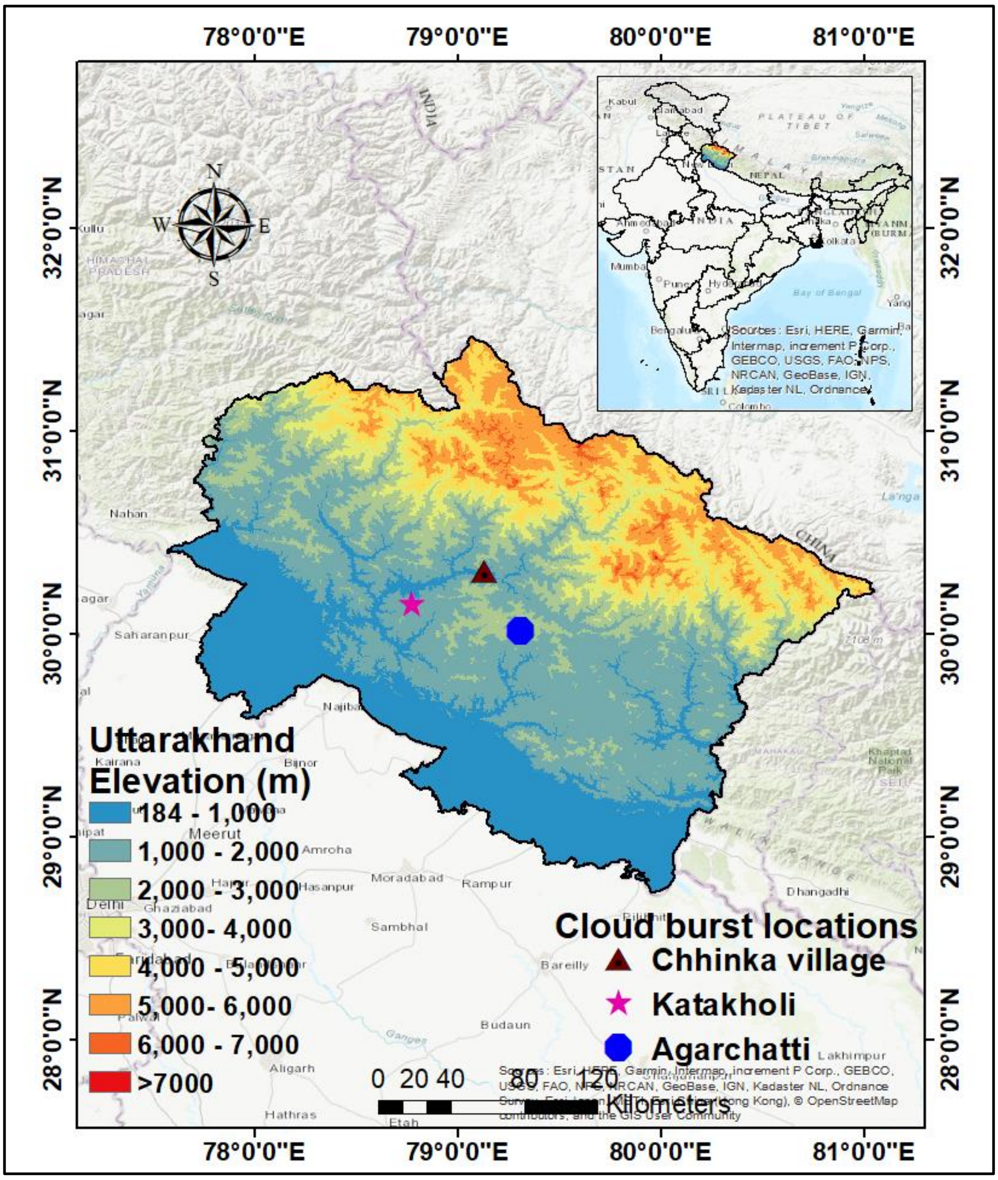

Fig. 1 Cloud burst sites over Uttarakhand region.

