Rapid update cycle scheme in numerical weather prediction system ALADIN/SHMU

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Abstract

Práca sa zaoberá prípravou a testovaním Rapid Update Cycle (RUC) schémy čiže cyklu zrýchlenej aktualizácie založenej na trojrozmernej variačnej asimilácii dát v numerickom predpovednom systéme ALADIN/SHMU. Schéma ja založená na frekventovanejšom asimilačnom cykle, čím poskytuje efektívnejšie využitie meteorologických pozorovaní a tým aj presnejšie predpovede počasia. Implementovali sme 3 hodinovú asimiláciu dát oproti pôvodnej 6 h asimilácii. Vplyv schémy RUC sme overovali na prípadových štúdiách, kedy za komplikovaných atmosférických podmienok nastal výraznejší odklon predpovede operatívneho modelu ALADIN/SHMU od reálneho vývoja počasia. Keďže operatívna verzia modelu ALADIN/SHMU nepoužíva variačnú asimiláciu dát, tak pre každý experiment so schémou RUC bolo potrebné vytvoriť najskôr referenčný experiment. Overovali sme nielen vplyv vyššej frekvencie asimilácie dát, ale aj využite dodatočných dát dostupných vo vysokom priestorovom a časovom rozlíšení. Výsledky prípadových štúdii sme subjektívne vyhodnocovali porovnávaním predpovedných máp zobrazujúcich relevantný meteorologický prvok voči realite a napokon sme výsledky overili objektívnymi verifikačnými testami.

Anotácia

Schéma RUC v numerickom predpovednom modeli je založená na frekventovanejšom asimilačnom cykle. Experimentálne nastavenie so schémou RUC zahŕňa väčšie množstvo meteorologických pozorovaní do asimilačného cyklu, čo vedie ku zlepšenej predpovede počasia. Výsledky experimentov RUC sme porovnávali voči výsledkom referenčných nastavení, voči realite ale aj voči predpovedí operatívneho modelu ALADIN/SHMU.

Kľúčové slová: numerická predpoveď počasia, trojrozmerná variačná asimilácia dát, rapid update cycle

Annotation

Rapid update cycle scheme (RUC) in numerical weather prediction models in based on higher frequency of assimilation cycle against native resolution. Assimilation cycle in experimental settings with RUC scheme count with greater number meteorological observations, which lead to better quality of weather forecast. Results of RUC experiments were compared to reference setting experiments, to reality and predictions of operative model ALADIN/SHMU.

Keywords: numerical weather prediction, three-dimensional variational data assimilation, rapid update cycle

1 Introduction

The thesis deals with Rapid Update Cycle (RUC) scheme, which is based on higher frequency of assimilation cycles. The aim of the work was implementing and testing RUC scheme into assimilation of ALADIN/SHMU model, what included editing of scripts, setting the right parameters, testing on case studies, and evaluating the results of tests.

Computational domain of Numerical Weather Prediction models can be whole Earth, which are global models, or models on smaller domain, which are Limited Area Models (LAM). LAM models have strictly defined boundaries of computational domain and they need Local Boundary Conditions (LBC). LBCs are providing input information about atmospheric parameters outside of computational domain.

Weather prediction in Slovakia is provided by Slovak Hydrometeorological Institute (SHMI), which is using adapted version of ALADIN model marked as ALADIN/SHMU. ALADIN/SHMU is LAM models and is using LBCs, from model ARPEGE. Nowadays is ALADIN/SHMU counted 4-timer per day, in times 00, 06, 12, 18 UTC. This means that meteorological observations from other times aren´t counted in assimilation cycle or in forecast production.

2 Numerical weather prediction

As we mentioned in the introduction, a NWP models need on beginning initial conditions, which are made by assimilation cycle of dates. Data Assimilation defines actual state of atmospheric parameter, what are initial conditions.

Numerical weather predictions in Slovakia are provided by ALADIN/SHMU models. Initial conditions for atmospheric variables are prepared by Blending method, specifically by Blending with digital filter (Belluš - Derková, 2007), while assimilation of surface variables is using method CANARI (Derková et al., 2017).

Rapid update cycle

The Rapid update cycle scheme offers place to include higher number of observations. There is assumption, that using more often observations with smaller time error we gain better quality of initial conditions for production of predictions.

