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USING A HIGH RESOLUTION TOPOGRAPHIC DATA SET AND ANALYSIS OF THE IMPACT ON THE FORECAST OF METEOROLOGICAL PARAMETERS*

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Abstract. The performance of the Weather Research and Forecast (WRF) model simulation was evaluated using different topographic data sets for the Southern Carpathians, Romania, and surrounding area, characterized by complex terrain. Since the goal is to better reproduce the near-surface parameters, two different topographical data sets were assessed. Globally, the model reproduced the observations, despite a significant overestimation of the wind speed. The increase of the topographical resolution data set alone is not enough to significantly improve the model performance, suggesting that error minimization can be achieved by testing and choosing a suitable numerical and physical configuration for the region of interest.

Key words: topography, model, simulation, evaluation.

1. INTRODUCTION

Complex topography can be defined as the landscape that is normally addressed as mountain. The terrain features influence and control air motion and mechanical turbulence in the lower atmosphere. The mountains, hills and valleys are a governing factor in the control of wind speed and wind direction [1]. For example, wind may be diverted around large hills and mountains and channeled through valleys.

The accurate simulation and prediction of the meteorological parameters is currently an important subject and a target of intensive academic and industrial research. Also the modeling of the increased occurrence of extreme weather events is still a major challenge to atmospheric modelers involved in meteorological research and applications.

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Regional meteorological models are a very powerful and useful tool to study and simulate meteorological variables. One of the principal limitations of the meteorological models at very high resolution is the inaccuracy of the real terrain representation (*i.e.* topography, albedo, LAI, vegetation fraction and land cover). The data supplied by the model generally have a coarser resolution than the simulation domains. Thus the modeled topographical features are smoother than it is in reality. In general, the mountains are represented having a lower elevation, and the valleys have a higher elevation. Another issue is the difficulty of the meteorological models to take into account the complexity of the air parcels dynamics in mountainous areas and the interactions between topography and synoptic circulation. The data which come along with standard models usually have a resolution of at most 1 km, while measurements are provided at even lower resolution. Thus, the correct representation of the topography is a key factor.

The model chosen to conduct the simulations in this study is WRF-ARW (Advanced Research Weather) version 3.4.1, a widely used community mesoscale model developed by the National Centre for Atmospheric Research (NCAR). It represents the current state-of-the-art in mesoscale model development, and was established as a successor to the long-standing Penn State/NCAR Fifth-Generation Mesoscale Model (MM5), sharing much of the same dynamics and model physics. A detailed description of this model can be found in the work of Skamarock *et al*. [2].

Awan *et al*. [3] and Carvalho *et al*. [4] showed that one of the sources of errors in the model is related to the physical parameterization schemes which are based on many assumptions and these assumptions can give an inadequate response to certain synoptic situations. As stated above, there are other sources of errors in the numerical models. Kapos *et al*. [5] and Kumar *et al*. [6] showed that the substantial orographic features (~25 % of earth's total dry land area) significantly influence the regional and global climate. They affect the dynamics of the atmospheric circulation, and interactions between the atmosphere and the land surface, thus they have considerable influences on weather and climate.

The aim of this study is to compare the numerical forecasted data with that observed in the field in order to validate the model ability to reproduce the observed parameters using two topographical data bases.

2. DATA AND METHODS

2.1. WRF MODEL SET-UP

In order to reproduce accurately the fine scale dynamics associated to the complex topography of the measurement sites in the mountainous areas we have used a (nested) modeling system that allows the use of two topographical data sets. To have a good resolution in meteorological forcing, it was decided to use two-way nesting for a large computational domain. WRF operates on the 5 km, respectively

1 km resolution domains. The WRF uses meteorological initial conditions and lateral boundary conditions from 6 h re-analyses from the ECMWF (European Center for Medium range Weather Forecast) having an horizontal resolution of 0.25 degrees and 15 vertical levels from 1000 hPa up to 10 hPa. These data were used in order to reduce the errors coming from the global atmospheric models. Data produced during pre-processing and modeling simulations of WRF are in the Lambert conformal projection.

