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THE INFLUENCE OF TOPOGRAPHY CHARACTERISTICS ON THE NUMERICAL WEATHER FORECAST WITH THE WRF MODEL IN CASES OF SEVERE WEATHER*

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Abstract. The aim of this study is investigating the influence of topography data over Romanian territory on the numerical weather forecast of the WRF (Weather Research and Forecasting) model in cases of severe weather events. The WRF model was run for two different weather events: 17 July 2011 and 3 February 2012. In both cases, heavy precipitation and strong wind were registered on Romanian territory. Topography data were used at three horizontal resolutions: 2 minutes, 30 seconds and 3 seconds. The use of the topography data at these resolutions resulted in differences between the numerical weather forecasts of the WRF model.

Key words: numerical weather prediction, topography data, convective case, frontal case.

1. INTRODUCTION

In the past few years, the constant increase in the number of severe meteorological phenomena in most countries has led to intense efforts in improving numerical weather forecasts at high resolutions. Research issues related to the development of a numerical model for the short to very short range forecast include: the increase of the horizontal resolution of the models, development of data assimilation systems, improvement of physical parameterizations included in the models [1], and the use of very accurate topography data at high initial resolutions.

The work of Jimenez [2] showed that surface wind speed and direction are controlled by terrain characteristics. One of the main concerns in numerical modeling is the use of appropriate topography data which offer a good approximation of the topography height, especially for domains with complex terrain features [3]. On account of this, in using the WRF (Weather Research and

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Forecasting) numerical model [4] the use of high resolution topographic data (as close as possible to the resolution of the model) is advised.

Romanian territory has a very complex topography. In order to obtain a better representation of terrain complexity, apart from the default topographic data (2 minutes and 30 seconds horizontal resolution, provided by USGS – United States Geological Survey), topography data at 3 seconds horizontal resolution were ingested in the WRF model [5]. The 3 seconds horizontal resolution data were obtained from the NASA SRTM (Shuttle Radar Topographic Mission, http://srtm.csi.cgiar.org/) database, which provides digital elevation data for over 80% of the globe. In this paper, the data were used for the area between 20–35 degrees longitude and 40–50 degrees latitude.

The aim of this study is to investigate the influence of topography data over Romanian territory on the WRF model forecast in cases of severe weather. Brief descriptions of the numerical experiments and model configuration and setup are given in Section 2. The results of the study and their implications are discussed in Section 3. The paper ends with a few conclusions regarding the use of topography data at different horizontal resolutions on the numerical forecast with the WRF model in the selected cases.

2. NUMERICAL EXPERIMENTS

The WRF model is a numerical weather prediction and atmospheric simulation system developed for research and operational applications across scales ranging from meters to thousands of kilometers [4]. The model is based on compressible, non-hydrostatic hydro-thermodynamical equations cast in flux form using variables that have conservation properties.

The model uses a time-split integration scheme. Low-frequency modes are integrated using a third-order Runge-Kutta time integration scheme. High-frequency acoustic modes are integrated over smaller time steps. Three formulations for turbulent mixing and filtering are available for spatial dissipation: diffusion along coordinate surfaces, diffusion in physical space and a sixth-order diffusion applied on horizontal coordinate surfaces [4].

The model was run using the WRF Single-Moment 5-class microphysics scheme following Hong [6]. Also the RRTM (Rapid Radiative Transfer Model) scheme for longwave radiation [7] and the Dudhia [8] shortwave radiation scheme were used. For the purpose of this study the 5-layer thermal diffusion land surface scheme [9] and the YSU (Yonsei University) scheme for planetary boundary layer were used [10].

The WRF model (version 3.4.1) using the ARW (Advanced Research WRF solver) as the dynamical core was integrated for two test cases (17 July 2011 and 3 February 2013) when strong wind and heavy precipitation were observed. For each situation, three numerical experiments were done, each of them with different topography data: 2 minutes (WRF2minutes), 30 seconds (WRF30seconds) and 3 seconds (WRF3seconds) horizontal resolution. The model was integrated at 3km horizontal resolution, 35 terrain-following vertical levels, without nest. The integration domain covered the area between 42.7–49 degrees latitude north and 20–30.9 degrees longitude east, with 261×191 grid points. In order to use the 3 seconds SRTM data, a Fortran procedure was developed to ingest these data into the WRF model. Terrain height values range between 0–2080 meters for 2 minutes resolution data, 0–2198.77 meters for 30 seconds resolution data and 0–2238.03 meters for 3 seconds resolution data. Terrain height measurements values for Romanian territory are between 0–2544 meters. It can be observed that the 3 seconds topography data-set is closer to real data.

