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# HIGH RESOLUTION EXPERIMENTS WITH THE AROME NUMERICAL WEATHER PREDICTION MODEL OVER HUNGARY

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## ABSTRACT

This paper summarizes the developments related to the spatial and temporal upgrade of the AROME non-hydrostatic numerical weather prediction model run at the Hungarian Meteorological Service. Horizontal and vertical resolution of the model is increased from 2.5 km to 1.3 km and from 60 to 90 vertical levels, respectively. Changes in the physical parameterizations related to the resolution increase are described and their impact is demonstrated by verification results from long time periods. It is shown that simulation of cloud cover is highly sensitive to the setting of the microphysical parameterization. The data assimilation system was also adapted to better represent severe weather events. The three hourly assimilation cycle of AROME was increased to an hourly Rapid Update Cycle. Results show that in the case of precipitation and temperature, the use of the hourly assimilation leads to some improvement which is especially useful for the purpose of short-range forecasting and nowcasting.

**Keywords: data assimilation, cloud microphysics, numerical weather prediction, physical parameterization, rapid update cycle, verification**

## 1. INTRODUCTION

For this study, the AROME non-hydrostatic high resolution model was used [1]. The development of AROME (Application of Research to Operations at Mesoscale) was initiated at Meteo-France [2] at the beginning of the 2000's and is currently further developed in the ACCORD NWP modelling consortia. The AROME model has three main components: the non-hydrostatic ALADIN dynamical core [3, 4], the atmospheric physical parameterizations, which are taken from the French Meso-NH research model [5] and the SURFEX land-surface model [6]. A mesoscale data assimilation system with a three-dimensional variational (3D-VAR; [7]) scheme for the upper-air and an optimum interpolation [8] technique for the surface analyses provides reliable local initial conditions for the AROME model.

At the Hungarian Meteorological Service (OMSZ) the AROME model is run operationally since 2010 [9]. The model is integrated at 2.5 km horizontal resolution with 60 vertical levels and uses lateral boundary conditions from the IFS (Integrated Forecasting System) model of ECMWF. The AROME assimilation system, using conventional observations (SYNOP, radiosoundings, AMDAR), was operationally implemented in 2013 [10].

Currently, the AROME model is running eight times a day with lead times out to +48 h. The assimilated measurements are extended with Mode-S and GNSS data [11]. On the medium term it is planned to further increase both the model resolution (to 1.3 km) and the frequency of the runs (to hourly forecasts). In this way OMSZ can serve its users with more accurate weather forecasts at higher spatial and temporal resolutions and more frequent updates during the day. Such users are on the one hand internal users (forecasters) responsible for issuing warnings of severe weather and on the other hand external users mainly from the renewable energy industry (operating solar and wind power plants).

## 2. CHOICE OF PHYSICAL PARAMETERIZATIONS

To reflect users' needs both higher horizontal and vertical resolution of the AROME model was tested. In the horizontal, the resolution was increased from 2.5 km to 1.3 km by keeping the original physical size of the domain, resulting in about four times as much horizontal gridpoints. The number of vertical levels was increased from 60 to 90, resulting in more vertical levels in the Planetary Boundary Layer (PBL) and with the height of the first model level decreasing from 10 m to 5 m. Most of the settings in the dynamical core and physical

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parameterizations of this new 1.3 km AROME version are identical with the operational AROME run at Meteo-France [12]. To improve model performance some tuning regarding the microphysics scheme was performed which is described in the following. The goal of these first experiments with the higher model resolution was to get a comparable model performance to the operational 2.5 km AROME. Later, these high resolution model settings were serving as a basis for the high resolution data assimilation experiments (described in Section 3).

## *2.1. Experimental Setup*

The 2.5 km AROME version run operationally at OMSZ applies a diagnostic formulation [13] for the subgrid statistical cloud scheme, while at Meteo-France a prognostic one [14] is used. The two schemes produce a significantly different cloud cover: the diagnostic formulation simulates smooth cloud fields while the prognostic formulation tends to produce a cloud cover value with two categories ("zero or one"), with lower average values.

