Heavy Downpour Event over upper Sindh in September, 2012

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ABSTRACT

This study mainly focuses on the phenomenon of heavy downpour rainfall event which stuck up in the upper Sindh in September, 2012. High resolution regional model (HRM), developed by DWD (National Meteorological Service of Germany), output and National Center for Environmental Prediction (NCEP) Reanalysis data along with satellite imagery are used for the post analysis of this downpour. The analysis illustrates that the heavy rainfall occurred over the upper parts of Sindh was due to the orientation of monsoon currents. The monsoon currents penetrated deeper in latitude than normal due to variation in Tibetan high, Somalia's Jet and local prevailing condition in upper Sindh and Balochistan. A very prolonged hot condition of the region caused the maximum temperature to reach to 5° C as there was no precipitation for last three months over upper parts of Sindh. Comparatively more drier and hot condition than normal intensified a seasonal low than its normal intensity. A low pressure system developed over Bay of Bengal (BoB) passed over central India and entered in Pakistan on 9th September, 2012, afterwards the seasonal low over Balochistan helped it in intensifying and a strong Somalia's Jet acted as source of moisture supply from Bay of Bengal. This study has also concentrated on most of the phenomenon that are very influential and plays a major role in varying the intensity and orientation of the Monsoon weather system.

Key words: Tibetan High, Somalia's Jet, Monsoon orientation, Local prevailing conditions, Low pressure system, Monsoon weather system.

Introduction

It will take a long time for the people of Pakistan to remove the terrifying feeling developed in their minds after the devastating and startling event of Flash flood in 2010. This event diverted the attention of many concerned towards the management of natural calamities but before any practical steps been taken the heavy down pour event took place again in Sindh in August and September, 2011. The assorted nature of this event redirected the attention of researchers towards the dynamic of Southwest Monsoon. The annoyed nature continue it's devastation in 2012 and it turned out to be the third consecutive year which generated flood in the country. Now the air above our heads, which appears apparently void but full of secrets, start exerting a frightening feeling in the minds of the people and at the same time a challenge for the researchers to reveal the secrets of the most divers phenomenon of the nature known as South western Monsoon.

Monsoon circulation, its variability and heavy weather systems have been studied extensively by different scientist. (Chaudhry, Q. Z., 1991) fond inter annul variability of Monsoon rainfall and its relationship with global /regional circulation features by using a large data sets (1901-1990). He suggested that normal rainfall for country is 132.6 mm and Sindh contribute seasonal monsoon 67 % to the annual rainfall. In Pakistan, the main contribution in the annual rainfall is summer monsoon. Summer monsoon rainfall contributes almost 60 % of the total annual rainfall (Muslehuddin et al., 2005). The severe flood of 2010 was the direct result of interaction between westerly and easterly flows (Atif, R.M., 2011). In 2011 the rainfall in Sindh Occurred in two different spells. First spell occurred on account of direct effect of monsoon tilt during 09-15 August. During the 2nd event (29August-15 Sep) the main important component for this heavy rainfall was Mid Tropospheric Cyclone (MTC).

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Generally in the month of August and September (AS) low pressure system develops over Bay of Bengal which usually moves eastward over the central parts of an India and gradually intensifies and some time converts into depression and enters in Pakistan from the central eastern border and moves towards upper Punjab and normally dissipates but in 2012 the depression remain lower in latitude and continuously accumulated moisture from the coastal area of Mumbai, Ahmadabad, Karachi and surrounding. The depression remains active and got trapped over an area of upper Sindh, Southern Punjab and North eastern Balochistan. This spell produced unprecedented rains in Southern Punjab, Sindh and eastern parts of Balochistan in 5 days. The chief amounts of recorded rainfall are:-

Table 1: Rain recorded in 5 days of the spell (07 – 11 Sep, 2012) by PMD

S. No.	Station	Rain in millimeter
01	Jacobabad	481 mm
02	Khanpur	291 mm
03	Rahim Yar Khan	236 mm
04	Larkana	215 mm
05	Sukkar	206 mm
06	Shorkot	52 mm
07	Chhor	137 mm
08	Multan	136 mm
09	Toba Tak Singh	130 mm
10	Mithi	121 mm
11	Dera Ghazi Khan	120 mm
12	Badin	108 mm
13	Sahiwal	107 mm
14	Okara	103 mm
15	Hyderabad	90 mm
16	Dadu	90 mm

This heavy flooding in the above mentioned region has affected millions of people, hectares of crop, transportation, Civil Aviation flights and the whole infrastructure of the region. According to a report of National Disaster management Authority (NDMA) 5, 046, 462 people were affected. Out of which 480 were died and 2, 902 injured. Heavy rains and floods swept away 465, 526 houses, out of which 246, 813 houses were completely destroyed and the rest partially damaged as reported by the government's disaster management agency (NDMA, 2012). These people are stranded with no access to food, clean drinking water and other necessities of life. Maximum damage in terms of people and property were from Sindh province.

Geography of Study Area

Geographically the study area (Jacobabad, Kashmore, Larkana, Sukkur, and Khan Pur, or simply upper Sindh) is located at 27° 56' and 28° 27' N. and 68° and 69° 44' E near the central part of Pakistan with an

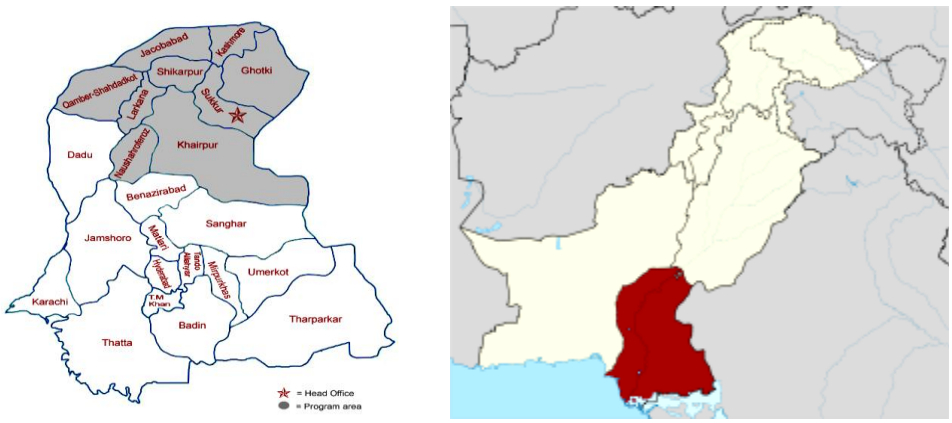


Figure 1: (a) Sindh Map with study area **(b)** Map of Pakistan

area of 6,790 km^2. It is surrounded by Suleman range in the North, Kherthar range in South west, Bahurai range in west, and a Thar Desert on eastern side. There is a giant Indus river flowing from north to south just at the South Eastern side of Jacobabad furthermore there are many streams and canals on the Northern, and Western side including Bolan River. The Northern, Western and South Western areas are the part of Balochistan plateau therefore the non perennial streams flow is always towards the Sindh province.

