Analysis of Heavy Precipitation Events Over Western Himalayan Region

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Abstract
An attempt has been made to identify the synoptic weather situations associated with Western Disturbances (WDs) that caused heavy to very heavy precipitation resulting in extensive avalanches during winter season 2011 over Western Himalayan region (WHR). Analysis suggest that heavy to very heavy precipitation events generally occurs in association with WD in the form of mid-tropospheric westerly trough over north Pakistan and neighbourhood (nearly along Longitude 65° E and north of Latitude 20° N) with induced cyclonic circulation over west Rajasthan & its neighbourhood.

Keywords: Precipitation, Synoptic analysis, Western Disturbances, Western Himalayan Region.

1. Introduction
A wide variety of weather systems such as monsoon, tropical disturbances, Western Disturbances (WDs), easterly waves etc. affect the Indian region. WDs identified on synoptic charts as the trough or cyclonic circulations in the mid-tropospheric westerlies that originate from the frontal systems over Mediterranean and Caspian Sea areas and move eastwards producing severe weather over the Indian region. Western Himalayan region (WHR) that includes Jammu and Kashmir, Himachal Pradesh and Uttarakhand states of India experiences extreme weather conditions like heavy snowfall/rainfall, cloud bursts, extensive avalanche etc. in association with active WDs in winter or due to its interaction with low level easterlies in southwest monsoon. In India, studies related to WDs and its impact on Indian weather are done by many researchers like: Bhaskara Rao and Moray (1971), Singh and Kumar (1977), Agnihotri and Singh (1982), Veeraraghavan and Nath (1989), Rangachary and Bandyopadhyay (1986), Dimri and Mohanty (1999), Hatwar et al. (2001), Hatwar et al. (2004), Hatwar et al. (2005), Yadav and Bhan (2010), Shekhar et al. (2014), Kumar et al. (2015) and others.

Bhaskara Rao and Moray (1971) studied the cloud systems associated with WDs. They classified cloud systems into five broad categories and found that these cloud patterns and synoptic conditions most commonly associated with each category of cloud systems. Agnihotri and Singh (1982) studied the WDs approaching northwest India and neighbourhood during winter period (November-March) with the help of satellite cloud imageries. Veeraraghavan and Nath (1989) studied about the temperature distribution of the top of the clouds associated with the WDs as seen from the infrared satellite pictures and made an attempt to understand the relation between the cloud top temperatures and the resultant rainfall. Rangachary and Bandyopadhyay (1986) have analysed the synoptic weather pattern associated with extensive avalanching in Western Himalaya due WDs. Dimri and Mohanty (1999) studied the snowfall statistics of some SASE field stations in Jammu and Kashmir, and studied the pattern of snowfall and its frequency distribution using statistical means. They also studied the variation of snowfall spells to understand spatial and temporal changes in their distributions. Hatwar et al. (2005) investigated two cases of intense WDs, which affected northwest India using IMD’s operational limited area analysis and forecast system. Yadav and Bhan (2010) studied the interaction of westward moving monsoon trough and eastward moving WD over north Pakistan.

During February 2011, WHR experienced extreme weather in form of heavy to very heavy precipitation that caused extensive avalanches over the region due to WDs. Therefore in present study, an attempt is made to identify the synoptic weather situations associated with WDs that caused extreme weather in form of heavy to very heavy precipitation over WHR.