Datasets & Methodology: INSAT 3D: INSAT 3D (Indian National Satellite 3D) is a Meteorological Satellite launched on 26.07.2013 with the payloads i) six-channel imager, ii) nineteen channels sounder, iii) Data Relay Transponder (DRT), and iv) Satellite aided Search and Rescue(S&SR) System. Several geophysical parameters are recorded by INSAT 3D. The data can be downloaded from https://www.mosdac.gov.in/. Out of that, the following have been used:

Outgoing Longwave Radiation (OLR): For the analysis of OLR, INSAT -3D level 2B OLR dataset with a temporal resolution of 30 min and spatial resolution of 4km is utilized. For estimating OLR, three spectral channels, namely WV (6.5-7.1µm), TIR-1(10.2-11.3µm), and TIR-2 (11.5-12.5µm) are used.

Hydro-Estimator Rain (HE-rain): For the analysis of rainfall, INSAT -3D level 2B rainfall dataset with a temporal resolution of 30 min and spatial resolution of 4km is utilized. For estimating rainfall, the brightness temperature obtained from the TIR band (0.7 µm) is used.

SRTM DEM: NASA's Shuttle Radar Topography Mission (SRTM) generated Digital Elevation Model (DEM) at a resolution of 1 arc-second (30 meters) has been used for the elevation information of the cloud burst sites. The SRTM DEM has a tile size of one degree and has been captured by utilizing the C band (wavelength 5.6 cm). SRTM DEM can be downloaded from https://earthexplorer.usgs.gov/.

Spatiotemporal analysis of OLR anomaly and rainfall is carried out for the cloud burst location sites. OLR anomaly is computed by subtracting the instantaneous OLR value from its one-hour prior value. Propagation of OLR anomaly denotes the propagation of cloud over the cloud burst location. Correlation analysis of OLR and rainfall over the cloud burst location is done for a better understanding of the correlation of spatial extent between OLR and rainfall.

Results & Discussion

Spatiotemporal analysis of OLR anomaly: As there is not any significant source of moisture over the NWH region, the Arabian Sea or the Bay of Bengal are the only sources of moisture. Since the OLR drops in a significant amount in the presence of more clouds, it is important to understand the origins of the moisture over the cloud burst site as well as the direction in which the OLR will dissipate. OLR anomalies are determined by subtracting the current value of OLR from its one-hour earlier value in order to account for the fact that cloud burst is a short-lived occurrence in contrast to the Indian Summer Monsoon.

From the spatiotemporal analysis of the OLR anomalies for the cloud burst event that occurred over the Agarchatti region on 10.08.2022 (refer to fig 2), it is identified that the Bay of Bengal acted as a source of moisture for that particular cloud burst event. From this analysis, it can be observed that OLR drop over the same location was started at 0900 UTC on the same day. OLR drop of around 80 W/m2 was observed over the Agarchatti region prior to the cloud burst event. After the cloud burst event, OLR anomalies dissipated in the northeast direction. Similar studies have been done for the other locations of cloud burst events & are presented in the tabulated form (refer to Table 2).

Table 2 Propagation velocity, direction & dissipation duration of OLR anomalies over the cloud burst.

l no	Location	Date	Time (UTC)	The velocity of OLR anomaly (m/s)	Direction of propagation	Duration of dissipation (hours)
1.	Katakholi panchayat	01.08.2022	0800-1300	5.5	North east	5
2.	Chhinka village	09.08.2022	0200-0800	6.3	North east	6
3.	Agarchatti	10.08.2022	1000-1700	3.33	North east	7