Climatology of the Study Area

Sindh is located in a subtropical region. It is hot in summer and cold in winter. Temperatures frequently rise above 46° C between May and August, and the minimum average temperature of 2° C occurs during December and January. The annual rainfall averages about seven inches mainly falling during July and August. The southwesterly monsoon wind begins to blow in mid-February and continues until end of September, whereas the cool northerly wind blows during the winter months from October to January. The thermal equator passes through upper Sindh, where the air is generally very dry. The highest temperature ever recorded in Sindh was 53.5° C, which was recorded in Mohenjo-daro on May 26, 2010. It was not only the hottest temperature ever recorded in Pakistan but also the hottest reliably measured temperature ever recorded in the continent of Asia and the fourth highest temperature ever recorded on earth. In winter sometimes the temperature falls to 0° C on rare occasions.

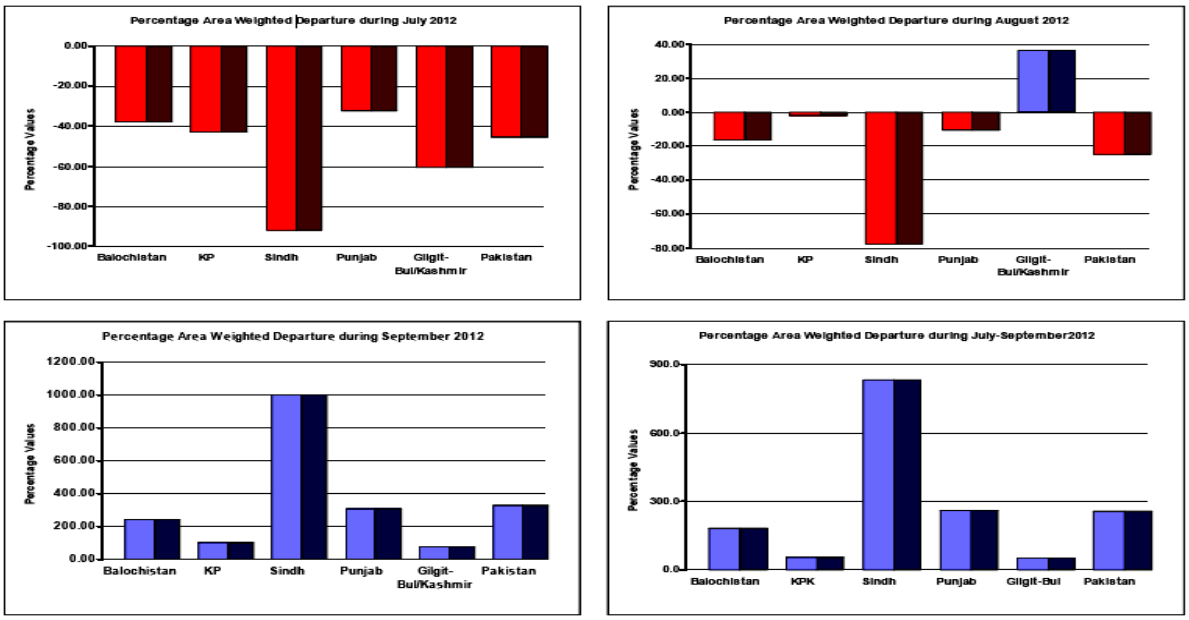


Figure 2: Percentage departure of rainfall during (July- September) 2012 by PMD

Annual precipitation in upper parts of Sindh is hardly 10 % of the annual evaporation therefore the water deficiency is nearly 90 %. In this way Sindh is a desert. The above figure shows the departure of rainfall in July, August and September. In July 2012, 46 % below normal rainfall was received in the country and in Sindh it was almost 90 % below normal and in August 2012, rainfall in the country was again below normal (-25 %) the maximum below normal rainfall was in Sindh (-78 %) but during September 2012, the amount of rainfall recorded was well above normal in the country (327 %), and maximum above normal rainfall was observed in Sindh which was 1000 % higher than normal.

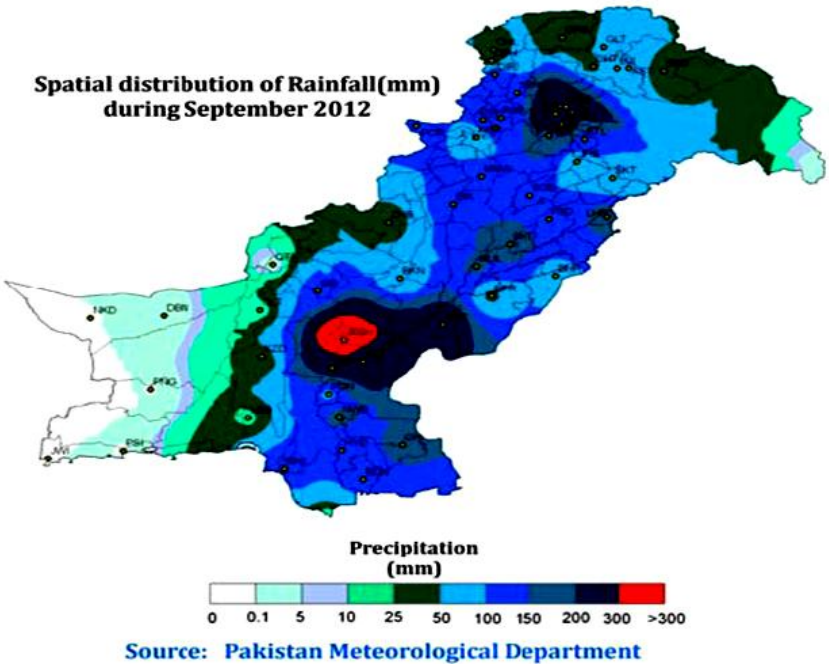


Figure 3: Spatial distribution of Rainfall (mm) during September 2012

The above figure clearly shows the area of Jacobabad, Larkana, Rahim Yar Khan and Khanpur of upper Sindh with a red color which indicates the highest rainfall (more than 300 mm) received in the country in September, 2012. This study is conducted to enlighten the physical phenomenon that produced the heavy rainfall event in upper Sindh.

