Use of Numerical Model for Weather Forecasting over Makkah Sectors

Abdellatif Esawy Awwad

drabdellatifesawy@gmail.com
Department of Environment and Health Research,
The Custodian of the Two Holy Mosques Institute of Hajj and Ummrah Researches,
Umm Al-Qura University

ملخص البحث

يعتبر التحدي الكبير لعلماء الارصاد في جميع أنحاء العالم وخصوصا في الآونة الأخيرة ليس فقط من اجل الحد من المخاطر ولكن لتحسين استخدام موارد المياه المتاحة من الأمطارهو العثور على الجواب الصحيح للأسئلة الرئيسية التالية. أين؟ متى؟ كم؟ وما هى شدة هطول الأمطار المتوقع هطولها؟ . الأجابات الدقيقة لهذه الأسئلة مهمة جدا من أجل المساهمة فى وضع سياسات صحيحة لمختلف القطاعات الخاصة والحكومية ذات العلاقة وتحسين إدارة المياه . من المعروف أن المملكة العربية السعودية ليس لديها وفرة فى الموارد المائية باستثناء المناطقالجبلية في الجنوب الغربى من البلاد بالاضافة المنطقة محدودة من المناطق الوسطى. في هذا البحث ، تم دراسة حالة الأمطار الغزيرة على قطاعات مكة المكرمة خلال الفترة من ١٩-٢٠ ديسمبر عام ٢٠١٢م باستخدام نموذج تنبؤ عددى (MM5) من النوع الغير الهيدروستاتيكي على نطاق يشمل المنطقة موضع الادراسة. وتمت مقارنة الامطار و كميات السحب الناتجة من النموذج مع الامطار المقاسة والسحب المشاهدة بواسطة الاقمار الصناعية وقد أثبت النموذج قدرته على التنبؤ بزمان ومكان حدوث الحالة بشكل مقبول ويتبقى عمل التطوير المطلوب على النموذج للوفاء ببقية التحديات و هى التنبؤ بكمية وكيفية سقوط الامطار وذلك لتعظيم الاستفادة من المنظومة كأحد الانظمة الفاعلة لدعم إتخاذ القرار .

Abstract

It is a great challenge for all scientists all over the world, especially at the recent times not only to minimize the risks and danger of the severe climatic and weather conditions but also to better use the rainfall budget. The major challenge is to find the right answer for the following key questions. Where? When? How much? and what the intensity of the rainfall will be? The right answers to these questions are very important in order to put the right policy for different private and governmental sectors and better managing the water since Saudi Arabia is a very poor water resources country, excluding mountainous area of the south west and a limited area of the central regions of the country. In this paper, the heavy precipitation over Makkah sectors during 19-20 December 2012 was modeled using non-hydrostatic numerical weather prediction Model (MM5). The simulated rainfall and the cloud cover were compared with the rain-gage observations and the satellite images, which revealed that; the model is able to reproduce the spatial pattern of the rainfall over the study area with slightly underestimation for the rainfall quantity. Further research is needed to achieve significant progress in the forecasting of rainfall amount and intensity to maximize the model benefits in the decision – making supporting system.

KEYWORDS

Makkah Floods; MM5; Heavy rainfall; Hazard weather; severe weather, rain fall prediction, Makkah

1. Introduction

Makkah city is situated in the western part of Saudi Arabia, eastern coast of the Red Sea and the capital of Makkah Province. It is located around 70 km away from Jeddah in a narrow valley at a height of 277 (m) above sea level. Its resident population in 2012 was 2 million, however, visitors multiple of this number every year during Hajj, held in the month of Dhu al-Hijjah and proposed to increase year by year. Makkah is the birthplace of the prophet Mohammad (peace be upon him), and the place of the revelation of the Holy Quran. Makkah is regarded as the holiest city in the religion of Islam because of the obligation of Hajj since Muslims are required to visit at least once in their life- time and perform a pilgrimage. In the modern times, Makkah has seen tremendous expansion in size and infrastructure. Today, more than 15 million Muslims visit Makkah annually, including several million during the few days of the Hajj. As a result, Makkah has become one of the most cosmopolitan and diverse cities in the Muslim world.

