Applications and Verification
Report

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Period:	January - June 2025
Date:	September 2025

Summary

The primary goal is to develop and adapt/use different specific applications into user-friendly mode. Many tools and software products were developed along the years for meteorological parameters. These days, it is imperative to have easy to use applications, maybe to find and to identify the operational activities, to make a common way for saving time and manpower resources. Nowadays, it is important to make the applications easy to implement without too much cost and to make a common way for saving time, computer costs and manpower. It is a big challenge to identify and to merge all the beneficial technical approaches and applications for all countries.

The report summarizes the Applications and Verification activities of the first 6 months of the year 2025:

- The results obtained by Martin Petráš, during his stay in Prague, in collaboration and supervised by Alena Trojáková, on the improvement of the integration of OBSOUL TEMP data into the existing HarpIO processing framework.
- In Hungary, documentation regarding the verification of cloud forecasts started with some methods based on MODE (Method for Object-based Diagnostic Evaluation) package from NCAR for sophisticated scores such as SAL or FSS and about the Panelification tool developed by the Austrian Team. Considering the reviewed methods, their pros and cons, the conclusion was to adapt Panelification in Hungary.
- In Croatia, the continuous work is based on an analog post-processing method for verification of 10-m wind speed for HR20 and HRAN systems and also for the verification of 2-m temperature for HR40 and HRAN. The validation was done for the whole year 2024, for synop stations from Croatia, for different statistical scores. Also, the validation was done for certain case studies. The whole remarkable work will be published in two articles. At the moment of this report, the articles are submitted.
- In the Czech Republic, the work continued on extending the operational verification (using the VERAL package) from six hours to three hours, as well as on implementing the snow depth verification in VERAL.
- In Romania, taking into account the work of Martin Bellus based on the experiments of the ensemble system generated by the ALARO model at 750 m horizontal resolution and 87 vertical levels covering a domain centered on Slovakia territory, a validation was performed for the severe event from 13th September 2024. The evaluation was performed, by using the HARP system for 443 synop stations from the OPLACE database, for several meteorological parameters: temperature at 2 m (T2m), relative humidity at 2 m, mean sea level pressure, cumulated precipitation in 1 hour, wind speed and direction at 10 m.
- In Hungary, they continued the work related to HARP, for pressure level verification based on TEMP observations of 6 stations within the AROME/HU domain. The number of used pressure levels for verification are 28. The computed scores are Bias and RMSE for geopotential, wind speed, relative humidity and temperature parameters.
- Also in Hungary they started to develop an automatic and objective method: the daily maximum wind gust for a given location is calculated by interpolation of station

measurements onto a fine grid, enhanced with background information from high-resolution numerical weather predictions. The MISH (Meteorological Interpolation based on Surface Homogenized data basis) method is used for spatial interpolation, a method developed by the Hungarian Meteorological Service specifically for meteorological purposes. They made an evaluation of the wind gust forecasts of AROME, AROME-RUC and AROME-EPS. From AROME-EPS, the ensemble mean was used, because the interpolation cannot involve “proper” ensemble predictions for technical reasons.

- In Poland, they are doing the preoperational tests with CY46T1 export version runs daily for ALARO CMC with horizontal resolution 2.45 km, with our packages of code changes developed by the Czech LACE team in Prague were included in the local model version. The results validation was done for January and August 2025, based on the BIAS and RMSE for various meteorological fields. Also, a new version of HARP was installed locally and work has been done to adjust it for operational verification for ALARO, AROME, IFS and GFS. So far point-base verification is ready for ground stations as well as for radiosondes. Work is ongoing for spatial verification of deterministic and ensemble models.
- The Hungarian team continued the work based on the AROME-EPS EMOS postprocessing using data from groups of similar stations. The aim is to provide post-processed forecasts for any selected location that improve the CRPS score of the raw EPS as much as possible. For this purpose, the observation stations considered their certain properties and chose “similar ones” for the (regional) EMOS runs were classified. Similarity was quantified based on model error (CRPS) characteristics, incoming solar radiation climatologies (derived from observation data) or geographical distance.
- In Czech Republic, the main topic was the extension of the operational verification (using the VERAL package) from 6 hours to 3 hours.They are also working on implementing the snow depth verification in the VERAL.

[MQA1] Development of HARP

Description and objectives:

The main topic of Martin Petra's stay at CHMI is related to the improvement of the integration of OBSOUL TEMP data into the existing HarpIO processing framework. A comparison between OBSOUL and VOBS datasets highlighted key differences in temporal coverage and archiving practices was performed. OBSOUL mostly contains soundings at standard synoptic hours and only sporadically includes off-time launches. VOBS, on the other hand, captures a wider range of observation times and regularly includes additional ascents. These differences stem from national processing and archiving policies and impact how suitable each dataset is for different types of verification tasks.

Development of HARP Extending harpIO to enhance its functionality for upper air verification within the OBSOUL framework.(Slovakia and Czech Republic)

1) Martin Petras, during his stay in Prague, with Alena Trojáková helping, worked on extending harpIO to enhance its functionality for upper air verification within the OBSOUL framework.

This report advances the HARP OBSOUL TEMP implementation through two primary objectives:

• Data analysis part: comparing the upper-air radiosonde (TEMP) observation dataset in two available formats (OBSOUL and VOBS), they aim to identify geographic and temporal gaps in the datasets, characterize patterns of data sparsity, and verify that the updated code functions as intended.

• Verification results: in this section, they present verification results and compare them against local verification tools available at the Czech Hydrometeorological Institute (CHMI) to evaluate the consistency of the verification scores.

• Technical part: errors detected during the data analysis phase were addressed and updates were made to the relevant code. The measures that have been implemented and the enhancements that have been made are outlined in this section.

Using OBSOUL TEMP data in HARP enhanced vertical and temporal resolution in verification, leading to better forecast quality assessment for the LACE community.

An evaluation was made for upper-air temperature observations (parameter T) for June 2025, for the regularity of reporting and identifying the stations suitable for the use of consistent verification. The R code utilized HARP's read point obs() function to retrieve temperature data at pressure levels. The temporal range analyzed spanned from 1 June 2025 00:00 to 30 June 2025 23:00 hours. The present analysis was focused on Europe, although OBSOUL contains global data. Also, data can be spread over some time interval, focused on specific hours. To assess station participation at synoptic hours (00h, 06h, 12h, 18h), the percentage of expected observation intervals (30 days × 4 hours = 120 expected reports per station) was calculated. A geographic plot visualizes the resulting availability percentage across all stations.

These plots highlight spatial patterns in data coverage, showing strong availability in Central Europe and notable gaps in southeastern and eastern regions (Figure 1). Additionally, only a small number of stations have more than 75% data availability. This is because only a small percentage of stations launch radiosondes more than twice a day.

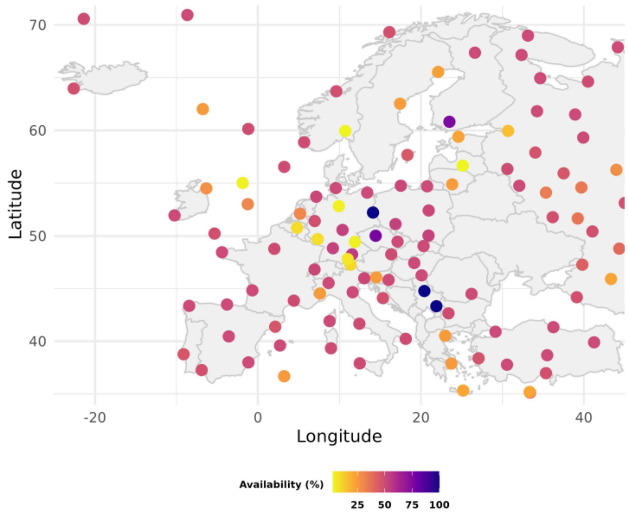

Figure 1. European station availability at synoptic hours.

While many stations follow the standard synoptic observation schedule (00h, 06h, 12h, and 18h), a considerable number report data at irregular or non-standard hours. As shown in Figure 2, the maximum data availability at these non-synoptic times is generally very low and does not exceed 5%. This low availability occurs because the expected number of observation intervals is set to 600 (30 days in June × 20 non-synoptic hours per day, excluding 00h, 06h, 12h, and 18h). This approach highlights that only a few stations occasionally perform additional soundings outside the regular synoptic times. To better understand which non-synoptic hours are most relevant, they conducted a more detailed analysis by calculating the availability per station and per hour. This method examines, for each station and each non-synoptic hour, how many days had at least one observation. By applying this method and focusing on higher-availability occurrences, they identified four specific station-hour combinations where the availability in June reaches at least 70%.

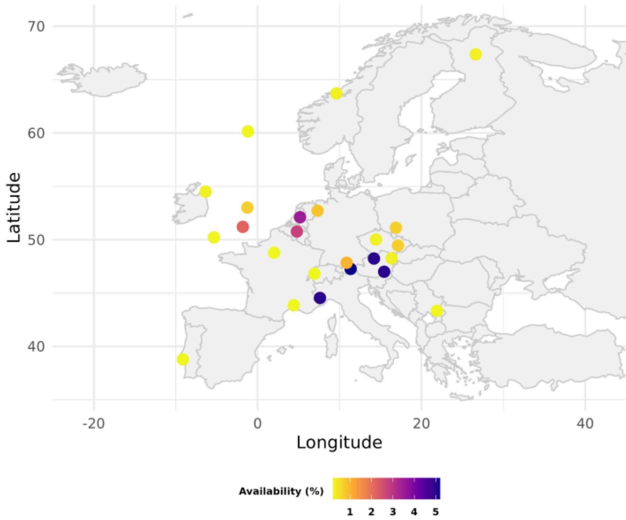

Figure 2. European station availability at non synoptic hours.

SID	hour	available_days	expected_days	availability_percent
11010	2	29	30	96.7
11120	2	27	30	90.0
11240	2	27	30	90.0
16113	10	30	30	100.0

Table 1: Non-synoptic hour availability for selected stations in June.

For example, in Table 1, it can be seen that station 11010 at hour 2 (2 a.m.) had reported data on 29 out of 30 June days (96.7% of days covered), while station 16113 reported data at hour 10 (10 a.m.) on every day of the month (100% of days covered). These exceptions indicate that only a handful of stations perform regular observations at the same non-synoptic hour, most likely due to the following reasons:

• On-demand launches: Such releases may be driven by particular meteorological events, urgent forecast needs, or specific research campaigns.

• Airport station: Stations located at major airports display an increased observation frequency, with many launches occurring outside the standard schedule. This likely reflects the requirement for more frequent local atmospheric profiling to support aviation safety and operations.

In terms of hourly data availability from OBSOUL files, the dataset demonstrates sparse coverage (Figure 3). The high availability data are almost exclusively concentrated at 12h and 00h. This phenomenon can be attributed to the processing of OBSOUL data by OPLACE, where data received between 11:00 and 12:00 are grouped and recorded as 12-hour reports. A similar grouping is applied to the 00, 06 and 18 time slots (A. Trojáková, personal communication, July 2025). Only a small number of stations exhibit irregular reporting at non-standard hours (e.g. 05h, 06h, or 14h), and even in these cases, the frequency is very low. These sporadic observations are frequently made in the context of airports or as a consequence of on-demand radiosonde launches. Local processing within OPLACE may also be a contributing factor.

For the VOBS files evaluation, the analysis demonstrates substantially broader coverage of upper-air observations in comparison to the OBSOUL coverage. Across the majority of stations, data completeness is consistently high around the key synoptic hours of 00h and 12h, with higher availability shifted by one hour to 23h and 11h (Figure 4). This suggests that the VOBS data are stored in order to ensure greater consistency with the precise time at which the radiosonde was launched. Beyond the primary synoptic intervals, the VOBS dataset demonstrates substantial data availability at off-synoptic hours for numerous stations.

In VOBS, the inclusion and categorization of off-synoptic measurements are managed such that a broader range of reporting times is systematically preserved and accessible, whereas OBSOUL tends to concentrate data primarily around the standard synoptic hours.

