Comparative Evaluation of High Resolution Numerical Weather Prediction Models COSMO-WRF

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1 Introduction

The COSMO-Model is a nonhydrostatic limited-area atmospheric prediction model, designed for both operational numerical weather prediction and various scientific applications on the $meso - \beta$ and $meso - \gamma$ scale. The COSMO-Model is based on the primitive thermo-hydrodynamical equations describing compressible flow in a moist atmosphere. Model equations are formulated in rotated geographical coordinates and a generalized terrain following height coordinate. A variety of physical processes are taken into account by parameterization schemes.

The purpose of this paper is to present the results of the comparative evaluation of the quality of high resolution weather forecasts from numerical weather prediction models COSMO - 2.8km (Consortium for Small Scale Modelling) and WRF - 3km (Weather Research and Forecast model).

The numerical weather prediction model COSMO - 2.8km is currently being run at the National Meteorological Administration once a day, at 00 UTC. WRF is a non-hidrostatic numerical weather prediction model developed by NCEP (National Centre for Environmental Prediction) in collaboration with the international meteorological comunity. In order to compare the performance of the two models, the WRF model was implemented at the 3km resolution and integrated with 00 UTC data for a test period. The integration domains of the two models cover the entire Romanian territory (COSMO-2.8km 361 × 291 grid points and WRF-3km 261 × 191 grid points, see figure 1).

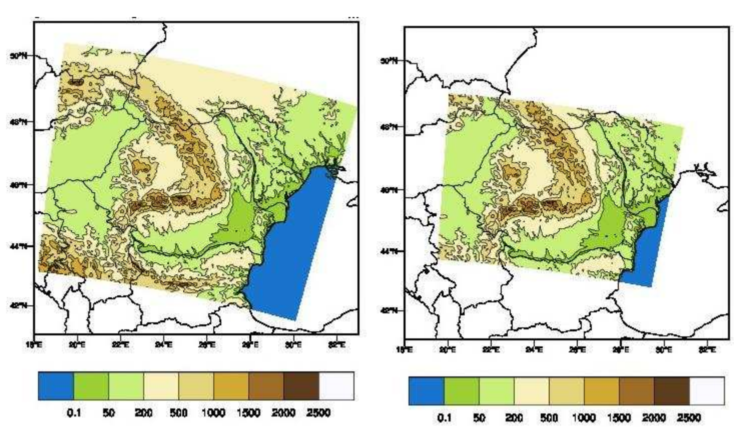

Figure 1: Model domains: COSMO-2.8km (left) and WRF-3km (right).

Both models were integrated for the test period with the same initial and boundary conditions from the output of the COSMO-7km model. In standard configuration, the WRF model uses initial and boundary conditions from the GFS global model (Global Forecast System). In order to use the output of the COSMO-7km model for the run of WRF model, a series of interpolation methods from rotated latitude / longitude grid into regular latitude / longitude grid were necessary. For these procedures, the post-processing software tool "Fieldextra" was used. "Fieldwxtra" is a generic tool to manipulate numerical weather prediction model data and gridded observations, developed by MeteoSwiss. Post-processing of the WRF-model output was made using the ARWpost software package.

The test period for which the numerical weather forecasts of the two models were compared is AUGUST 2011.

2 Parameters Evaluation

In order to point out the quality of the numerical weather prediction of the two high-resolution models, statistical scores were computed for different meteorological parameters:

- 2 m air temperature
- mean sea level pressure
- 10 m wind speed

The scores computed were based on forecast - observation differences, using nearest grid point method.

The first step of the evaluation consisted of computing mean error and mean squared error taking into account all synoptic stations in Romania. The second step of the analisys is represented by separating the Romanian meteorological stations in four categories (according to landform altitude):

- stations on the seaside of the Black Sea (7 stations)
- plain stations (88 stations with altitudes under 300 m)
- hillside stations (43 stations with altitudes between 300 m and 800 m)
- mountain stations (25 stations with altitudes over 800 m)

For each of these categories, the same scores were computed as in the previous stage.

