Heavy Rainfall Forecast by High Resolution Regional Model (HRM) and its Validation over Pakistan

Ali, G.[1, 2], T. Mahmood[2], W. Iqbal[2], S. A. A. Bukhari[2], F. S. Syed[2], G. Rasul[2]

Abstract

A hydrostatic High Resolution Regional Model (HRM) is being used operationally for weather forecast at Pakistan Meteorological Department. The model is run twice a day at 00 UTC and 06 UTC for 72 hr and 48 hr weather forecast respectively. The model takes the initial and boundary conditions from the Global Model GME (Global Model for Europe) developed by Deutscher Wetterdienst (DWD) Germany. To evaluate the performance of HRM for precipitation forecast, five events of moderate to heavy intensity in 2010 and 2011 are simulated by HRM with domain 7˚N-45˚N latitudes and 55˚E-96˚E longitudes at horizontal resolution of 11 Km. The events selected for the study are from winter (8th Feb 2010 and 13th Feb 2011), from pre-monsoon season (17th May 2010) and two events from summer monsoon season (27th - 29th Jul 2010 and 11th - 12th Aug 2011). The model simulated precipitation has been compared with actual precipitation on station to station basis as well as taking the area averages both for observed and model predicted precipitations. The analyses of this study show that there exists station to station random variation in the model predicted precipitation but spatially the model output is reasonably within the acceptable range. Analyzing the area averages it has been observed that the model predicted precipitation deviates from the actual precipitation by about -18 % to +16 % on different occasions. On 17th May, and 28th Jul 2010 the model underestimates the actual precipitation by -18.4 % and -0.5 % respectively. In case of precipitation on 8th Feb, 27th Jul, 29th Jul 2010 and 13th Feb 2011 the model overestimates the observed precipitation by 6.4 %, 4.5 %, 14 % and 16.4 % respectively. This bias in the model output is random and it has no clear dependency upon precipitation intensity or the season. An anomalous behavior has been observed in case of heavy precipitation on 11th and 12th Aug 2011. Analysis of this event shows that the model has underestimated the observed precipitation. Close observation of the model output images for 24 hr precipitation on 11th and 12th Aug 2011 at 00 UTC shows that the model predicts maximum precipitation at a place over India, eastward from the region in Pakistan where maximum precipitation was observed. Thus in this event a longitude wise shift has been observed in the model output.

Key Words: Global Model, Regional Model, Interpolation, Area Average, Topography.

Introduction

Weather forecast is getting an increasing importance because of the vital role of weather in all walks of life. In the fields of agriculture, transportation, defense and a number of other human activities the need of an early warning system is an inescapable necessity. Apart from the conventional methods of weather forecast, Numerical Weather Products (NWPs) have made this important task very simple and now their use is increasing day by day. A large number of Numerical Weather Products are being used all over the world and they are treated as helping tools for the weather forecasters because they help them to predict the behavior of atmosphere so that the forecast may be made with more confidence and precision. Due to chaotic nature of the atmosphere there always exist uncertainties in its behavior as predicted by a model. Therefore the predictability of every model needs to be verified and validated in its domain. In a case study of heavy rainfall over Karachi and surrounding areas during 27-29 July 2003, a non-hydrostatic numerical model "Mesoscale Model generation 5" (MM5) was used. The analyses of study show that model MM5 has overestimated rain than the observed and model has shifted the rain belt somewhat to southward (Rasul et al., 2009). HRM was used to diagnose the reasons for heavy rainfall during March 30 to April 2, 2007 over upper parts of Pakistan. HRM output was compared with NCEP reanalysis datasets

[1] gohar.met@gmail.com
[2] Pakistan Meteorological Department, Pitras Bukhari Road, Sector H-8/2, Islamabad, Pakistan.

and results of the study showed resemblance between NCEP and HRM output (Qudsia and Rasul, 2009). HRM was used to calculate the atmospheric water vapors over Antarctica. The results were found satisfactory when HRM simulated water vapors were compared with data derived from Global Positioning System (GPS) (Johnsen et al., 2004). To test the performance of HRM, another study was made for the calculation of water vapors over Europe. The results of the study had been found satisfactory when amount of water vapors measured by HRM was compared with water vapors calculated by remote sensors (Johnsen and Kidder, 2002). K. P. Johnson and B. Rockel (2000) validated HRM against ground based GPS data within the Baltic region. In this study the vertically integrated water vapor content (IWV) derived from both HRM and GPS show a high correlation coefficient. The mean values of IWV derived from HRM data were slightly greater than the GPS data.