Model ALADIN/SHMU, which is using in operative mode Blending with digital filter is not using observations and CANARI method is using only SYNOP observations. The consequence of the fact that the Blending method does not work with observations is that the setting of the operational model cannot be completely used as a reference experiment for the RUC scheme. Therefore, it was necessary to use an adapted version of the operational model. It contains an objective analysis of 3D-Var (three-dimensional variation data assimilation method), also the CANARI method, has a 6-hour assimilation frequency and meteorological observations such as SYNOP, AIREP and TEMP enter the assimilation/production window. We have designated this as reference version (REFE). Data assimilation also includes short-term forecasts from the NWP model. Short-term forecasts provide an estimate of the state of the atmosphere, while the temporal validity is identical to meteorological observations. Such an estimate is referred to as a preliminary field (called Guess). The preliminary field serves as an initial state for assimilation. Guess is supplemented and combined by meteorological observations to minimize the resulting error of the initial conditions.

Implementation of RUC scheme into reference setting of experiment (REFE) we gain experiment with higher assimilations frequency (RUC1). The implementation required orientation and subsequent reprogramming in the key lines of the source code of the reference setting REFE. The necessary adjustments are explained in the sections below. The RUC scheme used is based on a 3-hour data assimilation cycle, which is shown in Figure 1.

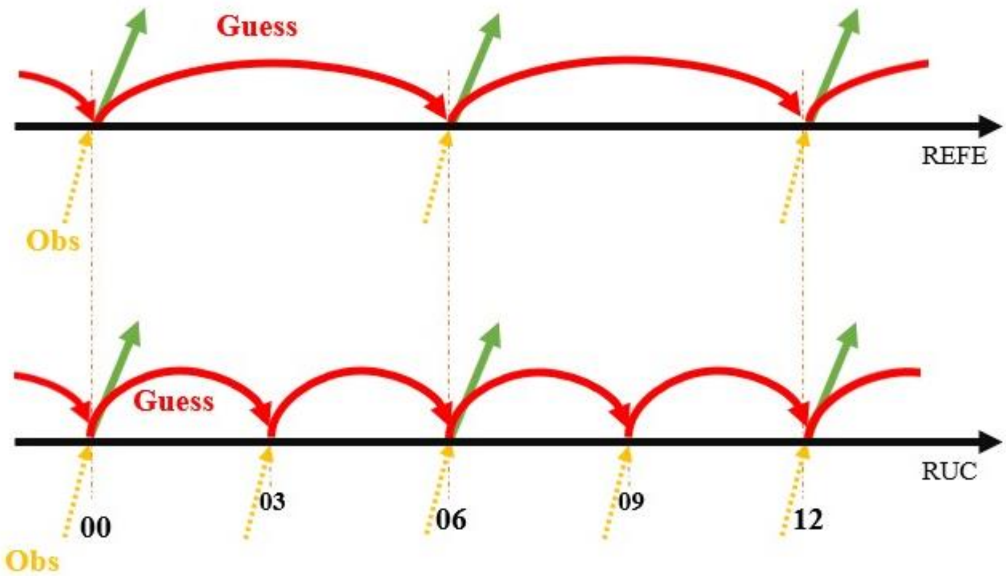

Figure 1. Scheme of 3- and 6-hour assimilation cycles. The RUC1 setting runs every 3 hours while REFE setting runs every 6 hours. Orange coloured dashed arrow indicates input of observations; full red arrow indicates usage of Guess analyses from previous assimilation cycle and full green arrow indicates output for forecast production.

LBCs for RUC1 setting are also from global model ARPEGE, in the same way as REFE setting but usability is different. The usage of LBCs had to be adjusted as they are not available every 3 hours. These problems had to been solved and the solutions is explained on example, how we deal with it.

The RUC1 experiment, which is triggered at inter-synoptic time e.g., 03 UTC needs LBC for this time, but are not available for 03 UTC. Therefore, we decided to use the LBC available for 00 UTC. LBCs available for 00 UTC are available for 6 hours, with three-hour intervals. This means that LBCs with validity +0000, +0003 and +0006 are available for time 00 UTC (designations +00 (00/03/06) indicate the time validity of LBC data). Therefore, the execution of the RUC scheme for 03 UTC will use the LBC from the previous date (00 UTC), specifically the LBC with validity +0003 will be used. It is this LBC that will represent the initial boundary conditions for time 03 UTC. Then it uses an LBC with a time validity of +0006, which are the boundary conditions for calculating the forecast for time 06 UTC.

If RUC1 setting is triggered at main synoptic time e.g., 06 UTC than RUC1 settings uses the LBC with validation +0000 from time 06 UTC, as initial boundary conditions. The LBC with validation +0003 will be used for calculating the forecast for time 09 UTC.