The initial and lateral boundary conditions for all experiments were obtained from the output of the COSMO (Consortium for Small-Scale Modeling) model run at 7 km horizontal resolution. For this purpose, the COSMO output was transformed from rotated grid to regular lat-lon grid and interpolated into the grid of the WRF model. The update frequency of the initial and lateral boundary conditions was 3 hours. The COSMO integration domain covers the area between 38.5–51.5 degrees latitude north and 16–36 degrees longitude east, with 201×177 grid points. If lateral and boundary conditions from the COSMO model are used, the WRF model can be run at higher resolutions without intermediate nesting, thus reducing the integration time for the model. The quality of WRF coupled with the COSMO model was assessed previously in the work done by Iriza *et al*. [11].

3. RESULTS

The first case was selected because the models currently run in the National Meteorological Administration at coarser resolutions were not able to predict this weather event (the strong wind in the afternoon of 17 July 2011). The COSMO model run at 2.8 km horizontal resolution was the only one which captured this event. The second case (3 February 2012) was selected because it is a classic blizzard (severe snowstorm) situation for the Romanian territory. For both cases, we analyzed precipitation amounts between 6 and 30 hours lead time excluding the first 6 hours of the forecast (spin-up period) and wind speed values between 6 and 24 hours lead time (when wind intensification was observed).

The first case study was performed for the 17th of July 2011, when a cyclonic nucleus of Icelandic origin, developed on the entire troposphere column, moved towards the Center and South of the continent. In the South-Eastern area of Europe, a South-Western and then Southern atmospheric circulation was developed. This type of circulation favourized the inflow of a tropical air mass. At the same time, a short wave through determined cold altitude air-mass pulsations West of Romania.

This mesoscale configuration caused an intense atmospheric instability in the South area of Romania.

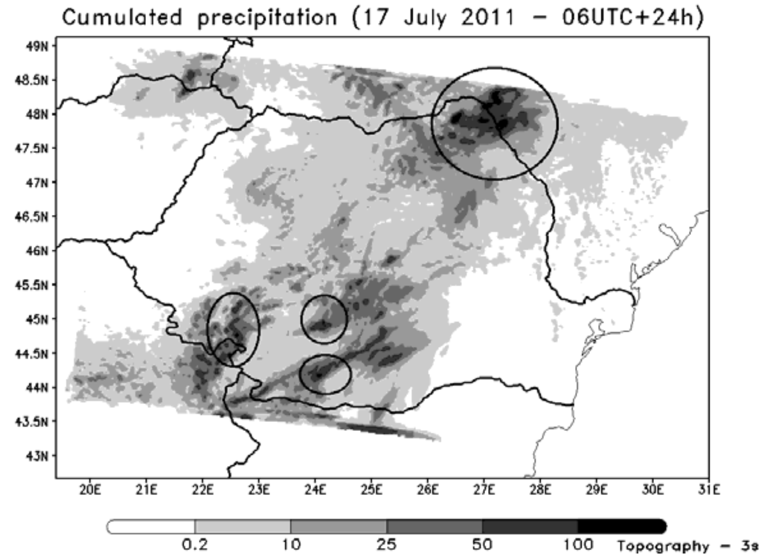

Fig. 1 – WRF3seconds cumulated precipitation 17 July 2011– 00UTC run.