For the numerical forecast of 2m temperature (figure 2), both models overestimate values of this parameter for the mountain stations. Moreover, the errors from the WRF-3km model forecast reach up to $4°C$, while the errors from the forecast of the COSMO-2.8km vary between $1°C - 2°C$. The situation differs for seaside stations. The COSMO-2.8km model underevaluates the values for this parameter, the error keeping between $-2°C$ and $0°C$, while the WRF-3km model overestimates these values, with errors of $0°C$ up to $3°C$. For hillside and plain stations, the models have opposite behaviour.

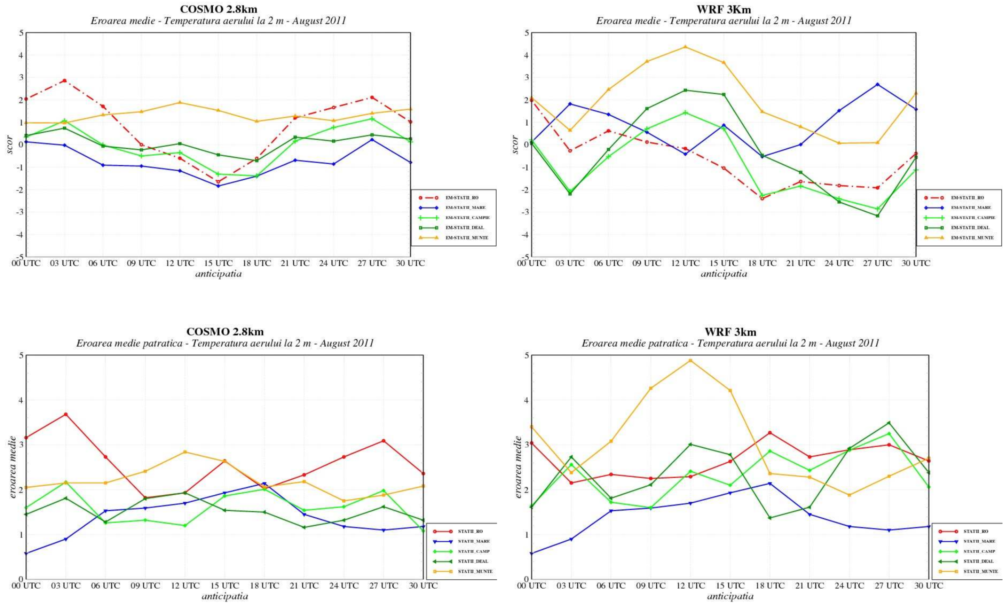

Figure 2: 2 m temperature BIAS score (first row) and RMSE (second row): COSMO-2.8km (left) and WRF-3km (right); seaside stations - blue, plain stations - light green, hillside stations - dark green, mountain stations - orange, all Romanian stations - red.

After comparing the forecast of the two models for mean sea level pressure for the test period, it can be stated that both the COSMO-2.8km model and the WRF-3km model have the same tendency, forecasted values being very close, with errors for both models mostly between -1 and 1 (figure 3).

