Forecasting of Flash Floods over Wadi Watier – Sinai Peninsula Using the Weather Research and Forecasting (WRF) Model

Moustafa S. El-Sammany

***Abstract*—**Flash floods are considered natural disasters that can cause casualties and demolishing of infra structures. The problem is that flash floods, particularly in arid and semi arid zones, take place in very short time. So, it is important to forecast flash floods earlier to its events with a lead time up to 48 hours to give early warning alert to avoid or minimize disasters. The flash flood took place over Wadi Watier - Sinai Peninsula, in October 24th, 2008, has been simulated, investigated and analyzed using the state of the art regional weather model. The Weather Research and Forecast (WRF) model, which is a reliable short term forecasting tool for precipitation events, has been utilized over the study area. The model results have been calibrated with the real data, for the same date and time, of the rainfall measurements recorded at Sorah gauging station. The WRF model forecasted total rainfall of 11.6 mm while the real measured one was 10.8 mm. The calibration shows significant consistency between WRF model and real measurements results.

***Keywords*—**Early warning system, Flash floods forecasting, Wadi Watier, WRF model.

I. Introduction

FLASH flood events can cause severe damage and loss of life in arid and semi arid regions such as Sinai Peninsula. Moreover, flash floods represent constrains to area development in addition to their environmental negative impacts such as erosion and pollution.

On the other hand, floodwaters are important source for sustainable development in these regions. Flash floods forecasting is considered a difficult task, particularly in arid and semi arid zones, since they take place in very short time interval [1]. In our case, Sinai Peninsula is subjected to flash flood events especially during the fall and winter seasons. Hence, the forecasting of rainfall is very much necessary for providing early warning before the flash flood events to avoid or minimize disasters. Therefore, the main objective of this study is to adopt the Weather Research and Forecasting (WRF) model to forecast rainfall by 48 hours pre flash flood events. The WRF model will be applied onto Wadi Watier area. The output rainfall maps will be exported to the rainfall-runoff and hydrodynamic models to forecast the flash flood occurrence and impacts.

Flash floods take place because of high intensity storms, steep slopes of catchment, poor or sparse vegetation cover that result in high velocity flows and rapidly rising hydrographs, since the catchment has no capacity to resist and delay flows [2]. In arid regions such as Sinai in Egypt, rainfall is mainly generated by squall line and convective cloud mechanisms and by low intensity frontal rain, i.e. medium-to-small weather systems causing flash floods.

Meteorologically, convection refers primarily to atmospheric motions in the vertical direction. Convectional rainfall occurs when the energy of the sun heats the earth's surface, bubbles of hot air (called thermals) rise upward from the warm surface. A thermal cools as it rises and becomes diluted as it mixes with the surrounding air. An air parcel will rise naturally if the air within the parcel is warmer than the surrounding air. Therefore, if cool air is present aloft with warm air at lower levels, thermals can rise to great heights before losing their buoyancy.

Successive thermals following the same path usually rise higher than previous ones, and if a thermal is able to rise high enough to cool to its saturation point, the moisture within condenses and becomes visible as a cloud. When a deep stable layer exists just above the cloud base, continued vertical growth is restricted and only cumulus, which have 5-40 minutes lifetime, clouds are able to form. However, if a deep unstable layer (cold air aloft) is present, continued vertical growth is likely, leading to the development of a cumulonimbus (Cb) clouds.

Cumulonimbus clouds (Cb) are much larger and more vertically developed than cumulus clouds. They can exist as individual towers or form a line of towers called a squall line. Fueled by vigorous convective updrafts (sometimes in excess 50 knots), the tops of cumulonimbus clouds can easily reach 12,000 meters or higher. Lower levels of cumulonimbus clouds consist mostly of water droplets while at higher elevations, where temperatures are well below 0 degrees Celsius, ice crystals dominate. Under favorable atmospheric conditions, harmless cumulus clouds can quickly develop into large cumulonimbus clouds associated with powerful thunderstorms known as super cells [3], [4].

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II. Study Area

Wadi Watier is located in the south eastern part of Sinai Peninsula. It is considered one of the most active wadis in South Sinai. Its catchment area is about 3600 km^2. It is characterized by steep hills up to 1600 m above mean sea level. The hills mainly consist of impermeable rock, whereas the streams are filled with a highly permeable mixture of gravel and sand. The main wadi runs from the north to the south and terminates its discharges into the Gulf of Aqaba near the city of Nuweiba. An international road runs through the main wadi as shown in Fig. 1.

