DIAGNOSIS OF THE IMPACT OF DEEP DEPRESSIONAL ACTIVITY IN NORTHERN ARABIAN SEA OVER KARACHI DURING MONSOON

Muhammad Hasan Ali Baig*, Ghulam Rasul*

Abstract:

The burgeoning usage of Numerical weather prediction techniques provide numerous dimensions to forecasting in modern days. As reliance on these models is increasing, hectic involvements to address the shortcomings of their applications is also in full swing. In this study an attempt has been made to diagnose the devastating dust/wind storm accompanied by torrential pre-monsoon rain which lashed Karachi and smashed the city's infrastructure. Sudden and rapid development of supercell Cumulo nimbus (Cb) clouds over Karachi in the outskirts of strong Deep Depression over Arabian Sea followed by severe wind storm (whole gale) which deceived the forecasters has been analyzed here. High Resolution Regional Model (HRM) has been utilizing by PMD for forecasting purposes. In this study simulations based upon the U.S. National Centre for Environmental Prediction (NCEP) and Albany data under the scope of conventional techniques have been analyzed and compared with HRM simulations to diagnose the causes of this disastrous activity and to address the discrepancies/limitations of the HRM. Model successfully predicted the pressure fall, and upper atmospheric conditions at 1200 GMT. Little deviation has been observed in HRM's simulations for humidity and temperature to the actual data recorded at different meteorological stations of PMD. Almost complete deviation is observed in simulations for predicting wind, cloudiness and precipitation from actual record. This event has forced the modelers to review its physical processes, parameterization and numerical schemes for capturing wind, cloud cover and precipitation to realistic limits.

Key Words: *Deep Depression, Pakistan Meteorological Department, Monsoon, High Resolution Regional Model, Numerical Weather Prediction, Mesoscale Phenomenon.*

Introduction:

Pakistan is located in South Asia and extends northeast to southwest from the Arabian Sea between latitudes 24 o N to 37 o N and longitudes 60 o E to 75 o E. It has a typical characteristic climate by virtue of its peculiar orographic features, such as the Himalaya and Hindu- Kush ranges in the north and northwest respectively (Chaudhry et al, 2007, Khan, 1993). These features play an important role in establishing all four seasons in Pakistan. In the present study, our main focus is on the dust/thunderstorm activity took place on 23rd June, 2007 in Karachi, which devastated the metropolitan city. Inhabitants of Karachi experienced the unforgettable event of their lives in the form of severe thunderstorm and heavy rain with strong gusty winds, which started almost at 1145UTC

* Pakistan Meteorological Department

(4:45 pm of PST). This mesoscale phenomenon of monsoon deceived the forecasters and modern techniques in pursuit of its rapid development. Pakistan Meteorological Department (PMD) issued a communiqué but that much sudden development of Cb clouds during such a short interval of time accompanied by wind storm was never expected. Karachi is situated at 24.86o N and 67.01o E along northern coast of Arabian Sea. This windstorm lashed the infra-structure of the city. Carnage by weather had been reported by media, the strong wind and rain late Saturday wreaked havoc in Karachi, which received 17.2mm of rain within one hour. Death toll of 228 people had been reported (Dawn, June 24, 2007). Pakistan Meteorological Department issued an advisory report on June 22, 2007 which predicted widespread heavy rain by declaring strong monsoon weather system (deep depression) over India as a cause of such unusual climatic change.

In June, at least one thunder or dust storm is expected every year in Karachi. Thunderstorm may be accompanied with strong squalls (Shamshad, 1988). The rainfall over Karachi in summer months is generally inadequate which occurs mostly due to local heat thunderstorms (Khan, 1993). Because during pre-monsoon season South-Westerly flow in the presence of strong convection gives rise to occasional strong buildups of Cumulonimbus clusters to produce intense rain and strong down drafts.

The weather we experience on our planet is caused by the complex atmospheric and oceanic processes governed by certain physical laws. NWP relies on the fact that the gases of the atmosphere obey a number of known physical principles like the hydrostatic equation describes vertical motion in the atmosphere and the first law of thermodynamics is used to predict changes in temperature that result from the addition or subtraction of heat or from expansion and compression of air (Lutgens, 2004) Depending on the ranges for which forecast is being made, there are different models, like a global model for a medium range forecast (4 to 10 days), a regional model (a limited area model) for short range forecast (few hours to few days) and a meso-scale model for a very short range forecast (up to 12 hours) (NCAR,2002). A regional climate model (RCM) is a downscaling tool that adds fine scale (high resolution) information to the large-scale projections of a global general circulation model (GCM).

Normally a global model provides boundary conditions for regional model and a regional model provides boundary values for a mesoscale model (Das,2002). There are three types of technique for obtaining regional climate change projections: statistical, dynamical and hybrid (statistical-dynamical) techniques. RCMs fall into the dynamical category. Basically two types of mesoscale prediction models can be identified, the non-hydrostatical and hydrostatical mesoscale prediction models. The non-hydrostatic mesoscale models are of very high horizontal (<20 km) and vertical (0.5 km) resolution (Pielke et al., 1992). However, the hydrostatic mesoscale prediction model operates with horizontal grid resolution of roughly 20 to 100 km and vertical resolution of about 1 km. But the hydrostatic High Resolution Regional Model (HRM) can be used upto the resolution of ~11km.The non-hydrostatic Mesoscale model equations are formulated in advection form, using temperature and pressure as prognostic variables, along with the velocity components and moisture fields (Black, 1994).

When developing 10∼20 km numerical weather prediction (NWP) models, hydrostatic water loading should be evaluated in preference to adopting non-hydrostatic models, while a non-hydrostatic model with hydrostatic water loading is thought to be recommendable for a high-resolution NWP model (Kato, 1997).

In this paper an effort has been made to investigate the merits and shortcomings of the model in forecasting the mesoscale phenomenon so that in future more careful reliance and correlation between conventional forecasting techniques and Numerical Weather Prediction can be made in a cautious manner.

The high resolution model, popularly known as HRM, is a regional numerical hydrostatic model used for short-term forecasts. It is based on a set of equations that describe the evolution of variables such as temperature, wind speed, humidity, and pressure defining the weather or the state of the atmosphere. The HRM uses a hybrid sigma pressure coordinate system. Near the surface, the model follows the terrain with sigma coordinates while the upper atmosphere employs the pressure coordinate system. δ-Two stream radiation scheme including long- and shortwave fluxes in the atmosphere and at the surface; full cloud - radiation feedback; diagnostic derivation of partial cloud cover (relative humidity and convection) is employed in the model. Grid-scale precipitation scheme including parameterized cloud microphysics is also used. Mass flux convection scheme differentiating between deep, shallow and mid-level convection is utilized.Level-2 scheme of vertical diffusion in the atmosphere, similarity theory at the surface and for soil seven-layer model including snow and interception storage is used (Majewski, D., 2007). It comprises of 40 vertical layers while the horizontal resolution of 22 km (0.22o) has been utilized here.

The process starts with analyzed data using observations and previous forecast to obtain the best estimate of the current state of the atmosphere. A global model (GME) is used to produce a forecast by the Deutsche Wetterdienst (DWD), the Meteorological Service of Germany. The Pakistan's area of interest is then singled out to provide the initial and boundary conditions of the limited area model HRM. At the receiving station the HRM can run in parallel to the GME at DWD using the interpolated GME analysis as initial state and GME forecasts from the same initial analysis as lateral boundary conditions. This is a considerable step forward because up to now most regional National Meteorological services (NMS) have to use 12h "old" lateral boundary data which degrade the regional forecast quality by more than 10%.

