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Movements of western disturbance and associated cloud convection

***Ramesh Chand and Charan Singh**
India Meteorological Department, Mausam Bhavan, Lodi Road, New Delhi-110003
*Corresponding Author: r58.chand@gmail.com

ABSTRACT
Western disturbances have a long history of climatological, synoptic and satellite observations based studies. In present study an attempt has been made to understand the different aspects of western disturbances like movement, associated convection, induce systems and associated weather. The western disturbances (WDs) during post monsoon and winter season have been selected for the study as they are mainly responsible for precipitation over western Himalayan region and adjoining plains of northwest India. The areal extension of precipitation increases, in cases when westerly trough or WD interacts with southwesterly winds from Arabian Sea and easterly/southeasterly from Bay of Bengal. It caused rain/snow over western Himalayan region and rain/thundershowers with sometimes hailstorm over northern plains.

In present study 10 recent cases of WDs have been analyzed in detail to comprehend the characteristics of WD's. Study revealed that the normal movement of the mid-level westerly trough (WD) is about 440 km/day i.e. longitude 4.5^0 day^{-1}.In general WDs moves faster in case of typical synoptic situations like low pressure area or a cyclonic circulation ahead of the system in lower tropospheric levels. In case of slower moving WDs, it was observed that ridge/anticyclone is ahead of the system in lower levels. The maximum convection associated with westerly trough is located in an average 1200 km ahead of the westerly trough and coldest pixel north-east of the southern tip of the westerly trough. In general the cloud top temperature associated with western disturbances ranges from-40.0 to -60.0^{0}C. It is also observed that the WDs become intense when southern end of the trough in mid-level westerlies dips up to Arabian Sea.

INTRODUCTION

The WD's are primarily seen as a trough in mid–tropospheric westerlies, sometimes it also observed in lower levels. Western disturbances are non-monsoonal precipitation systems in the westerlies. These systems usually originate over the Mediterranean Sea and the Atlantic Ocean with moisture from there. When the WDs reaches over Afghanistan, Pakistan and India and trough extends to low latitude they start taking moisture from Arabian Sea, at this stage these intensify. Under the influence of WDs, circulations/low pressure areas are developed ahead of these systems. These systems are known as induced circulation or induced low pressure areas.

Rao and Srinivasan, (1969) described the WDs as a trough in mid-level westerly winds which originate over Mediterranean Sea and move eastwards. Pisharoty and Desai, (1956) has defined western disturbance as an eastward-moving upper air trough in the sub-tropical westerlies, often extending down to the lower atmosphere of the north Indian latitude, during the winter months. Sometimes, these are observed as closed cyclonic circulations at the sea-level. Due to their movement as mid-level westerly trough form west to east, these systems are known as WD in Southeast Asian region and over India. The term WD is also applied to a low or trough either at surface or in the upper air in the region of westerly winds north of latitude 20.0^0 north in general. In the absence of cloud and precipitation, it is more common to refer them as troughs. During post-monsoon and winter season months WDs are the main sources of precipitation over western Himalayan region and northern plains of India. The winter precipitation over these regions is very important from the point of view of agriculture; particularly snowfall is very good for apple, tulip and some other crops over western Himalayan region. It also feed the rivers of north India, which fulfill the requirements of water for agriculture; hydro-electric projects, drinking and factories etc. Precipitation caused by western disturbances is the key of livelihood and happiness of human beings mainly in north India.

In operational forecasting the WD's are considered as a troughs or circulation in mid-level westerlies according to their intensity. These WDs are tracked by the trough in mid-tropospheric westerlies, cloud patterns and movement, rise in temperature and fall in surface pressure are also the indicator of movement. Reaching over northern parts of Pakistan and India, they intensify mainly due to incursion of moisture over the region from Arabian Sea. In addition, orography also contributes in enhancing the intensity in term of cloud convection. During winter months high reaches of western Himalayan region experience rain/snow and low lying area including northern plains rain/thundershowers. The WD during 3-7 February, 2013 caused wide spread rain/snowfall over western Himalayan region and rain over adjoining plains. However, precipitation also occurred over these regions in other months also, but the amounts of precipitation due to WDs are very less. At the same time this precipitation is very useful for Rabi crops and storage of water.

