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Date: 15/05/2024 09:38:19

Green Book 2024 - aka Use and verification of ECMWF products in the Member and Co-operating States

Fields marked with * are mandatory.

Introduction

Welcome to ECMWF new "Green Book" online submission system (aka "Use and verification of ECMWF products in the Member and Co-operating States")

This time we have two options for completion:

- Filling out the online questionnaire below (new for this year based on feedback from the Meteorological Representatives meeting in November 2023)
- Producing a single report offline (as done in previous years), and emailing the report as detailed in Section 1.

Both methods ask the same questions, however the questionnaire method requires no formatting and aims to make analysis of all responses easier. The questionnaire option also allows you to part-complete, and save your entries to come back to later (using the "Save as Draft" button in the top right corner of this page). Note that the EUSurvey page will timeout after 60 minutes of no activity, responses are usually saved however to be sure please "Save as Draft" to avoid losing responses.

The deadline for all submissions is 23:59UTC on Wednesday 15th May 2024

A summary of responses will be presented at UEF2024 with a summary report available in the ECMWF Publications library in due course.

Section 1: Background - please fully complete

* **1.1 Which Country is your submission for?**

HU - Hungary

*** 1.2 Please provide your name(s)**

Boglárka Tóth, Gabriella Tóth, Anna Kuntár-Molnár, Balázs Fehér, Zita Ferenczi, Gabriella Szépszó, István Ihász

*** 1.3 Please provide your organisation**

HungaroMet Hungarian Meteorological Service

*** 1.4 Please select your preferred submission method:**

- ○ Producing a single report offline
- ◉ Online questionnaire

Online questionnaire

Please answer the following questions, and illustrate your answers, where appropriate, by also uploading clearly annotated images with image/figure numbers (max 1MB per file). More questions or options may appear, depending on answers to particular questions. Mandatory questions are marked with a '*'. Free text boxes appear to have a 5000 character limit (if your answers are longer than this please email them to Becky and they will manually added), answers don't need to fit the box size given, the boxes expand.

Responses to the questionnaire can be saved and returned to at a later date before submitting. To do this click the 'Save as Draft' button on the left, this will provide you with a link which you can return to to continue /complete your submission.

Section 2: Summary of major highlights

*** Please detail major highlights since January 2022**

You may wish to complete this section at the end, after completing all others**.**

The objective verification of ECMWF forecasts has been continued on all time ranges from medium range to seasonal forecasts as in the previous years

Section 3: Forecast products

3.1. Please outline what direct use you make of standard ECMWF model products (on ecCharts / OpenCharts / own workstation), for operational duties, in the following 4 categories (noting that new AI model output should be dealt with separately, via question 3.4).

*** a) Medium Range (e.g. for high impact weather forecasting)**

A wide range of ECMWF model forecasts has been used from medium range to seasonal forecasts via extended range forecasts too (Ihász and Modigliani, 2019). The ECMWF high resolution (HRES) and the ensemble predictions (ENS) are available in our local visualization system, HAWK-3. All forecasters have access to ecCharts. Open access to OpenCharts is welcome, it provides good opportunities for colleagues at our meteorological service. HRES and ENS model products are widely used, including precipitation type, visibility, clear air turbulence (CAT) and ecPoint Rainfall products too

* **b) Extended Range (monthly)**

Since introducing cycle 48r1 extended range forecasts are daily available. Locally derived graphical products are available on our intranet and public web site too

* **c) Long Range (seasonal)**

Locally derived graphical products are available on our intranet and for some registered external users.

* **d) CAMS and Fire-related output (ecCharts mainly)**

CAMS's model forecasts for the main pollutants are available for the domain of the Carpathian Basin with daily updates. Using the CAMS's chemical transport model results EPSgrams for Hungarian big cities from the 11 different models are produced. All forecasters and air quality experts have access to this information through the HAWK3 visualisation system.

3.2. ECMWF cycle 48r1 went live at the end of June 2023. Changes included a much higher resolution medium range ensemble, and much more frequent monthly forecasts.

* **a) Please describe any <u>positive</u> impacts of model cycle 48r1 for your service**

In our meteorological service before introducing 48r1 there was not systematic comparison between former and new model cycles on ecCharts or on local visualization system.
Same horizontal resolution of the ensemble model (ENS) and high resolution model (HRES) provides beneficial concept for making better forecasts of high impact weather.

If you have any annotated graph/diagram/plot that would help clarify your answer to the previous question, please upload here.
File types: most accepted, File Size: max 1MB per file.

* **b) Please describe any <u>negative</u> impacts of model cycle 48r1 for your service**

In our local objective verification system we extended the verified products, control run has also verified beside HRES. In some cases quite large difference was seen between the HRES and the ensemble members on ensemble plumes for precipitation (i.e, HRES was often an outlier; not shown here). Some verification results confirms this (e.g. Fig. 3). After introducing 48r1 in some cases convective situations were not performed well, a few tickets were put on Support Portal. In these situations none of the applied NWP models provided good forecast, so we can not say there is in connection to changing model cycle.

If you have any annotated graph/diagram/plot that would help clarify your answer to the previous question, please upload here.
File types: most accepted, File Size: max 1MB per file.

* **c) Have you noticed any systematic changes in forecast output since model cycle 48r1 was implemented?**

- ○ Yes
- ◉ No

* **3.3: Do you modify ECMWF model output to create 'derived fields' (e.g. post-processed output, regimes, probabilities).**

- ◉ Yes
- ○ No

Please describe what you modify and how

Besides the operationally available products in HAWK-3, a lot of special products (Cséke and Ihász, 2022), like ENS meteograms, ENS plumes, cluster products are available on the intranet for the whole community of the meteorological service. ENS meteograms are available for medium, monthly and seasonal forecast ranges. ENS calibration using VarEPS reforecast dataset was developed in 2008 (Ihász et al., 2010, Mátrai and Ihász, 2017, Ihász et al., 2018). Since 2003, ensemble clustering focusing on central European meteorological patterns has been run operationally using resources provided by ECMWF's Ecgate Cluster Service (Ihász, 2004). Ensemble vertical profiles have been operationally produced since 2011 (Ihász and Tajti, 2011). In 2021 it was extended for some other locations too for times a day (00, 06, 12, 18 UTC). Some ecPoint Rainfall products have been operationally available since 2018 (Tóth and Ihász, 2021).

If you have any annotated graph/diagram/plot that would help support your answer to the previous question, please upload here.
File types: most accepted, File Size: max 1MB per file.