The characteristics of schema, described above, had to be implemented in the scripts used to run the experiments. Table 1 schematically shows the procedure described above. In the first column we can see the LBC data times and in the first line we can see the RUC scheme start times.

Table 1. LBCs used to run assimilation of the RUC scheme.

RUC / LBC	00 UTC	03 UTC	06 UTC	09 UTC	12 UTC	15 UTC	18 UTC	21 UTC
00 UTC	+0000 +0003	+0003 +0006						
06 UTC			+0000 +0003	+0003 +0006				
12 UTC					+0000 +0003	+0003 +0006		
18 UTC							+0000 +0003	+0003 +0006

On the Figure 2 are illustrated graphs, which are describing quantity of observations entering assimilation process of settings RUC1 and REFE. After control checking, observations acquired status: Active, Passive, Rejected or Blacklisted. Total amount of individual types of observations indicates that the RUC scheme works with a larger amount of data, which helps to a more precise analysis.

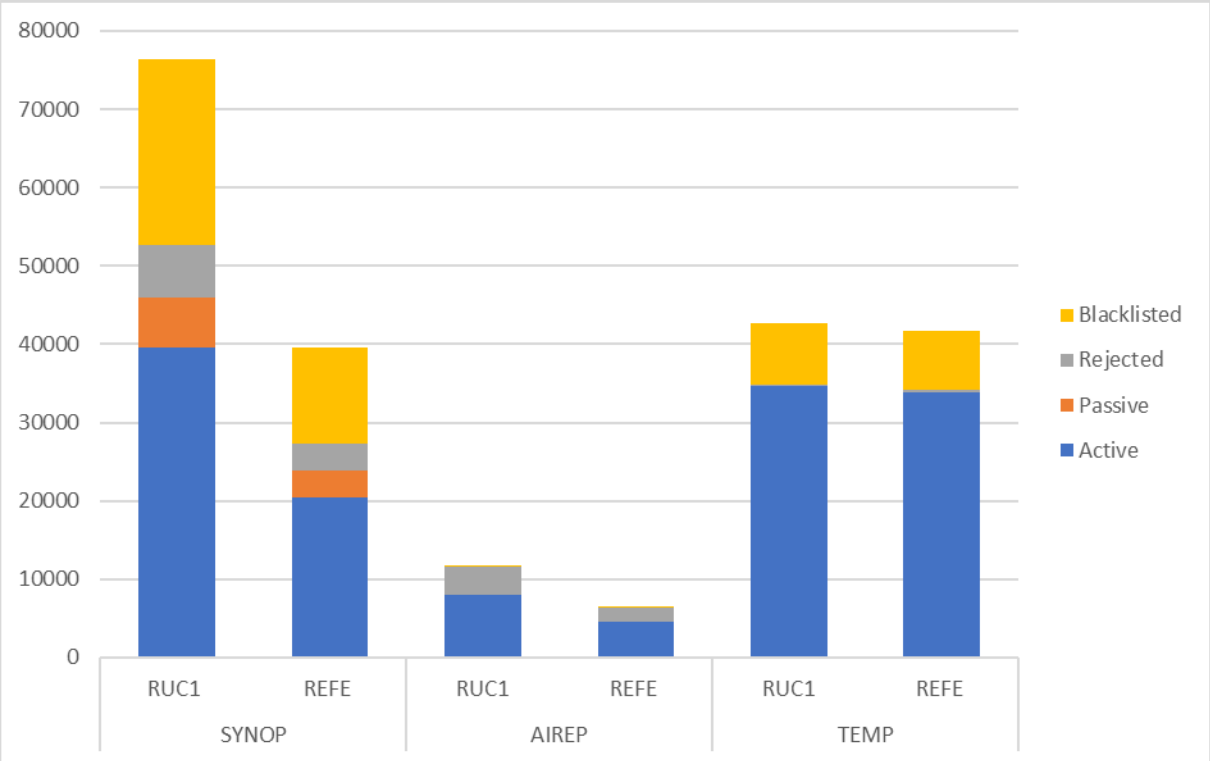

Figure 2. Graphs are showing the number of observations that enter the assimilation cycle calculation during a randomly selected day 16.02.2021. The first assimilation was started at 00 UTC and the last at 21 UTC. Graphs are for experiment with the RUC scheme (left columns) and for the REFE experiment (right columns) for each type of observation.

Methods of work and setting up experiments

Adaptation of the basic experiments REFE and RUC1 led to the second version of the experiments (designation REF2 and RUC2). These versions contain meteorological observations available from Automatic Weather Stations (AWS) of the surrounding states of Slovakia.