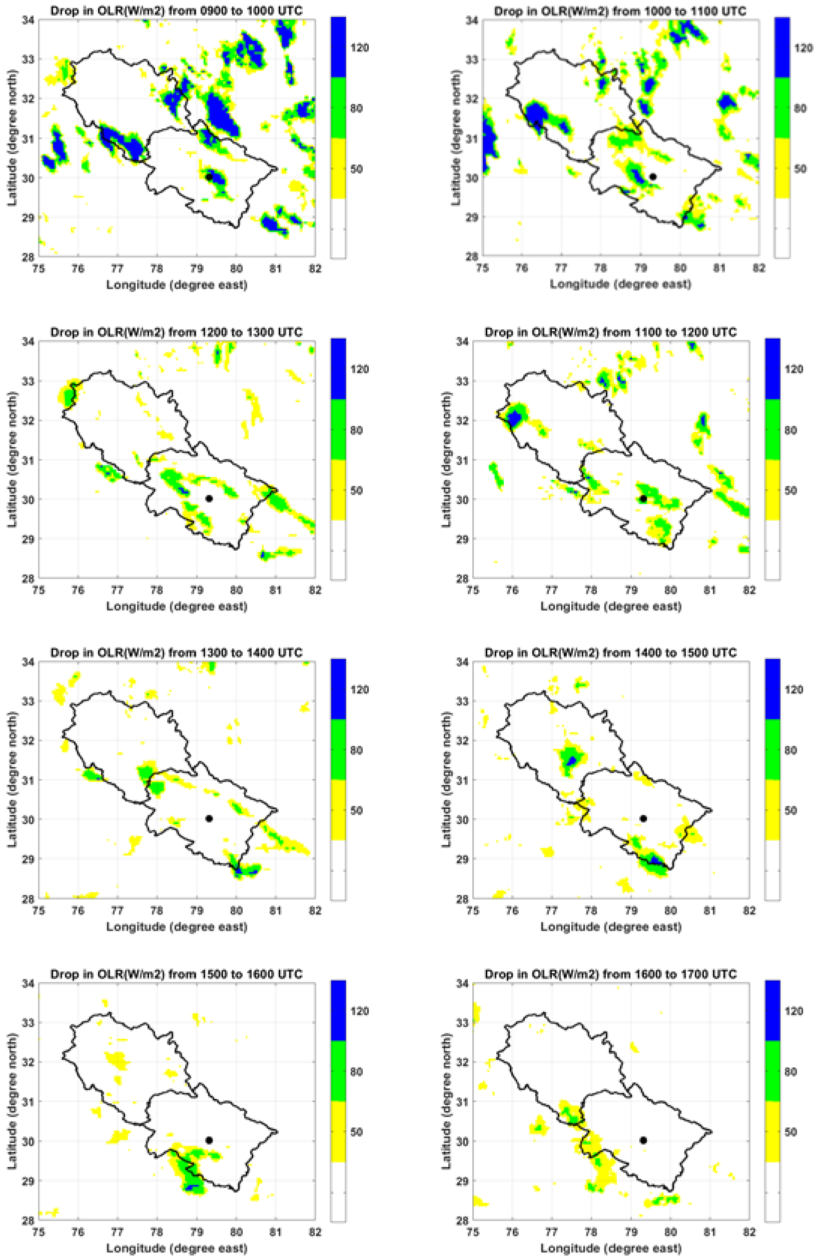

Fig. 2 Propagation of OLR anomalies for the cloud burst event that occurred over the Agarchatti region on 10.08.2022 (black dot indicates the location of Agarchatti region).

Spatiotemporal analysis of Rainfall: The spatiotemporal analysis of rainfall has been carried out for a better insight into the spatial correlation between the OLR & rainfall. Comparative analysis of the spatiotemporal variation of OLR anomalies and rainfall depicts that, although the OLR drop occurs over a large spatial domain, the rainfall is observed over a comparatively smaller area during the cloud burst events over the Agarchatti region (refer to Fig 3). This comparison in turn denotes the cause behind the lower value of the coefficient of determination between OLR and rainfall correlation (refer to Fig 4). The spatiotemporal analysis of rainfall has been carried out for other cloud burst event and similar kinds of results have been obtained.