Data and Methodology

To understand a complete picture of any weather phenomenon, It is important to acquire a three dimensional picture of meteorological parameters of a domain larger than the region of interest. Therefore numerous tasks have been achieved to accomplish the objective of the study. The average monthly climate data for Jacobabad was obtained from Climate Data Processing Center (CDPC) Karachi in coded form in hard copy for a period of 2000 to 2010. It was converted in a soft copy and updated with a last two year data from Met Squadron SHAHBAZ, Jacobabad. PMD have installed many rain gauges in this area therefore the rainfall data of September of study area and nearby stations like Larkana, Rahim YAR Khan, Khanpur and some other stations was obtained from Pakistan Meteorological Department (PMD). Synoptic charts of PMD (for all four main synoptic hours) and satellite images were also obtained for the month of September, 2012. NCEP (National Center for Environmental Prediction) Reanalysis II data is utilized with a temporal resolution of six hourly and spatial resolutions (2.5° x 2.5°) along with 17 vertical pressure levels from (100 - 1000 hps). The domain of 05° - 50° North and 30° – 100° South has been selected so that monsoon track and movement can easily be studied.

A high resolution model (HRM) which developed by the German weather service (Deutscher Wetherdienst - DWD) in 1999 used for simulation of the event. The model was provided with the initial and boundary conditions with 3 hourly data derived from the German Global Model (GME – Global Model Europe) to initialize the simulation. High Resolution Model (HRM) deployed at horizontal resolution of 11 km along with 60 vertical levels. The approximate latitude and longitude range of the domain was 05° – 50° N and 45° – 95° E respectively. Furthermore the anomalies in intensity and orientation of Tibetan high, Seasonal Low, Sub-Tropical Jet stream, ENSO index, Easterly Jet and Sea surface temperature were investigated during the month of September, 2012.

Results and Discussion

The rainfall event that occurred in a time period of 7 to 12 September, 2012 is analyzed horizontally and vertically and their anomalies are discussed respectively.

Rainfall Event

The review of the rainfall event of September, 2012 is explained below.

Pakistan receives 60 % to 70 % annual rainfall in summer monsoon mostly in a time period of July to September. Generally July and August remains the wettest month of the year but in 2012 maximum rainfall occurred in the month of September. The heaviest rainfall occurred from 7 – 12 September, 2012 in the southern parts of the country including upper Sindh and North eastern Balochistan. On 2nd September, 2012 afternoon a low pressure starts building over Bay of Bengal and its trough was extended over central parts of India till central eastern border of Pakistan at that time that low pressure moved with variable intensities, speed and orientation over Central parts of an India and entered Pakistan from eastern border of Sindh. This low pressure produced heavy rainfall at different places on its path but its heaviest down pour taken place at upper part of Sindh, where it also dissipated, which produced a flash flood in that region.

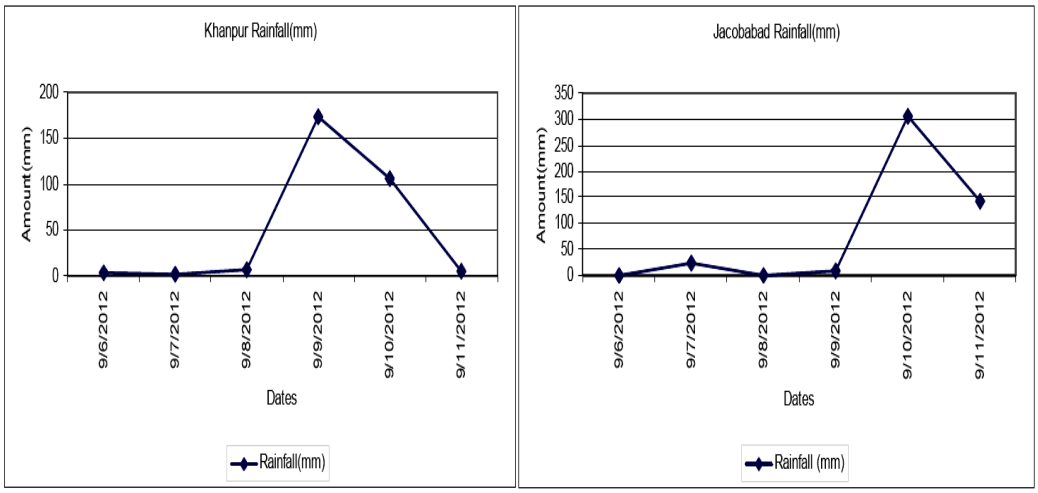


Figure 4: (a) Rainfall (mm) in Khanpur and **(b)** Jacobabad during this Spell

Jacobabad has received a record breaking rainfall of 481 mm during this spell earlier it was 251.5 mm in July 1988. Khanpur, Rahim Yar Khan, Larkana and Toba Tek Singh have also received a widespread rainfall as shown in Table1.

There are some very important summer and annual weather phenomenon that affect the South Western Monsoon in terms of Intensity, track and duration. The Anomalies of monsoon 2012 are discussed below:-

Synoptic Situation

The feature on the day to day synoptic chart in September, 2012 demonstrates a rather un-organized Monsoon circulation pattern and in Figure 5 the withdrawal of SW monsoon 2012 was sluggish than the normal pattern of Monsoon as shown with green and red lines. The month of September is generally considered a less wet month than July and August but in 2012 this month emerged as the wettest of Monsoon 2012.