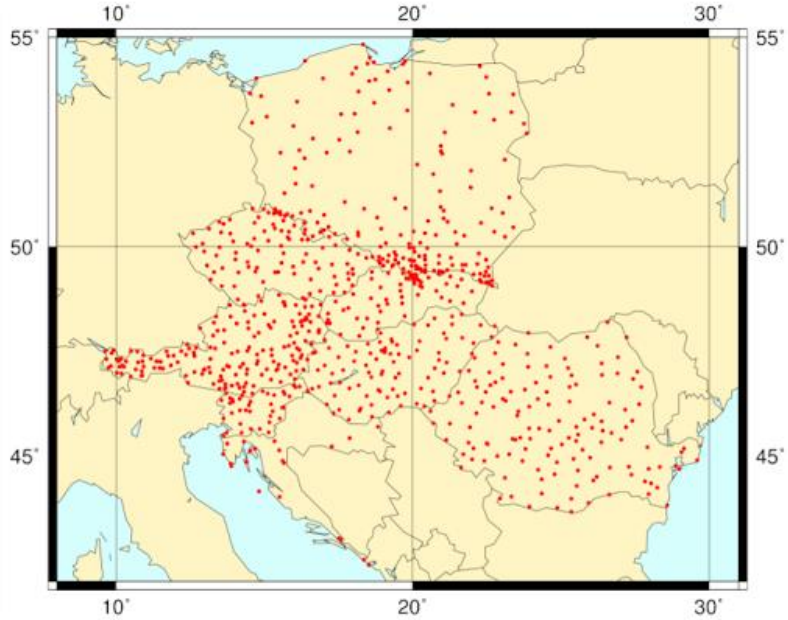

Figure 3. Spatial distribution of local AWS stations in the territories of individual states.

The third version, respectively the third adaptation use hourly LBCs (designated REF3 and RUC3). So far the coupling frequency, coupling of the solution with the global model, was performed at 3-hour intervals. Hourly LBCs were not always available, so the third version of the experiments could not be run in all case studies. The third version of the experiments is an extension of the second version. This version of settings uses four hourly LBC data in inter-synoptic (03 UTC, 09 UTC, 15 UTC, 21 UTC) and in main synoptic times. The given adaptation is described in Table 2.

Table 2. Usage of hourly LBC data in the RUC3 experiment.

RUC / *LBC*	*00 UTC*	*03 UTC*	*06 UTC*	*09 UTC*	*12 UTC*	*15 UTC*	*18 UTC*	*21 UTC*
00 UTC	+0000 +0001 +0002 +0003	+0003 +0004 +0005 +0006						
06 UTC			+0000 +0001 +0002 +0003	+0003 +0004 +0005 +0006				
12 UTC					+0000 +0001 +0002 +0003	+0003 +0004 +0005 +0006		
18 UTC							+0000 +0001 +0002 +0003	+0003 +0004 +0005 +0006

The fourth version of the experiments contains a new type of observation (designated REF4 and RUC4). When a transmitted signal from a satellite, from the network of the global satellite navigation system through the atmosphere to surface, occurs refraction i.e., the signal is delayed in the zenithally direction (Zenith Total Delay - ZTD). For applying the ZTD observations was used the setting of the second version of the experiments (REF2, RUC2) as the initial setting of the experiments. Due to the absence of hourly LBCs for all case studies, we did not use third version.

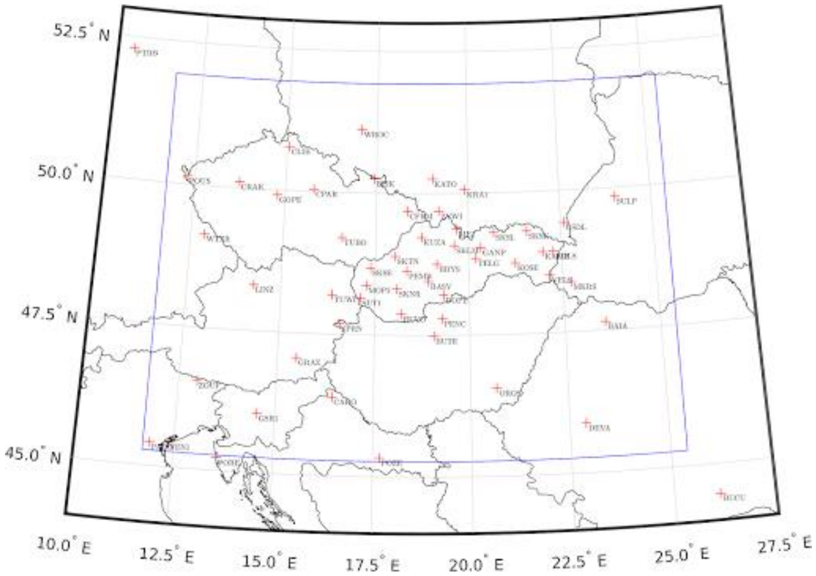

Figure 4. Location of meteorological stations measuring ZTD observations.