2. Case Studies and Data Used
In February 2011, there was torrential precipitation in form of rain and snow over many parts of western Himalayas and its some parts also experienced gusty winds along with torrential precipitation. As a result, there were avalanches in the parts of western Himalayas. Therefore in present study,
we have considered the three cases of WDs that caused extreme weather over the region in February 2011. The 1st WD was from 3 to 8 February 2011 and it has caused widespread (more than 75% area) precipitation over the region with maximum intensity upto 12 cm in 24 hours. The 2nd WD was from 11 to 17 February 2011, it also caused widespread precipitation with maximum intensity upto 21 cm in 24 hours over the region. 3rd WD was of slightly less intensity and was from 19 to 20 February 2011. During this period, the western region also experienced widespread precipitation, but the maximum intensity was upto only 5 cm (in 24 hours). The analysis of these systems are carried out by using upper air charts plotted through Synergie system installed at India Meteorological Department, New Delhi. Meteosat-7 derived products (University of Wisconsin – Cooperative Institute for Meteorological Satellite Studies [CIMSS]) are also used in the study. In addition, MERRA ((Modern Era Retrospective-analysis for Research Applications) and National Centers for Environmental Prediction (NCEP) operational reanalysis (Kalnay et al., 1996) is also used to see the inter-comparison with the synoptic analysis.

3. Results and Discussion

3.1. Case-I

3.1.1. Synoptic Situation

On 3rd morning, a WD was seen as a trough in mid-tropospheric westerlies nearly along Longitude 50° E and north of Latitude 22° N. It moved eastwards and on 4th, it laid nearly along Longitude 57° E and north of Latitude 20° N with an induced cyclonic circulation over central Pakistan and neighbourhood in lower levels. Westerly trough as well as its induced cyclonic circulation further moved eastwards and were seen over north Pakistan, and adjoining Jammu and Kashmir (nearly along Longitude 63° E and north of Latitude18° N), and West Rajasthan and neighbourhood, respectively (Fig 1) on 6th. In addition, there was high moisture incursion into the system from Arabian Sea at lower levels and a strong jet maxima of the order of 100 knots was seen over north Pakistan, and adjoining Jammu and Kashmir in upper level winds on 6th. On 7th, Mid-tropospheric westerly trough laid nearly along Longitude 70° E and north of Latitude 24°N with its induced cyclonic circulation persisting over West Rajasthan and neighbourhood (Fig 1). Jet maxima in upper level winds shifted eastwards and seen over Jammu and Kashmir and neighbourhood on 7th. The surface pressure fell by 3-4 hPa on 5th, 3-5 hPa on 6th and further by 8-10 hPa on 7th over WHR. On 8th, WD laid over eastern parts of Jammu and Kashmir (mid-tropospheric westerly trough nearly along Longitude 75° E and north of Latitude 30° N) with induced cyclonic circulation over Haryana and neighbourhood. No further pressure fall was observed. On 9th, WD moved eastwards as was evident from streamline analysis and also from pressure rise, which was of the order of 2 hPa over the WHR.

In MEERA reanalysis, westerly trough at 500 hPa in Geo-pontantial Height (GPH) ran nearly along Longitude 50° E and north of Latitude 22° N on 3rd. On 4th, it was along Longitude 58° E and north of Latitude 22° N. Thereafter, trough moved eastwards and seen nearly along Longitude 60° E and north of Latitude 23° N.

In NCEP reanalysis, on 3rd, westerly trough at 500 hPa in GPH ran nearly along Longitude 52° E and north of Latitude 22° N. It was along Longitude 60° E and north of Latitude 24° N on 4th and along Longitude 62° E and north of Latitude 23° N on 6th.

3.1.2. Satellite Imageries

Geo-stationary satellite’s infrared imagery, water vapour imagery and water vapour winds are very useful products to get the prior indication of an approaching WD. Klapana-1 infrared imagery showed that comma shaped intense convective bands clouds in association with the WD (3-8 February 2011) over the WHR. The cloud top temperatures were as low as -65°C as observed in IR imagery of 1800UTC of 6th Feb 2011 (Fig 2a). Water vapour winds (Fig 2c) and imagery (Fig 2b) indicate that upper and middle level trough (place of maximum cyclonic curvature of the boundary between bright and dark regions) is over south Pakistan and neighbourhood area and lot of moisture incursion is taking place from north Arabian Sea. The degree of darkening indicates the deepening of the trough over that region. Water vapour winds at 500-351hPa layer show an upper air vortex, centred near 33ºN/65ºE in association with WD over the area. This is vortex is more clear in Kalpana-1 water vapour imagery (Fig 2b) where, the pattern of bright and dark regions are wrapped in spiral form. Upper air winds (100-250hPa) shows jet stream maxima over Jammu and Kashmir, and adjoining Pakistan.