As in the operational AROME the diagnostic formulation has a positive bias for cloud cover, it was decided that the prognostic formulation is tried for the 1.3 km version (further referred to as "vsig2"). However, this resulted in too low cloud cover, consequently some tuning was applied for the VSIGQSAT parameter. VSIGQSAT is a parameter from the subgrid condensation scheme that is linked to the width of the probability density function (PDF) of the subgrid variance of the saturation departure. This parameter is only used in the case of the prognostic formulation of the statistical cloud scheme. The higher the VSIGQSAT is, the larger the variance of the PDF and it is easier for the model to condense water in a fraction of the grid, thus simulation more clouds. The default value of VSIGQSAT is 0.02 and in the sensitivity experiments a value of 0.06 was tested (referred to as "vsig6").

The first experiments with the higher vertical and horizontal resolution were not using data assimilation, as this would require the recomputation of the background error covariance matrix which in turn needs the running of the model. Atmospheric initial conditions for the 1.3 km AROME runs were interpolated from the IFS forecasts of ECMWF. Initial soil fields (soil moisture and temperature) were interpolated from the operational AROME model on the first day of the experiment and soil was running freely (i.e. without soil assimilation) during the whole experimental interval.

These experimental 1.3 km runs (with 90 levels) were compared to the operational AROME run at 2.5 km and 60 levels (using data assimilation, referred to as "oper") and to a reference 2.5 km run with 90 levels and no data assimilation (referred to as "ref_2.5km90L"). To assess the impact of the subgrid statistical cloud scheme, a run with 1.3 km resolution and the diagnostic cloud scheme was also completed (referred to as "losig_F"). Main settings of these experiments are summarized in Table 1.

**Table 1. Main settings of the experiments related to physical parameterizations.**

| **Experiment** | **oper** | **ref_2.5 km90L** | **losig_F** | **vsig2** | **vsig6** |
|---|---|---|---|---|---|
| Resolution | 2.5 km | 2.5 km | 1.3 km | 1.3 km | 1.3 km |
| Vertical levels | 60 | 90 | 90 | 90 | 90 |
| Data assimilation | yes | no | no | no | no |
| Statistical cloud scheme | diag | diag | diag | prog | prog |
| VSIGQSAT | - | - | - | 0.02 | 0.06 |

Three longer time periods were run (around 25 days each): in January 2021, in May 2021 and in July 2021. During these periods, 30-hour long forecasts were made starting at 00 UTC each day. Results were basically similar in the three time periods, consequently, in the following only results from the July period are shown. This summer period (from 7 to 28 July) was abounded with high precipitation and other severe weather events.

## *2.2. Verification*

In order to assess the impact of the resolution increase and the physical parameterization tuning to the quality of the forecast, pointwise verification was carried out using the Objective Verification System (OVISYS), which is a software developed by OMSZ. OVISYS compares the forecast to the observations measured by the national synoptic stations and calculates different indices (e.g. root mean square error, bias) that can be used to evaluate the quality of the forecast.

Figure 1 shows the impact of the different configurations on the simulation of cloud cover. If we compare "oper" with "ref_2.5km90L" we can note that increasing the vertical resolution increases the cloud cover. If we increase the horizontal resolution as well using the same parameterization settings (comparing "ref_2.5km90L" with "losig_F"), then cloud cover is overestimated even more. If we use the prognostic cloud scheme with the default value of VSIGQSAT ("vsig2") then cloud cover is significantly underestimated. This can be improved by tuning the VSIGQSAT parameter (comparing "vsig2" and "vsig6"). If we compare the "ref_2.5km90L" and "vsig6" experiments, we can conclude that increasing the horizontal resolution and applying the new physical parameterization settings at the same time improves the quality of cloud cover forecasts.