* **3.4: Do you currently use Artificial Intelligence (AI) and/or Machine Learning (ML) techniques in your service, in conjunction with standard ECMWF model output?**

- ○ Yes
- ◉ No

*** 3.5: Does your NMHS use ECMWF data for modelling purposes - e.g. by providing initial/boundary conditions for limited area model runs, or for hydrological models, or for dispersion models, etc...**

- (x) Yes
- ( ) No

Please describe these activities

The Hungarian limited area modelling activity consists of three systems and all of them uses LBCs interpolated from ECMWF forecasts in framework of Optional BC Programme.

The hydrostatic ALADIN model with 8 km resolution is coupled with hourly frequency and in 6 hourly time-lagged mode to ECMWF HRES since 2008 (Bölöni et al., 2009). It runs four-times per day: at 00 and 12 UTC up to 60 hours, at 06 UTC up to 48 hour and at 18 UTC up to 36 hours. The initial conditions are resulted by local data assimilation.

The non-hydrostatic AROME model has 2.5 km horizontal resolution and it is coupled with hourly frequency and in 6-9 hourly time-lagged mode to ECMWF HRES since 2012. It runs eight times per day: at 00, 06, 12, 18 UTC up to 48 hours and at 03, 09, 15, 21 UTC up to 36 hours. The initial conditions are resulted by local data assimilation (Tóth et al., 2021).

The AROME-based limited area ensemble prediction system of HungaroMet, AROME-EPS is operational since February 2020 (Jávorné Radnóczi et al., 2020). It runs twice per day at 00 and 12 UTC up to 48 hours. Lateral boundary conditions for 11 members are provided by the first 10 members and the control forecast of ECMWF ENS running at 18/6 UTC with hourly coupling. Local perturbations are added using the ensemble of data assimilation method.

If you have any annotated graph/diagram/plot that would help support your answer to the previous question, please upload here.
File types: most accepted, File Size: max 1MB per file.

*** 3.6: In the last year or so ECMWF has made available, on ecCharts and OpenCharts, selected fields from AI models (e.g. Pangu Weather, AIFS). Were you aware of this?**

- (x) Yes
- ( ) No

*** a) What are your views on this initiative?**

Our forecasters occasionally study the AI model products on OpenCharts.

*** b) Do you currently use AI forecasts for operational purposes?**

- ( ) Yes
- (x) No

What would you need in order to use AI models in your forecast activities?

Since May 2024 AIFS products have been available in ECPDS too. We intend to use this these products in the very near future.

Section 4: Verification

ECMWF does extensive verification of its products in the free atmosphere. However, our verification of surface parameters is more limited and can be constrained to only using synoptic observations. More detailed verification of these surface weather parameters by National Services is always valuable to us. We are most interested in results for the last 1 or 2 years. Also, any evidence you have of performance changes since the introduction of cycle 48r1 would be very valuable.

* **4.1 Do you routinely verify raw model output from ECMWF model(s) and/or other operational models /ensembles?**

- (x) Yes
- ( ) No

Please describe your verification activities and show and discuss related scores in the the two lead-time categories shown below, including, where possible, comparisons with your own models /ensembles, and other models/ensembles.
Ideally focus on surface weather parameters in your own territory. Inclusion of conditional verification results is also strongly encouraged - e.g. stratification by a weather type - as these can provide very useful insights into model weaker points.

a) Short Range and Medium Range

The objective verification is performed via the Objective Verification System (OVISYS) developed in the Hungarian Meteorological Service. More details on OVISYS are available in “Verification of ECMWF products, 2006”. The results might be compared with the ones shown in “Application and verification of ECMWF products, 2021” for the verified models.
In this sub-section the 00 UTC runs of ECMWF-HRES, ALADIN/HU and AROME/HU models are compared for the first 48 hours with 1-hour (in case of surface parameters) and 12-hour (in case of upper air parameters) time steps. The forecast values are taken from the (highest resolution: 0.1°x0.1°) grid box from the ECMWF-HRES, a 0.1°x0.1° post-processing grid from the ALADIN/HU, and from a 0.025°x0.025° grid from the AROME/HU model. Thanks to the IFS Cycle 48r1, the medium-range ensemble system has the same horizontal resolution as the HRES, so from 01/08/2023 the ENS control member was also displayed for comparison. The RMSE (Root Mean Square Error) and bias scores are computed using the observations and measurements of the 319 Hungarian SYNOP stations under 400 m above sea level for 2022 and 2023 as well.
Figure 1 shows the verification of 12-hour forecasts of 2 m dewpoint and temperature for 2022 and 2023. Concerning the 2-metre dewpoint, a lower RMSE was characteristic of the ECMWF HRES throughout the year, apart from the January cases, when the dewpoint is mostly underestimated. Comparing the two years, there was high uncertainty in early spring in dry, weak windy weather situations which improved in 2023 by which improved the minimum temperature errors. In case of the 2-metre temperature, the winter forecasts of ECMWF HRES are less accurate than in other seasons, because of the overestimated daily temperature connected with the earlier dissipated clouds in anticyclonic weather. A systematic underestimation was experienced in the LAMs except for the summer season. There was no significant difference between the

ECMWF HRES and ECMWF EPS control member.
Figure 2 shows RMSE (solid) and bias (dashed) in function of lead time in case of some surface parameters. For every model a temperature daily cycle can be observed with a night time overestimation and a daytime underestimation. The dewpoint forecast of ECMWF HRES FBI equally well at the times of the day outperforming the other models, only at the beginning of the convection period had a small positive bias. The 2 m relative humidity of ECMWF HRES had a very similar daily cycle in systematic error like the 2 m dewpoint, while a higher overestimation of humidity occurred in AROME, AROME-EPS mean and ALADIN models during the daytime. In the 10-metre wind speed forecasts, the performance of AROME, AROME-EPS and ECMWF HRES were competing with each other, however, AROME forecasts were clearly the best for the wind gust, and the AROME ensemble forecast showed significant added value.
In the following the frequency bias (FBI) and the extreme dependency score (EDS) of 24 hour precipitation amount of the five forecasts (ECMWF HRES, ECMWF EPS control, AROME, AROME-EPS mean, ALADIN) can be seen in the 30-hour forecast from 1 August 2023 to 31 December 2023 as a function of certain precipitation thresholds (Fig. 3). These verification measures are independent of each other. The score of a perfect forecasts for the FBI and the EDS is +1 as well. According to the FBI, a significant differences were appeared between the ECMWF HRES and the ECMWF EPS control. The ECMWF EPS control less often predicted heavy rain situations, even less than HRES, which is also proved by the lower probability of detecting extreme events. AROME forecasts are more accurate in terms of EDS, especially at the higher threshold values.
Spatial verification of ECMWF HRES forecasts
In addition to OVISYS results, spatial verification was prepared to evaluate the convective season of last summer (from 10 May 2023 to 05 September 2023), using the three component object-based SAL (Structure, Amplitude, Location) verification. To compute the location and structure components, first precipitation objects are defined separately for the observed and forecast precipitation fields, using a dynamic threshold (Pmax / 15). As the summer of 2022 and 2023 were completely different, with little precipitation in 2022 and lots of high impact precipitation in 2023, we compared the 2023 results to the ones of 2020 which was similarly rainy. The intensity of precipitation objects are usually underestimated by ECMWF HRES and overestimated by AROME wrt. radar data, however, this latter has greatly reduced since 2020. The maximum of convection activity was generated a bit earlier than the truth by the ECMWF HRES, while the other models predicted it a little bit later and kept the intense rain longer. These effects gave rise to phase error penalty in an objective pointwise verification.