3.1.3. Precipitation

In association with WD, fairly widespread (50% to 75% stations reported precipitation) has been reported over WHR on 4th with maximum precipitation of 45 mm over Bimbhat LC. On 5th and 6th, there was widespread precipitation (more than 75% stations reported precipitation) with maximum precipitation was 50 mm over Bimbhat LC on 5th and 60 mm over Sonmarg on 6th. The spatial distribution and intensity of
Fig 1: Streamline analysis based on 0000 UTC (a) at 850 hPa of 06-02-2011, (b) at 500 hPa of 06-02-2011, (c) at 850 hPa of 07-02-2011 and (d) at 500 hPa of 07-02-2011.

Fig 2: (a) Kalpana-1 infrared imagery with cloud top temperature for 1800 UTC of 06-02-2011 (b) Kalpana-1 water vapour imagery for 0000 UTC of 07-02-2011 (c) Meteosat-7 derived mid-upper level winds at 2100 UTC of 06-02-2011.
the precipitation was maximum on 7th with highest precipitation over Banishal (120 mm), Qazigund (100 mm), Stage- II (79 mm) and Dhundi (70 mm). On 8th, precipitation decreased in intensity and shifted eastwards. Mainly dry weather was reported on 9th.

3.2. Case-II

3.2.1. Synoptic Situation

On 11th, a WD was seen as a trough in mid-tropospheric westerlies nearly along Longitude 52º E and north of Latitude 23º N. On 12th, it moved eastwards and laid nearly along Longitude 55º E and north of Latitude 25º N with induced cyclonic circulation over central Pakistan. The surface pressure fell by 2-3 hPa over the region. On 13th, it laid nearly along Longitude 63º E and north of Latitude 20º N with induced cyclonic circulation over west Rajasthan and adjoining Pakistan (Fig 3) and surface pressure fell by 5-7 hPa over the region. On this day, there was good moisture incursion into the system from Arabian Sea and a strong jet maxima was seen over north Pakistan, and adjoining Jammu and Kashmir in upper level winds on 12th and 13th. Thereafter, it was seen along Longitude 70º E and north of Latitude 25º N with induced cyclonic circulation over west Rajasthan on 14th (Fig 3). The surface pressure further fell by 2-3 hPa over the region. The system further moved eastwards and laid over Jammu and Kashmir, and neighbourhood on 15th and 16th with westerly trough nearly along Longitude 72º E and north of Latitude 28º N with induced cyclonic circulation over Haryana and adjoining Punjab and Rajasthan. With eastward movement of the system, surface pressure rose by 3-5 hPa over Jammu and Kashmir, butfell by 1-2 hPa over Himachal Pradesh on 15th. There was no significant precipitation reported on 15th. As the trough moved further eastwards, precipitation shifted eastwards and pressure rise by 2-4 hPa was also observed over the WHR.

In MEERA reanalysis, westerly trough at 500 hPa in GPH is not seen on 11th. It ran nearly along Longitude 52º E and north of Latitude 22º N on 12th. On 13th, it was seen nearly along Longitude 60º E and north of Latitude 22º N. Thereafter, it ran along Longitude 70º E and north of Latitude 25º N on 14th and along Longitude 72º E and north of Latitude 25º N on 16th. It moved eastwards on 17th. In NCEP reanalysis, westerly trough at 500 hPa in GPH ran along Longitude 50º E and north of Latitude 30º N on 11th. It ran nearly along Longitude 55º E and north of Latitude 25º N on 12th. On 13th, it laid nearly along Longitude 63º E and north of Latitude 20º N. It laid along Longitude 70º E and north of Latitude 20º N on 14th and along Longitude 72º E and north of Latitude 20º N on 16th. Thereafter, it moved eastwards on 17th.

