Diagnostic analysis and numerical simulation of Jeddah rain storm on November 25, 2009

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Abstract

On November 25, 2009, Jeddah, Makkah, Rabigh and other regions in Western Saudi Arabia, were hit by heavy rainstorms. The impact of the severe convective weather process caused more than 90 millimeters (3½ inches) of rain to fall in Jeddah in just four hours.

This study presents a diagnostic analysis of this heavy rainfall event, and the results of a numerical simulation using the Weather Research and Forecasting (WRF) model. The results show that: (1) An upper level cold trough in the Eastern Mediterranean moves from west to east, and a warm blocking high is situated on the southeast Saudi Arabia and Arabian Sea. In addition, an evident low level shear line set up in the northwest of Jeddah, and the southeast movement of the shear line caused dynamic lifting and unstable energy release over Jeddah. (2) The water vapor transport mainly happened below 700hPa, and low-level jet transports the water vapor from the Red Sea to Saudi central. Furthermore, the blocking high in southern Saudi Arabia is favorable for maintaining water vapor passage for a long time. (3) Thermo-dynamic factors, such as pseudo-equivalent potential temperature, wind shear, CAPE, and vertical velocity etc, are favorable for severe convection. (4) Jeddah lies in the coastal plain of the Red Sea, bordered by the Hijaz plateau on the east. Topography also has played a role in the enhancement of convection. (5) The simulated rainfall intensity and location are closed to TRMM data.

1 Introduction

On November 25, 2009 Jeddah, Makkah, Rabigh and other regions in western Saudi Arabia, were hit by heavy rainstorms. As the impact of the severe convective weather process, more than 90 millimeters (3½ inches) of rain fell in Jeddah in just four hours[1], [2]. This is nearly twice the average for an entire year[3]and the heaviest rainfall in Saudi Arabia in a decade[4].

This study presents the results of a numerical simulation using the Weather Research and Forecasting (WRF) model, and a diagnostic analysis of this heavy rainfall event. The results successfully reproduce the intensity and location of the rain storm. Further, the atmospheric circulation, meso-scale trigger mechanism, diagnoses of physical quantity (such as, unstable atmospheric thermal stratification, vertical wind shear, equivalent potential temperature, CAPE etc.) and the effect of topography has been analyzed.

The paper is structured as follows. Section 2 contains brief descriptions of the model setup. Section 3 presents diagnostic analysis of this heavy rainfall event and simulation results. Summary is given in section 4.

2 Model setup

The Weather Research and Forecasting (WRF) model version 3.2 is employed in this study. Its simulation domain is shown in Fig. 1. The WRF model was run on 2 domains for a 48 hour (00 UTC, 24 November 2009-00 UTC, 26 November 2009). The outermost grid has 331 x 280 points with 15km horizontal resolution. The second grid consists of 708 x 528 points with 5 km resolution. Vertical atmospheric structure is described by 41 model levels from the surface up to about 50mb km.

The initial and boundary conditions were provided by National Center for Atmospheric Research Global Forecast System (NCAR-GFS). Model simulations start at 00 UTC, 24 November 2009. Numerical integration: 3rd order Runge-Kutta.

The model physics options used in the WRF simulation include: WRF single moment

5-class (WSM5) scheme for microphysics; rapid radiative transfer model (RRTM) for long-wave radiation; MM5 (Dudhia) scheme for short-wave radiation; MM5 similarity theory for surface layer; Kain-Fritsch scheme for cumulus parameterization; and YSU planetary boundary layer; Noah-Land surface model for soil model.

