Vol. 4 Issue No. 1, January-March 2022 e-ISSN 2456-7701

Journal of Science and Technological Researches

A Peer Reviewed Journal

Origin of Innovation

Domain: www.jstr.org.in, Email: editor@jstr.org.in

WESTERN DISTURBANCE ACTIVITY OVER INDIAN DOMAIN

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Date of Received	**17 February, 2022**
Date of Revised	**11 March, 2022**
Date of Acceptance	**25 March, 2022**
Date of Publication	**31 March, 2022**

DOI : https://doi.org/10.51514/JSTR.4.1.2022.37-43

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ABSTRACT

The study examined a few cases of Western Disturbances (WDs) that usually affected the Indian region with the changes in the meteorological elements like pressure, temperature, rainfall and humidity over the region. These changes in weather elements generate the situations like cold wave, for etc. over the regions starting from extreme north to peninsular India and disrupt the normal life. Since, during winter north India faces several eastward moving systems and it gives winter precipitation in most parts of the country which supports the countrymen in many ways therefore it is the bread and butter in many parts of North West India and boon for farmers. Sometimes persistence or quasi permanent features of the weather system can cause disastrous situations in many parts of the country.
WDs movement and upper air circulation features and its association with quasi stationary trough and ridges are given in this paper which helps in understanding better the atmospheric drivers of WDs and their impacts on human society.

Keywords: *Western Disturbance (WD), Precipitation, Trough in westerlies, induced systems*

INTRODUCTION

Western disturbances (WDs) initially originated from Black sea or Caspian sea as a frontal system and lost their frontal characteristics after approaching the Indian domain. Therefore these systems appeared as trough or low pressure systems at surface or induced cyclonic circulation in the upper air in the regions of eastward moving winds, northern side of high pressure belt at subtropical region. Their origin in the Mediterranean Sea or regions adjoining Caspian Sea filled them with moisture and then these systems migrated eastward across Iran, Saudi Arabia, Pakistan, Afghanistan and then entered into J & K region of North India initially throughout the year. During winter season in India (December to February) across North India causes an inflow of warm and moist air from relatively southern latitudes ahead of the WD's along with the stream of dry and cold air which enters northern parts in the rear of the western disturbance. WDs also brings markedly cold and dry air from much higher latitudes into northwest India and the adjoining regions and then spreads to other parts of the subcontinent as a cold wave (mainly north of 20°N).

Eastward moving systems are generally known as mid and upper troposphere synoptic-scale systems which are entangled in the other prominent winter weather features known as subtropical westerly jet stream (STWJ) and therefore often associated with extreme rainfall events in north India and Pakistan during boreal winter (Hunt et al. 2018). Various authors in the past (Singh, 1979, Agnihotri & Singh, 1982 & Mohanty et al. 1999) show that the precipitation large scale indications of lower and mid troposphere air masses significantly affected the winter weather over the region. This interaction filled them with a latent heat flux in a cloud mass to conserve the mass continuity. Therefore it was felt by various authors in the past to examine eastward moving systems precipitation, vertical distribution of wind and geo-potential height during the passage of WD's, this will help to examine further the weather system in detail. By seeing the frequent occurrence and its association with social activities, a new index known as WD Index (WDI) was a support for measuring the strength of winter precipitation and this is related to the difference of geo-potential height at 200 and 850 hPa levels (Mithuna et al 2020).

Forecast driven by numerical weather prediction models is not new and it has a history of continuous development. In this direction two different cases of intense western disturbances in the year 2002 January, 13th to 17th and February 5th to 8th affected the northwest India was analysed by India Meteorological Department's operational limited area model (LAM) analysis and forecast system (Hatwar et al. 2005) and found that winter precipitation was picked up well by LAM forecast . It is generally known that, the rainfall associated with eastward moving westerly systems (WDs or induced low) in winter is normally confined to the north of 20 degree north and moves eastward as the system moves (Sharma & Subramanian, 1983). The WD's affect India throughout the year in different

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time and spatial domains depending on the presence of upper air trough and ridges movement in the middle and upper troposphere. It has been generally observed in the past during movement of these weather systems the cold air mass suddenly replaces the warm air with rapid fall in temperature of the order of 5–10°C. Therefore, intensity of the initially originated frontal system observed in winter is much higher than those observed in spring and summer.