Global warming and climate change have made the process of weather forecast much tedious and a challenging job in a changing climate pattern. High Resolution Regional Models are required to predict the weather events in a particular region. Pakistan Meteorological Department is responsible for providing meteorological services throughout Pakistan to the people who require weather information. Apart from other disciplines weather forecast on small and medium scale is one of the foremost discipline of the department. In order to facilitate the forecasters a hydrostatic High Resolution Regional Model (HRM) is being used by Pakistan Meteorological Department (PMD) for operational weather forecast up to 72 hours. In this era of global warming and climate change extreme precipitation events are being observed frequently. Accurate and advance prediction of such events may be very useful for human beings. As discussed in the preceding lines, different studies have been conducted to validate HRM output regarding different parameters but no study regarding the validation of HRM precipitation output has been found, especially in Pakistan. Therefore the current study is a first attempt of this kind to validate HRM output for the predictability of rainfall in different seasons in Pakistan.

HRM Model Configuration

High Resolution Regional Model (HRM) is developed by Deutscher Wetterdienst (DWD) Germany which is a flexible tool for Numerical Weather Prediction. The hydrostatic model HRM is designed to simulate or predict mesoscale and regional scale atmospheric circulation. HRM simulates 43 meteorological parameters such as precipitation, maximum and minimum temperature, wind, cloud cover, geopotential height, vorticity etc at different pressure levels. This model treats some variables like surface pressure, temperature, water vapors, cloud water, cloud ice and several surface/soil parameters as prognostic variables, and vertical velocity ω, geopotential height φ and cloud cover as diagnostic variables. To derive the initial state of HRM, interpolation of the analysis of DWD's Global Model for Europe (GME) to HRM grid is used whereas for the lateral boundary conditions of HRM forecast of GME is used. DWD prepares topographical datasets for any region of the world containing mesh size between 20 km and 5 km. The GME data contains 7 soil layers and 60 vertical model layers but for the current study 40 vertical model layers have been used. Adiabatic part of model HRM cannot generate some atmospheric processes (cloudiness, precipitation) therefore a set of physical parameterization modules in HRM is used to simulate such important parameters. The physical parameters used by HRM are radiation and cloud, Grid-scale precipitation, convection, Sub grid-scale orographic effects parameterization, soil model and sea ice model.

Data and Methodology

GME data is actually the analyses and forecast of Global Model for Europe (GME). DWD provides GME data to HRM users four times (d00, d06, d12, d18) daily at horizontal resolution of 20 Km from 1st Apr 2012. Earlier this data has been provided at horizontal resolution of 30 Km. Observed daily rainfall data from PMD observatories have been used in this study. GrADS (Grid Analysis and Display System) software is used to extract point data and view output images from HRM output. The current study focuses on verification of HRM precipitation output for Pakistan. For this purpose the selected rainfall events are simulated by model at 11 Km grid resolution. Point data from HRM output is extracted through

GrADS software. The point data is compared with actual precipitation data using Microsoft excel. Both the datasets for all the stations in the area getting heavy rain are also averaged for the whole area. Again the two averaged datasets are compared and a percentage difference between the two is calculated.

Result and Discussion

In order to validate the performance of HRM in forecasting heavy precipitation five events of moderate to heavy intensities have been discussed here in this study. The events under discussion are:

- Two events in the winter season (8th Feb 2010 and 13th Feb 2011.)
- One event in the pre-monsoon season (17th May 2010) and
- Two events of very high intensities in the monsoon season (27–30 Jul 2010 and 11–12 Aug 2011)

Winter Season

In the events from winter season, on 8th Feb 2010, in 11 stations out of 21 the model underestimates the precipitation while in the remaining 10 stations the model overestimates the actual precipitation. On the average the model predicts 6.4 % more precipitation than the actual precipitation measured. Similarly on 13th Feb 2011, the model underestimates the observed precipitation in 9 stations out of 18 while overestimates in the remaining 9 stations with an average of 16 % more than the actual precipitation measured. Figure 1a and 1b represent HRM output precipitation for 8th Feb 2010 and 13th Feb 2011 respectively. Figure 1c and 1b shows station wise comparison of model output and actual precipitation for aforementioned dates respectively.