In order to reduce truncation errors associated with the integration time, the model was integrated for 30 hours period, using segmented simulation until the completion of the desired period of simulation. The first 6 hours of integration represent the spin-up period and they are disregarded. The time step of output data has been set to 1 hour, thus the analyzed results have a daily variability from 00 UTC until 23 UTC.

The coarse domain has 160×140 grid points, and the nested domain has 281×151 grid points (Fig. 1). Both domains involved in the calculation have 28 vertical levels up to 50 hPa, and they use for the microphysics option the Thompson scheme [7], for long wave radiation the Rapid Radiative Transfer Model (rrtm) scheme [8] and for shortwave radiation the Dudhia scheme [9], for the boundary layer we used a two first-order closure scheme – the Yonsei University (YSU) PBL [10].

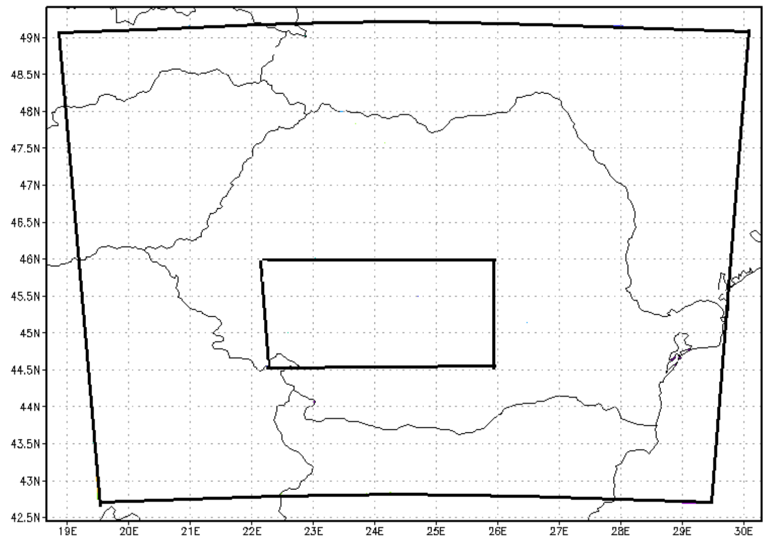


Fig. 1 – WRF integration domains.

2.2. TOPOGRAPHICAL DATA SET USED IN THE SIMULATION

As shown by the work of Arnold *et al*. [11], for the simulations performed at resolutions close to 1 km, in generally the smoothing of high-resolution topographic features occurs, with lower mountain peaks and elevated valley floors. The correct representation of the land surface characteristics has been recognized as an important issue in general [12, 13]. Thus, to adequately simulate local meteorological processes highly resolved and up-to-date surface data are desirable.

The data set provided by WRF is the USGS (U.S Geological Survey) data at 30s (about 1km) horizontal resolution.

In order to better reproduce the complex topography associated with the Southern Carpathians, Romania, the SRTM (the NASA Shuttle Radar Topographic Mission 90 m Digital Elevation Data) at 3s (about 100 m) horizontal resolution were used [14]. The ingestion of SRTM data into WRF was made following the specifications given by ARW User Guide [15].

Two set of simulation were carried out for this study. For the first simulation the USGS data set at 30” horizontal resolution was used for both domains involved in calculation, while for the second simulation the SRTM data at 3” horizontal resolution was used for both domains.

The differences between the default USGS topographical data set at 30” resolution (further named WRF-30s) and the SRTM data set at 3” resolution (further named WRF-3s) range between – 419.61 m and 335.21 m.

2.3. OBSERVATIONAL STATIONS

In order to asses the capacity of WRF to correctly reproduce the observations, we used for comparison the observational stations of the National Meteorological Administration network located inside the nested domain. These stations are located in the Southern Carpathian Mountains, Romania, and surrounding area, thus we have information at 12 high altitude stations and 25 low altitude stations.

