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HIGH-RESOLUTION DYNAMICAL ADAPTATION OF THE ALADIN/ROMANIA MODEL'S SURFACE WIND FORECAST

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Abstract: The high-resolution dynamical adaptation procedure of the surface wind consists in the dynamic adjustment of the wind field obtained by the ALADIN/Romania model, interpolated to a higher resolution, taking into account the new description of orography. It is well known that the wind field is highly influenced by the orography described in a numerical model. By increasing resolution, the orography is improved, and consequently the surface wind field is expected to be better forecasted. Two domains have been selected for its meteorological and economical interest. Besides a general evaluation in terms of statistical scores, the model results obtained with the high-resolution dynamical adaptation method for the surface wind forecast have been analysed for the case of two snowstorms. The aim of the paper is to compare the hydrostatic and non-hydrostatic ALADIN/Romania models' wind forecasts, when the high-resolution dynamical adaptation method has been applied.

Key words: dynamical adaptation, high-resolution, limited area model

1. INTRODUCTION

The wind field forecast in the planetary boundary layer is highly influenced by the orography described in the numerical weather prediction (NWP) model. There are many situations when the surface wind is mis-forecasted, mainly in the mountainous regions or on the seaside, because the model orography is smoother than in reality. The "surface wind" name is referring here to the 10 m wind.

The method used in this paper has been developed by Zagar and Rakovec (1999) and consists in a dynamical adaptation of the wind field forecast performed by the NWP model, interpolated to a finer grid. By increasing the horizontal resolution, the model's orography has been improved, its description being more accurate. As the wind field is following the new orography details, a better prediction of the field is expected to be obtained. It has to be mentioned, that during the model integration, parts of the physical parameterizations (which describe the moist and radiation processes) are not activated or are treated in a simplified manner. Therefore, the method is less expensive from the point of view of the computational cost than the operational model.

The present paper describes the results obtained using the high-resolution dynamical adaptation of the ALADIN/Romania hydrostatic and the non-hydrostatic mesoscale limited area models' surface wind forecast. In section 2, the application of the method for a dynamical adaptation of a coarse resolution NWP model forecast to a finer grid is explained in detail. At the beginning of section 3, a comparison against observations (in terms of statistical scores) of the operational forecast and using the dynamical adaptation method for the hydrostatic model, has been worked out for the surface wind during a period of five months, in order to validate the method. The high-resolution dynamical adaptation method has been developed to be applied for the hydrostatic limited area model. In this paper, results of the method for the non-hydrostatic ALADIN model are presented. In the second part of section 3, forecasts of the 10 m wind field obtained with the hydrostatic and non-hydrostatic ALADIN/Romania models' high-resolu-tion dynamical adaptation method are illustrated during two snowstorms. The conclusions are summarized at the end.

2. METHOD DESCRIPTION

The experiments for this study have been performed using the ALADIN spectral model. ALADIN is the limited area version of the **ARPEGE/IFS** global model, which has been operationally integrated at Météo-France and ECMWF. In 1987, the two centres put the basis of a new forecasting system. Thus the project is named IFS (**I**ntegrated **F**orecasting **S**ystem) at ECWMF, and ARPEGE (**A**ction de **R**echerche **P**etite **E**chelle **G**rande **E**chelle) at Météo-France. In the specialized literature, it is often referred to as "ARPEGE/IFS". In many European countries, the ALADIN model has been integrated in dynamical adaptation mode, which means that the model does not have its own analysis, and the initial state and the lateral boundary conditions are obtained through the interpolation of the ARPEGE analyses and forecasts onto the high-resolution grid of the limited area model (Horanyi *et al*., 1996). The coupling is carried out using the Davies relaxation technique, where the relaxation zone of the domain ensures the continuous transition between the boundary conditions and the ALADIN solution obtained every time-step. Because of the noise produced by the interpolation from the global to limited area geometry, the ALADIN model is using initialization to remove the fast propagating inertia-gravity waves from the initial conditions, which would cause numerical instability at the beginning of integration. Therefore, the time integration is preceded by the digital filter initialization (DFI) (Lynch *et al*., 1997).

The surface wind forecast dynamical adaptation procedure at high-resolution is performed in two steps. First the ALADIN/Romania model's wind forecast is interpolated from the 10 km horizontal resolution to a finer grid of about 2.5 km. At this moment, the interpolation process does not bring any new information about the atmospheric state. Then the model is integrated for a short period of time (for 30 minutes with the time step of 60 seconds) in order to dynamically adapt the wind field to these new characteristics of the relief. Due to the fact that the integration time for the dynamical adaptation is shorter than necessary to initialize some physical processes such as temperature changes due to radiation, water vapour condensation into a cloud layer, formation of the precipitation, these processes are further omitted. As mentioned by Zagar and Rakovec (1999) if the coupling model forecast is bad (mainly in the cases of local thermal circulation or circulation caused by convective processes), the dynamical adaptation of the wind field at higher resolution cannot be improved.

