Application and Verification of ECMWF Products 2021

Hungarian Meteorological Service, István Ihász, Boglárka Tóth, Gabriella Tóth, Gabriella Szépszó, Balázs Fehér

1. Summary of major highlights

The objective verification of ECMWF forecasts have been continued on all time ranges from medium range to seasonal forecasts as in the previous years. Due to ECMWF's invitation Hungarian Meteorological Service (OMSZ) intensively took part in validation of ecPoint rainfall products for territory of Hungary. The 11-member convection-permitting AROME-EPS forecasts, that is operational since February 2020, are evaluated in a case study to compare with ECMWF ENS forecasts which provide the lateral boundary conditions.

2. Use and application of products

2.1 Direct Use of ECMWF Products

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 ecChart. Open access to ECMWF web charts are welcome, it provides new opportunities for colleagues at our meteorological service.

2.2 Other uses of ECMWF output

2.2.1 Post-processing

Several tens of stability indices and shear parameters are generated from the basic ECMWF fields (model levels) to support severe convection and hail forecast on operational level. Upon these parameters, encompassing five years of archive ECMWF output and incorporating radar measurements to detect hail, a simple machine learning method (logistic regression) was applied to separate weather conditions supportive to hailstorms from environments favouring storms with no hail. The results obtained from that research are used operatively in the 2021 convective season.

2.2.2 Derived fields

Besides the operationally available products in HAWK-3, a lot of special products, 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.*, 2008, *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 computing cluster (*Ihász,* 2004). Ensemble vertical profiles have been operationally produced since 2011 (*Ihász, 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).

2.2.3 Modelling

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 3-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 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 AROME-based limited area ensemble prediction system of OMSZ (*Jávorné et al.,* 2020), AROME-EPS is operational since February 2020. It runs once per day at 00 UTC up to 48 hours. Its 11 members are the downscaling of the first 10 members and the control forecast of ECMWF ENS running at 18 UTC with 3-hourly coupling.

3. Verification of ECMWF products

3.1 Objective verification

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, 2019*' for the verified models.

3.1.1 Direct ECMWF model output (both HRES and ENS), and other NWP models

Point verification of ECMWF HRES forecasts

In this chapter the 00 UTC runs of ECMWF HRES, ALADIN and AROME models are compared for the first 48 hours using OVISYS. The forecast values are taken from the (highest resolution) grid box from the ECMWF HRES, a 0.1°x0.1° post-processing grid from the ALADIN, and from a 0.025°x0.025° grid from the AROME model. The verification is performed for the following variables: **2 m temperature and dewpoint**, **total cloudiness**, **relative humidity at 2 m, 10 m wind speed** and **wind gust**. The near-surface variables are evaluated in every hour, while the upper-level variables are at 00 and 12 UTC. The RMSE (Root Mean Square Error) and bias scores are computed using the observations and measurements of 267 Hungarian SYNOP stations under 400 m above sea level.

Figure 1 shows the verification of the 24-hour forecasts of 2 m temperature and relative humidity for 2019 and 2020. Higher RMSE values are typical in spring and summer and ECMWF HRES outperforms the limited area models. The winter forecasts are more accurate, but the LAMs perform better than ECMWF HRES for relative humidity. The 2-metre temperature is mostly overestimated, while underestimation is seen for relative humidity. The results were very similar for 2019 and 2020, therefore only the year 2020 are presented hereafter.