Methodology:

In pursuation of the goal of analyzing the devastating extreme event in the form of severe wind storm by the eye of HRM, firstly the data acquired from the Climatological Data Processing Centre (CDPC), Karachi has been analyzed. Then NCEP Reanalysis data was used for studying the synoptic situation of the atmosphere above and around Karachi. The NCEP/NCAR Reanalysis 1 project is using a state-of-the-art analysis/forecast system to perform data assimilation using past data from 1948 to the present. Besides NCEP charts, manually prepared synoptic charts at Main Analysis Centre, Karachi were also analyzed in detail for grasping the true picture.

For supporting the recorded data, Satellite pictures were also considered to grasp an accurate picture of surface and atmosphere of the selected region. Finally, HRM model has been used for prognosting the situation. Some analysis developed by using the software 'Digital Atmosphere' based on the data of University of Albany, New York are also presented where coarse resolution of NCEP data created hurdles. All these simulations are visualized by using GrADS software.

Related Surface Data

In the following table the trend of fall in pressure and rise in temperature is presented from the 00Z of the 22nd June, 2007 to the onset of devastating thunderstorm nearly just before 12Z of 23rd June, 2007. While data given in the table shows the high humidity just before the occurrence of event and rise in maximum temperature on that day. From the table it is evident that almost northerly winds have been recorded which were blown from land and cause rise in temperature with maximum velocity at the time of onset of thunderstorm. Rain recorded for 24 hours from 03Z of 22nd June to 23rd June has been mentioned under 22nd June and that from 03Z of 23rd June to that of 24th June has been mentioned under 23rd June. It is important to note here that 17.2mm rain has been recorded for just one hour as no rain was recorded other than that heavy downpour up to 03Z of 24th June. Sky was totally covered with clouds at the time of occurrence of event.

Table 1: **Pressure and Temperature with other data recorded at M.O., Karachi**

Parameters	22nd June, 2007			23rd June, 2007			Corresponding Differences		
	0000 UTC	0300 UTC	1200 UTC	0000 UTC	0300 UTC	1200 UTC	0000 UTC	0300 UTC	1200 UTC
Pressure(hPa)	997.9	998.6	994.6	995.9	996.6	992.6	-2	-2	-2
Temperature(oC)	27	30.5	38.5	32.5	35	29	+5.5	+4.5	-9.5
Temperature(oC) (Maximum)	39.3			42			+2.7		
Temperature(oC) (Minimum)	23			31.5			+8.5		
Humidity (%)	-----	-----	50	-----	-----	78	-----	-----	+28
Wind (knots)	0 (N-360o)	0 (N-360o)	6 (NW-225o)	4 (N-360o)	6 (N-360 o)	60 (NE-45o)	+4	+6	+54
Rain (mm) 24-Hrs	19.4			17.2			-2.2		
Clouds (Oktas)	7	4	5	0	4	7	-7	0	2

Analysis of Synoptic Condition

The sagacious and discreet analysis of the NCEP simulations along with synoptic conditions and available data at CDPC reveals that three days prior to this incident, a depression was present over India which later intensified in the form of deep depression. This system sucked all the moisture from Arabian Sea caused the wind to blow from northeast direction over entire lower Sindh including Karachi. Under the influence of this deep depression, a low was formed over northeast Arabian Sea and adjoining areas of lower Sindh. All the winds from surface level to 300hpa level were north easterlies. This northeast flow caused the day temperature to rise as high as 42 °C with relative humidity 78% on that particular day, i.e. on 23rd June, 2007. The temperature rising trend i.e. from 36.5 °C to 42 °C persisted for preceding six to seven days with unusual high humidity having resulted in huge energy accumulation, owing to tremendous convective instability around Karachi. And the final result was the outburst in the form of tornado/gale winds followed by heavy dust/thunderstorm that lashed the city in few minutes. The maximum wind speed of 60 knots was recorded at Meteorological Observatory (M.O) Karachi Airport. The surface visibility was as low as 500m at airport with approaching to zero in some parts of city.

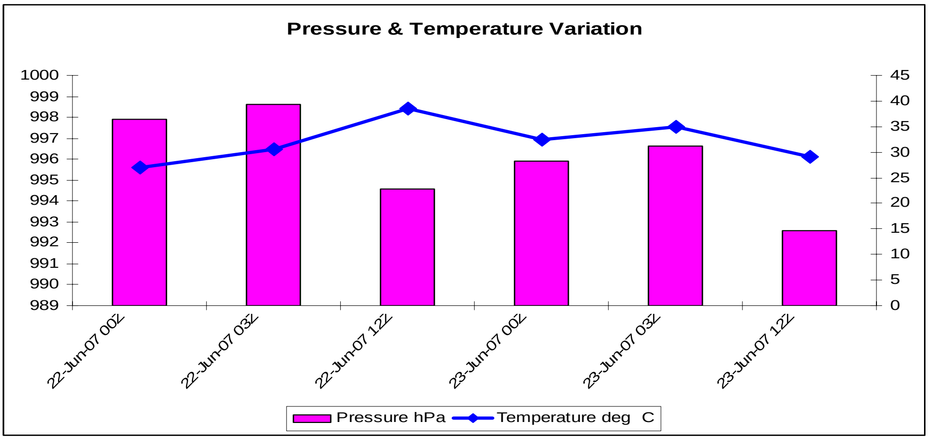


Figure 1: **Analysis of Falling Pressure and Rising Temperature trends.**

Synoptic History of this historic incident reveals that an area of convection developed and persisted in the central Bay of Bengal on 19th of June about 165 nautical miles east of the Andaman Islands. It was observed that observed that deep convection was increasing near a developing mid to low-level circulation, and surface observations in the area had revealed P24 (24-hour Pressure change) of -1.5hPa. While the upper level environment was characterized by diffluent flow, a strong tropical easterly jet was contributing to 20-30 kts of vertical shear. The disturbance drifted slowly to the west, and by the next day the Low Level Circulation Centre (LLCC) had consolidated some and the potential for development was upped to 'fair'. Although the environment was still not particularly favourable for cyclogenesis, surface pressures had continued to fall by about P24 = -2.0. At 0300 UTC on 21st of June, the Pressure area was coined to a depression with winds estimated at 25 knots by Indian Meteorological Department (IMD).

On 21st of June, the deep convection had developed over the well-defined LLCC. At 1200 UTC of 21st June, 2007 IMD classified the system as a deep depression while at the same time warning issued by the Joint Typhoon Warning Centre (JTWC) declared it as Tropical Cyclone 03B. the system was centred about 100 nm south-southeast of Visakhapatnam and moving west-northwestward at 14 knots. Deep convection was located primarily over the south-western quadrant of the LLCC. TC-03B was tracking westward along the southern periphery of a mid to upper-level ridge over northern India.