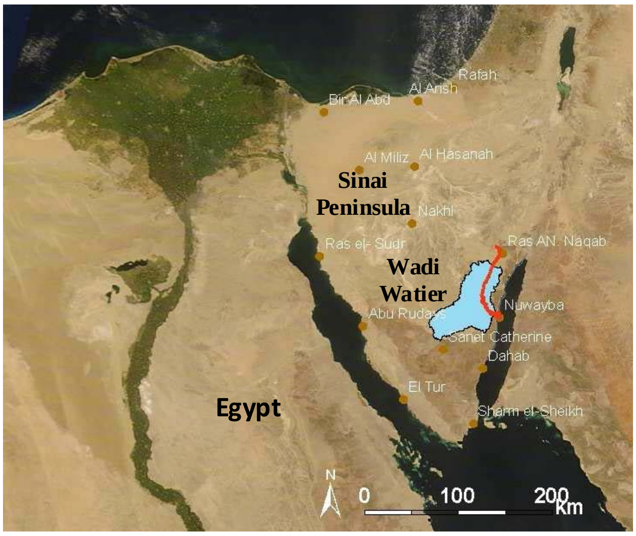

Fig. 1 Study area location (Wadi Watier)

The climate is hyper-arid where aridity index is < 0.05 [5]. The average annual rainfall ranges from 10 mm in the low coastal areas to 50 mm in high altitude areas. The wadi is attacked by severe storms, accompanied by flash floods; occur on the average every 2 to 3 years. Fig. 2 shows the severe impact of the flash flood event of October 24^{th}, 2008 on the international road.

Fig. 2 Sever flash flood impact on the international road

III. WRF Model

The Weather Research and Forecasting (WRF) model is the latest mesoscale Numerical Weather Prediction (NWP) model. WRF was developed by the National Center for Atmospheric Research (NCAR) and designed to serve both operational forecasting and atmospheric research needs. WRF is designed to be a flexible, state-of-the-art atmospheric simulation system that is portable and efficient on available parallel computing platforms. Different physics options are implemented for the atmospheric microphysics, cumulus parameterization, and planetary boundary layers. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers. Skamarock et al. [6] presented full description for WRF model. Fig. 3 illustrates the flow chart of the three different WRF-ARW components.

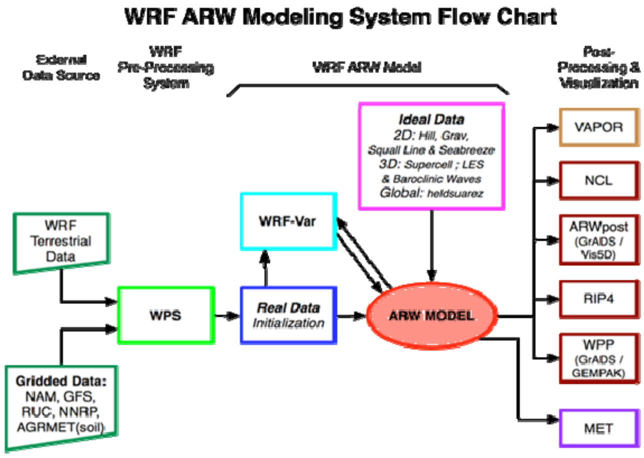

Fig. 3 WRF model components

IV. Rainfall Forecasting using WRF Model

WRF-ARW model was utilized to study some historical cases of flash flood events which took place in Egypt, particularly in Wadi Watier, during the last decade. The WRF model outputs had been calibrated with the available ground rainfall measurements. Hence, the WRF model became operationally and has been put under investigations.

The flash flood event that occurred in Wadi Watier - Sinai Peninsula in October 24^{th}, 2008 is simulated, investigated and analyzed using new resources available at Water Resources Research institute (WRRI). The WRF-ARW model was initialized at 00 UTC of October 24^{th}, 2008, and integrated until 00 UTC October 25^{th}, 2008, during which Sinai was hit by a flash flood event. The model nested grid size was downgraded from 30 km at regional scale to 9 km at the study area boundary then to 3 km and finally at 1 km resolution for the study area itself. The downgrade of the nested grid size was done step by step to keep the boundary conditions stable and smooth.