Table 1 shows the information about the real elevation and the model elevation simulated for both topographical data sets used in this study. For the P2, P3, P4, P6, P7, P8, and P9 simulation points, the use of the SRTM data leads to a better representation of the real elevation in comparison with the default topography at 30s horizontal resolution for mountainous area. For the low altitude area, using SRTM data we are able to reproduce the real elevation for the majority of sites as can be seen in Table 2.

Table 1

The real and simulated elevations for the mountain stations using two different topographic data bases

Station ID	Station name	Real elevation	30s elevation	3s elevation	Observed - 30s elevation	Observed - 3s elevation
P1	Paltinis	1453.0	1428.76	1377.87	24.24	75.13
P2	Postavaru	1784.0	1412.86	1504.29	371.14	297.71
P3	Balea Lac	2037.0	2198.84	2180.75	-161.84	-143.75
P4	Vf. Omu	2504.0	2264.52	2310.0	239.48	194
P5	Ob. Lotrului	1348.0	1430.26	1463.17	-82.26	-115.17
P6	Fundata	1384.0	1215.72	1185.59	168.28	198.41
P7	Predeal	1090.0	1104.87	1086.48	-14.87	3.52
P8	Semenic	1433.0	753.28	814.56	679.72	618.44
P9	Cuntu	1450.0	1605.32	1522.61	-155.32	-72.61
P10	Tarcu	2180.0	2010.49	1925.84	169.51	254.16
P11	Parang	1548.0	1536.29	1383.90	11.71	164.1
P12	Sinaia	1510.0	1754.94	1930.32	-244.94	-420.32

Table 2

The real and simulated elevations for the low altitude stations using two topographic data bases

Station ID	Station name	Real elevation	30s elevation	3s elevation	30s - observed elevation	3s - observed elevation
S1	Deva	240.0	222.76	280.48	17.24	-40.48
S2	Sebes	253.0	288.52	273.98	-35.52	-20.98
S3	Fagaras	428	426.35	424.06	1.65	3.94
S4	Sf. Ghe. Munte	523.0	540.02	531.43	-17.02	-8.43
S5	Sibiu	443.0	433.05	408.83	9.95	34.17
S6	Boita	518	416.23	408.8	101.77	109.2
S7	Petrosani	607.0	745.34	671.04	-138.34	-64.04
S8	Brasov	535.0	536.69	532.65	-1.69	2.35
S9	Voineasa	573.0	713.07	785.00	-140.07	-212
S10	Campulung Muscel	681.0	641.94	644.5	39.06	36.5
S11	Tg. Jiu	203.0	183.87	197.40	19.13	5.6
S12	Pades	251	276.18	273.35	-25.18	-22.35
S13	Polovragi	531.0	612.62	593.50	-81.62	-62.5
S14	Dedulesti-Morarești	548	469.03	471.36	78.97	76.64
S15	Rm. Valcea	237.0	202.51	276.06	34.49	-39.06
S16	Curtea de Arges	449.0	460.12	459.52	-11.12	-10.52
S17	Campina	461.0	916.81	831.01	-455.81	-370.01
S18	B. Herculane	190.0	371.38	318.95	-181.38	-128.95
S19	Tg. Logresti	262.0	266.68	290.47	-4.68	-28.47
S20	Pitesti	316.0	353.96	381.00	-37.96	-65
S21	Targoviste	296.5	288.46	294.06	8.04	2.44
S22	Dragasani	280.0	201.48	185.08	78.52	94.92
S23	Dr. Tr. Severin	77.0	83.48	80.14	-6.48	-3.14
S24	Halanga	74.0	101.55	88.63	-27.55	-14.63
S25	Titu	159.0	143.53	154.82	15.47	4.18

The standard deviation for high altitude stations shows a value of 405.51 for the real elevation, while using the topographical data set we obtain almost the same deviation, 445.19 for WRF-30s and 448.92 for WRF-3s. For the low altitude station we have a deviation of 172.69, while the use of the SRTM data with a deviation of 202.73 shows an improvement when WRF-3s is used, compared to the USGS data which gives a deviation of 214.94.