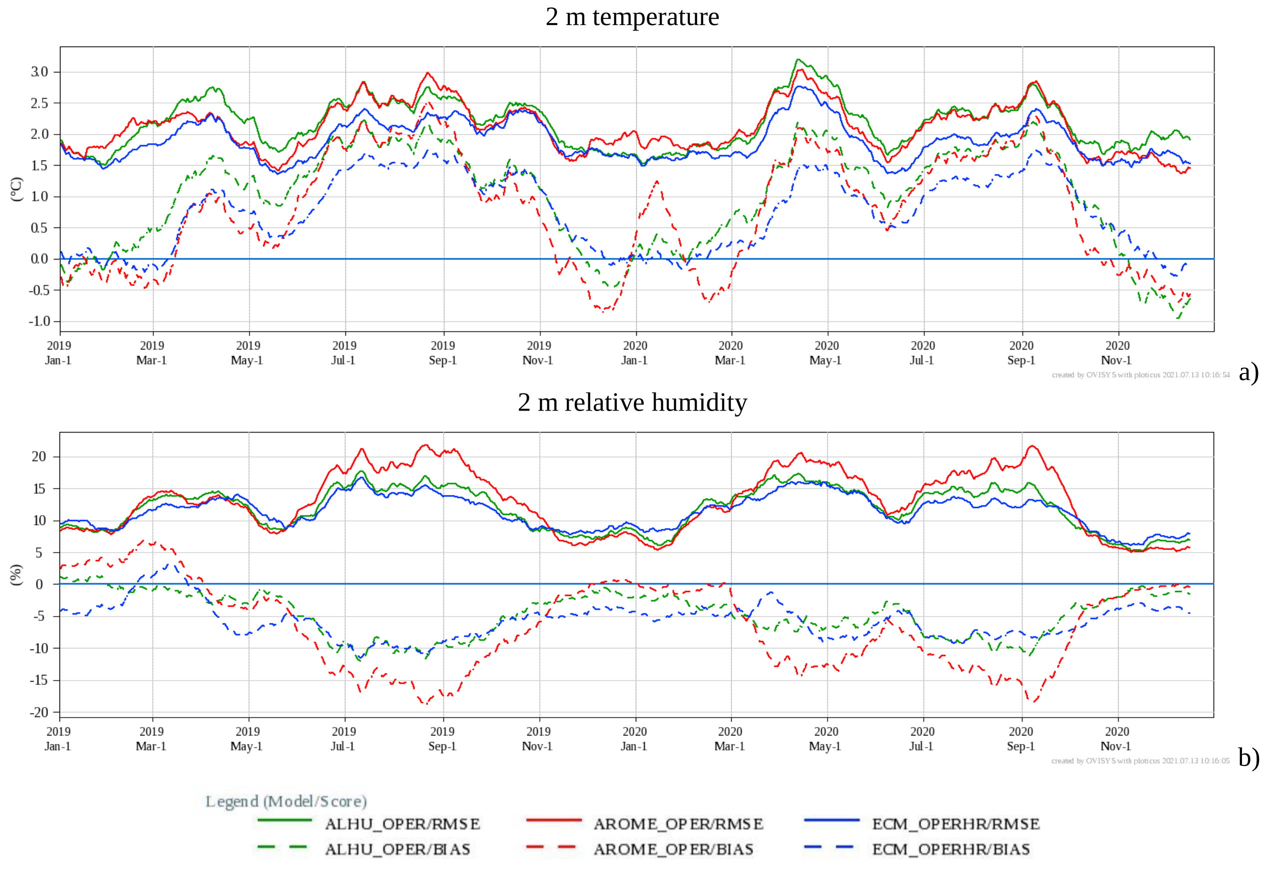

Fig. 1 31 days moving average of RMSE (solid) and bias (dashed) of 24-hour forecasts for a) 2 m temperature and b) 2 m relative humidity between 1 January 2019 and 31 December 2020 using the observations of the SYNOP stations under 400 m above sea level over Hungary.

The 2-metre temperature is mostly overestimated by ECMWF HRES in 2020, apart from the afternoons (Fig. 2). The dewpoint forecasts of ECWMF HRES performs equally well at all times of the day outperforming the ALADIN and AROME models in terms of RMSE The smallest underestimation of 2 m relative humidity occurs during the day in ECMWF HRES, while similar cannot be seen in case of verification of upper-levels (Fig. 3). In the 10-metre wind speed forecasts, the performance of AROME and ECMWF competing with each other, however, AROME forecasts are clearly the best for wind gust.