If you have any annotated graph/diagram/plot that would help support your answer to the previous question, please upload here.
File types: most accepted, File Size: max 1MB per file.

7a1ecd81-c5ed-4b85-958e-0d1bcfee51cd/hun24_fig01.png
a73f4706-3448-4f41-8b1f-3ded4b2f6efc/hun24_fig02.png
3a24090e-8fb9-40a0-adb5-cd9ab28c6108/hun24_fig03.png
6831918e-2ea6-46df-a6b9-1d4ead1b22c6/hun24_fig04.png

b) Extended Range (Monthly) and Long Range (Seasonal)

As soon as it was possible in 1998 investigation of the applicability of ECMWF's seasonal forecasting system was done. Forecasts for the 2-metre maximum and minimum temperature and the amount of precipitation, for six regions of Hungary are issued in every month (Fig. 5).

If you have any annotated graph/diagram/plot that would help support your answer to the previous question, please upload here.
File types: most accepted, File Size: max 1MB per file.

36af1459-426e-4abe-8ebd-01d49e6c6a93/hun24_fig05.png

* **4.2 Do you routinely verify post-processed products and/or tailored products delivered to users?**

- (●) Yes
- ( ) No

Please describe these activities and show and discuss related scores

Some energy companies need daily mean temperature forecast calculated between 07 and 06 local time. They found a good correlation between this data and the daily gas consumption. The verification of this product is made for some cities (Fig. 6).

If you have any annotated graph/diagram/plot that would help support your answer to the previous question, please upload here.
File types: most accepted, File Size: max 1MB per file.

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* **4.3 Do you perform any subjective verification of forecasts?**

- ( ) Yes
- (●) No

4.4: Case Studies. Please describe and illustrate any case study verification you have undertaken. Examples of both good and bad model performance are welcome. Severe weather events (and non-events) are of particular interest to us.

a) Case Study 1 - Please describe the forecast(s) and what happened

4.4.1 Case studies from summer 2023
Several weather situations challenged the Hungarian forecasters in summer 2023. While 2021 and 2022 were years of drought and heatwaves in the Carpathian Basin, in the year of 2023 the heat continued, but in the convective period more than average precipitation fell in the form of thunderstorms often with hail and severe wind gust. Thus, forecasts of this summer were evaluated with special care.
Although subjective feeling of the forecasters suggested extraordinarily weak model performance, the objective verification does not confirm this. The verification scores from the last 6 years (Fig. 7) shows similar magnitude. Moreover, AROME-EPS (available for 3 years) has considerable added value wrt. AROME.
In stormy and severe windy weather, when more intense gusts are dominated, the 10-metre wind gust were slightly overestimated by EMCWF HRES, but not as much as ALADIN/HU and this improved significantly by the second day along 2023. In these case, the AROME/HU and AROME-EPS mean provided much better forecasts in the night hours and the underestimation during the day turned into an overestimation for the highlighted convective period (Fig. 8). The weather situation used for the conditional verification was determined by the forecasters based on the observations. In this variable convective period, the precipitation structure was more discrete and isolated, thus the number of precipitation objects became more accurate in AROME based on SAL, while the hydrostatic models predicted too large cells (Fig. 9).

If you have any annotated graph/diagram/plot that would help support your answer to the previous question, please upload here.
File types: most accepted, File Size: max 1MB per file.

e4976b3b-947e-49db-a80c-9480426cb3a3/hun24_fig07.png
08aa6724-8065-4906-85e9-71080790e1eb/hun24_fig08.png
bd55e078-b711-4588-b4c5-2f9553941386/hun24_fig09.png

Case Study 1 is an example of:

- ○ Good model performance
- ○ Bad model performance
- ○ Mixed (good and bad) model performance
- ● Other (please describe above)

Add another Case Study?

- ● Yes
- ○ No

b) Case Study 2 - Please describe the forecast(s) and what happened

4.4.2 Case study with LBCs from the new IFS Cycle 48r1
Together with the IFS cycle change from cy47r3 to cy48r1, the resolution of the lateral boundary conditions (LBCs) for AROME/HU and AROME-EPS were also upgraded: from 15.4 km to 8.5 km horizontal resolution and from 60 to 137 levels. The new LBC resolution was tested with the AROME model for 4-5 May at 00 UTC, when a Mediterranean cyclone and a cold front affected Hungary. The most significant differences were found in the upper air fields of hydrometeors and humidity (Fig. 10).
The new setup was also tested for AROME-EPS between 30 May – 1 June at 00 UTC, when unstable atmospheric conditions prevailed in the Carpathian Basin favouring showers and thunderstorms. The differences were generally not significant, however, larger spread were produced with higher resolution LBCs in several cases, mostly after 36-hour forecasts (Fig. 11).

If you have any annotated graph/diagram/plot that would help support your answer to the previous question, please upload here.
File types: most accepted, File Size: max 1MB per file.

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c69a2e51-cfd8-41e7-b244-92c44ea7e244/hun24_fig11.png

Case Study 2 is an example of:

- ○ Good model performance
- ○ Bad model performance
- ○ Mixed (good and bad) model performance
- ● Other (please describe above)

Add a third Case Study?

- ○ Yes
- ○ No

Section 5: Output Requests

5. Please describe, and illustrate if necessary, any particular requests you may have for new or modified ECMWF products.

a) Product request 1 - title / summary

None.