The kingdom of Saudi Arabia has 2410 kilometers of sea coasts, of which 1760 kilometers stretch along the Red Sea and 650 kilometers represent the eastern coast of the Arabian Gulf. Normally, the weather of the western part, between the month of October and March every year, is subject to an extension of the Indian Ocean monsoons, which in cooperation with the higher mountain slopes cause severe rainfall that trigger hazardous flash floods as in the event of 25 November 2009, which was short-intense rainfall event and one of the most frequent type dangerous natural hazard phenomena in the western KSA. During this event the Jeddah city experienced its worst disaster in fifty years and produced one of the most catastrophic flash floods in the recent history of Jeddah, 122 people were killed and 350 were reported missing and enormous losses in properties and infrastructure .Again on December 30 in 2010 4 people were killed and in January 2011, when the flash flood event took place and leaving at least 11 people killed (Haggag and El-Badry, 2012).

In order to predict such kind of severe atmospheric conditions a limited area numerical weather prediction model (MM5) has been installed in the Department of Environment and Health Research, the Custodian of the Two Holy Mosques Institute of Hajj and Ummrah Researches, Umm Al-Qura University to forecast the weather over the sub-regions of Makkah. In present study, a preliminary case study is presented to simulate the rainfall event occurred on 19-20 Dec. 2012 over Makkah and adjacent areas.

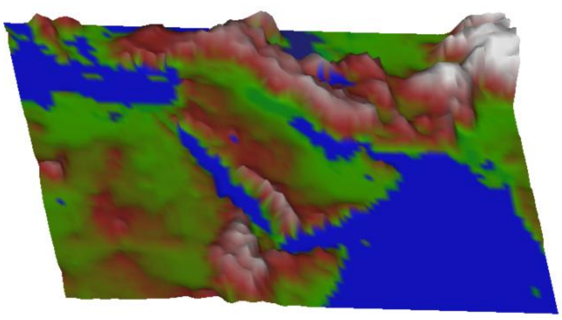

Fig. 1 Model domain topography

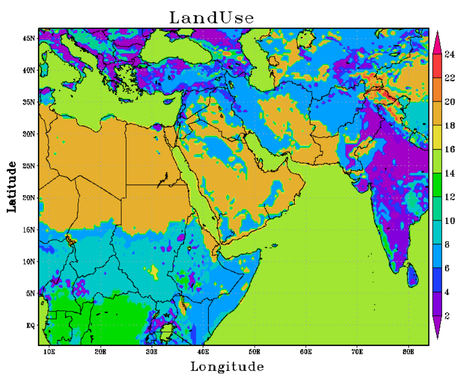

Fig.2 The landuse Field

The mesoscale model (MM5) was used to simulate the rainfall in a trial to answer the key questions concerning this parameter, Where? When? How much? and what the intensity of the rainfall will be? Sometimes the location of maximum rainfall is misplaced as compared to observations. Gao et al. (2002) analyzed the moist potential vorticity anomaly with heat and mass forcing in torrential rain systems by numerical simulation. Yang et al. (2008) simulated the asymmetric structure of the landfalling typhoon "Haitang". In order to better simulate heavy rainfall occurring on 19-20 December 2012over Makkah, the PSU-NCAR three-dimensional, non-hydrostatic mesoscale model (MM5 version3) is used for the present study. Preliminary analysis of the simulations revealed that the numerical model captured several qualitative details of the rainfall event. Section 2 describes briefly the model and its configuration. The model initialization is described in sec. 3, Data for validation and method in sec. 4, the synoptic description in sec. 5, the results in sec.6 and finally the conclusions are presented in the section 7.