Table 3 is for better orientation in versions of experiments settings.

Table 3. Descriptions of each experimental setting.

6-hour assimilations	3-hour assimilation	Short description
REFE	RUC1	Base settings
REF2	RUC2	Settings with observations from local AWS
REF3	RUC3	Settings with local AWS and hourly LBCs
REF4	RUC4	Settings with local AWS and ZTD observations

As we mention, the influence of RUC scheme on ALADIN/SHMU model was tested on case studies. We have selected several terms in which the operative forecast of the ALADIN/SHMU model failed to correctly predict the real course of the weather. We compared the individual forecasts of selected meteorological elements in these terms with the real weather situation. Reality is represented by the outputs of the INCA system. The INCA system is a set of programs that is used to analyse the current state of atmospheric parameters and give very short-term forecast (nowcasting). The inaccuracy of the prediction of the operational model has aroused interest in examining the term by other experimental settings or methods.

Firstly, the results of given cases/terms were subjectively evaluated by visualizing of forecasts for selected meteorological elements in map form. In second step were results verified by verification tests, which provided the „objective“ evaluation of forecast quality for each experiments using the Root Mean Square Error (RMSE) and BIAS score.

The term objective in this case is not entirely true, because the interpretations of test results from one or two predictions is contrary to the requirement of a large statistical set. As a result of such „objectivity“ it is necessary to understand the results of verification tests rather as a comparison of individual experiments or their comparison with a set of measurements and as a control of the above conclusions of case studies. For the sake of clarity, compactness and informative value are given graphs, in which are compered all experimental settings with the RUC scheme with the basic reference setting REFE. The analysed meteorological elements were selected due to their connection with the given case study or due to their contributions to the analysis of the forecast, we did not present graphs with relatively identical scores.

Case study

On February 17, 2021, the frontal system advanced through the area of the Slovak Republic towards the east of the country. This system was also connected to the cyclone, a low-pressure area above the north-eastern part of Atlantic Ocean. At the given date, we tested and obtained results from all four pairs of experimental versions (REFE and RUC1, REF2 and RUC2, REF3 and RUC3, REF4 and RUC4). Before calculating the production forecast for the researched term, we firstly started a 24-hour assimilation cycle. The first data assimilation started on 16.02.2021 03 UTC for all experiments with RUC scheme and assimilation of reference experiments for time 16.02.2021 06 UTC. The last data assimilation was started on 17.02.2021 00 UTC, for both types of all experiments. For the date of the last data assimilation, the calculation of the production forecast was ran with a forecast of 12 hours. The predictions of the temperature field experiments at 2 m above the model surface (hereinafter referred to as the temperature field) and the wind field experiments at 10 m above the model surface (hereinafter referred to as the wind field) are graphically processed in Figure 7. The pair in the row in Figure 7 consists of the reference experiment of the given version (left side map) and the experiment with the RUC scheme of the given version (right side map). For comparison, we also graphically processed the predictions of the ALADIN/SHMU model and the INCA system, which are in Figure 5.

Comparing the prediction of wind field in Figure 7 with the real flow represented by the INCA system analysis in Figure 6, can be see that all predictions of the experiments using 3D-Var method are similar and do not correspond to reality. The experiments predicted a stronger north-western flow in the south-western region, while there was only a weak variable wind in the south-west of Slovakia, which could not disturb the clouds