Due to the fact that the wind forecast is mainly influenced by orography, the number of vertical levels in the higher troposphere and stratosphere has been reduced, while in the lower troposphere, it was increased. Thus, from the 41 levels the ALADIN/Romania model's operational version has, 26 levels were kept (being considered as a reasonable number), located especially in the lower part of the troposphere (Figure 1).

3. EXPERIMENTAL RESULTS

The aim of the first experiments using the method developed by Zagar and Rakovec (1999) was to see whether the method is able to improve the ALADIN/Romania model's surface wind forecast. In this respect, the results have been compared for a period of five months with the real measurements and the operational forecasts. Thus, the verification scores against observations are presented in the first part of this chapter.

As mentioned before, the dynamical adaptation method has been developed to be applied for the hydrostatic limited area model. It was interesting to see how the results are influenced using the non-hydrostatic model. In the second part of this chapter, the hydrostatic and non-hydrostatic ALADIN/Romania models'surface wind field forecasts are compared during two snowstorms.

The experiments have been realized using the ALADIN/Romania limited area model. This model is operationally integrated at the National Meteorological Administration, twice per day, for 00 UTC and 12 UTC, obtaining the weather forecasts for 48 hours. For a high-resolution of the surface wind forecast, two domains have been used. The first one is covering the Danube Delta and the Romanian Black Sea coast (called here as domain A), and it was selected to see whether a better description of the orography can significantly improve the wind forecast.

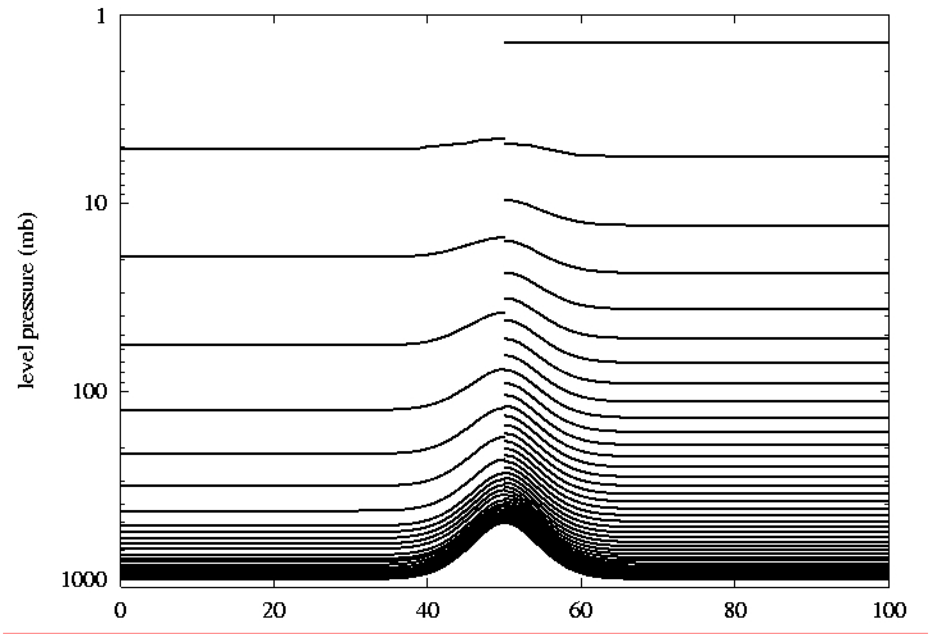


Figure 1. Distribution of vertical levels for the ALADIN/Romania model in high-resolution dynamical adaptation at high resolution (left side) and for the operational version (right side)

The second one is located in the mountainous regions (where the topography is expected to be described more accurate), including the Prahova and Olt Valleys (domain B).

3.1. General evaluation

The analyses (the model's initial states) and forecasts were verified against all the surface observations inside the domains, using simple statistical scores, as mean error (BIAS), root mean square error (RMSE) and mean absolute error (MAE). These objective scores are computed for the model results using high-resolution dynamical adaptation, and also the operational one, with respect to the surface measurements. A period of five months (11.10.2004 – 11.03.2005) were considered for the general evaluation. The compared fields are the surface wind's direction and intensity.

