Working Area Predictability

Progress Report

Prepared by:	Area Leader Martin Belluš/Clemens Wastl
Period:	2020
Date:	March 2021

Progress summary

Due to the COVID-19 crisis and several unfavorable circumstances connected to it, there were no research stays organized this year. The RC LACE stay of Réka in Bratislava was planned for April/May, then postponed to June/July, to be finally cancelled. Also the stays of Endy, Martin and Iris in Vienna did not take place and are postponed to next year. Nevertheless, this difficult situation doesn't necessarily mean a stagnation in work progress. There has been done a lot of work, locally with the remote access. All three ensemble systems within RC LACE (A-LAEF, C-LAEF, AROME-EPS) are running in full operational mode - A-LAEF received the TC2 status on July 22 2020. They are running very stable and smoothly and the usage of EPS at the meteorological centers is constantly increasing. Also the scientific work is progressing well, new developments (EDA in Hungary, SPP and AROME-RUC Peps in Austria, etc.) and EPS applications (visualizations, maps, EPSgrams) have been made in the RC-LACE countries in 2020. In the verification subject it seems that more and more countries (Slovakia, Poland, Hungary, Austria) are using the R-based HARP package for verifying EPS additionally to the LAEF verification package. Some papers have been published and the EPS related work has been presented at international workshops and conferences.

Scientific and technical main activities and achievements, major events

S1 Action/Subject/Deliverable: Optimization of A-LAEF

Description and objectives: This subject summarizes ongoing and completed tasks of the A-LAEF research and development. Achieved results, new tested implementations and gained expertise are going to be used for the further improvement of our common regional ensemble forecasting system.

- ❑ **Topic 1: A-LAEF operational runs (case studies)**

In the first half of 2020 a lot of work was done on the A-LAEF suite in order to achieve the status of the time critical application (see more details in S2) - final TC2 status was approved by EMCWF on July 22 2020.
Since May 12 the full 3-day forecasts from A-LAEF suite were disseminated to the two RC LACE members (Slovakia and Slovenia) via operational ECPDS streams. 2020 was full of severe weather events in Central Europe which served as a good basis for case studies and verification.

- **Central Europe - Windstorm of February 10, 2020**

Just one week after the intensive windstorm called Petra (February 4th) with the wind gusts 25 to 30 m/s at the AT-SK-HU borders, there was a strong wind situation again - during the cold front passage on February 10, 2020 (see Figure 1).

This time wind gusts were over-predicted by the deterministic model (see Figure 3). That might have been a reason why the highest warning level (3rd) for strong wind was issued again, even though the reality was not that bad. This was subsequently confirmed by the A-LAEF ensemble, where the threshold for level 3 wasn't reached (or better saying it was with very small probability only, see Figure 2). Unfortunately, that time A-LAEF forecasts were not yet available to the forecasters in real time.

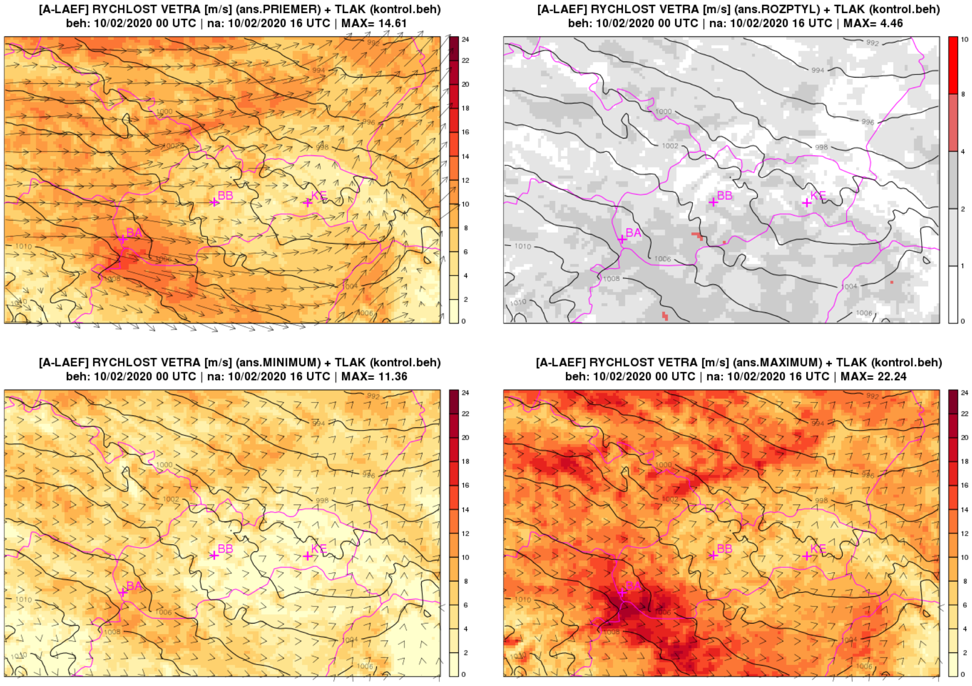

Figure 1: A-LAEF forecast of average wind speed and direction (ensemble mean top left, ensemble spread top right, minimum of ensemble bottom left, maximum of ensemble bottom right), in the background with MSLP from a control run. Valid at 16 UTC, February 10, 2020.

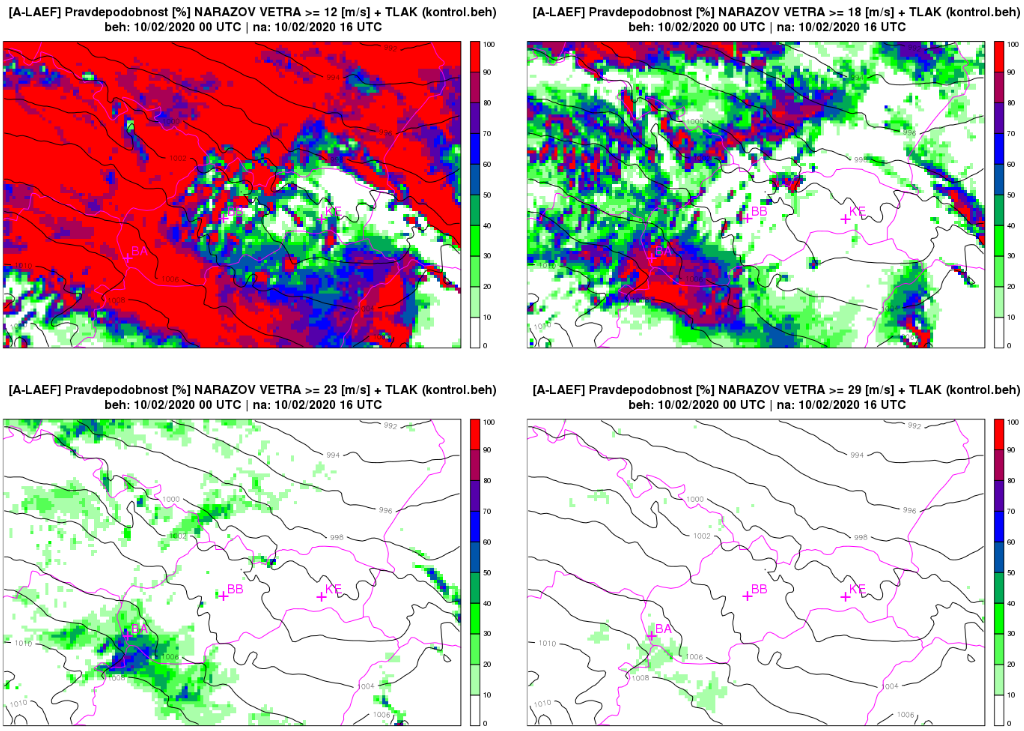

Figure 2: Probability of wind gusts for thresholds 12, 18, 23 and 29 m/s according to the A-LAEF ensemble forecast from February 10, 2020, 00 UTC valid at 16 UTC, in the background with MSLP from a control run.

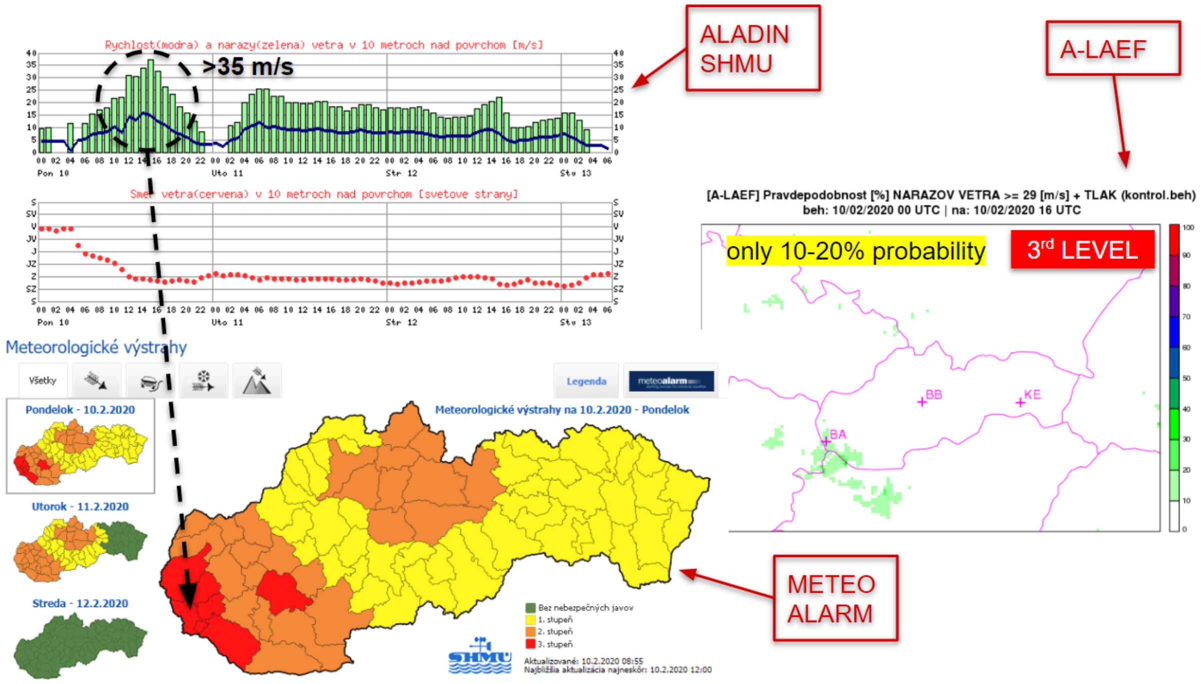

Figure 3: The operational deterministic forecast of wind gust in the form of meteogram for Bratislava, A-LAEF wind gusts probability for threshold >= 29 m/s and issued meteorological warnings, for February 10, 2020.

- **Hungary - Extensive floods of July 24-25, 2020**

There were extremely high precipitation totals in just 24 hours (from July 24, 06 UTC till July 25, 06 UTC) in south-western part of Hungary.

According to the precipitation analysis by OMSZ (see Figure 4, bottom left), up to 178 mm of precipitation fell, which caused extensive floods. The situation was captured by deterministic models, but the localization of maxima wasn't good enough to refine the warnings, as the precipitation amounts above 100 mm in 24 hours were predicted over relatively large territory.

The A-LAEF ensemble mean (or maximum of the ensemble) better corresponds to the real distribution of the precipitation field (see Figure 4). The situation is also well illustrated by the probabilities of 24-hourly precipitation totals for the threshold values of 10, 20, 50 and 100 mm on Figure 5.

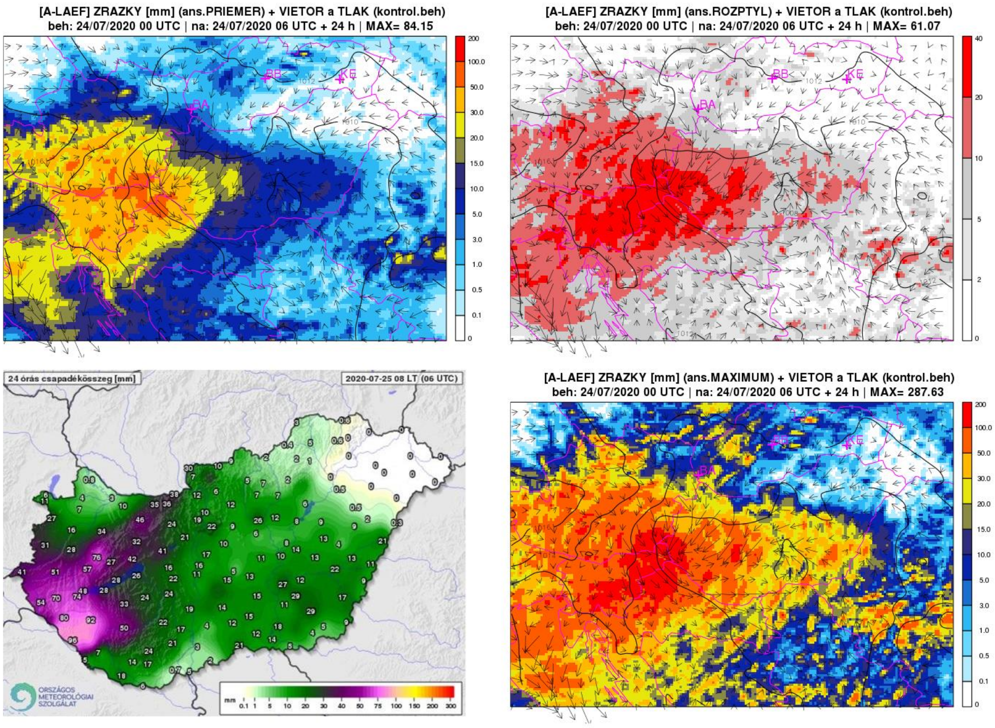

Figure 4: Total precipitation forecast for the period from July 24, 06 UTC to July 25, 06 UTC (A-LAEF ensemble mean top left, ensemble spread top right, maximum of ensemble bottom right), in the background with MSLP and wind barbs from a control run, and the analysis of 24-hourly precipitation totals for the same period in Hungary (bottom left, source: OMSZ). Note: maps are not on the same scale.

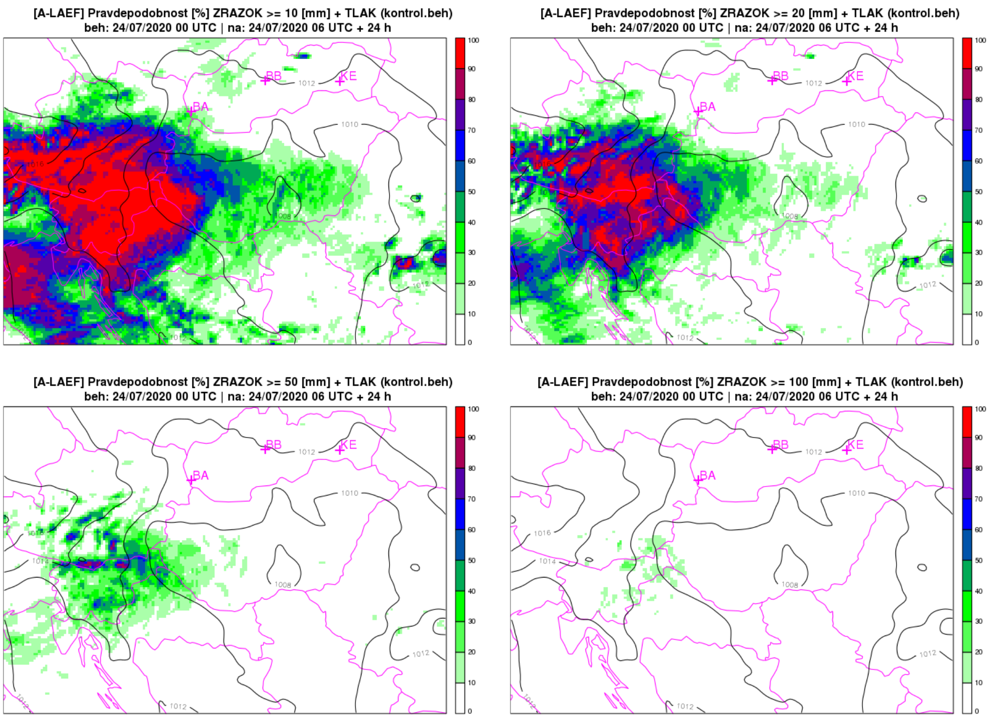

Figure 5: Probability of total precipitation for the threshold values of 10, 20, 50 and 100 mm in 24 hours, predicted by A-LAEF ensemble for the extreme precipitation event of July 24-25, 2020, in the background with MSLP from a control run.

- **Slovakia - Night storm case of July 28, 2020**

During the night hours a strong line of deep convection accompanied by shelf cloud was propagating in the low-pressure trough from west to east part of Slovakia (see Figure 6, bottom left).

According to the Slovakian Presidium of the Fire and Rescue Service, the storm activity associated with strong wind gusts required 83 firefighters' interventions. In most cases, they helped remove fallen trees from roads, houses, buildings and parked vehicles. In 13 cases, their help was needed to drain water from flooded cellars, garages and streets.

The A-LAEF ensemble system predicted the situation very well, i.e. the intense precipitation formed into a line of instability propagating from west to east (see Figures 6 and 7) and the associated strong wind and wind gusts (see Figures 8 and 9).

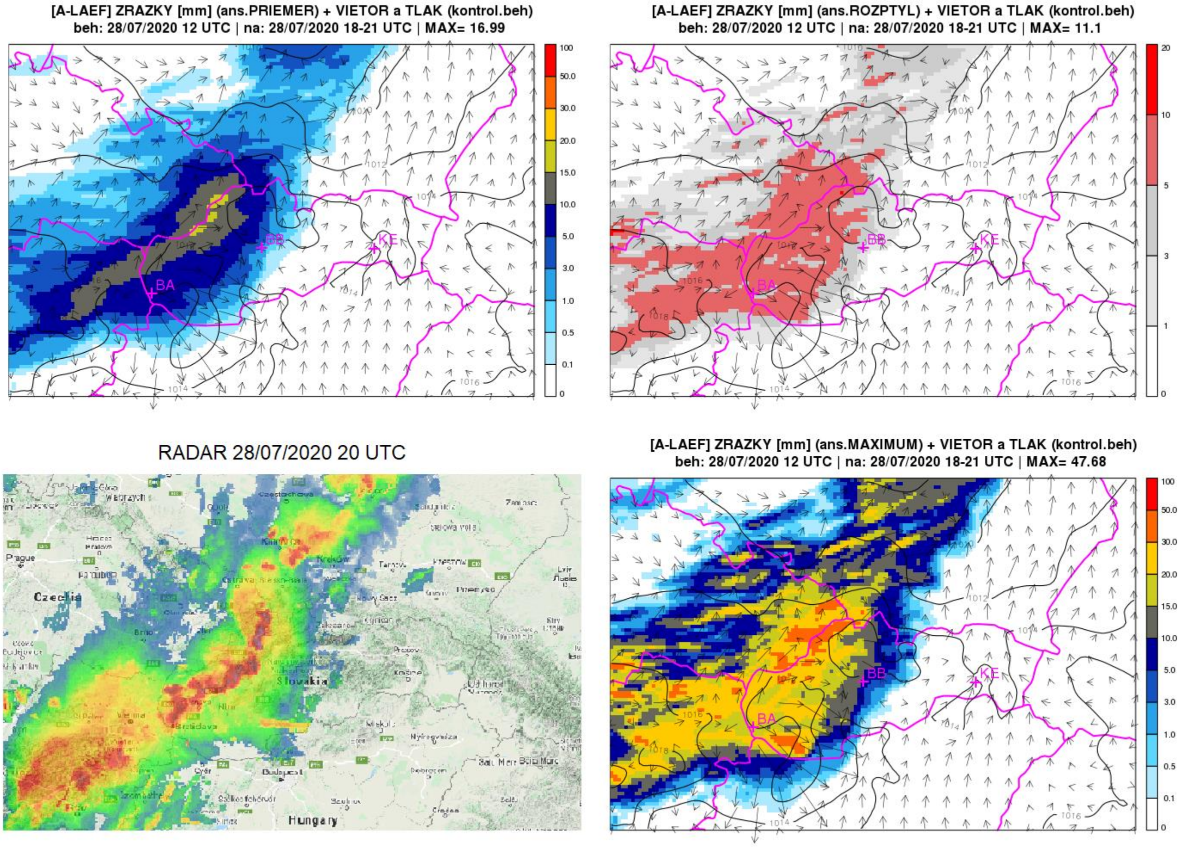

Figure 6: A-LAEF cumulative precipitation forecast of July 28, 2020, 12 UTC valid for 18 to 21 UTC (ensemble mean top left, ensemble spread top right, maximum of ensemble bottom right), in the background with MSLP and wind barbs from a control run, and combined radar information of July 28, 2020, at 20 UTC (bottom left).