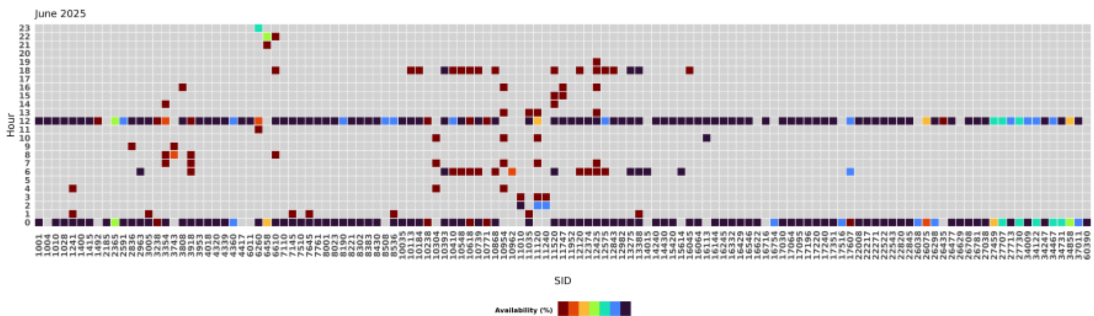

Figure 3: Hourly OBSOUL data availability per station, June 2025. Rows = hours; columns = station IDs. Colours indicate the percentage of days with data at each hour.

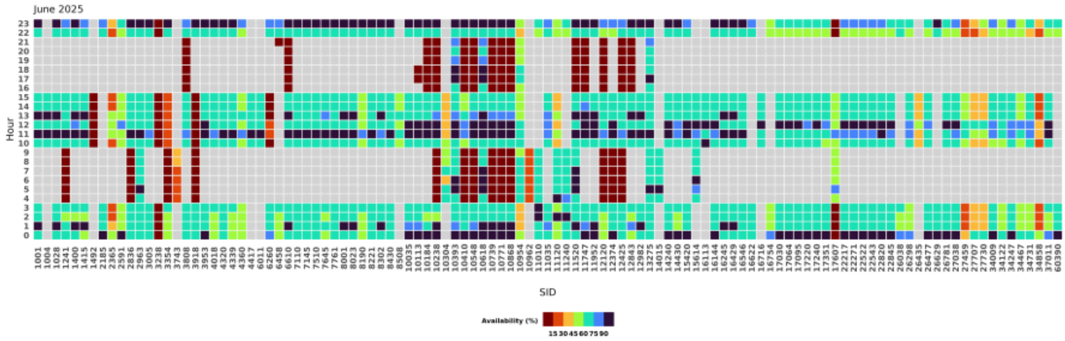

Figure 4: Hourly VOBS data availability per station, June 2025. Rows = hours; columns = station IDs. Colours indicate the percentage of days with data at each hour.

In Figure 5 each facet corresponds to a distinct standard pressure level, displaying the frequency of stations across the range of availability percentages. Also, the focus is on European stations only. Across most pressure levels, especially those between 70 hPa and 925 hPa, the distribution of availability is sharply skewed toward 100%. This indicates that a large fraction of stations consistently reported observations at these standard levels throughout the observation period. At the highest levels (e.g., 10, 20, 30 hPa), there is a notably broader and flatter distribution.

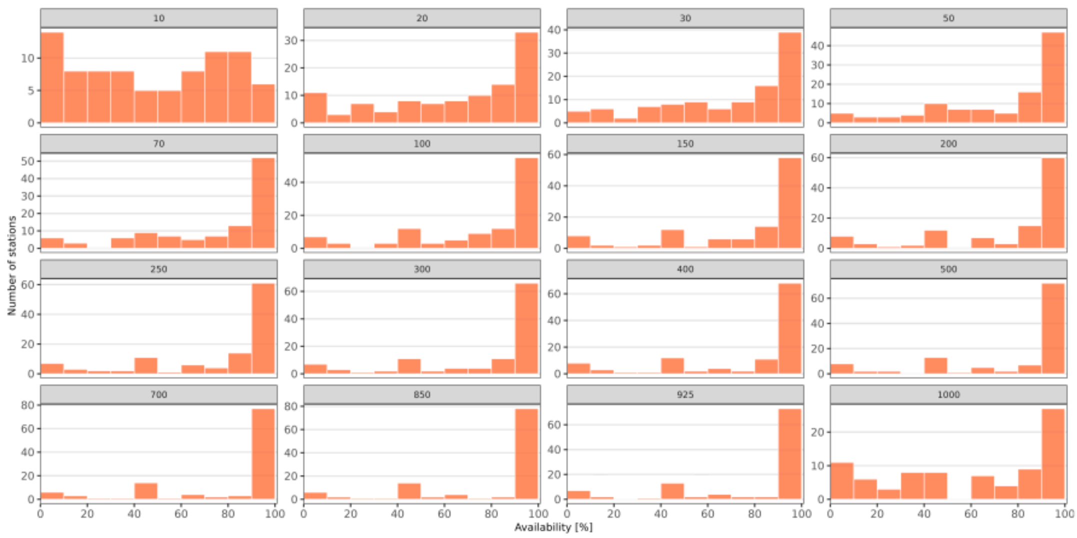

Figure 5: Histogram of station availability distribution by pressure level. Each subplot shows the number of radiosonde stations (y-axis) categorized by data availability in percent (x-axis), for a specific pressure level in June 2025.

Another important objective of this work is to evaluate the performance of Harp upper-air verification using radiosonde data in OBSOUL format. The validation was performed for the ALARO-DEODE versus ALARO + ISBA model of 2.3 km CHMI, for

48-hour model forecasts. The verification scores will be compared with those from the CHMI verification package (VERAL). The domain covers a large part of the Alps and the northern Adriatic, and the horizontal resolution is 500m (Figure 6). Observations are provided from OPLACE in OBSOUL format. Within the domain considered, data was obtained from seven stations. However, not all stations report data at every expected time interval, so the count of stations included in the verification varies depending on lead time and valid date (Figure 7).

- Model I: deode_clim: CY48t3_ALARO_CRO_500m;
- Model II: deode_clim_init: CY48t3_ALARO_CRO_500m
- Domain: Alps and the northern Adriatic; $\Delta x = 500$ m;
- Initial conditions: Model I: global Digital Twin; Model II: CHMI operational ALARO+ISBA model of 2.3km

Figure 6: Experiment domain coverage

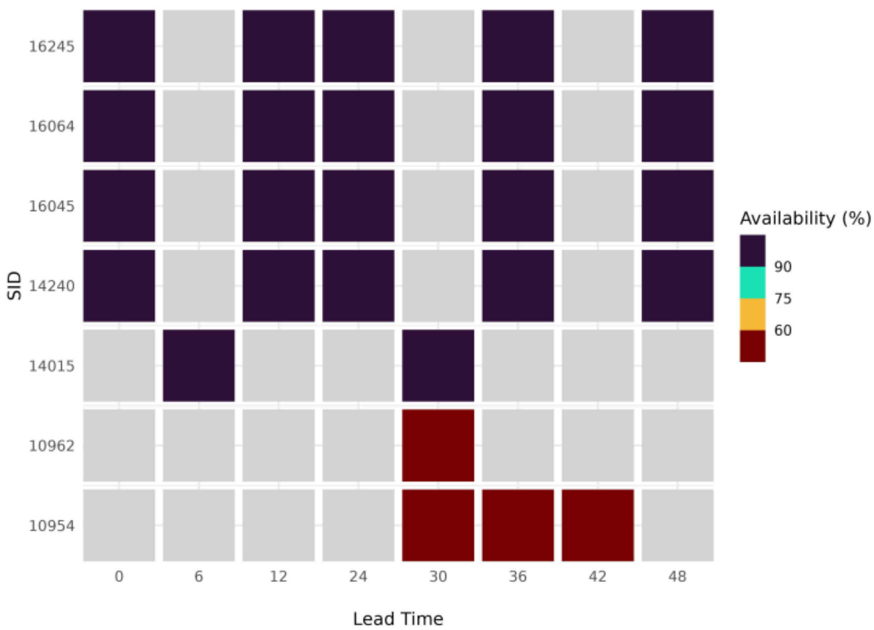

Figure 7: Availability of soundings as a function of lead time.

Furthermore, in lead time 36, data from five stations are included. However, for station 10954 at this lead time, the availability of data is x ≤ 60%. This reduced availability occurs because this station only reported data for the second day 2024-11-03 and data for the first day 2024-11-02 are missing (Table 2).

The evaluation was done for selected parameters at the level of 850 hPa and compared them with those of the CHMI verification package (VERAL). Due to technical constraints, a comparison could only be performed for the initial 24-hour period. Good agreement was found between the verification scores of Harp and VERAL with regard to temperature and wind at 850hPa, see Figure 8, Figure 9, Figure 10.

fcst_model	lead_time	num_cases	num_stations	bias	rmse	mae	stde
deode_clim	0	95	4	0.0380	0.758	0.455	0.761
deode_clim	6	20	1	-0.0266	0.812	0.524	0.832
deode_clim	12	96	4	0.243	1.13	0.779	1.11
deode_clim	24	95	4	0.0123	0.706	0.527	0.710
deode_clim	30	38	3	0.0402	1.20	0.641	1.21
deode_clim	36	107	5	0.285	1.27	0.833	1.24
deode_clim	42	10	1	0.190	0.676	0.567	0.685
deode_clim	48	96	4	0.00876	0.960	0.622	0.965
deode_clim_init	0	95	4	-0.0252	0.731	0.538	0.735
deode_clim_init	6	20	1	-0.0284	0.668	0.432	0.685
deode_clim_init	12	96	4	0.341	1.22	0.812	1.18
deode_clim_init	24	95	4	0.0512	0.750	0.541	0.753
deode_clim_init	30	38	3	0.0492	1.24	0.644	1.25
deode_clim_init	36	107	5	0.355	1.34	0.866	1.30
deode_clim_init	42	10	1	0.216	0.700	0.585	0.702
deode_clim_init	48	96	4	0.0659	0.987	0.630	0.990

Table 2: Verification summary scores for different forecast models and lead times.

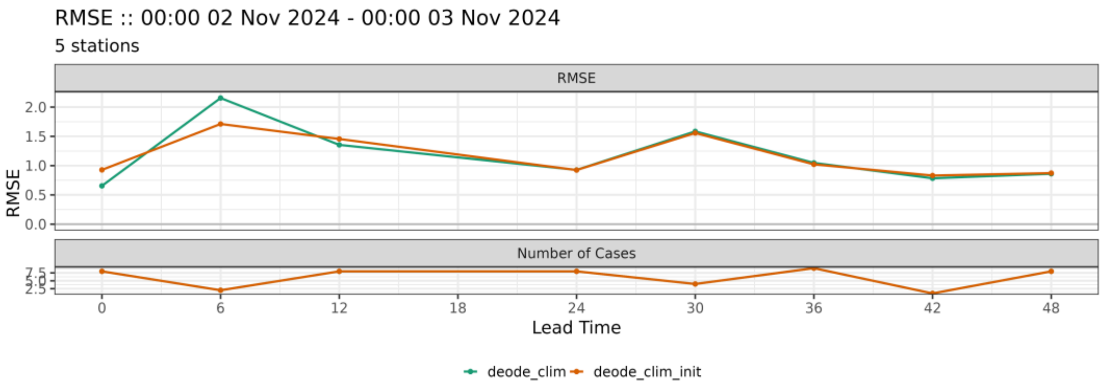

Figure 8: RMSE of temperature for level 850hPa for Model I (deode clim) in green and Model II (deode clim init) in brown by Harp.

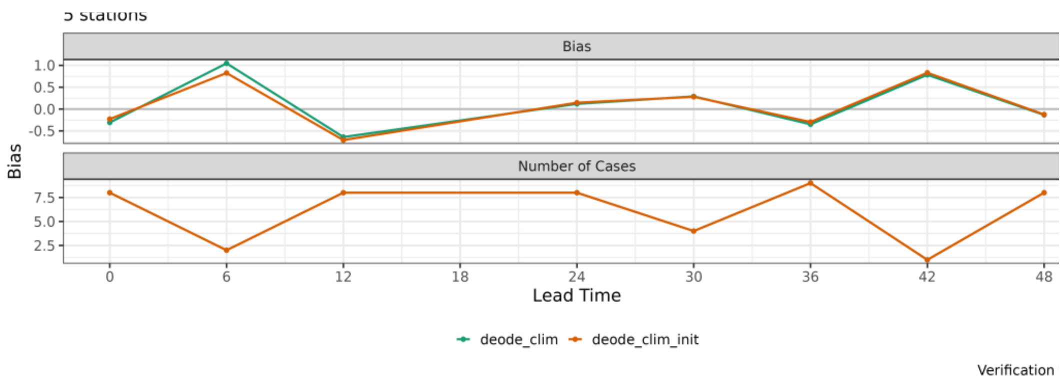

Figure 9: BIAS of temperature for level 850hPa for Model I (deode clim) in green and Model II (deode clim init) in brown by Harp.