Three different types of the verification scores representation are analysed further. For each station of the two domains, the statistical scores were expressed as percents of three different performance classes, namely *good* (when the wind direction error is less than 30 degrees), *medium* (when the wind direction error is between 30 - 60 degrees) and *bad* (when the wind direction error is higher than 60 degrees). For a better visualisation, the difference between the percents of each performance classes were computed, thus the positive values represent higher values for the model using the high-resolution dynamical adaptation method than the operational version, while the negative values illustrate the reverse. One can see in Figure 2 that the most significant improvements in January 2005 were found for the following stations from domain B: Miercurea Ciuc (15170), Dumbraveni (15189), Fagaras (15217), Sfantu Gheorghe (15238), Fundata

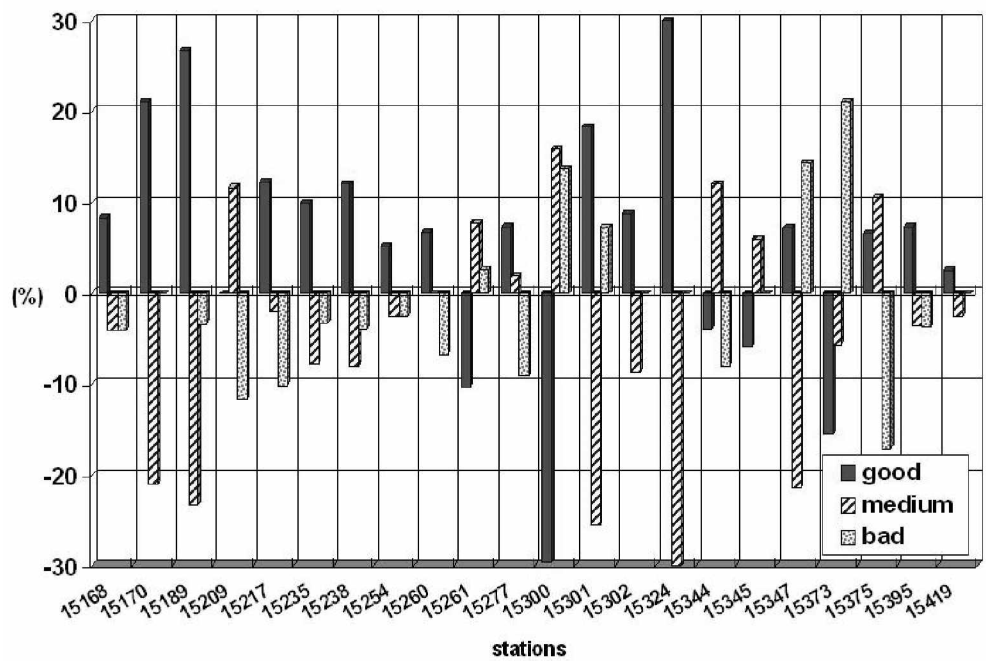


Figure 2. Difference between the percents of different performance classes (good, medium, bad) for the 10 m wind direction, obtained by the ALADIN/Romania model's 6h forecast in dynamical adaptation at high resolution and for the operational version, for some stations in domain B, in January 2005.

(15301), Campulung Muscel (15324), while the operational forecast scores look better for Intorsura Buzaului (15261), Brasov (15300), Pitesti (15373). There are also some stations where the operational model and the hydrostatic model with the dynamical adaptation method performed equally well (not shown). Generally the topography has been improved as a result of increasing horizontal resolution. Thus new valleys and higher peaks appeared. But there are few stations whose height is not described so accurate by the model, which leads to a mis-forecast of wind direction.

The surface wind direction verification for domain A showed a positive impact of the high-resolution dynamical adaptation method, only that smaller correction of orography, than for the other chosen domain. While the highest altitude for domain A is situated at around 350 m, in the mountainous region (domain B), it can reach even 2300 m height.

The representation of statistical scores (BIAS, MAE, RMSE) revealed again the improvements brought to the surface wind forecast by the high-resolution dynamical adaptation method, mainly for domain B, where the changes in orography are more important. Figure 3 presents the root mean square error distribution for the operational model's 6h surface wind speed forecast, and the high-resolution dynamical adaptation method, for the stations in domain A. One can see that the most significant improvements,