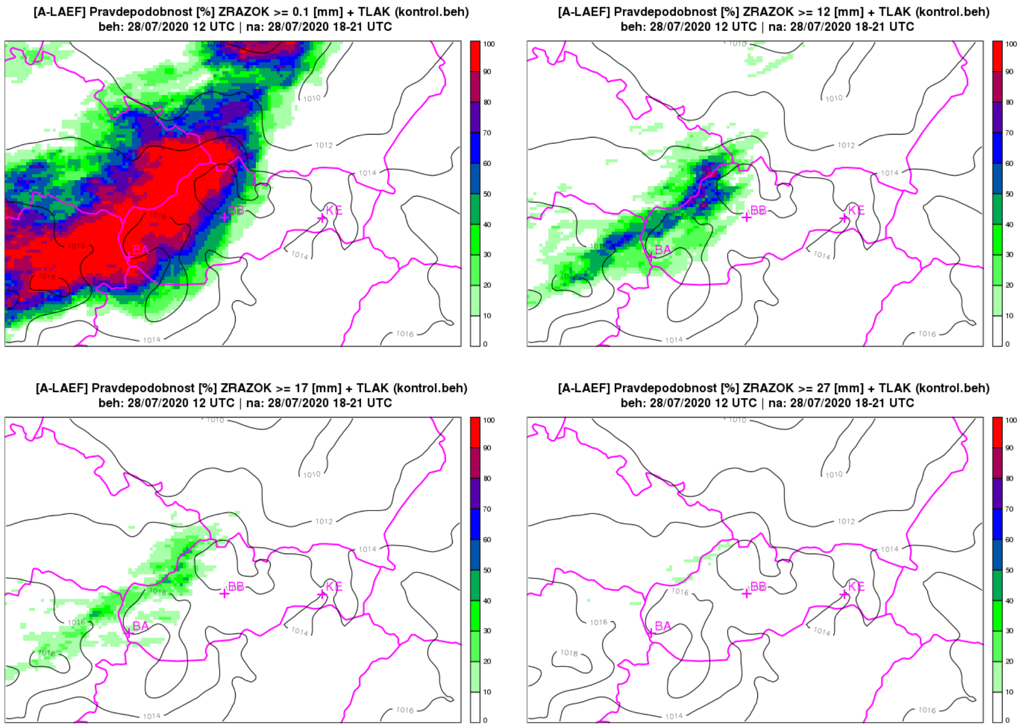

Figure 7: Probability of precipitation on July 28, 2020, valid for 18 to 21 UTC for the threshold values of 0.1, 12, 17 and 27 mm in 3 hours according to the A-LAEF ensemble forecast, in the background with MSLP from a control run.

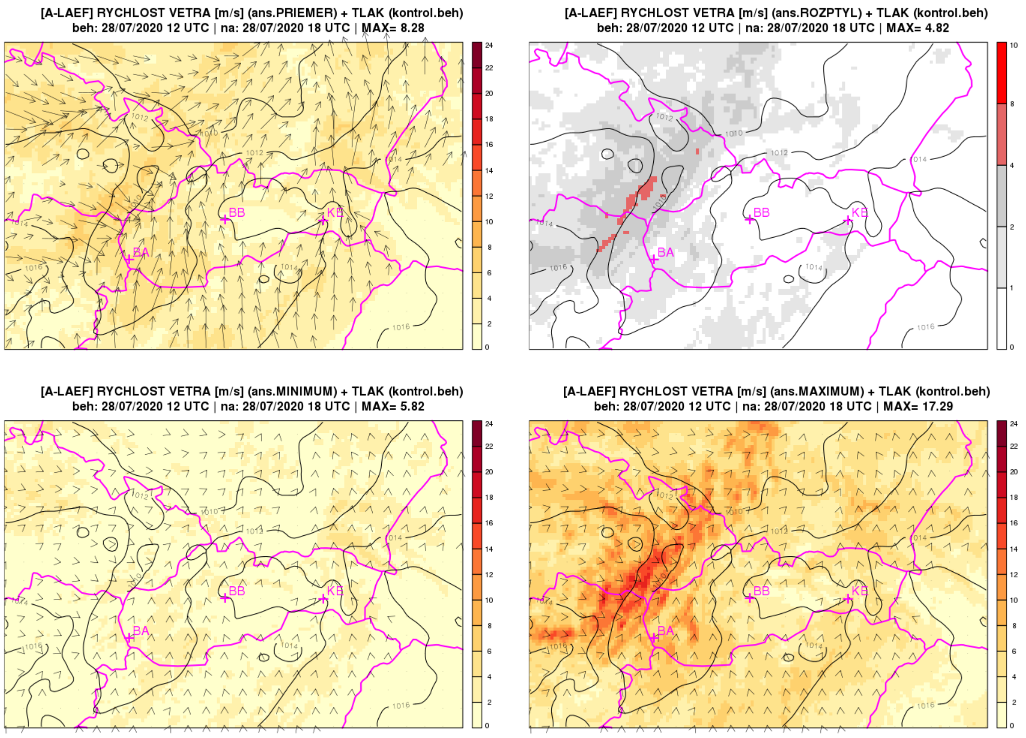

Figure 8: A-LAEF forecast of average wind speed and direction (ensemble mean top left, ensemble spread top right, minimum of ensemble bottom left, maximum of ensemble bottom right), in the background with MSLP from a control run. Valid at 18 UTC, July 28, 2020.

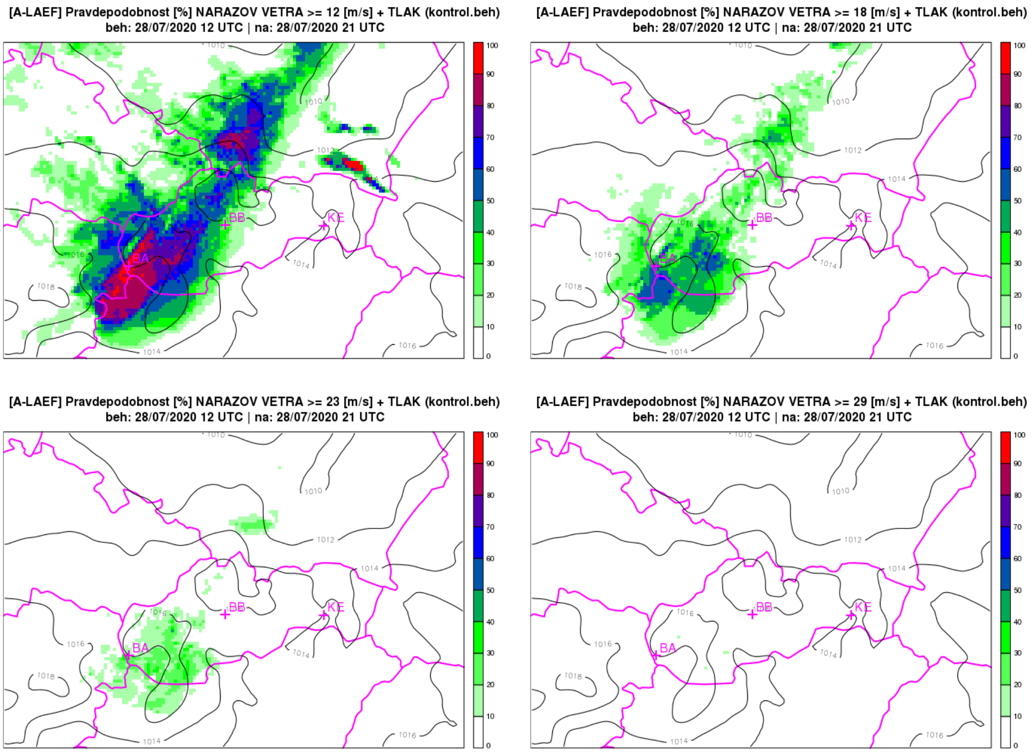

Figure 9: Probability of wind gusts for thresholds 12, 18, 23 and 29 m/s according to the A-LAEF ensemble forecast from July 28, 2020, 12 UTC valid at 21 UTC, in the background with MSLP from a control run.

- **Slovakia – Flood situation of October 13-14, 2020**

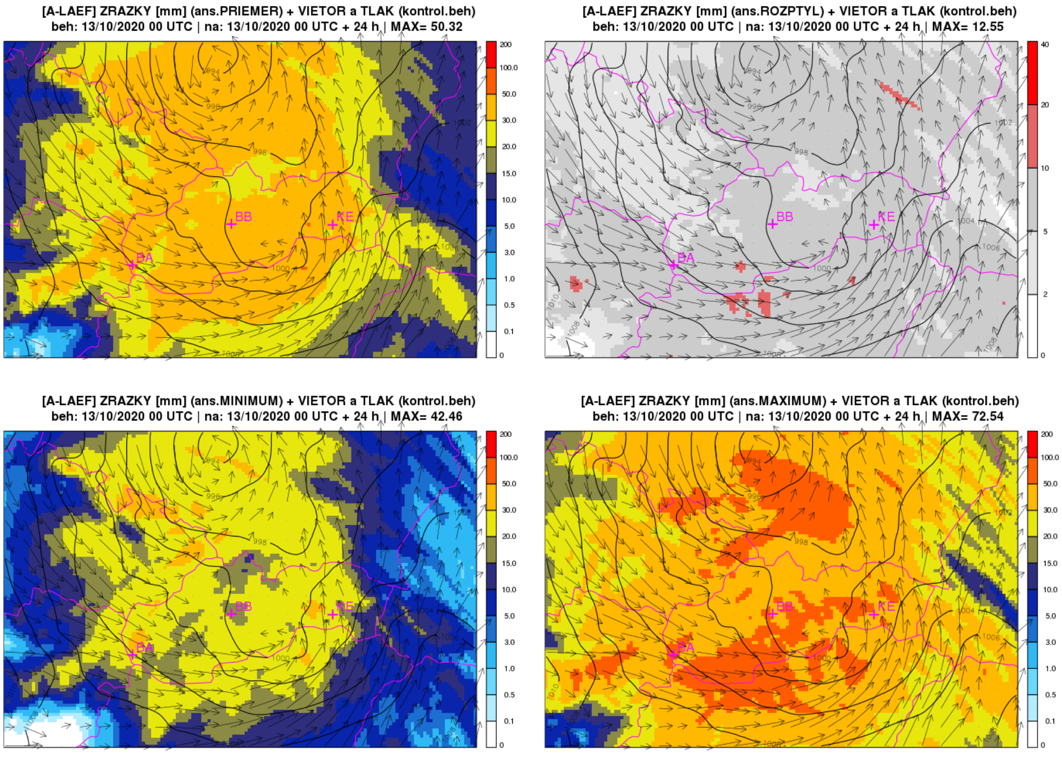

Figure 10: A-LAEF forecast of 24-hourly precipitation sum. EPS (mean, spread, min and max).

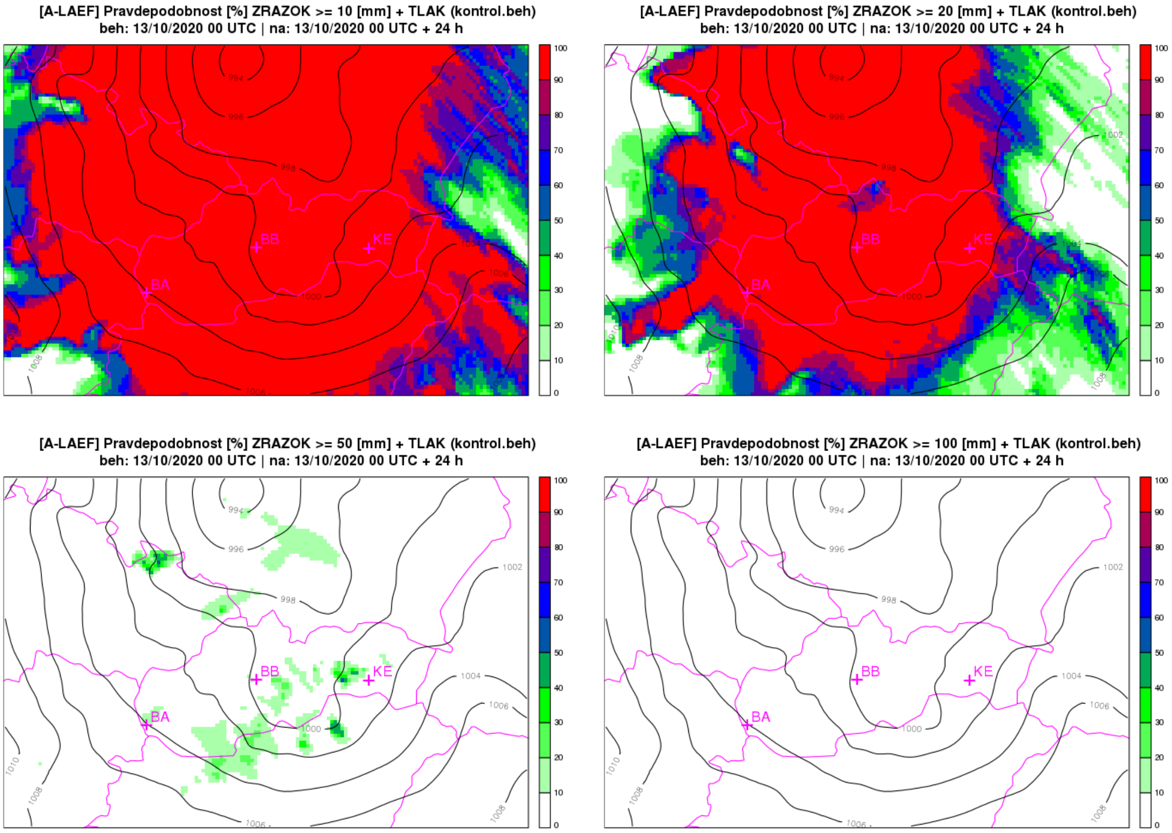

Figure 11: A-LAEF probability of precipitation for thresholds 10, 20, 50 and 100 mm/24h.

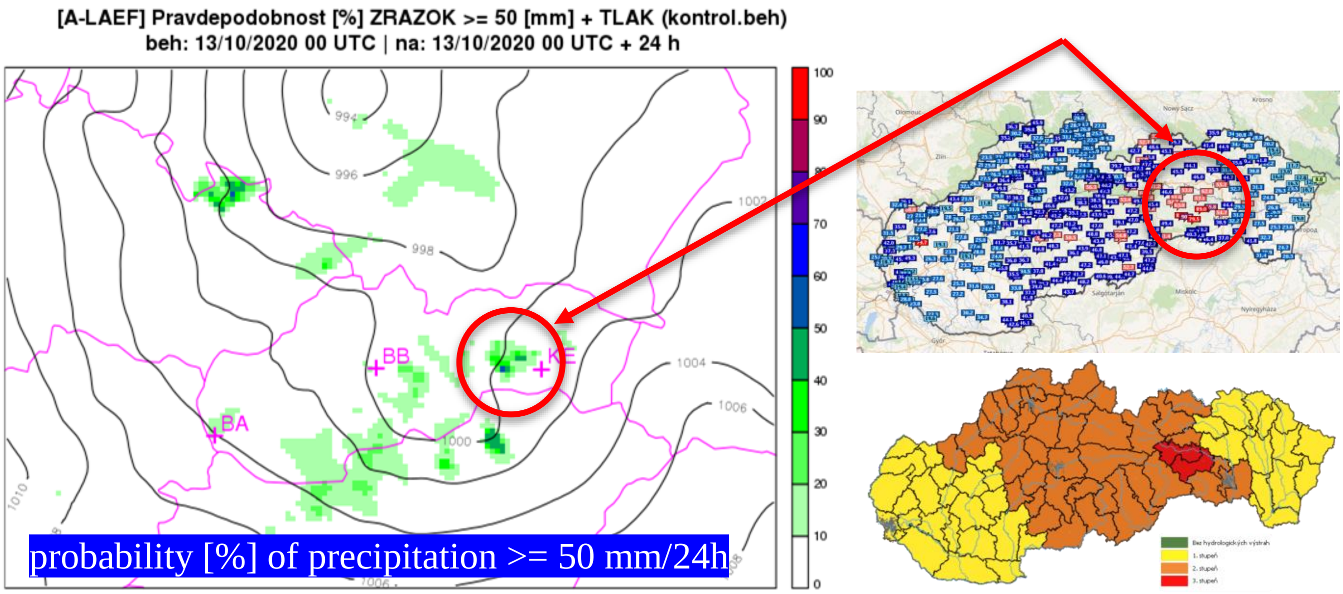

Figure 12: A-LAEF probability of precipitation > 50mm/24h (left) and observed precipitation - 24h accum. (right up), and hydrological warnings (right bottom).

- **Slovakia – Fog situation of November 24, 2020**

On 24/11/2020 there was an anticyclone over Central Europe. Fog was present over large territories and remained during the whole day over lowlands. The visibility dropped to 100 m or even less at some places (which is relatively rare in Slovakia). Previously, there was temporal cold advection at mid-tropospheric levels (e.g. 850 hPa) but this was soon replaced by advection of warmer air from the southwest. Several NWP models and even EPS systems (ECMWF) predicted sunny/relatively warm weather for the noon hours (there should have been a break in the foggy character of previous and later days) and as high temperatures as +5 , +6 °C but in the reality, the temperature remained somewhat over 0°C for many stations in southwest of Slovakia. A-LAEF - several members also predicted that the cloudiness will vanish, somewhere completely (see the EPS minimum) but low cloudiness was still present in many members, as can be deduced from the EPS mean and EPS maximum cover forecast. Probability of low cloudiness with the coverage above 60% was still quite high (40-80%) (Figures 13-15).

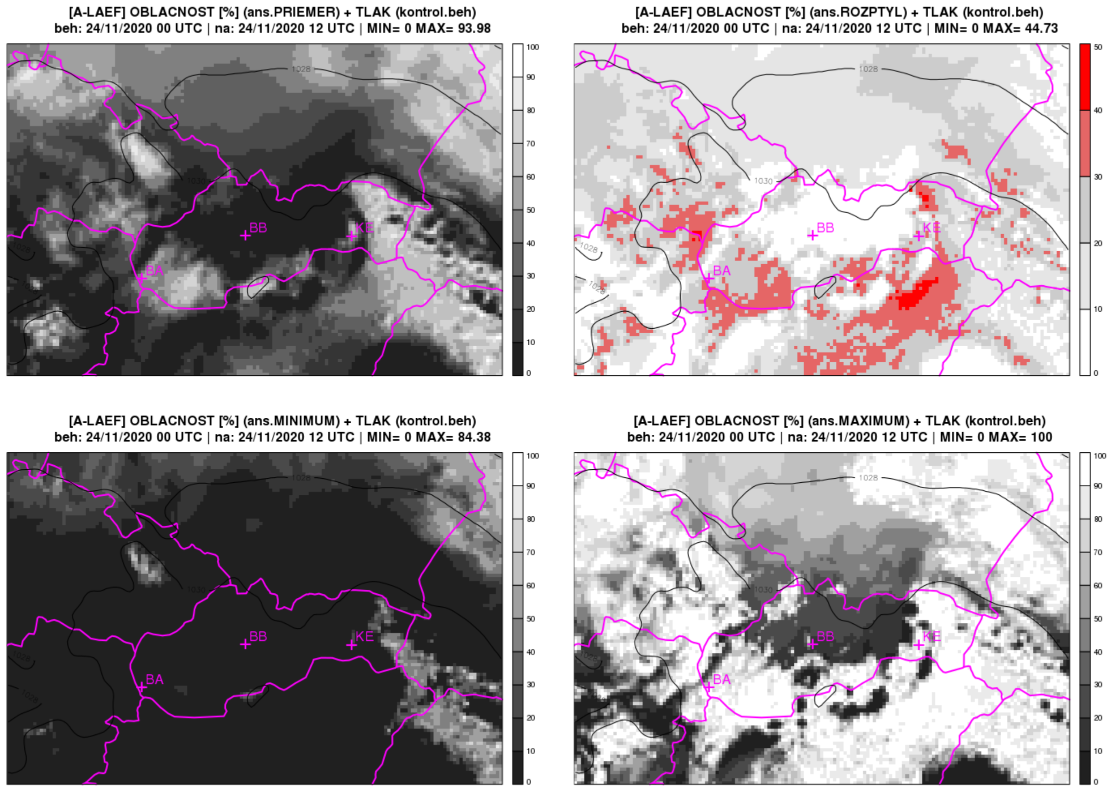

Figure 13: A-LAEF EPS cloudiness [%] 24/11/2020 12 UTC.