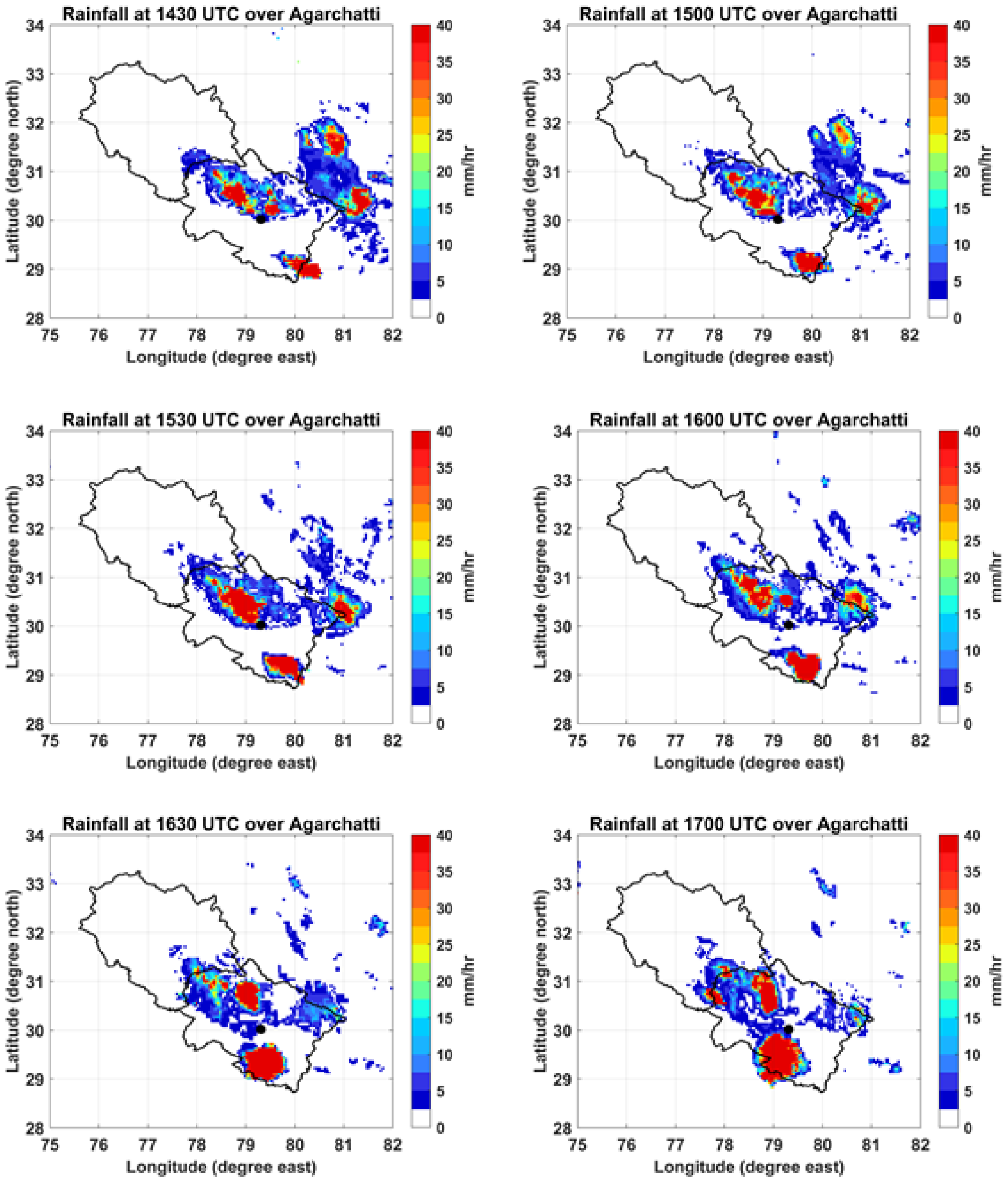

Fig. 3 Spatiotemporal analysis of rainfall over Agarchatti region on 10.08.2022 (Black dot indicates the location of Agarchatti region).

Correlation between Outgoing Longwave Radiation (OLR) and rainfall: From this graph, it can be seen that the rainfall and OLR hold a power law relationship which can be written as, Rainfall = 0.0026*OLR – 1.1107*OLR + 114.12. The value of the coefficient of determination for OLR and rainfall is 0.621 for the cloud burst event over the Agarchatti region. Lower value of the correlation coefficient is obtained for other events also. The lower value of the coefficient of determination indicates that during the cloud burst event, OLR drops over a larger spatial domain as compared to the corresponding rainfall. Additionally, a lower coefficient of determination value suggests that a substantial amount of rainfall is observed during a cloud burst event when the OLR decreases to a significant level rather than for a lower drop in OLR.