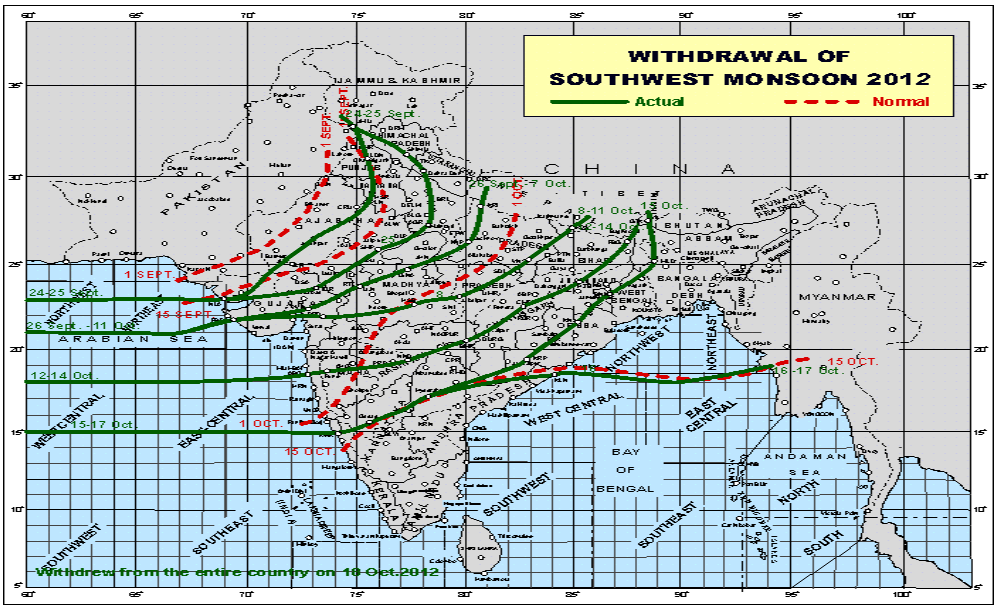
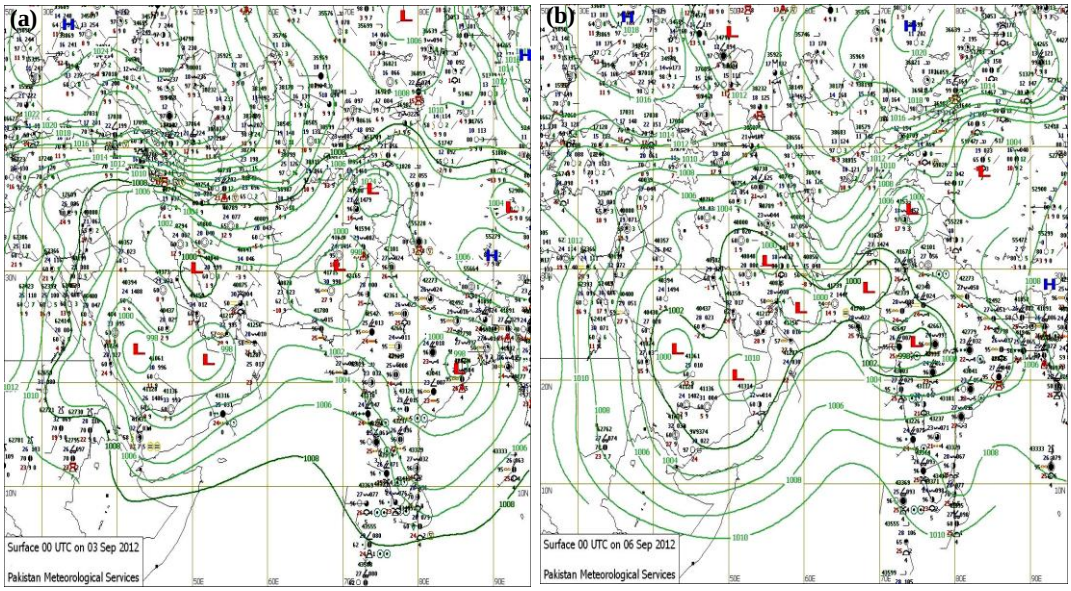


Figure 5: Withdrawal of SW Monsoon 2012 (Source: Indian Met Org)

In Figure 6 (a) shows a surface pressure pattern of 3rd September, 2012 when a Monsoon low pressure on eastern coast of India first time appeared on synoptic chart. At that time a seasonal low over Balochistan was located over the Northern areas of Balochistan and southern area of Khyber Pakhtoonkhwa with moderate intensity having a weak trough extended till Rajasthan. In Figure 6 (b) the Monsoon low pressure shifted over East Rajasthan and Gujarat. The Intensity of the low pressure remained high due to the continuous moisture supply from Arabian Sea and Bay of Bengal. In the meanwhile the seasonal low over Balochistan also deepened and slightly shifted lower in latitude. Low pressures located over Iran, Persian Gulf and Middle East also helped in supplying the moisture from Arabian Sea. A strong ridge suspended from the north along the western border of Pakistan till southern parts of Afghanistan blocked the further westward movement of Monsoon low pressure. On 10th September, 2012 when the record breaking rainfall was recorded in the area of upper Sindh the concentrated Monsoon low pressure was located at the central parts of Sindh with a continuous moisture supply from Arabian Sea as shown in Figure 6 (c). This low pressure remained almost stagnant over the same location for nearly 24 hours with slightly variable intensity.



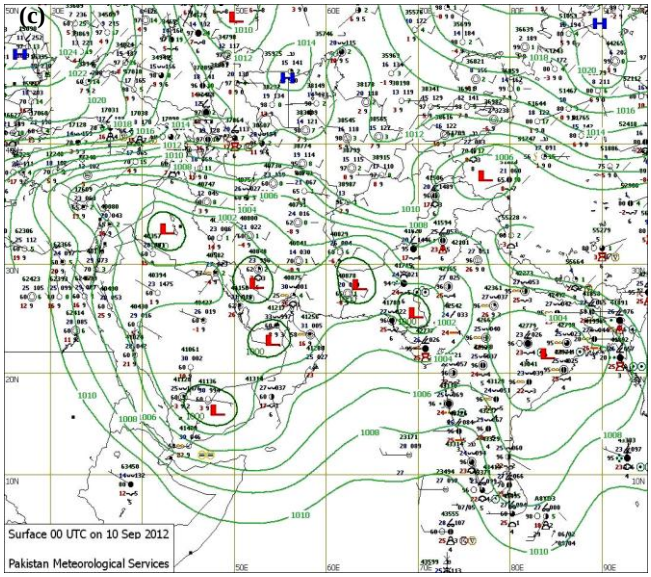


Figure 6: Progression of Surface Pressure Pattern in September 2012

Generally in July or August a Monsoon low pressure develops over Bay of Bengal move towards west till Rajasthan than enter Pakistan from Southern Punjab and start shifting towards North moving along eastern border of Pakistan and dissipate before reaching upper Punjab. The Northern movement of Monsoon low makes the Arabian Sea moisture difficult to continuously pour in the system which resulted up in little earlier dissipation but this was not experienced in Monsoon 2012.

Somalia's Jet

The low level jet stream centered around 850 mb, originating in the western Indian Ocean over low lying areas of Ethiopia and Somalia and emerges in the Arabian Sea. It flows across central parts of Arabian Sea towards coast of India. The study of Findlater (1969-1971) shows that the low level jet plays a major role in the monsoon activity over Indian subcontinent. The strength and location of the low level jet flow into the Indian subcontinent thus plays a vital role in determining the strength and track of the monsoon activity.