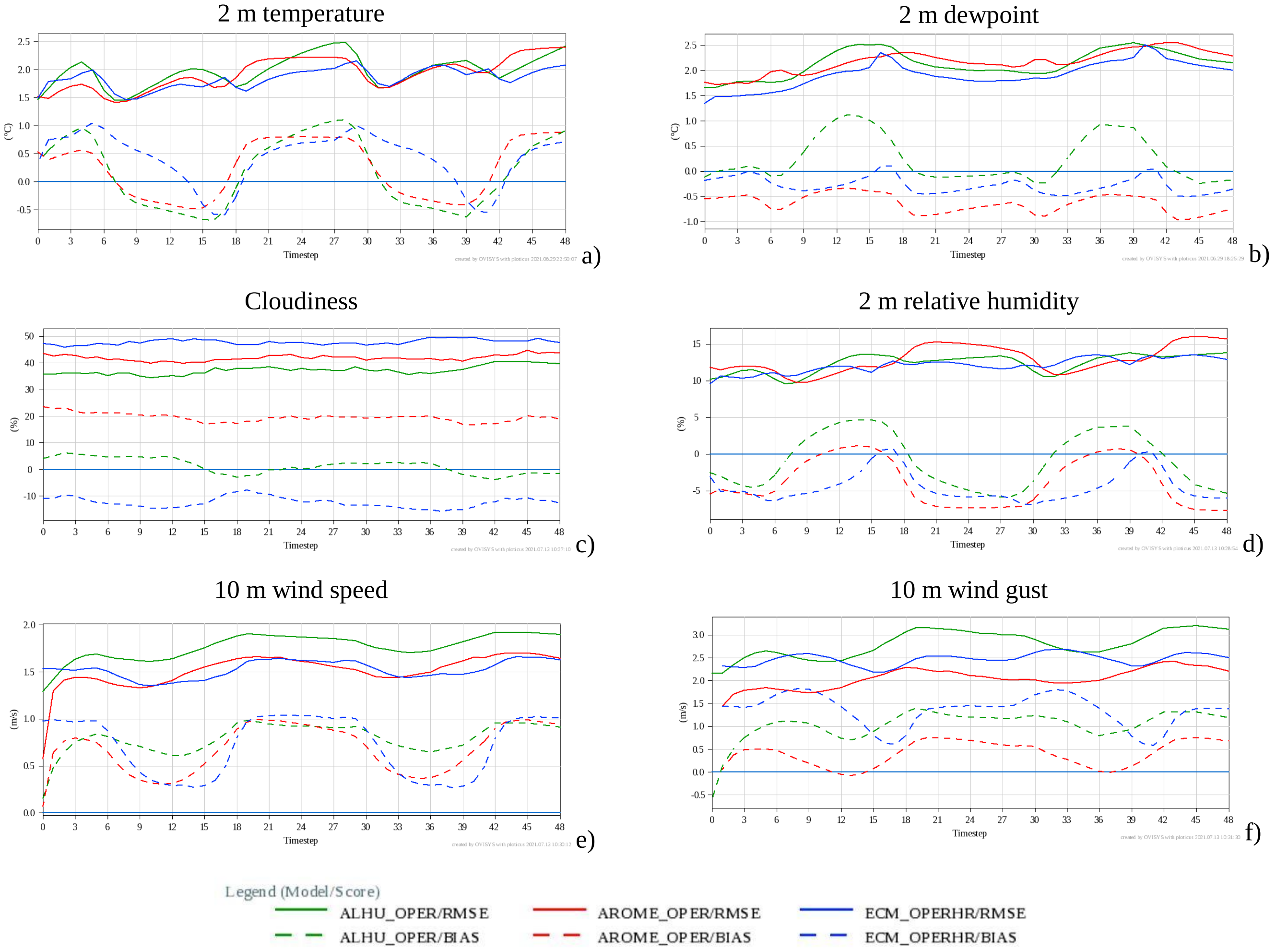

Fig. 2 a-f RMSE (solid) and bias (dashed) of a) 2 m temperature, b) 2 m dewpoint, c) total cloudiness, d) 2 m relative humidity, e) 10 m wind speed and f) 10 m wind gust forecasts of the 00 UTC runs of ECMWF HRES (ECM_OPERHR – blue), ALADIN/HU (ALHU_OPER – green) and AROME/HU (AROME_OPER – red) models in 2020 using the observations of the SYNOP stations under 400 m above sea level over Hungary.

In the following the frequency bias and the SEDI (Symmetric Extremal Dependence Index) verification scores of 24 h precipitation amount of the three models (ECMWF, ALADIN and AROME) can be seen in the 30-hour forecast for 2020 as a function of certain precipitation thresholds (Fig. 3). These verification measures are independent of each other. The score of a perfect forecast for the frequency bias and SEDI is +1. The range of frequency bias is between zero and infinity, and it is between -1 and +1 for SEDI.

