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Impact of surface data assimilation in operational NWP model AROME-BG on air temperature at 2m – first results

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Abstract: In the present study the operational suite (consisting of one hydrostatic and three cloud-resolving NWP models) at NIMH is presented with emphasis on the new surface data assimilation scheme, which is operational since the end of 2024. Forecast performance for air temperature at 2m of the model using data assimilation is compared to its deterministic version for the period January - October 2025. Results are promising, showing a forecast improvement for 50 % of the considered stations. However, a deterioration of forecast performance is visible for 25 % of the considered stations, mainly on mountain peaks and coastal side.

Keywords: Surface data assimilation, numerical weather prediction, AROME

1. INTRODUCTION

Accurately forecasting near-surface atmospheric conditions requires a thorough understanding of surface-atmosphere interactions. To achieve this, observations and previous model forecasts are combined using data assimilation (DA) techniques in numerical weather prediction (NWP). Different algorithms, such as optimal interpolation (OI) (Mahfouf et al., 2000, Giard and Bazile, 2000, Camino et al., 2003), variational methods (Fischer et al., 2005), and the Kalman Filter, are used to optimize the integration of observations with forecasts. OI focuses on minimizing the mean squared error, variational methods minimize the cost function, and the Kalman Filter adjusts for the flow dependence of background error covariance. In land surface assimilation, OI is most commonly used, although more advanced Kalman Filter variants like the extended Kalman Filter (EKF) and Simplified Extended Kalman Filter (SEKF) are gaining popularity (de Rosenay et al., 2013, Mahfouf et al., 2009).

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The AROME model, which combines the ALADIN dynamic core, Meso-NH atmospheric physics, and the SURFEX surface model, provides detailed atmospheric analysis. Initially, in the deterministic version of AROME model which run operationally at NIMH since 2017, surface analysis was interpolated from ALADIN model. Since 2023, thanks to the increase of the frequency of lateral and boundary conditions (LBCs) based on the ARPEGE global model provided by Meteo France, the initial conditions for the soil are interpolated from analysis fields of ARPEGE directly. This version is named AROME-105, due to the number of vertical levels which was increased from 90 to 105. Since the end of 2024, an additional version of AROME (named AROME-DA) is run operationally using an improved CANARI (Code for the Analysis Necessary for Arpege for its Rejects and its Initiation) optimal interpolation (Taillefer, 2002, Toth, 2004) to assimilate data from all Bulgarian synoptic stations, which determines soil temperature and moisture analysis based on the relationship between soil and near-surface variables. This process involves quality controlling observations, analysing 2-meter temperature and humidity, and adjusting surface and soil parameters like temperature and moisture.

In the present study the performance of AROME-DA for temperature at 2m is evaluated in comparison to AROME-105 with the aim to evaluate the impact of surface data assimilation on the forecast accuracy. In section 2 the operational suite at NIMH consisted of four NWP models is presented. In section 3 the incorporated data assimilation cycle is described. In sections 4 and 5 the methodology of the study and the results obtained for the comparison of AROME-105 and AROME-DA forecasts performances for the period January-October 2025 are presented respectively.

2. OPERATIONAL SUITES AT NIMH

Bulgaria through NIMH is in ACCORD (A Consortium for COnvection-scale modelling Research and Development) consortium since its creation on the 1st of January 2021 (https://www.accord-nwp.org), when ALADIN, HIRLAM and LACE consortia decided to merge. ACCORD connects 26 National Met Services to join more closely their scientific research efforts towards developing the tools of excellence for NWP on Limited Area Domains and enter into a large partnership. There are three main ACCORD Canonical System Configurations (CSC) developed in the frame of the consortium: AROME, HARMONIE-AROME and ALARO. At NIMH, four versions of the canonical configurations of ACCORD system (Table 1) are run operationally four times daily (at 00, 06, 12 and 18 UTC), based on cy43t2.