The average location and speed of Somalia Jet in a period of July to September at 850 mb is shown in Figure 7 (a) whereas on 10 September, 2012 the speed and location is shown in Figure 7 (b). The

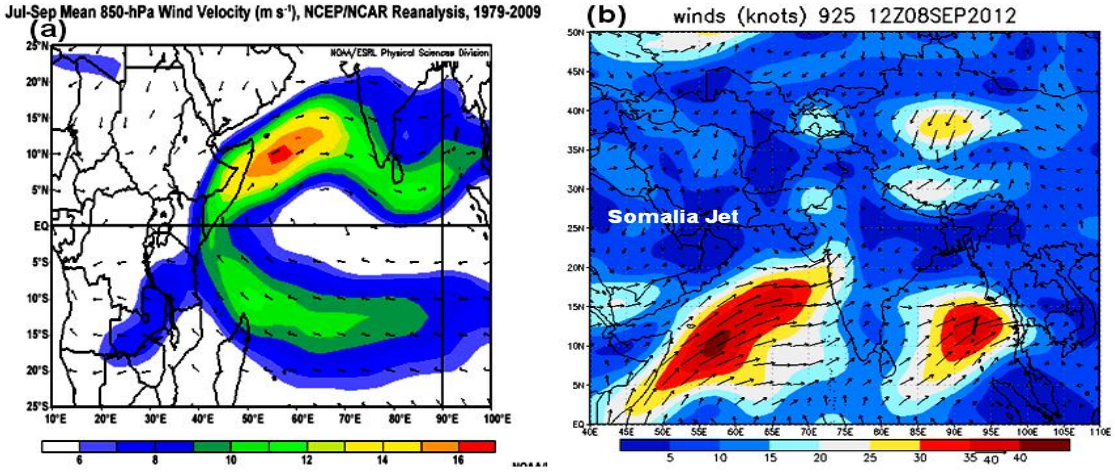


Figure 7: (a) Somalia Jet Normal speed in July to Sep **(b)** Somalia Jet on 10 Sep, 2012

anomalies in September 2012 can be easily identified. The speed of the low level Jet is around 35 kt in 2012 and it is positioned slightly eastward and higher in latitude than normal. This anomalous condition plays a major role in strengthening the monsoon activity that took place on second week of September, 2012. It helped the system in providing a continuous moisture supply from Arabian Sea and Bay of Bengal.

ENSO Index

On July 5, the NOAA Climate Prediction Center (CPC) and the International Research Institute for Climate and Society (IRI) announced that the consensus forecast (informed by outputs from over 25 ENSO forecast models from major forecasting centers around the world) reflects increased chances for a weak to moderate El Niño event beginning in August-September 2012 and continuing through early 2013 (Figure 8).

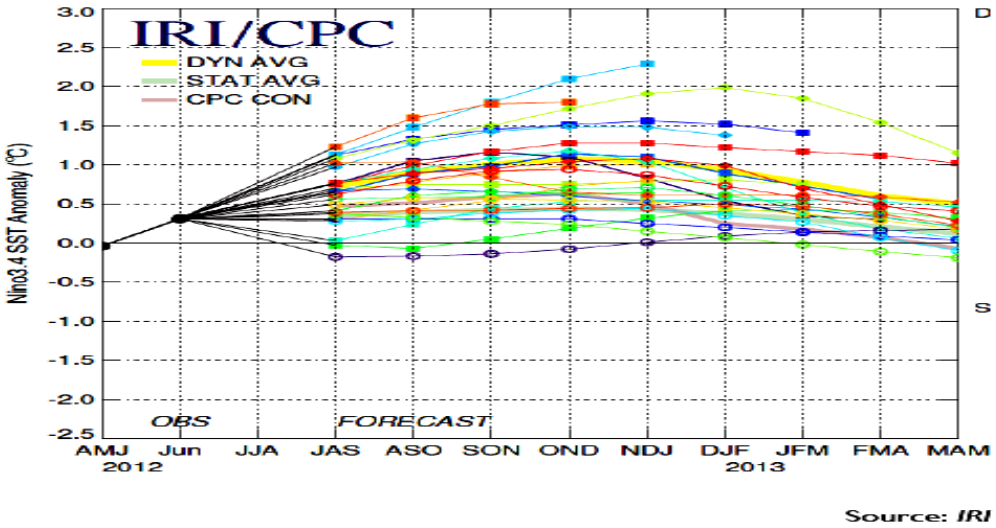


Figure 8: Mid-July 2012 Plume of Model ENSO Prediction

The strength of the El Niño event could change and will be refined over the coming weeks and months. The IRI/CPC Plume-based ENSO forecast puts the probability of El-Nino conditions in the Sep-Oct-Nov season at a little over 80 %. The probability of neutral conditions is pegged a little under 20 %. The chance of returning to La-Nina conditions is considered virtually nil.

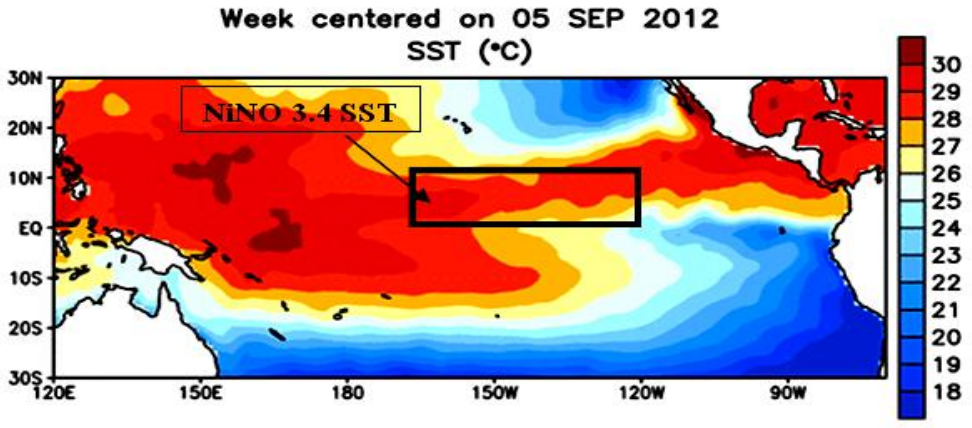


Figure 9: Sea Surface temperatures over Equatorial Pacific Ocean

From April 2012 until June 2012, tropical pacific sea surface temperatures, sea level pressure, cloudiness and trade winds were all at neutral levels. However from July 2012, sea surface

temperatures increased to weak El-Nino levels. Despite the Pacific Sea surface temperatures (SSTs) being warmer than average through August and early September, the atmosphere was not responding to warmer Pacific equatorial SSTs therefore the characteristics of El-Nino failed to develop and hence the ocean-atmosphere system remained in a neutral state and El-Nino condition were never formally declared. As of mid September most models were still forecasting development of weak El Nino conditions. This type of situation in Pacific Ocean is very uncommon and the equatorial Pacific Ocean Sea surface temperature always played a significant role in varying track and intensity of south western monsoon. Although yet there is no direct relationship developed between ENSO and monsoon rainfall but comparisons of the data suggests that La-Nina phenomenon supports rainfall in monsoon season over Pakistan whereas El-Nino suppresses the monsoon rainfall. The uncertain condition over Pacific Ocean may have caused some indirect affect on the event in focus.

Seasonal Low

In summer arid continent surrounding the Arabian sea start receiving great amount heat due to which a well marked shallow low pressure area develops over Balochistan, Eastern Iran and Southern Afghanistan from May till September every year is also known as Seasonal Low pressure area. The location, intensity and its orientation plays a significant role in varying the track and intensity of South Western Monsoon or more precisely monsoon spells. The East-West orientation of the seasonal low generally does not participate in bringing the monsoon rainfall over Southern parts of Pakistan whereas the North-South orientation of this low helps in pouring the moisture of Arabian Sea from south to the central and upper parts of the country. The intensity and orientation depends on the uneven heating of this region.