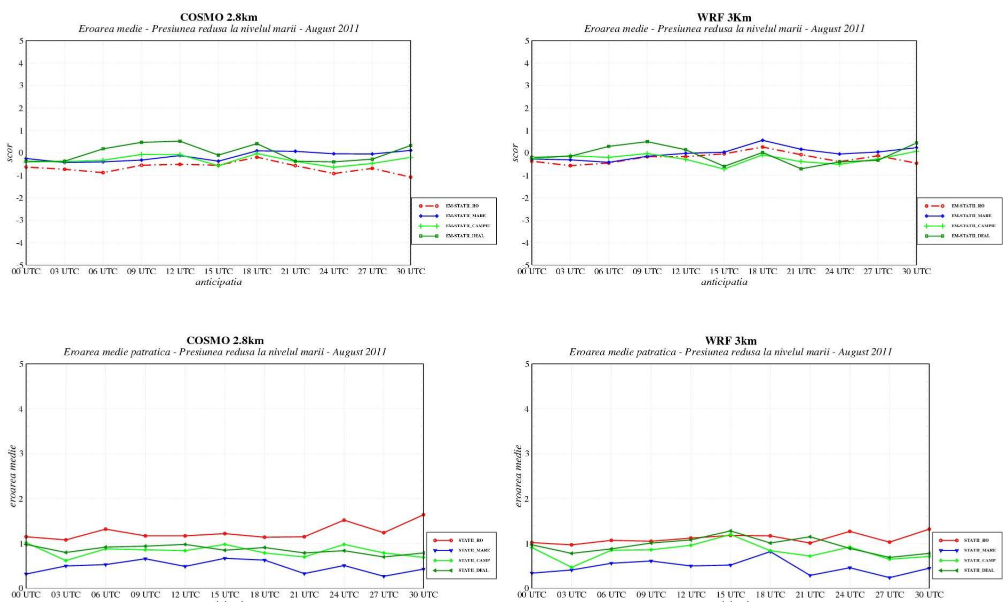

Figure 3: Mean sea level pressure BIAS score (first row) and RMSE (second row): COSMO-2.8km (left) and WRF-3km (right); seaside stations - blue, plain stations - light green, hillside stations - dark green, mountain stations - orange, all Romanian stations - red.

The last analised parameter in this stage of the evaluation is 10 m wind speed (figure 4). In forecasting this parameter for the time inteval 00 UTC - 06 UTC, both models show an important underestimation for mountain stations. In what concerns plain and hillside stations, the forecast errors for both models are between -1 and 1. The WRF-3km model overestimates forecasted values of this parameter for seaside stations, with errors up to 3. Except the initial period (until 06 UTC), the errors from the forecast of this parameter from COSMO-2.8km are very small for all types of stations.

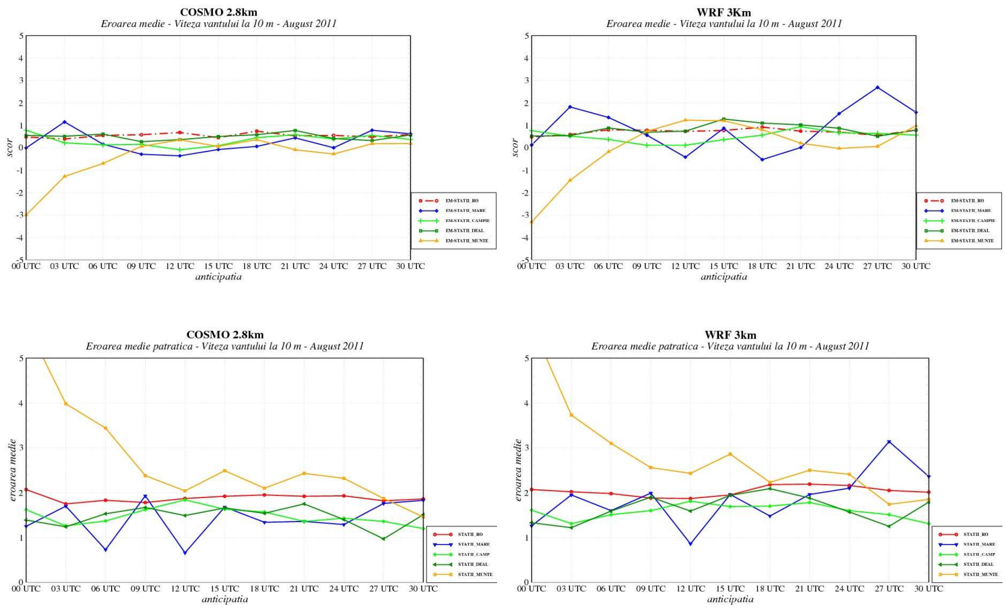

Figure 4: 10 m wind speed BIAS score (first row) and RMSE (second row): COSMO-2.8km (left) and WRF-3km (right); seaside stations - blue, plain stations - light green, hillside stations - dark green, mountain stations - orange, all Romanian stations - red.