2.1. ALADIN-BG

The ALADIN (Aire Limitée Adaptation Dynamique Développement International, International development for limited-area dynamical adaptation) System is a set of pre-processing, data assimilation, forecast model and post-processing – verification software codes shared and developed by the partners of the former ALADIN consortium (Termonia et al., 2018). It uses a spectral dynamical core with a two-time level semi-implicit semi-Lagrangian scheme. Bulgaria through the National Institute of Meteorology and Hydrology (NIMH) is in the ALADIN consortium since 1992, and the LAM model ALADIN is operational in the institute since 1999. Nowadays, the operational model configuration at NIMH is the following: the integration domain is covering a big part of the Balkan Peninsula (Figure 1), centered on Bulgaria, with a horizontal resolution of 5 km, 105 vertical levels, a time step of 300 s. At 06 UTC the forecast range is 96 h, at 18 UTC – 72h, and at 00 and 12 UTC – 48 h. It uses the global ARPEGE of Météo-France (Courtier and Geleyn, 1988; Courtier et al., 1991) output for lateral and boundary conditions. For the continental surface the SURFEX software (Masson et al, 2013) is used. Although ALADIN is not considered as an official ACCORD CSC and is not developed anymore since more than five years, it is still run operationally at NIMH and used for several purposes.

2.2. AROME-105

AROME is a non-hydrostatic limited area cloud-resolving model, used to improve the short range forecasts of severe events. It was developed by Meteo-France in close collaboration with national and international institutes so as to benefit from the latest research in atmospheric modelling. It uses mostly the physical parameterizations from Méso-NH model (http://www.aero.obs-mip.fr/mesonh/) and the dynamic core of ALADIN model (Termonia et al., 2018, Tsenova et al., 2022). AROME uses the surface modeling platform SURFEX (Masson et al., 2013). The operational AROME-105 model configuration (actually based on cy43t2) at NIMH is the following: the integration domain is covering Bulgaria (Fig. 1), with a horizontal resolution of 2.5 km, 105 vertical levels, a time step of 60 s. It is run four times daily - at 00, 06, 12 and 18 UTC with a forecast range of 72 h for 06 and 18 UTC, and 48 h – for 00 and 12 UTC runs. It uses ARPEGE output with a frequency of 1h for initial and boundary conditions.

2.3. AROME-IFS

It is the same CSC as AROME-105, differing only by the lateral boundary conditions (LBC) used that in this case are from the Integrated Forecasting System (IFS) of the European Center for Medium-Range Weather Forecasts (ECMWF) and the number of the vertical levels (90 instead of 105).

Table 1. Model versions run operationally at NIMH

	ALADIN-BG	AROME-105	AROME-IFS	AROME-DA
Horizontal resolution	5 km (245x189)	2.5 km (309x229)	2.5 km (309x229)	2.5 km (309x229)
Vertical levels	105	105	90	105
LBCs, frequency	ARPEGE, 3h	ARPEGE, 1h	IFS, 1h	ARPEGE, 1h
Forecast range	96h/72h/48h	72h/48h	72h/48h	72h/48h
Data assimilation	No	No	No	Surface data assimilation

2.4. AROME-DA

It is practically the same as AROME-105, but the surface field is initiated not only by the LBC (which in this case is used only to update sea surface temperature), but also by the so called “first guess” from the previous model run forecast and the measured SYNOP data. More details about the data assimilation cycle is presented in the next section.