BRIEF ON SOME PAST STUDIES RELATED TO WDS IN INDIA

Agnihotri and Singh, (1982) studied the cloud masses and concluded that WDs move at the rate of 10.0^0 longitude/day from the Middle-East to northwest India and neighborhood. Mohanty et. Al., (1999) studied latent heat flux and found that on the approach of WDs over northwest India, the latent heat flux initially increases over the Persian Gulf, northeast Arabian sea, Pakistan and Gujarat coast in India. They also found that the magnitude of latent heat flux become higher in active WDs. The total precipitable water content in the complete atmospheric column increases with the approach of a WD over northwest India. It increased to 24-25 kgm^{-2} (2.4-2.5 gm/cm^2) in case of intense and 14-15 kgm^{-2} (1.4 to 1.5 gm/cm^2) in case of normal WDs. After the passage of a WD, the water content fall to its normal values which is about 4-6 kgm^{-2} (0.4-0.6 gm/cm^2) in winter season Mohanty et. al., (1999). The WD's occasionally deepen when they reach over Indo-Pak area, particularly over Rajasthan and Punjab Rao and Srinivasan, (1969). Roy and Bhowmik, (2005) analyzed the vertical structure of the atmosphere over Delhi during the passage of a WD during January-2002. In association with this WD, Delhi received the first and most abundant rainfall of the winter season on 15 January 2002. Some of the WDs have their induced effects in the plains caused rain/thunderstorms activities over plains of northwest India, to find the cause of thunderstorms activities. Roy and Bhowmik, (2005) explores the thermodynamics of the atmosphere computing conditional available potential energy (CAPE), conditional inhabitant energy (CINE), moist static energy and other moisture parameters of Delhi based on model analysis fields of India Meteorological Department. A clear increase in the value of CAPE and decrease in the value of CINE is noticed on the days of occurrence of rainfall over the station (15-18 January, 2002). The surface moist static energy curve on the other hand, shows a significant increase in value two days prior to the occurrence of rainfall over the station. The precipitable water content profile of the column of the atmosphere above the station is seen to closely follow the rainfall pattern associated with the system. The model analysis field for moisture anomalies reveals increased moisture in the upper troposphere very much in advance of the actual outbreak of rainfall activity over the station, in association with a WD. Around the time of onset of rainfall activities at the station, these positive moisture anomalies come down to the lower troposphere. It is also observed that just prior to the onset of a WD over the station, due to the moisture influx over the station, the atmospheric density decreases.

Agnihotri and Singh, (1982) have studied the longitudinal and latitudinal movement of western disturbances to verify the earlier results by the help of satellite imageries. Overcast cloud masses are associated with westerly systems, which are first detected generally between longitude 25.0^0E to 35.0^0E and latitude 30.0^0N to 40.0^0N and approach towards northeast. Sometime, they are associated with the secondaries of the extra tropical depression moving north-eastwards from the Mediterranean Sea areas. These secondary systems generally form in the Persian Gulf-Black sea region and move east-northeastwards over an area of generally sparse data. These are mostly shallow system, cloud mass associated with them is observed in satellite images. These shallow systems take about 2 days to reach over northwest India from Persian Gulf area. On the contrary some cases are there when they developed over Indo-Pakistan region and move so fast that forecaster have no sufficient lead time to forecast well in advance. This type of system is completely surprised by sudden development Singh, (1979).

DATA SOURCE AND METHODOLOGY

Movement of mid-level westerly troughs, deepening of trough, associated convection and realized precipitation has been studied here in detail. For better perceptive of these parameters 10 numbers of WDs have been considered for study. All the WDs have been observed during October, 2012 to March-2013.

Speed of movement is calculated by the help of cloud motion vector winds of Meteosat-7 upper air winds of 0300 UTC between 351 to 500 hPa levels (http://tropic.ssec.wisc.edu/real-time/windmain). Longitudinal and latitudinal displacement has been estimated by satellite based derived winds (CMV) of each WD. The longitudinal and latitudinal positions of westerly trough were taken at 0300 UTC daily for its life span. On the basis of daily displacement, the average of longitudinal and latitudinal displacement has also been calculated to know the average speed of the movement and expansion of the westerly trough. Further for better assessment of movement, National Centre for Environment Prediction (NCEP) reanalysis mean sea level pressure, 925 and 500 hPa level winds charts have been utilized Kalnay et. al., (1996). Sea level and upper air charts also used from synergie system of National Weather Forecasting Centre (NWFC), India Meteorological Department (IMD). Intensity of clouds ahead of the westerly trough have been estimated by using Kalpana-1 satellite imageries of IMD utilizing grey to white shed theory of satellite meteorology. The smallest part of the image is the pixel, which stands for "picture element." The radiation coming from each pixel is presented in an

Table 1. Average longitudinal and latitudinal movement per day of mid-level westerly trough and associated coldest cloud top temperature (CTT)

S. N0.	Period of Western Disturbances (WD) Col.(1)	Longitudinal. Movement of WD (in Km/ day) Col.(2)	Latitudinal expansion of WD (in Km/ day) [southwards (+) & northwards (-)] Col.(3)	Coldest Cloud Top Temp. of the pixels (CTT in ^{0}K) Col.(4)	Location of southern tip of westerly trough at the time of coldest CTT Col.(5)	Longitudinal distance of coldest CTT from westerly trough (deg.) Col.(6)	Latitudinal distance of coldest CTT from westerly trough (deg.) Col.(7)
1	16-28 Oct 2012	278.7	100.8	214	32/63	20	19
2	21 Oct-2 Nov 2012	338.5	00	218	32/70	10.1	9
3	8-19 Nov 2012	485.8	-64*	215	28/42	12.5	19
4	11-24 Nov 2012	573.6	102.1	211	30/00	8	9
5	19 -30 Nov 2012	586.8	00	215	30/65	11.2	9
6	29Nov-11Dec 2012	287.7	59.2	216	18/52	11.2	16
7	12-20 Jan 2013	671.1	171.1	213	15/67	12.5	10
8	28 Jan-3 Feb 2013	473	33	222	22/82	16	13
9	29 Jan-9 Feb 2013	412.5	110	211	25/62	8.4	10
0	10- 17 Feb 2013	316.2	27.5	215	20/78	7.8	12
	Average	**442.3**	**46.6**	**215**	**----**	**11.7 (1287 Km/day)**	**12.6 (1386 Km/day)**

image format in terms of a gray scale. An image consists of 256 gray shades, ranging from 0 for pure black to 255 for pure white.