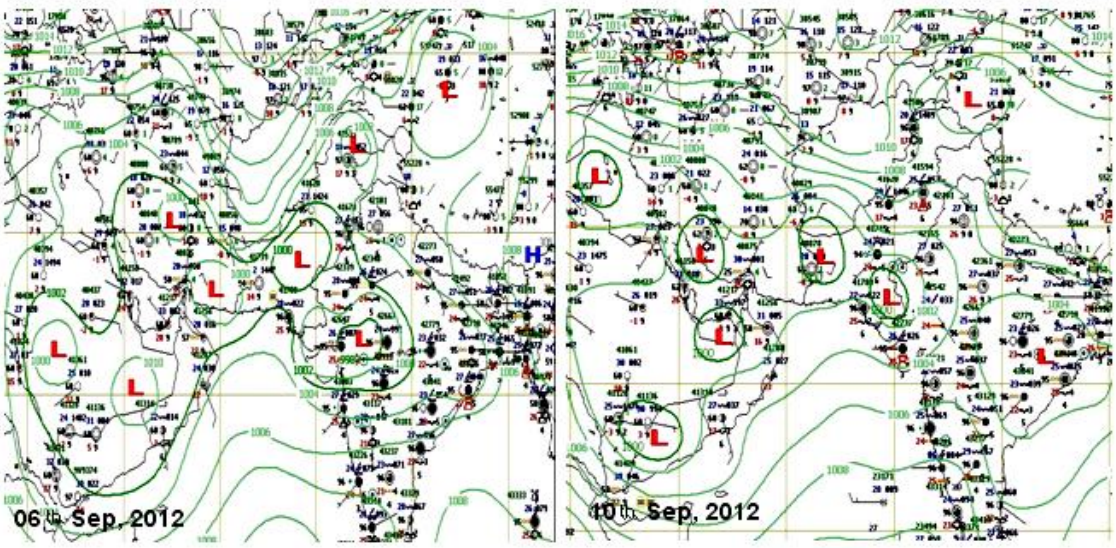


Figure 10: Seasonal Low Pressure

On 10th September, 2012 the Seasonal low was concentrated, lowered in latitude and orientated North-South which intensifies the system more when reached till lower eastern border of Pakistan as shown in figure below.

Tibetan High

Tibetan Plateau, also called the roof of the earth, is extended about 1000 km north to south and 2, 500 km east to west with an average elevation exceeding 14, 800 ft. It is bounded by massive mountain ranges in south Himalayan Ranges and to north Kunlun Range which separates it from Tarim Basin. Due to the geography of the land there is a well marked high pressure develops at 300 hpa which participate significantly in Monsoon dynamics. The intensity and orientation of this high pressure

have a great impact on monsoon weather system over Pakistan and India. The changing intensity and location of this high pressure changes the intensity and track of the South West Monsoon systems.

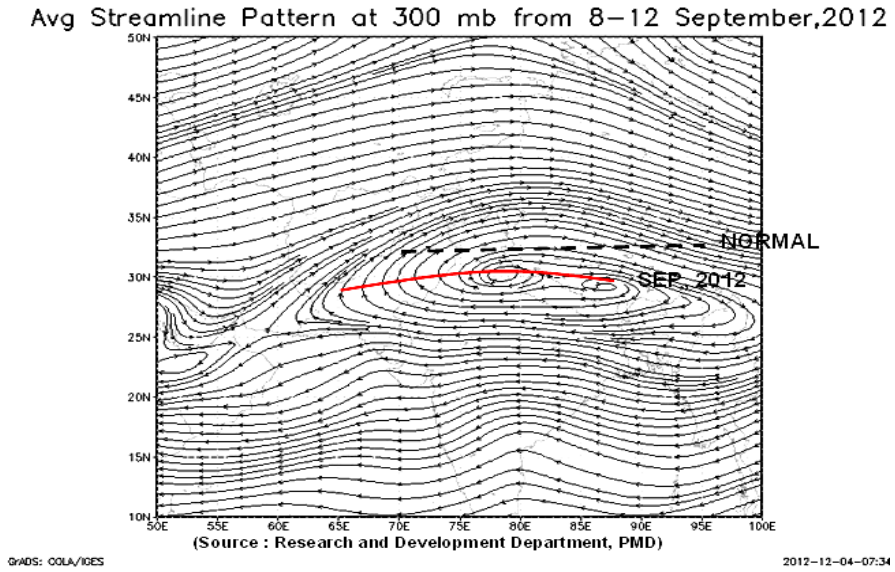
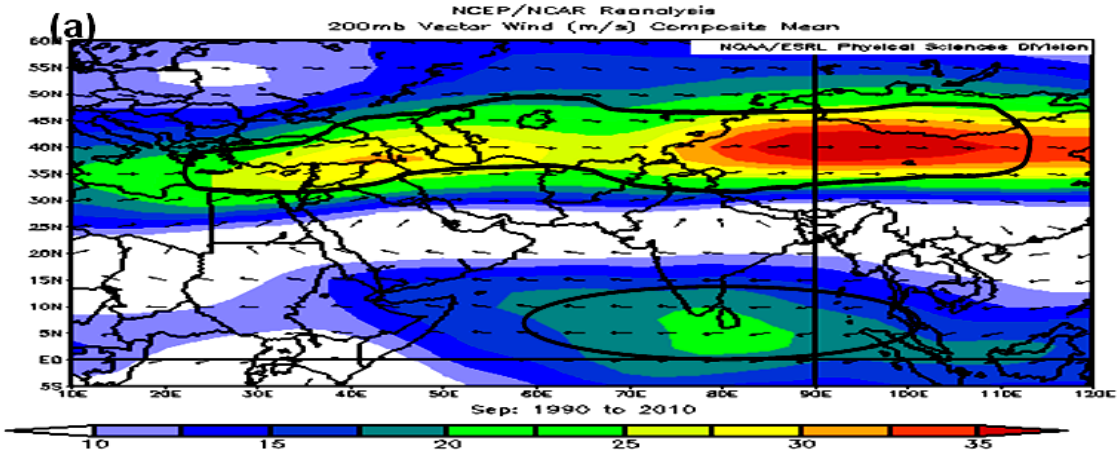


Figure 11: Anomaly in Tibetan high at 300 mb

As you can see in figure above, the normal position of Westward ridge of Tibetan high is approximately 28° N and 65° E but in September, 2012 it is lowered in latitude and extended till eastern border of Balochistan. The lower part of this ridge guided the Monsoon system to move towards the southern parts of Pakistan. Furthermore a very strong convergent flow over Afghanistan created a vorticity field over central parts of Pakistan which have attracted the system towards this region.