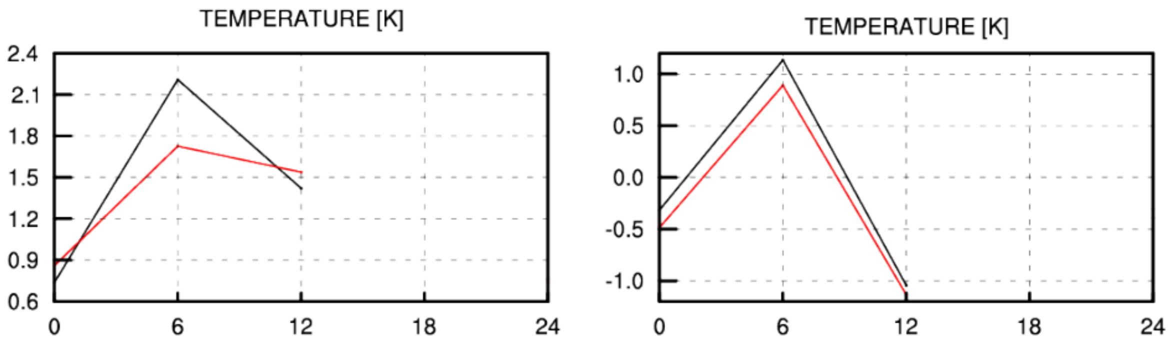

Figure 10: RMSE (left) and BIAS (right) of temperature for level 850hPa for Model I (deode clim) in black and Model II (deode clim init) in red by CHMI VERAL package.

There were issues with reading wind direction from GRIB files during preprocessing. Although GRIB files provide u and v wind components, HARP is designed to calculate wind direction from these values. In the past, this functionality worked correctly. While wind speed calculation operates as expected. The problem may be related to the GRIB2 format. The root cause remains unclear, and the issue was not resolved at the time of writing this report. Therefore, in this report, they present only results for wind speed at 850hPa, see Figure 11, Figure 12, Figure 13.

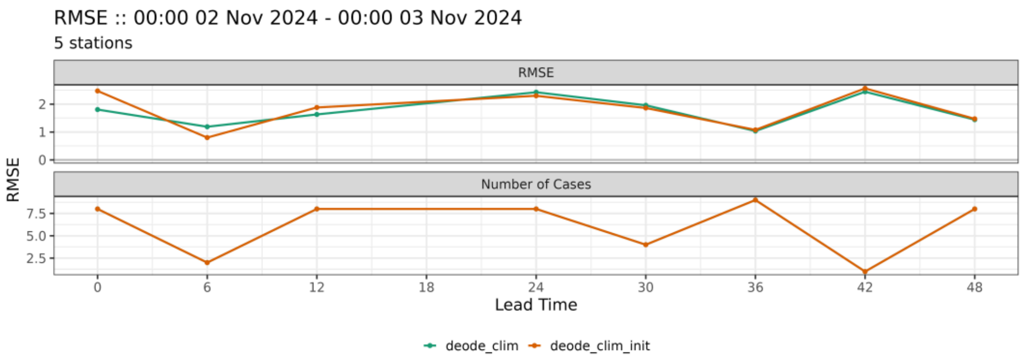

Figure 11: RMSE of wind speed for level 850hPa for Model I (deode clim) in green and Model II (deode clim init) in brown by Harp.

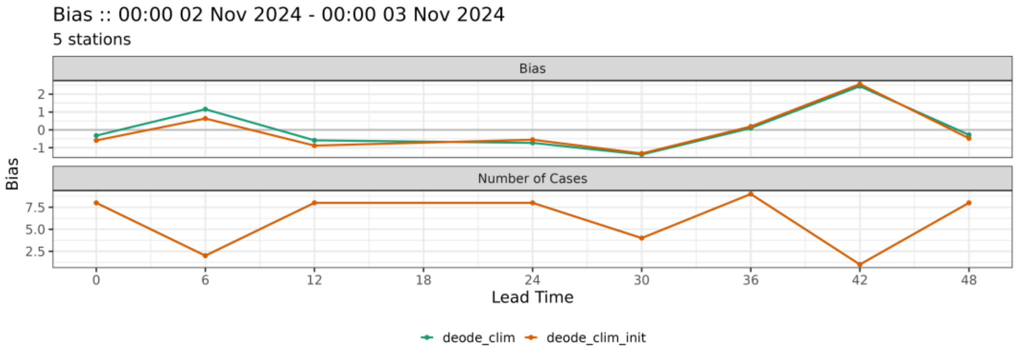

Figure 12: BIAS of wind speed for level 850hPa for Model I (deode clim) in green and Model II (deode clim init) in brown by Harp.

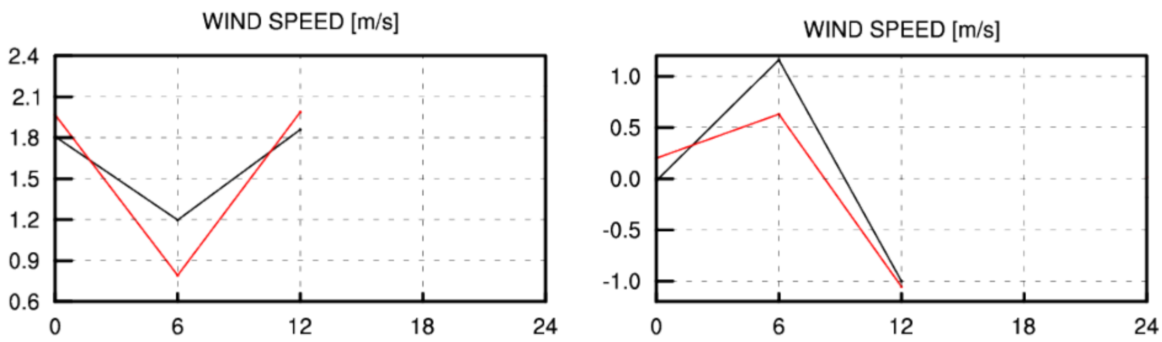

Figure 13: RMSE (left) and BIAS (right) of wind speed for level 850hPa for Model I (DEODE clim) in black and Model II (deode clim init) in red by CHMI VERAL package.

Due to time constraints and a lack of clarity, only the standard upper-air levels are being considered in this version.

• Consistent rounding was applied to standard meteorological levels. For example, pressure levels such as 249.8 hPa are now rounded up to 250 hPa.

• Improved data quality and processing consistency in the verification workflow. Minor code improvements were implemented for better preprocessing. In addition, outdated comments were removed and unit labels were cleaned and updated.

The updates have been incorporated into the latest development version of harpIO. For detailed technical information, please refer to Martin's report stay in Prague To review the complete set of code changes, see the pull request

https://github.com/harphub/harpIO/pull/124#issue-3243278823

Contributors, estimated efforts: Martin Petras (1 pm), Alena Trojáková (0.75 pm)

MQA1 total: 1.75 pm

[MQA2] Development of new methods for verification and validation

Description and objectives:

In Hungary, documentation regarding the verification of cloud forecasts started with some methods based on the MODE (Method for Object-based Diagnostic Evaluation) package from NCAR for sophisticated scores such as SAL or FSS and about the Panelification tool developed by the Austrian Team. Considering the reviewed methods, their pros and cons, the conclusion was to adapt Panelification in Hungary. Its comprehensive repository is available on github. First they will start to work with cloud mask and in a later stage, they intend to utilize cloud type.

Overview of the available methods and provide a concept for advanced verification of cloud forecasts (Hungary)

The application of spatial methods for cloud verification was examined. The Hungarian team have deeply reviewed the recommendations of research groups of ACCORD and NCAR (USA), covering approaches of object-, neighbourhood-, and distance-based measurements, spatial alignment and field deformation [1, 2, 3]. The majority of solutions rely on binary images derived from satellite data as observation and narrow the objective down to verifying cloud cover [4, 5, 6, 1, 3].

Method for Object-based Diagnostic Evaluation (MODE) was suggested by NCAR for cloud verification [1]. It is a diagnostic evaluation through 2D spatial operations, such as union, intersection, and error statistics (angle difference, centroid difference, etc.) after matching each observation object to their corresponding forecast equivalent. These object pairs are produced via Fuzzy Logic Engine selecting on 'Interest Value' base. The specific error types are available in the output attribute table, whilst overall performance is summed up in 'Total Interest' [7].

Another considered feature-based method is Structure-Amplitude-Location (SAL): its potential for cloud verification was investigated by [5] and [6]. However, reviews criticize its applicability pointing out high parameter sensitivity of object identification algorithm and threshold selection, which may drastically influence the resulting S (structure) and L (location) scores.

Hausdorff-distance and Baddeley's delta metric are distance-based metrics applied on binary fields [8, 9]. The Hausdorff-distance is based on the largest distance between the points of a cloud object and its weakness is that the scores can be largely degraded by even a single outlier. Baddeley's Delta method reduces this negative impact using the Lp-norm. Development Testbed Center specifically suggests using Baddeley's Delta metric to verify the multiple spatial aspects of cloud amount forecasting [3].

Measures of G and G_β [8] from Eric Gilleland quantify the degree of overlapping between forecasted and observed fields. In G_β the adjustable ß parameter controls the penalty threshold of location errors.

Image Warping was introduced for precipitation forecasts to extract errors in spatial, intensity, and even temporal dimensions [10, 11]. Warping is done by fitting the predicted field to the observed one; and as a result, the amount of applied transformations marks the quality of the forecast. Image Warping, along with G and G_β is recommended for cloud verification by NCAR [1, 2]. The limitation is that the Image Warping tool within Spatial Vx (R) is only available in a basic form [12].

Fractions Skill Score (FSS) tests the ability to hit fractions correctly within a specified size of spatial window frame [13]. Since FSS requires less accuracy for the cloud positions (by neighbourhood strategy), it is more aligned with the cloud cover expressed in percentage or octa. Fraction Skill Score is already widely used in ACCORD.

Panelification is a development of GeoSphere Austria [14, 15]. It is a smart integration of several features using small panels: a more advanced use of FSS with multiple parameter settings, complementary according to varying thresholds, percentiles, and window sizes.

Panelification enables tracking the performance of cloud forecasts on different horizontal scales and cloud object definitions controlled by thresholding the vertical levels, statistical scores (Pearson coefficient, RMSE, etc.), and comprehensive, visually explicable panels for performance tracking and diagnostic evaluation. It has a python version [14] and a version embedded in harp [15].

Considering the reviewed methods, their pros and cons, the plan is to adapt Panelification in Hungary. Its comprehensive repository is available on github. As an observation, they will rely on cloud mask and cloud type provided by the NWC SAF [17, 18]. Cloud type is supplemented with flags classifying the height referring to the top cloud layer. Cloud mask is prepared by using thresholds to identify cloud objects. First they will start to work with cloud mask and in a later stage, they intend to utilize cloud type.

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Contributors, estimated efforts: Virág Lovász (2.5 pm)

MQA2 total: 2.5 pm

[MQA3] Verification, evaluation and error attribution

Description and objectives:

In Croatia, the continuous work is based on an analog post-processing method for verification of 10-m wind speed for HR20 and HRAN systems and also for the verification of 2-m temperature for HR40 and HRAN. The validation was done for the whole year 2024, for synop stations from Croatia, for different statistical scores. Also, the validation was done for certain case studies. The whole remarkable work will be published in two articles. At the moment of this report, the articles are submitted.