Another way out of looking at the impact of these systems was that the Western Himalaya region received heavy precipitation due to passage of the western disturbances embedded in the eastward moving upper tropospheric Rossby wave train, especially in the winter months. Due to this interaction sometimes we will get WD's one after the other in a chain and have their cascading effect in terms of impact mostly over northern parts of India. This passage of the system can generate of foggy situations over the area of where WD passed and if a series of such systems passes over the same area then a persistent fog conditions will generate over that area and this is a part of global upper air circulation (Brijbhushan et al, 2003) and it can be used as a forecasting tool along with satellite imagery. Arrival of baroclinic waves in westerlies with tough axis about 90 °E and ridge with axis along about 65 °E and second upper layer flow pattern overlying horizontal cyclonic shear.

The topography has its own characteristics to modulate the weather and precipitation over the area and in other words we can say that the large-scale atmospheric dynamics plays an essential role in determining the amount of precipitation over this region (Para et al. 2017). It is seen that these synoptic scale weather disturbances, such as monsoon low pressure systems, sub-tropical cyclones, off-shore vortices, western disturbances, have been recognized for distributing rainfall during different phases of the monsoon season. Mesoscale cloud clusters and organizations within the synoptic scale systems have been identified to produce high impact on heavy rainfall events (Sikka, 2011).

India Meteorological department keep a record of WD's through its publications. In last 29 years(1986–2016) about ~500 WDs were observed as per India Meteorological Department (IMD) daily weather report (Mithuna et al 2020). There are 117 cases of WDs were observed during last five years (2017-2021) as per seasonal weather records of Mausam (an International Journal of Meteorology, Hydrology & Geophysics of IMD**)**. The origin of WD's is not a local interaction but it is associated with large scale flow of convection and hence either convection or shear instability acts as source mechanisms for the generation of mesoscale wave disturbances or within the exit region of a jet streak propagating toward an upper-level ridge axis (Uccellini & Kotch, 1987). Nature maintains mass balance and it will remain conserved. If by any means of weather activity or climate change scenario this balance gets disturbed then it will affect the weather activities globally and also its impact. Similar changes were projected for the Karakoram glaciers of the western Himalayan region by the researchers that globally averaged mass balance of glaciers and ice caps is going to be negative and in turn an anomalous gain of mass can be accumulated, to conserve the mass balance. Therefore it will modify the occurrences and impact of winter synoptic systems those who are influencing seasonal Himalayan snowfall or rainfall and consequently it influences the mass balance of regional glaciers (Ridley et al. 2013).

It is evident now that the advance information of these WDs is important for society, organizations involved men and machines are employed to operate in the open, for example, for defence purposes, agriculture, tourism and transport to reframe their activities in advance. Geographically, North India has complex Himalayan Mountain ranges of different altitudes and orientations all along this region which modulates the weather systems and their impact over the region. Due to the highly variable altitude and orientation of orographic barriers the prevailing weather conditions over the region is very complex (Dimri, 2006, Dimri & Chevuturi, 2014, Dimri et al. 2015, 2016). Different authors compiled, collecting and interpreting the WD's information in their own way. For example, Zafar and Rasul, 2009 selected only those systems that caused precipitation (at least over two stations) over Himachal Pradesh. Similar, with model reanalysis of National Center for Environmental Prediction (NCEP) or National Centre for Atmospheric Research (NCAR), Kalnay et al. 1996 analyzed through/circulation in mid-latitude westerlies associated with WDs from geo-potential height (GPH) at mid-tropospheric levels by using NCEP/NCAR reanalysis data and found that WD's movement is mainly governed by the mid latitude circulation activities. Therefore, to investigate further the movement and associated energy the WD's affecting India especially during winter, kinetic energy budget for an intense western disturbance that occurred over northwest India have been analyzed (Raju et al. 2011) and found that intense WD's have enough potential to modulate the rainfall /snowfall activity over the region.

Table 1: Average number values (decadel) of Cold waves (Source: Disaster weather events reports IMD)

No	State /UT	1971-1980	1981-1990	1991-2000	2001-2010	2011-2019	Sum
1	Punjab	6	6	6	7	3	28
2	Haryana	9	4	3	5	9	30
3	Delhi	4	3	4	5	4	20
4	Uttar Pradesh	8	3	2	4	6	23
5	Rajasthan	11	8	4	5	4	32
6	Sikkim	1	12	0	1	0	14
7	Assam	3	2	0	0	1	6
8	Madhya Pradesh	9	5	4	3	5	26
9	West Bengal	3	1	1	1	2	8
10	Bihar	5	4	3	4	6	22
11	Gujrat	6	4	2	3	1	16
12	Jharkhand	7	2	1	5	4	19
13	Odissa	2	3	1	2	3	11
14	Tripura	5	2	3	1	2	13
15	Chattishgarh	3	5	3	3	6	20
16	Maharashtra	7	2	5	3	5	22
17	Telengna	6	2	6	4	6	24
18	Andhra Pradesh	3	1	1	7	7	19
19	Karnataka	1	0	0	0	0	1
20	Tamilnadu	2	2	2	2	0	8