3 Case Studies

Because August 2011 lacked precipitations over the are of Romania, two case studies are presented in order to analyse the performance of the two numerical weather prediction models in forecasting this parameter. The two selected case studies were:

- 17^{th} July 2011
- 17^{th} October 2011

In both cases heavy rainfall and strong wind were registered.

17^{th} July 2011

The Icelandic Low moved towards the Center and South of the continent along with a strong high-altitude cyclonic nucleus. Atmospheric circulation in the South-Eastern part of Europe was made on the South-Western, then Southern component, which allowed the inflow of a hot tropical airmass. During the day (06 UTC - 18 UTC), a short wave trough determined cold altitude airmass pulsations West of Romania. This led to an atmospheric instability and the formation of mesoscale structures which were active in the South part of Romania (figure 5).

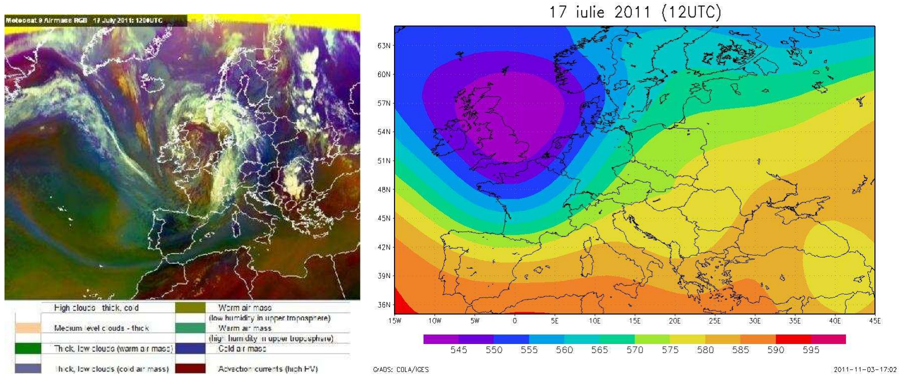

Figure 5: 17 July 2011 - 12 UTC: satellite image (left) and geopotential - 500hPa (right).

The maximum precipitations quantity registered in 24 hours was $127l/m^2$, in the South part of Romania (figure 6 - second row). The COSMO-2.8km model underestimated the quantity, forecasting between $50l/m^2$ and $100l/m^2$, while the WRF-3km model forecasted over $150l/m^2$, overestimating the values of this parameter and placed these quantities North of the area were they were actually registered. Both models overestimated the precipitation quantities in the North-East of Romania (COSMO-2.8km forecasted $25l/m^2$ and WRF-3km $150l/m^2$), where no precipitations were registered. Also, none of the models predicted the precipitations in the South-West region of our country (figure 6).