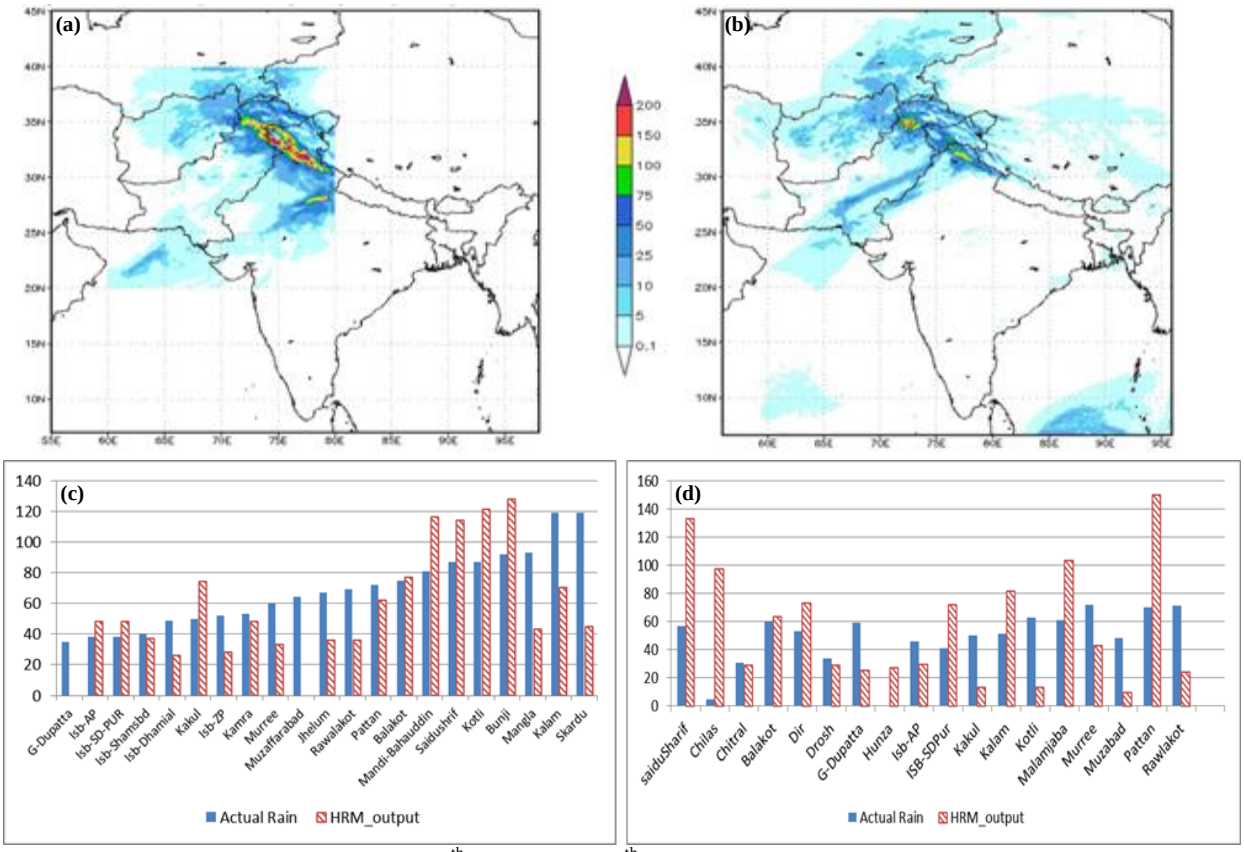


Figure 1: HRM output for **(a)** 8th Feb 2010 **(b)** 13th Feb 2011 and Station wise comparison of Model output and Actual Precipitation (in mm/day) **(c)** 8th Feb 2010 **(d)** 13th Feb 2011.

Pre Monsoon Season

On 17th May 2010, the model output for 10 stations is analyzed where in 7 stations the model underestimates and in the remaining 3 stations it overestimates the actual precipitation. On the average the model predicts about 18 % less than the actual precipitation measured. Figure 2a and 2b represent HRM output and station wise comparison of model output and actual precipitation respectively.