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In Romania, taking into account the work of Martin Bellus based on the experiments of the ensemble system generated by the ALARO model at 750 m horizontal resolution and 87 vertical levels covering a domain centered on Slovakia territory, a validation was performed for the severe event from 13th September 2024. The evaluation was performed, by using the HARP system for 443 synop stations from the OPLACE database, for several meteorological parameters: temperature at 2 m (T2m), relative humidity at 2 m, mean sea level pressure, cumulated precipitation in 1 hour, wind speed and direction at 10 m.

Verification of 10-m wind speed for HR20 and HRAN systems **(Croatia)**

In Croatia, efforts have been made for the evaluation of 10-m wind speed validation of the deterministic model HR20 at 2 km horizontal resolution and of the analogue method named HRAN. This approach is used in order to improve the forecast quality by reducing the systematic biases and to better capture the local wind characteristics. The verification is performed for 10-minute averaged 10-meter wind speed forecasts, for the both systems mentioned above, for the whole year 2024. The domain of the model HR20 consists of 450x450 grid points and is running four times per day (00, 06, 12 and 18 UTC). It is using the initial and later boundary conditions from HR40 which in turn is using IFS-ECMWF as input in a lagged mode.

The HRAN analog-based post-processing method was tested and optimized for wind speed forecasting at DHMZ. By applying this method, the historical forecasts which are similar to the current model state are identified. The preliminarily important steps are the usage of the weighted combination of selected meteorological parameters, and also the utilization of the corresponded observations. For the optimization of the predictor weighting are utilized eight meteorological parameters and training dataset, which based only on the forecasts from 00 UTC), consists of a one-year training dataset and another one from a separate eight-month testing dataset. In figure 14, it can be observed that the most important benefit of predictors is due to the wind direction and the smallest impact is given by the precipitation field.

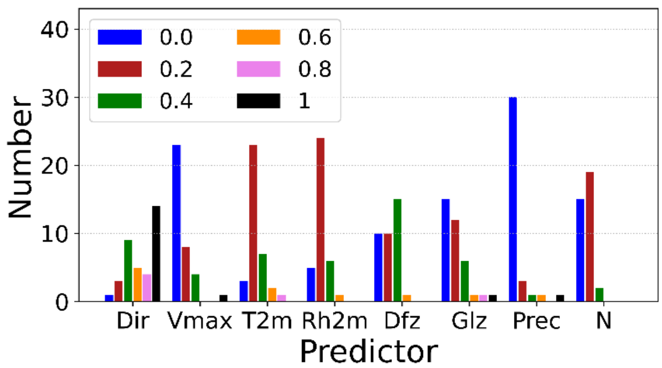

Figure 14. The meteorological predictors in the analogue method.

In order to perform the validation, quality control procedures were applied, excluding the stations having more than 10% data missing or those which were invalid data. The computed scores are: RMSE, BIAS, Standard Deviation, ETS (Equitable Threat Score) and EDI (Extremal Dependency Index). In figure 15, RMSE of 10-m wind speed is represented for different initialization times for HR20 and HRAN forecasts for the whole year 2024, by using 36 locations from Croatia. It can be observed that the lowest value of RMSE is obtained for the 18 UTC run. Figure 16 shows the decomposition into systematic and unsystematic components of RMSE, for different lead times. It can be noticed that at the initial forecast hour, the values of RMSE show a degradation of the forecast for both HR20 and HRAN, but this is not so important because the forecasts for the first hours are not available in real-time. The behavior of HR20 forecasts shows its overestimation of wind speeds values, especially during evening and nighttime hours. For the HRAN trend, it can be noticed that its forecasts are unbiased at night and a slight overestimation over daytime maximum. Also, HRAN represents more accurately the diurnal cycle phase, underestimating systematically the amplitude more than HR20. As an important result, the values of RMSE are lower for HRAN than HR20.

Figure 17 illustrates the positive bias for the whole year 2024 for HR20 forecasts, thereby an overestimation of 10-m wind speed parameter across all months, while HRAN has bias values close to zero and tends to systematically underestimate the amplitude of variability for the entire year 2024. In terms of RMSE, HRAN has lower values compared to HR20 compared to HR20.

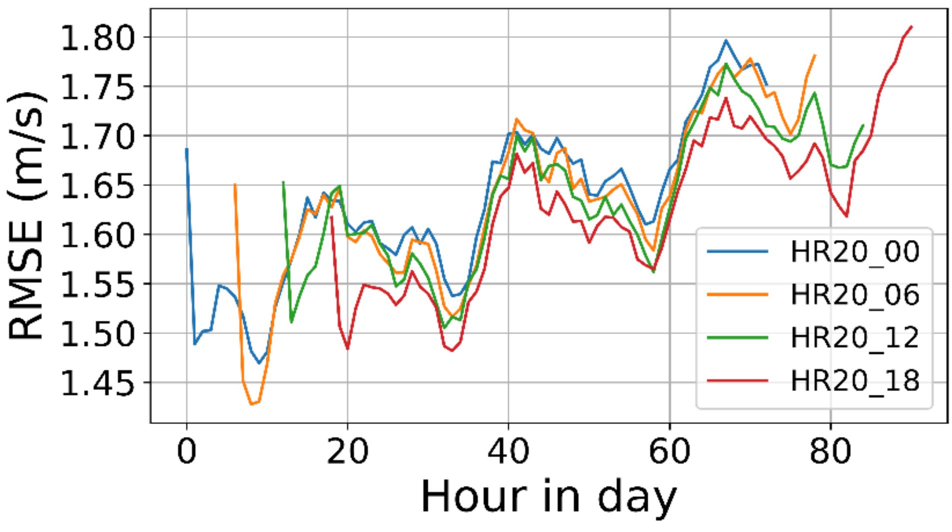

Figure 15. RMSE of 10-m wind speed for different initialization times for HR20 and HRAN forecasts for the whole year 2024, by using 36 locations from Croatia.

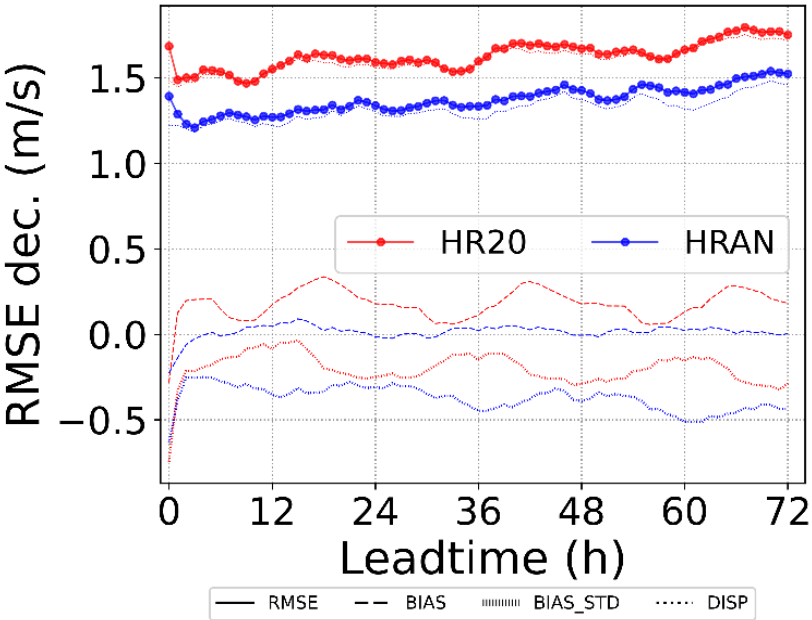

Figure 16. RMSE of different lead times from HR20 and HRAN forecasts initialized at 0 UTC during 2024 for 36 locations in Croatia.

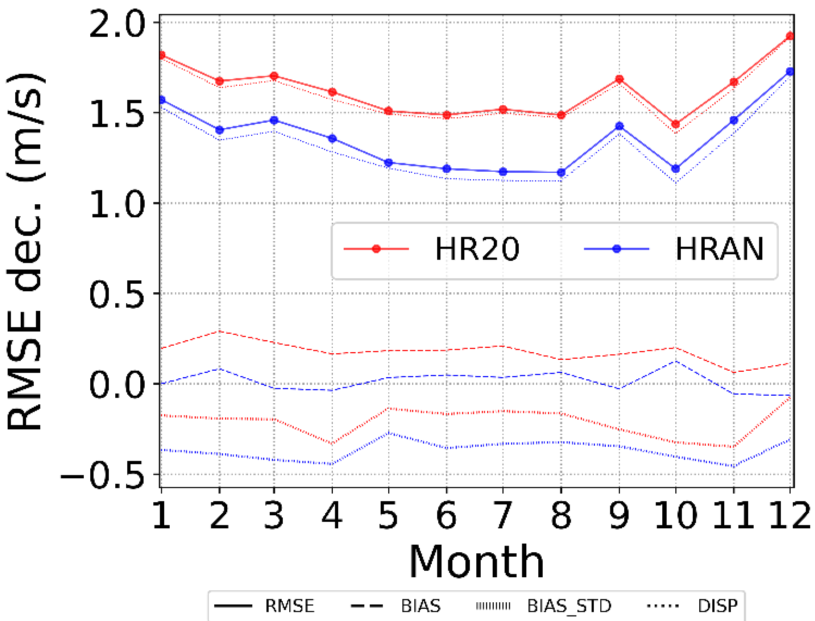

Figure 17. RMSE, with corresponding decomposition, for different months from 00 UTC forecasts of HR20 and HRAN, during 2024, from 36 stations in Croatia.

Case studies

In figure 18, for the both case studies (18 to 22 December 2024 and from 9 to 11 September 2024), it can be noticed that HRAN shows a clear improvement over HR20. For the first episode, the both systems identify the onset of the strong wind episode following several days of relatively weak winds. As for intensity, HRAN has a superior performance in contrast to HR20. For the second episode, both HR20 and HRAN performed comparably. They correctly captured both the onset and the peak of the event. In this situation, there doesn't exist a clear advantage of one product over the other.

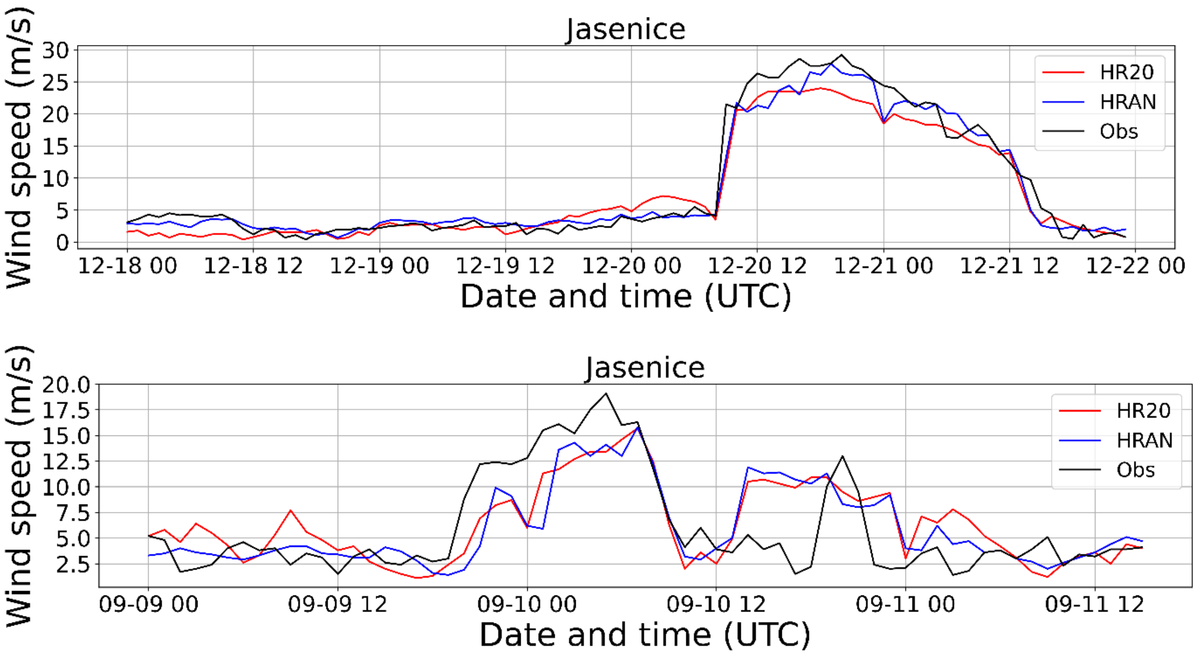

Figure 18. HR20 and HRAN forecasts at the Jasenice station for the time intervals from 18 to 22 December (top) and from 9 to 11 September (bottom).