Product request 1 - description of request

If you have any annotated graph/diagram/plot that would help support your answer to the previous question, please upload here.
File types: most accepted, File Size: max 1MB per file.

Add another Product Request?

- ○ Yes
- ◉ No

Section 6: References

6. Are there any recent internal or external publications that relate to the questions in this survey? Please list them including the respective link/s. For any publications that cannot be readily downloaded via a link please attach a copy below (or email Becky Hemingway (becky.hemingway@ecmwf.int) and Tim Hewson (timothy.hewson@ecmwf.int) if too large to upload here).

Bölöni, G., Kullmann, L., and Horányi, A., 2009: Use of ECMWF lateral boundary conditions and surface assimilation for the operational ALADIN model in Hungary. ECMWF Newsletter, 119, 29-35.
Cséke, D. and Ihász, I., 2022: Validation of precipitation type forecasts based on ECMWF's ensemble model.
Ihász, I., 2004: Experiments of clustering for central European area especially in extreme weather situations. Proceedings of the Ninth ECMWF Workshop on Meteorological Operational Systems, Reading UK, 10-14 November 2003, 112-116.
Ihász, I., Üveges, Z., Mile, M. and Németh, Cs., 2010: Ensemble calibration of ECMWF's medium-range forecasts. Időjárás, 114, 275-286.
Ihász, I. and Tajti, D., 2011: Use of ECMWF's ensemble vertical profiles at the Hungarian Meteorological Service. ECMWF Newsletter, 129, 25-29.
Ihász, I., Mátrai, A., Szintai, B., Szűcs, M., and Bonta, I., 2018: Application of European numerical weather prediction models for hydrological purposes. Időjárás, 122, 59-79. DOI:10.28974/idojaras.2018.1.5.
Ihász, I. and Modgliani, U., 2019: 25 years of cooperation between the Hungarian Meteorological Service and ECMWF, ECMWF Newsletter, 160, 9-10.
Jávorné Radnóczi, K., Várkonyi, A., Szépszó, G., 2020: On the way towards the AROME nowcasting system in Hungary. ALADIN/HIRLAM Newsletter 14, 65–69.
Mátrai, A. and Ihász, I., 2017: Calibrating forecasts of heavy precipitation in river catchments, ECMWF Newsletter, 152, 32-35.
Tóth, B. and Ihász, I., 2021: Validation of subgrid scale ensemble precipitation forecasts based on ECMWF's ecPoint Rainfall project. Időjárás, 125, 397-418. DOI:10.28974/idojaras.2021.3.2
Tóth, H., Homonnai, V., Mile, M., Várkonyi, V., Kocsis, Zs., Szanyi, K., Tóth, G., Szintai, G. and Szépszó, G., 2021: Recent developments in the data assimilation of AROME/HU numerical weather prediction model. Időjárás, 125, 521-553, DOI:10.28974/idojaras.2021.4.1 (pp. 521–553)

If you have any annotated graph/diagram/plot that would help support your answer to the previous question, please upload here.
File types: most accepted, File Size: max 1MB per file.

Section 7: Additional comments and Feedback

7.1. Please use the box below if you have additional comments on topics that have not been covered in any of the questions above

None.

If you have any annotated graph/diagram/plot that would help support your answer to the previous question, please upload here.
File types: most accepted, File Size: max 1MB per file.

7.2. This is the first time we have used a survey style structure for Green Book submissions. You thoughts and feedback on this process are very welcome

It is a very good idea. It is quite convenient to use it.

Thank you for taking the time to complete your Green Book report. Your feedback and comments are very valuable to us!