The WRF-ARW model's dynamic core, which uses the Ferrier, Thompson, and Schultz microphysics, was initialized by 1 hour time step for the 48 hours run case at 30 km, 9 km, 3 km and 1 km resolutions for the nested grid of the study area.

EL-Sammany [7] gives more information about using WRF model, data input, preparation, and simulation and output results, for the current case of study.

The WRF-ARW model improves prediction of mesoscale convective systems (MCSs) using explicit treatment of convection at 1 km grid, compared to prior forecasts of MCSs that employed a cumulus parameterization scheme at 10 km grid [8].

The WRF forecasts with explicit convection were found efficient enough to forecast the MCSs that actually occurred, the number of MCSs that would occur each day, and the organization of the precipitating systems and consequently improving the forecasting of a flash flood event with reasonable lead time. There is also evidence that the explicit version of WRF model can predict finer distinctions in the precipitation structure, such as super cell storms, and convective and stratified regions of squall lines, rather than other operational models.

V. Results and Analysis

The WRF-ARW model results indicated that the weather conditions associated with heavy rainfall over Egypt on October 24th, 2008, causes a flash flood event over Wadi Watier - Sinai Peninsula. Egypt was affected by the presence of low pressure (Sudan Monsoon Low) at the surface of the earth in October 24th, 2008, which led to increasing of the temperature of the air masses near the earth surface as shown in Fig. 4.

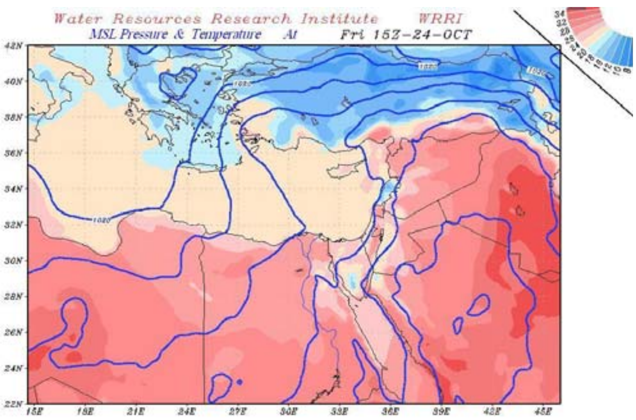

Fig. 4 Low pressure (Sudan Monsoon) at the earth surface over Egypt in October 24th, 2008

This warming leads to raise air (upward motion) to the upper atmosphere and associated with cold air in the upper atmosphere to form the convection clouds. The upper atmospheric charts for this day, from WRF model, indicates that the depression at the earth surface was coincided with the trough in the upper atmosphere which causing a mass of cold air brought from southern Europe and Mediterranean Sea in the upper atmosphere layers as shown in Fig. 5.

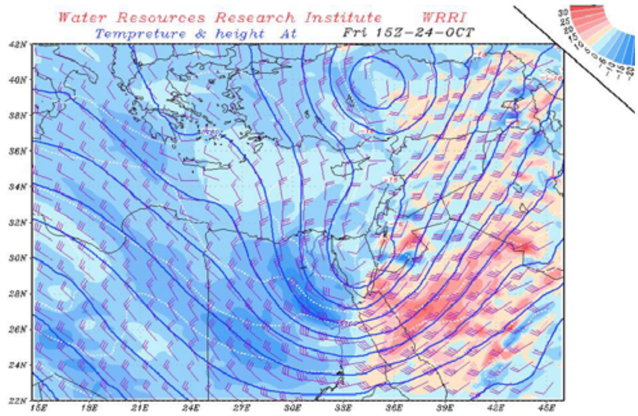

Fig. 5 The cyclone in the upper atmosphere over Egypt in October 24th, 2008

Also, the upper atmospheric charts showed that there was a south westerly subtropical severe jet stream as shown in Fig. 6. This jet stream lead to bring amount of clouds from the tropical region which caused an increasing of static instability hence increased convection clouds as shown in Fig. 7. This situation is accompanied by rainfall over northern Egypt and Sinai Peninsula as shown in Fig. 8.

The WRF model output file is a NetCDF file format. Nevertheless, ArcGIS software was utilized to display and reformat the output NetCDF files to Geotiff and/or text file formats to be suitable as input files for the rainfall-runoff and/or hydrodynamic models [9].