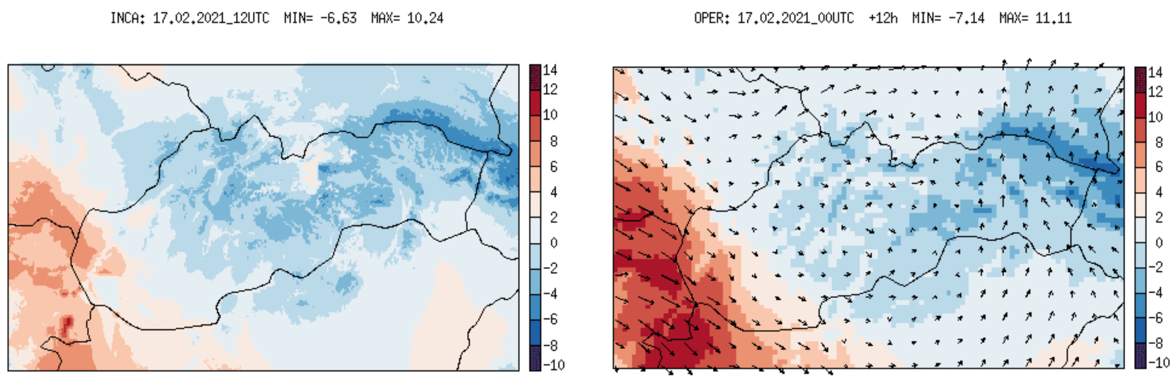

Figure 5. On the left side is a visualization of the temperature field of the INCA system and on the right side is a visualization of two composed fields in one prediction of the ALADIN/SHMU operational model, marked as OPER, at 12 UTC from the date 17.02.2021 00 UTC.

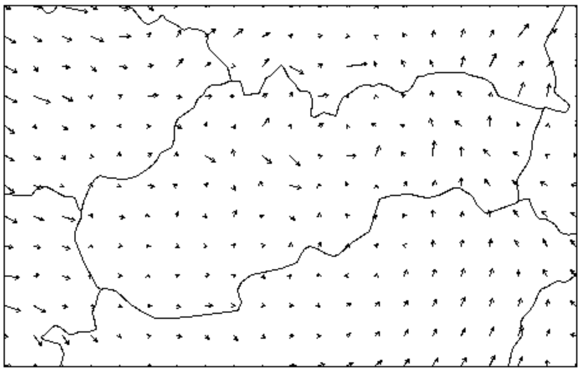

Figure 6. Visualisations of the wind field of the INCA system at 17.02.2021 12 UTC. Arrow size indicates value of wind speed and his rotation indicates direction of wind.