- ❖ More details can be found in the submitted article "*Verification of 10-m wind speed ALADIN-HR forecasts HR20 and HRAN*", authors: Iris Odak, Ivan Vujec, Mario Hrastinski

Verification of 2-m temperature for HR40 and HRAN systems (Croatia)

Another important topic in Croatia was the evaluation of 2-m temperature evaluation of the HR40 and HRAN systems. HR40 model is the version of the limited area model ALARO-1 version at 4 km horizontal resolution and 73 vertical levels, which is running up to 72 forecast hours, for four times per day at 00, 06, 12 and 18 UTC. HRAN system is the post-processing approach having the capability to remove the systematic errors which inevitably occur in the process of the model integration. A comparison of these two systems was performed for the year 2024 in relation with the correspondent observations. The evaluation was done for 34 stations from Croatia.

For 2-m temperature evaluation, for the optimization of the predictor weighting are utilized 6 meteorological parameters, by using a one-year training dataset from the integration of the model at 00 UTC. In figure 19, it can be noticed the impact of different meteorological predictors.

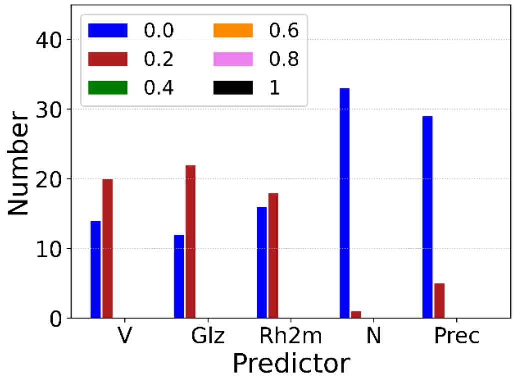

Figure 19. The number of the optimal weight values for individual predictors for temperature forecast. The optimization period is January 2022 – August 2022, for 34 stations.

As in the case of wind speed evaluation, the quality control procedures were applied for air temperature too. Therefore, the stations having more than 10% data missing or those which were invalid data were excluded from this validation. The used scores are: RMSE, BIAS, Standard Deviation, ETS (Equitable Threat Score) and EDI (Extremal Dependency Index). They were computed for the entire year 2024, for 36 locations in Croatia.In figure 20, it can be noticed that values of BIAS and standard deviation shows better results for HRAN in contrast to HR40. Also, in terms of RMSE, HRAN achieves lower values throughout the entire forecast length.

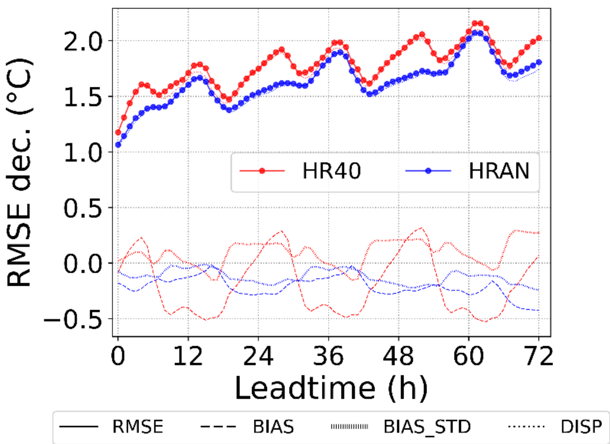

Figure 20. RMSE of air temperature for different initialization times for HR40 and HRAN forecasts for the whole year 2024, by using 36 locations from Croatia.

Figure 21 exhibits for the summer period a slightly greater bias compared to the whole year 2024 for both forecasts of air temperature, with a peak in August. In general, HR40 is underestimating the values of temperature throughout the year and HRAN is overestimating in the warmer months and is underestimating in the colder months. In terms of RMSE, HRAN outperforms HR40 in almost all months.

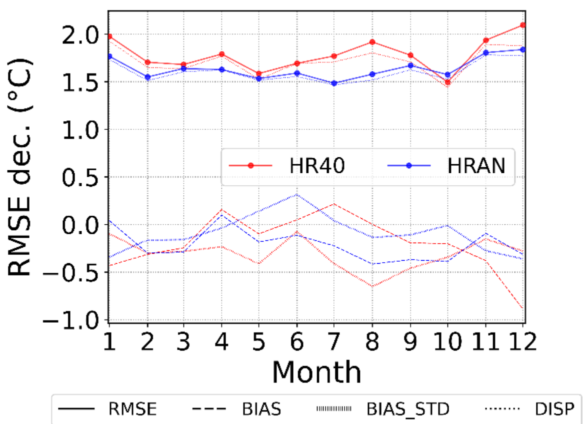

Figure 21. RMSE with corresponding decomposition, for different months from 00 UTC forecasts of HR40 and HRAN, during 2024, from 34 stations in Croatia.

Case studies

Two cases of large forecast errors were analyzed by the Croatian team too: the first one is from April 16, 2024 (figure 22 - top) and the second one from August 24, 2024 (figure 22 – bottom). In the figure for the first case, it can be observed that model which was initialized closer to the event (“*HR40-1st fcst day”* and “*HRAN-1st fcst day”*) shows better results from the temperature drop from April 16 and the both systems shows the same behavior. Almost the same results were obtained for the second case, though the magnitude of the temperature drop is underestimated by both of them.

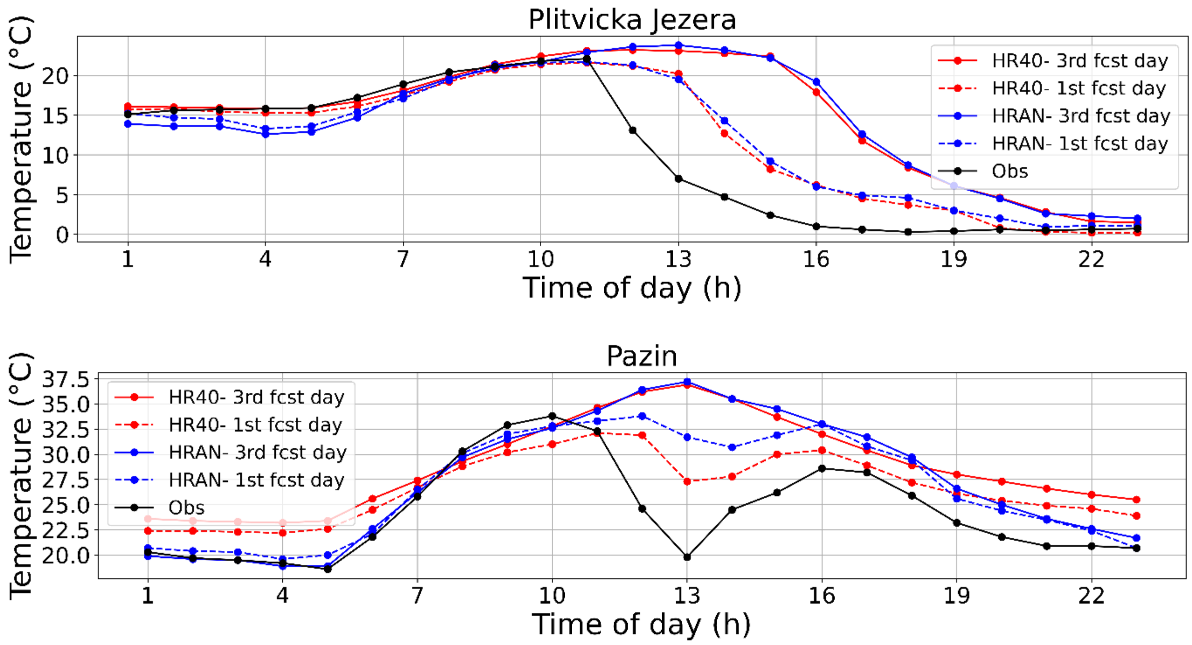

Figure 22. Time series of observation and forecast for two case studies: April 16, 2024 (top) and August 24, 2024 (bottom) for HR40 and HRAN forecasts.

- More details can be found in the submitted article: “*Evaluation of 2-Meter Temperature ALADIN-HR Forecasts from HR40 Model Configuration and HRAN Post-Processing*“, authors: Ivan Vujec, Iris Odak, Endi Keresturi

Contributors, estimated efforts: Iris Odak, Ivan Vujec, Mario Hrastinski Endi Keresturi (3 pm).

VERAL verification DE-330 (Czech Republic)

Work continued on extending the operational verification (using the VERAL package) from six hours to three hours, as well as on implementing the snow depth verification in VERAL.

Contributors, estimated efforts: Alena Trojáková (0.5 pm).

Using HARP for different experiments (Romania)

Taking into account the work of Martin Bellus based on the experiments of the ensemble system generated by the ALARO model at 750 m horizontal resolution and 87 vertical levels covering a domain centered on Slovakia territory, a validation was performed for the severe event from 13th September 2024. The ensemble consists of 6 members and 1 control run. Four versions of ALARO setup were used: hydrostatic (HS), non-hydrostatic (NH), no prognostic groupels (NOGRA), no stochastic physics (NOSPPT - i.e. only multiphysics). The calculation of the verification scores was done point-to-point verification by using the HARP system for 443 synop stations from the OPLACE database. The evaluation was performed for several meteorological parameters: temperature at 2 m (T2m), relative humidity at 2 m, mean sea level pressure, cumulated precipitation in 1 hour, wind speed and direction at 10 m.

In Figure 23 it can be noticed the mean bias of the four ensembles systems: HS_NOGRA_750m (green - hydrostatic, no groupels), HS_NOGRA_NOSPPT (blue - hydrostatic, no groupels, no SPPT), NH_NOGRA_750m (orange - non-hydrostatic, no groupels), HN_NOGRA_NOSPPT_750m (pink - non-hydrostatic, no groupels, no SPPT). The results of the hydrostatic experiments (HS_NOGRA_750m and HS_NOGRA_NOSPPT) are very similar. The same behavior can be observed for the non-hydrostatic versions of the ALARO setups (NH_NOGRA_750m and HN_NOGRA_NOSPPT_750m). Overall, the results of the hydrostatic versions show better results in terms of the mean bias of the ensemble.

Regarding the RMSE score of the ensemble mean (Figure 24), similar results are obtained. For the hydrostatic versions the pattern curves of the RMSE show better results compared to the non-hydrostatic versions. For the Spread-Skill evaluation, Figure 25 shows a very similar spread for all four experiments, but the differences appear in RMSE.

Figure 26 presents the results from a probabilistic point of view for the ensemble systems, by showing the computation of CRPS score. The results are also similar, showing the performance of the hydrostatic versions compared to the non-hydrostatic ones.

By illustrating the Bias and RMSE of each member for all 4 experiments (Figure 27 and Figure 28), it can be noticed that the members have a certain spread and they are able to show different possible weather situations. For this case, it can be concluded that the results of the hydrostatic versions (without groupels and one without SPPT scheme activated) lead to better results than non-hydrostatic versions (also without groupels and one without SPPT scheme activated). Another conclusion can be noticed from the fact that the individual members are different which shows a consistency for the ensemble systems.

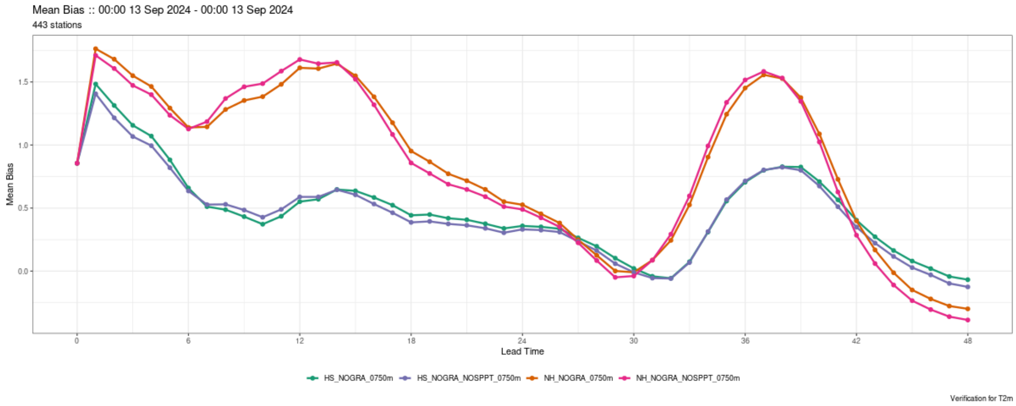

Figure 23. Mean Bias of T2m for four experiments: HS_NOGRA_750m (green - hydrostatic, no groupels), HS_NOGRA_NOSPPT (blue - hydrostatic, no groupels, no SPPT), NH_NOGRA_750m (orange - non-hydrostatic, no groupels), HN_NOGRA_NOSPPT_750m (pink - non-hydrostatic, no groupels, no SPPT).