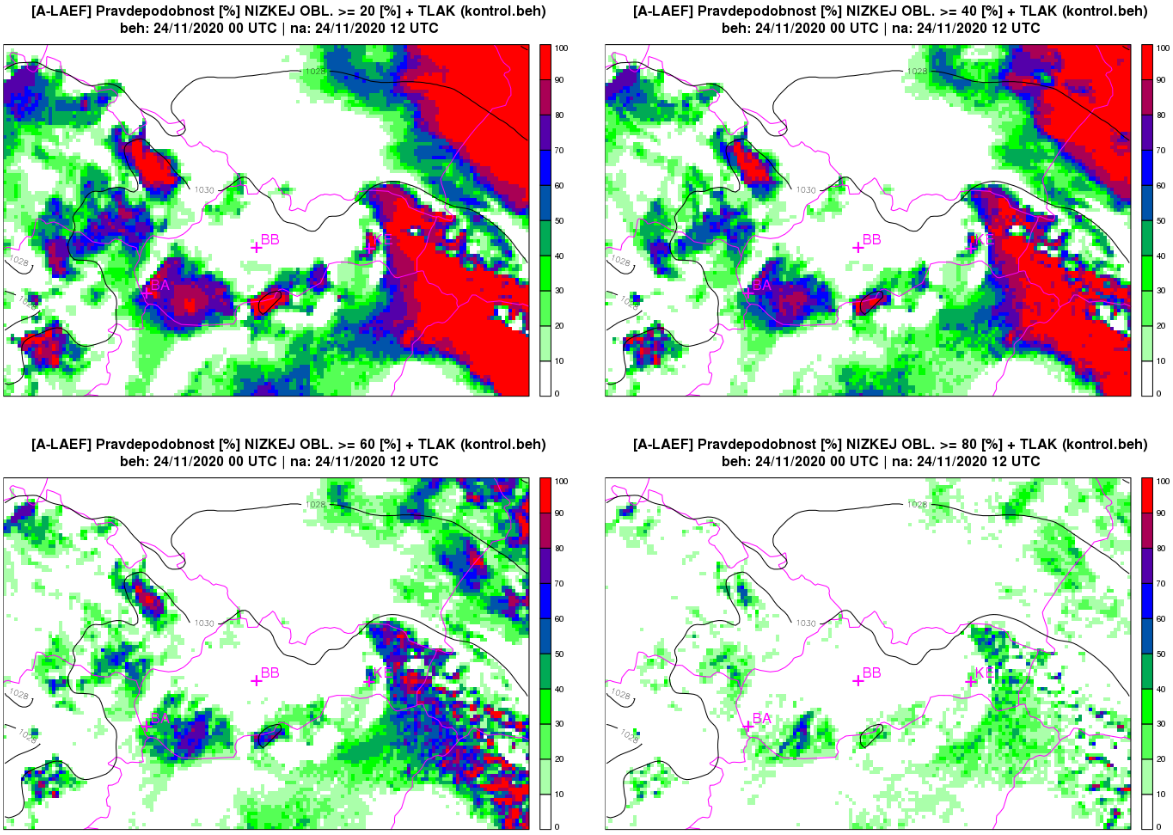

Figure 14: A-LAEF low cloudiness probability [%] > 20% (upper left), > 40% (upper right), > 60% (bottom left) and > 80 % (bottom right) on 24/11/2020 12 UTC.

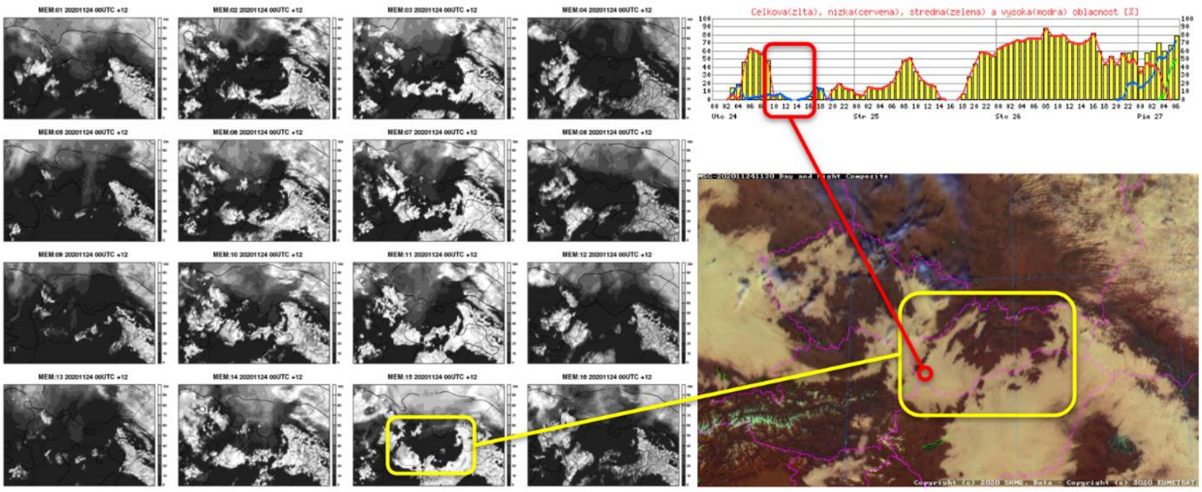

Figure 15: A-LAEF total cloudiness [%] for 16 perturbed members (left) and corresponding MSG composite image (right), with the deterministic forecast of total cloudiness in Bratislava in the form of meteogram (top right) for 24/11/2020 case study.

- **Slovenia - Precipitation case of August 29, 2020**

In Slovenian institute (ARSO), the A-LAEF operational grib files are now included in their Visual Weather environment and are available to the forecasters on a daily basis. They can easily switch between the old and new ensemble systems. Therefore, that was a great opportunity for the validation of new A-LAEF forecasts against the former (still operational) system.

In the Figures 16 and 17 there is just one example of +62h precipitation forecast for the Slovenian domain. Furthermore, in Figure 18 one can see a 6-hourly precipitation analysis based on 2 Slovenian radars and the observation network, valid for the same time period as the above ensemble forecasts.

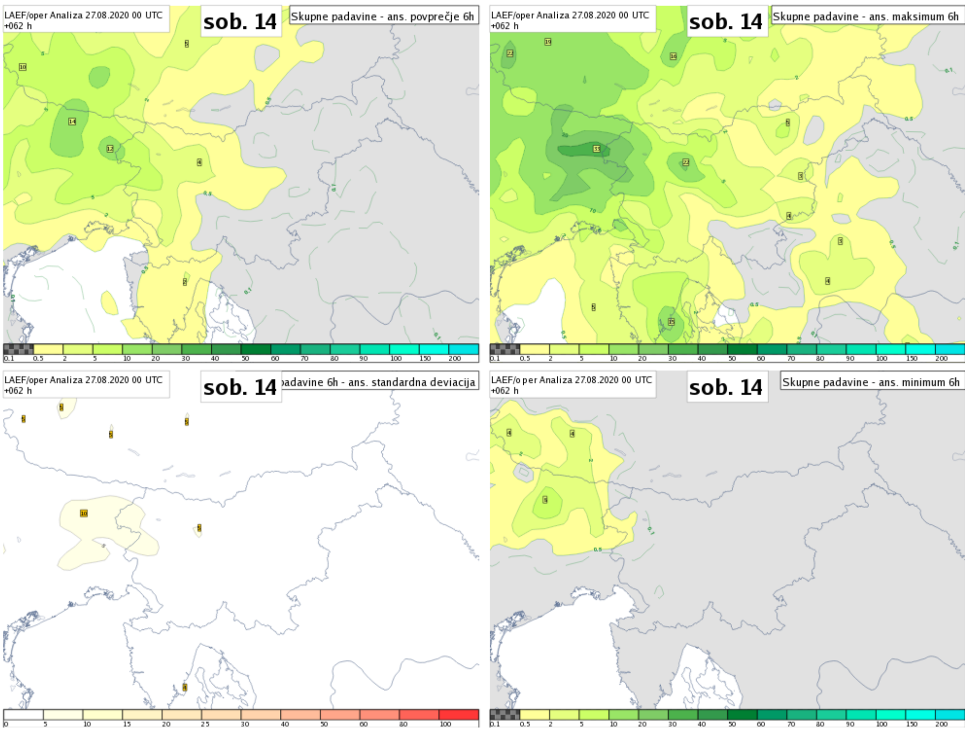

Figure 16: ALADIN-LAEF (old system) precipitation forecast of August 27, 2020, 00 UTC valid for August 29, 8 to 14 UTC (ensemble mean top left, maximum of ensemble top right, standard deviation bottom left, minimum of ensemble bottom right).

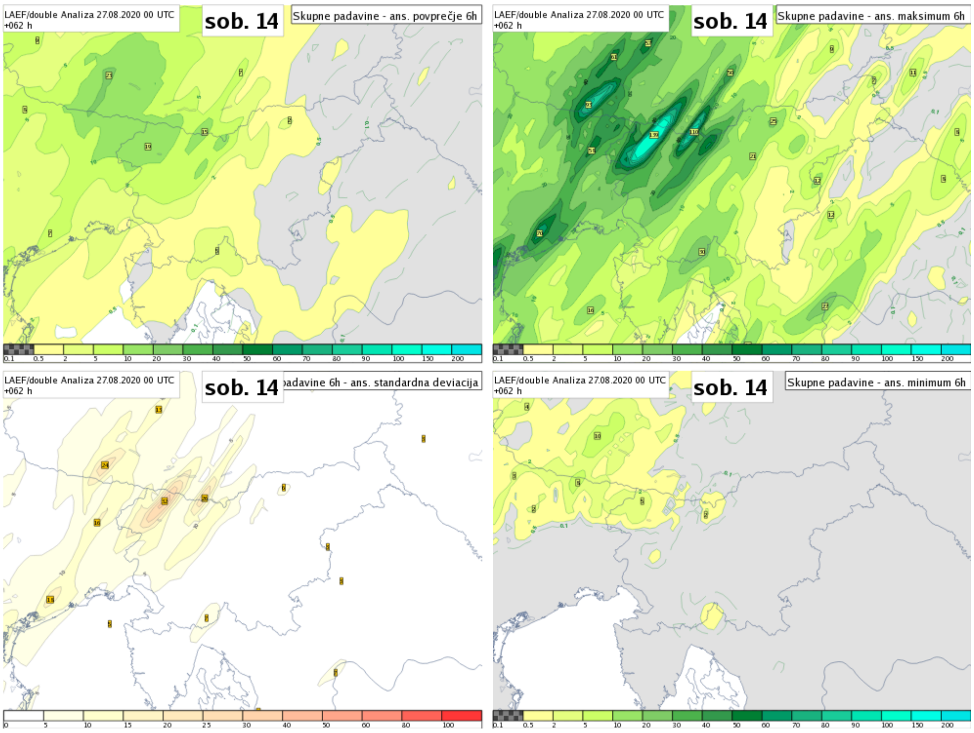

Figure 17: A-LAEF (new system) precipitation forecast of August 27, 2020, 00 UTC valid for August 29, 8 to 14 UTC (ensemble mean top left, maximum of ensemble top right, standard deviation bottom left, minimum of ensemble bottom right).

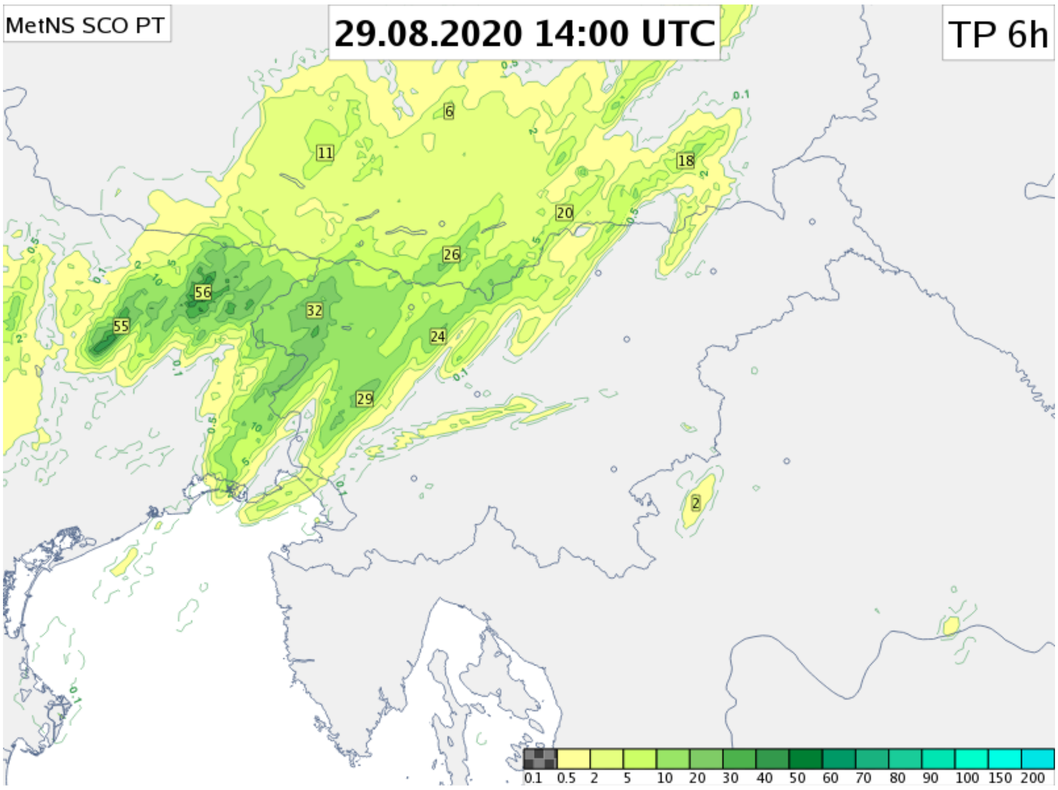

Figure 18: 6-hourly precipitation analysis based on 2 Slovenian radars and the observation network, valid for August 29, 2020, 8 to 14 UTC.

❑ Topic 2: A-LAEF operational maps

A set of probabilistic A-LAEF maps was prepared at SHMU and put to operations using a combination of Perl and R-script coding, exploiting parallel processing on the HPCF (hence the production of about 500 maps can be processed very quickly). The user interfaces for public websites and SHMU intranet were created to enable easy browsing through the A-LAEF probabilistic map products (see Figures 19 and 20).

The public website can be reached at http://www.shmu.sk/produkty/nwp/alaef/, but the whole presented information must be restricted to Slovakia (and close neighborhood). Therefore, also an intranet map browser exists to provide both zoomed (SK) and full size domain (LACE) maps, together with an even wider selection of products which are not available for the public. Both interfaces are also optimized for running on smartphone devices with small screens and touch control.

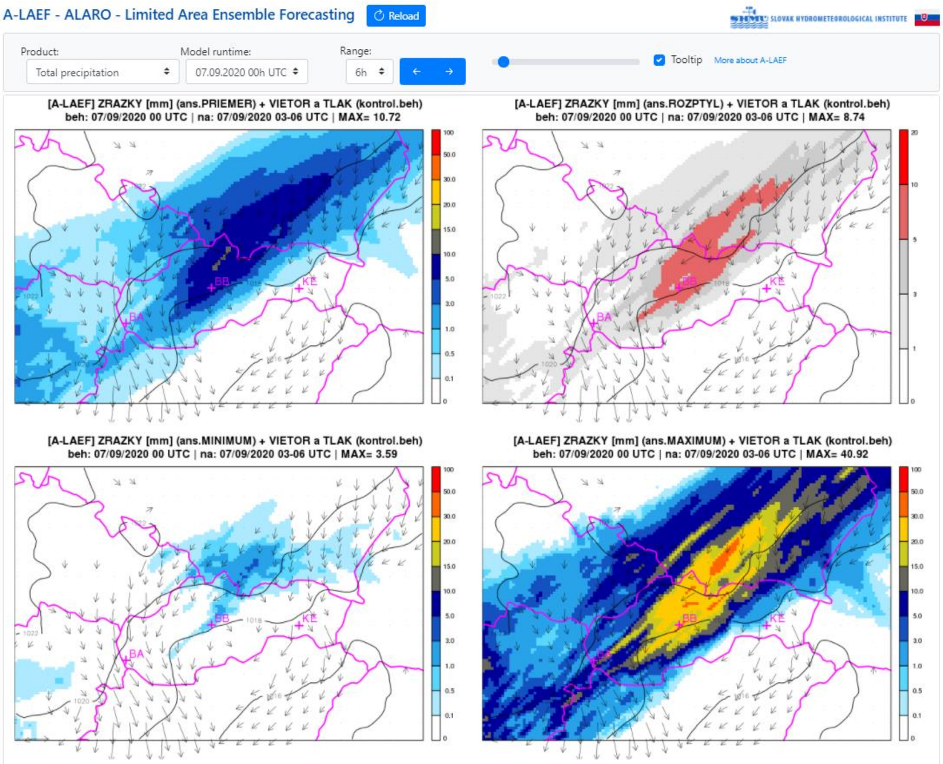

Figure 19: Public website with the operational A-LAEF maps.

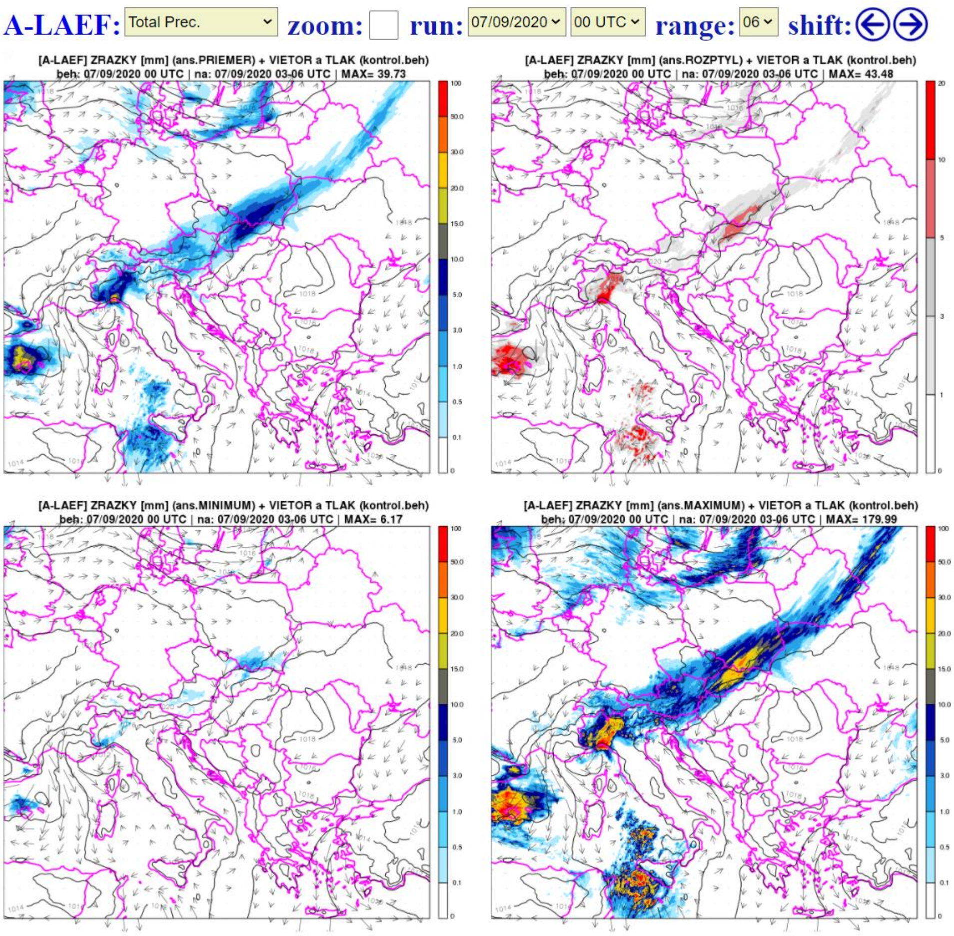

Figure 20: Local intranet site with the operational A-LAEF maps.