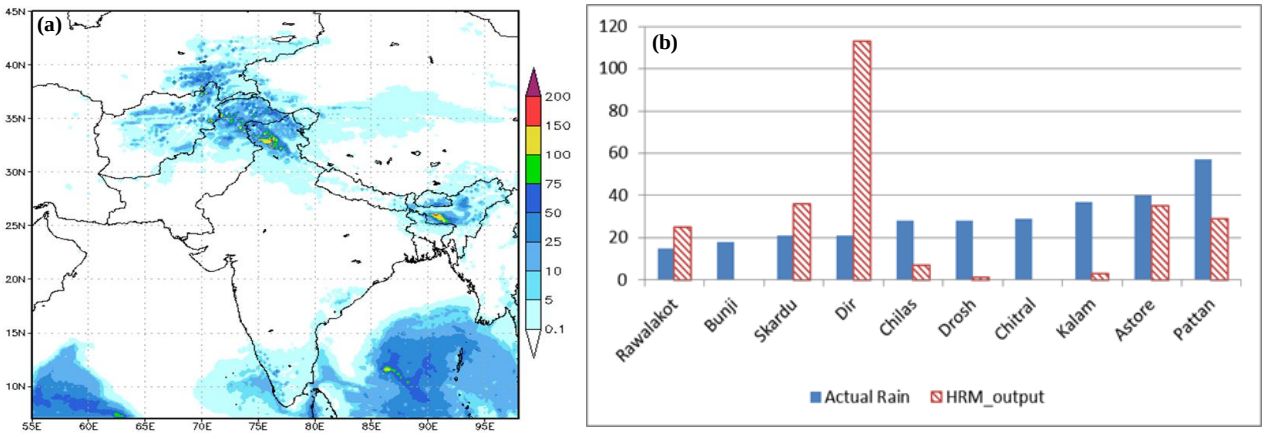
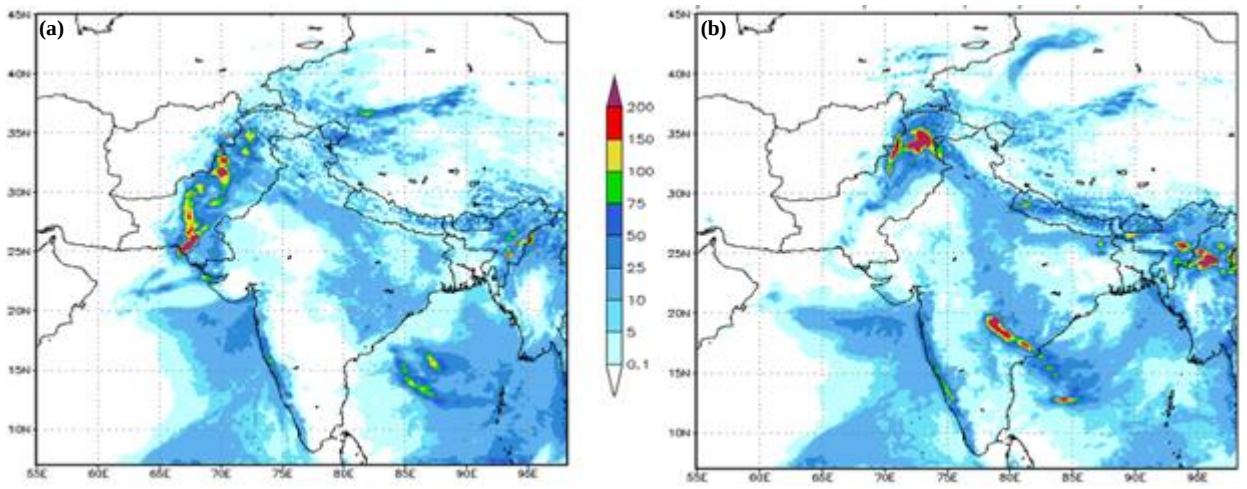


Figure 2: (a) HRM output **(b)** Station wise comparison of Model output and Actual Precipitation (in mm/day) 17th May 2010.

Monsoon Season (July 2010)

The rainfall event which occurred from 27–30 Jul 2010 is one of the major events in the history of Pakistan. Heavy downpour especially on 28th and 29th Jul caused cataclysmic floods originating from KPK and adjoining areas and devastated major parts of the country. On 28th Jul 2010 the model underestimated by 0.5 % while on 29th Jul it overestimated the actual precipitation by 14 %. Figure 3a and 3b represent model output precipitation while Figure 3c and 3d represent station wise comparison of model output and actual precipitation for 28th Jul and 29th Jul 2010 respectively.