2.5. Land surface description

As this paper concerns especially model surface fields it is worth to mention the surface model in the CSC. All mentioned above models use the surface modelling platform SURFEX. It is an externalized land and ocean surface platform that describes the surface fluxes and the evolution of four types of surfaces: nature, town, inland water and ocean. SURFEX can be run in offline mode (0-D or 2-D runs) or, as is in our case, in coupled mode (from mesoscale models to numerical weather prediction and climate models). For our operations, we use the last version SURFEX V8.1. Each model grid box is split into four tiles: land, towns, sea and inland waters (lakes and rivers). The interactions between soil, biosphere, and atmosphere (ISBA) parameterization (Noilhan and Planton, 1989) with three vertical layers inside the ground is activated over land tiles. The town energy budget (TEB) scheme used for urban tiles (Masson, 2000) simulates urban microclimate features, such as urban heat islands. Sea tiles use a bulk iterative parameterization, named ECUME (Belamari and Pirani, 2007). For inland waters Charnock (Charnock,1955) formulation is used. Physiographic data are initialized with the ECOCLIMAP database (Masson et al., 2003) at 1 km resolution. The orography is computed from the GMTED2010 database at 250 m resolution (Carabajal et al., 2011). The FAO HWSD database at 1 km resolution is used for the fraction of clay and sand in the soil. An orography–radiation interactions (Senkova et al., 2007) scheme has been adapted and implemented in the SURFEX version. Orographic shadowing and slope parameterizations are used operationally to modify solar direct radiative fluxes.

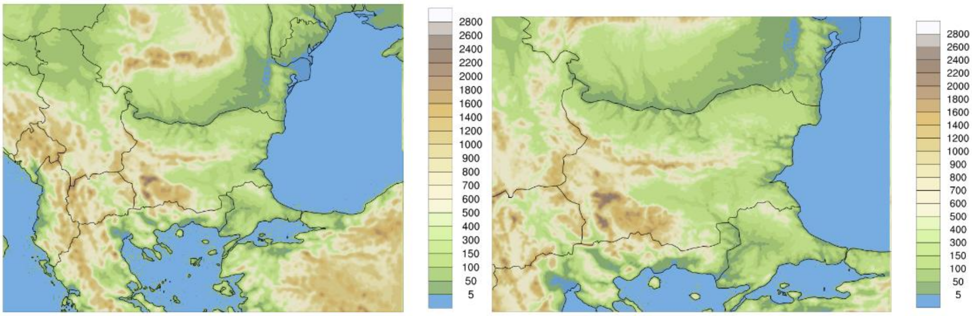

Fig. 1. Model domain of integration and orography of ALADIN-BG (left panel) and AROME-105 (right panel).

3. SURFACE DATA ASSIMILATION

A 6-hour cycle was created to assimilate the measured temperature and relative humidity data from 40 synoptic stations in the country (Figure 2). It has to be stressed that data from only 11 Bulgarian stations are transmitted to the WMO international exchange and are eventually included in global NWP models. In our case, every 6 hours, the model ground surface is updated by the measured temperature and relative humidity at 2 m at all Bulgarian synoptic stations using the OI method (Gyard and Bazile, 2000). 72/48-hours forecasts initialized by the assimilation package are run 4 times daily. The initialization uses an incremental digital filtering technique (Lynch et al. 1997). The analysis is performed in four consecutive stages, starting with a quality control of the observations. The height fields are analyzed using an incremental 3D variational method. The next step, called the land surface analysis, is a univariate analysis of the "screen-level" fields of temperature and relative humidity at 2 m and wind at 10 m, using the SYNOP. Finally, the temperature and humidity of the land surface are corrected using methods based on optimal interpolation from the measured temperature and relative humidity at 2 m. Since the distribution of the synoptic stations and the model grid differ, the grid fields obtained from the land surface analysis are used as approximations for the observed values. Technically, the surface assimilation is performed in the following steps:

- Downloading the synoptic telegram.
- Preparing the synoptic telegram into the form required for its processing using prep_synop procedure.
- Converting the processed synoptic telegram into bufr format using synop2bufr procedure
- Inserting the resulting bufr format file containing the observations from the synoptic stations into the AROME observation database using the BATOR procedure built into the CSCs.