- ❑ **Topic 3: QC based on A-LAEF spread**

The experiences gained through INCA nowcasting and high resolution ALARO-1 reanalyses on 1-2 km grids lead to a necessity of automatic quality control (QC). Without a proper QC, the automatic weather station (AWS) measurements often brought a spurious signal into the analysis. A physically consistent spread of the meteorological fields provided by the A-LAEF ensemble was the main motivation for its use in an automatic QC procedure (in a new software layer above MySQL database). It is something, the deterministic model cannot provide. As a first attempt the QC of 2m temperature was tested at SHMU. The suspicious AWS measurements with values out of the A-LAEF spread were identified (see Figure 21).

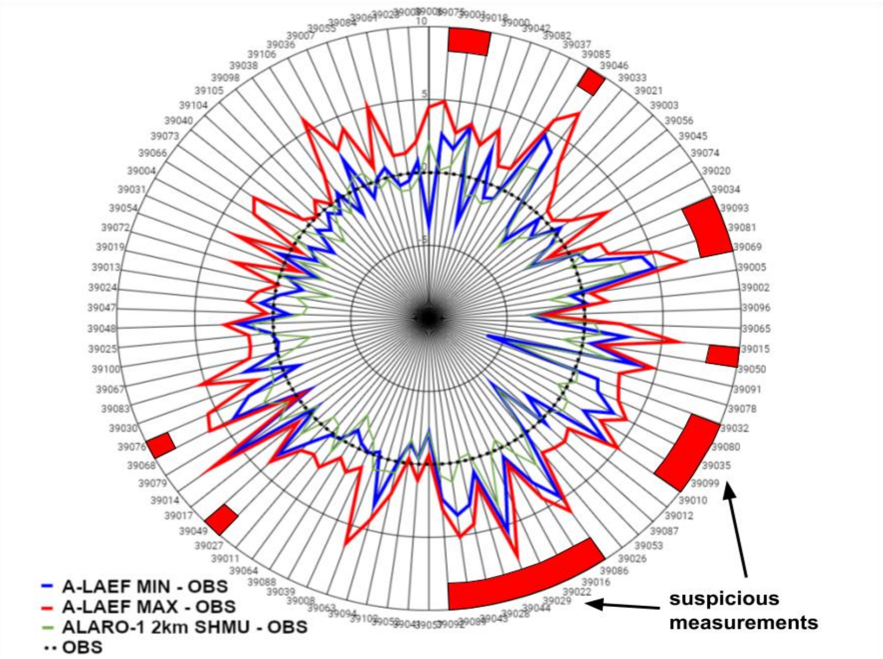

Figure 21: Quality control for the AWS measurements based on A-LAEF ensemble spread.

- **Topic 4: Set-up of a TC2-oper Esuite in ecflow**

For testing new developments and possible upgrades for the operational TC2 suite, an Esuite was set-up in ecflow under the standard user kmxy in autumn 2020. This work comprises the adaptation of Python scripts to generate and reload the Esuite, the adaptation of the Esuite tasks to a standard user (ENV, FS, Pbs queues) and some adaptations of ecflow tasks (Figure 22).

Efforts: 5 PM

Contributors: Martin Belluš (SHMU), Neva Pristov (ARSO), Michal Neštiak (SHMU)

Documentation: Reports on LACE stays; papers submitted to scientific journals; improvement of current regional ensemble system through the results and outcomes of R&D

Status: Ongoing

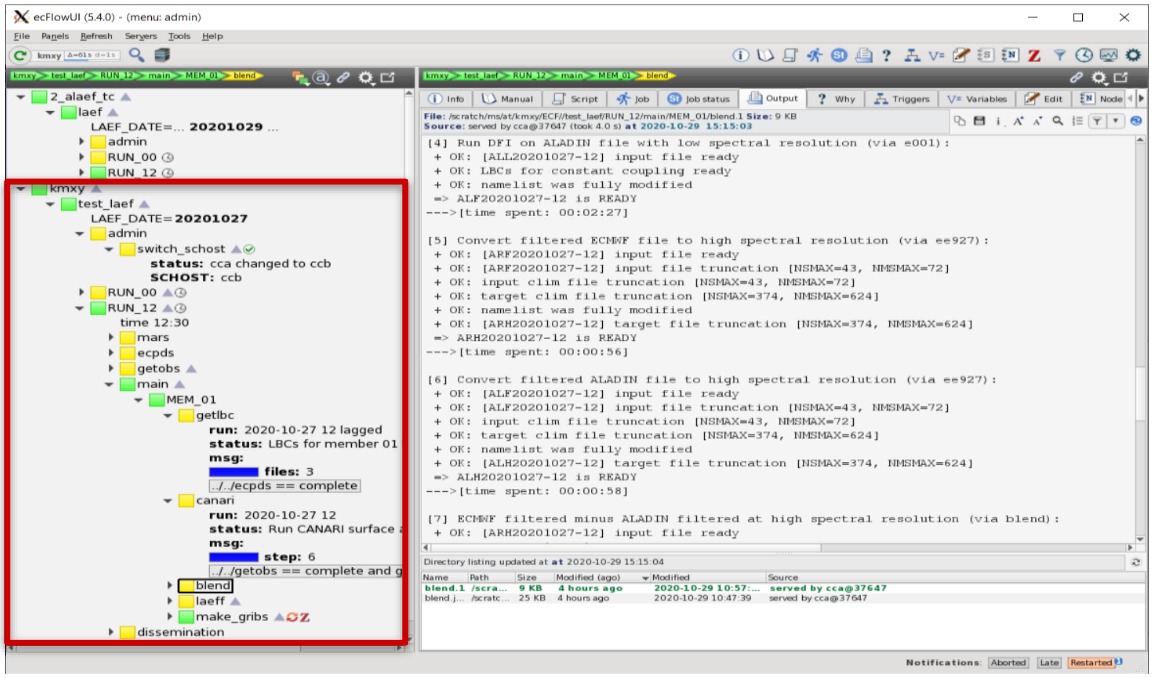

Figure 22: A-LAEF Esuite set-up under user kmxy for testing purposes.

S2 Action/Subject/Deliverable: A-LAEF maintenance

Description and objectives: The main objective of this task is to maintain and monitor the operational suite of A-LAEF running at ECMWF HPC facility. As a result a stable operational suite of A-LAEF is guaranteed and the delivery of probabilistic forecast products (GRIB files) for the LACE partners is ensured.

❑ Topic 1: A-LAEF TC2 operational suite under ecFlow

Development of A-LAEF system continued in the first half of 2020 very intensively, which eventually led to an acceptance of the suite as Time Critical 2 application on July 22nd 2020. The work was executed under the LACE's TC user at ECMWF HPCF remotely from SHMU (in particular from Home Office).

Huge effort was put into the final tuning and to several technical upgrades of the A-LAEF suite to meet the ECMWF's requirements for TC2 application. The suite was migrated to ecflow client/server 5.4.0 with schedule 1.7 allowing for proper implementation of ECF_KILL_CMD and ECF_STATUS_CMD (tools used mainly by the operators). The usage of disk space was optimized, reducing the temporal storage of big global input data delivered via local ECPDS distribution. Furthermore, a white list was implemented to ensure the access to the ecflow tasks only for the authorized users. For more advanced monitoring, the possibility to see live output from running jobs was included as well. Last but not least, the structure of the suite was reorganized in order to have a separate dissemination family to send the products to different destinations (see Figure 23). The benefits of such a solution are a) optimal load on the network lines, b) possibility to restart or suspend the entire distribution at once (if necessary) and c) distribution of products clearly separated from the rest of the suite (easy for the operators).

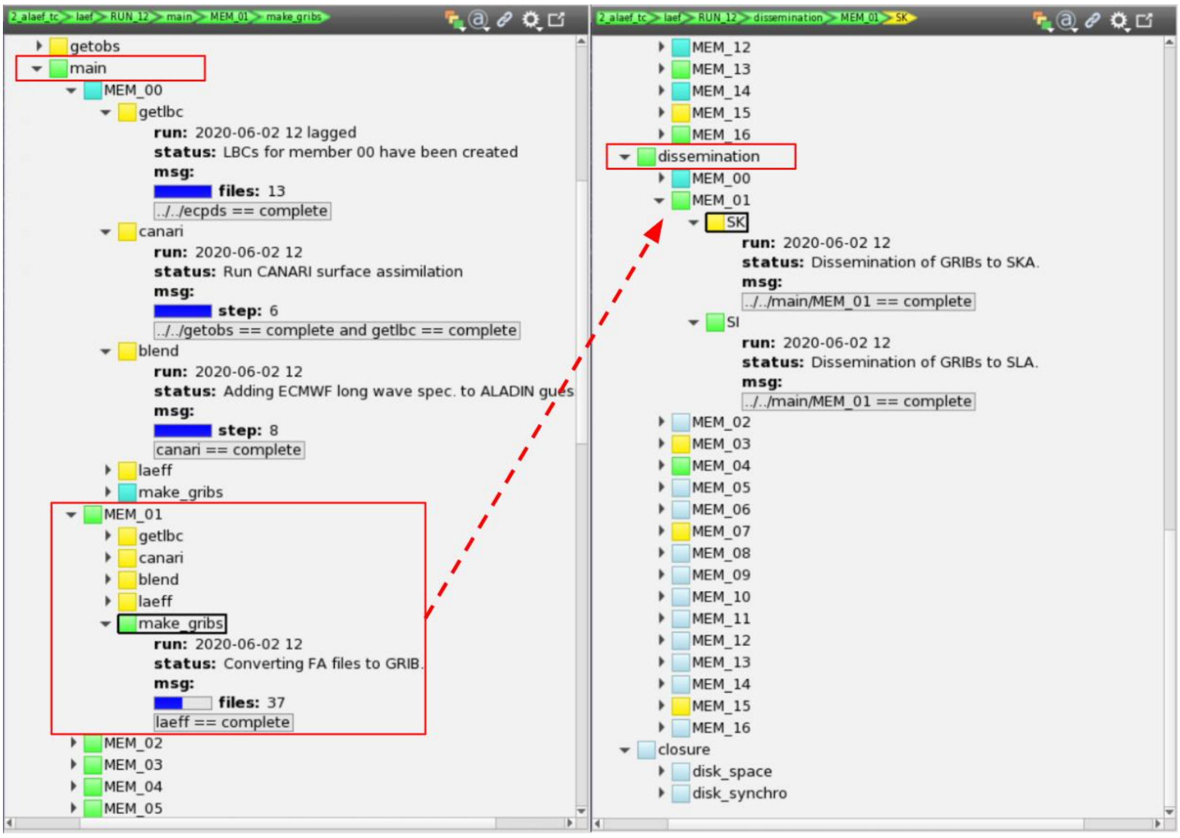

Figure 23: User interface (ecFlow) for A-LAEF suite with new dissemination family.

Except for the above technical upgrades of the suite, finally also the unperturbed control run was added into the A-LAEF ensemble. This was instantly utilized by the Croatian meteorological service who backed up its production at ECMWF after the earthquake (DHMZ building hosting also their computer was damaged in March 2020). To set up their data assimilation at ECMWF HPCF in such a short time was not possible. Instead, they have used the initial conditions obtained from the unperturbed member of A-LAEF ensemble (A-LAEF system involves the surface assimilation and the upper-air spectral blending by DFI).

The formal request to run A-LAEF of RC LACE consortium under the Member State time-critical option 2 was officially approved by ECMWF on July 22, 2020. Since then, timing of the operational A-LAEF tasks is very stable and the output grib files are available at about 03:30 UTC and 15:30 UTC for 00 and 12 UTC runs, respectively. The suite is running well (see Figure 24), and no single crash was present at least within the last 10 months (except the occasional delays due to queuing at HPCF when it wasn't yet running in the priority queues prior to July 2020).

During July also the available billing units (SBUs) used for running A-LAEF suite were almost depleted. Thanks to a prompt reaction of Slovenian partners the allocation of our operational account (allaefop) was increased by 20 mio SBUs. In September Turkey topped up the LACE account by 60 mio SBUs which was sufficient for the rest of the year 2020. For more details about the current status of A-LAEF suite at ECMWF, please see the updated technical documentation from February 2021 on the RC-LACE webpage.
https://www.rclace.eu/File/Predictability/project/A_LAEF_suite_description_02_2021.pdf

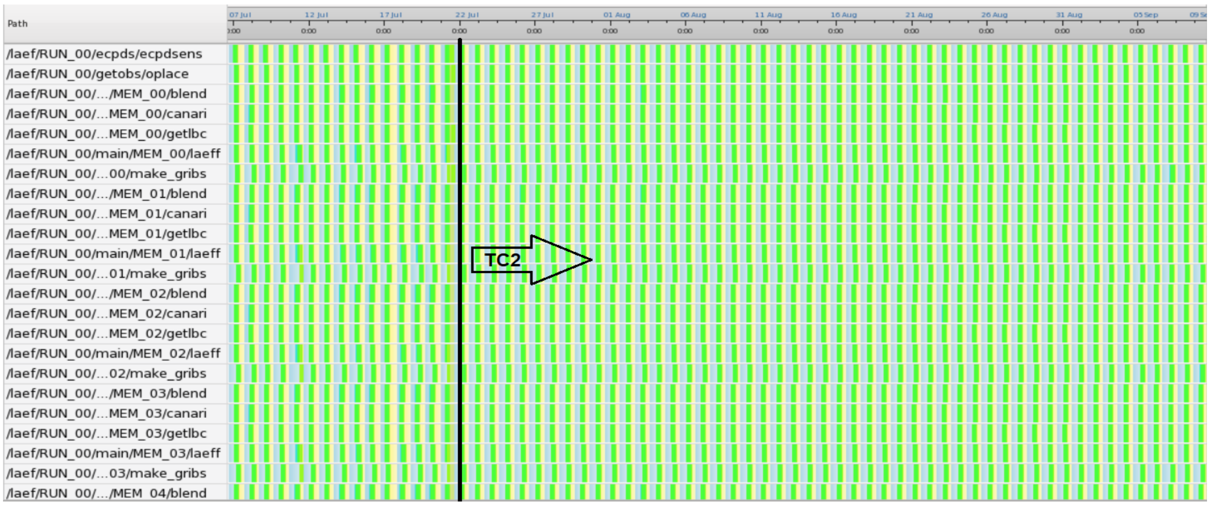

Figure 24: Timetable of some A-LAEF tasks from July 7 till September 9, 2020.

Table 1: Time duration of main A-LAEF tasks for +72h forecast length and their usual finishing wall clock time for 00 and 12 UTC runs.

Task	CPUs	+72h forecast	00 UTC	12 UTC
ecpdsens	1	00:22:00	00:52-00:54	12:52-12:56
oplace	1	00:00:30	00:53-00:55	12:54-12:56
getlbc	36	00:06:00	00:57-00:59	12:57-12:59
canari	288	00:02:45	01:00-01:02	13:00-13:05
blend	288	00:08:00	01:08-01:11	13:08-13:14
laeff	288	02:20:00	03:30-03:40	15:30-15:40
fpos_P|N	2x36	00:18:00	03:50-04:00	15:50-16:00
make_gribs	18	00:05:00	03:35-03:45	15:35-15:45
make_lalogribs	18	00:05:00	03:55-04:05	15:55-16:05

In autumn 2020, new post-processed fields have been added to A-LAEF Lambert multi-GRIBs (snow line, 0-isotherm height, @H100 - T, U, V, RH) and the automatic download of VOBs files from ECMWF for the HARP verifications has been implemented.

❑ Topic 2: Multi-domain off-line fullpos for Turkey and Czech Rep.

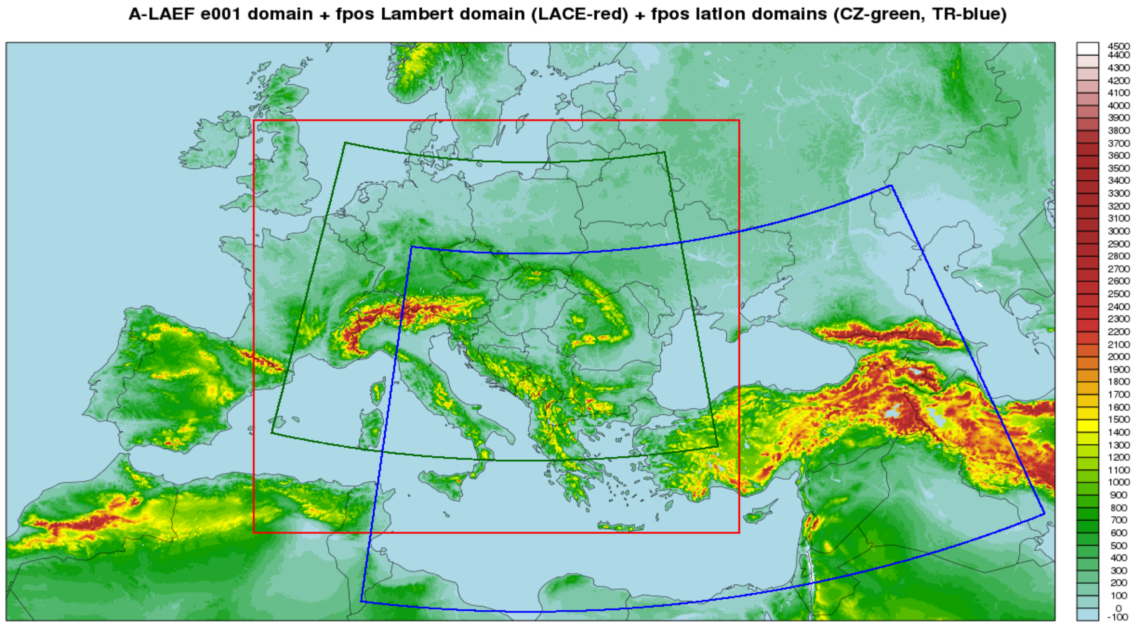

Figure 25: Off-line LATLON fullpos domains for Turkey (blue) and Czech Rep. (green).

In order to optimize off-line fullpos in the operational A-LAEF suite, a multi-domain off-line LATLON fullpos task was implemented for Turkey and Czech Republic in the second half of 2020. Additionally, tasks to directly convert LATLON Fa files to multi-GRIBs and to disseminate these multi-GRIBs to Turkey and Czech Republic (Figures 25 and 26) was established in autumn 2020.

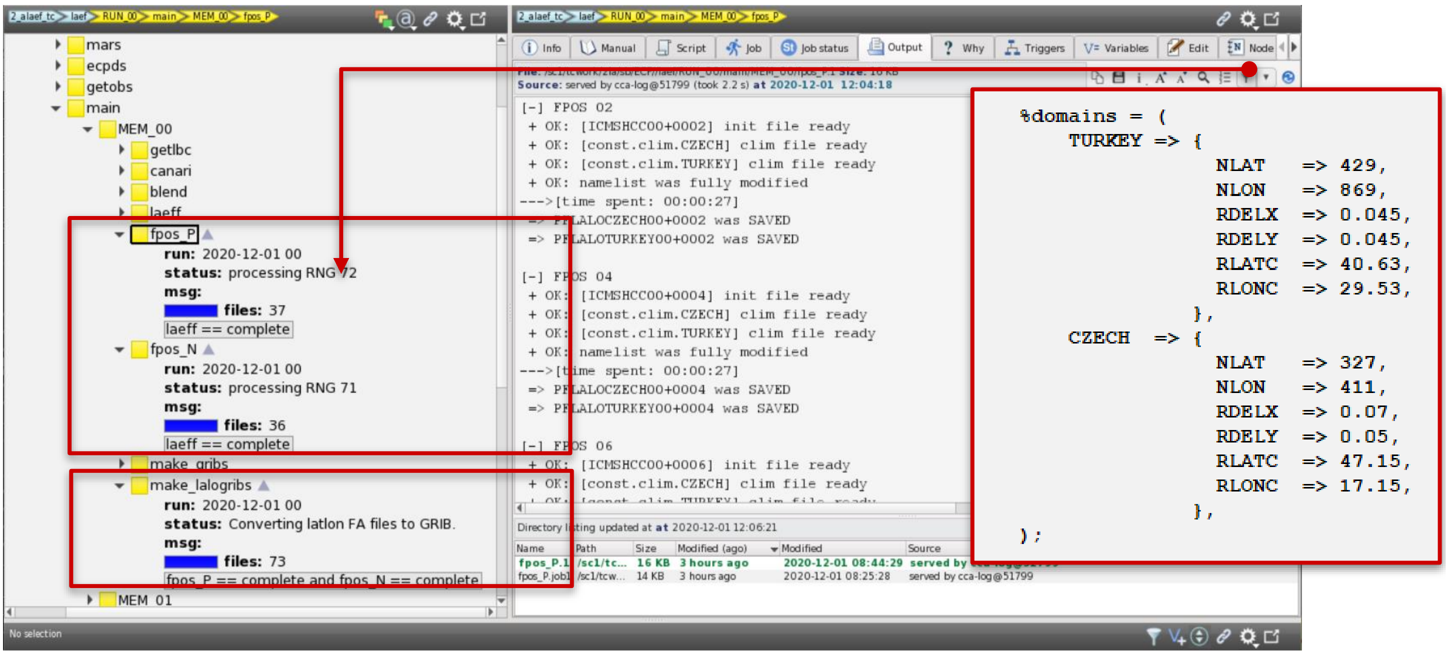

Figure 26: New multi-domain LATLON fpos and conv. to GRIBs in the operational A-LAEF suite.