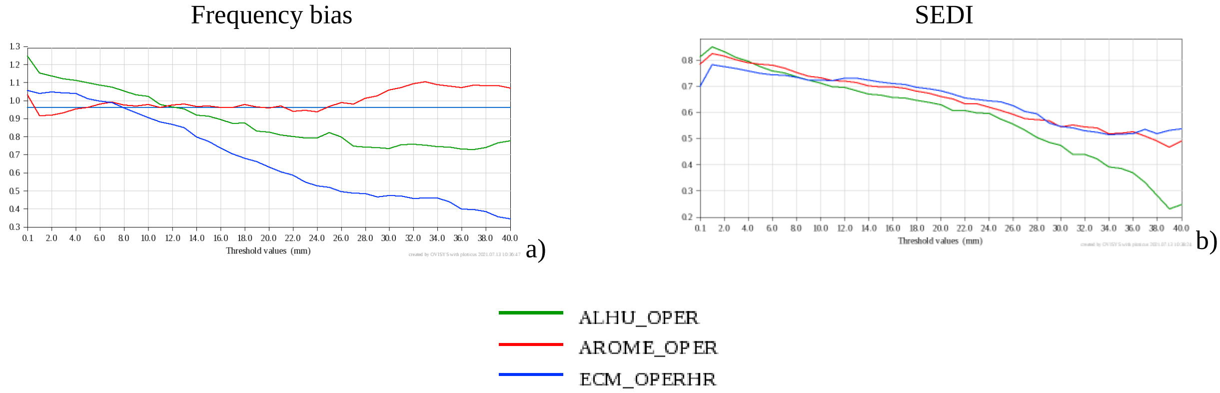

Fig. 3 a-b a) Frequency bias and b) SEDI values of 24h precipitation forecasts (in the 30th hour of the forecast) of the 00 UTC runs of ECMWF HRES (ECM_OPER – blue), ALADIN (ALHU_OPER – green) and AROME (AROME_OPER – red) models as a function of precipitation thresholds over Hungary for 2020 using the observations of the SYNOP stations under 400 m above sea level.

Concerning the values of frequency bias (Fig. 3), the AROME shows the best result at every threshold, especially up to the 27 mm/day, above this threshold a slight overestimation occurs. ECMWF and ALADIN underforecasted over 10-12 mm/day, and this underestimation has become more significant with increasing thresholds. Regarding the SEDI score, the AROME and ALADIN models give the highest (i.e. the best) scores under 11 mm/day. Above this threshold, very similar results are detected, but the ECMWF forecasts prove to be slightly better than the AROME forecasts.

Spatial verification of ECMWF HRES forecasts

In addition to OVISYS results, spatial verification was prepared to evaluate the convective season of last summer (from 15 May to 15 September 2020), 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. A dynamic threshold (Pmax / 15) was used to determine the objects, and then the precipitation field was characterized using various statistical metrics. In Fig. 4 the 00 UTC runs of ECMWF HRES, AROME, ALADIN and WRF models are compared with the radar data, where the average intensity of the 3 most intensive objects are shown as a function of lead time. With regard to the given precipitation characteristics, the daily cycle of the convective season is outlined, as well as one of the known phenomena of the ECMWF, according to which the model predicts the maximum of convection activity a few hours earlier. The intensity of objects is usually overestimated by non-hydrostatic models, while underestimated by hydrostatic models such as ECMWF and ALADIN.

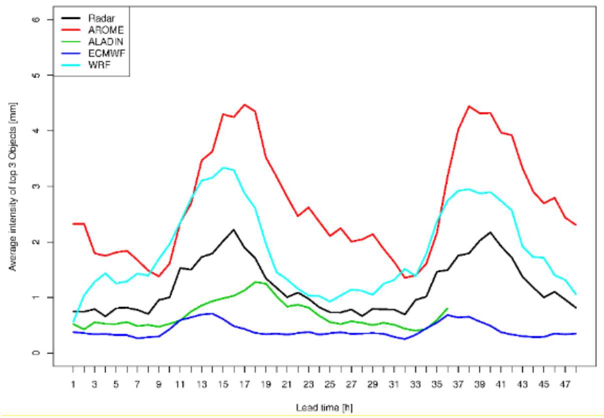

Fig. 4 Average intensity of top 3 precipitation objects of the 00 UTC runs of ECMWF HRES (blue), AROME (red), ALADIN (green) and WRF (cyan) models against the radar data (black) over Hungary from 15 May to 15 September 2020.

Conditional verification for ECMWF HRES

Finally, some results of conditional verification are presented for extended winter period (1 November 2019 – 29 February 2020) that is made with OVISYS as well. For 2 m temperature the 00 UTC runs of ECMWF HRES, AROME and ALADIN models are presented in Fig. 5 for those days when the sky was clear and when it was covered by stratus in Hungary. The weather situation was determined by the forecasters based on the observations, which was used for selection. When stratus was observed, the ECMWF forecasts overestimate the daytime temperature, while the overestimation in clear weather is slightly lower and an underestimation occurs in AROME and ALADIN models.