DATA AND METHODOLOGY

The Western disturbances data is taken from the reports compiled by India Meteorological Department (IMD) which is national weather forecasting agency under Government of India. The WD's events and associated weather information ssis compiled by IMD as a record and research purposes. Other supporting data like rainfall utilized to understand better WD cases is taken National Weather Forecasting Centre (NWFC) and Satellite division of IMD.

RESULTS AND DISCUSSIONS

The eastward moving upper air systems usually originate over the Mediterranean Sea and the Atlantic Ocean. These Extra-tropical systems are a global rather than a localized phenomenon with moisture usually carried in the upper atmosphere and localized behaviour like frontal systems in the beginning. The realized rainfall areas are associated with the strength of vertical mixing which again enhances the cyclonic vorticity in a complex topography plain and it results in increased precipitation over the areas. WDs are synoptic events that cause major influence over the winter-time weather over the northern Indian region as discussed in the chapter. Approximately 15% of annual precipitation is contributed by this Indian winter monsoon over north-western India (Yadav et al., 2012). The synoptic events and the associated precipitation have significant impacts over this region. The impact of WD events in winter mainly include rise of minimum temperature, increase of moisture especially over northern parts of India at the time of approaching the WD and after passing it appreciable rainfall, fog and an appreciable decrease of minimum temperature or sometimes cold wave conditions prevails over the area. This is clearly shown in Global Navigation of Satellite System (GNSS) derived Integrated Precipitable Water Vapour (IPWV in mm) increase and decrease in temperature during the WD event 02-06 January-2022 (figure 1, 2).

Case 1: 02-06 January-2021

INSAT-3D/3R Satellite derived products are useful in monitoring and assessing the potential of weather events even in data sparse regions through continuous coverage of Geo-imaging coverage. Winter season (December to February) in North India is generally under the influence of eastward moving weather systems. During 2nd to 05th January-2021 clouds movement have been organised and under the influence of southwesterlies winds it further interacted with lower level southeasterlies which are flowing over plains of northwest & adjoining areas including central India. This confluence and cooperative interaction of WD produced significant rain over the area. The NSAT-3D derived time series from 2nd to 5th January-2021 shows moderate (201-250 watt/m2, figure 3) to severe (≤200 watt/m2) with appreciable increase of moisture in upper atmospheric pressure levels (500 hPa and above). The city /district wise observed rainfall (08:30 IST of 2021-01-04 to 08:30 IST of 2021-01-05) is given in table (2).

Table 2: Observed Rainfall in association of WD (08:30 IST of 2021-01-04 to 08:30 IST of 2021-01-05)

City /District	Accumulated Rainfall (in mm)	City /District	Accumulated Rainfall (in mm)
Palam	14.5	Gr. Noida	6.3
Ridge	6.3	Gurugram	8.6
Ayanagar	6.3	Dhansa	16.9
Najafgarh	15.7	Delhi University	6.3
Sports Complex	6.3	Jafarpur	21.1
Faridabad	6.3	Pusa	6.3
Ghaziabad	6.3	Pitampura	6.3
Noida	6.3	Mungeshpur	15.7
Muzaffarnagar	8.6	Bijnor	6.3
Meerut	6.3	Baghpat	9.0
Bulandshahar	6.3	Sambhal	6.3
Panipat	38.4	Karnal	27.8
Kaithal	7.4	Jind	9.8
Hissar	11	Rohtak	25.4
Bhiwani	39.6	Jhajjar	26.5
Rewari	18.1	Narnaul	56.7
Nuh	6.3	Aligarh	0.0