3. RESULTS AND DISCUSSIONS

The period analyzed in this paper is 15 January-15 February 2012, when blizzard associated with low temperatures were registered in Romania. The models which currently run operationally in the National Meteorological Administration were not able to predict accurately the observed near surface parameters. In the study of Pietrisi and Tascu [16] it was shown that for this period high over-estimations were registered for the temperature.

For the high altitude stations, as can be seen in Fig. 2a) the use of the 3s resolution topographical data leads to an improvement of the forecast of the 2 m temperature for all sites. The 2m temperature BIAS values forecasted using WRF-3s are reduced from a factor of 2.85 for P1 site to a factor of 1.2 for P7 site in comparison with WRF-30s. This trend was also noticed from the RMSE analysis, the amplitude of errors is reduced for WRF-3s up to a factor of 1.17.

The improvement of predicted temperature is also visible for low altitude stations (Fig. 2b). WRF-3s improves the BIAS values up to a factor of 2.06 in comparison with WRF-30s. Because the differences between the real elevation and modeled observation are not quite large, the temperature is overestimated for the low altitude station in comparison with the high altitude station, where for both simulation the 2m temperature is underpredicted. The RMSE analysis for the low altitude stations led to a variations ranging from 2.34 ^{O}C to 3.48 ^{O}C, showing large amplitude of errors which is not visible from the averaged BIAS over the entire period.

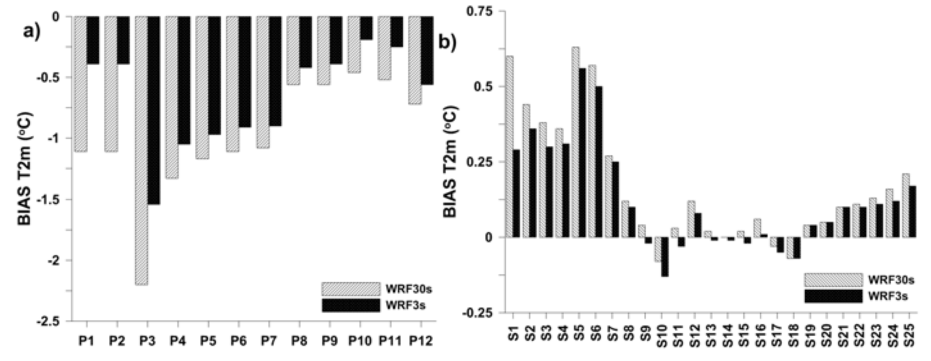


Fig. 2 – Temperature BIAS for mountain stations (a) and low altitude stations (b) during 15 January–15 February 2012 period.

At high altitude stations, the relative humidity is generally underestimated for all simulation points, and the use of 3s topographical data set leads to an increase in mean error, up to a factor of 3 (Fig. 3a). However, for P3 and P4 stations, WRF-3s gives a visible improvement of the forecast, in case of point P3 the difference between WRF-30s and WRF-3s is within a factor of 10.06. One possible explanation can be related to the fact that the WRF model is not able to capture the situations when the mountains top are in-cloud. For the low altitude stations, as we expected, the differences between both simulations for relative humidity are not so important, due to the fact that the differences of terrain height between the both topographic data sets are not significant (Fig. 3b). However, analyzing the RMSE score for high altitude stations we can notice that even the error is reduced for WRF-3s, the amplitude of errors is almost the same for both data sets, varying between 16.42% and 19.59%. This can be observed also for low altitude stations, where the RMSE varies between 16.99% and 22.21%.