Clear sky Low level clouds

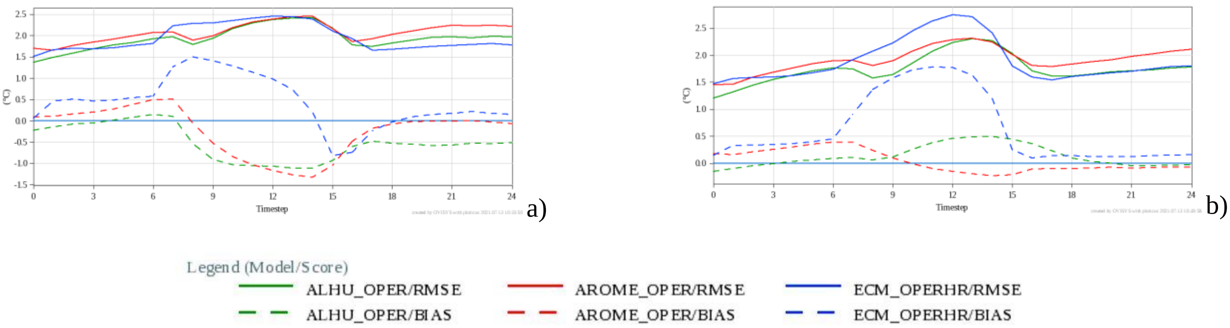

Fig. 5 a-b RMSE (solid) and bias (dashed) values of 2 m temperature forecasts of the 00 UTC runs of ECMWF HRES (blue), ALADIN/HU (green) and AROME/HU (red) models over Hungary when the sky was a) clear and b) covered by low-level clouds over the most parts of the country.

Comparison of ECMWF ENS with local LAMEPS

A convective situation was chosen to compare AROME-EPS to ECMWF ENS. A high-pressure system dominated over western and central part of Europe on 30 May 2021, while a cold air drop induced some instability over the Carpathian Basin. Some showers and thunderstorms are generated during the day over North Hungary and moved to Southeast during the night. Three sets of ensembles are evaluated: (1) 11-member AROME-EPS running at 00 UTC on 30 May; (2) 51-member ECMWF ENS running at 00 UTC on 30 May; (3) 11 members of ECMWF ENS running at 18 UTC on 29 May. Comparing set 1 and set 3, we assess the added value of AROME-EPS with respect to its LBCs, while investigating set 1 and set 2, we can compare the ensemble predictions available for forecasters at the same time.
The spatial structure and the amount of small-scale precipitation are well captured by the convection-permitting AROME-EPS. The coarser resolution ECMWF ENS spread the rain over the country on the first forecast day. Its first 10 members overestimated the precipitation amount which was improved by downscaling with AROME-EPS (Fig. 6). The shift of precipitation towards Southeast was predicted by all forecasts on the second day, but the chance of higher quantity was shown only by AROME-EPS (not shown). The corresponding wind gust and temperature forecasts were closer to the reality in AROME-EPS, whereas most members of ECMWF ENS overestimated the wind gust and underestimated the temperature (Fig. 7) over West.

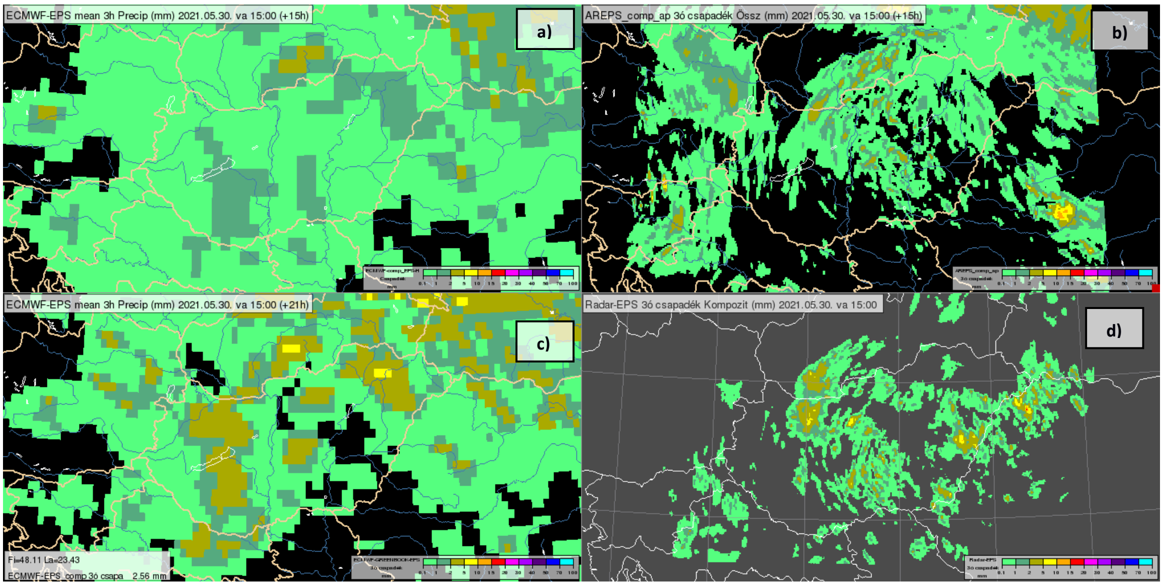

Fig. 6 Ensemble mean of 3-hour precipitation forecasts on a) 30/05/2021 00 UTC + 15h by 51-member ECMWF ENS, b) 30/05/2021 00 UTC + 15h by 11-member AROME-EPS, c) 29/05/2021 18 UTC + 21h by 11-member ECMWF ENS, and d) Hungarian radar data.