Kalpana-1 satellite full disc infrared imageries have been utilized to see the coldest CTT area. CTT is the proxy to estimate the convection and height of the clouds. Different ranges of CTT indicate the category of severity of convection. Intensity scale depending upon the minimum CTT threshold values ranges are:(i) weak convection CTT is more than -25.0^{0}C, (ii) moderate convection -25.0^{0}C to -39.0^{0}C, (iii) intense convection -40.0^{0}C to -69.0^{0}C and (vi) very intense convection less than -70.0^{0}C Tyagi et. al., (2012). These criteria are being followed in operational forecasting in IMD.

RESULT AND DISCUSSION:

Movement of mid-level westerly trough:

In all cases of mid-level westerly troughs, overcast cloud mass with intense convection were found far ahead of trough. The conventional observational data over western Himalayan region, Iran, Iraq, Afghanistan and north Arabian Sea were sparse; try has been made to locate the mid-level westerly trough and convection area with the help of satellite imageries and products over these areas. Troughs were clearly identified in westerlies where formation and movements of the system over Indo-Pakistan region could be established with confidence with the help of upper air meteosat derived winds and satellite imageries. Radio sonde / Radio wind (RS/RW) observed upper air winds have also been taken into consideration to identify mid level westerly trough and induced circulation. The case to case movement and average longitudinal and latitudinal movement per day of westerly troughs were computed and average displacement of all 10 cases is given in Table-1.

It is observed from the table-1 that the movement of trough in mid–level westerlies varies system to systems and day to day in each case. There is no much similarity in horizontal movement of the trough as many troughs have easterly component, a few have east-southeasterly component and one or two have northeasterly component. However, all troughs have mainly easterly component in their movement. Out of total 10 WDs two moves eastwards, seven extends southeastwards slightly while moving eastwards and in one cases extends north-northeastwards. Present study revealed that trough in mid-level westerlies moved with the speed ranges from 278 to 671 km/day. However, the speed of the westerly trough in each case is different; it is also differ in each day. The present study of 10 WD's revealed that the trough moved with the average speed of about 440 km/day. In case of WD during 11-24

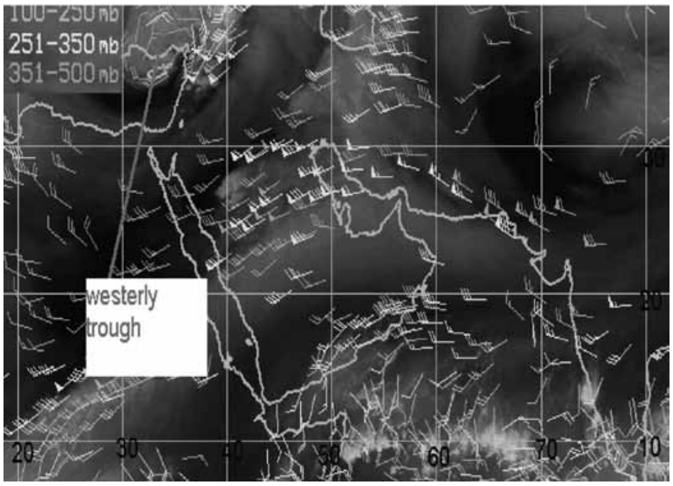

Figure 1(a). Meteosat-7 mid-tropospheric westerly winds between 500-350 hPa levels at 03 UTC of 11 November 2012 showing westerly trough, lay at 21.0^0N/30.5^0E. Southwestrely winds between 350-251 hPa level prevailing between latitidue 20.0-30.0^0N ahead of trough.

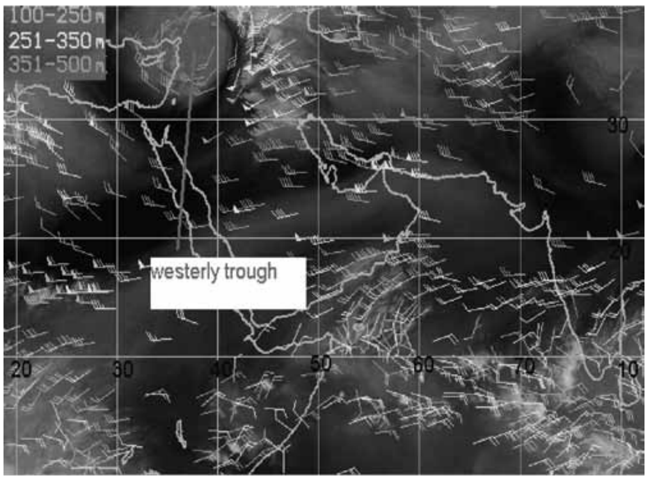

Figure 1(b). Meteosat-7 mid-tropospheric wesetrly winds between 500-350 hPa at 03 UTC of 12 November, 2012 showing westerly trough lay at 20.0^0N/35.5^0E. Southwestrely winds between 350-251 hPa levels prevailing latitidue north of 30.0^0 N ahead of trough

November, 2012, the westerly trough lay along longitude 30.5^0E on 11 November and along longitude 35.5^0E on 12 November- 2013 at 03 UTC [Fig.1 (a&b)].