Role in modulating the weather

WD's role is important and its frequency, intensity, position and strength affect the society in different ways. Sometimes it is boon or sometimes its effects are hazardous to the public and it can cause the loss of lives and property. Their frequencies and coverage modulates the regional weather in many folds. This year Mid-March to end of April-2022 have India faced unprecedented heat and dry weather in almost the entire country. One obvious reason is that very few number of WD's approached at lower latitudes of the Indian domain that could bring rain and a comfortable situation for the country. The genesis of these systems affects globally and even countries like Spain, Portugal, Western Russia, Kazakhstan, Pakistan and Afghanistan etc. also face abnormal rise of temperature (~ 10 °C more) due to persisting La-Nina conditions. Temperature in almost all parts of the world will likely to rise in March and April despite the cooling influence of the La Nina weather phenomenon said by WMO latest forecasts generated from WMO global producing centres of long range forecasts indicate a moderate likelihood (65 %) that La-Nina event will continue in February and April -2022 (WMO, 2021).Therefore, WD's activity modulates the weather systems like in winter months and pre-monsoon months it produces intense snowfall activity over high reaches of J & K, Himachal Pradesh and heavy rainfall /snowfall may lead to landslide, flood etc. The prolonged presence of WD's sometimes support Rabi Crops (wheat in winter) and sort out water recharge problems but unprecedented rain /snow or persistence of WD can cause loss of life and property.

CONCLUDING REMARKS

Global Circulation Model (GCM) Model projections shows the decreasing trend of future WD's, Hunt et al, 2019 observed that WD's activity is attributed with the strength of the subtropical westerly jet in winter, wind shear and its meridional distribution and temperature gradient which is decided by the temperature gradient tendency at middle troposphere level which is also known as mid-tropospheric baroclinic vorticity tendency. The variations in jet strength and changes in baroclinic vorticity tendency can affect the intensity of WD's.

The month of March and April 2022 shows unusual warming conditions almost throughout the Indian domain. World Meteorological Organisation (WMO) a nodal United Nation (UN) agency responsible for deciding the weather norms and regulations all over the world in his statement indicates a moderate chance (about 65%) of the current La Niña conditions continuing during March-May 2022, and about a 35% chance of their further weakening to El Niño/Southern Oscillation (ENSO)-neutral conditions. This information was generated from the WMO Global Producing Centres of Long-Range Forecasts. The occurrence of WD's at lower latitudes help to bring rain in Indo Gangetic Plains including central & peninsular India by picking up moisture from the Arabian Sea and sometimes even over the Indian Ocean due to a pre-existing subsurface low over western India. Figure 4 shows extremely heavy rain observed 23-25 September-1988 (max. 31.6 cm) due to deep trough and continuous moisture supply from Arabian Sea during the retrieving phase of south west monsoon over northwest, central and southern parts of India. Sometimes not only rainfall but cold /severe cold and fog conditions also prevail during winter time.

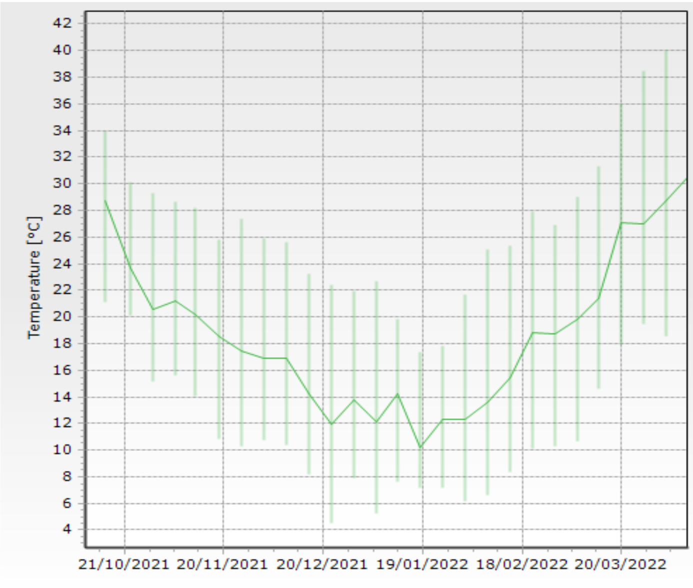

Fig 1: Daily Temperature of last 6 months (Max /Min °C) Values for Delhi (Source: IMD)