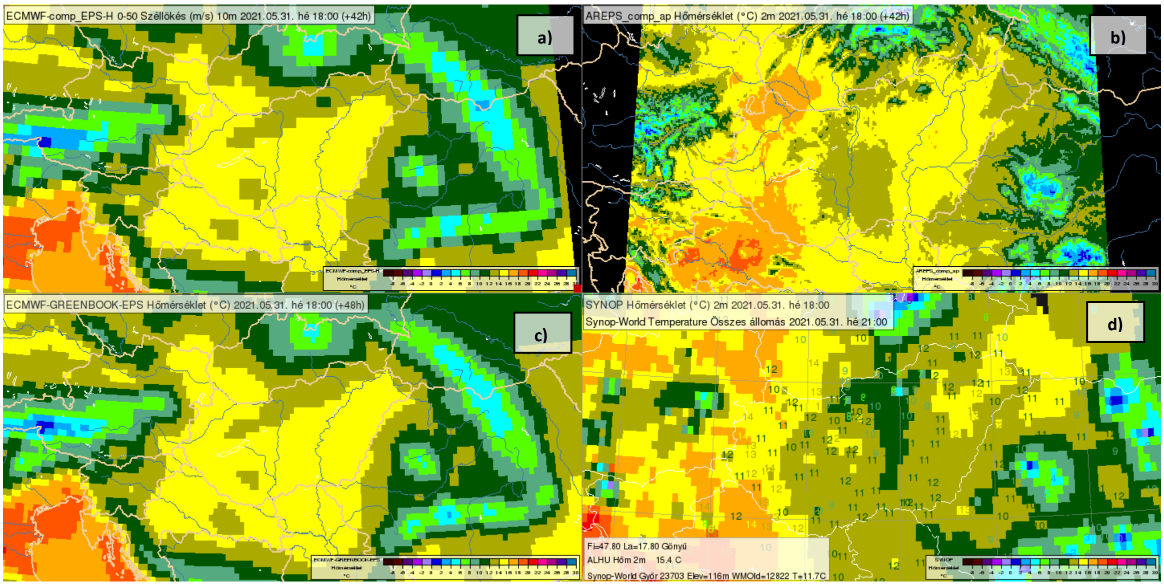

Fig. 7 Ensemble mean of 2m temperature forecasts on a) 30/05/2021 00 UTC + 42h by 51-member ECMWF ENS, b) 30/05/2021 00 UTC + 42h by 11-member AROME-EPS, c) 29/05/2021 18 UTC + 48h by 11-member ECMWF ENS, and d) SYNOP observations.

3.1.2 Post-processed products and end products delivered to users

Verification of ecPoint Rainfall products

In the framework of the ecPoint Rainfall project ECMWF has developed a probabilistic point-rainfall product to support the prediction of flash floods across the globe (*Pillosu and Hewson*, 2017). The product resulted by a post-processing method aims to describe localized heavy rainfalls on the time range beyond the target of high-resolution limited area ensemble prediction systems. In summer 2018 OMSZ was invited to take part in validation of experimental products. Ecpoint Rainfall products are more and more integrated into the operational practice in general forecasts and warnings too. These products are primarily useful in heavy rainfall situations, in addition it was used a few times for determining the existence of precipitation too.

Tóth and Ihász (2021) achieved an objective verification of the ecPoint-Rainfall product for summer in 2018. They selected an optimal set of ecPoint-Rainfall percentiles and assessed its ability to predict extreme (localized) rainfall events. The Talagrand diagrams (Figs. 8 and 9) demonstrate that the ecPoint Rainfall forecasts outperform the ensemble forecasts in the examined period for both low and hightime steps ensemble time steps serial numbers. Each category occurred with a relative frequency of 2-4%, suggesting low systematic failures of ecPoint Rainfall. Meanwhile, in the Talagrand diagrams of the raw ECMWF ENS an L-shape stands out, alluding to a systematic overestimation. If we compare the charts from the 12-hour forecasts with the ones from the 108-hour forecasts, significant differences can not be seen. As the target forecast range of ECMWF ensemble predictions is from 2 to 10 days, its ensemble spread is optimized in this range, and the ensemble precipitation forecasts have typically less spread in ultra-short range or short range scale.