The average movement of this system is about 574 km/day given at S.No.4 in Table 1. The WDs during 25-29 January 2013 and 11-17 February 2013 were the fast developing systems over Afghanistan and adjoining north Pakistan due to favorable environment conditions and moisture incursion from Arabian Sea.

Induced cyclonic circulation and low pressure areas

When a westerly trough deepens to low latitude while moving eastwards, an upper air cyclonic circulation develop ahead of the trough over Pakistan and adjoining northwest India. Under the influence of these induced cyclonic circulation, some time low pressure area/depression also developed over northwest India and adjoining Pakistan. While moving the mid-level westerly troughs, some time moisture incursion takes place from Arabian Sea by moderate to strong southwesterly winds in lower levels.

For example WD during 3-7 February 2013, had caused to form a western depression over west Rajasthan and neighbourhood on 5 February due to deepening of the southern end of westerly trough in lower levels up to 15.0^0N over Arabian Sea, which caused moisture incursion to the western depression and topography of the region. The mean sea level pressure shows western depression [Fig.2(a)] and 850 hPa wind charts shows induced cyclonic circulation and moisture incursion over northwest and adjoining central India from Arabian sea and Bay of Bengal [Fig.2(b)].

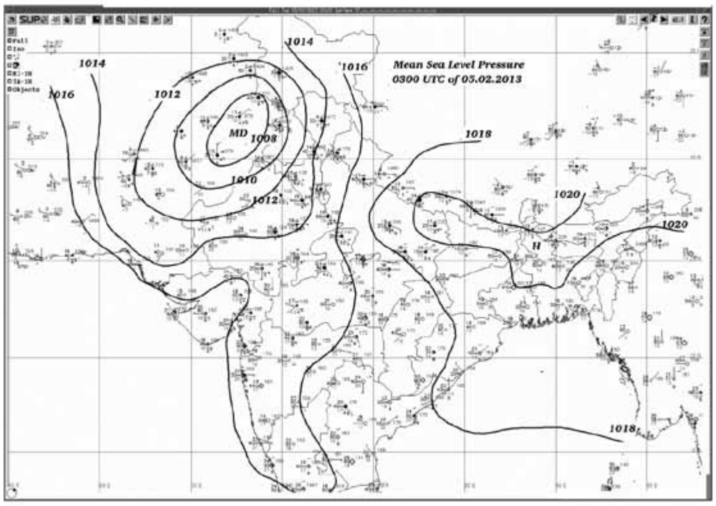

Figure 2(a). Mean sea level charts at 03 UTC of 5 February 2013, shows a western depression with pressure fall of the order of 6-8 hPa over Pakistan and adjoining west Rajasthan, just ahead of the westerly trough in mid-levels.

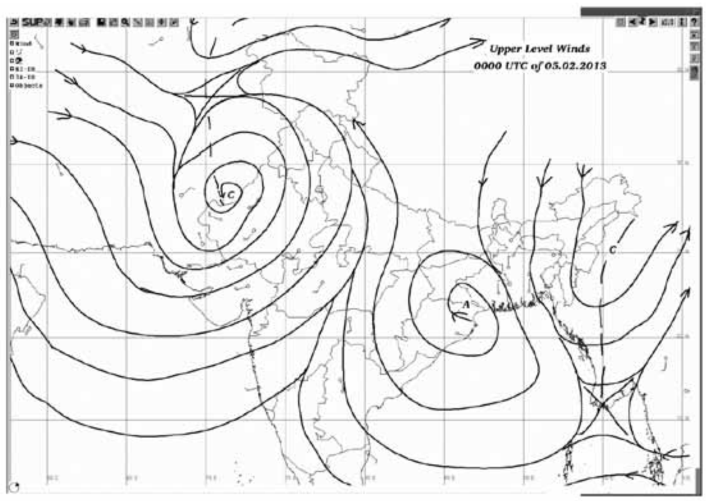

Figure 2(b). 850 hPa winds at 00 UTC of 5 February 2013 shows a cyclonic circulation over central Pakistan & adjoining Rajasthan in association with western depression. Moisture incursion is taking place over northwest and central India from Arabian Sea as well as from Bay of Bengal.