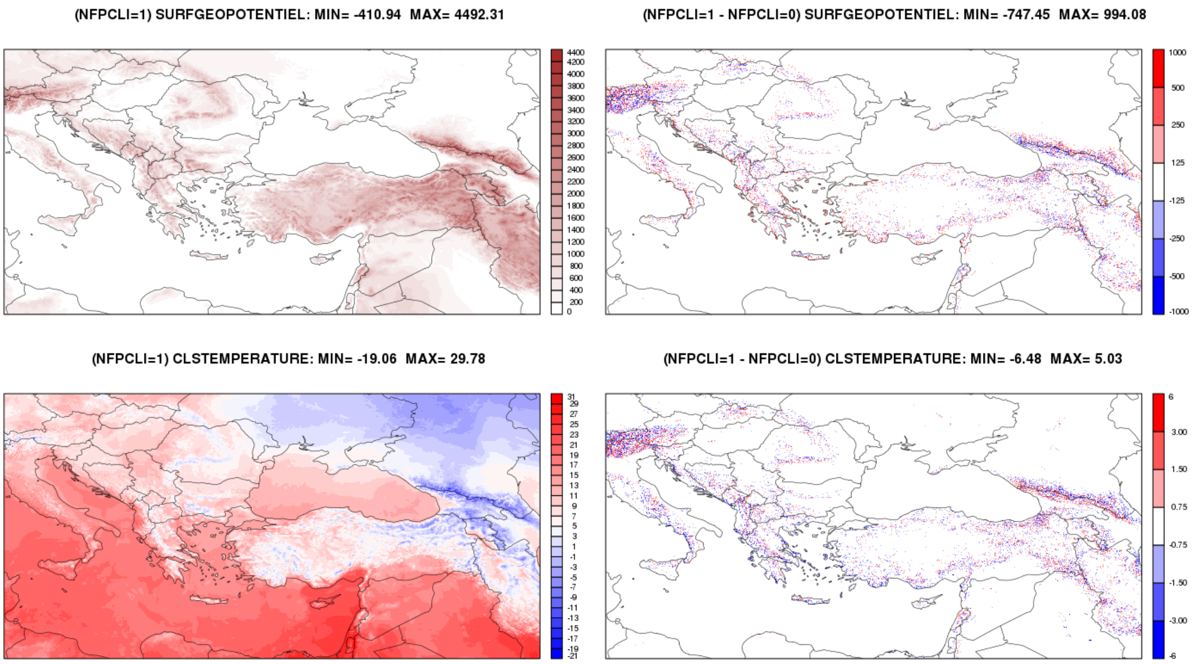

Figure 27: Impact of using orography from separate fullpos climate files (NFPCLI=1) instead of using model orography (NFPCLI=0) on surface geopotential (top) and 2m temperature (bottom)

In context of establishing the new multi-domain fullpos tasks, the impact of using separate CLIM files in fullpos with fitted orography for the target domain (NFPCLI=1 in fullpos namelist block NAMPHY) instead of using the interpolated original orography from the model (NFPCLI=0 in fullpos namelist block NAMPHY) was tested. The usage of interpolated orography (NFPCLI=0) can lead to unnecessary noise in the mountainous areas with differences in the surface geopotential of up to nearly +/- 10000 m2/s2 in the Alps and in the Kaukasus region (Figure 27). This has of course also an impact on the 2m temperature where we can see up to +/- 5 degrees difference in the respective areas.

Efforts: 6.5 PM

Contributors: Martin Belluš (SHMU), Martina Tudor (DHMZ), Neva Pristov (ARSO)

Documentation: **:** A-LAEF operational suite running at ECMWF HPCF; probabilistic forecast products delivered to the LACE partners; Flow charts; presentations; reports; technical documentation of A-LAEF TC2 suite running at ECMWF

Status: Development and upgrade of ecFlow scripts; A-LAEF suite implementation under the time critical environment at ECMWF HPCF; maintenance tasks

S3 Action/Subject/Deliverable: AROME-EPS

Description and objectives: This task covers research and development of the convection-permitting ensembles. Such high-resolution ensembles utilizing non-hydrostatic model AROME are developed concurrently in Hungary at OMSZ and in Austria at ZAMG.

❑ Topic 1: EPS related development at OMSZ

At OMSZ, a non-hydrostatic convection-permitting system AROME-EPS is being developed and operationally used, running on their new HPCF. New system runs once per day coupled to the 18 UTC run of ECMWF ENS. In the lagged mode the forecast from 00 UTC is produced for the next +48h. The ensemble comprises 10 members + 1 control forecast, and covers a Carpathian Basin domain with the horizontal grid spacing of 2.5 km (see Figure 28). For the time being there is no assimilation cycle involved and the initialization uses first guess (hydrometeors) and surface analysis of deterministic AROME, which runs with a 3-hourly assimilation cycle. The upper-air fields are downscaled from the boundary conditions.

AROME-EPS runs operationally at OMSZ since February 4, 2020, with the following configuration:

- Forecast range: +48h (00 UTC)
- LBCs: ECMWF ENS at 18 UTC (6-hourly lagged)
- Coupling frequency: 3h
- Resolution: 2.5 km with 60 vertical levels
- Domain: AROME/HU
- Number of ensemble members: 10 + 1 control forecast
- Data assimilation: not yet available
- Model: AROME cy40

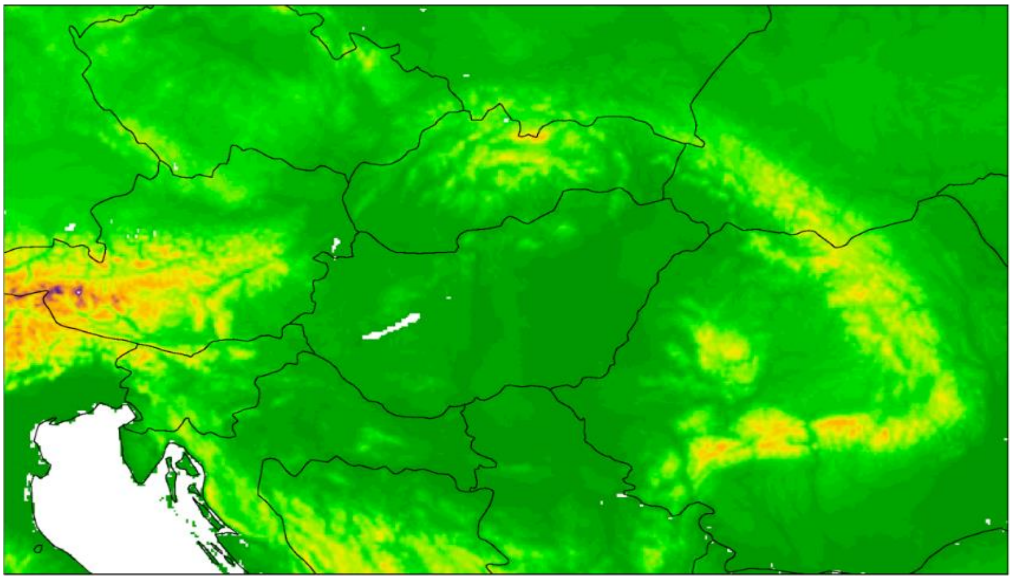

Figure 28: Integration domain of the operational AROME-EPS.

To see the strengths and weaknesses as well as the seasonal variation of AROME-EPS quality, a comparison of ALARO-EPS (ALEPS) and AROME-EPS (AREPS) has been made for a longer period (from June 2019 till January 2020), covering three seasons of parallel run. For the main surface parameters, the following conclusions can be drawn:

- Wind gust is getting better for the ensemble mean of the convection-permitting EPS in all seasons (on average with ca. 0.5 m/s; see Figure 29, left). For the average wind, this is also true, except for the convective season (June – September) in the afternoon hours.
- For 2-meter temperature, relative humidity (see Figures 30 and 31), total cloudiness, and in the convective season, also mean sea level pressure (MSLP) have a lower RMSE of EPS mean for AROME-EPS in the daytime hours, but get worse during the night. Except convective months, AROME-EPS has a better quality in these parameters, than ALARO-EPS. This can be an important aspect for users (e.g. for renewable energy sector).
- For precipitation, one can see lower RMSE values in winter and autumn, and higher values in summer for the AROME-EPS forecast, especially in the afternoon hours, when thunderstorm activity and heavy precipitation events occur most frequently (see Figure 29, right).

It must be stressed that a point-wise verification method was applied, therefore the other methods are being initialized, e.g. investigating the interesting events through case studies.

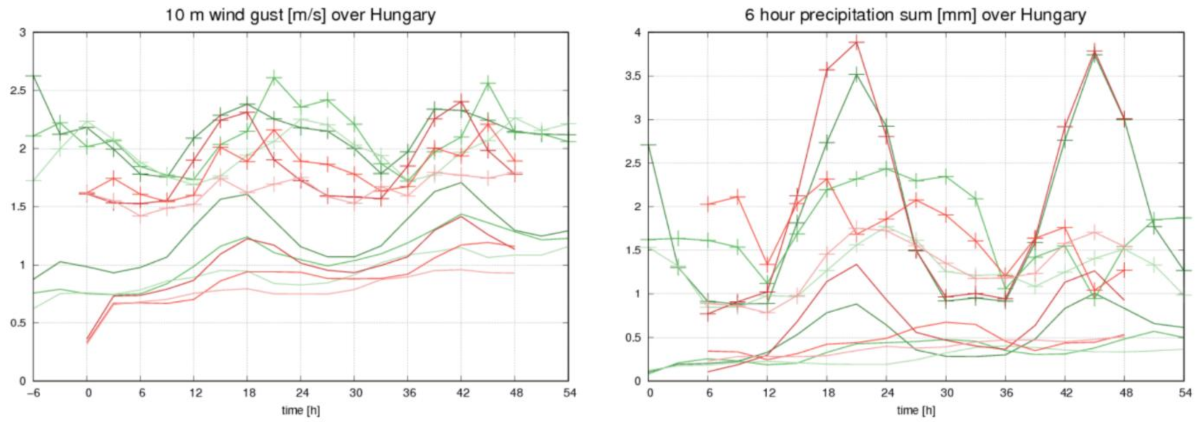

Figure 29: RMSE of ensemble mean (symbols) and EPS spread (solid) of ALARO-EPS (green), AROME-EPS (red) for wind gust (left), 6-hourly precipitation sum (right), for three months in the convective season: July, August and September 2019 in dark/base/light colors, respectively.

Verification of control member and EPS mean for July and for summer 2019 showed similar results. Additionally, for most parameters RMSE of EPS mean is lower than that of deterministic 00 UTC AROME run. In the seasonal average, this is the case for 10-meter wind speed, wind gust, cloudiness, 2-meter temperature and precipitation, which underlines the advantages of EPS in contrast to a deterministic forecast (see Figure 32).

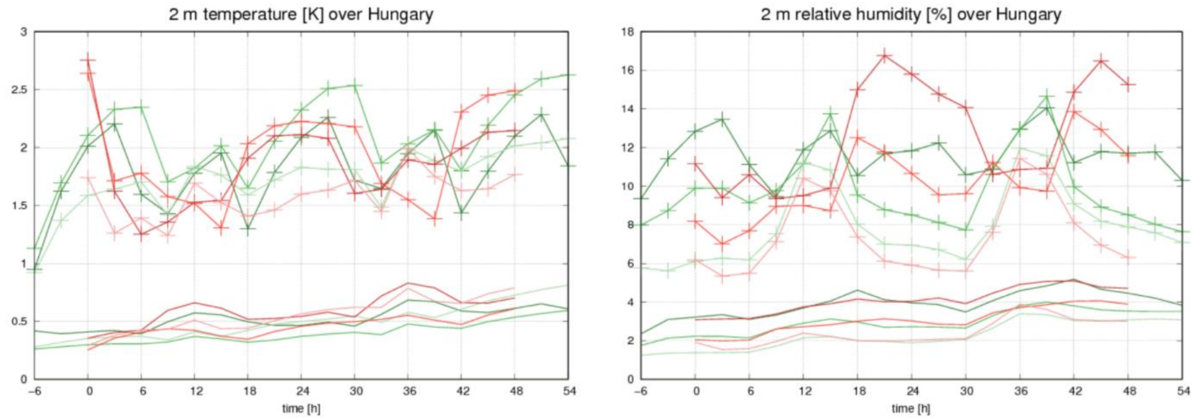

Figure 30: RMSE of ensemble mean (symbols) and EPS spread (solid) of ALARO-EPS (green), AROME-EPS (red) for 2m temperature (left) and relative humidity (right), for autumn 2019: September, October, November in dark/base/light colors, respectively.

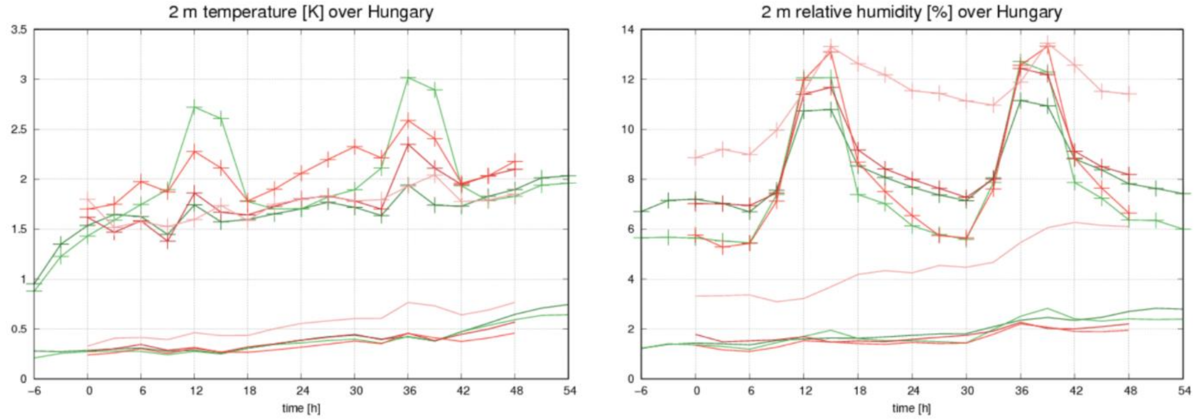

Figure 31: RMSE of ensemble mean (symbols) and EPS spread (solid) of ALARO-EPS (green), AROME-EPS (red) for 2m temperature (left) and relative humidity (right), for winter 2019-2020: December 2019, January and February 2020 in dark/base/light colors, respectively.

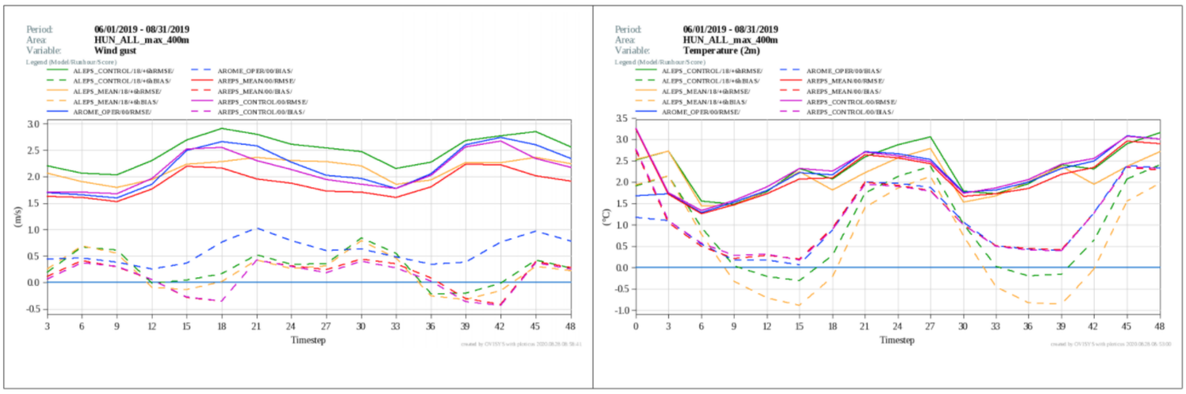

Figure 32: RMSE (solid) and bias (dashed) of AROME-EPS mean (red), control (purple), ALARO-EPS mean (yellow), control (green), compared to AROME deterministic run (blue) for wind gust (left) and 2m temperature (right), for the summer 2019 (June, July, August).

Because the forecasters are satisfied with the new AROME-EPS outputs, the parallel run of ALARO-EPS was finally terminated as of July 22, 2020.

In the second half of 2020 the impact of adding assimilation cycle and/or observation-perturbations in EDA (ensemble of data assimilation) on the Hungarian convection-permitting probability forecasts was tested. Test runs were accomplished for the periods of 28 May – 19 June 2019, July 2019 and January 2020. Furthermore, a case study for a single windy day 25th April 2020, reported by forecasters, was investigated. The EDA experiment was set up similarly to EPS operational run: 48 (or 24) hour forecasts started at 0 UTC with 11 members. The main characteristics of these experiments are.

- 3 hourly assimilation cycle identically to the operational deterministic AROME analysis
- using surface OI for surface and 3DVAR for upper air analysis
- conventional and GNSS ZTD measurements were used, the same as in AROME/HU assimilation
- 3 hourly coupling to ECMWF ENS
- operational AROME/HU domain (over the Carpathian Basin)
- resolution of 2.5 km, 60 vertical levels
- Model cycle 40

Perturbation of observations was executed offline before surface assimilation and after screening by routine PERTCMA written by A. Storto (adapting the version used in Czech Hydrometeorological Institute). Perturbation scaling was added (all perturbations were multiplied by a real number). Results were compared to operational AROME-EPS, which does not include data assimilation. A cold start was made from initial state taken from operational deterministic AROME forecast analysis for all EPS members. First a 10-day spinup period was applied for the assimilation cycle, and it was increased in the later experiments, after drawing the conclusions from previous runs. In addition, lead time was reduced to gain computing time, because from the first experiments we concluded that EDA affects mostly the first 6-18 hours of the forecast.

List of experiments:
Period of 28 May – 19 June 2019, spinup: 10 days, lead time: 48 hours:
• without perturbations (scale=0.0)
• without upscaling of perturbations (scale=1.0)

Period of 1-31 July 2019, leadtime: 24 hours:
• perturbation scale=1.0. spinup: 40 days (guess taken from previous experiment)
• perturbation scale=1.4. spinup: 15 days

Period of 1-31 January 2020, spinup: 15 days, lead time: 24 hours
• perturbation scale= 1.0
A single day: 25 April 2020, spinup: 15 days, lead time: 48 hours
• perturbation scale= 1.0

In the following Figures, the scores of control member are shown separately, because the only difference from the deterministic AROME/HU forecasts is that the control member is coupled 3 hourly to ECMWF ENS control, while deterministic run 1 hourly to ECMWF HRES).