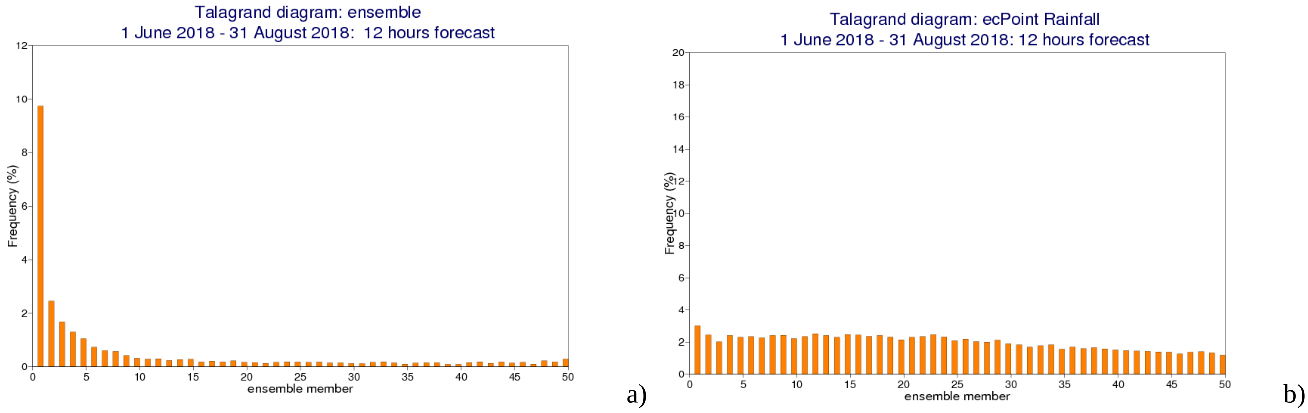

Fig. 8. Talagrand diagrams of 12-hour precipitation amount for 12-hour a) ensemble forecasts and b) ecPoint Rainfall

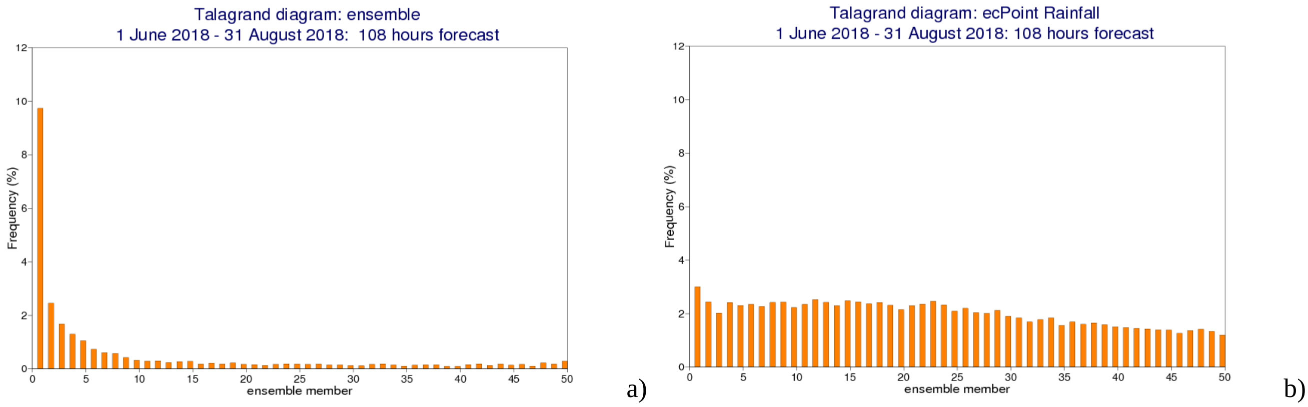

Fig. 9. Talagrand diagrams of 12-hour precipitation amount for 108-hour a) ensemble forecasts and b) ecPoint Rainfall

Verification of daily forecasts used and produced by forecasters

Objective verification of the regional (ALADIN, AROME, WRF) and global (ECMWF HRES, ECMWF ENS MEAN, GFS) models as well as human forecasts (IEO) based on them are available in Fig. 10. It can be seen that forecasters improved the daily minimum and maximum temperature up to day 7.