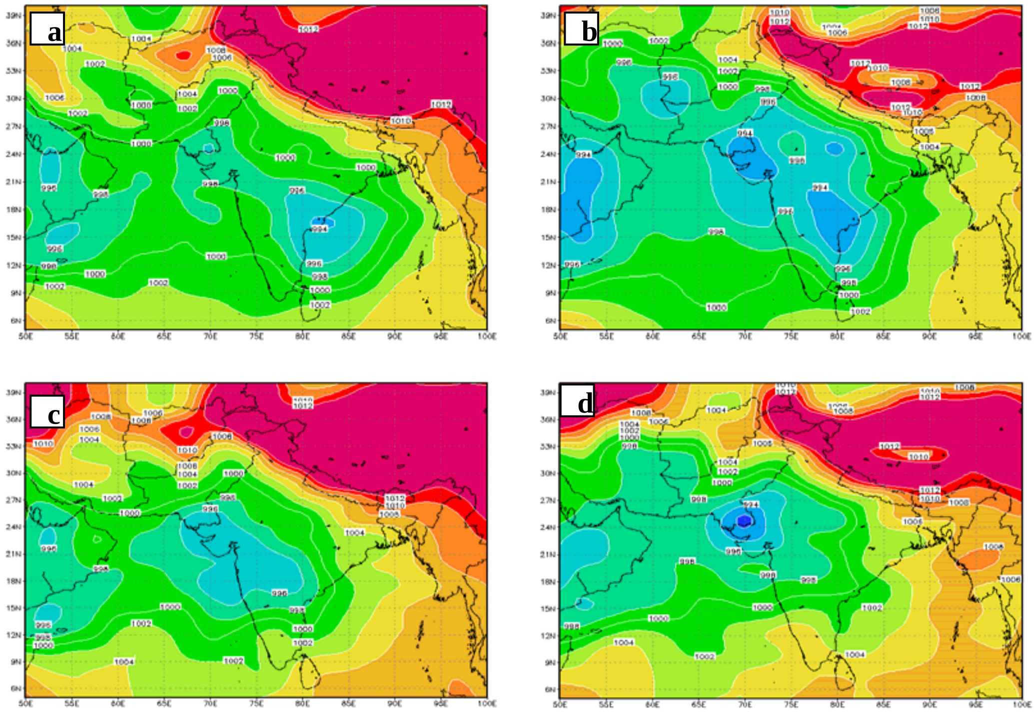


Figure 2: **Surface Pressure patterns (a-d) before the incident from 0000 UTC of 22nd June,2007 to 1200 UTC of 23rd June,2007 with 12 hrs intervals.**

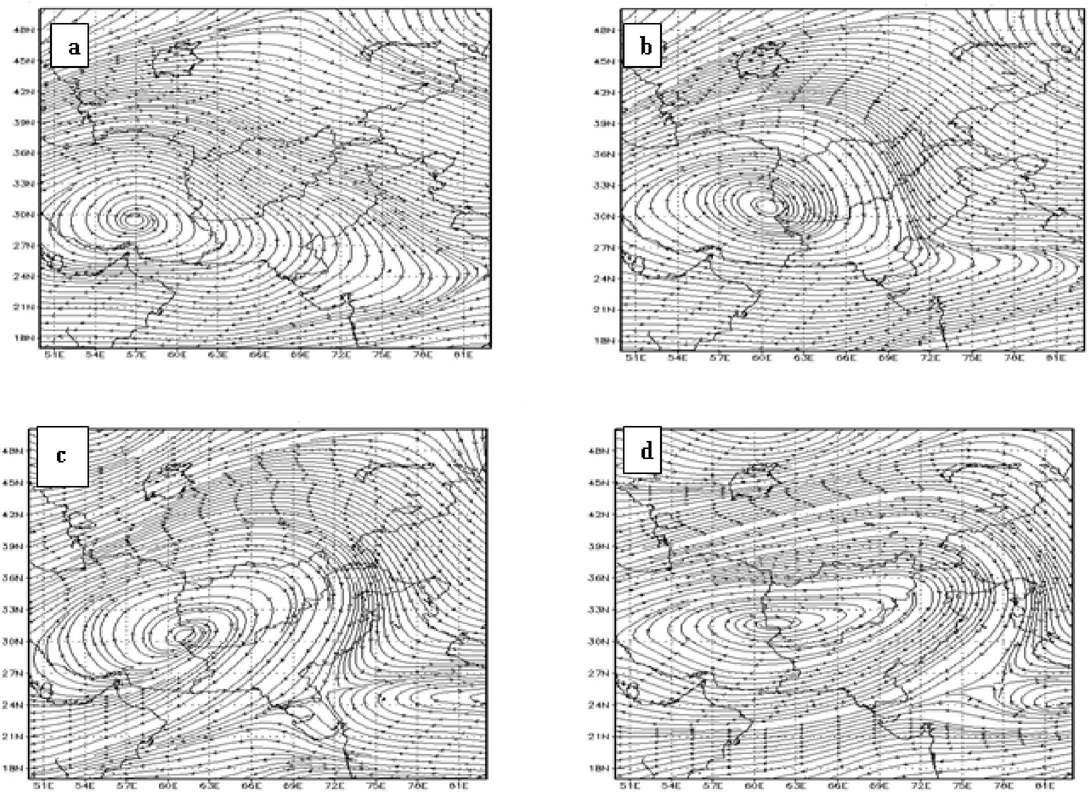


Figure 3: **Stream Lines Analysis at 200hPa (a-d) showing strong Anti-cyclonic Circulation from 0000 UTC of 22nd June,2007 to 1200 UTC of 23rd June,2007 with 12 hrs intervals. It shows that almost Easterly Regimes were predominant over the Arabian Sea in the beginning but later they started to transform into Cyclonic Circulation.**

Pakistan's area of interest started when deep depression (which was later declared by PMD as TC-Yemyin) started subsequently moved westward and inland into coastal Andhra Pardesh around 0000 UTC of 22nd of June,2007 as evident from the figure 2(a). At the same time bubble low or cut of low (996 hPa) was developed at 70° E and 24° N in the trough of above discussed deep depression which itself was centred at 82° and 17° N with pressure of 994 hPa.

North-westward movement was tracked by this deep depression while low at SE part of Pakistan intensified further upto 994 hPa with more or less on the same location at 1200 UTC of 22nd June. At 0000UTC of 23rd June both lows merged in single low with troughs extending NW, SW and SE-wards. At 0600 UTC, North Western trough converted into mesoscale low while the South Western trough merged with the above system. A shallow low was present in the South Eastern trough. At 1200 UTC, it further intensified upto 992 hPa and located at 70o E and 25° N. At this time severe wind storm was observed by the inhabitants of Karachi in the periphery of this deep depression.

Upper air conditions also supported the deep depression to become more intense. Strong anti-cyclonic circulation was pervasive at 200 hPa with centre over Iran and extension in the form of ridge was dominant over sub-continent as shown in the figure 3(a & b). But a clear trough was present (refer figure 3: c & d) between two anticyclonic circulatios i.e. one over Iran and second over the Nort-Eastern India at 0000 UTC of 23rd June, 2007. These two highs supported the convergence over land in the form of deep depression

At 500 hPa situation is also anti-cyclonic below the same anti-cyclonic centre of 200hPa. But strong cyclonic circulation is evident in figure 4 (a-d) over South Western India and its extension over Arabian sea with second inter-linked cyclonic circulation over the coastal regions of Gulf. This Cyclonic circulation strengthened the deep depreession over Surface. Side by side if isotachs are also analyzed then it is revealed from figure 7(d) that wind was blowing fast upto >30knots almost over the surface's deep depression.