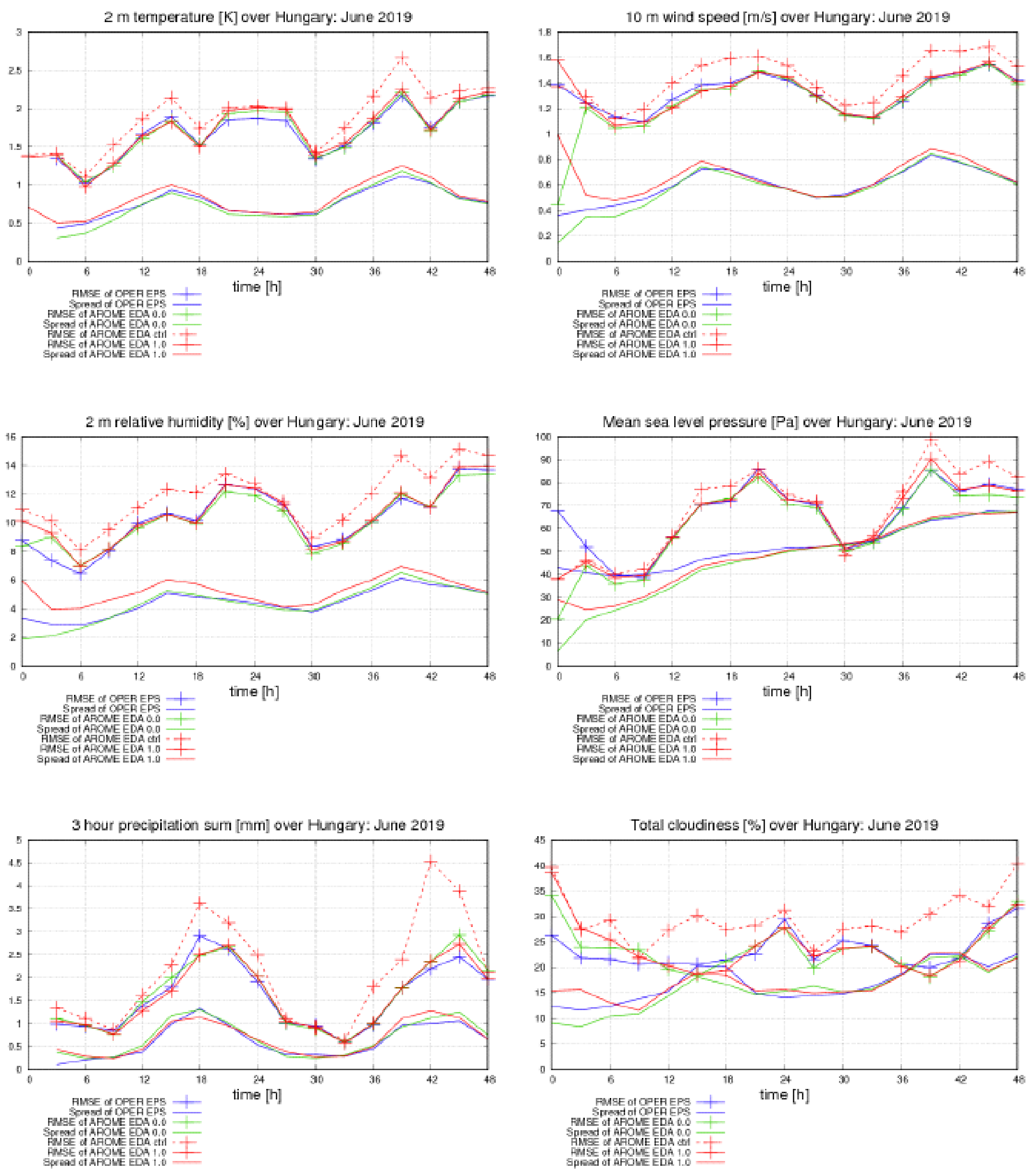

Figure 33: Spread (–) and RMSE (+) of surface parameters in the experiments from 28 May to 19 June 2019; averaged over 30 Hungarian stations. In this period, heavy rainfall was often. Operational EPS mean (blue), EDA with (red) and without perturbations (green), control member of (identical for both) EDA experiments (dashed) are shown.

Results for the 21-day period in May and June 2019 (Figure 33) indicate that daytime temperature and relative humidity are better in the EPS forecasts than in deterministic AROME/HU. For mean sea level pressure (MSLP) there is a similar effect, but rather in the afternoon/evening hours. For wind, improvement is typical for the whole forecast time. Precipitation shows also smaller RMSE values for ensemble mean, but this can be caused by lower local precipitation amounts in EPS mean than in the individual members. EDA compared to downscaled EPS has a small positive effect on wind, temperature and precipitation on the first day (daytime). In the first 6 hours of the forecast, it has a large positive effect on pressure but causes worsening of humidity. For cloudiness, positive biases even grow with EDA, causing higher RMSE. For wind,

and a bit less for humidity, assimilation without perturbation shows in the first hours what we are expecting, but perturbation seems to induce too large spread, especially for wind. If we look at the 2nd day of the forecast EPS results (red and blue lines in Figure 33), we see that EDA has a relatively small effect compared to the 1st day, except a bit greater RMSE values for pressure, temperature and precipitation. We keep these in mind, but the following experiments were run only for 24 hours, focusing on the main characteristics caused by assimilation and perturbations.
Two cases were also studied: 28th and 29th May 2019. On 28th May heavy rainfall (maximum: 27mm/day) occurred and it was accompanied by wind gusts of 18 m/s which were underestimated by deterministic forecasts. With respect to operational EPS we got higher probabilities in EDA for wind gusts related to the convective activity; exceeding thresholds of 9 or 12 m/s in the EDA forecasts, but it was still underestimating measured values and located eastward from real occurrence (Figure 34). On 29th May precipitation maximum reached 84 mm/6 hours. EDA could not locate heavy rainfall events better than the operational run, although it gave somewhat higher probabilities for the high amount.

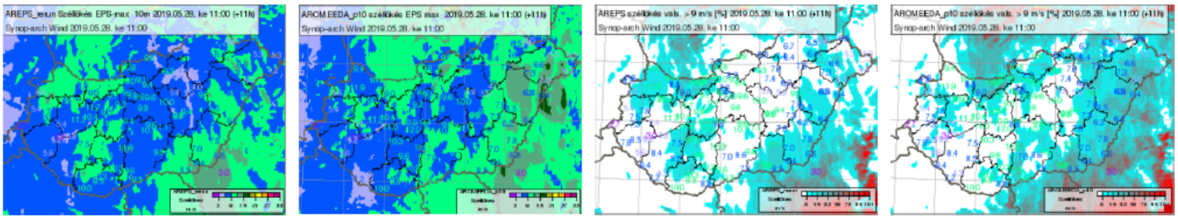

Figure 34: Wind gust forecasts at 11 UTC on 28 May 2019 in Hungary. From left to right: maxima of EPS members in the operational EPS and EDA, probabilities of wind gusts exceeding 9 m/s in the operational EPS and EDA.

For the next experiments, July 2019 was chosen: a month with convection events, similar positive temperature and wind bias and RMSE in operational EPS run as the proceeding months, but more dry periods. Comparison for some surface variables is shown in Figure 35. For temperature, initial state is much closer to the measured values in EDA run, and this lasts 15 hours. The assimilation seems to degrade the quality of wind speed at the beginning of the forecast but after 6 hours we get an improvement. The initial degradation is also true for humidity and only very little improvement can be seen later. In MSLP, assimilation causes great reduction of RMSE, but after 9 hours there is no difference from the operational EPS score, whereas ensemble spread gets unfortunately too low. Precipitation gets better in the afternoon hours, this is an important improvement with EDA. For cloudiness, EDA causes positive bias (not shown here), and therefore the rise of RMSE in the first 9 hours of the forecast, but after 12 hours, EDA forecasts are working well in the daytime hours, and again bring worsening during the evening/night. In RMSE, some very little additional improvement can be gained with inflated perturbation in humidity, wind and cloudiness. Control member for each experiment is also evaluated to see the effect of data assimilation separately from EPS behavior (1.0 EDA control member differs from 1.4 EDA control member only by a much longer spinup time.) Figure 35 shows similarly to Figure 33 that data assimilation is working well for most parameters, except humidity and cloudiness. However, when looking at upper air verification results (not shown here), we see also degradation in wind and temperature forecast skill which may be caused by too few observations in the high atmosphere. For June and July 2019, some further case studies are also planned to supply verification results.

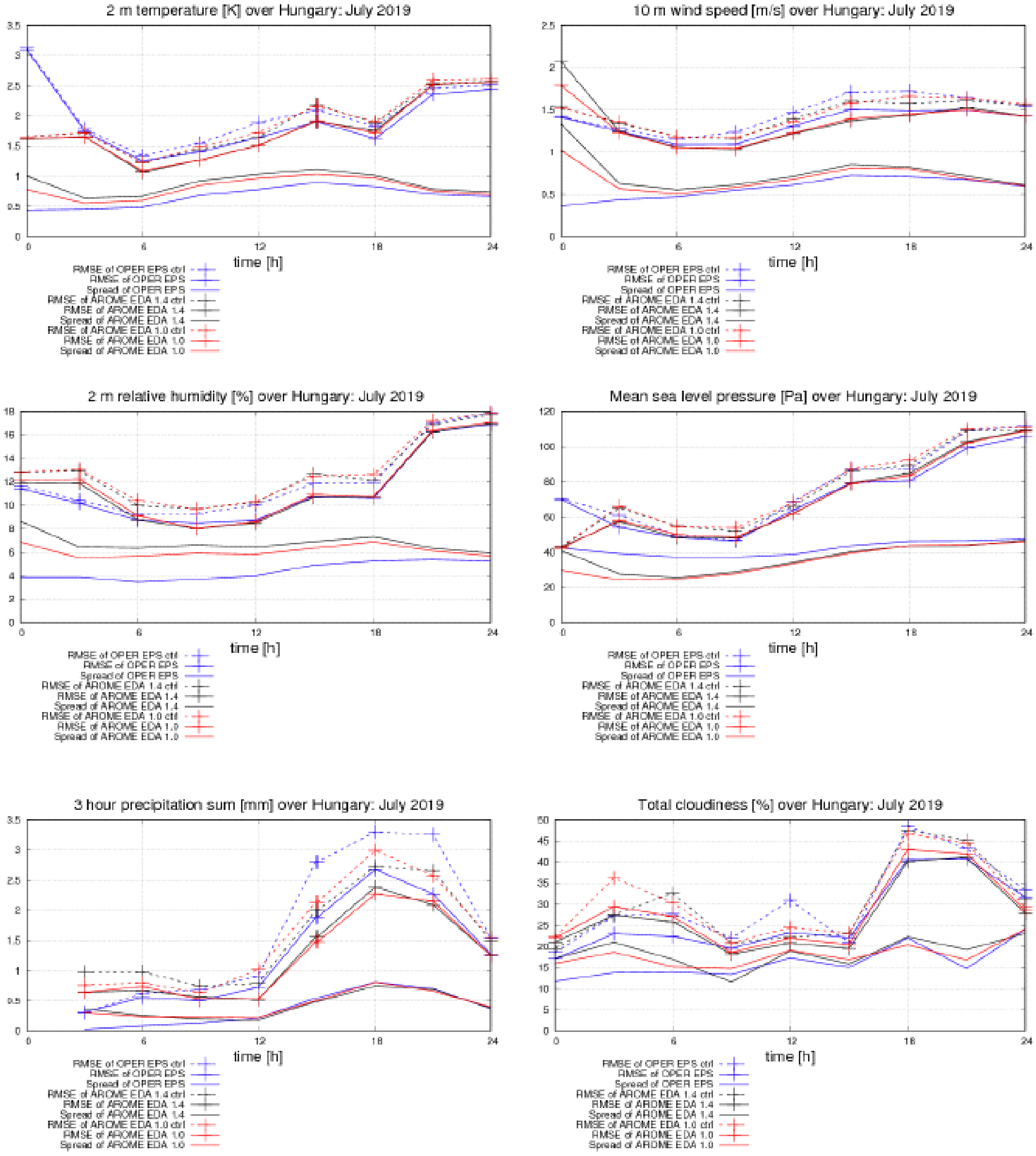

Figure 35: Spread (–) and RMSE (+) of surface parameters in the experiments for July 2019. Operational EPS (blue), EDA with perturbations 1.0 (red), with perturbations 1.4 (black) and corresponding control members (dashed) are also shown.

A winter period was also chosen for EDA experiments: January 2020, which was a dry month with average daily temperature lying not much below freezing point, with daily variance of about ±5 K. Cloudy days were often, at least half of the month. The verification results are similar to summer ones (Figure 36). For humidity, daytime RMSE values are quite high and for cloudiness there is a lack of spread in comparison with summer results. In both parameters high positive biases are present, likely caused by soil moisture problems, but further investigation is needed.

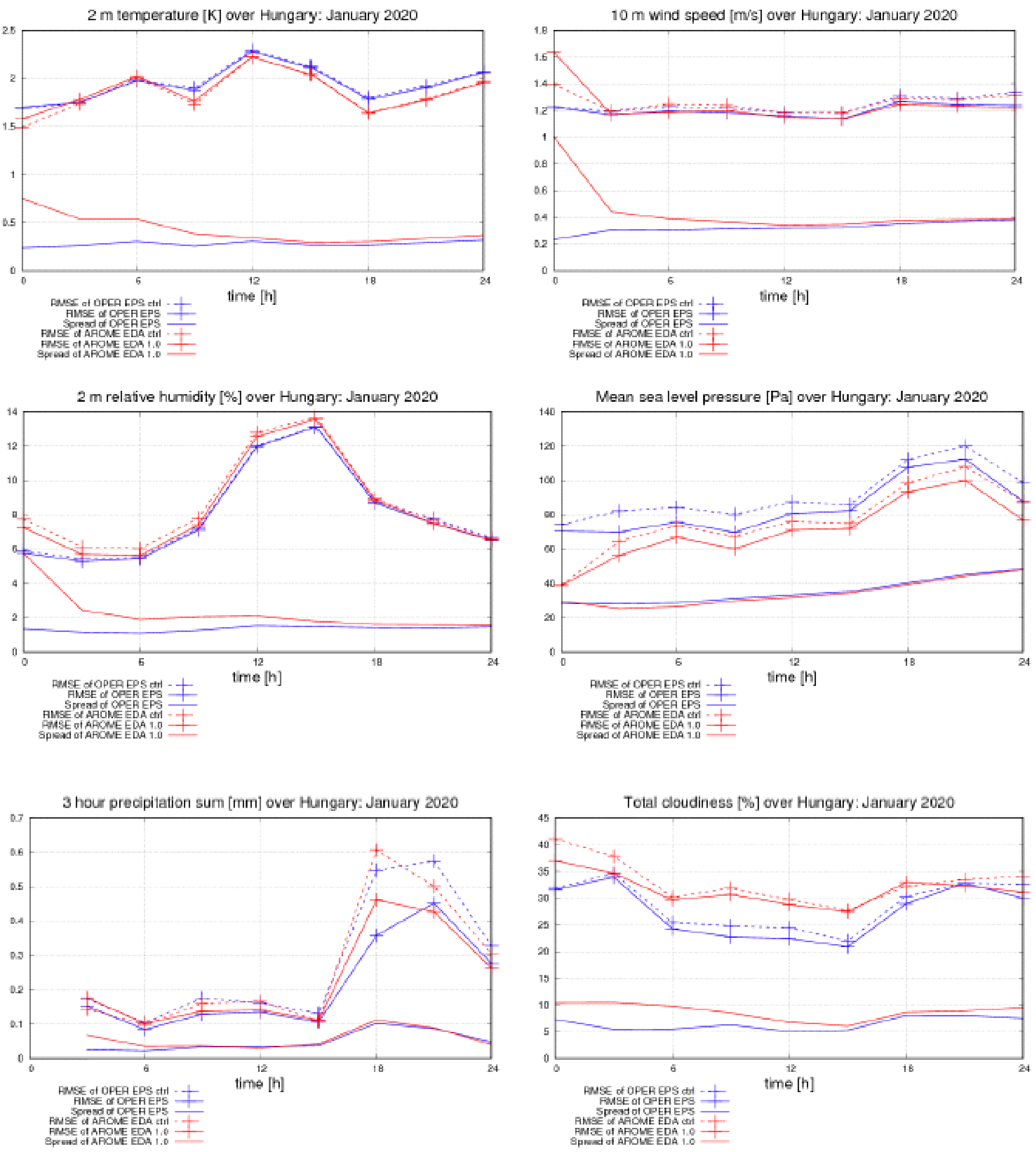

Figure 36: Spread (–) and- RMSE (+) of surface parameters in the experiments for January 2020. Operational EPS (blue), EDA with perturbations 1.0 in (red), and corresponding control members (dashed) are shown.

At last, the case study for 25th April 2020 is presented. A strong cold front passed over the Northeast of Hungary accompanied by robust flow in the upper atmosphere, and weaker wind near the surface. Due to convection, downward mixing of strong wind, followed by some precipitation was present on the Northeast of the country in the afternoon hours. The deterministic AROME/HU run slightly underestimated the maximum wind gust, which was even lower in the operational
AROME-EPS members, while precipitation values were similar to measured data in both forecasts. We expected that data assimilation can improve the EPS forecast, and indeed, applying EDA, we could reach relevant enhancement of wind gust forecast in all ensemble members, in the Northwest area of the country (although in the reality strong wind gusts expanded to a larger area). An illustration is shown in Figure 37. The impact of data assimilation and the growth of ensemble spread caused by perturbations can be seen on meteograms compared to operational EPS (Figure 38).

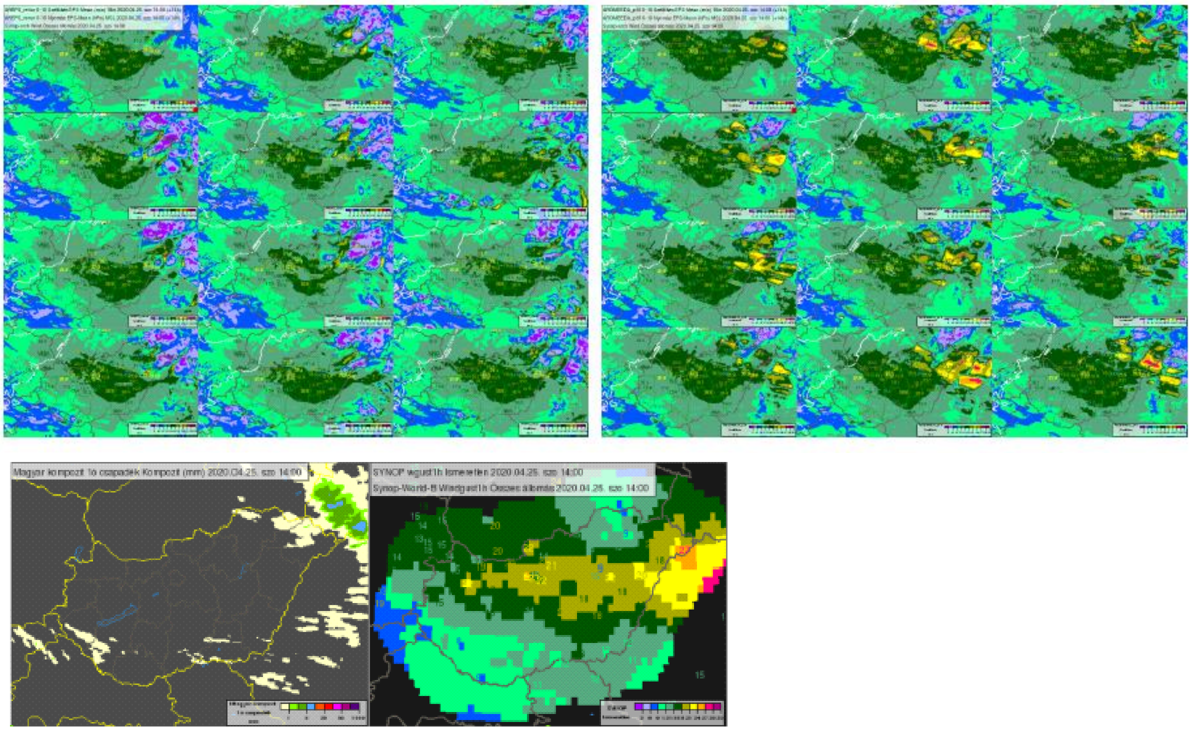

Figure 37: Hourly maximum wind gust in the forecast members of the operational EPS (top left stamp maps), and EDA (top right stamp maps), SYNOP observations (bottom right), and radar measurements for 1 hour precipitation sum (bottom left) at 14 UTC on 25 April 2020.