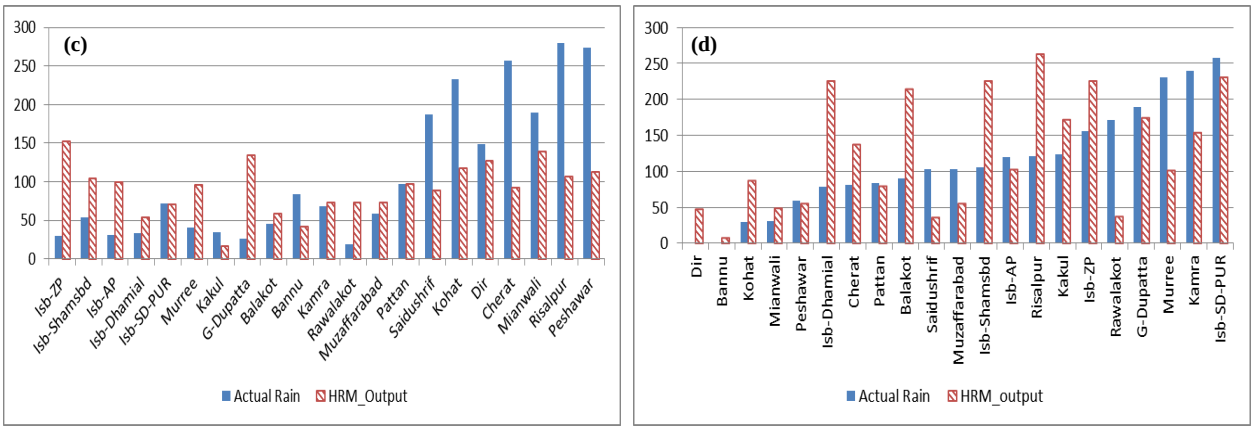


Figure 3: HRM output **(a)** 28th July 2010 **(b)** 29th July 2010 and station wise comparison of model output and actual precipitation (mm/day) **(c)** 28th July 2010 **(d)** 29th July 2010.

Monsoon Season (August 2011)

Then there comes the event of 11–12 Aug 2011. Another heavy downpour in the province of Sindh causing severe floods in most parts of the province. The chief amounts of precipitation recorded were 291 mm, 148 mm and 129 mm in Mitti, Badin and Chhor respectively on 11th Aug and 147 mm and 125 mm in Badin and Mirpur Khas respectively on 12th Aug 2011. Contrary to other events under discussion the model shows an anomalous behavior throughout this event. The model output almost completely underestimated the observed rain. Close observation of the model output images for 24 hr precipitation on 11th and 12th Aug 2011 at 00 UTC shows that the model predicts maximum precipitation at a place over India eastward from the region in Pakistan where maximum precipitation was observed. Thus in this event a longitude wise shift has been observed in the model output. Figure 4a and 4b show the model output on 11th and 12th Aug 2011.