Clouds and Cloud top temperature

Highest intense convection area associated with the WD's are observed about 800 to 2200 km ahead of the trough with average distance of 1287 km ahead to the northeast sector of the WD with cloud top temperature -50.0^0 to -60.0^{0}C. Though convection started just ahead of trough, the coldest pixel lay about 1287 km eastward (average of all 10 cases) and 1386 km northward of the southern tip of the westerly trough. The WD during 12-20 January, 2013, Kalpana-1 image of 03 UTC of 18 January-2013 shows that the coldest cloud shields lay over western Himalayan region and adjoining plains of northwest India, northeast of southern tip of westerly trough when trough at 500 hPa level lay along longitude 70.0^{0}E [Fig.3(a)]. Cloud imagery also indicates the moderate convection associated with week westerly trough lay over central Pakistan and adjoining Afghanistan and intense convective cloud mass far away over western China [Fig.3(b)]. It is clear from [Fig.3 (a&b)] that the intense convection lay over far northeast of southern tip of westerly trough. It is also noticed that the convection has shifted northeastwards on 19 January in comparison of 18 October 2012.

WEATHER ASSOCIATED WITH WESTERN DISTURBANCES

The precipitation experienced is mainly due to the large-scale interaction between the mid-latitude and the tropical air masses. In present study it was also seen that

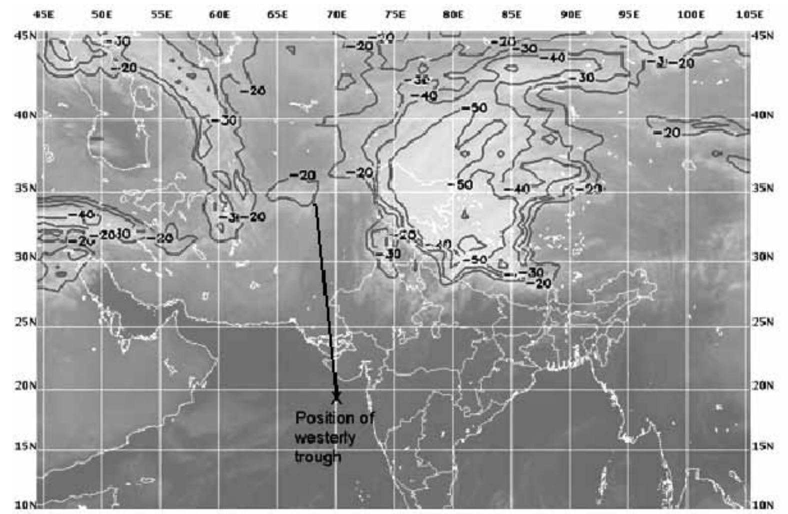

Figure 3(a). Kalpana-1 image with CTT contours at 03 UTC of 18 January 2013 the coldest cloud shields over western Himalayan region and adjoining plains of northwest India. The coldest cloud shields lay over northeast of southern tip of westerly trough.

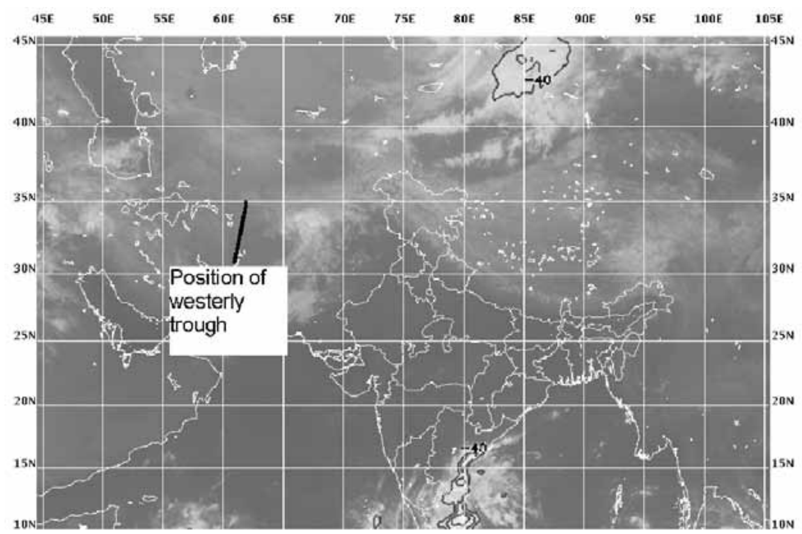

Figure 3(b). Kalpana-1 Infrared imagery with CTT contours at 03 UTC of 19 October 2012 indicates moderate convection associated with week westerly trough over central Pakistan & adjoining Afghanistan and intense convective cloud mass far away over western China. The convection is lay over northeast of westerly trough.

the interaction of southwesterly winds from Arabian Sea with easterlies winds from Bay of Bengal took place over northwest India, caused widespread to fairly widespread rain/snow over western Himalayan region and rain/thundershowers over northern plains. In some cases western Himalayan region received isolated to scattered heavy snowfall and thundersquall. Rain/thundershowers at a few places accompanied with hailstorm at one or two places also observed over northern plains. It has been observed from the satellite images and satellite derived winds that sometimes, an intense WD approached from the west suddenly weakened and passes off without causing any weather over the Indian region. In case of recent past the WDs during 27 January to 2 February and during 1-3 February-2013 have experienced very less precipitation over western Himalayan region.