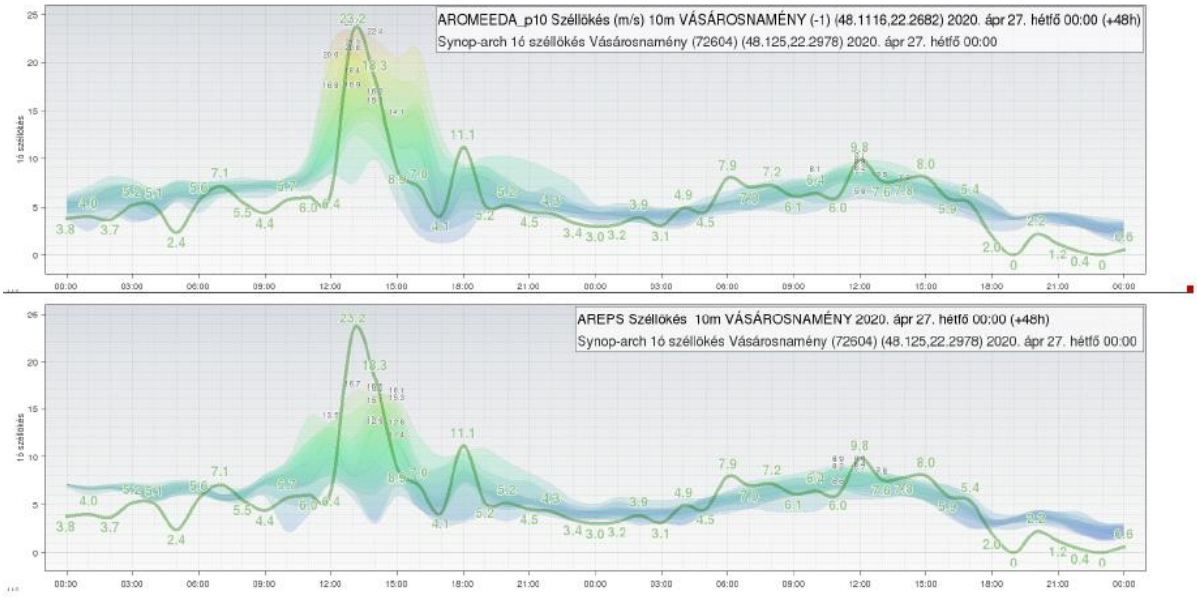

Figure 38: Hourly maximum wind gust forecasts of operational AROME-EPS (bottom) and AROME-EDA (top) run initialized at 0 UTC on 25 April 2020 and corresponding observations for Vásárosnamény, a city lying in the Northeast corner of Hungary.

As a summary, it can be concluded that adding ensemble data assimilation to Hungarian AROME-EPS can improve forecasts of surface parameters significantly: wind, temperature, mean sea level pressure and precipitation, especially in the summer season. Humidity and cloudiness seem to have higher error values at the beginning of the forecasts, probably caused by assimilation problems. However, for the later forecast times, this can be quite well covered by ensemble spread, at least in the convective season.

- **Topic 2: EPS related development at ZAMG**

Convection-permitting - Limited Area Ensemble Forecasting system (C-LAEF) is being developed at ZAMG, running operationally at ECMWF HPCF as a time critical 2 application since November 2019.

C-LAEF is based on the non-hydrostatic AROME model with a horizontal resolution of 2.5 km and 90 vertical levels. It has 16 perturbed members (and 1 unperturbed control run) coupled to the first 16 members of ECMWF-EPS. The initial condition uncertainties are represented by 3D-Var EDA with ensemble Jk method and by screen-level observation perturbations in CANARI. The assimilation cycles are performed every 6h. Model error is represented by a hybrid stochastic perturbation scheme, where perturbations of tendencies in shallow convection, radiation and microphysics are combined with parameter perturbations in the turbulence scheme.

C-LAEF runs operationally at ECMWF HPCF with 4 runs per day (00, 06, 12 and 18 UTC). The lead times vary between +60h (00 UTC), +48h (12 UTC) and +6h (06 and 18 UTC).

In 2020, the following activities were realized:

- Implementation of new cy43t2 at the ECMWF HPCF
- Local phasing of C-LAEF related code in cy43t2 (perturbation scheme, etc.)
- Preparation of bugfixes for cy43t2_bf11 phasing (orographic shadowing, sunshine duration, etc.)
- Re-coding Endi's EnsembleJK code for cy43 to get rid of external process step (using epygram) to switch between grid point / spectral representation for humidity in EnJk
- Set-up of a complete C-LAEF Esuite with cy43t2 including adaption of script system
- New observations (GNSS, Mode-S, satellite data) were tested in C-LAEF EDA; several short Esuites with different sets of new observations were prepared and verified (see Figure 39)
- Investigation of 2m temperature and humidity problem in C-LAEF – development of a new 2m diagnostics with weights depending on the orography (Figure 40)
- C-LAEF SPP scheme was extended by additional perturbations in physics parametrizations (Figure 41, Table 2)
- Implementation of precipitation type code to the C-LAEF Esuite (Figure 42)

- Time lagged EPS out of AROME-RUC was created using neighborhood methods (see Figures 43 to 45)
- Development and operational production of EPS maps and EPSgrams with Visual weather for forecasters and customers (Figure 46)

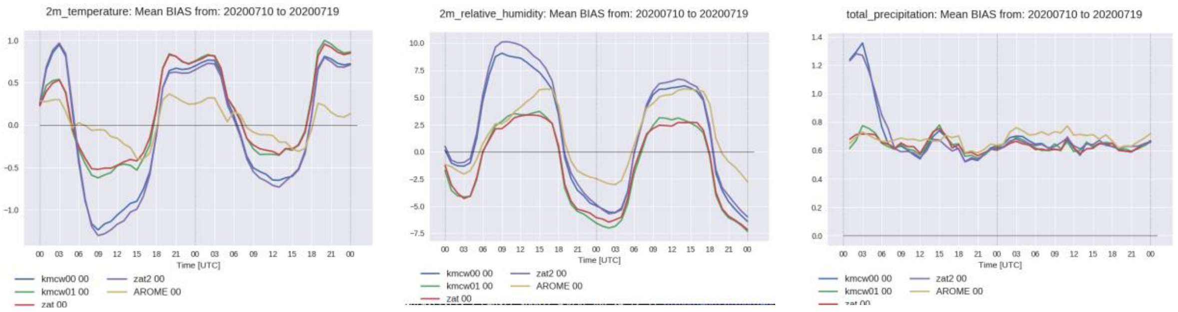

Figure 39: Verification of different sets of "new observations" for 1 week (July 10 – July 19, 2020).

The implementation of new observations to the assimilation in a C-LAEF Esuite resulted in a problem with 2m temperature and humidity during the day as the verification results show (Figure 39). There is also too much soil moisture, caused by a positive precipitation bias in the first forecast hours. The problem was identified to come from the variational bias correction for GNSS data. Adaptation time was set too long by default, which was already changed. Unfortunately, this could reduce the bias only slightly, there is still some problem when using GNSS data. Because of this it was decided not to use GNSS data operationally in C-LAEF at the moment. Mode-S and satellite data have a small, put positive impact on the scores in the first forecast hours (Figure 39).

A lot of work in 2020 was put to the identification of a screen level temperature problem in the operational C-LAEF forecasts during the night in Alpine valleys. Comparing the 2m temperature of the control run of C-LAEF with the operational deterministic AROME run revealed a strong positive temperature bias during clear nights in C-LAEF (see Figure 40). Several things were tested (exchange of orography, impact of soil, canopy scheme, etc.) and in the end it turned out that the setup of canopy levels is responsible for the differences. AROME and C-LAEF both use LCANOPY=.T. but due to unknown reason heights of canopy levels of our operational deterministic AROME are different from the default Canopy level setup which is used in C-LAEF. In AROME canopy lev=2 is slightly lower, thus CLS is colder (closer to surface) in AROME than in C-LAEF in such situations. Based in on these results, a modified 2m diagnostics for temperature and humidity has been developed which is weighting different canopy levels in dependence on the orography based on the openness (variation of the sky view factor). In Alpine valleys, where inversions are very likely during the night, lower canopy levels are weighted more than on slopes and at mountain peaks. With the new 2m diagnostics the 2m bias in C-LAEF is reduced significantly (Figure 40).

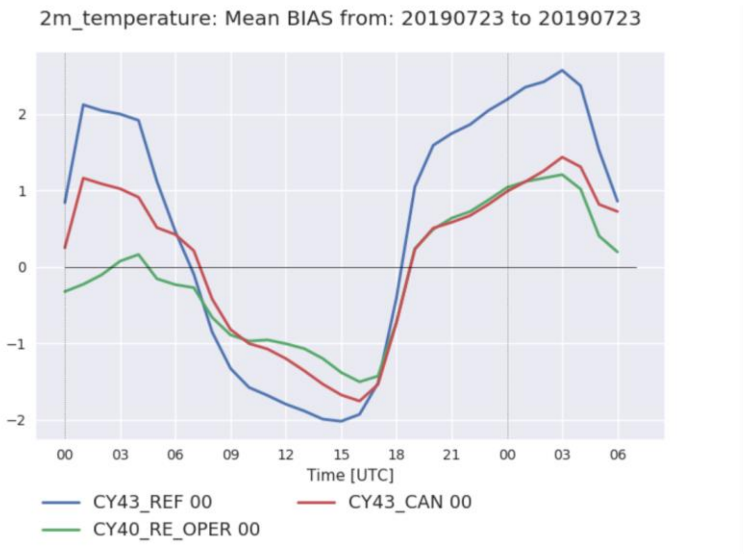

Figure 40: 2m temperature bias for stations in Alpine valleys for a test case on July 23 2020. With adaptations of the 2m diagnostics, the bias in C-LAEF is reduced significantly (from blue line to red line). The differences in the first 6 hours originate in different surface assimilation input.

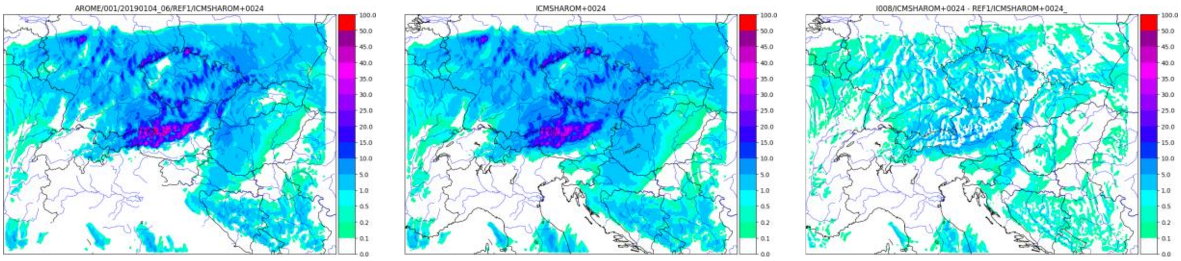

Figure 41: Sensitivity tests on sublimation of snow/graupel in wintertime in modified C-LAEF perturbation scheme (reference left, experiment with reduced sublimation middle, difference between EXP and REF right).

Some work has also been dedicated to the model error representation in C-LAEF. Model error in the operational C-LAEF version is currently represented by a hybrid stochastic perturbation scheme, where perturbations of tendencies in shallow convection, radiation and microphysics are combined with parameter perturbations in the turbulence scheme. To increase the physical consistency in the perturbation scheme, the SPP (stochastically perturbed parametrizations; Ollinaho et al., 2017) approach has been applied to the radiation, microphysics and shallow convection scheme in C-LAEF as well (Table 2). The perturbations are produced by the newly implemented SPG pattern generator (Tsyrulnikov and Gayfulin, 2017). Fist results are promising (e.g. Figure 41), but a lot of tuning considering the perturbation scale and range has to be made before final operationalization. It is also planned to add some more parameters (especially in microphysics) to the perturbation list.

Table 2: Key parameters and perturbation range for the stochastically perturbed parameters scheme (SPP) in the C-LAEF Esuite.

Perturbation	Description	Perturbs	Default mean value	Recommended range by physics experts
LPERT_PSIGQSAT	perturb saturation limit sensitivity	VSIGQSAT	changed from 0.02 to 0.03	0-0.06
LPERT_CLDDPTH	perturb threshold cloud thickness for stratocumulus/cumulus transition	RFRMIN(19)	2000	1000-4000
LPERT_CLDDPTHDP	perturb threshold cloud thickness used in shallow/deep convection decision	RFRMIN(20)	4000	1000-8000
LPERT_ICE_CLD_WGT	perturb cloud ice content impact on cloud thickness	RFRMIN(21)	1	0-2
LPERT_ICENU	perturb ice nuclei	RFRMIN(9)	1	0.1-10
LPERT_KGN_ACON	perturb Kogan autoconversion speed	RFRMIN(10)	10	2-50
LPERT_KGN_SBGR	perturb Kogan subgrid scale (cloud fraction) sensitivity	RFRMIN(11)	changed from 1 to 0.5	0.01-1 (bigger than 0 and less than 1)
LPERT_RADGR	perturb graupel impact on radiation	RADGR	changed from 0 to 0.5	0-1
LPERT_RADSN	perturb snow impact on radiation	RADSN	changed from 0 to 0.5	0-1
LPERT_RFAC_TWOC	perturb top entrainment	RFAC_TWO_COEF	2	0.5-3
LPERT_RZC_H	perturb stable conditions length scale	RZC_H	0.15	0.1-0.25
LPERT_RZL_INF	Asymptotic free atmospheric length scale	RZL_INF	100-	30-300

With the implementation of the new version of C-LAEF (cy43t2) in the Esuite at the ECMWF HPCF, also some new parameters have been included and tested. For example the precipitation type, which comprises 16 different types of precipitation (Figure 42). The new types such as rain, sleet, snow, drizzle, hail, etc. can be very helpful for warning issues in course of severe weather, especially in context of an ensemble prediction system where probabilities for the different types can be provided.

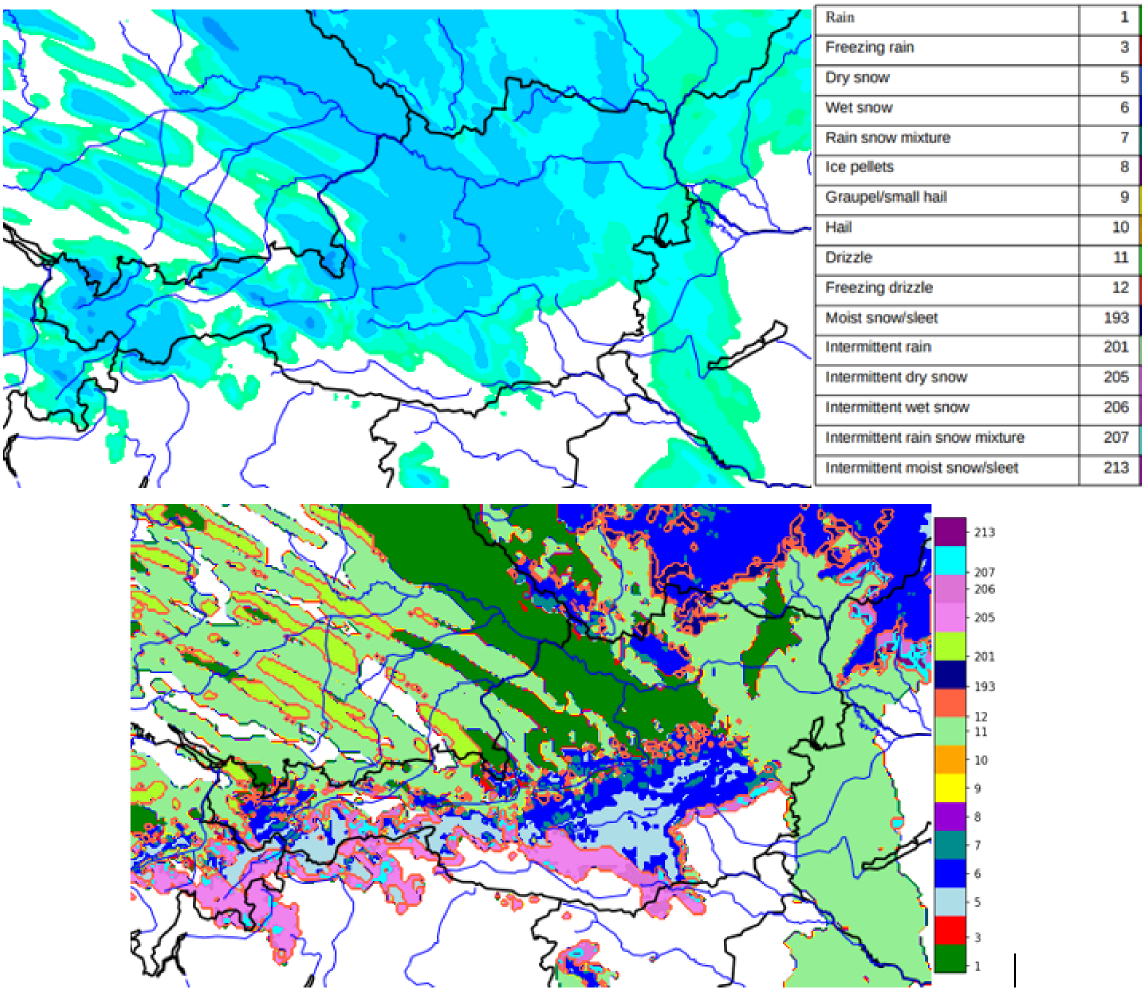

Figure 42: C-LAEF precipitation type forecast for a severe weather event on January 28 2021 in the operational version (upper) and in the cy43t2 Esuite (bottom).

Another work done in 2020 at ZAMG was the implementation of an AROME-RUC-PEPS system for precipitation. It runs regularly for selected INIT times of the AROME-

RUC, generating a lagged ensemble with 5 members (lag=0h, -1h, …, -4h), with forecast range up to +8h and output frequency of 15 minutes. AROME-RUC-PEPS visualization was implemented in Visual Weather (see Figures 43 to 45).

Post-processing of precipitation probabilities within AROME-RUC-PEPS:

- The calculation of upscaled probability fields was implemented
- Outputs being in grib (version 1) files that contain the calculated probability fields
- Probabilities for different thresholds and upscaled probabilities can be calculated for different search radius using different methods (maximum probability, mean probability, and further methods are subject of current work)
- The visualization of probability grib files has some technical issues in Visual Weather software

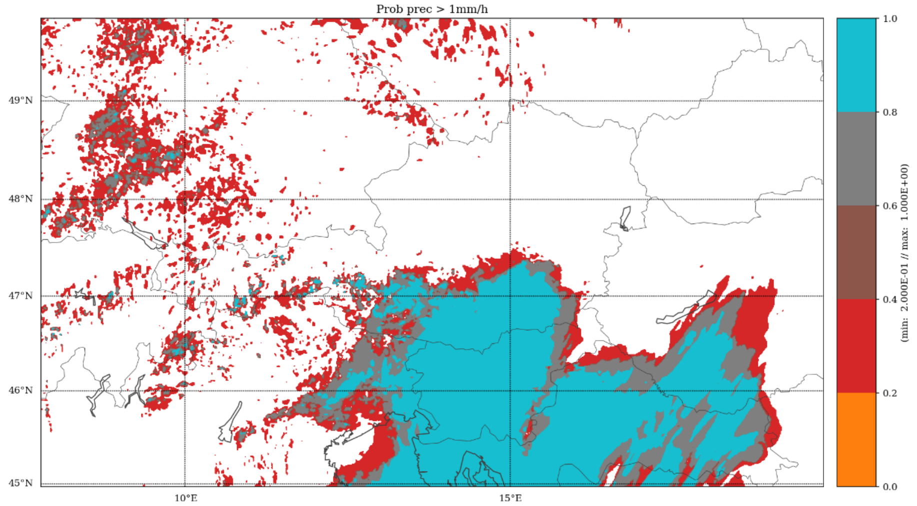

Figure 43: AROME-RUC-PEPS - the probability (grid-point wise).

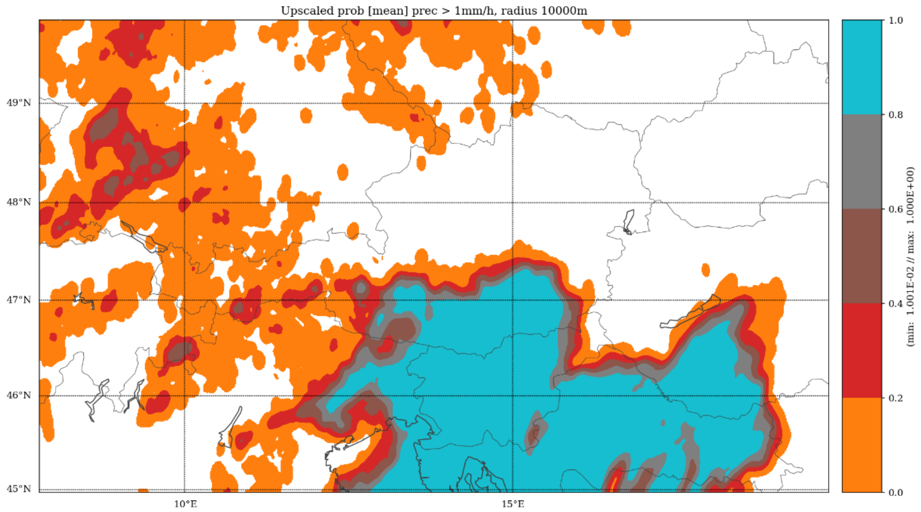

Figure 44: AROME-RUC-PEPS - upscaled probability (mean of all grid-points within 10 km radius).