3.2.2. Satellite Imageries

Main features seen in satellite imageries are described as: Klapana-1 infrared imagery showed that intense convective clouds have covered all northwest India north of latitude 30ºN and cloud top temperatures were as low as -60ºC as seen in IR imagery of 1200UTC of 13th Feb. 2011 (Fig 4a). Water vapour image (Fig 4b) and winds (Fig 4c) indicate that upper and middle level trough is extending upto north Arabian Sea and good moisture feeding is taking place from north adjoining central Arabian Sea. The degree of darkening in this case is slightly more than first WD which indicates that the trough is much deeper than previous case. Upper air vortex is also better organised over north Pakistan adjoining Afghanistan. Which is evident from the dry intrusion (north-south darkening in western side of upper air vortices) from Afghanistan to south Pakistan. The dry intrusion is a coherent region of air descending from near tropopause-level and it is closely related to the convective instability or the occurrence of convection due to the low equivalent potential temperature (Keith Browning, 1997). A jet maximum is observed over Jammu and Kashmir, and adjoining north Pakistan.

3.2.3. Precipitation

In association with WD, fairly widespread precipitation has been reported over WHR on 12th, the maximum precipitation was 20mm over Sonapindi. On 13th, the intensity of precipitation increased, there was widespread precipitation activity over WHR and the maximum precipitation reported was 60 mm over Banishal Top, 46 mm over Satege- II and 41 mm over Z- Gali. The intensity of precipitation further increased in term of spatial distribution and intensity on 14th, widespread precipitation with scattered heavy to very heavy falls reported on this day. The maximum precipitation reported was 211 mm over Banishal Top, 82 mm over Z- Gali, 80 mm over Banishal, 70 mm over Batote, 62 mm over Stage- II and 50 mm over Gulmarg. Thereafter, intensity of the precipitation decreased and it was widespread with isolated heavy falls over the region. Maximum precipitation reported was 70 mm over Batote, 30 mm over Haddan Taj and Banishal. Afterwards, precipitation shifted eastward and fairly widespread precipitation was reported over Jammu and Kashmir, widespread precipitation with isolated heavy fall reported over Himachal Pradesh on 16th. Maximum precipitation reported was 70 mm over Jogindernagar and 40 mm over Dharamshala on 16th.
On 17\textsuperscript{th}, fairly widespread light precipitation was reported over Jammu and Kashmir and widespread over Himachal Pradesh. Thereafter, WD moved away eastwards and mainly dry weather reported on 18\textsuperscript{th}. The conventional observations shows highest precipitation of 80 mm over Banihal reported on 14\textsuperscript{th}, where the additional AWS data of project PARWAT shows the 211 mm precipitation over Banihal top on the same day.

3.3. Case-III

3.3.1. Synoptic Features

A WD was seen as a trough in mid-tropospheric westerlies nearly along longitude 65° E and north of latitude 25° N with induced cyclonic circulation over west Rajasthan and adjoining central Pakistan on 19\textsuperscript{th} (Fig 5). The surface pressure fell by 2 hPa over WHR. On 20\textsuperscript{th}, trough moved eastward and laid nearly along longitude 71° E and north of latitude 25° N. There was no further fall in surface pressure.

In MEERA re-analysis, westerly trough at 500 hPa in GPH runs along Longitude 60° E and north of Latitude 20° N on 19\textsuperscript{th}; it ran nearly along Longitude 73° E and north of Latitude 20° N on 20\textsuperscript{th} and moved eastwards thereafter. In NCEP reanalysis, it runs along Longitude 65° E and north of Latitude 20° N on 19\textsuperscript{th} and runs nearly along Longitude 73° E and north of Latitude 20° N on 20\textsuperscript{th}.