- Making a first guess - adding the ground fields from the corresponding file from the previous run of the assimilation cycle to the height file from the new initial condition using IOASSIGN procedure.
- Mixing the land surface temperature from the previous run of the assimilation cycle with that from the first guess using IOASSIGN procedure.
- Mixing the sea surface temperature from the global model (the new initial condition) with that from the first guess using BLENDSUR procedure.
- Correction of temperature and relative humidity at 2m by interpolation of measured values at synoptic stations.

The 6-hour cycling data assimilation in the operational suite is presented in Table 2.

Table 2. Data assimilation procedure scheme in AROME

	00 UTC run	06 UTC run	12 UTC run	18 UTC run
LBC	ARPEGE from 18 UTC run	ARPEGE from 00 UTC run	ARPEGE from 06 UTC run	ARPEGE from 12 UTC run
Assimilated Surface data	BG synop data at 21 UTC	BG synop data at 03 UTC	BG synop data at 09 UTC	BG synop data at 15 UTC
First guess	DA 18 UTC run for 21 UTC	DA 18 UTC run for 03 UTC	DA 18 UTC run for 09 UTC	DA 18 UTC run for 15 UTC
Forecast range	51 h (starting from 21 UTC)	75 h (starting from 03 UTC)	51 h (starting from 09 UTC)	75 h (starting from 15 UTC)
Procedures	prep_synop, synop2bufr, BATOR (create_ioassign, merge_ioassign), OI_MAIN			

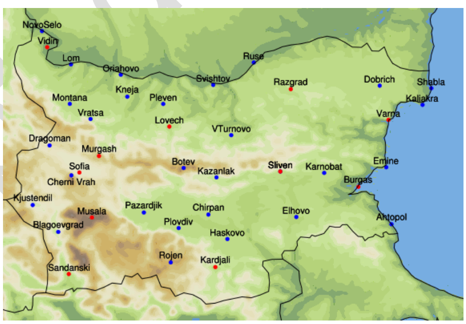

Fig. 2. Synoptic station in Bulgaria (in red are the stations transmitted in the WMO international exchange).

4. METHODOLOGY

For the present study the performance of the forecast of the 3 h temperature at 2m from AROME-105 and AROME-DA is evaluated by comparing their Root Mean Square

(RMSE) and BIAS based on measured at synoptic stations values for the period January-October 2025. At every 3 hours (separately for each run and each station) BIAS and RMSE are calculated following (1) and (2) for the two models and compared. Results are considered for cases between 3 and 72/48 h forecast range.

$$BIAS=\frac{1}{n}\sum_{i=1}^{n}\left(T2m\_forecast_i-T2m\_measured_i\right) \quad (1)$$

$$RMSE=\sqrt{\frac{\sum_{i=1}^{n}\left(T2m\_forecast_i-T2m\_measured_i\right)^2}{n}} \quad (2)$$

5. RESULTS

Figure 3a shows the comparison of the performances (or the percents of cases with lower RMSE) of the two models AROME-105 and AROME-DA for each synoptic station for the period January – October 2025. From the figure it is visible that the inclusion of data assimilation improves the model performance for about 60 or more percents of cases for 20 synoptic stations (shown in blue in Figure 3b). For 10 stations (shown in black in Figure 3b) the performances of AROME-DA and AROME-105 are similar (~50 % of cases with lower RMSE for the two models), which mean that for these stations for this period data assimilation did not affect significantly model performance. In Figure 3b stations with worsens of forecast performance while including data assimilation are shown in red. It is visible that these are mostly peak and coastal stations.