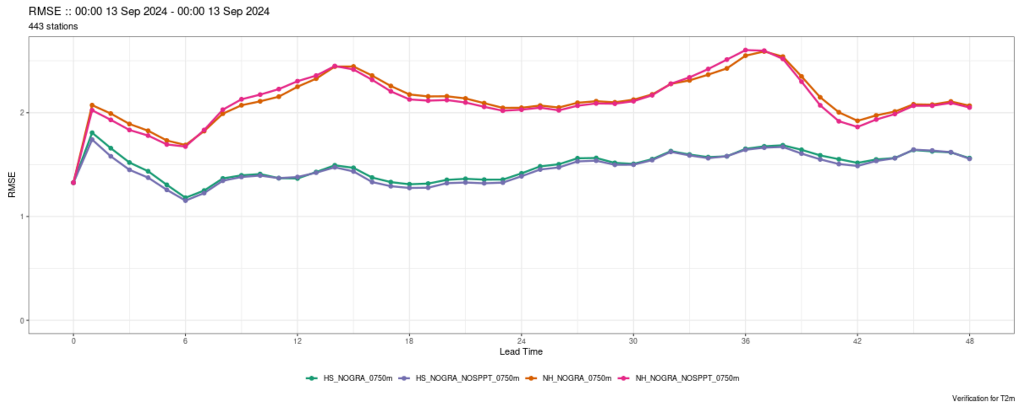

Figure 24. RMSE of the ensemble mean of T2m for four experiments: HS_NOGRA_750m (green - hydrostatic, no groupels), HS_NOGRA_NOSPPT (blue - hydrostatic, no groupels, no SPPT), NH_NOGRA_750m (orange - non-hydrostatic, no groupels), HN_NOGRA_NOSPPT_750m (pink - non-hydrostatic, no groupels, no SPPT).

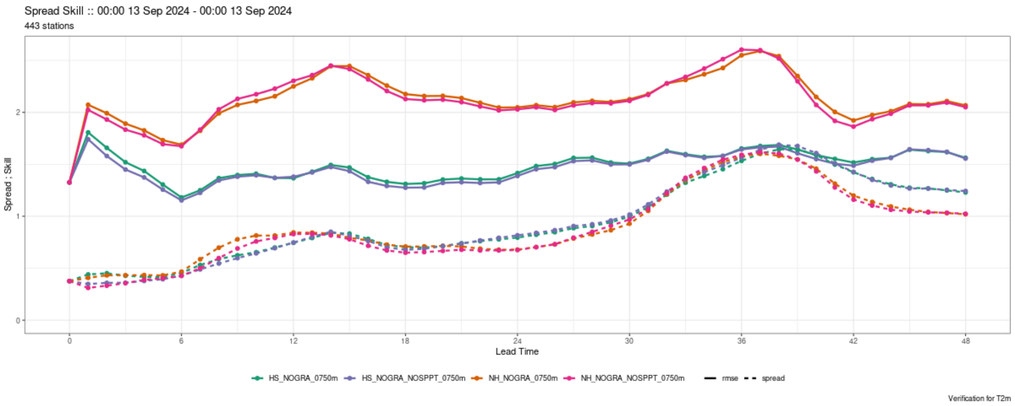

Figure 25. Spread Skill of T2m for four experiments: HS_NOGRA_750m (green - hydrostatic, no groupels), HS_NOGRA_NOSPPT (blue - hydrostatic, no groupels, no SPPT), NH_NOGRA_750m (orange - non-hydrostatic, no groupels), HN_NOGRA_NOSPPT_750m (pink - non-hydrostatic, no groupels, no SPPT).

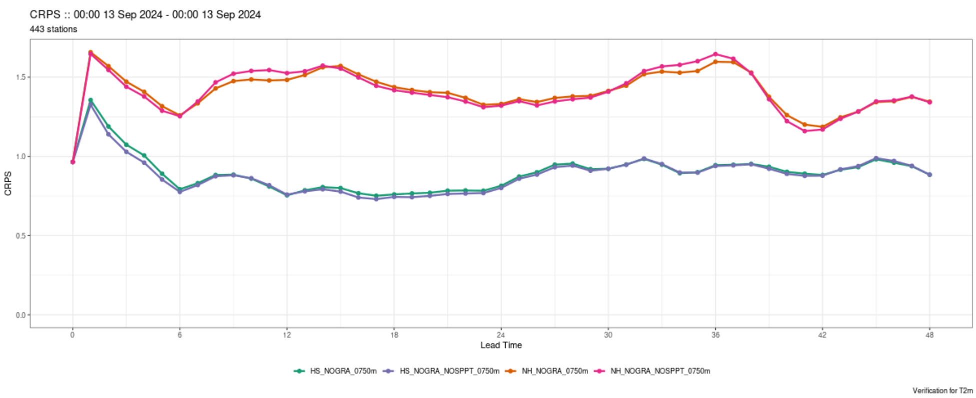

Figure 26. CRPS of T2m for four experiments: HS_NOGRA_750m (green - hydrostatic, no groupels), HS_NOGRA_NOSPPT (blue - hydrostatic, no groupels, no SPPT), NH_NOGRA_750m (orange - non-hydrostatic, no groupels), HN_NOGRA_NOSPPT_750m (pink - non-hydrostatic, no groupels, no SPPT).

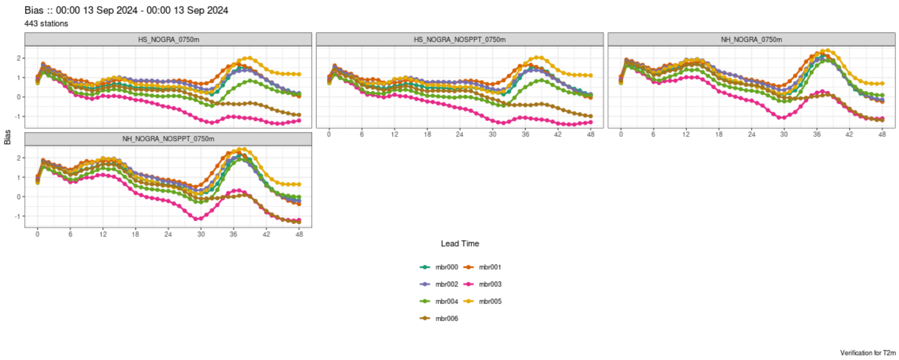

Figure 27. Bias of T2m for each individual member of the four experiments: HS_NOGRA_750m (first panel), HS_NOGRA_NOSPPT (second panel), NH_NOGRA_750m (third panel), HN_NOGRA_NOSPPT_750m (fourth panel).

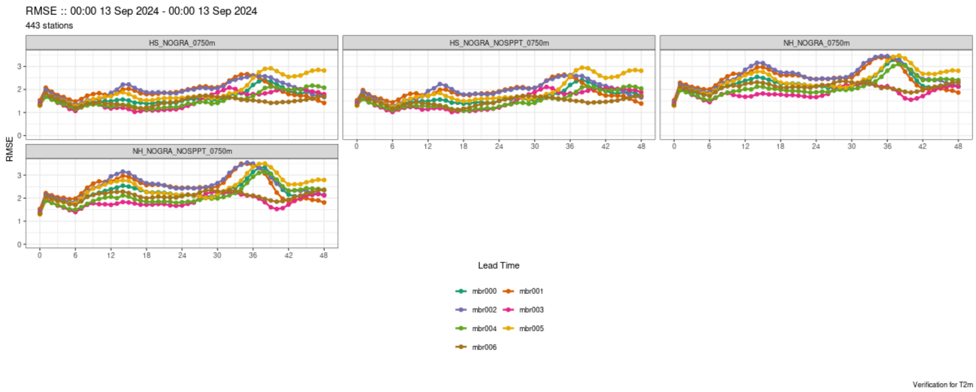

Figure 28. RMSE of T2m for each individual member of the four experiments: HS_NOGRA_750m (first panel), HS_NOGRA_NOSPPT (second panel), NH_NOGRA_750m (third panel), HN_NOGRA_NOSPPT_750m (fourth panel).

Contributors, estimated efforts: Simona Taşcu (1 pm)

MQA3 total: 4.5 pm.

[MQA4] Verification of operational forecasts and user information

Description and objectives:

In Hungary, they continued the work related to HARP, for pressure level verification based on TEMP observations of 6 stations within the AROME/HU domain. The number of used pressure levels for verification are 28. The computed scores are Bias and RMSE for geopotential, wind speed, relative humidity and temperature parameters.

Also in Hungary they started to develop an automatic and objective method: the daily maximum wind gust for a given location is calculated by interpolation of station measurements onto a fine grid, enhanced with background information from high-resolution numerical weather predictions. The MISH (Meteorological Interpolation based on Surface Homogenized data basis) method is used for spatial interpolation, a method developed by the Hungarian Meteorological Service specifically for meteorological purposes. They made an evaluation of the wind gust forecasts of AROME, AROME-RUC and AROME-EPS. From AROME-EPS, the ensemble mean was used, because the interpolation cannot involve "proper" ensemble predictions for technical reasons.

In Poland, they are doing the preoperational tests with CY46T1 export version runs daily for ALARO CMC with horizontal resolution 2.45 km, with our packages of code changes developed by the Czech LACE team in Prague were included in the local model version. The results validation was done for January and August 2025, based on the BIAS and RMSE for various meteorological fields. Also, a new version of HARP was installed locally and work has been done to adjust it for operational verification for ALARO, AROME, IFS and GFS. So far point-base verification is ready for ground stations as well as for radiosondes. Work is ongoing for spatial verification of deterministic and ensemble models.

Operationalization of verification on pressure levels with HARP (Hungary)

The work related to the setup of the operational verification in harp was continued, the next step was the operationalization of pressure level verification. For this purpose, TEMP observations of 6 stations within the AROME/HU domain are used. For most of the NWP forecasts verified at HungaroMet, data of 28 pressure levels are available during verification. Our previous verification system uses only data of 4 stations and 8 pressure levels. Bias and RMSE are calculated for four parameters, geopotential, wind speed, relative humidity and temperature. The forecast and observation data are read automatically daily from the corresponding netCDF files and stored in SQLite format for later use with harp. The verification scores are calculated monthly and then the results are summarized in a document in PDF format using the "rmarkdown" package. The results are displayed in recently added vertical diagrams for every 12-hour time step (Figure 29) and in diagrams for pressure level scores as function of lead time (Figure 30). The document is available for the users on the internal website.

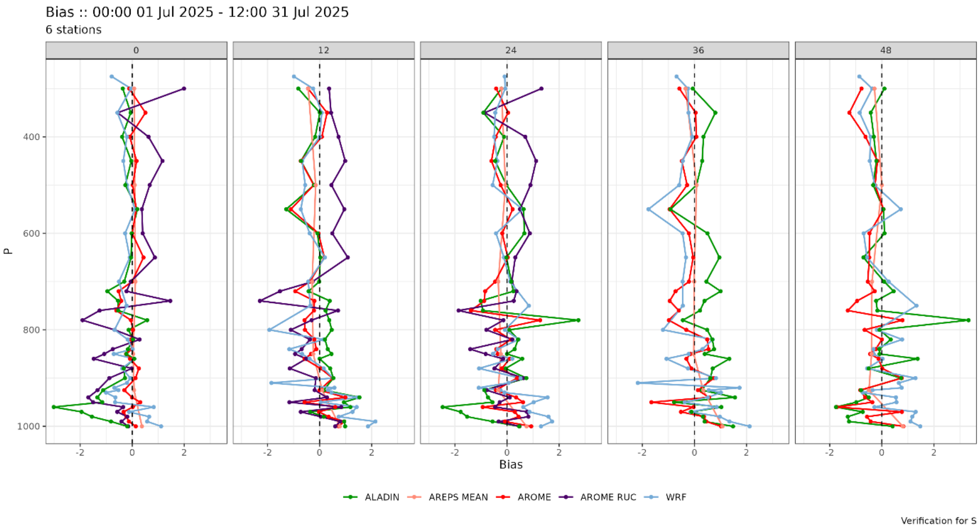

Figure 29: Bias of wind speed (in m/s) for 00 UTC forecast runs as function of pressure level (in hPa) for July 2025. The individual panels belong to 0-, 12-, 24-, 36- and 48-hour lead times.