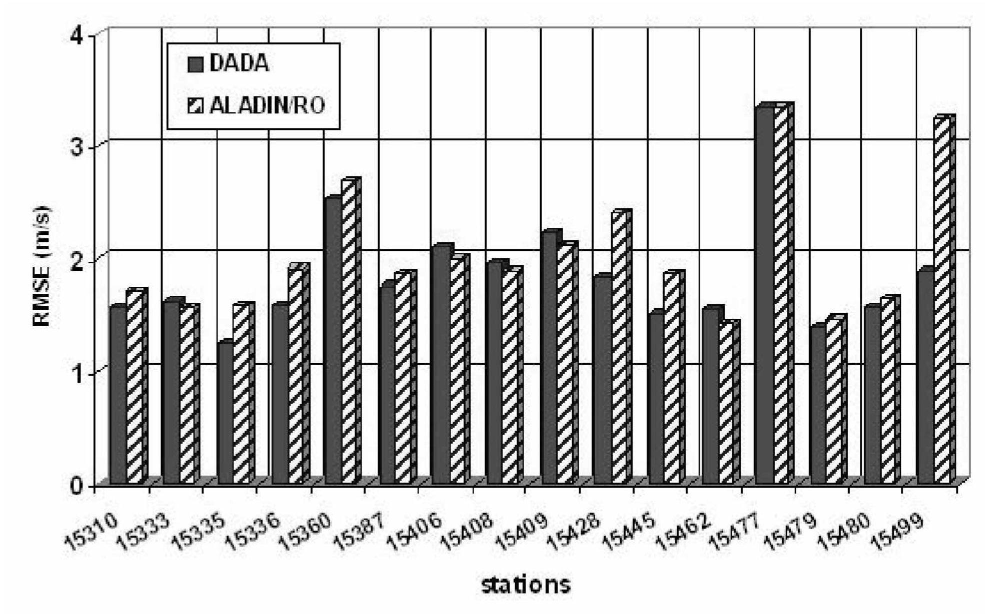


Figure 3. RMSE distribution of the 10 m wind speed, from the 6h forecast of the ALADIN/Romania model in dynamical adaptation at high resolution (named 'DADA') and for the operational version (named 'ALADIN/RO') between 11.10.2004 – 11.03.2005, for some stations from domain A.

meaning smaller values for the RMSE scores were obtained for Mangalia (15499), Gura Portitei (15428), Tulcea (15335), Sulina (15360) stations by the model using the high-resolution dynamical adaptation method, while for the difference is smaller than in the mountainous region (not shown). This small difference between results for the seaside domain was expected to a certain extent, because in these regions the increase of resolution leads to a

Harsova (15406), Corugea (15408), Jurilovca (15409), Medgidia (15462), the operational forecast had a slight advantage. The altitudes for each station, as it is in reality, and how they are considered in the two models, have been compared. Thus, it was seen that the hydrostatic model at 2.5 km horizontal resolution slightly under-estimated the height of the stations for which the operational forecast was better.

An average of mean absolute errors for the 6h forecast has been computed for each month, in order to see the evolution of the model performances over the entire domain. Generally, the high resolution dynamical adaptation method showed a more positive impact than the operational model, especially for domain B, where the orography was changed (Figure 4). Over domain A, the differences are quite small. These results confirm that, generally, in the regions where the topography is not very high, the increase of horizontal resolution brings just a small improvement to the orography. Therefore, significant changes in the surface wind forecasts cannot be expected.

In conclusion, the verification scores showed that the wind field's high-resolution dynamical adaptation method fits the observations better than the ALADIN/Romania model's operational version, as a result of a finer description of the orography at a higher resolution.

3.2. Results for two snowstorms

From the previous sub-chapter, it was seen that the dynamical adaptation method for the hydrostatic model had a bigger impact for domain B, than for domain A, due to changes in the model's orography. In this second part of the chapter the results of the high-resolution dynamical adaptation method for the hydrostatic and non-hydrostatic ALADIN/Romania models have been compared in some interesting meteorological situations, in order to assess whether the non-hydrostatic model can improve the surface wind forecast. The steps followed for the dynamical adaptation of the high-resolution of the non-hydrostatic model's wind forecast are the same as for the hydrostatic model, only that the first one implies more new

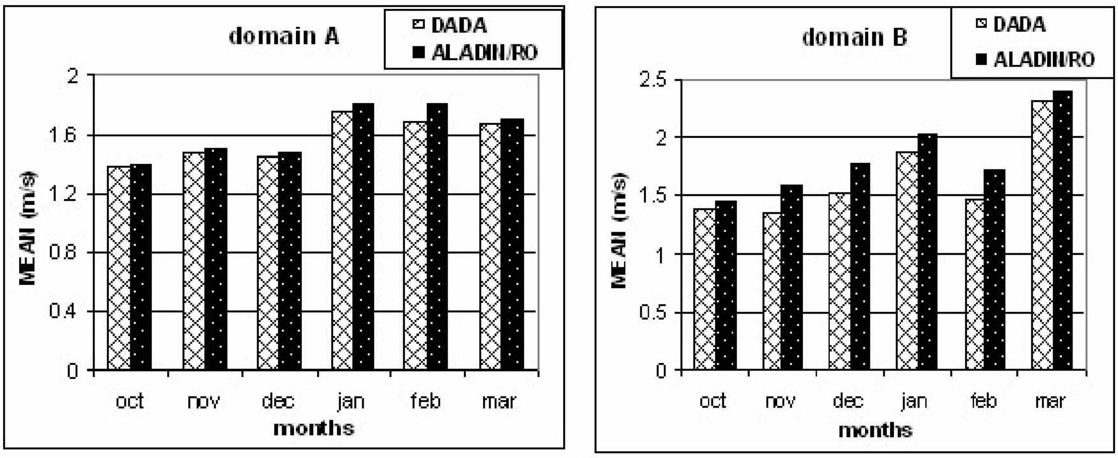
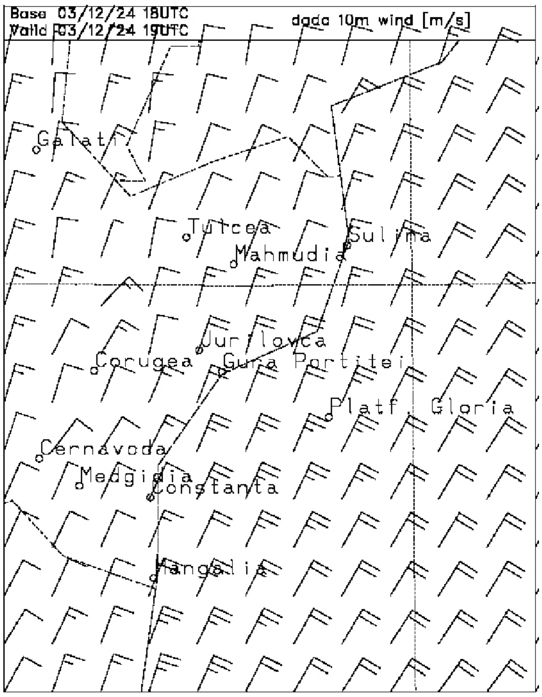