Moreover, ArcGIS was used to overlay the precipitation grid which is a raster data model (geotiff file format) over the catchment boundaries which is a vector data model (shape file format). Fig. 9 shows a GIS layer represent the accumulated total precipitation over Wadi Watier area in October 24th, 2008.

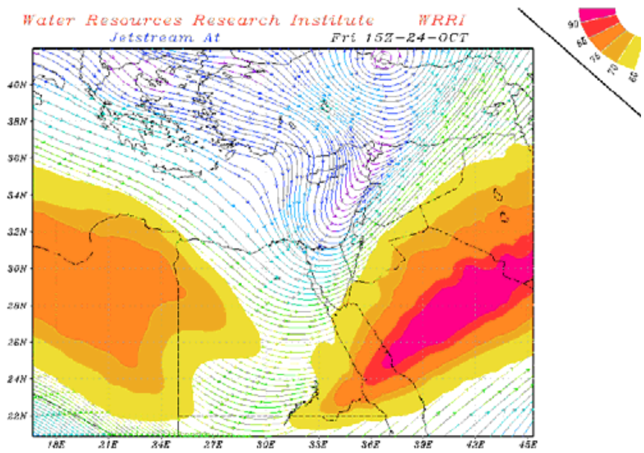

Fig. 6 The south westerly subtropical jet stream in October 24th, 2008

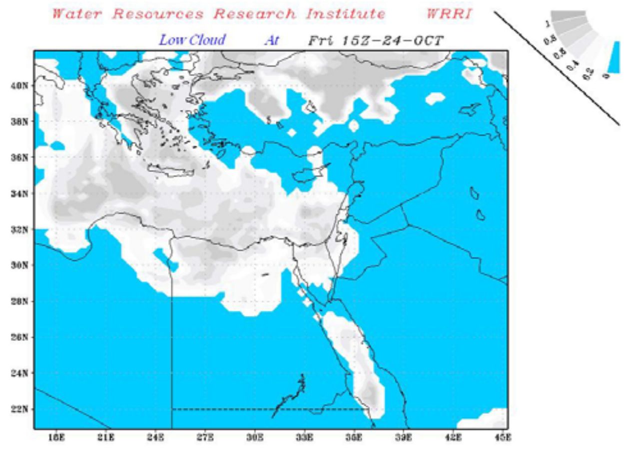

Fig. 7 The cloud pattern over Egypt in October 24th, 2008

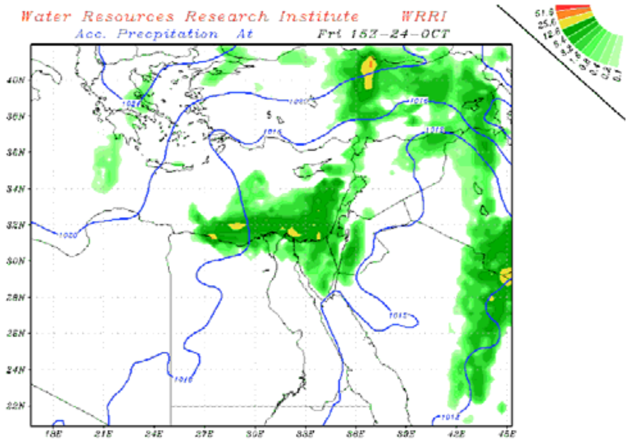

Fig. 8 Total precipitation over Egypt in October 24th, 2008

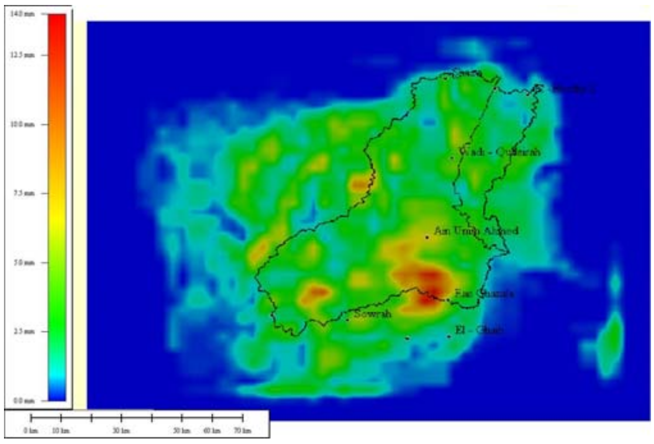

Fig. 9 A GIS layer represents the accumulated precipitation over Wadi Watier in October 24th, 2008