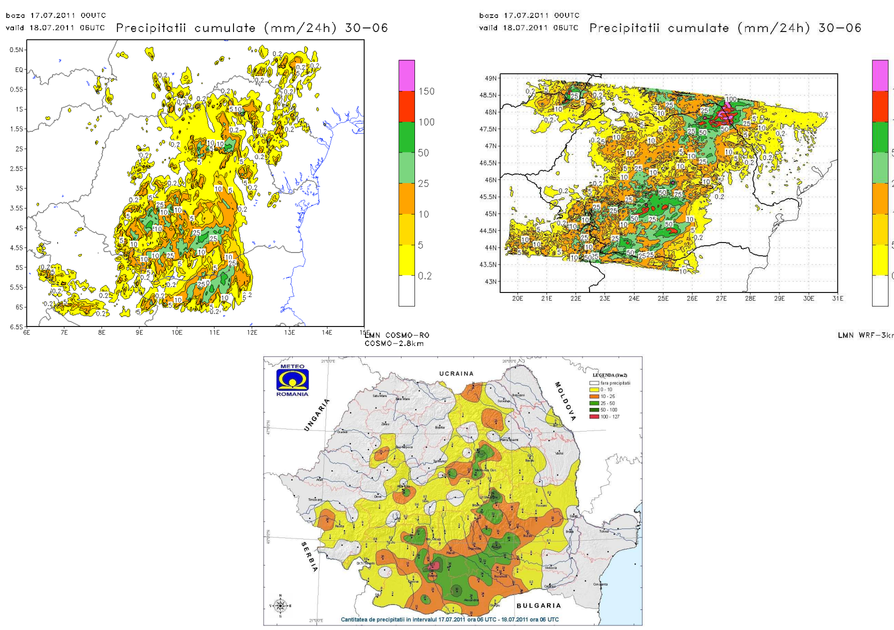

Figure 6: 17 July 2011 - 24 hours cumulated precipitations: COSMO-2.8km (left), WRF-3km (right), Observations (second row).

In order to compare the observations against the model forecast for the 10 m wind speed parameter, synoptic observations from meteorological stations in Romania were processed by interpolation in the grid of the model. Registered 10 m wind speed varied between $7m/s$ and $11m/s$, with wind gusts up to $16m/s$ at one meteorological station (figure 7 - second row). The COSMO-2.8km model predicted the wind speed values accurately and placed them correctly, forecasted values varying between $10m/s - 12m/s$ (figure 7). The WRF model run at the 3km spatial resolution did not forecast the wind intensifications.

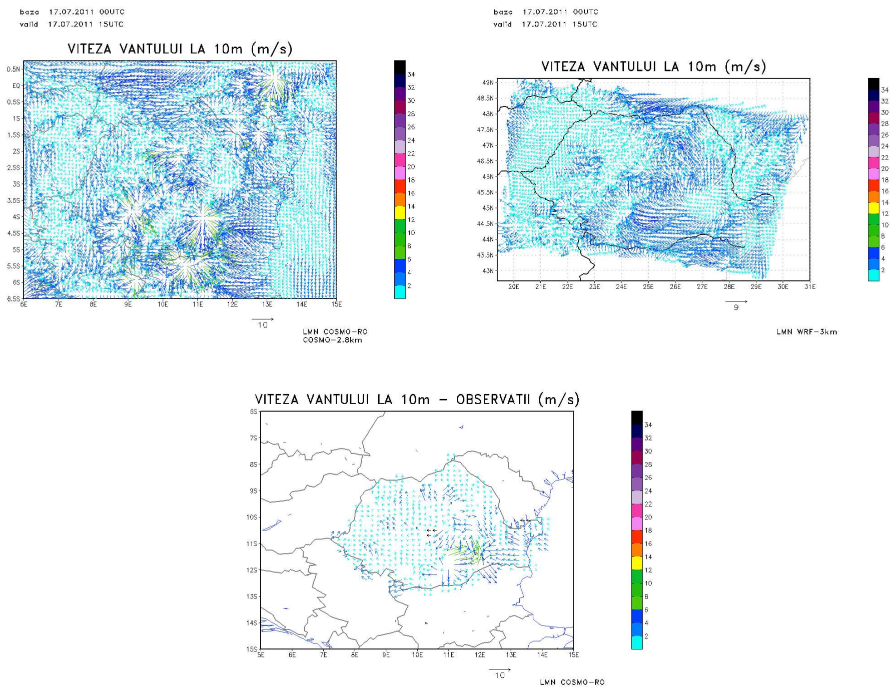

Figure 7: 17 July 2011 (00 UTC + 15 hours) - 10m wind speed: COSMO-2.8km (left), WRF-3km (right), Observations (second row).

17th October 2011

The mediterranean originated cyclone evolved on a transbalcanic trajectory towards the South-Western region of the Black Sea. The warm surface of the sea contributed to the reactivation of this cyclone. In the altitude, a quasi-stationary low pressure altitude nucleus was observed, centered over the South of Romania and North of Bulgaria. The low pressure nucleus in the altitude was powered with cold air, which determined the intensification of the surface cyclone (figure 8). This atmospheric activity led to heavy rainfall in the South of the Romanian seaside and strong wind gusts that reached up to 70km/h - 80km/h.

