Diagnostic Study of Heavy Downpour in the central part of Pakistan

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Abstract

Diagnosis of heavy rainfall event of July 2005 that caused urban flooding in Multan City, located in Punjab province of Pakistan has been carried out in the study. By using the conventional weather charts of Pakistan Meteorological Department (PMD), National Centre for Environmental Prediction (NCEP) reanalysis data plots and analysis of temporal and spatial distribution of different weather parameters at the surface and in the upper air have been done. It is diagnosed that the heavy rainfall occurred under the influence of approaching monsoon depression, westerly wave prevailing over Kashmir and surrounding Himalayan region and its interaction with the upper air easterly wave. Besides this, the mesoscale low slightly northeast of the study area and an intensified ridge penetrating from northeast up to west of the study area, created the area of discontinuity that caused the interaction of northeastern and southwestern currents. The intensive heating in the last week of June and due to influence of westerly, a mesoscale low was formed in the leading trough of depression. The seasonal low was also realigned due to its interaction with westerly wave and the depression. Streamlines at lower level indicate that moisture transport from Arabian Sea was started two days prior to the event with maximum transport from 3rd July Night. On the basis of these synoptic features the amount of rainfall can be predicted well in time and therefore, it may help in minimizing the flood damages in the form of losses of human lives, soil erosion as well as managing the sewerage channels.

Keywords: Conventional Weather Charts; Monsoon Depression; Mesoscale Low

Introduction

In the present world with increasing population, the demand of water is increasing day by day in various sectors like drinking water, industries, agriculture and many others. Pakistan is an agricultural country and its most of the economy, directly or indirectly depends upon the agricultural activities. Agriculture in Pakistan is directly linked with the amount of rainfall received during monsoon season. Widespread rainfall of moderate to heavy intensity was recorded for two consecutive days in Kashmir, Punjab and Khyber Pakhtun Khwa (KPK), while of light to moderate intensity was recorded at isolated places Sindh and Balochistan. In Pakistan the main contribution in the availability of water is the monsoon rainfall and also supplemented by the melting of glaciers. Heavy rainfall events affect the river flow and inundation as well as the sewerage systems of urban conurbation. The frequency of these heavy rainfall events is more in the upper parts of Pakistan as compared to the lower parts. Many studies have investigated the possible causes for the heavy rainfall events in different parts of Pakistan (e.g., Rasul et al., 2004, 2005; Majid and Akhtar, 2007; Sarfaraz, 2007; Jameel et al., 2007). Rasul et al., (2004) studied the weather systems causing extreme heavy rainfall over the twin cities of Pakistan (Rawalpindi & Islamabad) and proposed a physical model for sudden heavy rainfall. The monsoon depressions that originate over Bay of Bengal and Arabian Sea are the primary cause of rainfall over Pakistan during the summer season. The fluctuations in monsoon rainfall have a decided impact on the society and economy of monsoon dominated countries (Sajani et al., 2007). The heavy rainfall is often associated with organized mesoscale convective systems (Fang 1985; Iwasaki and Takeda 1993). Ninomiya and Akiyama (1992) widely considered that the mesoscale processes are more important in determining the actual behaviours of heavy rainfall systems. The heavy rainfall event over Multan City (300 12′ N Latitude and 710 26′E Longitude) has been selected for this study and an attempt has been made to understand the nature of rainfall events over that area. Furthermore, the main objective of this study is to improve the prediction of heavy rainfall which will be helpful in reducing the flood damages in future. Multan City is located in the southern part of the Punjab Province Pakistan where such kind of heavy rainfall events are

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very rare. However, the study area sometimes receives heavy rainfall during the monsoon season which has a greater direct effect on human well- being, the sewerage and the drainage systems of the city.

Climatology of Study Area

Multan features an arid climate with very hot summers and mild winters. The city witnesses some of the most extreme and harsh weather in the country in both the seasons. During the summers, temperatures reach approximately 50 °C, and in the winter −2 °C has been recorded. The average rainfall is roughly 127 millimetres. The mean air temperature remains above 30 °C for five consecutive months from May to September. The mean maximum temperature remains above 35 °C for almost six months in the year, from April to September. The mean temperature remains below 20 °C for only three months from December to February, while the mean minimum temperature remains below 20 °C for almost five months, from October to February.