Contact

Contact Form

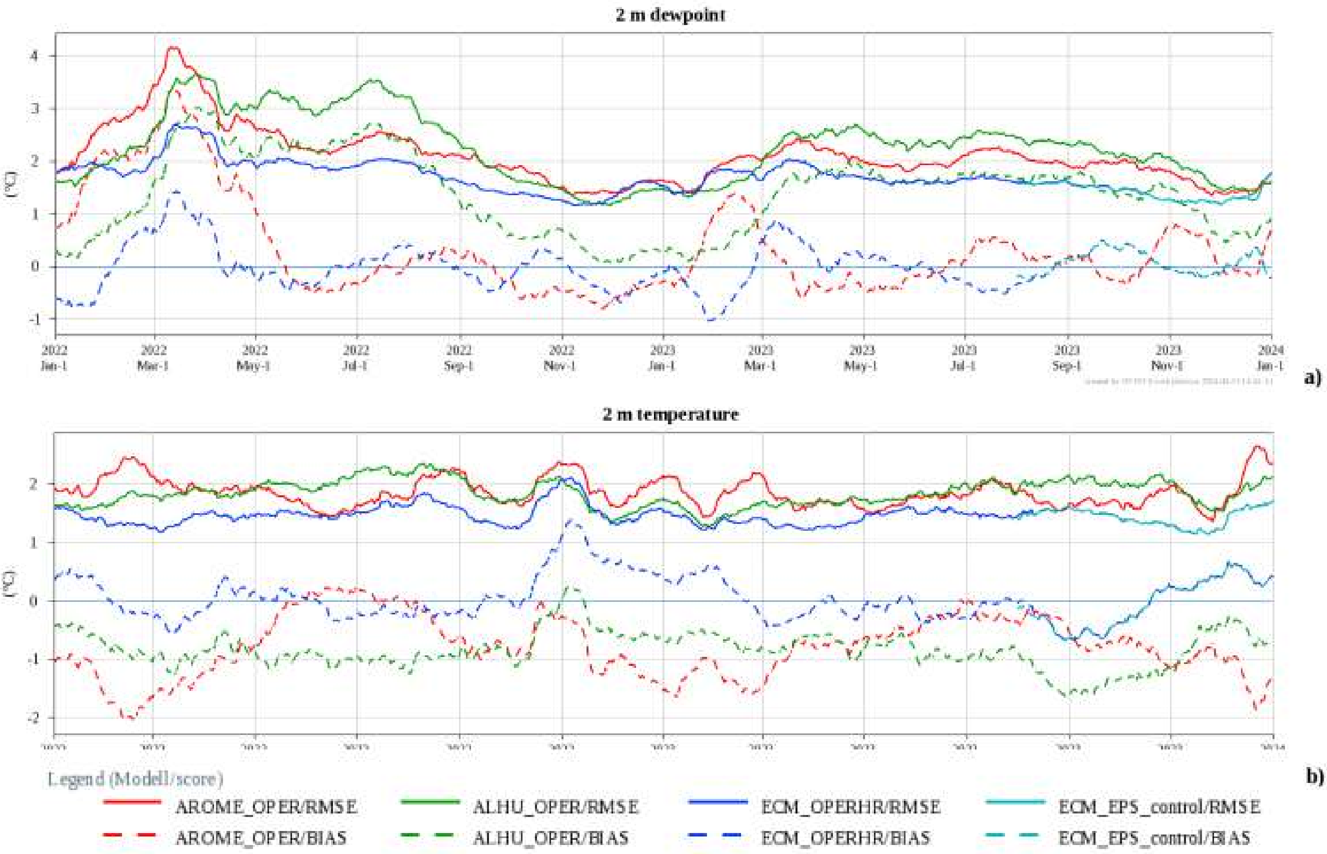

Fig. 1: 31 days moving average of RMSE (solid) and bias (dashed) of 12-hour forecasts (initialized at 0 UTC) for a) 2 m dewpoint and b) 2 m temperature between 1 January 2022 and 31 December 2023 using the observations of the SYNOP stations under 400 m above sea level over Hungary.

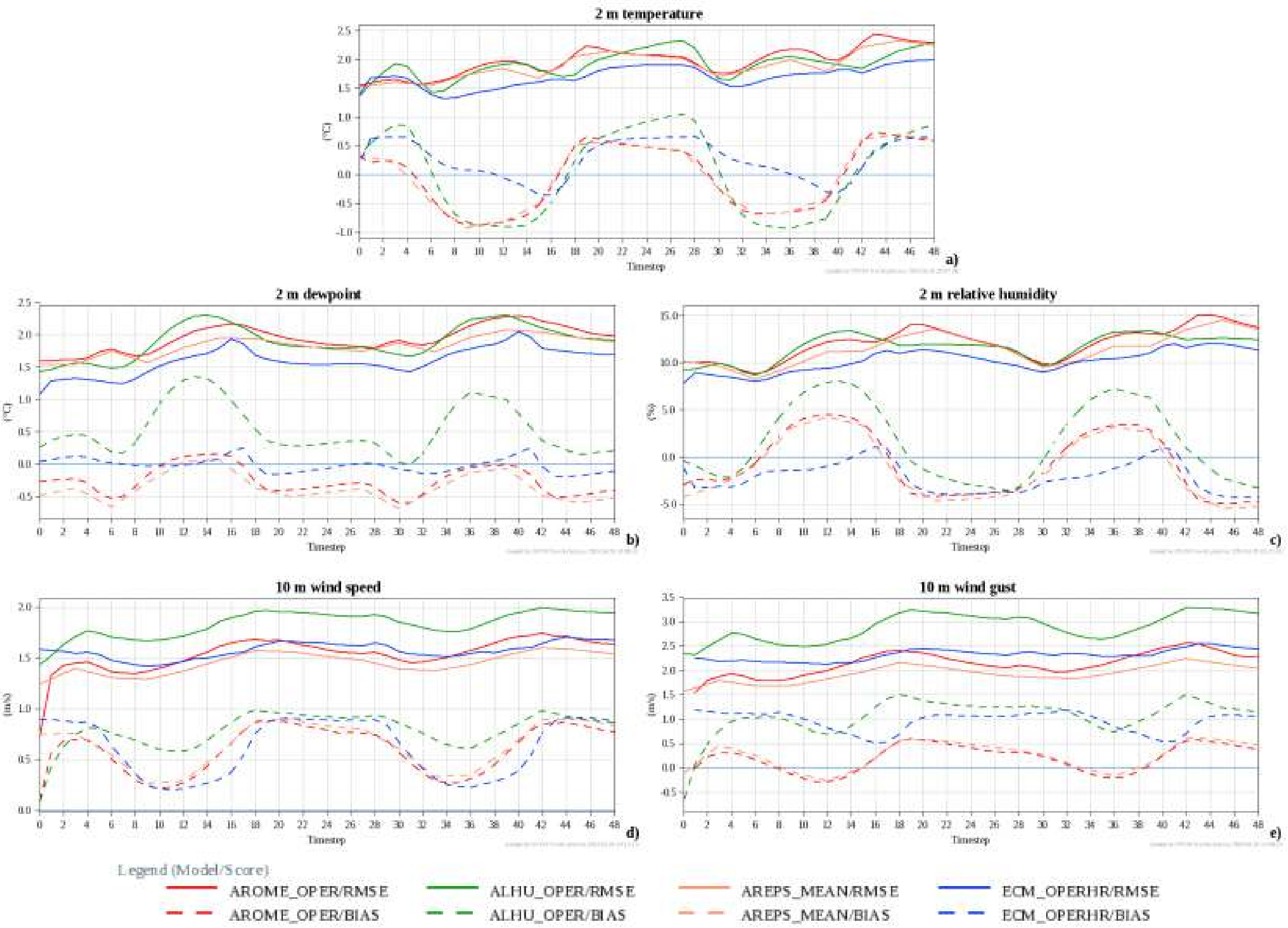

Fig 2 a-e: RMSE (solid) and bias (dashed) of a) 2 m temperature b) 2 m dewpoint c) 2 m relative humidity d) 10 m wind speed and e) 10 m wind gust forecasts of the 00 UTC runs of ECMWF HRES (blue), AROME (red), AROME-EPS mean (peach) and ALADIN (green) models in 2023 using the observations of the SYNOP stations under 400 m above sea level over Hungary.