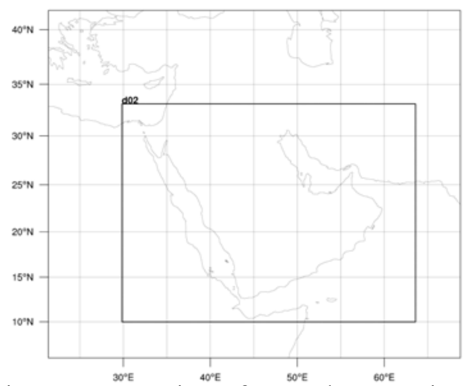

Figure 1 Domains of nested WRF simulation

3 Results and analysis

3.1 Synoptic situation

The rain storm have occurred in late fall and early winter, and in this season the climate of Saudi Arabia is generally controlled by the interaction of Siberian high pressure, the Mediterranean lows and the Sudan trough. The Mediterranean cyclones, which migrate from west to east in association with upper troughs active phases of subtropical and polar jets, are considered the main rain-producing synoptic systems [5]. Fig. 2 shows that two troughs and one ridge dominate West Asia and Northeast Africa. An upper level cold trough in the eastern Mediterranean moves from west to east, and a warm anticyclone (quasi stationary) is situated on the southeast Saudi Arabia and Arabian Sea. Additional, an evident mesoscale convergence line set up in the northwest of Jeddah (Fig. 3), and the southeast movement of the shear line caused dynamic lifting and unstable energy release over Jeddah. It shows that synoptic situation supports severe convective weather formation.

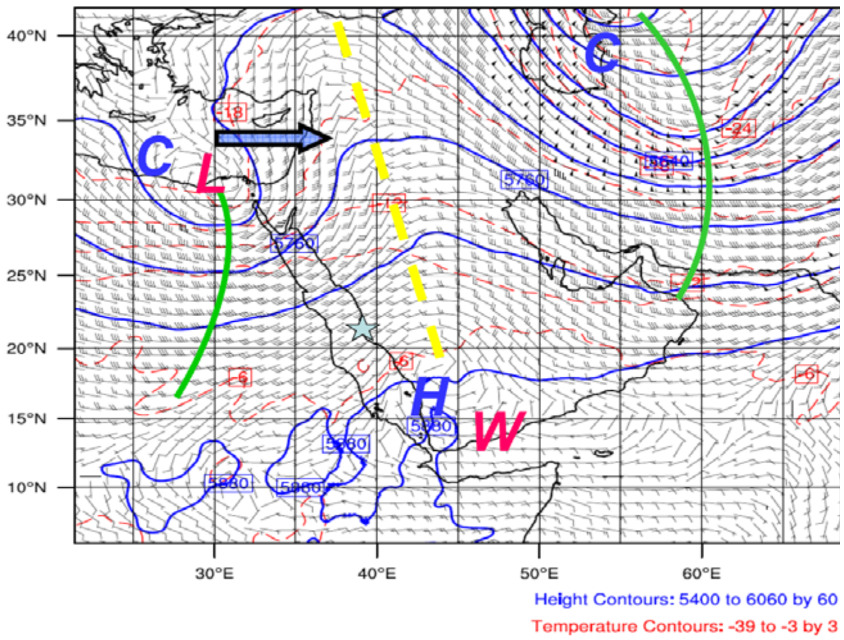

Figure 2 500hpa geopotential height (blue, solid), temperature (red, dashed) and wind (in knots) for 06UTC 11/24/2009. Location of Jeddah is indicated by star.