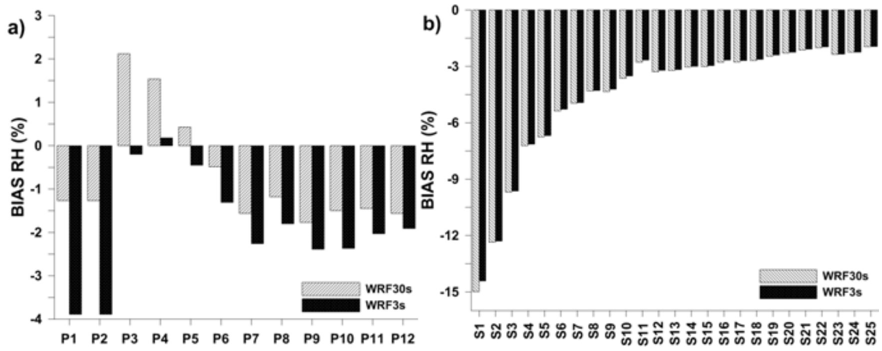


Fig. 3 – Relative humidity BIAS for mountain stations (a) and low altitude stations (b) for 15 January–15 February 2012 period.

For the wind speed forecast at high altitude, in general the WRF-3s forecasts give better values than WRF-30s. The BIAS registered using the WRF-3s configuration is reduced up to a factor of 4.53 compared to WRF-30s (Fig. 4a). This is explained by the high resolution of the SRTM database, thus WRF-3s gives better values of forecasted wind speed since the orographic features are less smoothed. As shown in Table 1, for the low altitude stations the terrain height ingested in WRF doesn't have large variations between the two topographical data sets. This explains why the wind speed BIAS does not indicate an improvement as in the case of high altitude stations (Fig.4b). The RSME for WRF-3s is reduced within a factor of 1.36 compared to WRF-30s for the high altitude stations, while for low altitude stations this factor is reduced to 1.03.

Contrarily to the wind speed BIAS, at high altitude stations, the BIAS of wind direction does not show a visible improvement when WRF-3s is used (Fig.5a). There are some differences in wind direction especially for the low altitude area (Fig. 5b). This can be explained as the result of the difference in topography data resolution which shows its influence on the atmospheric circulations. The RMSE analysis leads to a great variability in wind direction, varying between 64.18 and 72.35 degrees for the high altitude stations and between 69.43 and 85.52 degrees for low altitude stations.

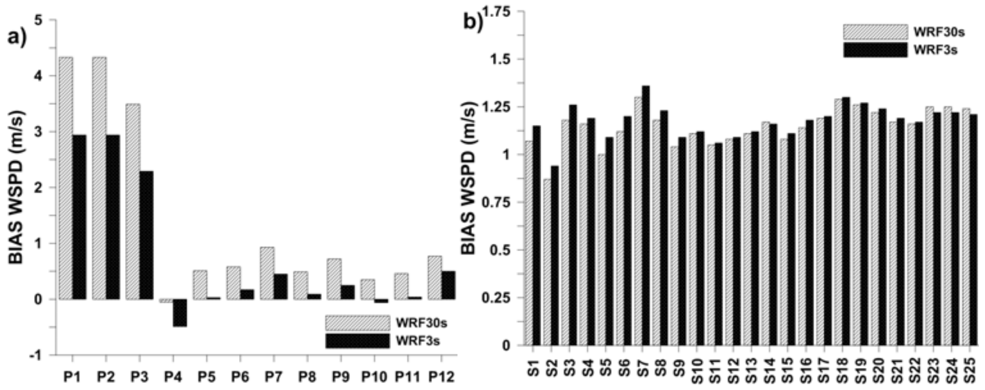


Fig. 4 – Wind speed BIAS for mountain stations (a) and low altitude stations;
(b) for 15 January – 15 February 2012 period.