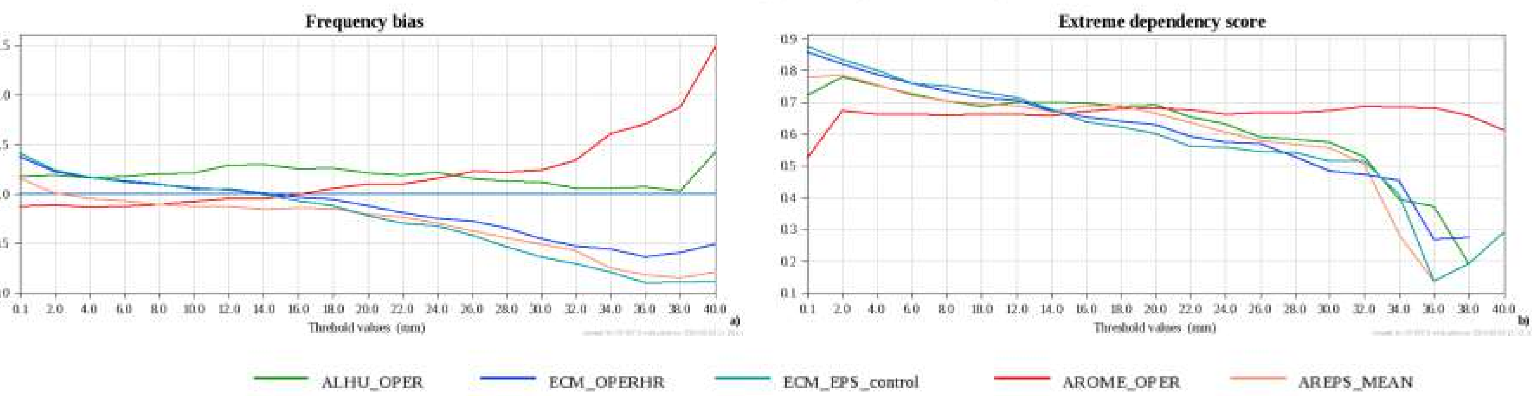

Fig. 3: a) Frequency bias (FBI) and b) extreme dependency score (EDS) of 24 hour precipitation forecasts (in the 30th hour of the 00 UTC runs of ECMWF HRES (dark blue), ECMWF EPS control (light blue), AROME (red), AROME-EPS mean (peach) and ALADIN (green) models as a function of precipitation thresholds over Hungary for 2023 using the observations of the SYNOP stations under 400 m above sea level.

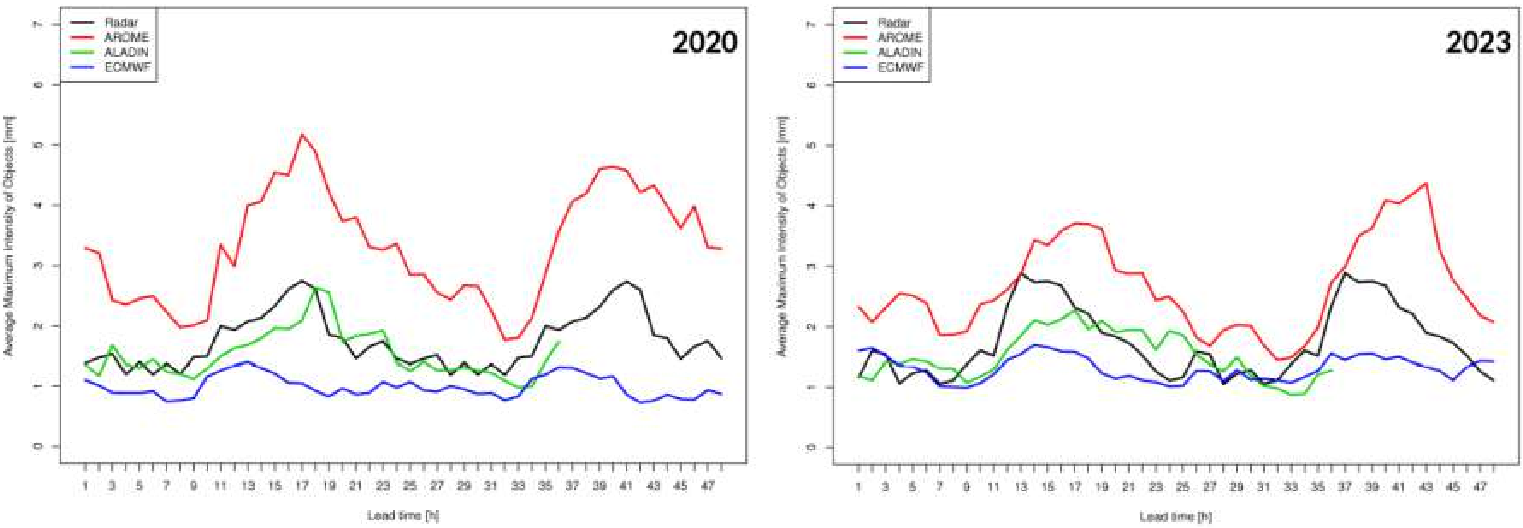

Fig. 4: Average intensity of objects of the 00 UTC runs of ECMWF HRES (blue), AROME (red) and ALADIN (green) models against the radar data (black) over Hungary in summer of 2020 (left) and 2023 (right).