CASE STUDIES

Out of 10 WDs a slow moving and another fast moving WDs have been discussed here. The criteria of slow and fast moving WD are based on the average eastward movement of the system (mid-level westerly trough). Synoptic situation of slow moving WD during 16-28 October-2013 are described below:

Slow moving WD: The western disturbance (16-28 October 2012) as an upper air trough in mid level westerlies (500 hPa) was at around longitude 49.0^0E at 0300 UTC

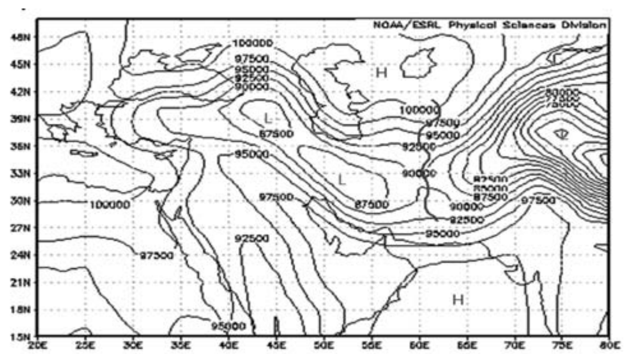

Figure 4(a). NCEP reanalysis of mean sea level pressure indicates a low pressure belts between latitude 30.0 to 40.0^{0}N and longitude 42.0 to 56.0^{0}E and ridge ahead of it on 16 October 2012.

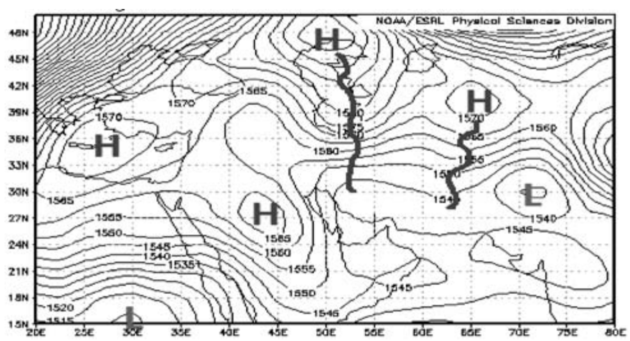

Figure 4(b). 925 hPa NCEP wind reanalysis shows an high/ ridge ahead of westerly trough lay along longitude about 56.0^{0}E and latitude 25.0 to 42.0^{0}N on 16 October 2012 whereas westerly trough at 500 hPa is around 49.0^{0}E.

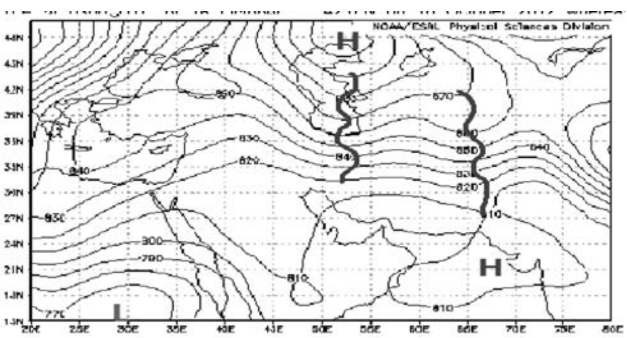

Figure 4(c). 850 hPa NCEP wind reanalysis shows a ridges ahead of westerly trough lay along longitude about 52.0^{0}E and latitude 32.0-50.0^{0}N and another ridge along longitude about 54.0^{0}E and latitude 30.0 to 42.0^{0}N on 16 October 2012 whereas westerly trough at 500 hPa is around 49.0^{0}E

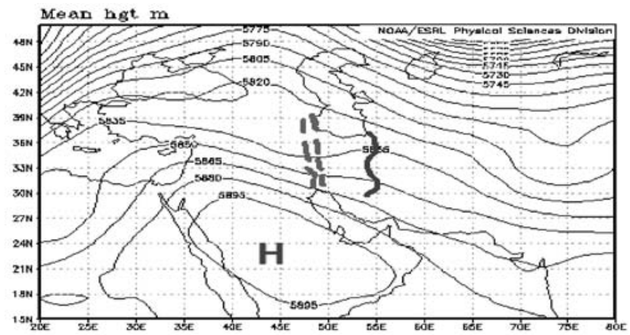

Figure 4(d). 500 hPa NCEP reanalysis showing shallow westerly trough lay along longitude 49.0^{0}E and shallow ridge lay along longitude 55.0^{0}E and latitude 30.0-40.0^{0}N on 16 October 2012.