Due to close proximity to the Cholistan desert Multan city is directly affected by the heat waves that originate in southwest Asia, especially the Indo-Pak region. Afternoon dust storms are common occurrence in this region in the pre monsoon and post monsoon seasons, which have greater impact on the horizontal visibility. The aviation activities of Pakistan Army and the Flights operations of different airlines from Multan airport are badly affected due to the poor visibility. Minimum Mean Sea Level Pressure drops up to 994 hPa in June and July, where as maximum rises up to 1019 hPa in December and January.

It is covered by desert and sandy plains from three sides, Cholistan in the South and Southeast, sandy plains in the East, agricultural fields from Northeast to West and the River Chenab flows along the western side of the city. Mango tree and gardens are common in this region, which are badly affected by the Pre monsoon wind/dust storms.

In 2005 an upper air cyclonic circulation was developed over northwest Bay of Bengal and under the influence of this circulation, increased wind shear and the differential heating, a low pressure area was formed over Northwest Bay on June 27th morning (Jayanthi et al., 2006). This low was changed into first monsoon depression over Gangetic West Bengal and neighbourhood area on June 27th evening and weakened over West Madhya Pradesh and neighbourhood. It initially moved in the westerly direction then west-northwesterly direction and finally in the Northwesterly direction. It caused widespread rains over most parts of upper and central India and after encountering with a westerly wave over Pakistan (Jayanthi et al., 2006).

Data and Methods

Data regarding different surface weather parameters (wind, pressure and precipitation) at the station was obtained from Regional Meteorological Centre (RMC) of Pakistan Meteorological Department at Lahore. The photographs of the conventional synoptic weather charts were obtained from Weather Central and Main Analysis Centre (WC&MAC) of Pakistan Meteorological Department at Karachi. For the study of the upper air profile of the atmosphere NCEP reanalysis data plots were obtained from NCEP website (http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.html) while the streamlines and vorticity were plotted by using the GRADs software. The NCEP/NCAR Reanalysis 1 project is using state of the art analysis and forecast system to do assimilation, thus providing data for the period starting from January 1948 to present for six hour interval, daily and monthly basis with resolution of 2.50. A large subset of this data is available from Physical Sciences Division (PSD) in its original 4 times daily format and as daily averages, (NCEP/NCAR Reanalysis 1: Summary). While getting the data plots from the NCEP website, we choose six hourly interval datasets and averaged over two intervals one from 0000 UTC to 1200 UTC and the other from 1200 UTC to 0000 UTC of the next day so that the short period extremes can be averaged over twelve hours period. Surface and Upper air re-analysis datasets have been used to investigate the reason of heavy downpour that caused urban flooding in the area.

Results and discussion

This section consists of two sections and in the first section detailed discussion about different synoptic features at the surface has been made while in the second section upper air atmospheric circulations, temperature and humidity and streamlines have been discussed in detail.

Weather parameters at the surface

In order to have the better weather forecasting of a locality, the local as well as the regional study of different meteorological parameters at the surface and in the upper air is very necessary. We have adopted the same technique to diagnose the heavy rainfall event of 4th July 2005 over Multan city.

During the month of June 2005, Sea Surface Temperature (SST) over all the sectors of the Arabian Sea, Bay of Bengal and Andaman Sea were warmer than normal (Jayanthi et al., 2006). Under the influence of upper air cyclonic circulation over northwest Bay, increased wind shear and the differential heating, a low pressure area was formed over Northwest Bay on June 27th morning. This low was changed into first monsoon depression over Gangetic West Bengal and neighbourhood area on June 27th evening and weakened over West Madhya Pradesh and neighbourhood.