2. Model Description and configuration

The 5th generation PSU/NCAR Mesoscale non-hydrostatic Model (MM5), described in detail by Dudhia (1993), has been adapted for real time mesoscale weather forecasting at Al-Qura University. The model configurations and parameterization schemes used in this study are as follows: the designed domain has a horizontal grid spacing of 45km and 140×190 grid points, centered at24 degree latitude and 46 degree longitude (fig.1) is used for initial testing. The model top is located at 100 hPa. The 23 vertical sigma levels are 1, 0.99, 0.98, 0.96, 0.93, 0.89, 0.85, 0.75, 0.7, 0.65, 0.6, 0.55, 0.5, 0.45, 0.4, 0.35, 0.3, 0.25, 0.2, 0.15, 0.1, 0.05, and 0.0. The model has been formulated using the terrain-following sigma-coordinate system, with enhanced vertical resolution in the lower troposphere to represent adequately the boundary layer processes and the Global Geological Survey (USGS) elevation data, USGS global 25-category land use data, global 17 category soil data are used to represent elevation, land use, soil, respectively. Also, the Real Time Global SST analysis data (RTG SST) available at horizontal resolution of 0.5° × 0.5° was used to represent the SST in the surrounding water bodies. The size of the outermost domain is chosen sufficiently large to minimize the influence of the lateral boundary conditions into the MM5 interior. MM5 includes parameterizations of dynamical and microphysical processes that are important for mesoscale systems. The model is adopted to predict and simulate mesoscale atmospheric circulation on regional scale (Dudhia et al., 2002), for cumulus parameterization in the model we use the Grell scheme (Grell et al., 1994), for boundary layer parameterization we use a non-local closure scheme. Explicit treatment of cloud water, rainwater, snow water and ice has been performed using the simple ice scheme of Dudhia (1996). Cloud radiation interaction is allowed between explicit cloud and clear air (IFRAD=2).For sub grid-scale convection, the cumulus parameterization scheme of Grell (Grell et. al.1991) is employed. Blackadar's high-resolution scheme (Blackadar 1979; Zhang and Anthes 1982) is adopted to calculate the turbulent fluxes in the PBL. The microphysics for explicit moisture processes is treated using the mixed-phase microphysics scheme of Reisner et al. (1998), in which five prognostic equations are solved for mixing ratios of water vapor, cloud water, rainwater, cloud ice, and snow. The physical options utilized in this simulation are stated in table 1.1

Table 1.1 Physics Options Used in the MM5

Explicit Moisture Schemes (IMPHYS)	Cumulus Schemes (ICUPA)	Planetary Boundary Layer (PBL) Scheme (IBLTYP)	Radiation Cooling of Atmosphere (FRAD)	Shallow Convection (ISHALLO)	Multi-Layer Soil Model (ISOIL)
Mixed Phase	Grell	MRF	Cloud	None	Yes

3. Model Initialization

During the 4 runs (120hrs forecast for each) for the period 16 - 19 December 2012 using the analysis of 0000UTC daily, The tendencies along the model coarse domain boundaries, specified by the differences of the fields between those times, were applied using a Newtonian relaxation approach (Grell, Dudhia and Stauffer, 1994). The simulation extended for 120hr, started at 0000 UTC, the model is initialized and forced at the boundaries by interpolation at 6-h intervals (00:00, 06:00, 12:00 and 18:00 UTC) using the archived Global longitude-latitude grid of the Global Forecast System (GFS) from NCEP at NCAR. The NCEP Final Analysis (FNL) data exist every 6 hours at a spatial resolution of 1° × 1° at 21 standard pressure levels under 100 hPa. The data includes two-dimensional variables including SST, sea level pressure and three-dimensional variables of temperature, geopotential height, U (define u and v) and V components and relative humidity. The 6-hourly global analyses are interpolated horizontally to model grid points. Then the standard upper air and surface observations are analyzed using a successive correction scheme on the base of first guess. No balancing between mass and wind fields is performed.

Finally, the analyses are interpolated to the model levels. No other observations used in this case. Thus, it will be a great challenge for the model to simulate the initiation and evolution of the convection band using only this amount of conventional observation data.