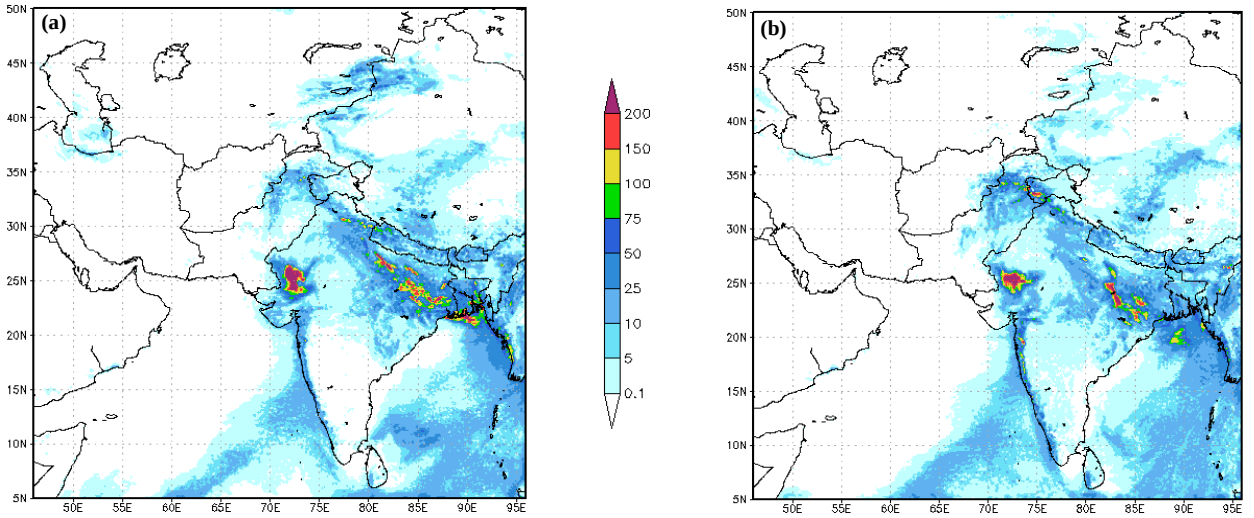


Figure 4: HRM output **(a)** 11th Aug 2011 **(b)** 12th Aug 2011

Figure 5 shows comparison between area averaged model output and actual precipitation and Figure 6 shows percentage deviation of model output from actual precipitation.

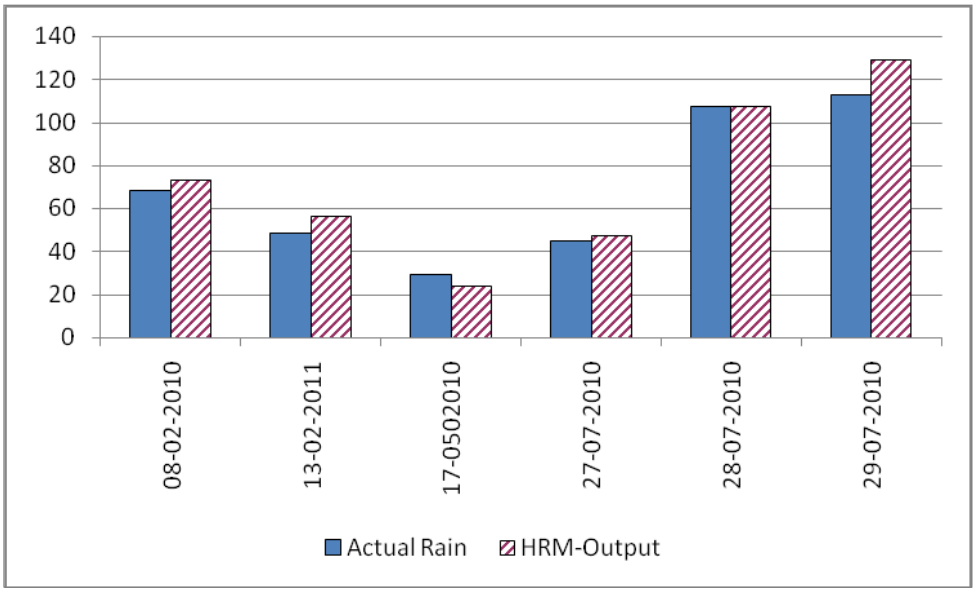


Figure 5: A comparison between area averaged model output and actual precipitation