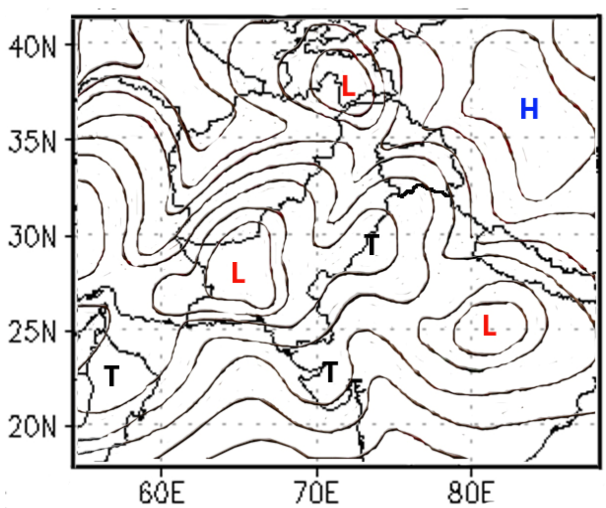


Figure 1: Mean sea level pressure analysis of 2nd July, 2005, 0300 UTC

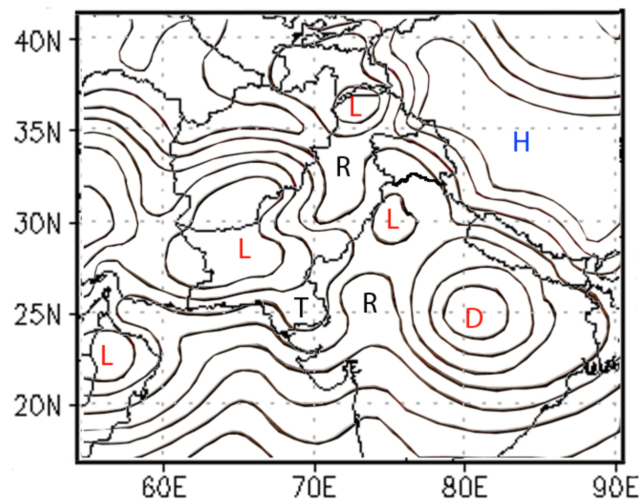


Figure 2: Mean sea level pressure analysis of 3rd July 2005, 0300UTC

The synoptic charts of 2nd and 3rd July 2005, for the diagnosis of the current event are selected. According to Fig.1 on 2nd July 2005, seasonal low is present over the south western parts of Pakistan and adjoining Iran with its troughs extending towards southeast and another intensified trough extending northeastwards up to the eastern neighborhood of study area. Close to this intensified trough is a ridge, penetrated from northeast up to the study area. Another low exists in the monsoon trough over the northwest central parts of India. The penetration of ridge between the trough of seasonal low and the mesoscale low created the area of discontinuity over Multan and neighborhood. The monsoon low was realigned by intensification of the easteren troughs and weakening the southwestern trough. This intensification in eastern troughs caused more accumulation of moisture around the eastern and northeastern parts of Multan city. The low over the central parts of India supported the moisture feeding from Bay of Bengal to the northwestern parts of India. This moisture was sucked and accumulated with the moisture feeded from Arabian Sea in the intensified trough. This accumulation of moisture produced 27.2mm of rainfall over Multan on 3rd July 2005, in three hours period from 0000 UTC to 0300 UTC. The satellite image of 3rd July 2005, at 0000 UTC clearly showing dense cloud clusters. One dense convection cloud cluster is present in the northeastern neighborhood while the other smaller cluster in the southwest of study area. Comparison of the two images reveals that image, a, has scattered cloud cells while image of 4th July (image b) has a single solid cell slightly northeast of the study area as shown in Fig. 3 (a & b).

By 3rd July 2005, as shown in above Fig.2, the low over the central parts of India has been changed into depression and seasonal low has been oriented in northsouth direction with a slight westwards shift. The modification of low over central parts of India into a depression with a slightly north westward shift in position enhanced the moisture feeding from the Bay of Bengal and now the moisture was directly reaching to the northeastern parts of Pakistan. The north south orientation of seasonal low supported the transport of moisture from Arabian Sea to the higher latitudes and its westward shift provided more area to the right side of seasonal low for the said transport of moisture as shown in Fig. 2. The northeast trough of monsoon low present on 2nd July 2005 over southeast Punjab and adjoining areas, has been changed into mesoscale low by 3rd

July 2005 and was centered in the monsoon trough. Another important feature of the 3rd July 2005 is the intensification of a ridge penetrating from northeast, which was shallow on 2nd July 2005. This ridge helped the heavy rainfall over the area in two ways:

1. It kept blocked the mesoscale low as to accumulate more moisture up till late night.
2. It enhanced the process of uplifting air and indirectly affecting the cloud formation by giving a close way to the uplifted air to be dispersed in the lower layer of the atmosphere thus limiting the moisture up to the lower troposphere.