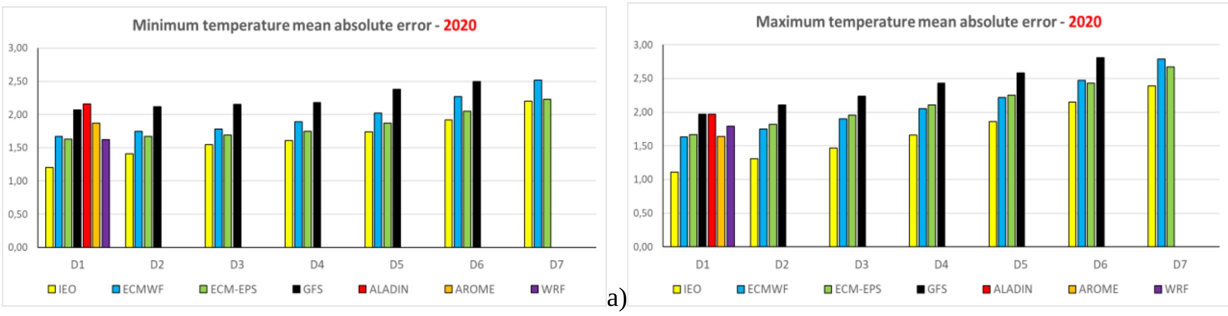

Fig. 10. Mean absolute error (MAE) of a) 2 m minimum and b) maximum temperature in case of ALADIN, AROME, WRF and the Human Forecaster (IEO) for 2020. D1, D2, etc. represent the days after the issue of the forecast.

3.1.3 Monthly and Seasonal forecasts

The applicability of ECMWF's seasonal forecasts over Hungary is investigated since 1998. Forecasts for the 2-metre maximum and minimum temperature and the amount of precipitation, for six regions of Hungary are issued in every month. Verification results averaged over the six regions can be seen in Fig. 11. It can be concluded that precipitation forecasts do not have added value beyond first month. Quality of maximum temperature forecasts is better than that of minimum temperature.

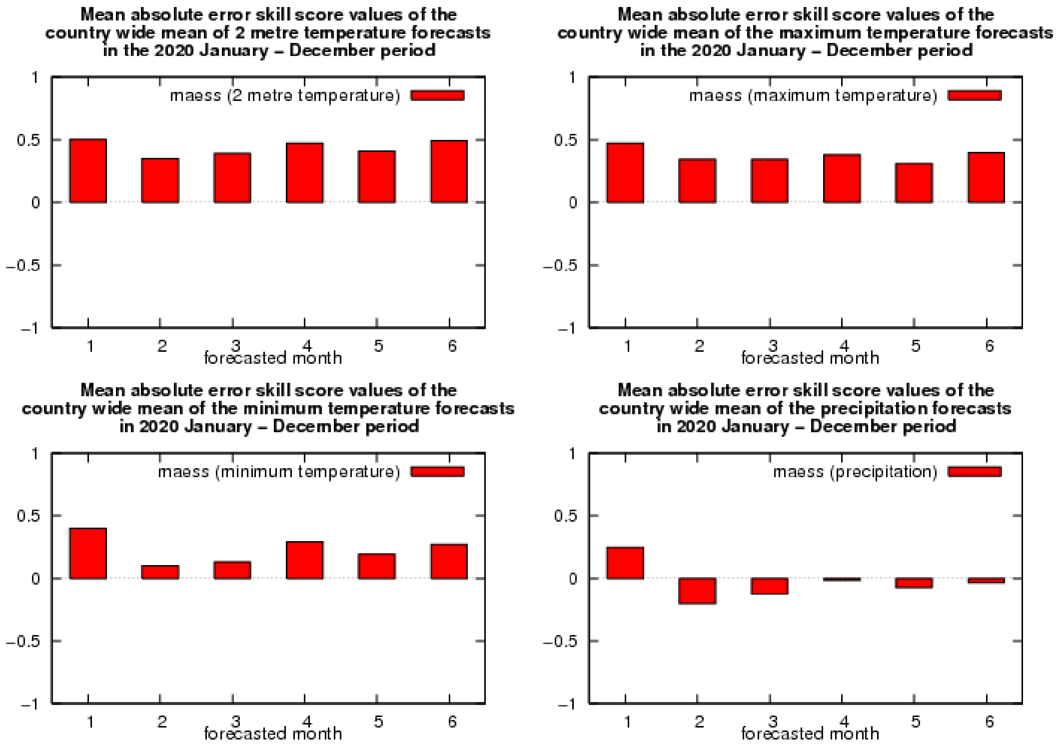

Fig. 11. Mean absolute error skill score of ensemble means of 2–metre temperature maximum and minimum temperature and precipitation over Hungary for 6 forecasted months in 2020. Reference forecast was the 30-year climatological mean.

3.2 Subjective verification

3.2.1 Subjective scores

None.

3.2.2 Case studies

None.

4. Requests for additional output

None.

5. References to relevant publications

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