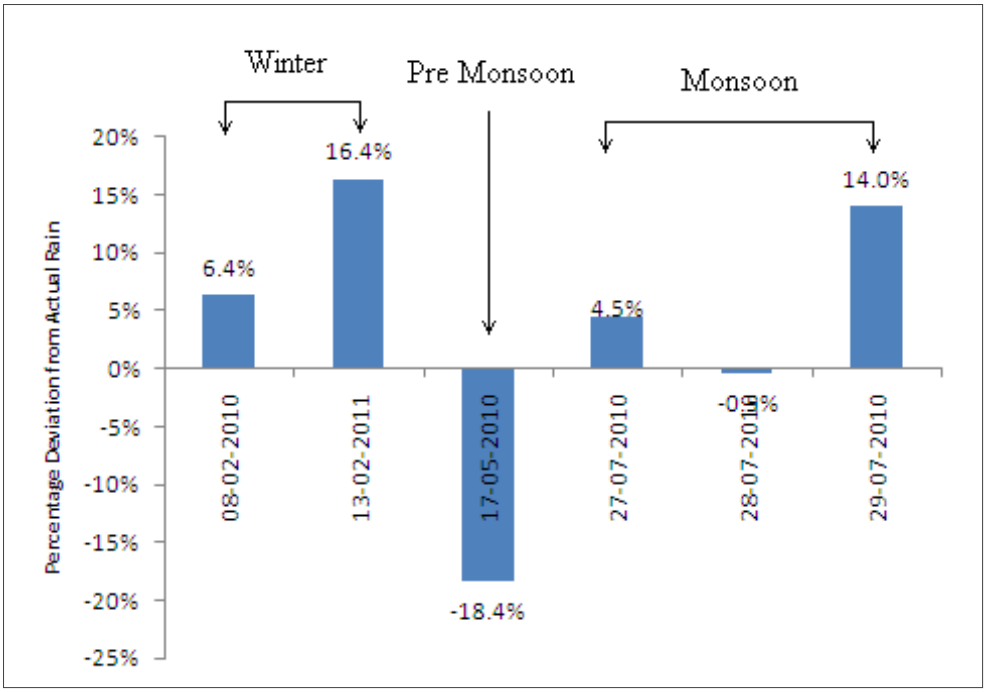


Figure 6: Percentage deviation of model output from actual precipitation.

Conclusion

In current study the hydrostatic regional weather forecast model HRM has been validated for precipitation forecast in Pakistan. Five rainfall events were simulated by HRM at horizontal resolution of 11 Km and analysis were made to test the performance of the model for the forecast of heavy rainfall events in the country. Observed precipitation data recorded at different meteorological stations of Pakistan Meteorological Department was used for comparison with HRM output. The model predicted

precipitation differs from actual precipitation with mostly overestimating trend. HRM overestimates the actual precipitation in winter and monsoon seasons with a slight underestimation on 28th July 2010 (about 0.5 %). The model has underestimated the actual precipitation in pre monsoon season i.e. 17th May 2010. The main findings of current study are:

- Analyzing 24 hourly precipitations it has been observed that on 2 days the model has underestimated the actual precipitation and on 4 days the model has overestimated the observed precipitation, excluding the event of 11–12 August 2011.
- The bias is random and is independent of the precipitation intensity and the season.
- The bias ranges from -18.4 % to +16.4 %.
- An anomalous behavior in the model output has been observed in heavy precipitation event of 11–12 August 2011. In this event the model has predicted precipitation very well spatially and temporally but there exists a latitude wise shift in the model output towards east.

On the basis of the above analysis it is concluded that HRM can be used for precise weather forecast apart from other methods in use.

References

Afzal, M., and Q. U. Zaman, 2010: Case Study: Heavy Rainfall Event over Lai Nullah Catchment Area. Pakistan Journal of Meteorology, 6(12), 39-48

Bei, N. F., S. X. Zhao, and S. T. Gao, 2002: Numerical Simulation of a Heavy rainfall event in China during July 1998. Meteorol. Atmos. Phys. 80,153-164.

Emardson, T., J. Johanson, G. Elgered, 2000: The systematic Behavior of water vapor estimates using four years of GPS observations, IEEE Transactions on Geosciences and Remote Sensing 38,324–329. HRM USER GUIDE, February 2010. pp. 5-20.

Johnsen, K. P., and B. Rockel, 2001: Validation of a Regional Weather Forecast Model with GPS Data. Phys. Chem Earth (B). 26, No 5-6, 415-419.

Johnsen, K. P., and S. Q. Kidder, 2002: Water vapor over Europe obtained from Remote Sensors and Compared with NWP model HRM. Physics and Chemistry of Earth, 27, 371-375.

Johnsen, K. P., J. Miao, and S. Q. Kidder, 2004: Comparison of atmospheric water vapors over Antarctica derived from CHAMPS/GPS and AMSU-B data. Physics and Chemistry of Earth, 29, 251-255.

Rasul, G., Q. Z. Chaudhry, and A. Mahmood, 2009: Numerical Simulation of Heavy Rainfall case in South Asia. Pakistan Journal of Meteorology, 6(11), 51-52.

Rasul, G., Q. Z. Chaudhary, S. X. Zhao, and Q. C. Zeng, 2004: A Diagnostic study of record heavy rain in twin cities Islamabad-Rawalpindi, Advances in Atmospheric Sciences, 21, 976-988.

Rocken, C., T. V. Hove, J. Johnson, F. Solheim, R. Ware, M. Bevis, S. Businger, and S. Chiswell, 1995: GPS/STORM - GPS sensing of atmospheric water vapor for meteorology, Journal of Atmospheric and Oceanic Technology, 12, 468-478.

Zafar, Q., and G. Rasul, 2009: Diagnosis and Numerical simulations of a Heavy Rainfall Event in winter over Upper part of the Country. Pakistan Journal of Meteorology, 5(10), 81-96.