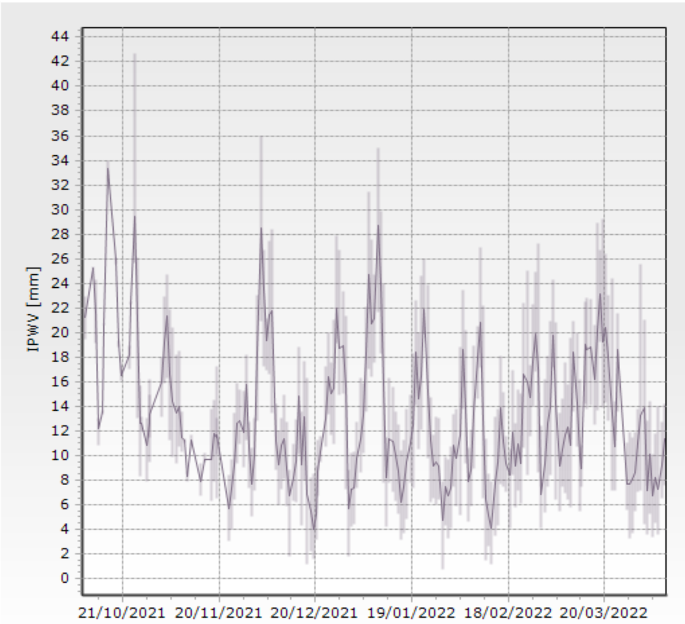

Fig 2: Daily IPWV of last 6 months (Max /Min in mm) Values for Delhi (Source: IMD)

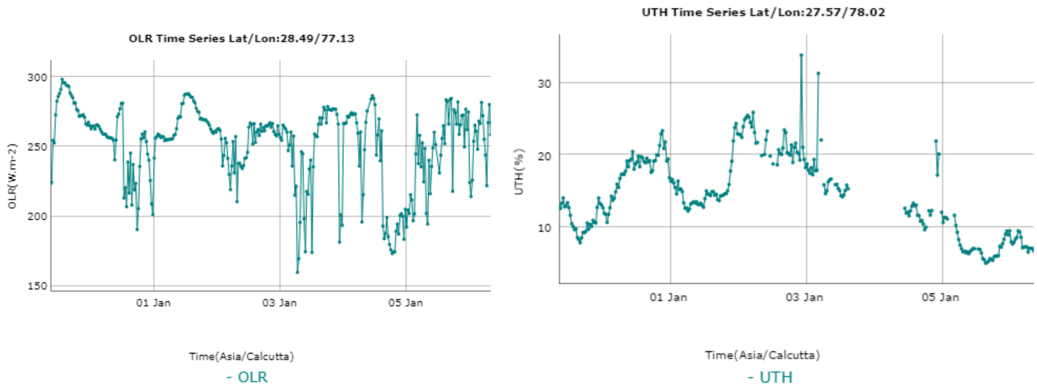

Fig. 3: INSAT-3D derived time series (02-05 Jan-2021) of Outgoing Long wave Radiation (OLR) and Upper Tropospheric humidity (UTH)

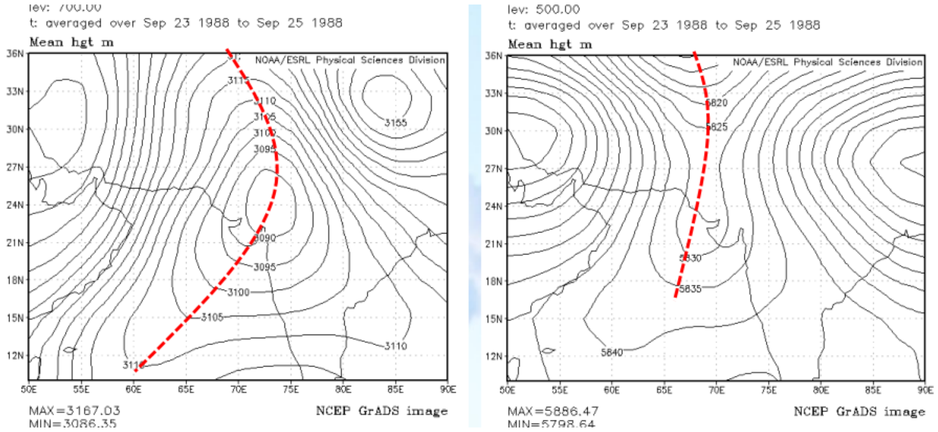

Fig 4: Heavy Rainfall case (23-25 September-1988)-deep quasi stationary trough seen in NCEP data analysis

ACKNOWLEDGEMENT

Authors are grateful data and interactive discussion with India Meteorological department officials especially DGM of IMD for data as well as weekly weather report support. Authors are grateful for data support for National centre of Environmental Prediction (NCEP) Centre for analysis the old case.

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