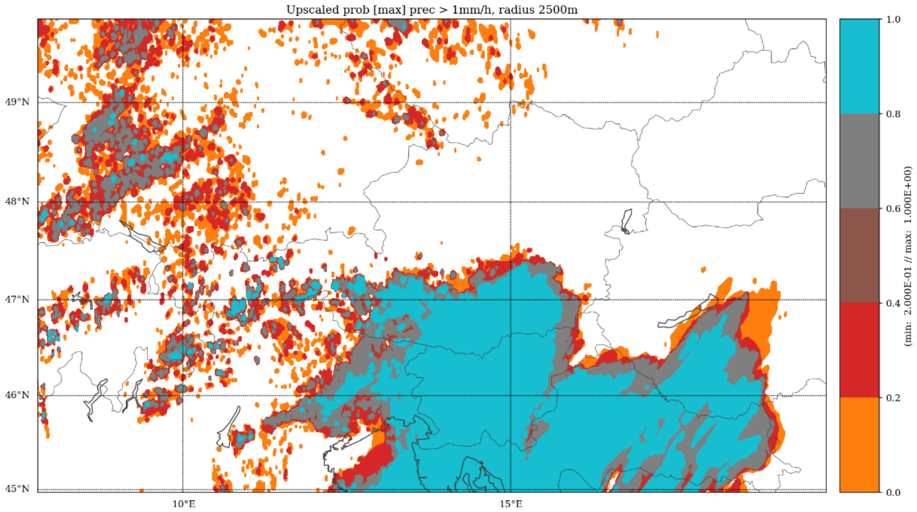

Figure 45: AROME-RUC-PEPS - upscaled probability (max of all grid-points within 2.5 km radius).

Strong focus on EPS related work at ZAMG in 2020 was put on the development and production of EPS maps and EPSgrams for forecasters and customers. In a close co-operation between model developers and forecasters needs and ideas were evaluated and specific probabilistic products and maps were developed. These products comprise classical probability maps such as probability of exceeding certain thresholds, extreme members, median, etc. but also EPSgrams for more than 250 points in the Alps (Figure 46). All these maps and EPSgrams are produced with the software Visual Weather. With the operational implementation of these EPS products, the acceptance and usage of C-LAEF within the routine work of the forecasters has significantly increased.

Ollinaho, P., Lock, S. J., Leutbecher, M., Bechtold, P., Beljaars, A., Bozza, A., Forbes, R. M., Haiden, T., Hogan, R. J. and Sandu, I. (2017). Towards process-level representation of model uncertainties: Stochastically perturbed parametrisations in the ECMWF ensemble. Quart. J. Roy. Meteor. Soc. 143, 408–422, https://doi.org/10.1002/qj.2931

Tsyrulnikov, M. and D. Gayfulin, 2017: A limited-area spatio-temporal stochastic pattern generator for simulation of uncertainties in ensemble applications, Meteorologische Zeitschrift 26(N 5), 549-566, DOI: 10.1127/metz/2017/0815.

Efforts: 19 PM

Contributors: Dávid Tajti, Katalin Jávorné-Radnóczi (all OMSZ), Christoph Wittmann, Clemens Wastl, Florian Weidle (all ZAMG)

Documentation: Reports on LACE stays; papers published in scientific journals; convection-permitting ensemble systems for operational use (ZAMG, OMSZ); EPS products and visualizations

Status: C-LAEF suite implementation operational under the time critical environment at ECMWF HPCF; C-LAEF Esuite running at ECMWF HPCF; AROME-EPS operationally running OMSZ

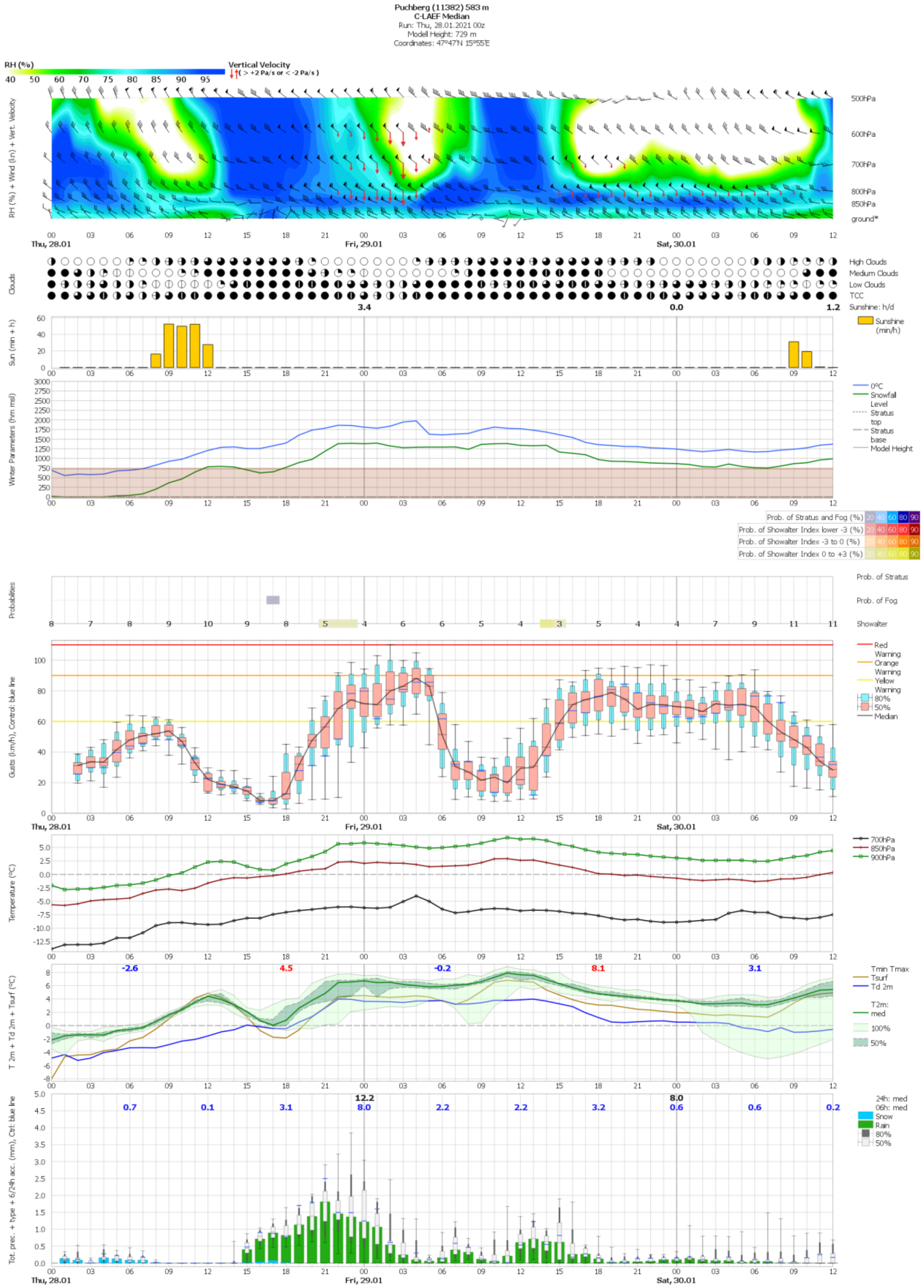

Figure 46: C-LAEF Epsgram for Puchberg in lower Austria on January 28 2021 produced with Visual Weather.

S4 Action/Subject/Deliverable: EPS - Verification

Description and objectives: A robust and reliable verification tool is needed in order to establish the quality and weaknesses of our probabilistic forecasting systems. The huge amount of data must be processed, which requires an appropriate, optimized and flexible verification software.

The LAEF verification tool has been developed, maintained and used already for several years. Since then, distinct versions of the source code have been created under the different users. These versions may diverge from each other and involve various levels of modifications and bug fixes. If we intend to use this verification tool further, it is necessary to merge the latest development under one common library and treat the known bugs equally. Unfortunately, such actions have been frozen since 2018. With the new area “Applications and Verification” starting in 2021, this topic might be restarted soon.

Another option is the HARP verification package, providing suitable tools for probabilistic and mesoscale forecast verification, with focus on spatial aspects as well. It was implemented at SHMU’s HPCF and tested on the operational A-LAEF grib files. The manipulation with big A-LAEF multi-gribs is very challenging and verification of a longer time period would require a lot of disk space and processing time. For the time being, just the very first results (more like a proof of concept) are available. One can see 10-days verification of 2m temperature against the Slovak OBS network in Figures 47 and 48.

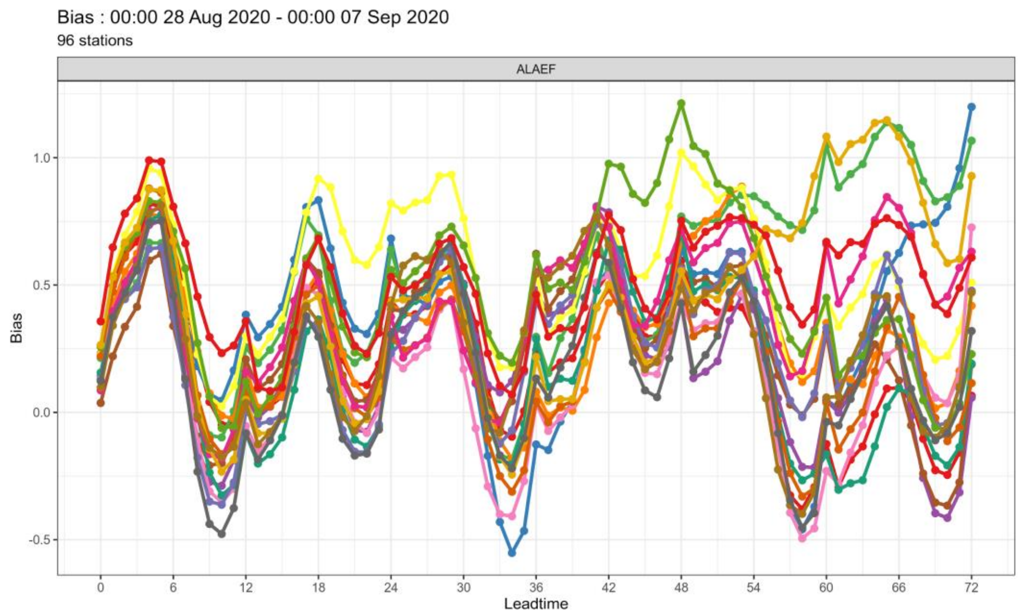

Figure 47: T2m BIAS of individual A-LAEF members for the verification period August 28 - September 7, 2020.

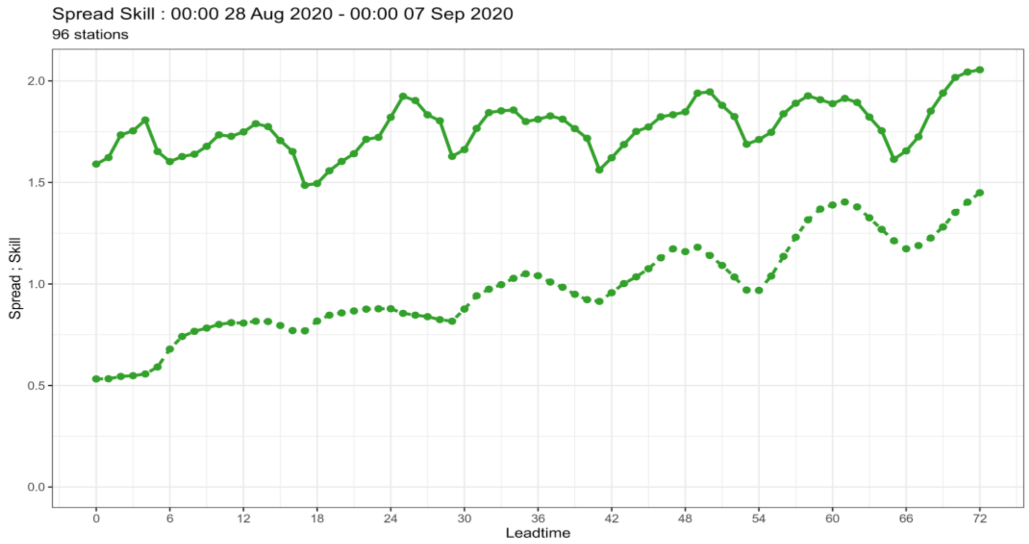

Figure 48: RMSE (solid line) and SPREAD (dashed line) of T2m A-LAEF ensemble mean for the verification period August 28 - September 7, 2020.

Also at OMSZ in Hungary and at ZAMG in Austria the R-based HARP 3 verification package was installed and tested. In Hungary, the adaptations of forecast output files and observations is work in progress. Forecasts are tried to read from GRIB, NetCDF, FA and vfld file format, searching for the best solution, while the local observations are handled in NetCDF format. At the moment a complete verification system for ensemble forecast is still missing at OMSZ (i.e., several tools for different measures are used).

In Austria the use of the verification package HARP is constantly increasing. Several tests of newly developed functionalities of HARP were performed with a special focus on the use of local, quality-controlled databases for observations and precipitation analysis fields originating from INCA and used for spatial verification.
HARP was finally set up to be used as the operational tool for CLAEF-verification. Several adaptions had to be implemented within different HARP functions to directly read from local grib-files. In addition, HARP was used for verifying several case-studies during the late development and early operational implementation phase of CLAEF. Visualization of verification results is based on the interactive application originating from HARPVis functionalities, as well as with standard R graphics functions.

IMGW in Poland is at the moment also starting to work with the HARP verification package.

Efforts: 3.5 PM

Contributors: Martin Petráš (SHMU), Dávid Tajti, Katalin Jávorné-Radnóczi (all OMSZ), Florian Weidle, Christoph Zingerle (all ZAMG)

Documentation: Local installations (SHMU, ZAMG, OMSZ, IMGW) and documentation of case studies with the HARP verification package

Status: Restored

S5 Action/Subject/Deliverable: Collaborations

Description and objectives: Activities merging different areas, collaboration with other consortia, applications, projects.

Except the standard cooperation between the ALADIN and HIRLAM communities and inter-area collaboration within RC LACE, there is almost nothing to report. An initiative regarding the special project at ECMWF with the aim of Limited Area Ensemble Forecasting has been started by DHMZ partner, involving researchers from SHMU, OMSZ and Meteo Romania. The request was approved by ECMWF (in January 2020), which gives us at least 5 mio SBUs to be spent in 2020 on R&D of the new A-LAEF system. Although, depending on the resource situation later in the year we might get additional 5 mio SBUs.

With the definition of the new ACCORD management group in early 2021 this topic might be renewed.

Efforts: 1 PM

Contributors: Martina Tudor (DHMZ), Martin Belluš (SHMU)

Documentation: Request for a special project 2020-2022; Exchange of the expertise between the other consortia and the new ACCORD consortium; contact with experts within the relevant projects

Status: Ongoing

S6 Action/Subject/Deliverable: Publications

Description and objectives: The scientific achievements of the LACE EPS R&D activities are being presented at the international workshops and published in the scientific journals.

2 papers were published in QJRMS, 1 paper in IDÖJARAS and one in Meteorologický časopis; due to not realized R&D stays there are no new reports available online via RC LACE portal; 1 doctoral thesis was defended;

The full list of recently submitted and published papers can be found in the Documents and publications chapter.

Efforts: 2.5 PM

Contributors: Yong Wang, Florian Weidle, Christoph Wittmann, Florian Meier, Clemens Wastl, Christoph Zingerle (all ZAMG), Endi Keresturi, Iris Odak Plenković, Martina Tudor (all DHMZ), Martin Belluš (SHMU)

Documentation: Reviewed papers

Status: In progress

List of actions, deliverables including status

S1 Subject: Optimization of A-LAEF

Deliverables: Reports on LACE stays; papers submitted to scientific journals; improvement of current regional ensemble system through the results and outcomes of R&D

Status: Ongoing

S2 Subject: A-LAEF maintenance

Deliverables: A-LAEF operational suite running at ECMWF HPCF; probabilistic forecast products delivered to the LACE partners; Flow charts; presentations; reports; technical documentation of A-LAEF TC2 suite running at ECMWF

Status: Development and upgrade of ecFlow scripts; A-LAEF suite implementation under the time critical environment at ECMWF HPCF; maintenance tasks

S3 Subject: AROME-EPS

Deliverables: Reports on LACE stays; papers published in scientific journals; convection-permitting ensemble systems for operational use (ZAMG, OMSZ); EPS products and visualizations

Status: C-LAEF suite implementation operational under the time critical environment at ECMWF HPCF; C-LAEF Esuite running at ECMWF HPCF; AROME-EPS operationally running OMSZ

S4 Subject: EPS - Verification

Deliverables: Local installations (SHMU, ZAMG, OMSZ, IMGW) and documentation of case studies with the HARP verification package

Status: Restored

S5 Subject: Collaborations

Deliverables: Request for a special project 2020-2022; Exchange of the expertise between the other consortia and the new ACCORD consortium; contact with experts within the relevant projects

Status: Ongoing

S6 Subject: Publications

Deliverables: 2 papers were published in QJRMS, 1 paper in IDÖJARAS and one in Meteorologický časopis; due to not realized R&D stays there are no new reports available online via RC LACE portal; 1 doctoral thesis was defended; for more details please see the list of publications down below

Status: In progress

Documents and publications

Published papers:

- ❑ Belluš M., 2020: New high-resolution ensemble forecasting system A-LAEF. Meteorologický časopis, 23 (2), pp. 75-86, ISSN 1335-339X (in Slovak)
- ❑ Plenković, I. O., I. Schicker, M. Dabernig, K. Horvath, E. Keresturi, 2020: Analog-based post-processing of the ALADIN-LAEF ensemble predictions in complex terrain, Quarterly Journal of the Royal Meteorological Society, 146: 1842– 1860, https://doi.org/10.1002/qj.3769
- ❑ Taşcu S., M. Pietrişi, C. Wittmann, F. Weidle and Y. Wang, 2020: Forecast skill of regional ensemble system compared to the higher resolution deterministic model. IDŐJÁRÁS / Quaterly Journal of the Hungarian Meteorological Service, 124 (3). pp. 401-418. ISSN 0324-6329
- ❑ Wastl C., Y. Wang, A. Atencia, F. Weidle, C. Wittmann, C. Zingerle, E. Keresturi, 2021: C-LAEF: Convection-permitting Limited-Area Ensemble Forecasting system. Quarterly Journal of the Royal Meteorological Society, 147: 1431-1451, https://doi.org/10.1002/qj.3986

Submitted papers: -

Iris Odak Plenković successfully defended her doctoral thesis “Wind speed prediction using the analog method over complex topography” in July, at the Faculty of Science, Department of Geophysics, University of Zagreb.

Endi Keresturi successfully defended his doctoral thesis “Initial condition perturbations in a convective scale ensemble prediction system” in February 2021, at the University of Zagreb

Activities of management, coordination and communication

- ❑ 34th LSC Meeting, 11-12 March 2020 (*online*)
- ❑ 35th LSC Meeting, 16-17 September 2020 (*online*)
- ❑ Joint 30th ALADIN Workshop & HIRLAM All Staff Meeting 2020, 30 March - 2 April 2020 (*online*), LACE EPS activities presented by Martin Belluš
- ❑ 42nd EWGLAM and 27th SRNWP Workshop, 28 September – 1 October 2020 (online), by Martina Tudor

LACE supported stays – 0 PM in 2020

Unfortunately, due to the first and second waves of COVID-19 disease, there were no research stays organized this year.

Summary of resources [PM] – 2020

Subject	Manpower		LACE		ALADIN	
	plan	realized	plan	realized	plan	realized
S1: Optimization of A-LAEF	11	4.5	1+2*			
S2: A-LAEF maintenance	4	6.5	1*			
S3: AROME-EPS	20	19	1	0		
S4: EPS – Verification	1.5	3.5	1*	0		
S5: Collaborations	2	1				
S6: Publications	6	2.5				
Total:	44.5	37	2+4*	0	0	0