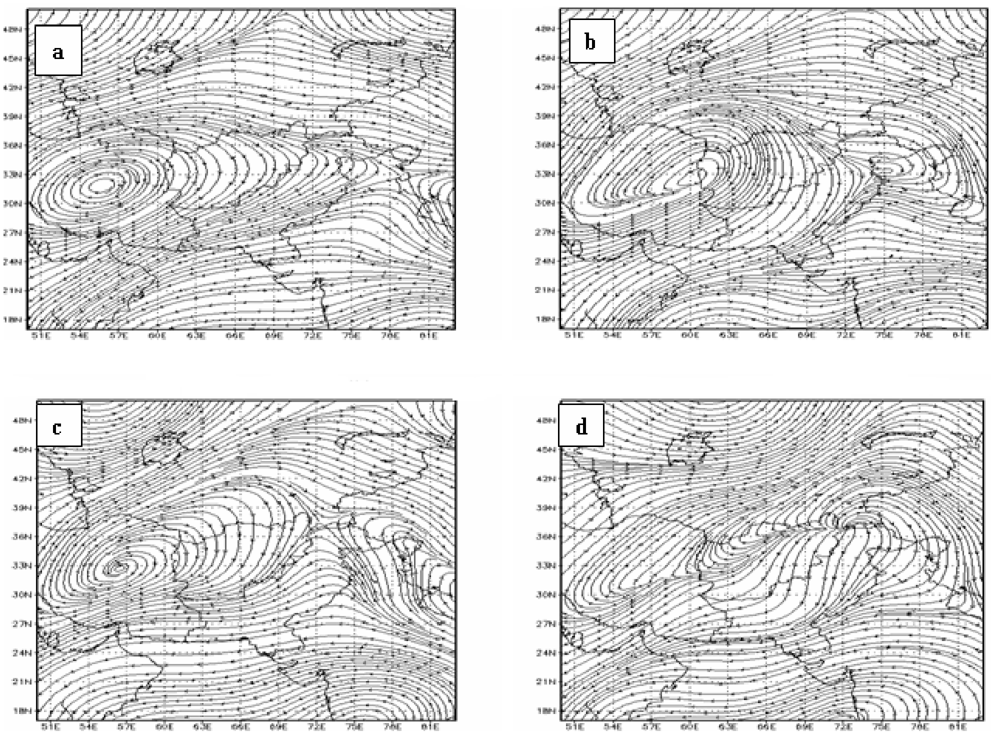


Figure 4: **Stream Lines Analysis at 500hPa (a-d) showing movement of Anti-cyclonic Circulation from SW direction with 0000UTC of 22nd June,2007 over Iran to 1200 UTC of 23rd June, 2007 over Afghanistan with 12hrs intervals. Cyclonic Circulation is also dominant over Arabian sea and South Eastern India.**

Analysis of wind stream charts of 700 hPa show that cyclonic circulation had been intensifying from 22nd June, 2007 till the day of occurrence of tragic wind storm. Two inter-linked patterns of strong cyclonic circulation can be seen in the attached figures. But shallow ridge was present over Karachi at 23rd of June, 2007. This ridge might become helpful in strong upward convective movement which led to support the formation of severe storm.

Upper air patterns of Geopotential heights can also be seen in figure 6 with isotherms. Geopotential heights of 200 hPa support parallel isotherms in normal conditions. If they are nearly perpendicular to the contours then it would be an indication of arrival of disturbances at surface after some duration which is important for forecasting. One High is persistent over Iran and Balochistan at 200 hPa. This High is normally form over the seasonal low of Balochistan. Surface systems are tilted NWard in the upper air. Analysis of figure 6 (a-d) makes it clear the Sub Tropical high (STH) had been intensifying gradually. Its orientation shows that it supported the cold air advection from higher latitudes of North towards South and created instability. Convective unstable vertical currents with lack of moisture supply usually develop to produce local dust/sand storms or simply dust devils. Sometimes, in the case of a moisture supply, they produce intense local showers (Rasul et al., 2005).

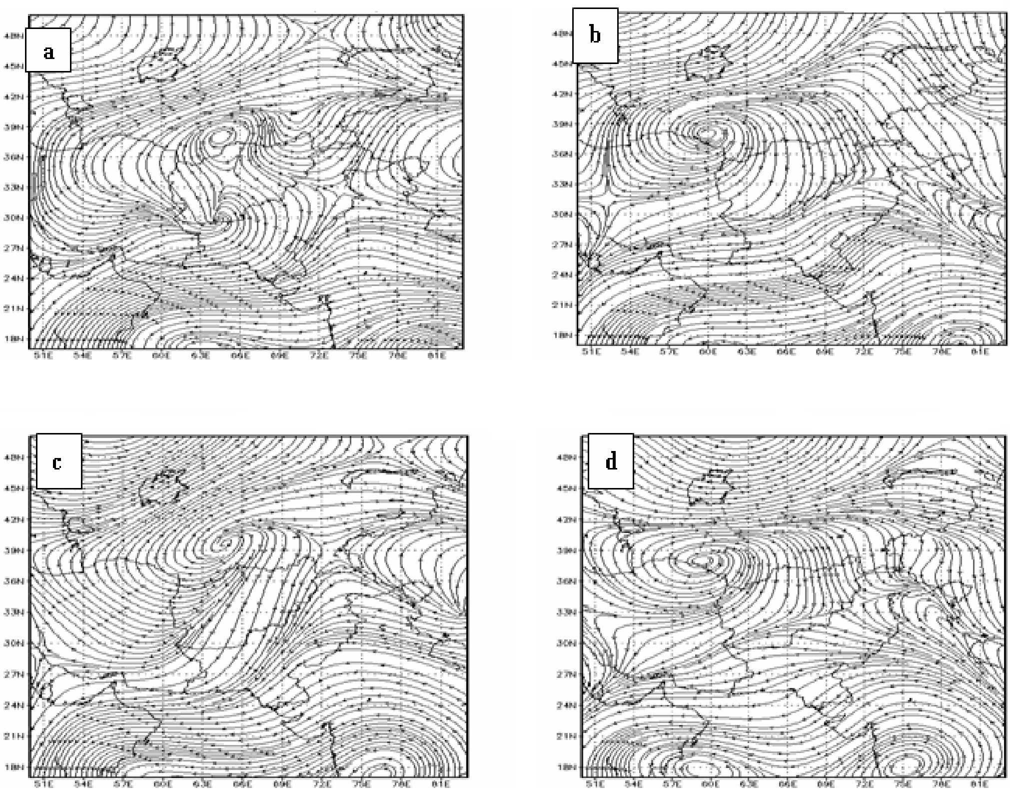


Figure 5: **Stream Lines Analysis at 700hPa (a-d) from 0000 UTC of 22nd June, 2007 to 1200 UTC of 23rd June, 2007 with 12 hrs intervals, showing intensification of Cyclonic Circulation over SW India, Arabian Sea and Coastal Belt of SE Gulf.**

When Isotherms are also analyzed then they are observed nearly perpendicular in some 200 hPa charts of 22nd June, 2007. 500 hPa charts reveal that core of Low was warm and the whole pattern was shifting towards South-Eastern Pakistan from 22nd of June, 2007 to 23rd of June, 2007. Interesting features of this deep depression unearth when isotherms of 850hPa and 700 hPa are analyzed. It is revealed from those charts that at these levels deep depression had a characteristics of Cold Core Low.