The above-mentioned mesoscale low accumulated the moisture during the whole day without any disturbance due to high temperature over the area. After midnight there was appreciable cooling and the warm moist air, which was persisting there during the day, released the latent heat in the condensation process thus enhancing the uplifting of the air over study area. This development is clearly seen on the satellite image of 4th July 2005 at 0000 UTC as shown in Fig.3 (b). This system produced 70 mm of rainfall in three hours period from 2100 UTC 3rd July, 2005 to 0000 UTC of 4th July, 2005 i.e. on the early morning of 4th July 2005 as shown in table 1 below.

Weather parameters in the upper air

Three main meteorological parameters (geopotential height, temperature and relative humidity), along with streamlines and vorticity have been studied. Their details are given below:

<u>Geopotential Height</u>

At 850 hPa more pronounced low pressure area is located at 68o E and 30o N having the height of 1395gpm on 1st July 2005 as shown in Fig.4 (a). This low became more intense over the same position with slightly eastward shift on 3rd July 2005 having the same value of height. On this day three low pressure areas are present, one over southern Punjab, other slightly north of Persian Gulf and third over the central parts of India over the position where depression lies at the surface on 3rd July 2005.Trough of low present over southern Punjab is extending up to northeast Arabian Sea, thus feeding the moisture to the study area direct from Arabian Sea. On 4th July 2005 the low present over the study area expanded and covered more area with appreciable decrease in the height up to 1380gpm. From 5th July 2005 and onward this low pressure cell shifted westward with increase in geopotential height.

Table 1: Surface meteorological data of different meteorological parameters (mean sea level pressure, wind and rainfall) for the synoptic hours (00,03,06,09,12,15,18 and 21hours UTC). The normal light and moderate amounts of rainfall has been shown in blue cel

Meteorological Data for MSLP, Rainfall and Wind over Multan									
Date	Weather Elements/Time	0000z	0300z	0600z	0900z	1200z	1500z	1800z	2100z
3/7/2005	MSLP	996.3	999.0	998.6	997.8	995.8	996.1	996.9	995
	RAINFALL	TR	27.2	0	0	0	0	0	TR
	Wind Speed/ Direction	06/S	C	08/NW	C	04/NE	06/NE	06/SE	20/N
4/7/2005	MSLP	995.1	997.1	997.1	996	993.6	994	996.1	995.3
	RAINFALL	70	0.5	0	0	0	0	0	0
	Wind Speed/ Direction	06/SE	06/SE	06/NE	04/N	06/E	04/E	C	04/NE
5/7/2005	MSLP	995	996.3	996.4	995.6	994.7	995.9	996.3	998.1
	RAINFALL	TR	2	0	0	0	0	8	TR
	Wind Speed/ Direction	04/NW	06/N	C	06/NE	06/E	C	14/SE	06/W