Figure 4. 10 m wind speed's mean absolute errors means for each month, for the ALADIN/Romania model's 6h forecast in dynamical adaptation at high resolution (named 'DADA') and for the operational version (named 'ALADIN/RO') obtained for the domains A (left side) and B (right side)

computations (for the non-hydrostatic part).

Thus two severe snowstorms, which affected Romania between the 23rd and the 25th of December 2003, respectively the 23rd and the 24th of January 2004, have been selected. The first case (during the Christmas time of 2003) has been distinguished due to the significant quantity of precipitation, which fell over large areas. Also the wind field intensity reached 15 m s^{-1} in the eastern and southern parts of the country (Andrei *et al.*, 2004).

All the results of experiments with the limited area model were checked against the observations, measured at the time when the forecast is valid. For domain A, in Figure 5 one can see the surface wind forecast obtained with high-resolution dynamical adaptation method for the hydrostatic model (in the left hand side) and for the non-hydrostatic model (in the right hand side). There are not differences in the wind direction between the two forecasts. Regarding the wind intensity, both models at 2.5 km resolution succeeded to give a rather similar prediction (as it is illustrated in Table 1), although the biggest values of the 10 m wind have not been forecasted. Again, we can recognize the highest mis-forecasts for the stations where the orography was slightly under-estimated.



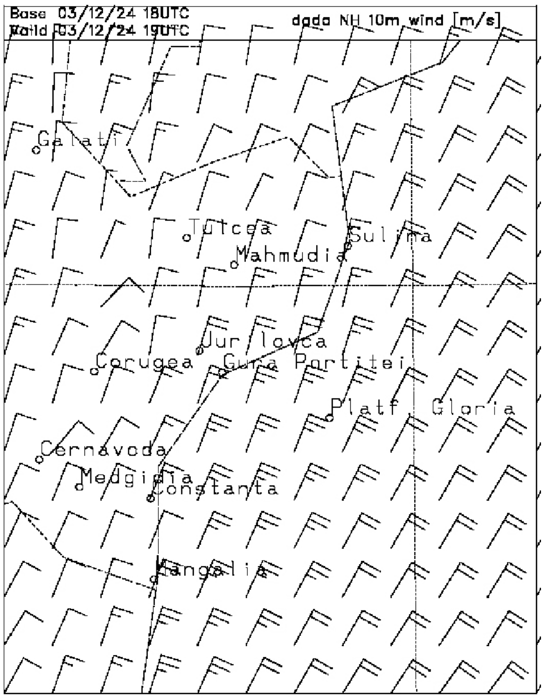


Figure 5: The 10 m wind forecast for domain A, using the high-resolution dynamical adaptation method for the hydrostatic (left side) and non-hydrostatic (right side) ALADIN/Romania models, from 24.12.2003 12 UTC run, valid at 24.12.2003 18 UTC

Table 1. The 10 m wind speed (ms^{-1}) at the stations in domain A, from the forecast of the hydrostatic (**H**) and non-hydrostatic (**NH**) ALADIN/Romania models, using the high-resolution dynamical adaptation method, and from the observations (**Obs**), valid at 24.12.2003 18 UTC

	Galati	Tulcea	Mahmudia	Sulina	Corugea	Jurilovca	Gura Portitei	Cernavoda	Medgidia	Ptf. Gloria	Constanta	Mangalia
H	8	4	6	9	7	9	12	4	5	13	7	9
NH	8	5	6	9	6	9	12	4	5	13	8	9
Obs	9	12	24	20	16	18	14	10	16	25	20	6