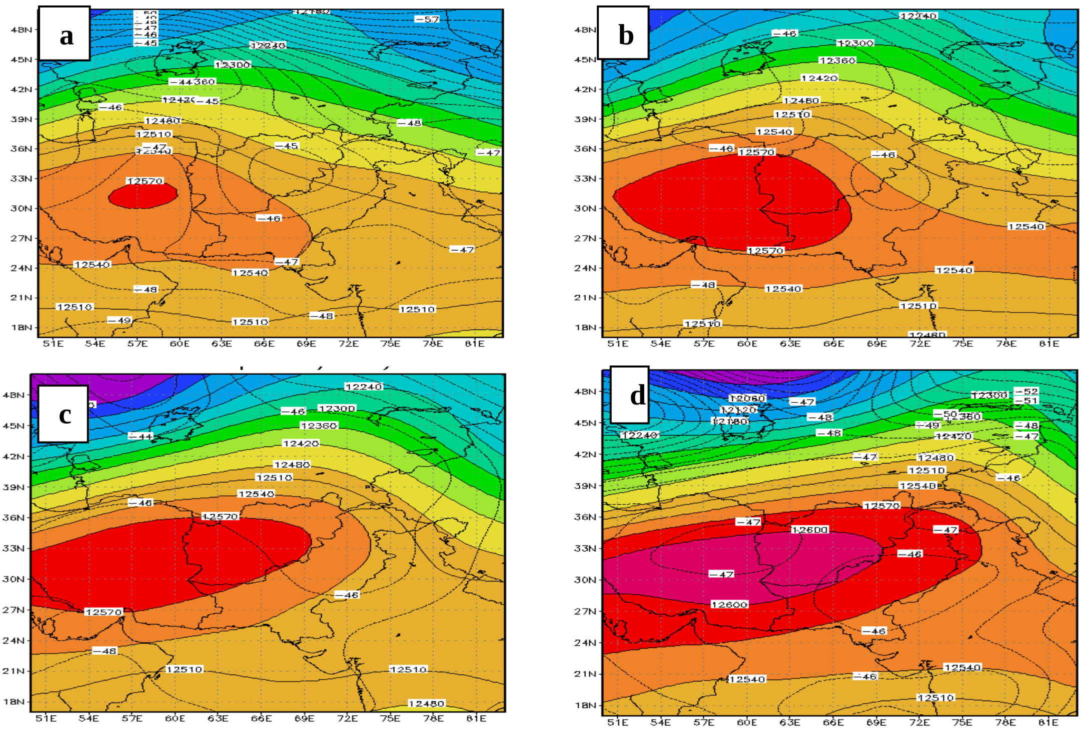


Figure 6: **Geopotential Heights (solid black line) and Isotherms (dotted black line) at 200 hPa with a & b representing 0000 UTC & 1200 UTC of 22nd June, 2007 and c & d representing 0000 UTC & 1200 UTC of 23rd June, 2007 respectively. Intensification of STH is evident over Afghanistan, Iran and Balochistan with the passage of time.**

Jet Stream is pervasive at 200 hPa and its movement can be analyzed as Westerly Jet Stream from North of Pakistan. Easterly Jet Stream can also be analyzed over Bay of Bengal, Southern India and Arabian Sea. Between these two Patterns High exists over the sub-continent at 200hPa. Isotachs at 500hPa also show the westerly Jet Stream over the same location.

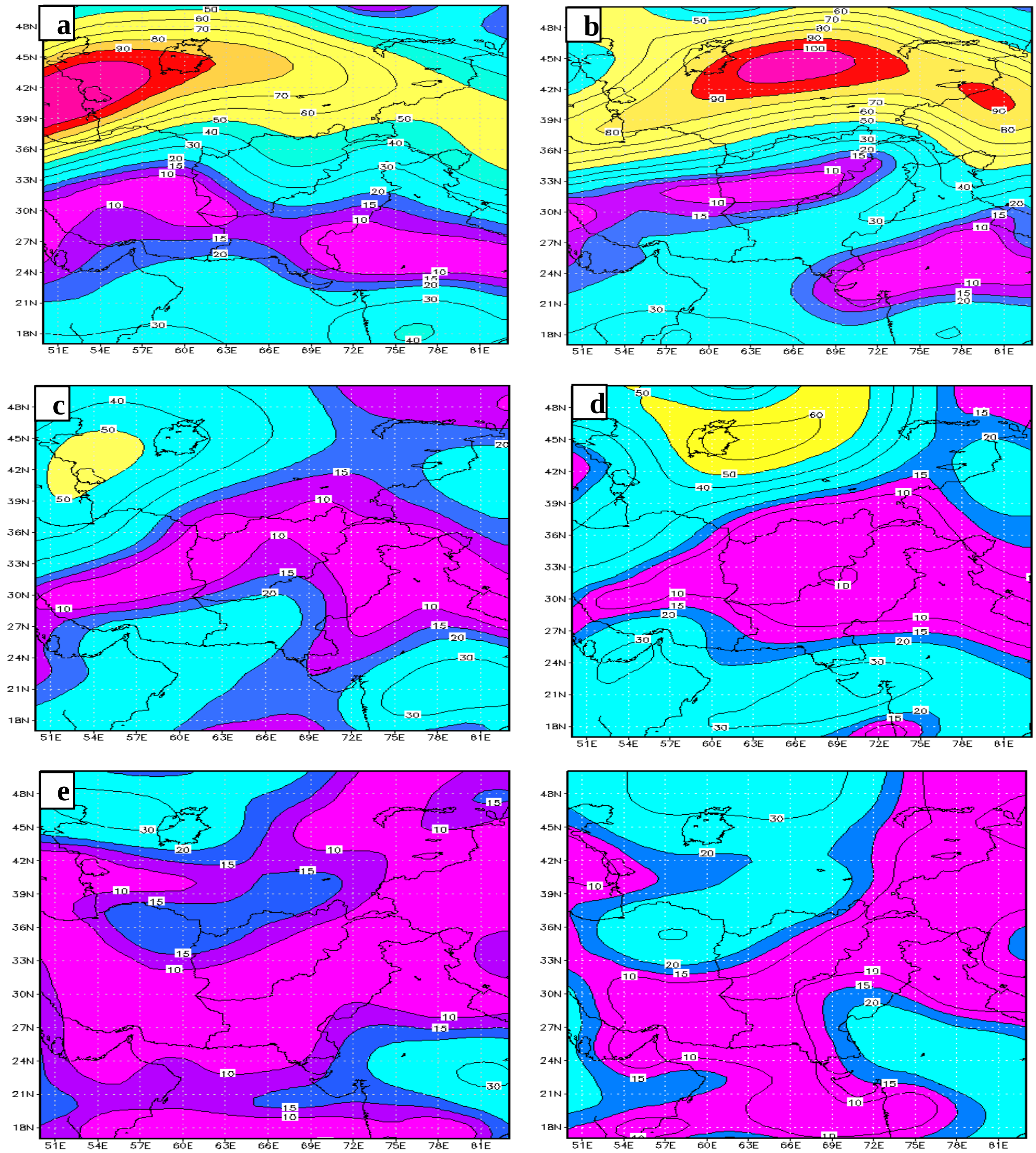


Figure 7: **Isotachs showing movement of strong Jet Stream (a: 1200 UTC of 22nd June, 2007 at 200 hPa; b: 1200 UTC of 23rd June, 2007 at 200 hPa; c: 1200 UTC of 22nd June, 2007 at 500 hPa; and d: 1200 UTC of 23rd June, 2007 at 500 hPa;) from West to North of Pakistan at 200hPa and weak Jet Stream at 500 hPa in 24 hrs. Strong Easterlies are pervasive over South-eastern India and Arabian Sea. In (e & f) Isotachs showing movement of strong currents accompanied by Depression at 850 hPa over Central India towards Pakistan (e: 1200 UTC of 22nd June, 2007 & f: 1200 UTC of 23rd June, 2007.**

But Easterlies were quite slower which helped in movement of deep depression towards West direction. Low level Jet stream catalysed the movement of the Deep Depression in the vicinity of Karachi. Synoptic history of cyclones reveals that strong activities over surface occur where Jet streams persist at upper troposphere and lower stratosphere.

Comparison b/w the Actual Pattern (NCEP real analysis) and HRM Forecast:

An excellent coincidence between the actual pressure present at Karachi with the prognostic pressure and the pressure recorded at Meteorological Observatory (M.O), Karachi has been shown in figure 8. In Figure 9, upper level geopotential charts based on NCEP data and HRM simulations are compared. These charts also show almost complete coincidence between actual data and HRM forecast. At 850 hPa real analysis of NCEP data shows Karachi under the contours between 1420 gpm and 1440 gpm while HRM simulation represents 1420 gpm over Karachi. At 500 hPa, contours between 5860 gpm and 5880 gpm are present over Karachi. While almost the same picture is represented by HRM simulation.