4. Data for Validation and Method

The data set for validation contains both the station data and the satellite images. The daily precipitation data are collected from several meteorological stations within Makkah. The high resolution satellite images (250m) acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS). MODIS is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. The satellite images collected from (http://lance-modis.eosdis.nasa.gov/cgi-bin/imagery/realtime.cgi) in order to visual compare the cloud cover forecasted by the model with the corresponding acquired by MODIS.

5. Synoptic Description

The favorable conditions leading to heavy rainfall (Fig. 3) over area are: (1) Low pressure in the north over the Mediterranean. (2) A stationary high pressure centered over the south- eastern the Arabian Peninsula, and (3) low pressure centered over Indian Ocean. So, two different convergence zones (Fig.4) have been created. The first one was created over Jeddah and the adjacent area by the effect of the anti-clockwise air flow from the Mediterranean low pressure in the north and the clockwise air flow from the high pressure over the center of the Arabian Peninsula. The second convergence zone was created over the Arabian Sea by the effect of the anti-clockwise air flow from the Indian low pressure in the south, and clockwise air flow from the high pressure over the center of the Arabian Peninsula. The first convergence zone is responsible for providing the cold air masses to the region while the second is responsible for supplying the region with the worm air mass with enough moisture and the third low pressure drive the huge moisture with enough power to cross the Red Sea mountainous tunnel to the area.

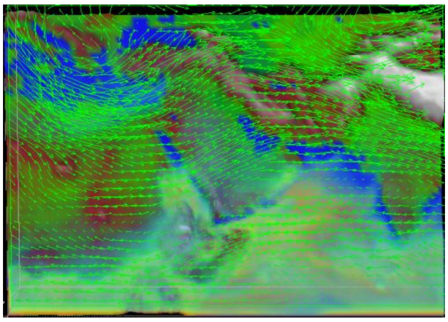

Fig. 3 the wind at 700hPa and the three dimensional Relative humidity at 21:00 UTC on 18 December 2012

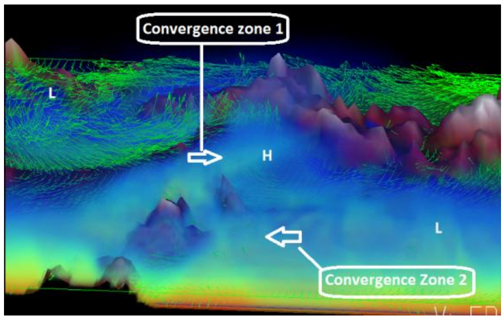

Fig. 4 Low-level convergence zones at 21:00 UTC on 18 December 2012

Now, the atmospheric theater has three players; two lows and one high pressure system combine together with the sloped mountains to provide favorable conditions for the heavy rainfall over the region.

The amount of moisture supplied from the Sothern low pressure and from the Red Sea in addition to the degree of mountains slopes is responsible for the quantity of rainfall, while the temperature gradient between the air mass supplied from the northern Mediterranean low pressure and the current air mass controls the intensity. The place of rainfall will be controlled by the net wind speed and direction. How much the Mediterranean low migrates from the west to the east and how much it vibrates from north to the south participating in the place of rainfall definition. A complete detail for the role of each component and the threshold condition to enhance and trigger the flooding will be studied in another study.

6. Results

In this study only the cloud cover and the rainfall among the several model outputs derived parameters are compared with their respective observed one.

6.1 Cloud pattern

MM5 model can simulate meteorological variables including temperature, wind velocity, humidity and rainfall both in time and space. As an example, Fig. 5, 6 show comparisons of satellite-observed and numerically simulated horizontal distributions of clouds. Four simulations have been performed based on the initial boundary data of 16-19 December 2012. By the visual comparison between the cloud cover produced by the model simulations shown in Figures 5.b, 5.c, 5.d, 5.e produced from the four simulations with the MODIS high resolution satellite images captured at 07:20 UTC for both 19 December 2012 as in fig. 5.a, and 20 December 2012 as in fig. 6. a. The comparison revealed that the model simulation of 18 December is much similar to the observed one for the two days.