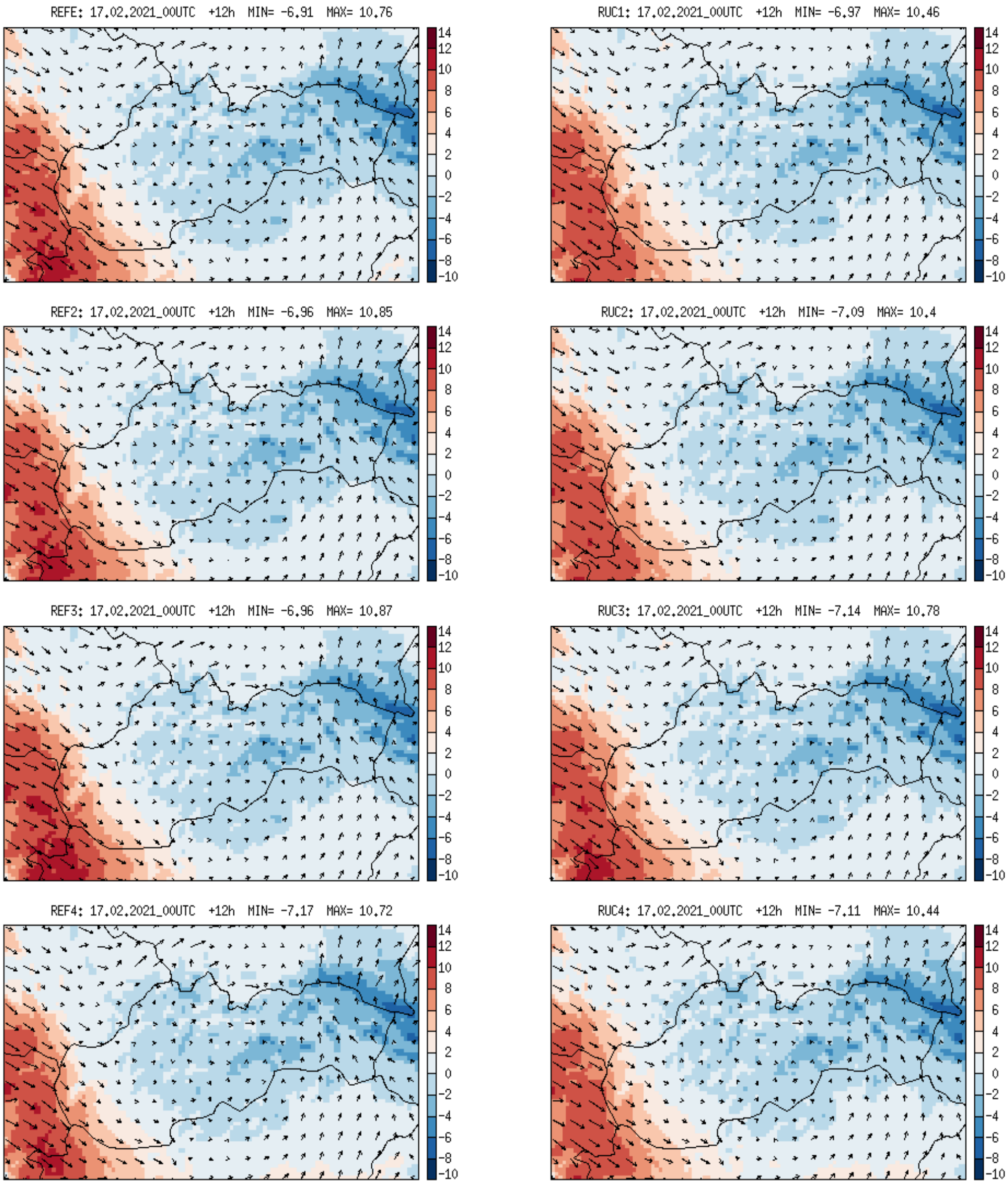

Figure 7. Visualization of the prediction of the temperature and wind composition at 17.02.2021 12 UTC. Forecast of reference experiments (on left side), experiments with RUC scheme (on right side) and corresponding pairs in the line represents each version of the experimental settings.

Results of experiments tested in this case study, were summarized in points:

- Usage of the 3D-var assimilation method significantly improved the temperature forecast over the operative forecast and the use of the RUC scheme has occurred additional improvement of prediction accuracy.
- Adding local AWS into data assimilation of reference setting was not highly visible in results/forecast map. More visible, it was in the forecast from experiment with the RUC scheme and especially in the areas from which the data was additional AWS stations (outside SR).
- In the forecasts of experiments with hourly LBC data assimilation is the temperature field slightly worse by the remaining experiments. However, the RUC3 experiment gave a slightly better prediction as the REF3 experiment.
- Adding the ZTD observation into experiments, clearly contributed to improving the prediction of an evaluated situation for the area.

General conclusion for the case study under review: RUC scheme in all settings of experiments, led to at least a slight improvement in the situation in a temperature field forecast at a height of 2 m above the model surface.

Figure 8 shows the verification scores for selected meteorological variables: temperature field (top left, T2m), field of pressure converted to sea level (top right, Mslp) and wind speed at 10 m height (bottom, U10m).

- The RMSE score values for the temperature field are closer to zero for all RUC experiments than for the reference experiment. This suggests that RUC analysis and subsequent forecast better corresponds to reality, at the beginning of the prediction. With increasing length of prediction, the impact of a better analysis loses because of impact the boundary conditions. The difference of RMSE values for RUC experiments and REFE is reduced. BIAS score is the best for experiment RUC3 at the beginning (~ 9 hours), later has the lowest BIAS experiment RUC1.
- The RMSE score values for the pressure field (Mslp) are at the beginning of the prediction (~ 3 hours) for RUC experiments below the REFE experiment, what is good. In the first 4 hours of prediction, are both scores for RUC3 experiment achieve the values closest to zero. The highest BIAS score values had an experiment RUC4 in the second half of forecast.
- For the wind speed (U10m), the RMSE score values are similar for all experiments throughout the prediction length. Differences between them are small. BIAS score values are almost the same for the entire prediction but at the interval 6-10 h prediction reached RUC3 higher score value.