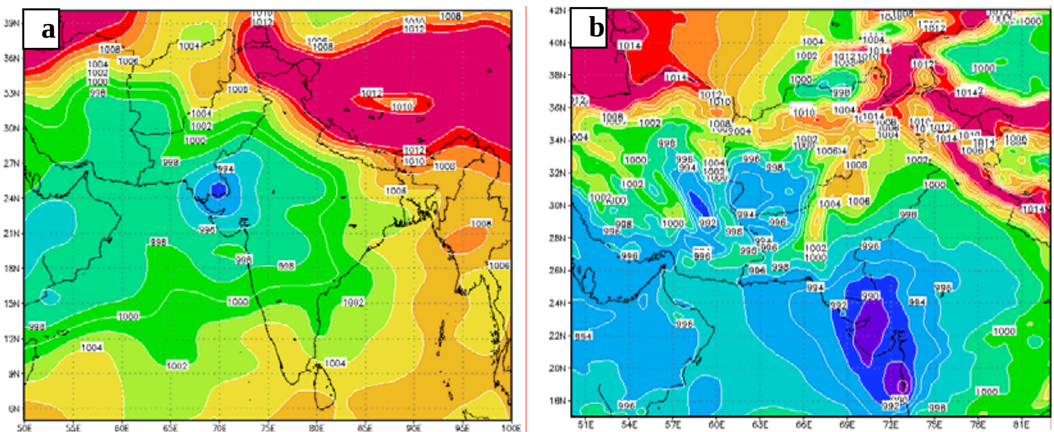


Figure 8: **(a) indicates the actual Sea Level Pressure Pattern with 992 hPa at South Western parts of Pakistan while HRM forecasts in (b) is indicating the more intense pressure almost over the same location with trough extending towards the coastal belt of India. HRM forecast was initialized at 0000UTC of 22nd June,2007**

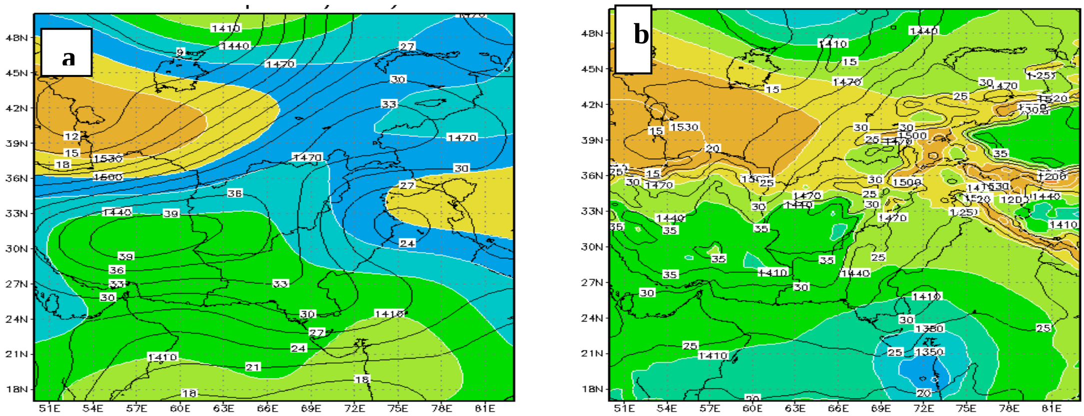


Figure 9: **(a) is representing the actual pattern of Contours at 850hPa with blackish dotted line representing the temperature. In (b) HRM forecast is showing the closed cell of almost equal low with extended Trough over Arabian Sea as indicated in (a). Black dotted line of Isotherm in (b) showing the low as Cold Core Low.**

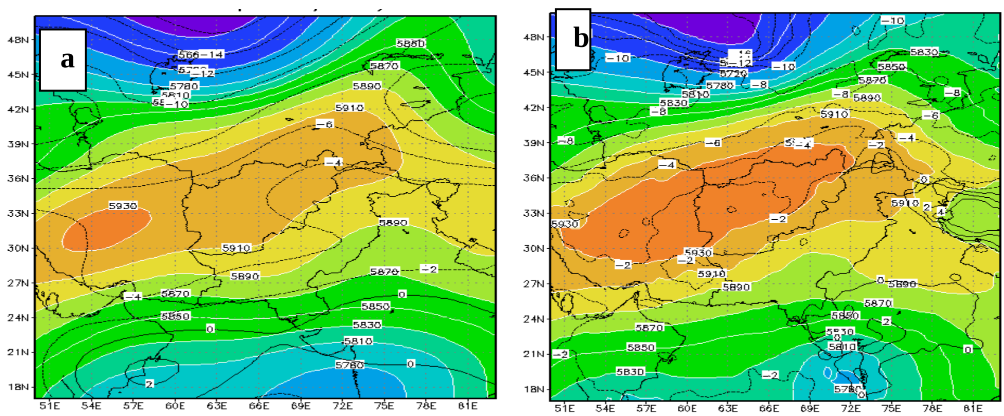


Figure 10: **(a) is representing the actual pattern of Contours (solid black line) at 500hPa 1200 UTC of 23rd June, 2007 with blackish dotted line representing the temperature. In (b) HRM forecast is showing the closed cell of almost equal low value with extended Trough over Arabian Sea as indicated in (a). Black dotted line of Temperature in (b) showing the centre of low at higher values in comparison to adjoining values of temperature.**

As far as temperature is concerned for comparison between the real analysis and HRM forecast, Table 1 indicates that the recorded temperature at 1200Z was 29 °C but HRM simulation gave temperature values between 40 ° C to 42 ° C which is much higher than the actual value. The fall in temperature at that time is due to cold downward advection of air at 12Z due to the presence of Cb clouds over Karachi. Deep Depression clearly appears as Cold Core Low with SST at the core of the Depression as 24° C in actual analysis while HRM forecasted SST as 25° C in the Depression region.

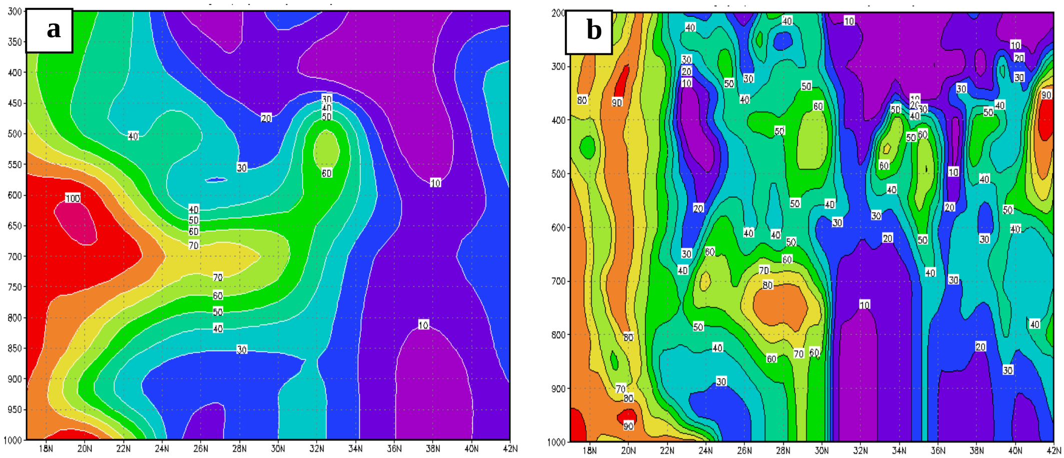


Figure 11: **Vertical Profile of Rel. Humidity at 67° E longitude of Karachi in actual scenario (a) and in HRM Forecast (b) at 1200 UTC of 23rd June, 2007.**

Figure 11 represents the comparison of the vertical profiles of relative humidity between NCEP simulations and HRM simulations longitudinally. Coincidence between both simulations is obvious although the recorded value of relative humidity was much higher than that presented by these simulations. As Karachi is located at 67.01° E, so a discreet look over this longitude shows almost 70% humidity above 760 hPa upto 680 hPa in NCEP simulation while almost 65% humidity is represented in HRM simulation between 760 to 680 hPa. At 19° N higher humidity in vertical profile indicates that the airmass of that region was highly unstable due to the presence of deep Depression there. When latitude of Karachi is fixed at 24.86° N, it was observed that 70% relative humidity was present between 720 hPa and 680 hPa besides more than 60% relative humidity presence at more vertical extent in NCEP simulation. Actual image shows that air was dry near the surface and wet aloft caused convective instability. It supported the development of Cb clouds with strong vertical updrafts which led to cause severe wind storm. While HRM simulation also coincides with NCEP simulation by showing more than 70% relative humidity between 760 hPa and 650hPa. It is important to mention here that relative humidity was much high at oceanic region near Karachi due to the presence of deep depression (which later became Tropical Cyclone Yemyin-03B) in the North Indian Ocean. NCEP data (Kalnay et al, 1996) which is used here provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at **http://www.cdc.noaa.gov/**