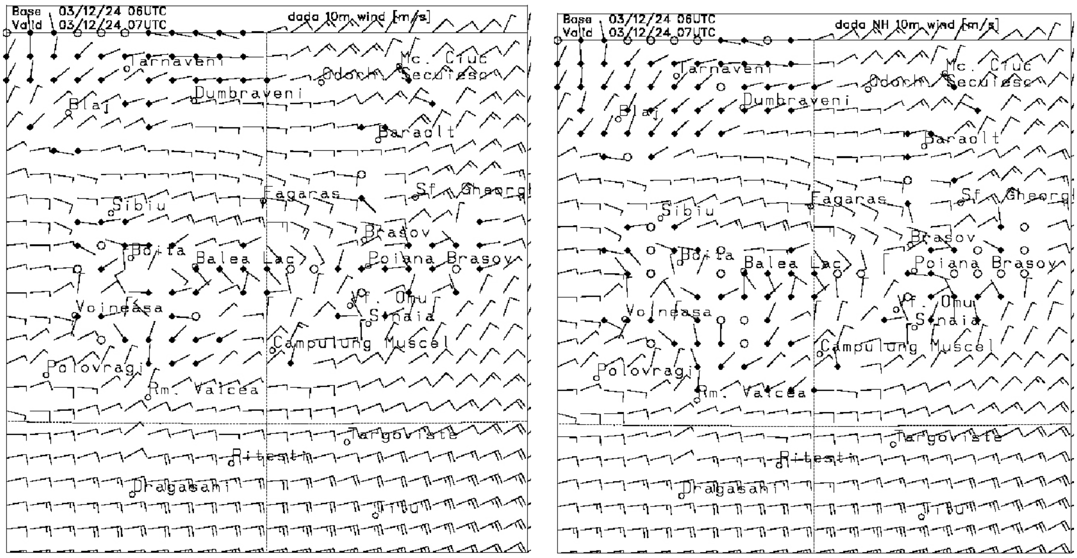


Figure 6: The 10 m wind forecast for domain B, using the high-resolution dynamical adaptation method for the hydrostatic (left side) and non-hydrostatic (right side) ALADIN/Romania models, from 23.12.2003 12 UTC run, valid at 24.12.2003 06 UTC

Figure 6 illustrates similar results for domain B, both in direction and intensity, obtained by the non-hydrostatic and the hydrostatic models, using the high-resolution dynamical adaptation method. The wind direction is following the details of the new orography, at 2.5 km horizontal resolution. Regarding the 10 m wind speed, one can see in Table 2 that the two models behave reasonably well, by comparison with the real measurements. There are some stations, for which the wind intensity has been over-estimated, as it is the case for Titu and Dragasani, due to not so accurate description of its altitude.

The second case used as a test bed for the dynamical adaptation of surface wind is also a snowstorm event that affected Romania. It was remarkable mainly due to the wind intensities and less to the precipitation amount. Thus, on 22^{nd} - 23^{rd} of January 2004, in some regions the wind speed measured even 70-80 km h^{-1}. The

Table 2. The 10 m wind speed (ms^{-1}) at the stations in domain B, from the forecast of the hydrostatic (**H**) and non-hydrostatic (**NH**) ALADIN/Romania models, using the high-resolution dynamical adaptation method, and from the observations (**Obs**), valid at 24.12.2003 06 UTC

	Tarnaveni	Od. Secuiesc	Mc Ciuc	Dumbraveni	Blaj	Baraolt	Fagaras	Sf. Gheorghe	Sibiu	Boita	Balea Lac	Vf.Omu	Poiana Brasov	Brasov	Voineasa	Campulung Muscel	Sinaia 1500	Polovragi	Rm. Valcea	Pitesti	Targoviste	Dragasani	Titu
H	2	4	4	3	3	3	7	6	2	2	2	5	4	3	2	5	3	6	4	8	8	8	13
NH	1	3	4	2	1	3	7	6	2	2	1	4	3	3	2	4	3	5	3	7	8	8	13
Obs	3	6	4	0	3	3	2	4	1	3	1	6	1	3	1	14	8	0	1	0	2	0	1