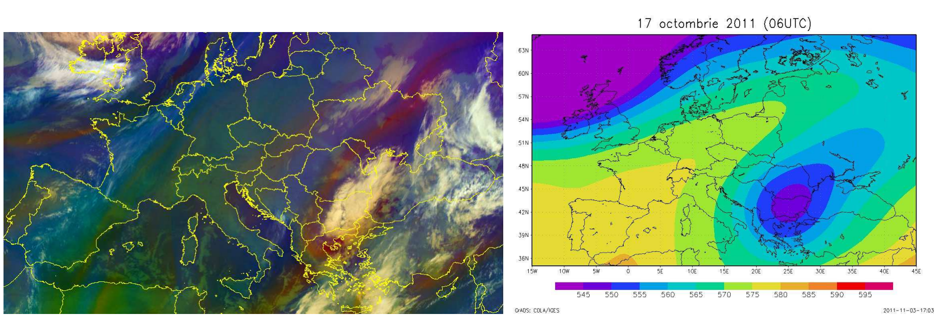

Figure 8: 17 October 2011 - 06 UTC: satellite image (left) and geopotential - 500hPa (right).

Both the COSMO-2.8km model and the WRF-3km model overestimated the precipitations in the South-East of Romania. In the South part of the Romanian seaside, up to 103l/m^2 were registered in 24 hours (figure 9 - second row). These quantities were correctly estimated by both models (figure 9).

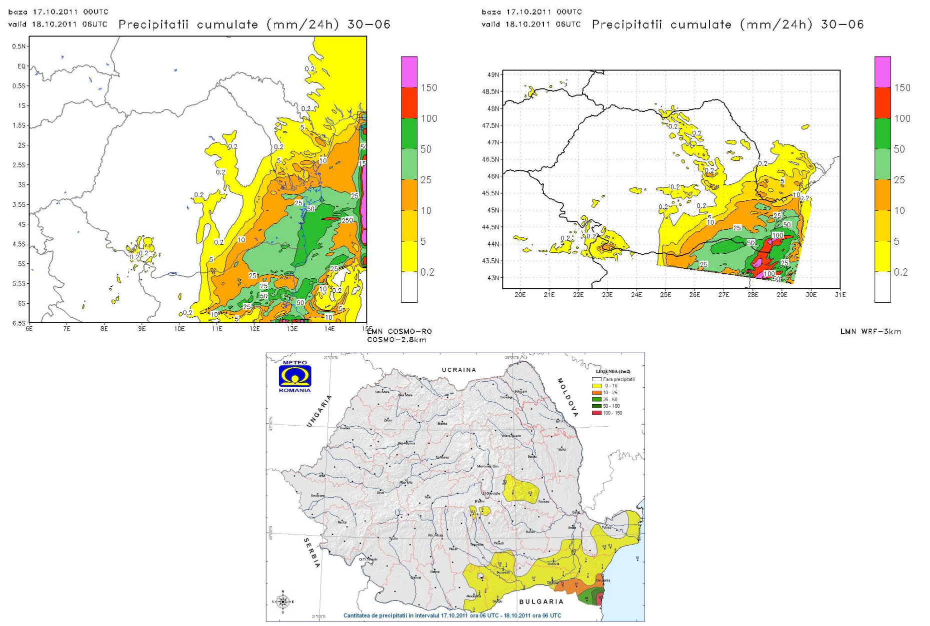

Figure 9: 17 October 2011 - 24 hours cumulated precipitations: COSMO-2.8km (left), WRF-3km (right), Observations (second row).