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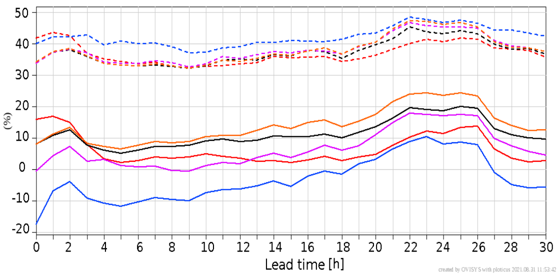


**Figure 1. Bias (solid lines) and Root Mean Square Error (dashed lines) of cloud cover from different AROME experiments computed by OVISYS. Experiments: red: "oper"; black: "ref_2.5km90L"; orange: "losig_F"; blue: "vsig2"; purple: "vsig6".**

Figure 2 shows the verification scores for 2 metre temperature. For this parameter the "oper" configuration is clearly the best, however, we have to note that this version uses such a 2 metre diagnostic which is not recommended for 90 vertical levels. If we compare only the 90 level configurations, we can conclude that "ref_2.5km90L" is the best, so for 2 metre temperature the higher horizontal resolution does not bring any benefit.

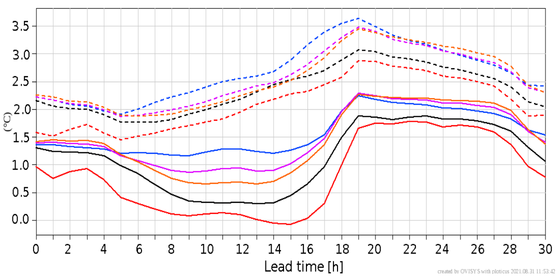


**Figure 2. Same as Fig. 1 but for 2 metre temperature.**

For the assessment of precipitation forecasts next to the computation of pointwise verification scores (not shown here) a spatial verification method using radar measurements was also applied [13, 14]. For summer convective precipitation, initial conditions are highly important in the first 6-8 hours of the forecast, so we should only compare the experiments without data assimilation (i.e. all experiments except for "oper").

Figure 3 shows the daily evolution of the average intensity of the three strongest precipitation objects. It can noted that the 2.5 km resolution AROME tends to overestimate convective precipitation in the morning hours and during nighttime, while it is more accurate during the afternoon hours. The 1.3 km resolution experiments are close to each other and all of them are underestimating convective precipitation in the afternoon. All model versions simulate the onset of convective precipitation fairly well.

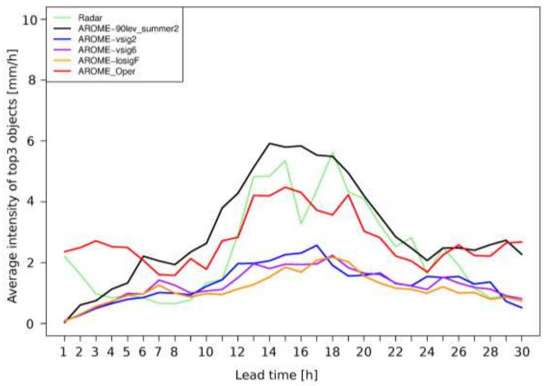


**Figure 3. Daily evolution of the average intensity of the three strongest precipitation objects computed from radar measurements (green) and AROME experiments (same colour notation as in Fig. 1).**

## 3. EXPERIMENTS WITH 1-HOURLY CYCLING IN DATA ASSIMILATION

With the introduction of a finer spatial resolution in the AROME numerical weather prediction model, it is possible to improve the quality of some forecast parameters as demonstrated in the previous section. However, there are several examples of specific weather events (especially the ones linked to convection) that demonstrate not only the need to model small-scale phenomena, but also to the need to adapt the time scale of the data assimilation to better represent these events. In addition, the growing number of observations with sub-hourly frequency (e.g. radars, wind profilers, Mode-S datasets) motivates the use of 1-hourly cycling in data assimilation, as it enables the use of the most recent observations in the forecast.