Figure 30: RMSE of relative humidity at 700hPa (in %) for 00 UTC (left) and 12 UTC (right) forecasts as a function of lead time (in h) for July 2025.

Contributors, estimated efforts: Dávid Tajti (1 pm)

Verification of wind gust forecasts of AROME, AROME-RUC and AROME-EPS for development of a wind hazard product (Hungary)

Wind hazards are assessed with special attention in Hungary in case of damage reports and insurance inquiries related to stormy winds. The users often require information for geographical locations where the Hungarian Meteorological Service does not have observation. To fulfil these requests, the current product of HungaroMet is prepared after human judgement considering station measurements for daily maximum 10-meter wind gust, radar reflectivity and lightning images. To replace this manual and strongly subjective method, they have begun to develop an automatic and objective method: the daily maximum wind gust for a given location is calculated by interpolation of station measurements onto a fine grid, enhanced with background information from high-resolution numerical weather predictions. For spatial interpolation the MISH (Meteorological Interpolation based on Surface Homogenized data basis) method is used which was developed by the Hungarian Meteorological Service specifically for meteorological purposes. To select the most appropriate background field, they conducted a comprehensive evaluation comparing the wind gust forecasts of AROME, AROME-RUC and AROME-EPS. (From AROME-EPS, they concentrated on the ensemble mean, because the interpolation cannot involve “proper” ensemble predictions for technical reasons.)

The verification period was between 1 September, 2024 and 21 January, 2025. During this period, AROME forecasts and AROME-EPS mean for wind gust had lower RMSE in many timesteps, but consistently underestimated the maximum values of 24-hour wind gusts (from 0 to 0 UTC). In contrast, AROME-RUC occasionally overestimated the maximum values, especially in extreme weather situations with high gust values, but still provided much more reliable forecasts, as shown in Figure 31. This is also supported by Figure 32, where AROME-RUC reduced the underestimation of the number of daily wind gust above 10 m/s threshold. Case studies were also conducted for stormy days, and the results were consistent with the objective verification scores. Based on the results, in addition to the measurements, AROME-RUC background information was also used at the interpolation and this configuration was running in test mode during the summer. They will continue with a comparative evaluation for the manual product and the test product for summer.

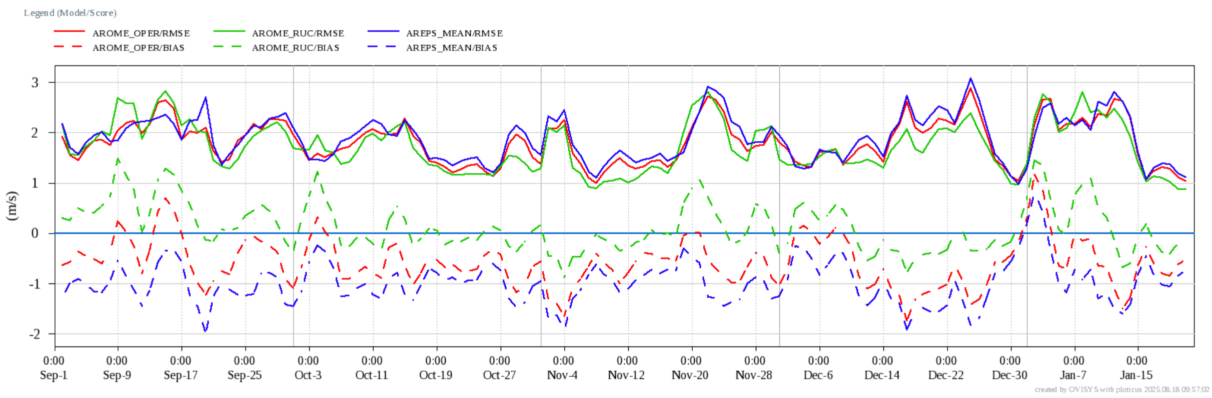

Figure 31: 3-day moving average of RMSE (solid lines) and bias (dashed lines) of 24-hour maximum wind gust (in m/s) based on AROME (red), AROME-RUC (green) and mean of AROME-EPS (blue) forecasts for the 00 UTC +24h between 1 September 2024 and 21 January 2025.

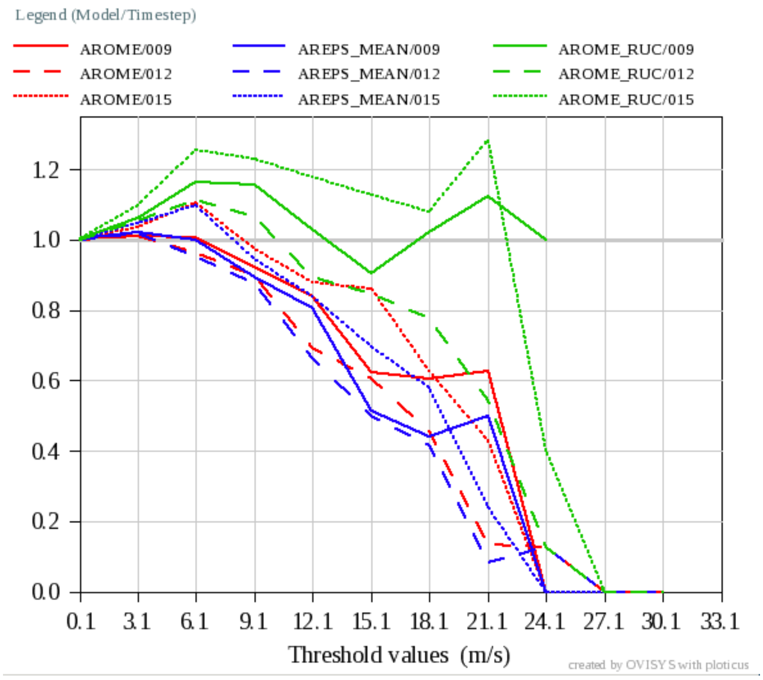

Figure 32: Frequency bias of hourly wind gust in the 9- (solid line), 12- (dashed line) and 15-hour (dotted line) timestep of the 00 UTC runs of AROME (red), AROME-RUC (green) and mean of AROME-EPS (blue) forecasts as a function of wind gust thresholds between 1 September 2024 and 21 January 2025.

Contributors, estimated efforts: Natália Szalontainé Gáspár (0.25 pm)

Pre-Operational tests of CY46T1 (Poland)

Preoperational tests with CY46T1 export version runs daily for ALARO CMC with horizontal resolution 2.45 km:

- the four packages of code changes developed by the Czech LACE team in Prague were included in the local model version
- the new ALARO domain E024 covers almost the same area as the operational E040 one
- there are 70 vertical levels
- timestep was reduced from 150s to 90s
- clim files were prepared according to procedure described in Jan Masek report
- parametrizations and dynamics of the model were adjusted to the 2.45 km horizontal resolution
- physics in the new domain still undergoes the process of tuning.

Below, the results of BIAS and RMSE for various meteorological fields in January and August, 2024, are listed.

January, 2024:

- T2m – BIAS reduced (minimum around 12 UTC), insignificant growth of RMSE in morning hours – Figure 33
- RH2m – Slightly worse results for E024, diurnal cycle for BIAS and RMSE; the highest error on the day
- CCtot – positive BIAS visible
- VS – growth of BIAS and reduction of RMSE for E024 in comparison with E040; RMSE for lowland stations is better for E024
- VD, PRES – similar results for both E040 and E024
- Wind gust – E024 with less RMSE and BIAS; possible problem with mountain stations (Kasprowy Wierch, Śnieżka) – Figure 34

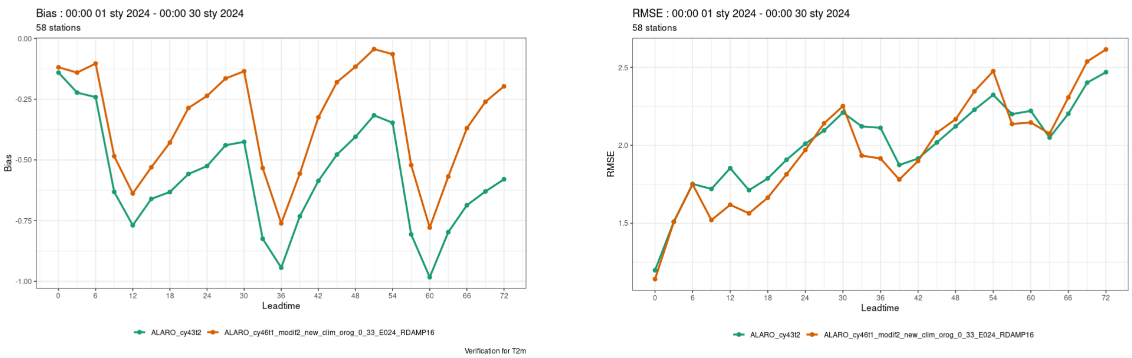

Figure 33: T2m: BIAS (a) and RMSE (b), January 2024.

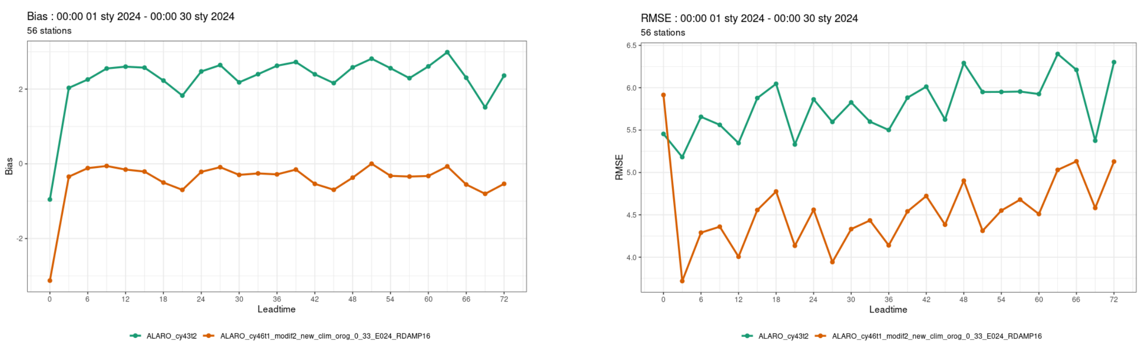

Figure 34: Wind Gusts (G10m): BIAS (a) and RMSE (b), January 2024.

August, 2024:

- T2m – RMSE and BIAS smaller for night time (E024 vs E040); more implicit treatment of the TKE/TTE solver – Figures 35
- RH2m – no significant change, diurnal cycle visible
- CCtot, VS, PRES – lack of significant changes

❖ VS – positive BIAS, RMSE similar for both domains

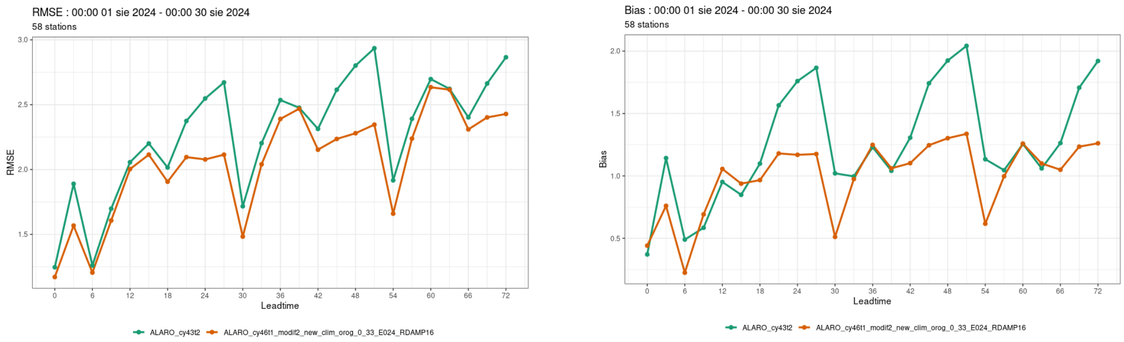

Figure 35: Wind Gusts (G10m): BIAS (a) and RMSE (b), August 2024.