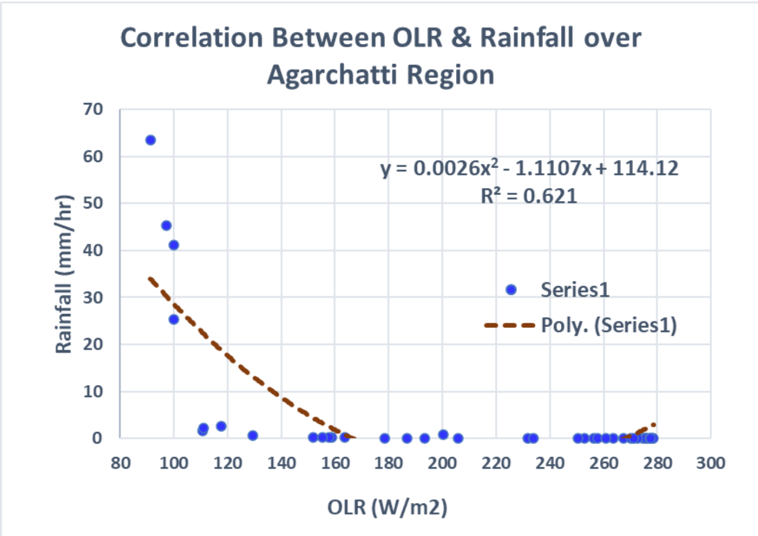

Fig. 4 Correlation analysis of rainfall over Agarchatti region on 10.08.2022.

Conclusions

The recent severe cloud burst events in the Northwest Himalayan region and growing concerns about their behavior in the future necessitated an investigation into the meteorological features of the cloudburst. Three cloud burst incidents that occurred in August 2022 over the Indian state of Uttarakhand are investigated thoroughly in the current study. The following are noted from this extensive analysis of a number of meteorological variables associated with cloud burst events:

1. The spatiotemporal analysis of OLR & rainfall over the cloud burst depicts that the Bay of Bengal acts as a source of moisture supply over the cloud burst location. Also, the OLR drop occurs over a larger area. However, the rainfall is confined over a smaller region which in turn denotes the smaller value of the coefficient of determination between rainfall & OLR.
2. The correlation analysis between Rainfall & OLR indicates that these two meteorological parameters hold a power law relation. The lower value of correlation denotes that the spatial extent of OLR drop and corresponding rainfall is not comparable.

Although a detailed analysis of cloud burst events has been carried out still there are limitations of this study. They are mentioned as follows:

1. Satellite data are near real-time, not the real-time. Since the cloud burst event is a short-span phenomenon, there may be some underestimation or miss out of information.
2. Although 24 hours of continuous data should be available ideally but continuous data set for 24 hours was not available due to some instrument error and some other causes. Due to these missing data, there is some underestimation or miss out of information.

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References

Bharti, Vidhi. 2015. "Investigation of Extreme Rainfall Events Over the Northwest Himalaya Region Using Satellite Data," 72.

Bharti, Vidhi, Charu Singh, Janneke Ettema, and T. A.R. Turkington. 2016. "Spatiotemporal Characteristics of Extreme Rainfall Events over the Northwest Himalaya Using Satellite Data." *International Journal of Climatology* 36 (12): 3949–62. https://doi.org/10.1002/joc.4605.

Joshi, Varun, and Kireet Kumar. 2006. "Extreme Rainfall Events and Associated Natural Hazards in Alaknanda Valley, Indian Himalayan Region." *Journal of Mountain Science* 3 (3): 228–36.

Kumar, Amit, Anil K. Gupta, Rakesh Bhambri, Akshaya Verma, Sameer K. Tiwari, and A. K.L. Asthana. 2018. "Assessment and Review of Hydrometeorological Aspects for Cloudburst and Flash Flood Events in the Third Pole Region (Indian Himalaya)." *Polar Science* 18: 5–20. https://doi.org/10.1016/j.polar.2018.08.004.

Nandargi, S., and O. N. Dhar. 2011. "Evénements de Précipitations Extrêmes Dans l'Himalaya, Entre 1871 et 2007." *Hydrological Sciences Journal* 56 (6): 930–45.

Navale, Ashish, and Charu Singh. 2020. "Topographic Sensitivity of WRF-Simulated Rainfall Patterns over the North West Himalayan Region." *Atmospheric Research* 242 (April): 105003. https://doi.org/10.1016/j.atmosres.2020.105003.

Rana, Naresh, Sunil Singh, Y. P. Sundriyal, and Navin Juyal. 2013. "Recent and Past Floods in the Alaknanda Valley: Causes and Consequences." *Current Science* 105 (9): 1209–12.

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