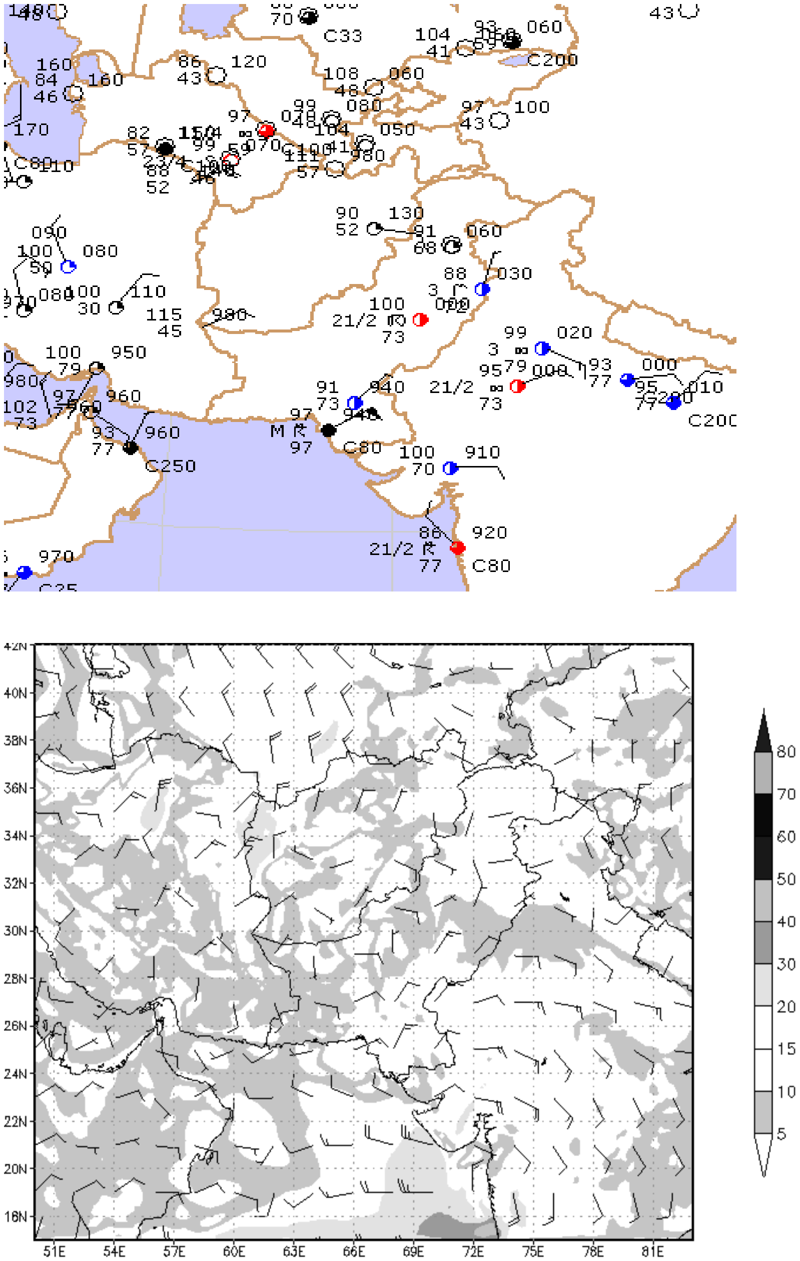


Figure 12: **Wind Speed (Knots) representation in actual observation at different stations of Albany data (a) is clearly indicating the 60 Knots Wind at Karachi. (b) is representing the HRM forecast of 10 knots at the same station.**

Figure 12 represents the comparison between the images of winds of Albany data and HRM forecast. 60 knots wind can be seen in a barb form at station of Karachi in the image of Digital Atmosphere but less than 15 knots wind is shown by HRM simulation which shows the complete deviance from the recorded one.

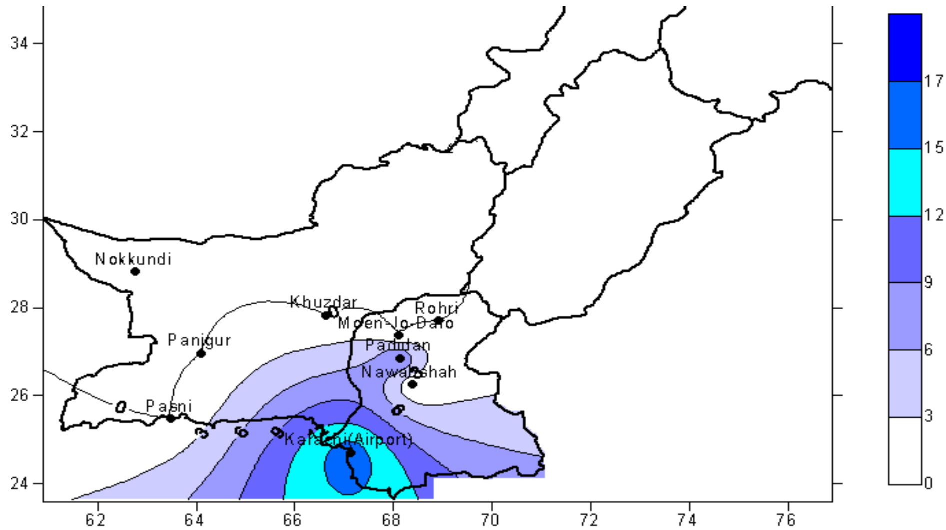


Figure 13 (a): **Recorded Rain for Karachi and adjoining areas of Sind and Balochistan with more than 16mm rain at Karachi Source: Climatological Data Processing Centre(CDPC), Pakistan Meteorological Department.**

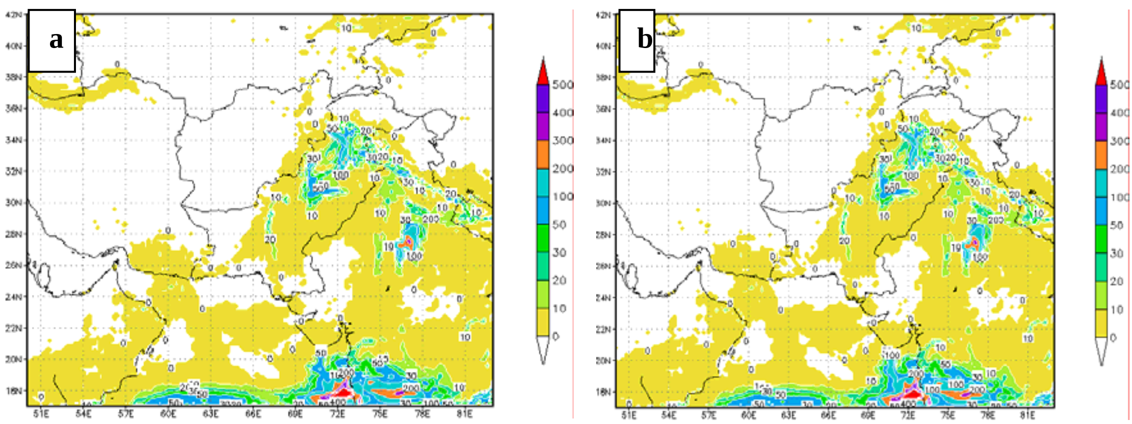
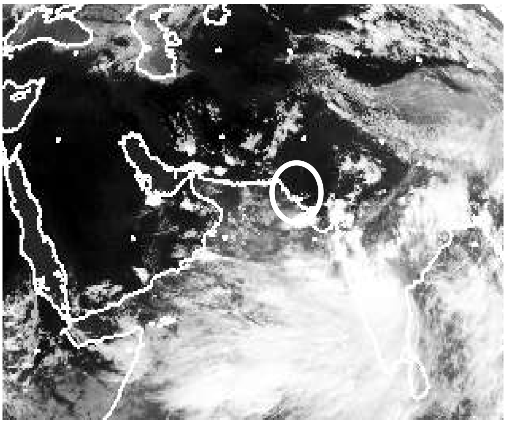