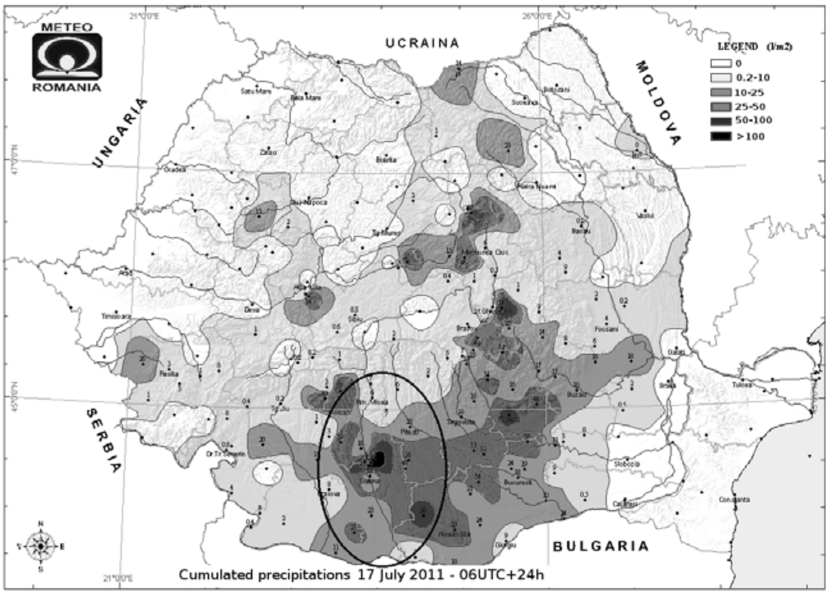

Fig. 2 – Cumulated observed precipitation 17 July 2011 06UTC – 18 July 2011 06UTC. (Source: National Meteorological Administration).

In all three numerical experiments performed for this situation, the model offered an overall good forecast of the precipitation area (Fig. 1) compared to observations (Fig. 2), but restricted towards East, especially in the case of the WRF2minutes experiment.

In experiments WRF30seconds and WRF3seconds, a slightly better placement of the precipitation area can be noticed. The maximum precipitation quantities in the South of Romania (up to 127 l/m^2 at one meteorological station), were only captured by the WRF3seconds experiment (Fig. 1).

In the North-East of Romania, the general tendency of the model in all the numerical experiments is to forecast high values of this parameter, in contrast to the observations (no precipitation were observed in this area, as shown in Fig. 2). The most severe overestimation of the precipitation quantities for this region is given by the WRF30seconds experiment.

In order to better asses the results of the three numerical experiments, mean error was computed over different areas. The scores were based on forecast – observation differences (each observation was compared with the forecast obtained using the nearest grid point method). The areas for which the mean error was computed were between 21.5–28 degrees longitude east, 43.5–46 degrees latitude north (area 1) and 25–28 degrees longitude east, 44.5–48 degrees latitude north (area 2). Analysis of the 24 hours mean error over these areas (Southern and North-Eastern parts of the domain) shows that the model underestimates the observed precipitation in area 1 (best results for WRF3seconds). For area 2 the first two configurations of the model underestimate the observed precipitation, while WRF3seconds slightly overestimates them (Fig. 3, left).

In the afternoon and evening of the same day strong wind was observed in the South part of Romania (up to 16 m/s at meteorological stations in Bucharest). The WRF2minutes did not forecast this phenomenon. In the two other numerical experiments, the WRF model generally captured the strong wind but also the spatial and temporal evolution of the mesoscale systems which were active in the South of Romania and led to strong wind. For both numerical experiments, the model predicted the 10 m wind speed better than in the WRF2minutes experiment and offered a good spatial placement of the phenomenon, with a slight delay towards East. The WRF30seconds model offered a better spatial approximation of the wind parameter. Although hourly wind speed mean error over the affected area (between 24.5–28 degrees longitude north 44–45 degrees latitude north) showed a slight overestimation during the first part of the day, once with the wind intensification we can see that the model slightly underestimates the observed wind gusts (Fig. 3, right).