of 16 October 2012. A low pressure belts lay between latitude 30.0^0 to 40.0^{0}N and longitude 42.0^0 to 56.0^{0}E on 16 October and ridge ahead of it around longitude 62.0^{0}E [Fig.4(a)]. At 925 hPa ridge lay along longitude about 56.0^{0}E and latitude 25.0^0-42.0^{0}N and at 850 hPa the ridge lay along longitude about 52.0^{0}E and latitude 32.0^0-50.0^{0}N and another ridge along longitude about 54.0^{0}E and latitude 30.0^0-42.0^{0}N on 16 October 2012 whereas westerly trough over 500 hPa is around 49.0^{0}E [Fig.4 (b&c)]. NCEP reanalysis of 500 hPa level shows the westerly trough lay along longitude about 49.0^{0}E. NCEP reanalysis 500 hPa contour and upper and middle level meteosat winds suggest the westerly trough lay along about 49.0^{0}E [Fig.4(d)]. The movement of the westerly trough was slow during this period till it reaches at 70.0^{0}E, afterwards it acquire its normal speed of movement. The trough in westerlies over 500 hPa lay along longitude 49.0^{0}E on 16 and along longitude 69.0^{0}E on 22 October. Another important feature also noticed in this case that the deepening of this system reach up to latitude 20.0^{0}N on 22 October 2012. It is clear from the sea level and upper level analysis that the westerly trough moved slowly as ridge lay ahead of the westerly trough throughout its lifespan.

Fast moving WD: The western disturbance (12-20 January 2013) was fast moving system. On 16 January a trough in mid level westerlies lay along longitude about 57.0^{0}E. Its induced low pressure area lay ahead of mid-level westerly trough on 16 January 2013 [Fig. 5(a)]. At 925 hPa an upper air cyclonic circulation lay between longitude 55.0^0-80.0^{0}E and latitude 15.0^0-35.0^{0}N and at 850 hPa an upper air cyclonic circulation lay between longitude 58.0^0-76.0^{0}E and latitude 20.0^0-32.0^{0}N on 16 January [Fig 5(b&c)]. NCEP reanalysis shows the westerly trough at 500 hPa lay around longitude 57.0^{0}E whereas at 700 hPa level an upper air trough lay along longitude about 65.0^{0}E [Fig.5(d & e)] on 16 January 2013. NCEP reanalysis of 500 hPa level shows the westerly trough lay along longitude about 57.0^{0}E whereas in upper and middle level meteosat winds the westerly trough lay along about 55.0^{0}E. The low pressure area or cyclonic circulation ahead of westerly trough is conducive for fast movement of westerly trough, this type of lows some time described

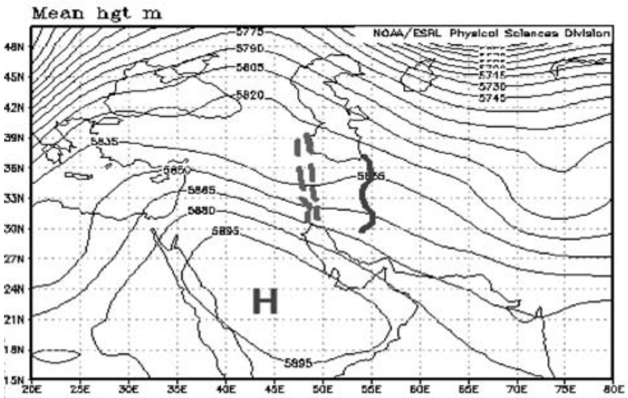

Fig.5(a): Mean sea level pressure NCEP reanalysis shows a low pressure area at surface lay ahead of mid-level westerly trough east of long 70.0^{0}E between latitude 28.0^{0}N to 40.0^{0}N, whereas westerly trough at 500 hPa is around 57.0^{0}E on 16 January 2013.

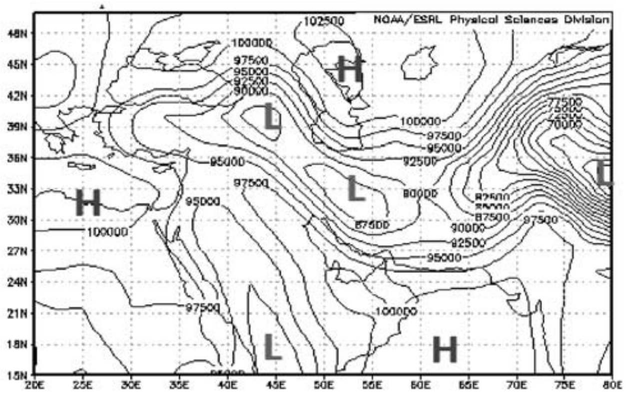

Fig.5(b): 925 hPa NCEP reanalysis shows an upper air cyclonic circulation lay between longitude 55.0-80.0^{0}E and latitude 15.0-35.0^{0}N whereas westerly trough at 500 hPa is around 57.0^{0}E 16 January 2013.

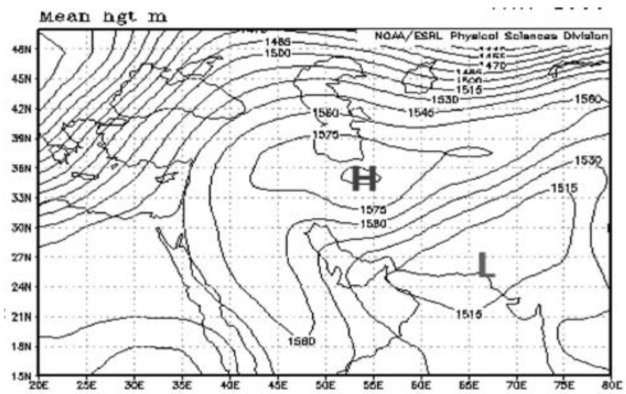

Fig.5(c): 850 hPa NCEP reanalysis shows an upper air cyclonic circulation lay between longitude 58.0-76.0^{0}E and latitude 20.0^0-32.0^{0}N whereas westerly trough 500 hPa is around 57.0^{0}E 16 January 2013.