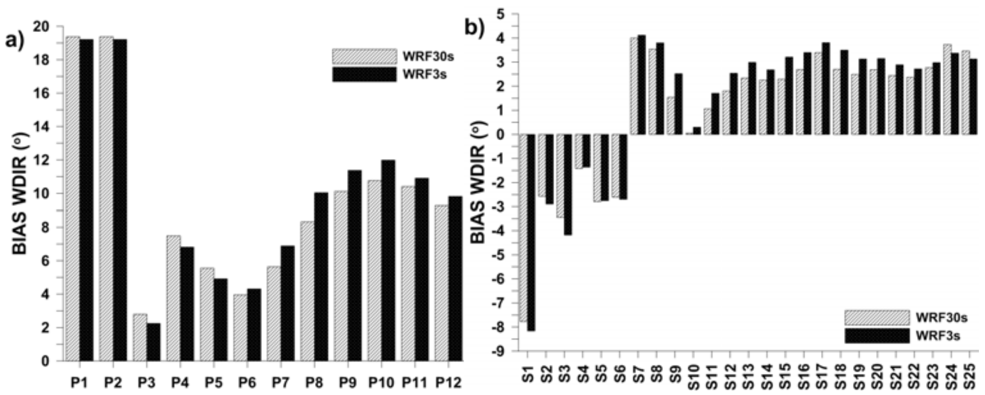


Fig. 5 – Wind direction BIAS for mountain stations (a) and low altitude stations;
(b) for 15 January – 15 February 2012 period.

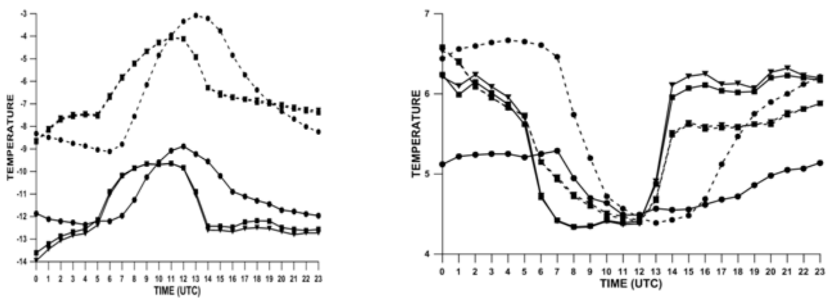
The daily mean variation of the temperature shows that for both configurations the model is not able to reproduce accurately the moment when the maximum is registered neither for the high altitude station nor for the low altitude station (Fig. 6a, left panel). It can be observed that for the modeled daily mean for low altitude stations the model generally overestimates the observations, while for the high altitude stations excepting the morning hours, the model underestimates the observed mean values. The standard deviation shows the same variation during mid-day hours (Fig. 6a, right panel) for both low and high altitude stations. It can be noticed that for the high altitude stations the deviation provided by the model is higher compared with the deviation resulting from the observations, while for the low altitude stations we observe the opposite behavior.

The daily mean variation of the relative humidity shows that for both high and low altitude stations the modeled results lead to an underestimation, except for the afternoon hours (Fig. 6b, left panel). While in case of the observation the mean daily variation have the same trend for both low and high altitude stations with a low peak during mid-day hours, this is not kept for the model. For the high altitude stations the minimum peak was forecasted 6 hours earlier, while for the low altitude stations it was predicted 2 hours earlier. The standard deviation shows a large daily variability for both high and low altitude stations, while for the model the standard deviation is almost constant during the day (Fig 6b, right panel).

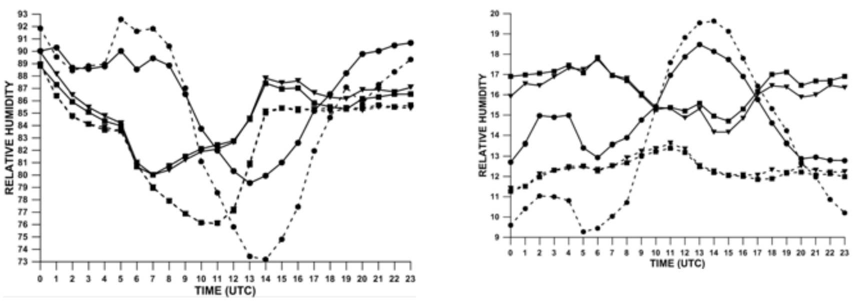
In case of the wind speed, the mean variation gives an overestimation of the modeled results for both low and altitude stations (Fig. 6c, left panel), while the standard deviation does not give significant variations for the low altitude stations and has almost the same values. On the contrary, high altitude stations have a higher deviation for the model compared with that for the observations (Fig. 6c, right panel).