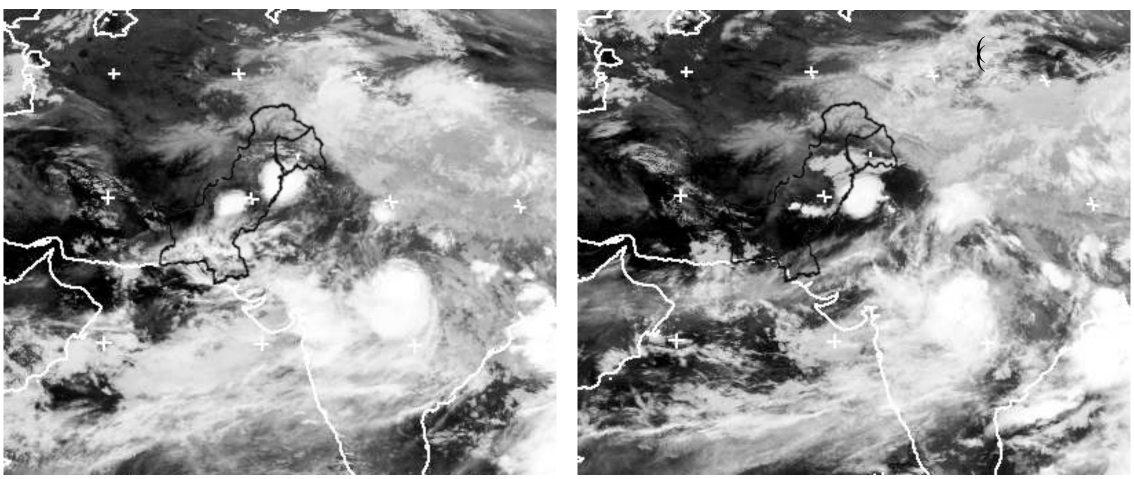
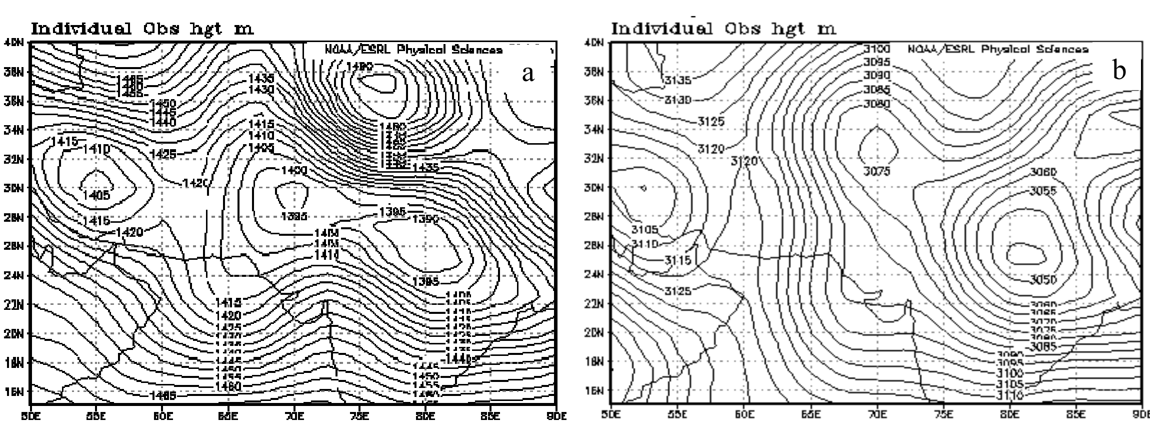