Subtropical Jet Stream

A jet stream develops where air masses of differing temperatures meet, so surface temperatures help determine where they will form. The Subtropical Jet stream (Figure 11 (b)) September 2012, shows almost same location as its normal in September, 2012 (Figure 11 (a)) but there is prominent difference in the speed of the Jet. In September, 2012 the speed is very higher reaching approximately up to 80 kt while the normal speed of the Jet is about 30 to 40 kt. it is because the surface temperature difference between the area above 35° N and below 30° N reached to a higher value than the normal temperature difference. The Tibetan high at 300 hpa also helped the Subtropical Jet in strengthening it more than the normal speed.



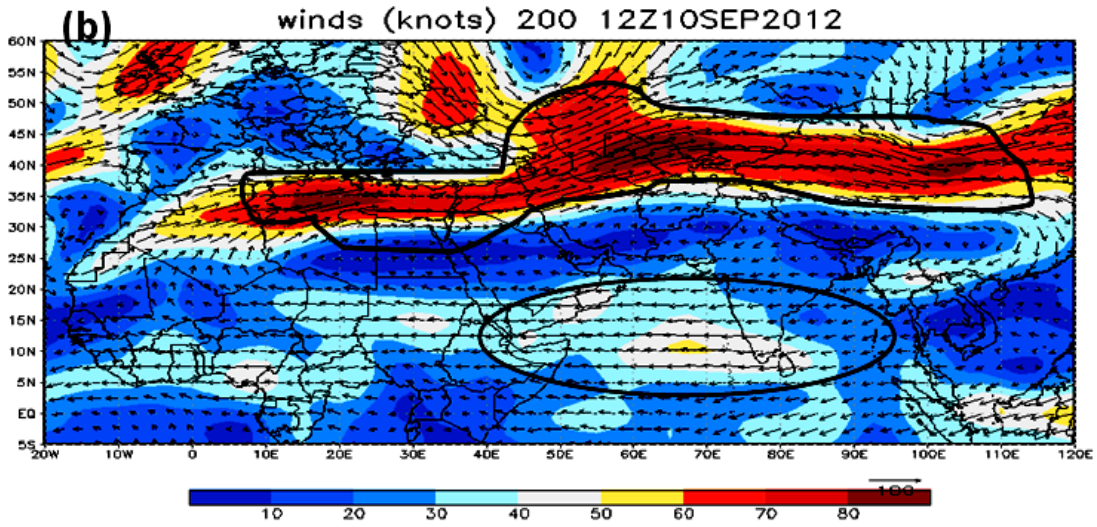


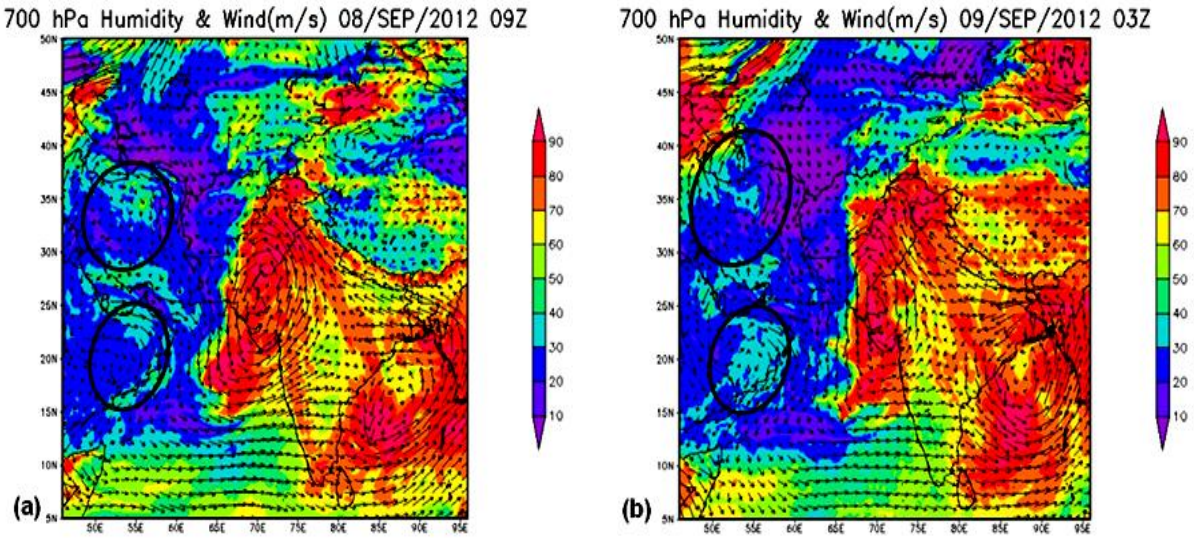
Figure 12: Subtropical Jet Stream Anomalies **(a)** Normal **(b)** Sep, 2012

Furthermore in this image the easterly jet appeared to be stronger in September, 2012 where it is cruising up to 50 to 60 kt than the normal easterly Jet speed which is around 30 kt. This anomaly has a great influence in terms of the intensity and track of the weather system developed in September, 2012.

High Pressure System at (500 mb and 700 mb)

High resolution regional model (HRM) is a short range weather forecasting model developed by DWD (National Meteorological Service of Germany). The model is installed on a high performance computing cluster system of 184 cores. HRM is derived by initial condition from the GME (Global Model of DWD) which has a 30 km horizontal grid resolution and 60 atmospheric pressure levels. This model also supports the Global Forecasting Model (GFS) mechanism but it is specially designed for Pakistan.

The Monsoon spell of September, 2012 was also well identified by HRM (Figure 12). The important aspect to note is the high pressure that have developed over Iran and upper Middle East at 700 hpa and 500 hpa and it restricted further Westward movement of the Monsoon system. Moreover it also contributed in creating a vorticity field over Sindh and surrounding areas which pulled the Monsoon system towards this region.