### *3.1. The Rapid Update Cycle*

The Rapid Update Cycle (RUC) is an assimilation method developed by Benjamin et al. [17, 18] with the primary purpose of addressing the above mentioned issues. The 1-hourly RUC is designed to use the most recent observations each hour, which are then combined with the forecast from the previous hour in order to produce a new analysis as an estimate of the current state of the atmosphere. This estimate is then used to produce the background field for the next hour.

In theory, this approach of high-frequency data assimilation is highly beneficial for the purpose of short-range forecasting, however in practice, the use of the 1-hourly RUC does not guarantee more accurate forecasts, especially if the quantity or quality of the high-frequency observations to be used in the RUC are not adequate (see [18] for a detailed description of the potential issues).

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### 3.2. Experimental Setup

Two experimental setups were used in order to assess the impact of applying the 1-hourly RUC. The first experiment (EXP_1.3) was created with 1.3 km horizontal resolution and 90 vertical levels as explained in the previous section, while the second experiment (EXP_2.5) used 2.5 km horizontal resolution with 60 levels. Both experiments were based on the current operational AROME model (OPER) with the common difference being the use of the 1-hourly RUC which is not present in the operational setup. EXP_1.3 was also modified to use the VSIGQSAT value of 0.06 instead of the default value of 0.02 to match the 'vsig6' experiment described in the previous sections which yielded the best results compared to the operational forecast. Based on earlier experiments, a symmetrical assimilation window was chosen: –30 and +30 minutes in hourly RUC experiments, –90 and +90 minutes in the 3-hourly operational forecasts.

The most important parameters for each setup are provided in Table 2.

**Table 2. Main parameters of the two experimental setups and the operational AROME model.**

| Experiment | EXP_1.3 | EXP_2.5 | OPER |
|---|---|---|---|
| Resolution | 1.3 km | 2.5 km | 2.5 km |
| Vertical levels | 90 | 60 | 60 |
| Cycling | 1-hourly | 1-hourly | 3-hourly |
| Assimilation window | –30 min/+30 min | –30 min/+30 min | –90 min/+90 min |
| VSIGQSAT | 0.06 | 0.02 | 0.02 |

Both experimental setups were run on the three week period (i.e. between 7 and 28 July 2021 with a spin-up period between 1 and 7 July) studied in the previous sections, as the summer forecast may benefit the most from the application of 1 hourly cycling. During this period, 30 hour long forecasts were made at 00 UTC each day.

### 3.3. Verification

In order to assess the impact of implementing the 1-hourly RUC on the quality of the forecast, pointwise verification was carried out using OVISYS.

It can be concluded that both experiments using the 1-hourly RUC yield somewhat better forecasts than the operational model, albeit the results vary greatly for different meteorological parameters. For instance, Figure 4 illustrates the quality of the 21 hour long forecast of the 6-hourly sum of precipitation using the Equitable Threat Score (ETS). The ETS is an index that compares the given forecast to a fictional random forecast in relation to pre-defined threshold values and by definition gives a value on a scale between –1/3 and 1, where 1 would indicate a perfect forecast and 0 a random forecast (negative values indicate that the given forecast is even worse than a random one). As demonstrated in Fig. 4, the ETS scores for precipitation are the highest for EXP_1.3, while in the case of EXP_2.5 only the scores for the higher precipitation thresholds are improved compared to the OPER. Using different indices and forecast lengths show similar results, therefore it can be concluded that the combination of the high resolution model and the 1-hourly RUC can be expected to improve the quality of the forecast the most, at least in the case of precipitation.