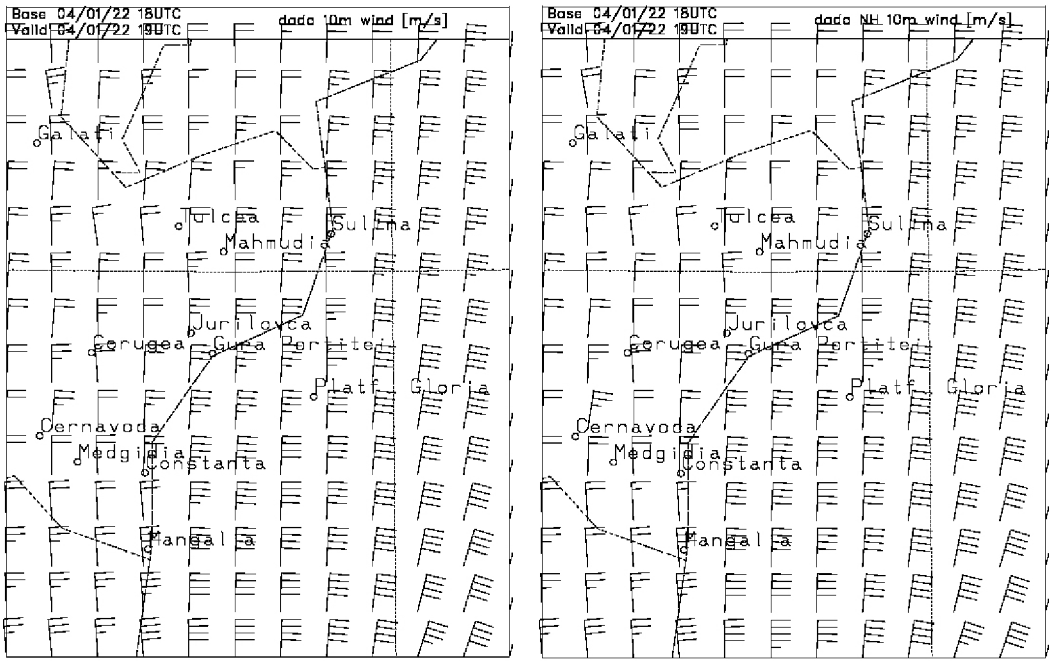


Figure 7. The 10 m wind forecast for domain A, using the high-resolution dynamical adaptation method for the hydrostatic (left side) and non-hydrostatic (right side) ALADIN/Romania models, from 22.01.2004 00 UTC run, valid at 22.01.2004 18 UTC

wind blew unceasingly, producing waves of up to 8 m height over the Black Sea (Andrei *et al.*, 2004).

The forecasts obtained in dynamical adaptation at a high-resolution by the non-hydrostatic and hydrostatic models, for domain A, emphasize the significant 10 m wind intensities. Generally, Figure 7 illustrates similar results for wind direction. Also, regarding the wind speed, only very small differences (not higher than 1 m s^{-1}) between the two models are shown in Table 3. By comparing with the observations, one can see the strong wind predicted over the Black Sea.

Table 3. The 10 m wind speed (ms^{-1}) at the stations in domain A, from the hydrostatic (**H**) and non-hydrostatic (**NH**) ALADIN/Romania models' forecast, using the high-resolution dynamical adaptation method, and from the observations (**Obs**), valid at 22.01.2004 18 UTC

	Galati	Tulcea	Mahmudia	Sulina	Corugea	Jurilovca	Gura Portitei	Cernavoda	Medgidia	Ptf. Gloria	Constanta	Mangalia
H	12	9	13	15	14	12	18	10	10	20	11	13
NH	11	11	13	14	13	12	18	11	11	20	12	13
Obs	9	12	24	20	16	18	14	10	16	25	20	6

Table 4. The 10 m wind speed (ms^{-1}) at the stations in domain B, from the hydrostatic (**H**) and non-hydrostatic (**NH**) ALADIN/Romania models' forecast, using the high-resolution dynamical adaptation method, and from the observations (**Obs**), valid at 22.01.2004 18 UTC

	Tarnaveni	Od. Secuiesc	Mc Ciuc	Dumbraveni	Blaj	Baraolt	Fagaras	Sf. Gheorghe	Sibiu	Boita	Balea Lac	Vf.Omu	Poiana Brasov	Brasov	Voineasa	Cp Muscel	Sinaia 1500	Polovragi	Rm. Valcea	Pitesti	Targoviste	Dragasani	Titu
H	7	3	4	3	5	2	5	3	2	3	6	5	4	5	3	6	8	10	8	4	1	7	1
NH	7	3	4	3	5	2	5	3	3	3	6	5	3	5	2	6	8	9	8	4	1	7	1
Obs	11	0	2	4	4	3	12	3	4	2	5	12	2	6	2	8	12	2	7	4	2	5	1

The difference of 5 m s^{-1} for Gloria Platform appeared due to the fact that the station is situated at about 30 m height, while both models consider the grid point at sea level.

For the same case, the high-resolution dynamical adaptation procedure has been performed as well for domain B, even if the snowstorm has not affected too much this region. Changes in wind direction were not observed, both models using the same orography at 2.5 km horizontal resolution (not shown). The forecasted and observed wind speed values are presented in Table 4.

Again, the differences between the non-hydrostatic and hydrostatic models, using the dynamical adaptation method, are very small. There are some stations where the model under-estimated the orography (Tarnaveni, Varful Omu, Sinaia), causing thus an under-estimation of the wind speed. However, the dynamical adaptation method performed reasonably well.