Figures 5,6 show the MODIS high resolution satellite images at 07:20 UTC for both 19 and 20 December 2012. The MODIS imagery indicates that a cloud band covered the area of interest the eastern coast of the Red Sea

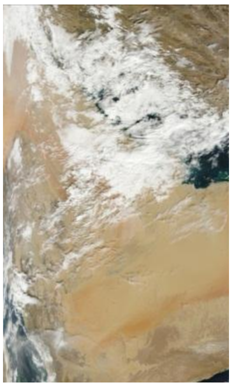

Fig.5.a Satellite image at 0720 UTC on 19 Dec 2012

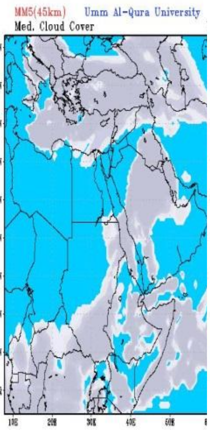

Fig. 5.b model cloud cover at 07:00 UTC (initial at 16 Dec:00)

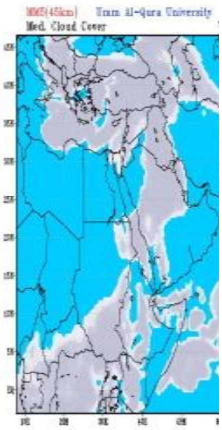

Fig. 5.c model cloud cover at 07:00UTC (initial at 17 Dec:00)

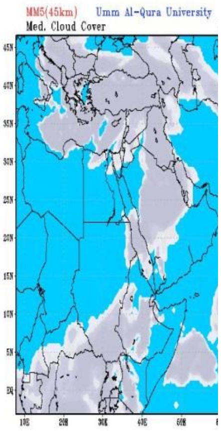

Fig. 5.d model cloud cover at 07:00 UTC (initial at 18 Dec:00)

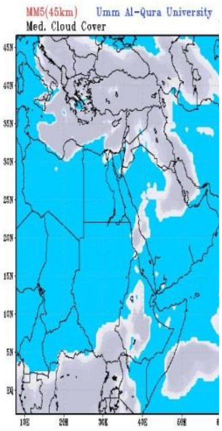

Fig. 5.e model cloud cover at 07:00 UTC (initial at 19 Dec:00)

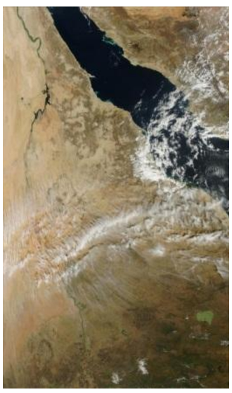

Fig.6.a Satellite image at 0720 UTC on 20 Dec 2012

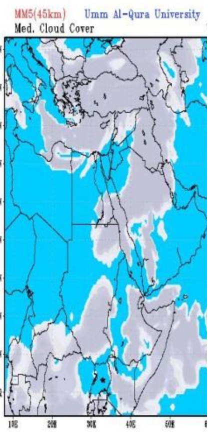

Fig. 6.b model cloud cover at 07:00 UTC (initial at 16 Dec:00)

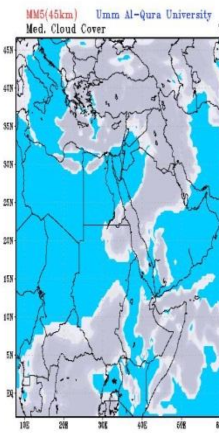

Fig. 6.c model cloud cover at 07:00UTC(initial at 17 Dec:00)

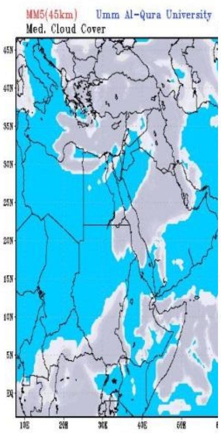

Fig. 6.d model cloud cover at 07:00 UTC(initial at 18 Dec:00)