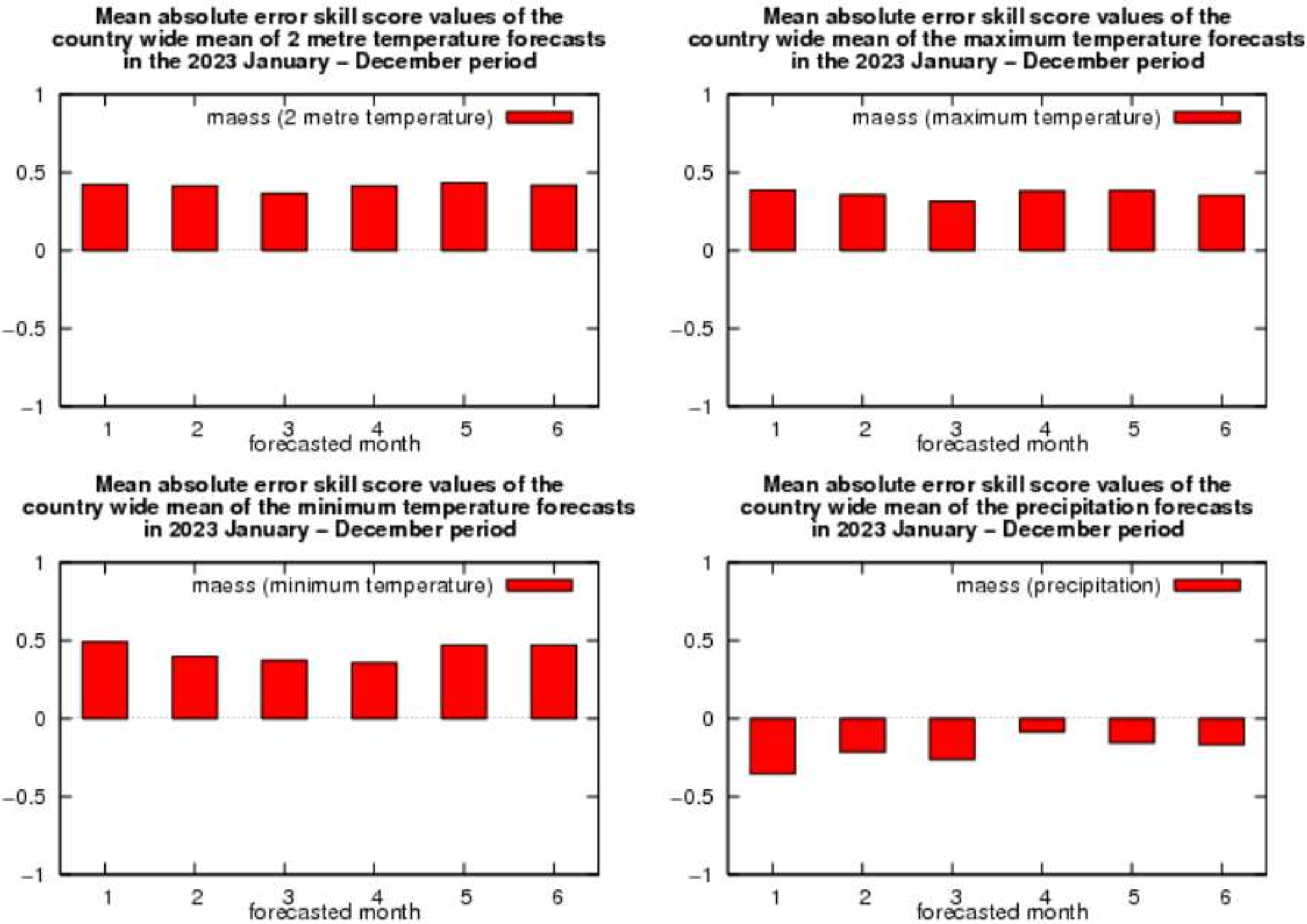

Fig. 5: Mean Absolute Error Skill Score of ensemble means of 2 meter mean, maximum, minimum temperature and precipitation for the 6 forecasted months in a forecast for 2023. Reference forecast was the 30-year climatological mean.

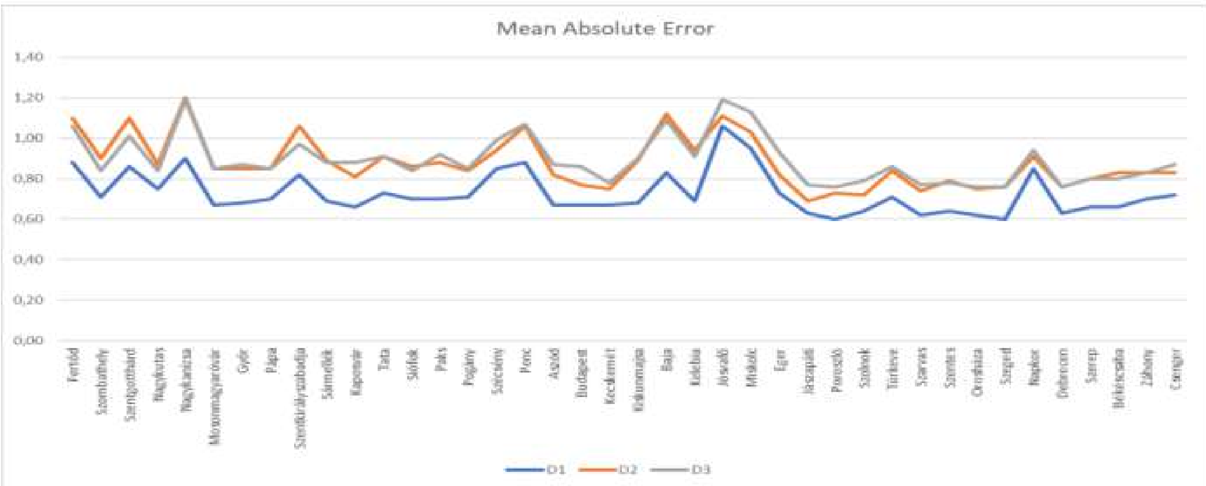

Fig. 6: Mean Absolute Error of daily mean temperature (07-06 LT) for some cities.

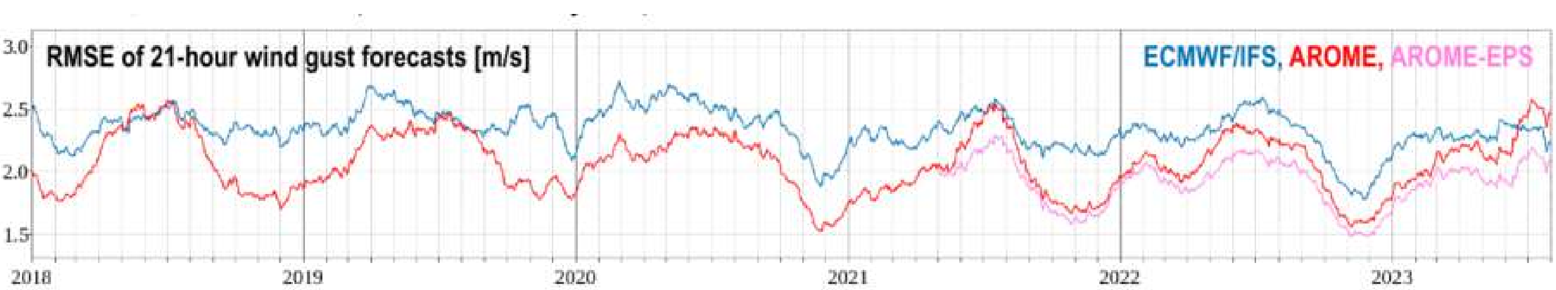

Fig. 7: 31 days moving average of RMSE of 21-hour wind gust forecasts of the 00 UTC ECMWF HRES (blue), AROME (red) and AROME-EPS mean (pink) models over Hungary between 2018 and 2023.

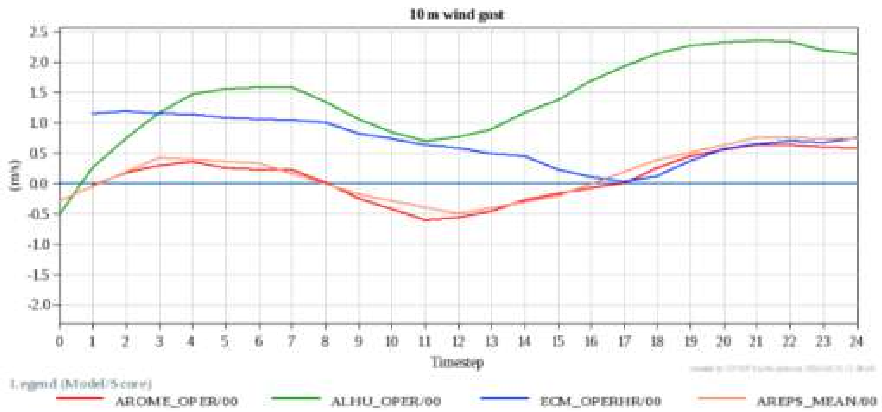

Fig. 8: Conditional verification of bias of 10-metre wind gust forecasts of the 00 UTC ECMWF HRES (blue), ALADIN/HU (green), AROME/HU (red) and AROME-EPS mean (peach) models over Hungary for the days when windy and stormy weather formed in 2023.