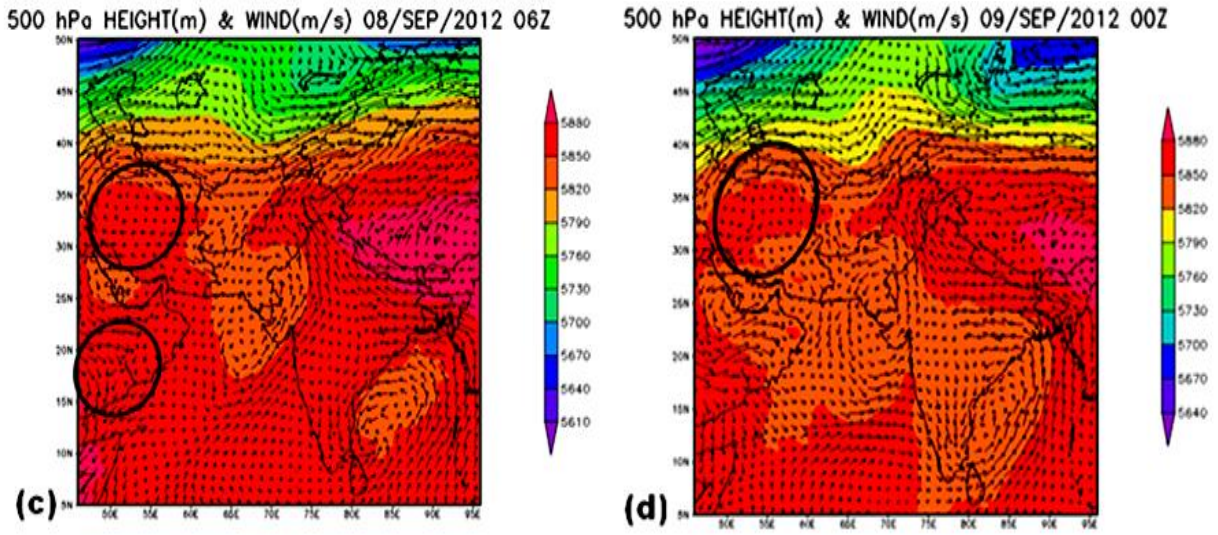


Figure 13: HRM Forecasted Wind at 700 mb and 500 mb (Source: PMD)

Local Condition

Jacobabad is the station which has received the highest rainfall in Monsoon spell of September, 2012. According to climatology of the station the average rainfall of July is 42 mm, August 35 mm and September 11 mm but in 2012 May, June, July and August (MJJA) remained the driest month and no rainfall has occurred over the station. The maximum temperature at Jacobabad shoots up to 50° C in May, 2012 which ultimately contributed in intensifying the seasonal low pressure located over Balochistan. The hot and dry condition in MJJA has also played a very important role in attracting the Monsoon low pressure system towards the southern parts of the country.

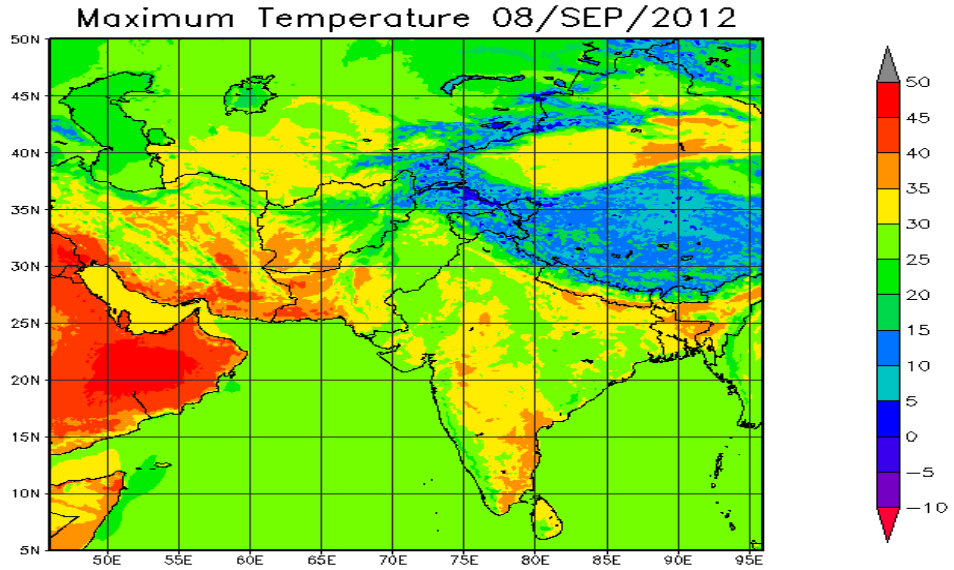


Figure 14: Maximum temperatures forecasted by HRM Model.

Comparison of current event with July, 2003 event

The heavy rainfall event of Karachi that took place in July 2003 which is diagnosed and analyzed well in detail by (Rasul G., 2005) was little different from the September, 2012 event. The event of heavy rainfall

over Karachi took place in July, 2003. This event occurred at the inception of the monsoon season when the platform for the monsoon was just started to set. Generally all elements that control the dynamics of the monsoon are at premature state in the month of July. The sudden intensification of the Bay of Bengal depression occurred when it merged with a mesoscale low located at South Eastern border of Pakistan where the strong part of the low was well connected with an Arabian sea which becomes a healthy source of moisture supply to the system.

The event of September, 2012 took place when the monsoon season generally pulls out from the region. The Somalia Jet played a primary role in pouring moisture supply to the system. The upper part of Sindh, a well marked pre heated region due to local climate condition, was capable of holding abundant amount of moisture was offered with continues moisture supply by the Somalian Jet which resulted in heavy down pour event. Moreover the intensity of the subtropical jet stream was very high than the normal intensity in the month of September. The upper jet convergence over north of Iran have caused a divergence on the surface which have blocked the depression from moving further westward. The strong jet also helped in intensifying the eastern jet over Indian Ocean at 300 mb and the local condition of the region has significantly increased the thirst of the atmosphere.

The differences in both events are not of significant nature because of the fact that the study area is more or less same and the weather system is monsoon in both the cases. Furthermore the controlling elements of monsoon orientation are also same which formulate both the cases identical but if radiosonde data is provided for the study area in both the cases than a sharp line could have been drawn between the events.

Conclusion

Following conclusions are drawn from the diagnostic study of Monsoon Spell in September, 2012.

a) The orientation of monsoon trough remained south westward over lower parts of an India therefore the depression formed over Bay of Bengal, moved westwards during season instead of their northwest movement which ultimately resulted in heavy rains over upper Sindh.

b) The Tibetan high location and intensity significantly contributed towards the track of this Monsoon spell. It restricted the Monsoon low pressure to move towards upper parts of Punjab and KPK.

c) The Somalia's Jet participated towards the intensity of this Monsoon spell. It continuously added the moisture from Arabian Sea and restricted the weakening of the system.

d) The North-South orientation of Seasonal low over Balochistan further enhanced the Monsoon Low when it approached near eastern border of Sindh.

e) Local condition of Jacobabad set the stage for this event to occur.

Recommendations

Following are the recommendations after analyzing the complete event.

a) Standardized sewerage and drainage system should be given first precedence to deal at first with any type of heavy rain over the region in future.

b) The blockages of the perennial and non-perennial streams coming from Balochistan that is North and Western parts of Jacobabad must be removed before the next Monsoon season.

c) The banks of the river and canals should be made green with planting trees or with escalating hard stones at the base of the banks to mitigate the erosion during the normal or heavy flow of the water.

d) Small or Large dams should also be included in the future plan as it will save the water and also prevent the region from flood condition.

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