Implementation of new version of HARP (Poland)

A new version of HARP was installed locally and work has been done to adjust it for operational verification of NWP models used in IMGW-PIB. So far point-base verification is ready for ground stations as well as for radiosondes, for ALARO, AROME, IFS and GFS. Work is ongoing for spatial verification of deterministic and ensemble models (Figure 36).

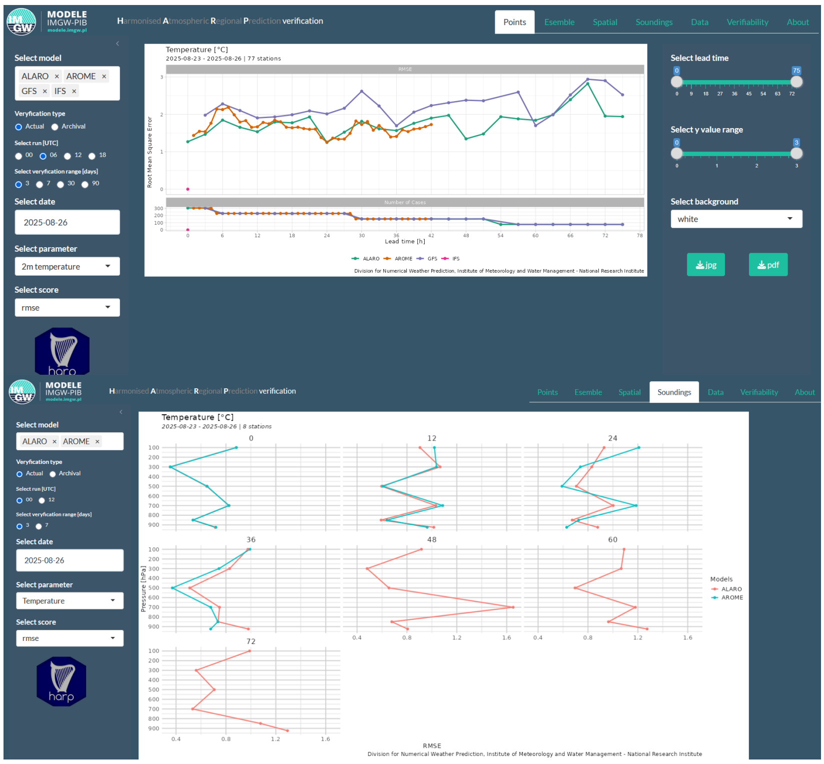

Figure 36: HARP in IMGW-PIB

Contributors, estimated efforts: Poland team (5 pm)

MQA4 total: 6.25 pm

[E6.3] Ensemble calibration by use of the machine learning and deep learning algorithms

Description and objectives:

The Hungarian team continued the work based on the AROME-EPS EMOS postprocessing using data from groups of similar stations. The aim is to provide post-processed forecasts for any selected location that improve the CRPS score of the raw EPS as much as possible. For this purpose, the observation stations considered their certain properties and chose “similar ones” for the (regional) EMOS runs were classified. Similarity was quantified based on model error (CRPS) characteristics, incoming solar radiation climatologies (derived from observation data) or geographical distance.

Testing improvement possibilities of AROME-EPS EMOS postprocessing for radiation (Hungary)

The Hungarian team continued to tune the AROME-EPS EMOS postprocessing using data from groups of similar stations. The study is motivated by the fact that in the operational version of EMOS, data from different parts of Hungary are used together, and consequently the improving effect of the postprocessing is not optimal (sufficient) for all stations. Our aim is to provide post-processed forecasts for any selected location that improve the CRPS score of the raw EPS as much as possible. To achieve this, it was classified the observation stations considering their certain properties and chose “similar ones” for the (regional) EMOS runs. Similarity was quantified based on model error (CRPS) characteristics, incoming solar radiation climatologies (derived from observation data) or geographical distance, based on Lerch and Baran 2017 [1].

A meteorologist student in the work was involved in order to run test experiments for the period of August to October 2023, by using radiation measurements from a private company for more than hundred stations, besides 35 HungaroMet stations [2]. The test period was chosen because of the availability of the partner´s measurements and the large differences between measured and forecasted photovoltaic electricity production. Test experiments were run for three target locations, specially chosen to improve the CRPS characteristics. Because the partner´s piranometers are tilted to the south, their data was recalculated to the horizontal plane, using the position of the Sun, and empirical correlation between the diffuse fraction of radiation and sky clearness index [3].

It was found that using data of “similar” stations (based on model error characteristics) in EMOS can improve the performance of the EMOS method significantly for a target station with respect to the other operational configuration. Partner measurements (i.e. from a private company) were only involved in tests based on geographical distance. Their involvement does not necessarily improve CRPS. In addition, when focusing only on the first day of the forecast, a 7 days shorter (i.e. 24-day) training period and/or using more stations’ data, could also improve the postprocessing performance for most target stations. An example can be seen in *Figure 37*, which shows CRPS and bias for Sármellék (located near Lake Balaton). In this case the weakest scores belong to 6 additional (5 partner and one HungaroMet), geographically nearest stations (“test2” in Figure 38) and 31 days training period, while the best one are produced using data of 8 similar (based on error-metrics similarity) HungaroMet stations (“test1” in Figure 38), with 24 days training period. Average improvement for this station with respect to CRPS of the raw EPS was 5.2% in the former, and 16.6% in the latter case.

The work was continued with testing the method involving more stations and a more recent period.

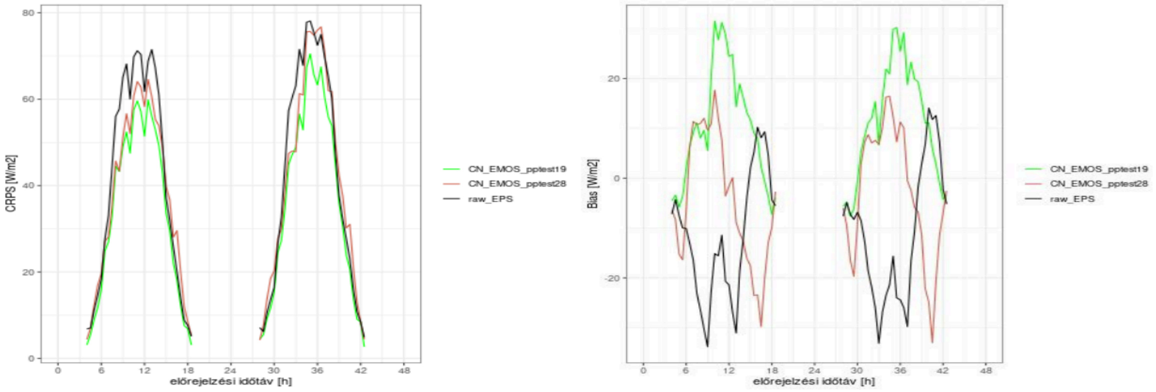

Figure 37: CRPS (left) and bias (both in W/m^2) (right) of radiation ensemble forecasts for Sármellék station between 1 August and 29 October 2023 as a function of lead time (in h). Comparison of the raw EPS (black) and the postprocessed versions with the best (green) and worst (red) performing set of stations based on the first day CRPS Figure found in [2].

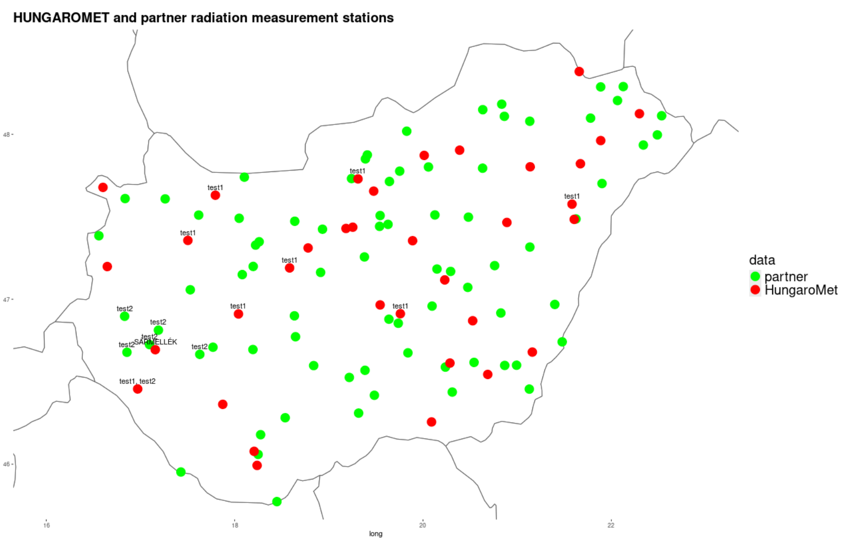

Figure 38: Locations of HungaroMet (red) and partner (green) observation stations. Stations involved in tests giving the best and the weakest results for station Sármellék are marked with test1 and test2, respectively.

References

[1] Lerch, S. and Baran, S. (2017): Similarity-based semilocal estimation of postprocessing models. Appl. Statist. 66, Part 1, 29–51.

[2] Glück, K. (2025): Development of operational post-processing for AROME-EPS global radiation forecasting. Master´s thesis, Eötvös Loránd University, Budapest (in Hungarian).

[3] Pashiardis, S., Kalogirou, S. A., and Pelengaris, A. (2022): Shortwave Radiation on Horizontal and Incline Surfaces – One Year of Solar Radiation Measurements at Athalassa, an Inland Location in Cyprus. Appl. Sci., 12.

Contributors, estimated efforts: Katalin Jávorné Radnóczi (2.5 pm)

E6.3 total: 2.5 pm

[COM3.1] Maintenance and Partners' implementations of the ACCORD system

Verification using VERAL (Czech Republic)

The main topic was the extension of the operational verification (using the VERAL package) from 6 hours to 3 hours.They are also working on implementing the snow depth verification in the VERAL.

Contributors, estimated efforts: Alena Trojáková (1 pm).

COM3.1 total: 1 pm

Publications

- Iris Odak, Ivan Vujec, Mario Hrastinski: "*Verification of 10-m wind speed ALADIN-HR forecasts HR20 and HRAN*", submitted 2025
- Ivan Vujec, Iris Odak, Endi Keresturi: "*Evaluation of 2-Meter Temperature ALADIN-HR Forecasts from HR40 Model Configuration and HRAN Post-Processing*", submitted 2025

❖ Szalontainé Gáspár, N., Tóth, B., Szépszó, G., Lancz, D., Jávorné Radnóczi, K., Magyar, L., Tóth, H., Oláh, S., Tajti, D., 2025: Implementation of AROME/HU cy46t1 model version with modified town fraction. ACCORD Newsletter 7, 16-22.

Summary of resources [PM]

Subject/Action	Resource (realized)	LACE stays
[MQA1] Development of HARP	1.75 pm	1 pm
[MQA2] Development of new verification methods	2.5 pm	
[MQA3] Verification, evaluation and error attribution	4.5 pm	
[MQA4] Verification of operational forecasts and user information	6.25 pm	
[E6.3] Ensemble calibration by use of the machine learning and deep learning algorithms	2.5 pm	
[COM3.1] Maintenance and Partners' implementations of the ACCORD system	1 pm	
Total	**18.5**	**1 pm**

Activities of management, coordination and communication

1. 44th LSC Meeting, 6-7 March 2025, Krakow
2. 5th ACCORD All Staff Workshop 2025, March 31 – April 4 2025 (Zalakaros), online participation
3. 45th LSC Meeting, 10-11 September 2025, Ljubljana