Figure 3: Satellite image at 0000UTC of 3rd and 4th July 2005



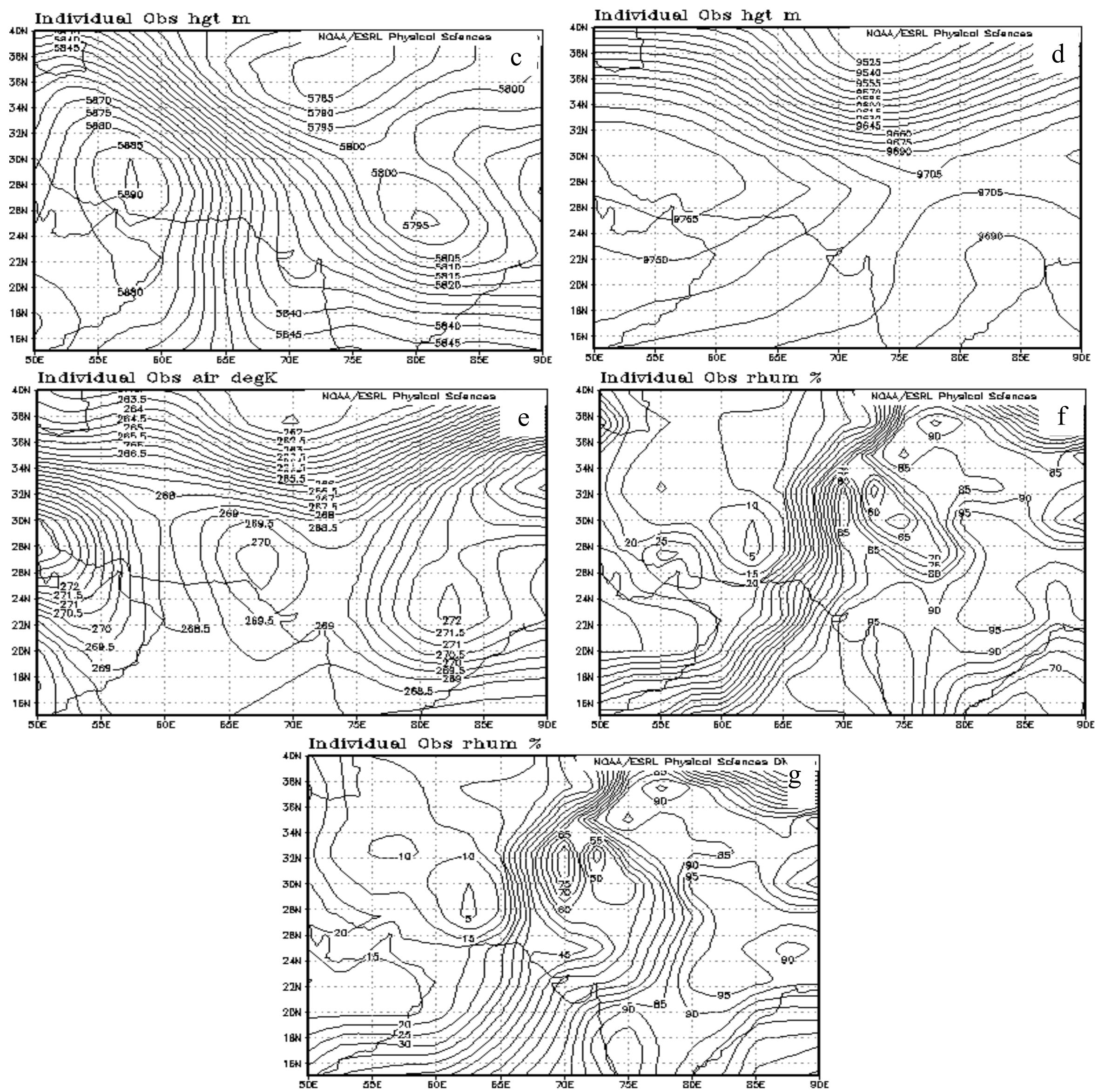


Figure 4: **(a-f)**. Charts of different weather parameters at different levels in the upper air for the period averaged from 1200 UTC of 3rd July to 0000 UTC of 4th July 2005. **(a)** Observed Geopotential height (Obs hgt) in meter at 850 hPa indicates the low pressure cell over the study area. **(b)** Observed Geopotential height (Obs hgt) in meter at 700 hPa showing the presence of cut off low slightly north of the study area. **(c)** Observed Geopotential height (Obs hgt) in meter at 500 hPa showing the presence of cut off low slightly north of the study area. **(d)** Observed Geopotential height (Obs hgt) in meter at 300 hPa indicates the interaction of upper air westerly and easterly waves. **(e)** The cold air intrusion is more pronounced at 500 hPa level temperature in Kelvin (air degK **(f)** Observed Relative humidity (Obs rhum) in percent at 925 hPa shows the presence of 90% relative humidity slightly north of the study area. **(g)** Observed Relative humidity (Obs rhum) in percent at at 850 hPa also shows the moisture accumulation over the study area. Source (http://www.esrl.noaa.gov/psd/data.ncep.reanalysis.html)

At 700 hPa the low pressure cell was present over central parts of India with a deep trough extending northwestwards up to the study area on 1st July 2005. A cut off low was developed in this trough on 2nd July 2005. As shown in Fig.4 (b) on 3rd July 2005 the cut off low was exactly centered at 32°N and 71°E (north of the study area), it accumulated the moisture in a very limited area and caused the heavy rainfall over that area. From 4th July 2005 and onward the trough gradually weakened and the cut off low in the trough was absent. The synoptic scale westerly weather system is clearly visible at 500 hPa as shown in Fig. 4(c), the cut off low with two closed contours is centered at 25°N and 80°E and depression at the surface is exactly following this cut off low. Contours at 500 hPa are penetrating the Pakistani area from northwest thus providing the cold air at this level and this cold air penetration is more visible in fig 4(e).

Fig. 4 (d) indicates the interaction of upper air westerly and easterly waves at 300 hPa level chart. This interaction occurs at 28oN and 80oE on 1st July, gradually shifted westwards and lies at 29oN and 78oE on 3rd July 2005. This interaction enhanced the continued rainfall activity over the area 300 to 500 km westward of this interaction i.e. over the study area.