VI. WRF Model Calibration

The forecasted rainfall resulted from WRF model has been calibrated with the ground rainfall gauge measurements. Fig. 10 illustrates the measured and forecasted rainfall intensities at Sorah rain gauge station for the flash flood event of October 24th, 2008. The WRF model forecasted total rainfall of 11.6 mm while the total measured rainfall was 10.8 mm. The results show that the forecasted rainfall from WRF model is more or less identical with the measured one. Only slight difference has been noticed at beginning and the end of the forecasted rainfall due to the stability of the boundary conditions used in the WRF-ARW model.

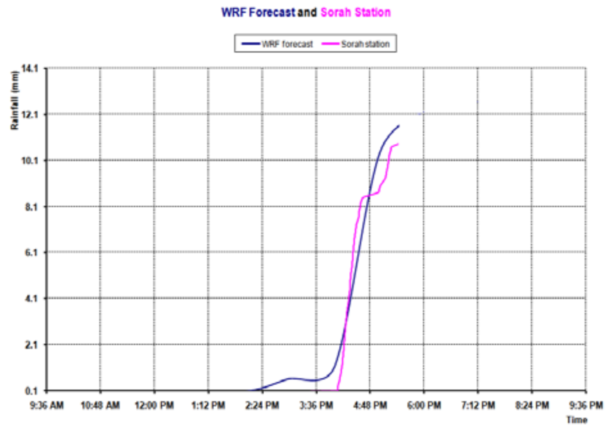

Fig. 10 WRF model results versus real rainfall measurements

VII. Conclusion And Recommendations

The results show that the WRF model is a reliable short term forecasting tool for flash flood events over Sinai Peninsula. The calibration shows significant consistency between WRF model results and real rainfall measurements. The prediction of small or mesoscale hazards such as tornadoes, severe thunderstorms, squall lines and flash floods requires the early detection of signatures, a near-instantaneous assessment of the threat and a rapid dissemination of alerts to the end users. The WRF model succeeded to simulate flash floods events; hence, it can be used as a component of an early warning system. Useful forecasts of the behavior of the larger scale weather systems such as tropical storms, cyclones, intense depressions and sever flash floods can be prepared several days in advance using WRF model. Nevertheless, more calibration is required to check the response of the WRF model in different flash flood events and consequently assure its validation. Moreover, a network of rain gauging stations, over the study area and Sinai Peninsula, should be designed and established as soon as possible. The more the measured real rainfall data, the more accuracy of the WRF model will be achieved.

Acknowledgment

This research was conducted as a part of FlaFloM project which was co-funded by the European Commission under the LIFE Third Countries Fund (project number LIFE/TCY/ET/000232) from January 2007 to December 2009. The author gratefully acknowledges this financial support and all the facilities offered by Water Resources Research Institute, Egypt, to conduct this research.

REFERENCES

[1] X. Lin, "Flash floods in arid and semi-arid zones," IHP-V Technical Documents in Hydrology, no. 23, 1999.
[2] K. Smith, and R. Ward, "Floods – physical processes and human impacts," John Wiley & Sons Ltd., Chichester, UK, 1998.
[3] R.A. Houze, "Cloud dynamics," Academic Press, 573pp, 1993.
[4] R.A. Houze, "Stratiform precipitation in regions of convection," Bull. Amer. Meteor. Soc. 78, 2179-95, 1997.
[5] UNEP, "World atlas of desertification," United Nations Environment Programme, 1992.
[6] W. Skamarock, J. Klemp, J. Dudhia, D. Gill, D. Barker, M. Duda, X. Huang, W. Wang, and J. Powers, "A description of the Advanced Research WRF version 3," NCAR Technical Note NCAR/TN–475+STR, NCAR, Boulder, Colorado, 2008.
[7] M. El-Sammany, "Tool to analyze remote sensing data for rainfall forecasting," FlaFloM (Flash Flood Manager), report no. 21, Water Resources Research Institute, Cairo, Egypt, 2009.
[8] J. Done, C. Davis, and M. Weisman, "The next generation of NWP: Explicit forecasts of convection using the Weather Research and Forecasting (WRF) model," Atmos. Sci. Letters., **5**, pp. 110-117, 2004.
[9] ESRI, "ArcGIS Version 9.3," http://www.esri.com