Concerning 10 m wind speed, observations values of this parameter were between $16m/s - 25m/s$. Both models forecasted correctly the strong wind in the are of the Romanian seaside (figure 10 - second row). The two models estimated values up to $24m/s$ for this parameter for the analysed period of time. Compared to the COSMO-2.8km model, the WRF-3km model overestimated 10 m wind speed values East of the seaside, forecasting values up to $18m/s$, while values from observations only reached up to $8m/s - 10m/s$ (figure 10).

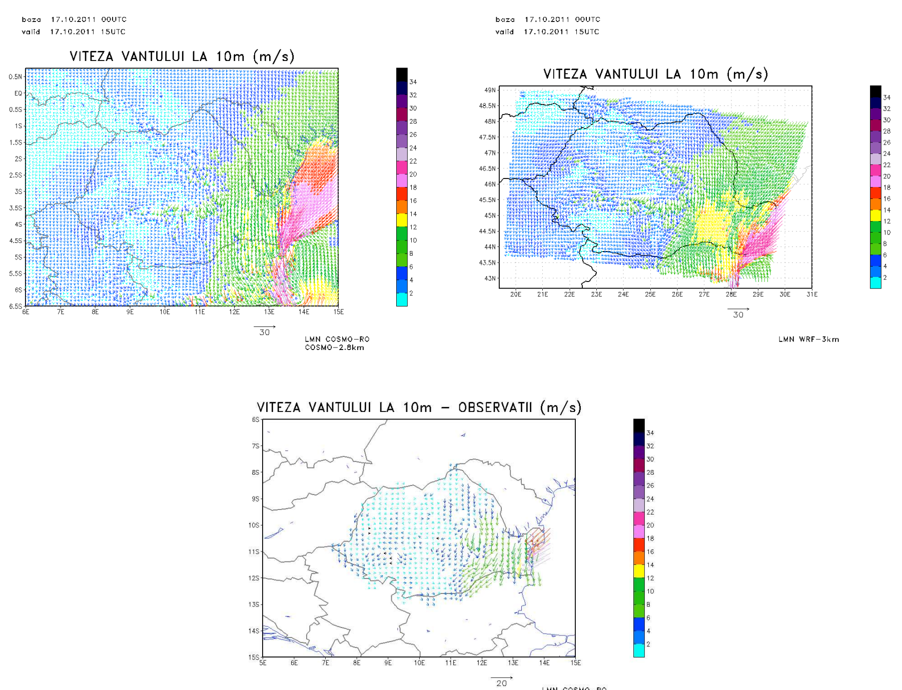

Figure 10: 17 October 2011 (00 UTC + 15 hours) - 10m wind speed: COSMO-2.8km (left), WRF-3km (right), Observations (second row).

4 Summary and Outlook

As a result of the analisys of computed statistical scores, it was decided that the results of the two high-resolution numerical weather prediction models are comparable. For the parameters selected in this evaluation, differences are noticeable depending on forecast times and altitude levels as follows.

For mean sea level pressure, both models offer correct estimates of this parameter, with small mean errors (between -1 and 1), with a tendency to underestimate values for most forecast times taken into account.

Forecasting 2 m temperature displays mostly an opposite behaviour of the two models (except for mountain stations). We also note that mean errors of the forecast from the WRF-3km model for this parameter are greater than the ones from the COSMO model run at the 2.8 km resolution.

Apart from underestimating 10 m wind speed values at mountain stations in the first forecast period, both models give a good forecast for this parameter, with small mean error values. For the WRF-3km forecast of 10 m wind speed, mean error values are slightly greater.

In the analysed cases with heavy rainfall, the high-resolution COSMO and WRF models estimate the precipitation area correctly, but the WRF-3km model has slightly higher over-estimates of this parameter.

References

[1] Stanski, H.R., and L.J. Wilson, W.R.Borrows, 1989: Survey of Common Verification Methods In Meteorology, WWW, *Technical Report*, No. **8**, WMO/TD.,No. 358.

[2] http://www.cawcr.gov.au/projects/verification/

[3] http://www.cosmo-model.org/content/model/documentation/core/default.htm

[4] http://www.mmm.ucar.edu/wrf-WRF-ARW