Temperature

The same temperature pattern was observed up to 700hPa for all the days except the orientation of isotherms changed from northwest-southeast to north-south direction from 4th July 2005 and onward. The temperature effect is more pronounced at 500hPa level. Intrusion of Cold air at 500hPa with the presence of warmer air at lower layers of the atmosphere over the study area favored the condensation at mid tropospheric level and supported the heavy rainfall on 4th July 2005 as shown in Fig.4 (e). Slightly warmer areas are present at both sides, east and west of this intrusion of cold air. The temperature at 300 hPa level has no prominent connection with the rainfall due to this only the 500 hPa level temperature chart showing temperature in degrees Kelvin has been included here.

Moisture

Only the lower level charts of 925, 850 and 700 hPa show the moisture accumulation over the study area. Moist areas with relative humidity values from 90% to 100% were present over the study area at these levels from 1st to 4th July 2005. On the 3rd July 2005 when heavy rainfall occurred these moist areas were elongated in the north-south direction both at 925 and 850 hPa levels Fig.4.(f and g). At 700 hPa level relatively less moist cells are persistent on 1st and 2nd day only. The northsouth elongated moist area is also present slightly north of the study area at 500hPa level indicating that moist air was present up to mid troposphere. The streamlines at lower level i.e. 850 hPa, indicate that moisture has started accumulating in the vicinity of the study area two days prior to the heavy rainfall. The streamlines chart at 850 hPa indicate that on the evening of 2nd July along 70 °E, moisture was transported longitudinally and with the passage of time accumulation continued as shown by curved streamlines on 3rd July, at 1800 UTC chart fig.5-a. This chart is also showing the interaction of northeastern and southwestern streamline over the study area as shown in fig.5-b. It continued till the morning of 5th July as shown in fig. 5-c. By continuous monitoring of moisture penetration and accumulation, heavy rainfall forecast can be done two three days earlier.

Conclusion

Heavy rainfall event over the study area was under the influence of two synoptic scale weather systems and a mesoscale low. The approach of monsoon depression and the westerly wave were the synoptic scale systems. The presence of mesoscale low slightly northeast of the study area and an intensified ridge penetrating from northeast up to west of the study area enhanced the moisture accumulation and holding in atmosphere during the day time.

A trough of westerly wave was also present over the higher latitudes over Pakistan and a cut off low with two closed contours was centered at 25°N and 80°E at 500 hPa level and depression at the surface was exactly following this cut off low. This cut off low helped in intensification of the system at the surface and supplied additional moisture to the system. The presence of upper air easterly wave along with three other above systems enhanced the moisture contents, causing the heavy rainfall.

The mesoscale low was present slightly east of the study area and this low accumulated the moisture in small area and producing the heavy rainfall over Multan.