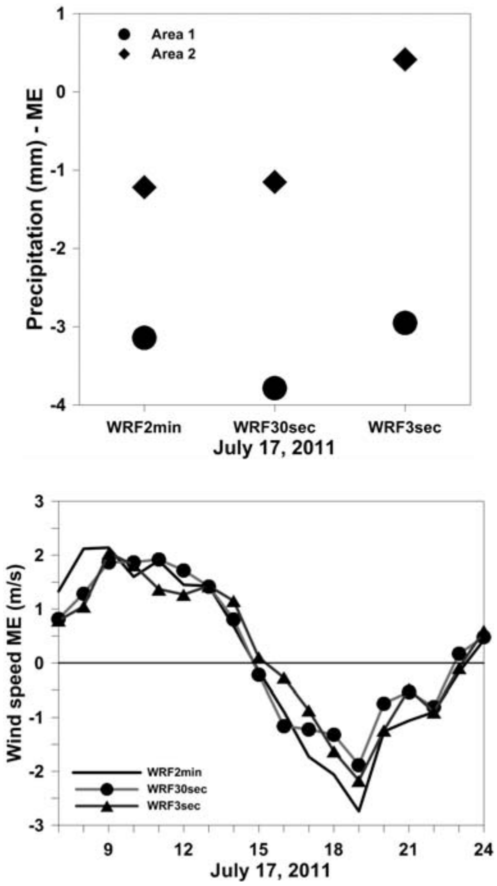

Fig. 3 – Cumulated precipitation 17 July 2011 06UTC – 18 July 2011 06UTC – mean error (left); wind speed – hourly mean error (17 July 2011 06 UTC – 24UTC) (right).

The second case analyzed here was a classic blizzard situation for the Romanian territory. Such events were previously studied by Drăghici [12], Cordoneanu *et al.* [13] and Georgescu *et al.* [14]. On February the 3rd 2012, the dominant component of the airflow in the lower levels of the troposphere had a South-Eastern component, while in the altitude the airflow was South-Western. During this entire period the contact area between the East-European anticyclone and the Mediterranean cyclone was situated in the Eastern and South-Eastern part of Romania. This resulted in precipitation over most part of Romania and strong wind in the East and South-East of the country.

In all three numerical experiments performed for this case, the model gave a generally good approximation of the precipitation area. In the South-Eastern area of the domain, the forecasted values of this parameter in all three numerical experiments were overestimated in comparison to the observed values (Fig. 4). For this region, the best estimation of the precipitation quantities was given by the WRF3seconds experiment (Fig. 5).

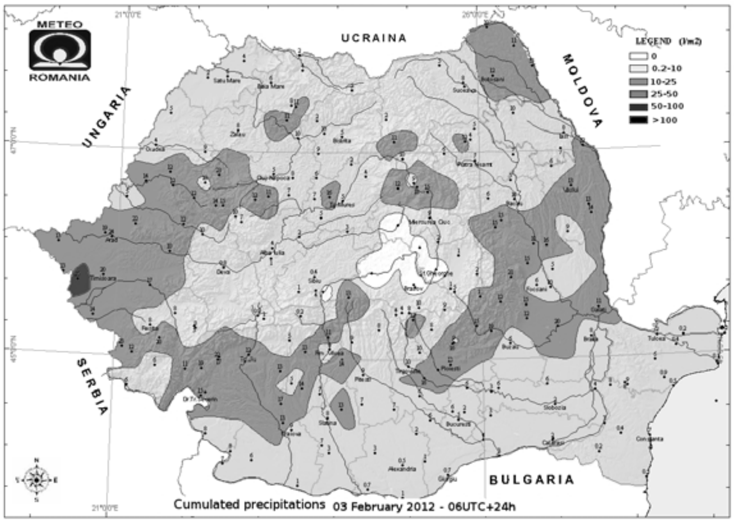

Fig. 4 – Cumulated observed precipitation 3 February 2012 06UTC – 4 February 2012 06UTC. (Source: National Meteorological Administration).

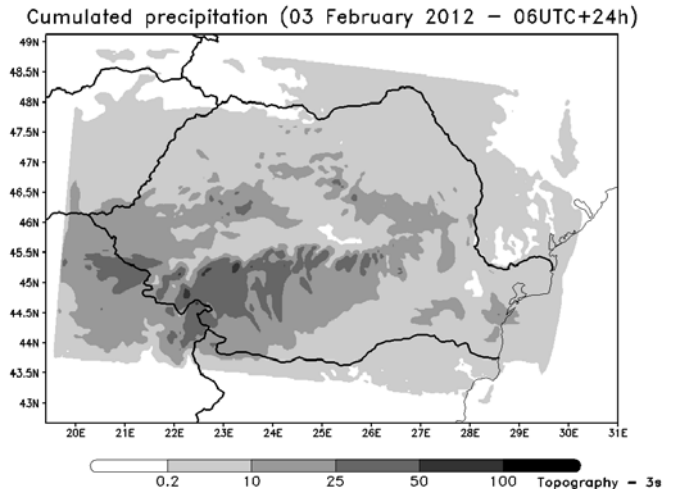

Fig. 5 – WRF3seconds cumulated precipitation 3 February 2012 – 00UTC run.