3.3.2. Precipitation

In association with WD, widespread precipitation has been reported over Jammu and Kashmir, and scattered light precipitation over Himachal Pradesh on 20\textsuperscript{th}, the maximum precipitation is reported was 50 mm over Banihal Top and 44 mm over Stage-II. There was mainly dry weather on 21\textsuperscript{st}.

3.3.3. Satellite Imagery

Main features seen in satellite imagery are described as: At 1200 UTC of 19th Feb 2011, the cloud top temperatures were observed around -50°C in Klapana-I infrared imagery (Fig 6a). The degree of darkening in Klapana-I water vapour image of (Fig 6b) indicate that upper and middle level trough is not so strong and there was no upper air vortex as well.

4. Conclusions

In the study, synoptic aspects of three WDs that have caused extreme weather over WHR are analysed-
by using upper air synoptic charts, satellite derived parameters and reanalysis products like NCEP and MEERA data. The major objective is to analyse the synoptic and satellite features associated with these systems, so that the same can be used for weather forecasting. The detailed analysis of these three cases provides the following insights:

a. Synoptic analysis showed that heavy to very heavy precipitation events occurred in association with WD in form of mid-tropospheric westerly trough over north Pakistan and neighbourhood (nearly along long. 65º E and north of lat. 20º N) with induced cyclonic circulation over west Rajasthan and its neighbourhood. Also, the presence of strong jet maxima over north Pakistan and adjoining Jammu and Kashmir in upper level winds is favourable for very heavy precipitation over WHR.

b. Geostationary satellite’s infrared imagery, water vapour imagery, and water vapour winds are found to be very useful products to get the prior indication of an approaching WD from data sparse regions. The maximum cyclonic curvature, more degree of darkening in moisture boundary and
presence of dry intrusion indicates the severity of
the system.
c. By comparing the synoptic analysis with MERRA
and NCEP operational reanalysis, study shows that
both the reanalysis are close to synoptic analysis,
however, NCEP operational re-analysis is found
more close to synoptic analysis.

Fig 6: Klapana-1 images of 1200UTC of 19-02-2011 (a) Infrared image with cloud top temperature, and (b) water
vapour image.

References
Agnihotri CL and Singh MS (1982). Satellite study of
Bhaskara Rao NS and Moray PE (1971). Cloud systems
associated with western disturbances: A preliminary
Browning KA (1997). The dry intrusion perspective of ex-tratropical cyclone development. Meteorology Applied, 4:
317-324.
Dimri AP and Mohanty UC (1999). Snowfall statistics of
some SASE field stations in J and K and a case study of
western disturbance. Defence Science Journal, 49: 437-
45.
Hatwar HR, Lal B, Rama Rao YB, Sud AM and Kalsi SR
(2001). A study of heavy snowfall over Western Himalayas during winter months. Proceedings of the Workshop
on Mesoscale Modeling for Mountain Weather Forecast, Manali.
Forecasting heavy precipitation events over Western
Himalayas-IMD efforts. International Symposium on
Snow Monitoring and Avalanches, Manali, 363-372.
Hatwar HR, Yadav BP and Rama Rao YV (2005). Prediction
of western disturbances and associated weather over
Kalnay E, et al. (1996). The NCEP/NCAR Reanalysis 40-
year Project. Bulletin of American Meteorology Society,
77: 437-471.
frequency of western disturbances and precipitation
indices over Himachal Pradesh, India: 1977-2007. Atmósfera,
Rangachary N and Bandyopadhyay BK (1986). An analysis
of the synoptic weather pattern associated with
extensive avalanching in Western Himalaya. IAHS,
162: 311-316.
Shekhar MS, Sravan Kumar M, Joshi P and Ganju A (2014).
Mountain Weather Research and Forecasting over
Western and Central Himalaya by using Mesoscale Models,
Singh MS and Kumar S (1977). Study of a western
Yadav BP and Bhan SC (2010). Meteorological factors
associated with July 2005 floods in river Jhelum.
Mausam, 61:39-46.