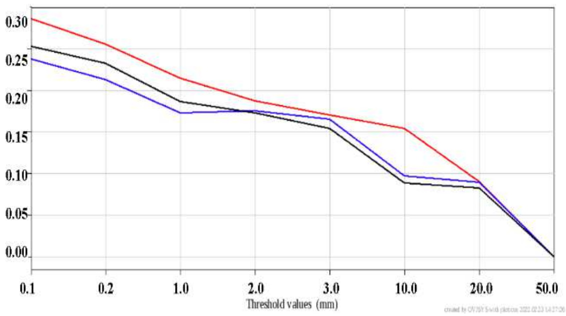


**Figure 4. Equitable Threat Scores (ETS) for 21 hour long forecasts of 6 hour sum of precipitation in the EXP_1.3 (red) and EXP_2.5 (blue) experiments and the OPER model (black) in relation to the pre-defined thresholds for precipitation.**

Regarding three other parameters, a substantial improvement can be observed in the case of 2 metre temperature (Figure 5), especially in the EXP_1.3 setup.

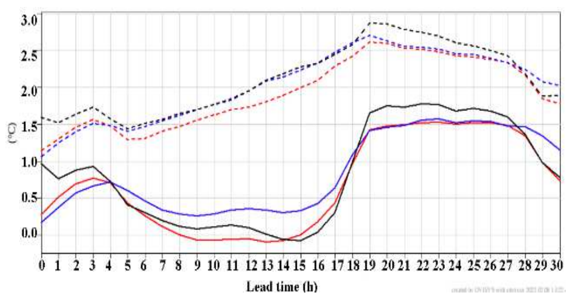


**Figure 5. Bias (solid line) and RMSE (dashed line) scores of 2 metre temperature for different forecast lengths in the EXP_1.3 (red) and EXP_2.5 (blue) experiments and the OPER model (black).**

In contrast, the cloudiness and 10 metre wind parameters and also the upper level wind forecasts demonstrate much greater errors in both experiments than those observed in the OPER model (Figure 6). Further investigation is needed in

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order to determine the cause of this deterioration of wind forecast quality in the 1-hourly RUC setups.

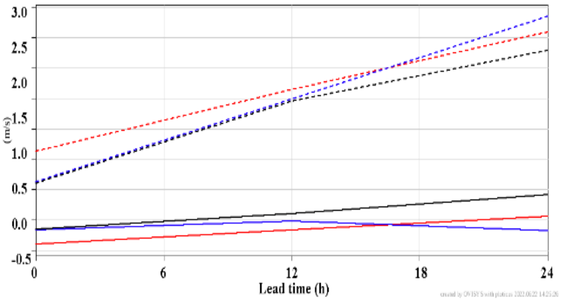


**Figure 6. Bias (solid line) and RMSE (dashed line) scores of 925 hPa wind speed for different forecast lengths in the EXP_1.3 (red) and EXP_2.5 (blue) experiments and the OPER model (black).**

## 4. CONCLUSIONS AND PLANS

The present paper describes the experiments of the AROME NWP model using higher horizontal and vertical resolution and associated developments in the data assimilation system.

Regarding the model settings it can be concluded that the resolution increase alone does not necessarily improve the forecasts, however, if certain changes and tunings are applied in the parameterization of microphysical processes then some improvement can be obtained as compared to the operational AROME version.

Based on the verification results, it can be concluded that combining the high resolution AROME model with 1-hourly cycling in data assimilation is a potentially effective way of improving the quality of the forecast. The results shown in this paper suggest that in the case of some meteorological parameters, such as precipitation and temperature, the use of the 1-hourly RUC already leads to some improvement which is especially useful for the purpose of short-range forecasting and nowcasting. However, in order to effectively adapt the RUC into the operational setup, the experimental settings need to be further tweaked to reduce or eliminate the negative impact to cloudiness and wind forecasts. After finding an optimal RUC setup, it may also be beneficial to add more types of observations (e.g. radar and Mode-S datasets) in order to utilise the full potential of the 1-hourly RUC.

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