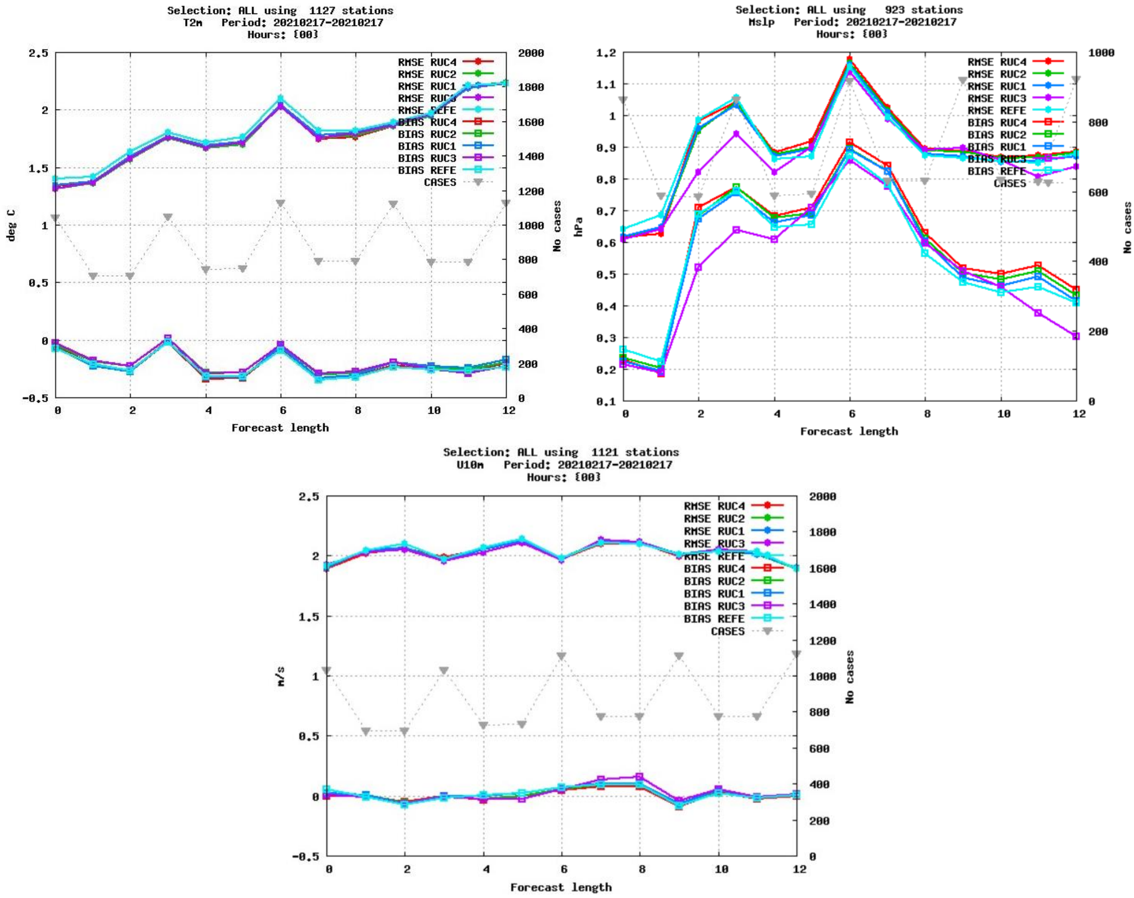

Figure 8. Shows BIAS verification score (bottom curves in graphs) and RMSE (upper curves in graphs) for 12 hour forecasts of temperature field (T2m, left up), pressure field (Mslp, top right) and wind speed field (U10m, bottom) for selected experiments on 17.02.2021 from 00 UTC.

In general, verification tests have not shown significant improvements in the quality of experiments forecasts. Verification tests do not indicate deterioration for predictions. We consider that, based on verification tests, there is no reason to doubt the results and conclusions that we have reached in subjective evaluation of maps forecasts of meteorological elements.

Experimental settings were also run for terms:

- 24.11.2020 focused on cloud forecasting,
- 07.06.2020 focused on precipitation forecasting,
- 07.02.2021 focused again on forecasting of fields of temperature, pressure, wind speed and direction.

Due to the scope of the contribution we did not mention all case studies, more detailed are described in bachelor thesis (Petrovič, 2021).

3 Conclusion

By visually (subjectively) comparison of map predictions of individual experiments and reality, we were able to evaluate the benefits of the basic scheme of RUC and also its modified versions. The analysis of results of experiments shows that the use of the RUC scheme has a demonstrable impact on the prediction of the numerical model.

Secondly, was the verification of used RUC experiments and REFE experiment against to measurements. The performed verification tests do not provide objective evaluation of results but they have a checking character. If an error occurs in the experiment, the settings will show a significant deterioration of the verification test scores to reference. For real objective assessment of the effects, of used RUC settings, we would need to run experiments for longer periods not only on individual case studies.

The overall benefit is a successful application of Rapid Update Cycle data assimilation schemes in the forecast model ALADIN/SHMU, or his adapted versions. This scheme was not used before for Slovak Hydrometeorological Institute. We have shown that RUC scheme can improve predictions, especially with additional types of high time and spatial resolution measurements (automatic weather stations, ZTD measurements), where the higher frequency of the assimilation cycle can use these data effectively. However, not all examined case studies of experiments with RUC scheme showed improvements. To evaluate the causes, it would be necessary to run more experiments and test other settings of the assimilation system.

4 References

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