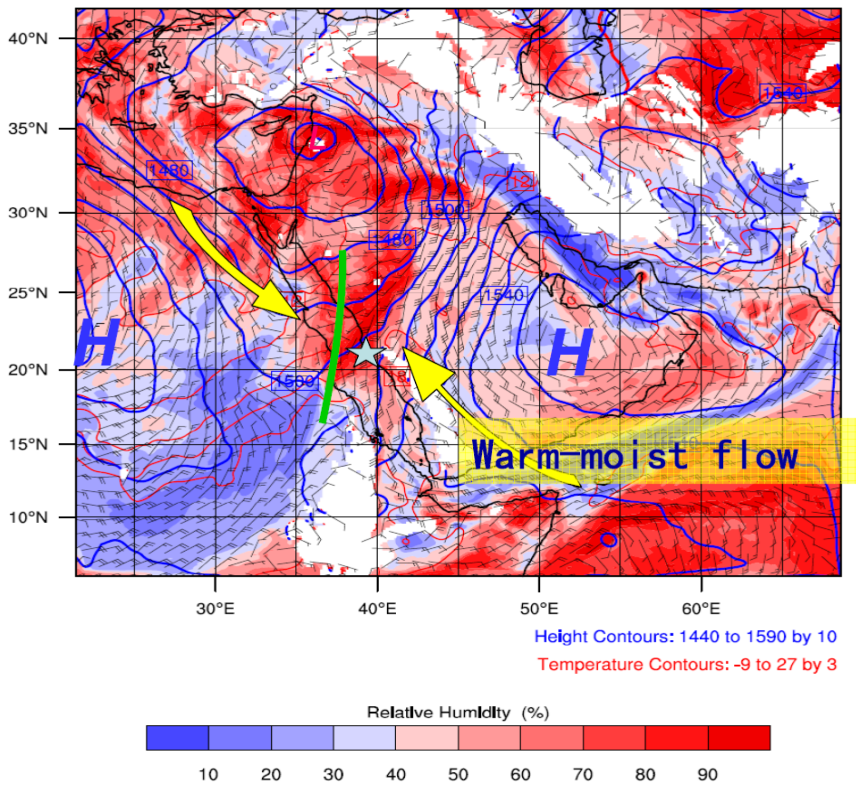

Figure 3 850hpa geopotential height (blue, solid), temperature (red, dashed), wind (in knots) and relative humidity for 03UTC 11/25/2009. Shear line is indicated by blue line.

3.2 Water vapor conditions

Water vapor transport is very important for the duration of rain. In this case, the water vapor transport mainly happened below 700hPa. A low-level jet is located over Sudan central - Red Sea- Saudi central, and the southern flow transports the water vapor from the Red Sea to Saudi central. Additionally, an anti-cyclone in southern Saudi Arabia and a ridge of high pressure formed a blocking situation, maintaining water vapor passage for a long time.

3.3 Thermo condition

3.3.1 Convective instability

The difference of pseudo-equivalent potential temperature (Θse) between 850hpa and 500hpa represent convective instability of atmosphere. In Jeddah, $(\Theta se)_{500hpa}-(\Theta se)_{850hpa} < 0$, which indicate that Θse decrease with the increasing altitude, and the atmosphere was instable.

3.3.2 CAPE

Convective Available Potential Energy (CAPE) is a measure of the amount of energy available for convection, and directly related to the maximum potential vertical speed within an updraft. In this case, before 00UTC 25 Nov CAPE was weak in Jeddah. 08UTC 25 Nov, it began to increase and the maximum exceeds 1422 j/kg at 09UTC. With the rain occurrence, the energy released. This indicates that CAPE quickly accumulated in a short time prior to the rain occurrence and released after 10UTC.

3.3.3 Temperature advection

Wind profile in Jeddah shows that wind shear turned clockwise below 700hpa with warm advection, and the stratification of dry at high level and wet at low level formed. In addition, the water vapor is increased between 700hpa and surface layer, the wet-warm weather is suitable for instable energy accumulated.

3.4 Terrain effect

The Arabian peninsula is bordered by the Red Sea to the west, the Arabian Sea to the south and the Persian Gulf to the east. To the west, The Mountain belt of Scarp-Hijaz-Asir, form a barrier from the sea, and extends the full length of the Arabian Peninsula, parallel to the Red Sea, from the Gulf of Aqaba in the north to Bab Almandab in the south. In the southwest, there are mountains reaching 3,000 m in height [6]. Further west, the Tihama is the coastal plain of the Red Sea, and Jeddah lies in Tihama, approximately at 21.5N, 39.2E.

Topography also seems to have played a role in the enhancement of convection. The lower-level southerly flow across the Red Sea was ascending with the terrain lifting effect. The moving upper-trough that approached the region from the west supplied the conditions that transformed this moisture and instability into heavy showers and the resulting floods.

3.5 Numerical simulation of precipitation and TRMM satellite rainfall

Fig. 4 and Fig. 5 show the simulated and TRMM 3-hour accumulated rainfall respectively. The simulated rainfall intensity and location are closed to TRMM data.