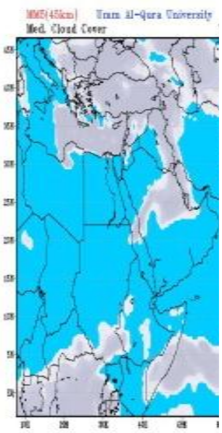

Fig. 6.e model cloud cover at 07:00 UTC (initial at 19 Dec:00)

6.2 Rainfall Distribution

Because of the significant spatial and temporal variation of rainfall, comparison of the rainfall amount simulated by a numerical model to that observed at one point in space is inherently limited. With the awareness of this limitation, a case of rainfall observed in-situ is compared to the simulated one. As shown in Figure 7, the observed total precipitation that occurred from 18to 22 December 2012 is presented and showed 20mm on the 19th of December at 1200UTC. The simulated precipitation pattern and quantity of the same time of the observed rainfall (Fig 8) seems in good agreement in terms of pattern. The simulated rainfall amounts are much lower than the observed value. The model can reproduce the location of the observed heavy rainfall.

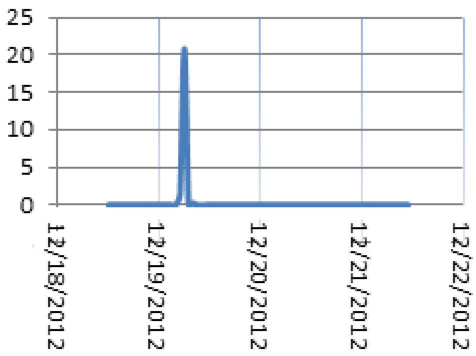

Fig. 7 observed rainfall (mm) over AlAzizyah (longitude 40.4 & Latitude 39.86)for the period 18-22Dec.2012

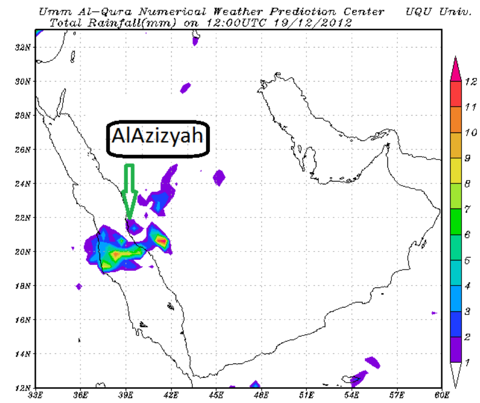

Fig. 8 the Simulated rainfall pattern and quantity in (mm) over the Kingdome of Saudi Arabia 19 Dec.2012 based on 18:00 UTC data

7. Conclusions

This paper presented a numerical study of December 19-20 in 2012 rainfall event over Makkah. Although it was not of the catastrophic one but it showed that nonhydrostatic meso-scale model (MM5) is able to capture the event. Also, the synoptic situation stated by the model was very promising in addition to the cloud cover fitness with the satellite images especially for the model based 24hr before the event. The model was able to capture the rainfall event; however the rainfall quantity was under estimated compared to the observed one. This may be attributed to the lower resolution of the model simulations or model's internal physical scheme including convective parameterization, the horizontal advection scheme and complex terrain features of the model domain. Finally, Based upon the above comparative analyses conducted at various temporal and spatial scales we draw following the conclusions. It is recommended to perform further research to modify present schemes to overcome the model's limitations and to improve its quantitative abilities. This could be achieved through:-

- Providing the necessary support to establish the "center of Umm Al-Qura International Weather Forecasts" in order to perform the necessary researches for the purpose of issuing weather forecasts in a timely and easy manner and with higher accuracy for most of the atmospheric elements;

- Supporting the monitoring network to measure meteorological variables that can be used for both training the models and validating the results;
- Supporting international cooperation and collaboration with research centers and academic organizations to enhance the our capacity and to reach the international level.

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