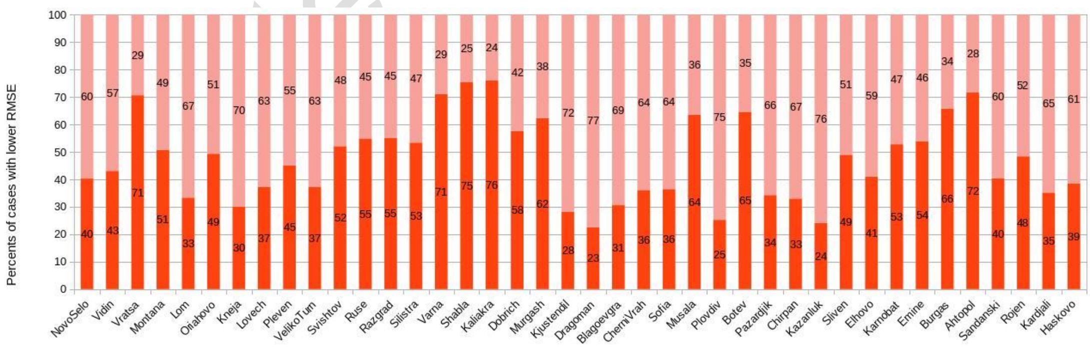

Fig. 3a. Comparison of the performances of AROME-DA (in pink) and AROME-105 (in red) for every synoptic station in Bulgaria.

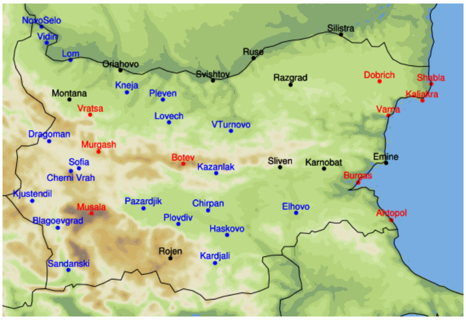

Fig. 3b. Stations with improved (in blue), similar (in black) and worsened (in red) model performance while surface data assimilation is included for the period January-October 2025.

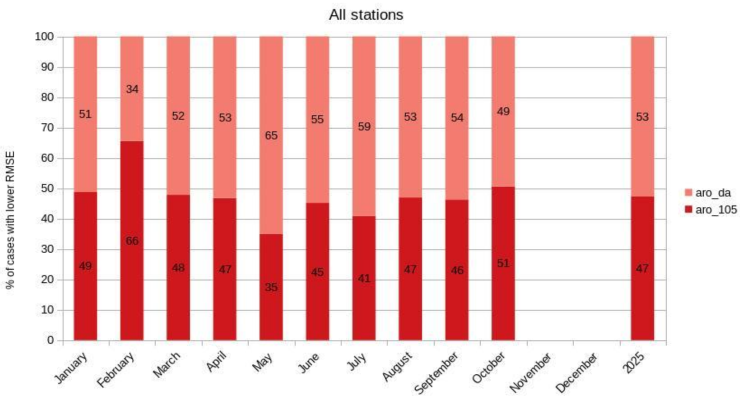

Fig. 4. Comparison of the performances of AROME-DA (in pink) and AROME-105 (in red) for every month of the considered period January-October 2025 and for 2025.

Figure 3a shows the comparison of the performances (or the percents of cases with lower RMSE) of the two models AROME-105 and AROME-DA for each synoptic station for the period January – October 2025. From the figure it is visible that the inclusion of data assimilation improves the model performance for about 60 or more percents of cases for 20 synoptic stations (shown in blue in Figure 3b). For 10 stations (shown in black in Figure 3b) the performances of AROME-DA and AROME-105 are similar (~50 % of cases with lower RMSE for the two models), which mean that for these stations for this period data assimilation did not affect significantly model performance. In Figure 3b stations with worsens of forecast performance while including data assimilation are shown in red. It is visible that these are mostly peak and coastal stations.

The comparison of two models performances on a monthly base for all considered stations for the period January-October 2025 (Figure 4) shows that almost during all months more temperature forecasts of AROME-DA are with lower RMSE in comparison to AROME-105, except of October and especially February (with only 34 % of cases with lower RMSE for AROME-DA). From the figure it is visible that the best performance of AROME-DA is during the summer months, especially in May.