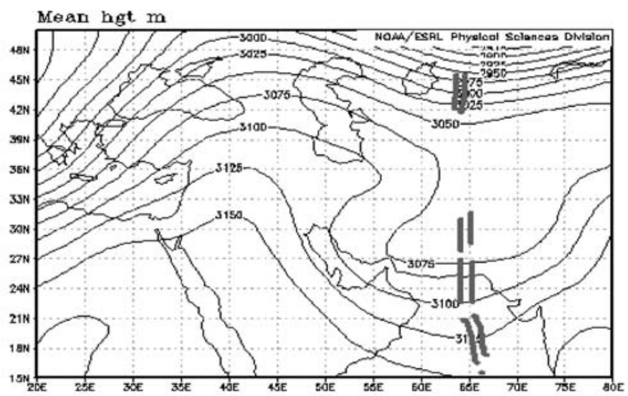

Fig.5(d): 700 hPa NCEP reanalysis shows an upper air trough lay along longitude about 65.0^{0}E whereas westerly trough at 500 hPa is around longitude 57.0^{0}E 16 January 2013.

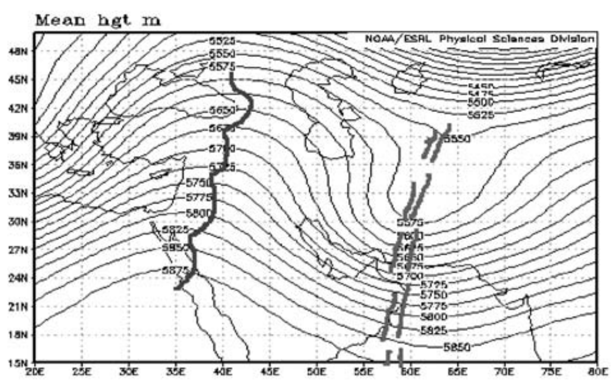

Fig.5(e): 500 hPa NCEP reanalysis shows an upper air trough lay along longitude about 57.0^{0}E 16 January 2013.

as cut-off low pressure areas in synoptic meteorology. It is observed that the fast moving mid-level westerly trough during 12-20 January 2013 moves with the average speed of 671 km/day. It can be considered as a fast moving western disturbance as present study shows the average speed is about 440 km/day.

CONCLUSION

Based on the study of 10 western disturbances which formed during October 2012 to February 2013, the following inferences can be drawn.

Convective clouds are seen over Middle-East and Indo-Pak region, which moves towards northeast from Mediterranean Sea, Turkey, Black Sea, Georgia and Caspian Sea areas and get enhanced over the area between longitude 25.0 to 50.0^{0}E and latitude 30.0 to 35.0^{0}N.

Movement of the trough in mid-level westerlies is west to east and varies case to case as well day to day. It is found that the speed of the movement of westerly trough ranges from 275 to 675 km/day. The average speed of these troughs is about 450 km/day. It is also found that in some cases the trough extends towards south or north while moving eastwards.

The southward deepening of WD's noticed with the stationary to 171 km/day with an average of 46 km/day. There is an exceptional case during the study period when WD (8-19 November 2012) expand northwards with a speed of 64 km/ day. Out of 10 cases of the WDs, 2 move almost eastwards without north-south expansion.

Coldest cloud top temperature pixels associated with the WDs are observed around 800 to 2200 km ahead of the westerly trough with average distance of 1700 km northeast of the southern tip of the westerly trough. The average longitudinal shift is about 1250 km/ per day. In most of the cases coldest CTT is -50.0^0 to -60.0^{0}C .It is also observed that the very intense convection is rare; the convection associated with western disturbance is mostly of moderate to intense category**.**

Study revealed that the WD moves fast in case of typical synoptic situation like low pressure area or an upper air cyclonic circulation lay ahead of the system in lower tropospheric levels and moves slow in case the ridge/ high pressure lay ahead of the westerly trough.

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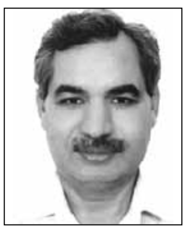

Ramesh Chand obtained MSc (Mathematics) from Chaudhry Charan Singh University, Meerut. He is working in programme division of Ministry of Earth Sciences –India Meteorological Department (MoES-IMD). He is responsible to conceive, plan, coordinate and implement various scientific, technical and operational service programmes of IMD. He has contributed to many departmental technical reports/books. He has 15 research papers in peer reviewed Journals of Meteorology. He has experience in Synoptic Meteorology, particularly weather forecasting i.e. tropical cyclone, heat wave, cold wave, fog, monsoon rainfall and thunderstorms forecasting. He has also experience in Satellite Meteorology (Synoptic Application).He participated in many seminars/workshops at National & International level