As in the previous case, we also computed the average mean error over two areas of interest: 20–24 degrees longitude east, 44–47 degrees latitude north (area 1) and 26–28.5 degrees longitude east, 44–47 degrees latitude north (area 2).

Analyzing the average mean error over these areas where most precipitation were observed, we are able to see that for area 1 the model slightly underestimates the observed precipitation. For the second area, the modeling results led to a higher overestimation (Fig. 6 left). For both areas, the best results were obtained with the WRF3seconds.

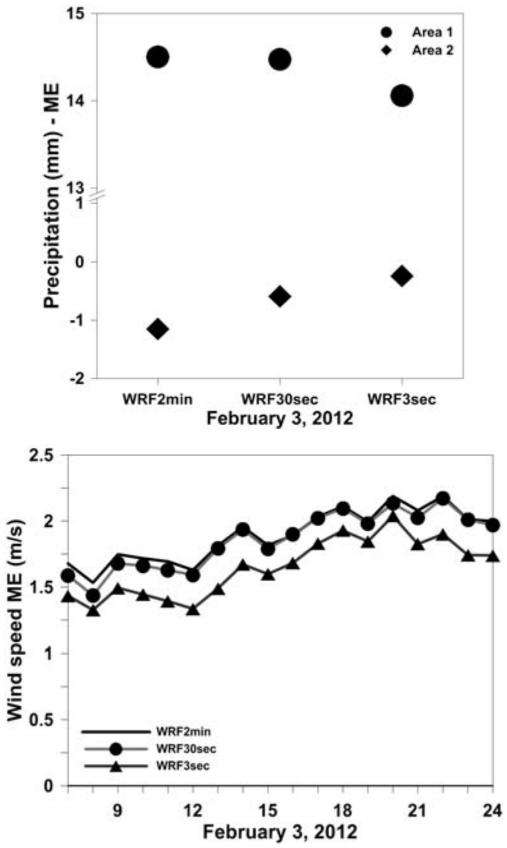

Fig. 6 – Cumulated precipitation 3 February 2012 06UTC – 4 February 2012 06UTC – mean error (left); wind speed – hourly mean error (3 February 2012 06 UTC – 24UTC) (right).

The forecast of the WRF model in all three numerical experiments performed for this case captured the wind intensification over the Romanian territory. In the south-east of the Carpathian Mountains, the forecasted values for wind speed were slightly overestimated compared to the observations, especially for the WRF2minutes forecast. This can be seen in Fig. 6 (right), were we present the hourly mean error for the area between 24–28.5 degrees longitude north 44–46 degrees latitude north.

4. CONCLUSIONS

In order to investigate the influence of topography data over Romanian territory on the numerical weather forecast of the WRF model in cases of severe weather, two different weather events were selected: a strong convective case and a classic blizzard for the Romanian territory.

For the convective system the results showed noticeable differences in the forecasts of the three numerical experiments. The best results were obtained with the WRF3seconds configuration, which offered the best spatial distribution of the precipitation area and forecasted values compared to the observed precipitation quantities.

For the wind parameter, both the WRF30seconds and the WRF3seconds captured the wind intensifications. The best spatial distribution was given by the WRF30seconds configuration, while the best forecast for wind speed values in area of interest were given by the WRF3seconds.

The second case study in this paper was a classical blizzard for the Romanian territory. For this case, there were no noticeable differences between experiments, showing that the topographical features do not impact on the numerical forecast for this case. All three numerical experiments performed gave good spatial distributions of the cumulative precipitation.

The model also captured the wind intensification, slightly overestimating the values of this parameter in the south-eastern area of the Carpathian Mountains, compared to the observations.

Between the experiments performed for both case studies respectively, differences between the precipitation and wind speed parameters were most significant in the mountainous areas of the integration domain. This is consistent with the influence of local topography characteristics on the forecast of WRF in cases of sever weather.

For the two cases analyzed in this study, comparison of experiments showed that high-resolution topography data has a stronger influence on the forecast of the WRF model in the case of the mesoscale convective structure, rather than in the frontal case.

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