Figure 13 (b & c): HRM Forecast of Rain at Karachi at 1200 UTC and 1300 UTC on 23rd June, 2007 with 0mm rain in both simulations

Table 1 is a proof with satellite picture of 14(b) that sky was almost overcast over Karachi at the time of thunderstorm/windstorm while less than 1 oktas of clouds were forecasted by HRM in its simulation (figure is not given here). This again represents variance from the actual cloud coverage.

Observed rain of Karachi and adjoining areas of Sind and Balochistan has been analyzed in the form of contours which is representing more than 16 mm of rain at Karachi (recorded rain was 17.2mm) in figure 13(a) while HRM forecasts no rain at Karachi which shows the complete mismatch with the actual one (figure 13: b & c).



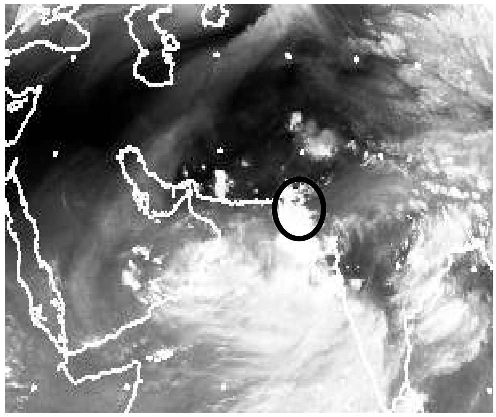


Figure 14: **(a)Met-7 (Dundee), 22-June-2007, 1200Z (b): Met-7 (Dundee), 23-June-2007, 1200Z**

Satellite pictures are showing the cloud picture of clouds at different time intervals. Dense cloud cover was present over Arabian Sea before the historic wind storm at Karachi. At 1200 UTC strong Cb clouds can be seen in figure 14(b). This shows that system covered almost whole Karachi with severe wind storm of Gale intensity.

Results and Discussion:

It is a crystal clear fact which from the above analysis and diagnosis of synoptic conditions that a quagmire in a form of deep depression was present over Arabian Sea near Karachi two to three days prior to this devastating thunderstorm. It was fait accompli that deep depression became a peculiar cause of unpredicted and accidentally happened thunderstorm of Karachi. When satellite pictures are being analyzed expeditiously in the context of all synoptic charts, as a professional demeanour, forecaster found himself between the two fire lines in predicting the exact time of thunderstorm activity as a mesoscale phenomenon. That deep depression and the convective movement of air over Karachi due to rise in temperature exacerbated the situation that resulted in a form of burst which led to severe wind storm.

In monsoon season at 300 hPa or so there exists a well marked anticyclone over Iran and another over Northeastern India and Bangladesh. As these two anticyclones are the reflections of surface low pressure areas in the upper air, their position governs the general circulation of monsoons over the southern Asia. The trough of low pressure (with its core over Balochistan) over the Gangetic plain (Monsoonal Trough) plays an important role in determining the weather conditions in Monsoon period. The axis of this trough is a semi-permanent zone of convergence. Generally the outbreak of monsoon showers is preceded by squalls and thunderstorms. Afternoon thunderstorms accompanied by dust storms occur frequently over the country (Shamshad, 1988). Dust storms of gradient and instability types caused the peak of wind speeds in squalls just before the onset of the monsoon. Vertical Wind Shear (which was present in this activity) where winds increase or change direction with height serves to enhance rather than weaken the strongest storms through wind removal of precipitation from the updraft summit, and in some cases introduction of updraft rotation as in the case of Supercell thunderstorms. Generally the strongest and most violent tornadoes are spawned by these supercell thunderstorms. As strong winds were present in the upper atmosphere in the vicinity of Jet Stream so divergence aloft played an important role in this activity and intensification of deep depression into Tropical Cyclone. Upper air trough was present as discussed earlier, so an area of upper air divergence and surface cyclonic circulation developed downstream from an upper-level trough. As from the scrutiny of surface and upper atmospheric patterns it is somewhat clear that divergence aloft exceeded convergence at ground level which caused surface pressure to fall and intensified the cyclonic storm. As mid-level of troposphere was analyzed as cooler especially at the centre of deep depression, so this mid-level tropospheric cooling forced strong localized upward motions at the leading edge of the region of cooling which then enhanced local downward motion at the time of thunderstorm. In the mature stage of Cb clouds when strong updrafts and downdrafts are pervasive and tornado activity was also there, severe wind storm blew up the infrastructure.

At surface a low was formed over east-central Bay of Bengal on 20th June. It later concentrated into a depression at 0300 UTC of 21st June. It further intensified into a deep depression at 1200 UTC of 21st June and lay centered near 16.0° N and 84.0° E. It then moved west-northwestwards and crossed Andhra Paradesh coast around 2300 UTC of 21st June. It continued to move in a west-northwesterly direction and on 23rd June, 2007 at 1200 UTC, it was at 70° E and 25° N during which at its outskirt, Karachi faced severe wind storm. As the recorded wind was 60 knots, so it is classified according to WMO standards as ‘Severe Cyclonic Storm’. It behaved like a tornado and uprooted strong trees with devastation of infrastructure and sign boards.

Conclusions:

In this paper the devastating severe wind storm accompanied by thunderstorm and rain (17.2mm in 1hr) produced by a mesoscale convective system over Karachi in pre-monsoon season adjacent to inten se deep depression over Arabian sea has been studied and an attempt is made to address the causes of its development by detailed synoptic analysis. It is tried to diagnose its behaviour for forecasters with special emphasis on NWP tool i.e. HRM which is being used by Research and Development Division (R&D), Islamabad of Pakistan Meteorological Department in collaboration of Deutsche Wetterdienst (DWD), Germany. The main results are:

- The trend of rise of temperature due to north easterly winds coming from the more hot land and fall in pressure supported by the strong deep depression over Arabian sea made easy for the rapid and sudden development of meso-scale convective system to get moisture from Arabian sea.
- Pressure gradient was enough and heavy downdrafts of air resulted in creation of severe wind storm (at least 60knots) accompanied by torrential rain lashed the human-made installations of the metropolitan coastal city of Pakistan.

- Continuous supply of water vapours and instability due to warm surface as compare to upper air paved a way for moist vertical currents to develop marvelous Cb cloud.
- High Resolution Regional Model went good for prognosting fall in pressure and trend of contours at different geo-potential levels. Model appears to some what satisfactory in prognosting parameters of relative humidity and temperature.
- Model appears almost fail in correct simulation of wind, cloudiness and precipitation.

Recommendations:

It is recommended that the mere reliance on model itself may lead to failure for micro- and mesoscale phenomenon, therefore conventional techniques must also be taken into account. Need of further case studies to address the shortcomings of the model is realized. There appears a necessity of upper atmosphere data for plotting Tephigram which is a strongest tool for forecasting mesoscale thunderstorm activity over a particular station. In addition to HRM, it is advisable that side by side we should avail the opportunities of other regional models along with further modification in HRM itself according to our own topography.

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