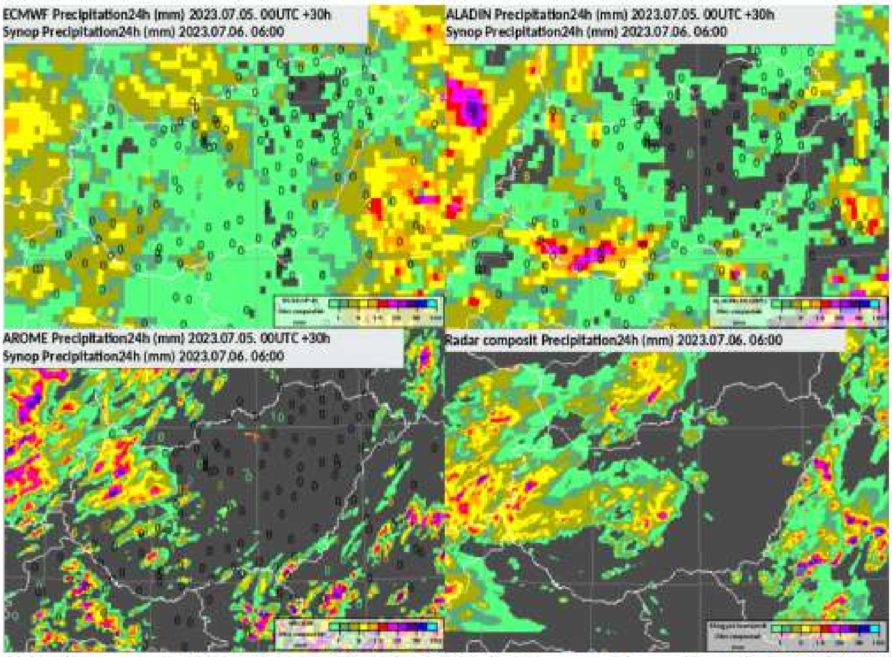

Fig. 9: 24-hour precipitation sum at 06 UTC on 06 July 2023 in Hungary based on the ECMWF HRES (top left), ALADIN/HU (top right), AROME (bottom left) forecasts and the Hungarian composite radar image (bottom right).

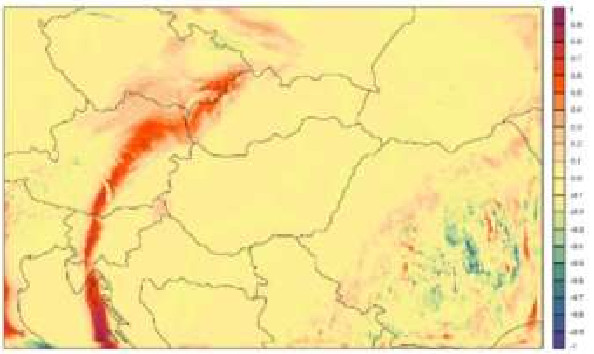

Fig. 10: Differences between the 36-hour AROME forecasts (initialized at 0 UTC) with LBCs from the previous (15.4km horizontal resolution with 60 vertical level) and the new (8.5km horizontal resolution and 137 vertical level) resolutions for cloudiness on 4 May 2023. The line of frontal cloudiness provided by the run using the LBC from cy48r3 located further Northwest.

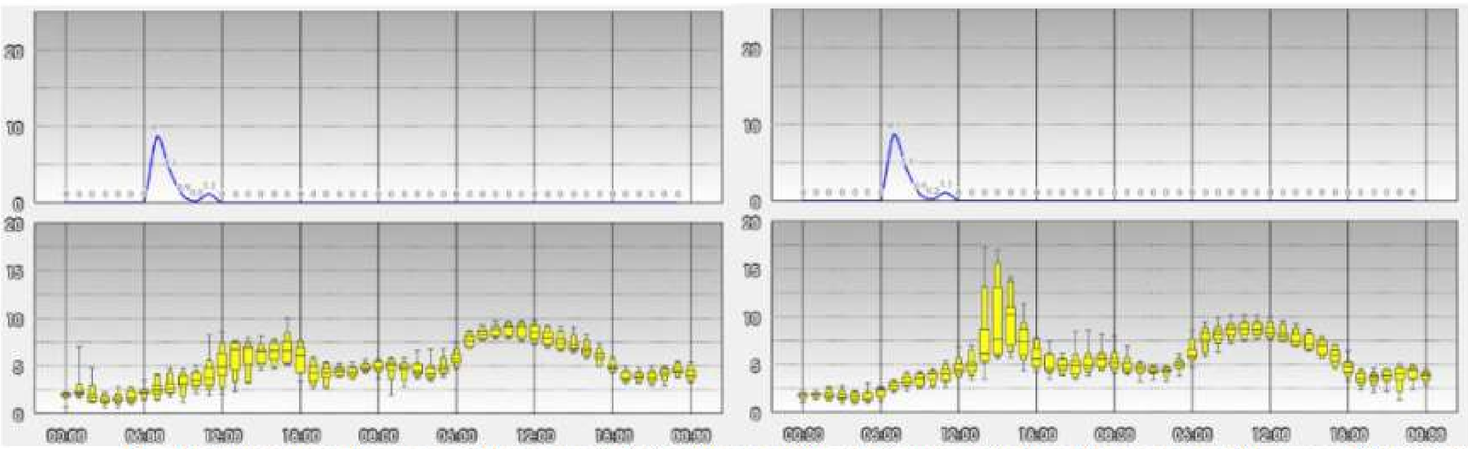

Fig 11: Meteogram diagrams of 1hour precipitation (top panel) and 10 meter wind gust (bottom panel) between 00 UTC 30 May and 00 UTC 1 June 2023 for station Kunszentmiklós based on AROME-EPS forecast, using the LBCs from previously operative cy47r3 (left) and from cy48r1 (right). The applied resolution for both runs was horizontally 15.4km with 60 vertical levels.