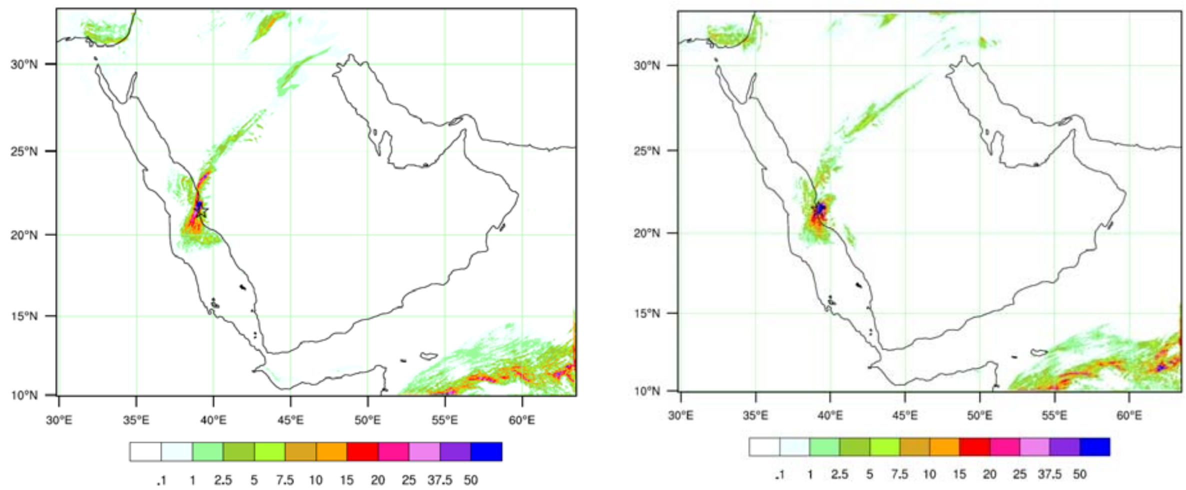

Figure 4 Simulated 3-hourly accumulated rainfall ,

06UTC 25 Nov - 09UTC 25 Nov (left), 09UTC 25 Nov - 12UTC 25 Nov (right).

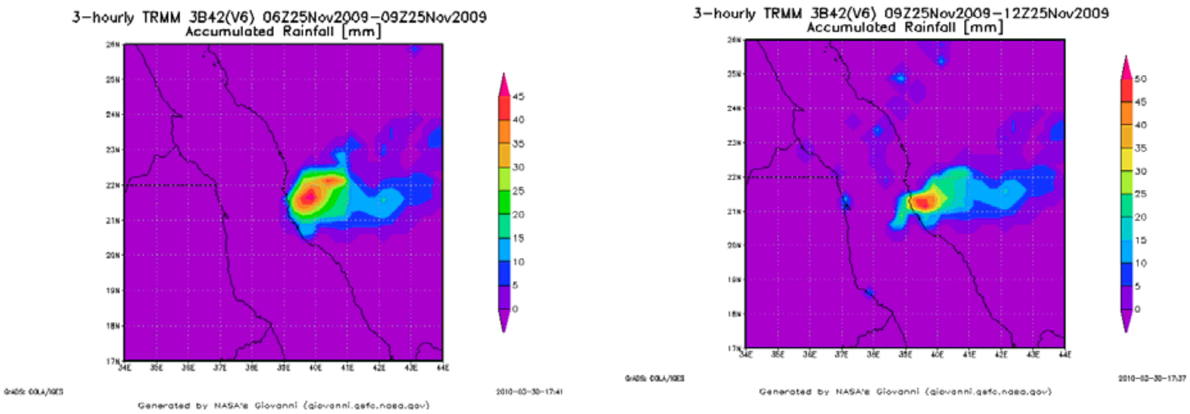

Figure 5 TRMM 3-hourly accumulated rainfall ,

06UTC 25 Nov - 09UTC 25 Nov (left), 09UTC 25 Nov - 12UTC 25 Nov (right).

4 Summary

This study presents the results of a numerical simulation using the Weather Research and Forecasting (WRF) model, and a diagnostic analysis of this heavy rainfall event. The results show that:

(1)An upper level cold trough in the Eastern Mediterranean moves from west to east, and a warm anticyclone (quasi stationary) is situated on the southeast Saudi Arabia and Arabian Sea. In addition, an evident low level shear line set up in the northwest of Jeddah, and the southeast movement of the shear line caused dynamic lifting and unstable energy release over Jeddah. It shows that synoptic situation supports severe convective weather formation.

(2) Water vapor transport is very important for the duration of rain. In this case, the water vapor transport mainly happened below 700hPa, and low-level jet transports the water vapor from the Red Sea to Saudi central. Furthermore, the blocking high in southern Saudi Arabia is favorable for maintaining water vapor passage for a long time.

(3) Thermo-dynamic factors, such as pseudo-equivalent potential temperature, wind shear, CAPE, and vertical velocity etc, are favorable for severe convection.

(4) Jeddah lies in the coastal plain of the Red Sea, bordered by the Hijaz plateau on the east. The lower-level southerly flow across the Red Sea was rising with the terrain lifting effect.

Topography also has played a role in the enhancement of convection.

(5) The simulated rainfall intensity and location are closed to TRMM data.

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