Besides comparing the results obtained from the two models, it was interesting from the "operational" point of view to assess the computing time needed for running the dynamical adaptation procedure.

Figure 8 presents the evaluation for a SUN E4500 workstation, which is used at the National Meteorological Administration, for the operational ALADIN suite. The non-hydrostatic interpolation of only one forecast range from 10 to 2.5 km (labeled in the picture as “EE927”) is performed in about 17 seconds (for domain B, considering that it is larger than domain A) in comparison with the 12 seconds, necessary for the hydrostatic one. Due to the new computations involved by the non-hydrostatic model, wherein some physical parameterizations are not even used, its integration using the dynamical adaptation method (step “C001”) lasts more than two times longer (almost 120 seconds) for only one forecast range, in comparison with the hydrostatic model (about 52 seconds).

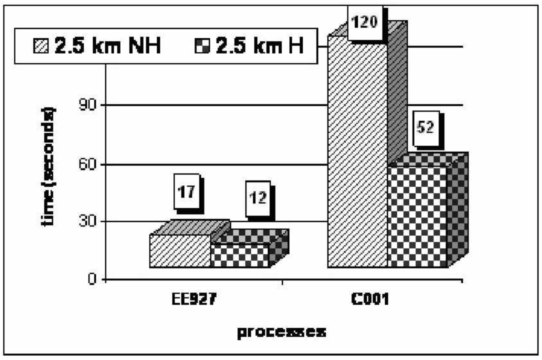


Figure 8. The processing time (in seconds) necessary for only one forecast range performed by the non-hydrostatic (**2.5kmNH**) and hydrostatic (**2.5kmH**) ALADIN/Romania models, using the high-resolution dynamical adaptation method.

One can see that the main part of the computation time is dedicated to the non-hydrostatic model’s integration. Still, a comparison between the results presented before has not proved a better performance of the non-hydrostatic model, using the dynamical adaptation method, than that of the hydrostatic model. In this regard, it is preferable to use operationally a less computational method for the dynamic adjustment of the surface wind field.

Therefore, the results presented in this section have proved that the high-resolution dynamical adaptation procedure for the hydrostatic model can improve the surface wind forecast due to a better description of the model’s orography and to the higher horizontal resolution, at a lower cost than the non-hydrostatic model.

4. CONCLUSIONS

In this paper, an efficient method of improving the surface wind forecast at a high-resolution has been presented. The method consists in the dynamical adaptation of the wind forecast, obtained by the ALADIN/Romania limited area model (operationally integrated at 10 km horizontal resolution), when it has been interpolated at a higher resolution (of 2.5 km). The increase in resolution over new domains leads to a more accurate description of the orography. It is well known that the relief influences the surface wind field, therefore a better prediction than the operational forecast is achieved. It must be mentioned that, during the model integration, parts of the physical parameterizations (which describe the moist and radiation processes) have not been activated, thus decreasing the computational time and the cost of the method. For the experiments performed with this method two domains of meteorological and economical interest have been selected. One includes the Romanian Black Sea coast and the Danube Delta, and the other, the Prahova and Olt Valleys.

The general evaluation of the method has been realized by comparing the analyses and forecasts obtained through the operational version and using the high-resolution dynamical adaptation method for the ALADIN/ Romania hydrostatic model, with the observations. The verification period covered five months, in order to have representative conclusions regarding the results of the dynamical adaptation method at a higher resolution. The statistical scores (mean error, root mean square error and mean absolute error) have revealed significant improvements of the surface wind field especially in the mountain regions, where the orography has been described more precisely. Also for the domain including the Romanian Black Sea coast, the verification scores illustrate a slight advantage for the dynamical adaptation method.

Two severe snowstorms, which affected Romania during the winter of 2003 – 2004, have been used for comparing the method applied in the hydrostatic and non-hydrostatic ALADIN/ Romania models. The first case has been distinguished mainly by important precipitation amounts, while the second one, by strong wind. For both cases, the results of the hydrostatic and non-hydrostatic models are relatively similar. Regarding the wind direction, there have not been seen significant differences between the forecasts of the two models. Also the 10 m wind speed predictions obtained during the snowstorms differ by only 1 m/s.

In conclusion, this paper has shown that the dynamical adaptation of the surface wind field at a higher resolution is a very useful method for improving the ALADIN/Romania model's forecast. Considering the needed integration time of the non-hydrostatic model (almost 2.5 times longer than for the hydrostatic model), the results of the experiments have not proved the need to use operationally the non-hydrostatic model for the dynamical adaptation procedure of the wind field. Similar results can be obtained with the hydrostatic model, at a lower cost. Therefore, it has been decided to use operationally the dynamical adaptation method for the hydrostatic ALADIN/Romania model, in order to provide the surface wind forecast at a high-resolution for the two domains described above.

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