The diurnal tendency of AROME-DA model performance (in comparison to this of AROME-105) is shown in Figure 5. It is visible that model performance increases roughly from 21 UTC until 06 UTC and then decreases until 18 UTC for all model runs. Based on these results, it could be speculated that AROME-DA gives better temperature forecast during night hours, while AROME-105 – during daily hours when considering all stations and all months from January to October 2025.

It has to be stressed that generally RMSE of the two models does not differ significantly (~0.5 K). However, the inclusion of data assimilation worsens the temperature at 2 m forecast at peak stations Botev and Musala during the winter months, and at coastal stations during the summer months. A more profound analyses of the mean monthly BIAS of the models shows that for peak stations Musala and Botev AROME model (with or without data assimilation) tends to be colder than what was registered between 18 and 06 UTC, which is strongly reinforced for winter months and slightly weakened for summer months when data assimilation is included. For coastal stations, AROME tends to be colder than what was registered between 06 and 18 UTC for summer months, which is significantly reinforced when surface data assimilation is included.

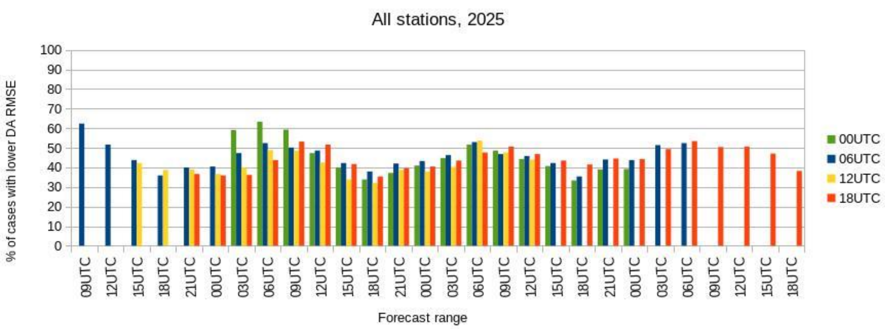

Fig. 5. Percents of cases with lower RMSE for AROME-DA (in comparison to AROME-105) as a function of forecast range (expressed as corresponding daily hours) for the four daily model runs – at 00 UTC (green), 06 UTC (blue), 12 UTC (yellow) and 18 UTC (red).

6. DISCUSSIONS

In the present study the performance of the forecast of the 3 h temperature at 2m from AROME-105 and AROME-DA is evaluated by comparing their Root Mean Square (RMSE) and BIAS based on measured at synoptic stations values for the period January-October 2025. Results show that:

- the inclusion of data assimilation improves the model performance for 50 % of the Bulgarian synoptic stations; for 25 % of the stations the performances of AROME-DA and AROME-105 are similar; for 25% of the stations (mostly peak and coastal stations) it worsens the forecast performance;

- during all months more temperature forecasts of AROME-DA are with lower RMSE in comparison to AROME-105, except of October and especially February (with only 34 % of cases with lower RMSE for AROME-DA); the best performance of AROME-DA is during the summer months;

- AROME-DA model performance (in comparison with AROME-105) increases roughly from 21 UTC until 06 UTC and then decreases until 18 UTC for all model runs;

- generally, RMSE of the two models does not differ significantly; for peak stations Musala and Botev AROME model (with or without data assimilation) tends to be colder than what was registered between 18 and 06 UTC, which is strongly reinforced for winter months and slightly weakened for summer months when data assimilation is included; for coastal stations, AROME tends to be colder than what was registered between 06 and 18 UTC for summer months, which is significantly reinforced when surface data assimilation is included.

It has to be stressed that the results presented here are obtained for the limited period of 10 months. However, this is the first attempt to include surface data assimilation in the operational suite of numerical weather prediction in NIMH and the results obtained are promising. Studies will be performed to remove the negative effect of data assimilation especially on peak stations. It involves the removal of stations with orography differing significantly from the model one. Further additional data will be included to be assimilated with the aim to improve forecast performance, as data from European synoptic stations falling in the domain of integration of AROME-DA and data from automatic stations in the territory of Bulgaria.

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