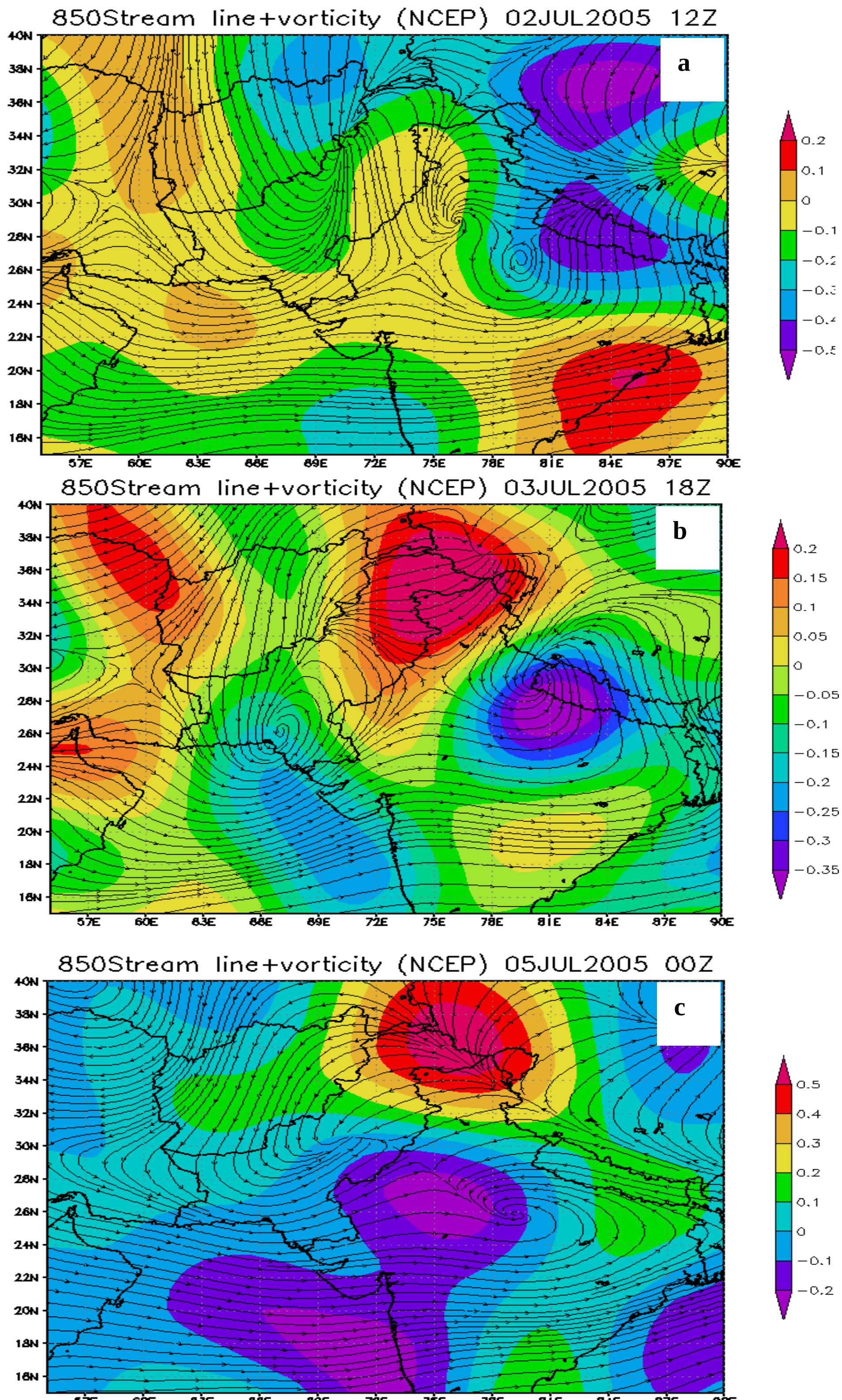


Figure 5: (a) Showing the streamlines, two days earlier, **(b)** one day earlier and **(c)** next day of the occurrence of the event.

Furthermore, the presence of ridge close to this low supported the heavy rainfall over the area in two ways: It kept blocked the mesoscale low as to accumulate more moisture until late at night when it approached the study area and giving a close way to the uplifted air to disperse in the lower layer of the atmosphere, thus limiting the moisture to a small area and to lower layer of the atmosphere. Late night cooling enhanced the uplifting and the cloud formation process by the heat evolved during the condensation and cloud formation processes. The intrusion of cold air at 500 hPa level amplified this condensation process by cooling the lower layers of atmosphere. The frequency and intensity of rainfall were higher in the early mornings as shown in table 1. The maximum intensity (70mm of rainfall) was on 4th July 2005 early morning (from 2100 UTC 3rd July, 2005 to 0000 UTC of 4th July, 2005) while only 0.5mm rainfall was recorded between 0000 and 0300 UTC of 4th July,2005 this makes that the heavy rainfall was stopped before 0000 UTC on that day.

The orientation and direction of streamlines also showed that moisture was transported and accumulated slightly west of the study area. On 3rd july at 1800 UTC these streamlines were curved and there was an interaction between the streamlines from southeast and northeast around 30 degree latitude. This interaction created the area of discontinuity over Multan thus producing heavy rainfall

On the basis of these facts we can predict the heavy rainfall two-three days prior to occurrence. On the basis of this prediction water storage in different dams and diversion in different distributaries can be efficiently managed along with minimising flood risks and human/property losses through timely forecast and early warning system. At the same time the information from such study can also be equally utilized in the flood forecasting works reducing the damages of life and property.

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