The daily mean of wind direction shows a large variability of the observed values compared with the modeled ones for the low altitude stations, while for the high altitude stations the daily mean variations have the same behavior for both observations and modeled values (Fig. 6d, left panel). The daily standard deviation shows that for both low and high altitude stations, the observations have a higher deviation compared with the deviation obtained for the modeled wind direction (Fig. 6d, right panel).

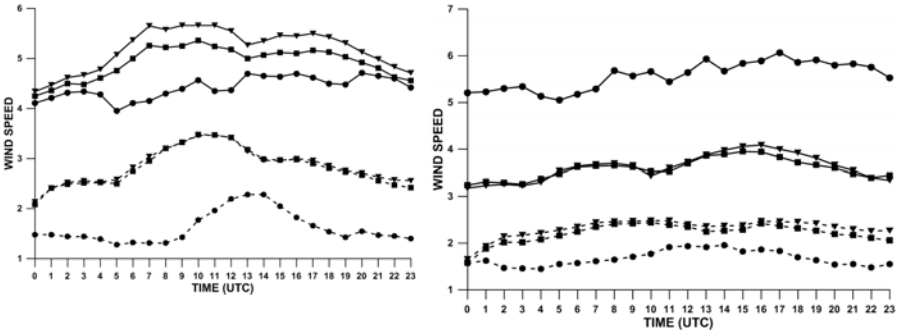
a)



b)



c)



d)

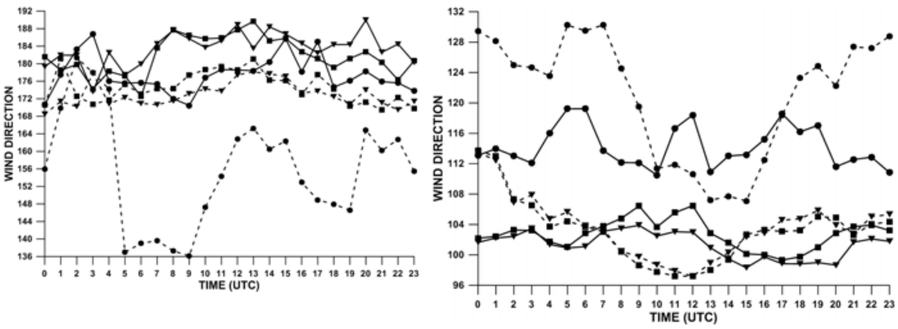


Fig. 6 – The mean (left panel) and standard deviation (right panel) variation for high altitude stations (solid lines) and low altitude stations (dashed lines) during the 15 January – 15 February 2012 period for a) temperature; b) relative humidity; c) wind speed and d) wind direction. The circle denotes observations, the square – results for WRF-3s and the triangle – results for WRF-30s.

4. CONCLUSIONS

Two tests with the WRF meteorological model were performed, aiming to evaluate the impact of the use of different topographical database in the simulation of the surface parameters. Due to its complex topography, the area of the Southern Carpathian Mountains and their vicinity was used to evaluate the model performance.

This study proved that the use of a finer resolution topographical database led to a better performance in reproducing the near-surface parameters. Generally the WRF-3s gives better results than WRF-30s for the majority of the parameters involved in the evaluation, except for the relative humidity. Concluding, from this study we saw that the SRTM 3” data should be directly implemented in the operational use of WRF for Romanian territory.

Since this analysis was centered in the near-surface parameters, the physical options related to the boundary layer processes influence the accuracy of the forecasted parameters. Due to the multiple choices of physical parameterizations provided by WRF, further sensitivity studies are required in order to establish the best model configuration suitable for the Romanian territory. Although a large set of numerical and physical options are available in the model, it will not be efficient to use all in the model configuration, the impact of surface layer parameterization, planetary boundary layer parameterization and land-sea model together with the impact of numerical options on the WRF model forecast should be studied for a better performance of the model in the region of interest.

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