Working Area Predictability

# Progress Report

**Prepared by:** Area Leader Martin Belluš
**Period**: 2019
**Date**: March 2020

## Progress summary

Since the beginning of 2019 huge effort was put into the preparation of new operational ensembles. We have currently three independent systems, the common RC LACE EPS with 4.8 km horizontal resolution based on ALARO-1 physics running on a big European domain (A-LAEF), Austrian convection-permitting EPS with 2.5 km horizontal resolution utilizing AROME model on a middle European domain (C-LAEF) and similar convection-permitting EPS configuration in Hungary.

There were only 3 regular RC LACE stays realized in 2019, with the total length of 3 months. Iris Odak Plenković (DHMZ) spent twice 4 weeks at ZAMG (Q1 and Q4) in continuation on her work on the analog-based post-processing method for the high resolution wind field, this time using already probabilistic analog inputs from LAEF ensemble as well. Endi Keresturi spent 4 weeks also at ZAMG combining lagged deterministic AROME forecasts with the new C-LAEF system in order to increase its reliability.

There were several other RC LACE stays planned for 2019, but must have been postponed for different reasons. Nevertheless, a lot of technical and validation work was done locally within A-LAEF development at SHMU, C-LAEF development at ZAMG and AROME-EPS at OMSZ.

## 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: Implementation and testing of A-LAEF under TC user**

The development of common RC LACE regional ensemble system A-LAEF (ALARO - Limited Area Ensemble Forecasting) was executed at SHMU. The implementation under the LACE's TC user at ECMWF HPCF was performed remotely. Several technical issues must have been tackled in the early stage and also later on since the end of July, when the regular runs of A-LAEF started.

- **DFI instability**

Along with more runs performed within the regular suite updates, it happened occasionally that one or more members of the ensemble crashed in blending task while processing the ECMWF coupling file. When this happened, it was always within the DFI integration in low spectral resolution, which is a part of complicated spectral blending procedure. It was recognized as an instability due to longer time steps used in low spectral resolution. The solution was to ignore the theoretically possible but practically not applicable long time steps. In reality, when this problem occurred, we always decreased RTDFI (time step for DFI), TAUS (filter time span) and increased NSTDFI (number of steps within filtration) consistently with the theory. This was an iterative procedure. In principle, we gradually tried available configurations with shorter and shorter timesteps till the job was successfully done. The procedure was repeated when this happened again after several days. Eventually, we ended up with a stable configuration, which is already running since then without a single crash (RTDFI=480s, TAUS=14400s, NSTDFI=11).

- **systematic cold bias**

Generally, there is a big discrepancy between the IFS soil/surface moisture fields and those of ARPEGE/ALADIN (see figure 2, 3 - first and last column) as well as for the corresponding temperature fields (see figure 4 - first and last column). Since the cold start of new A-LAEF was carried out from the IFS ENS boundary conditions, the soil moisture and surface moisture were initially too large and hence the surface temperature cold bias was developed within the several integration hours. This undesirable effect should be normally progressively reduced by the assimilation of RH2m (already after several assimilation loops, see figures 2, 3 and 4). Unfortunately, by coincidence the new ALARO-1 integration namelists within the upgraded multiphysics configuration were missing some non-standard surface fields:

➢ SURFXFLU.MEVAP.E - instantaneous evaporation flux

➢ SURFXEVAPOTRANSP - instantaneous evapotranspiration

➢ ATMONEBUL.BASSE - cumulated low cloud cover

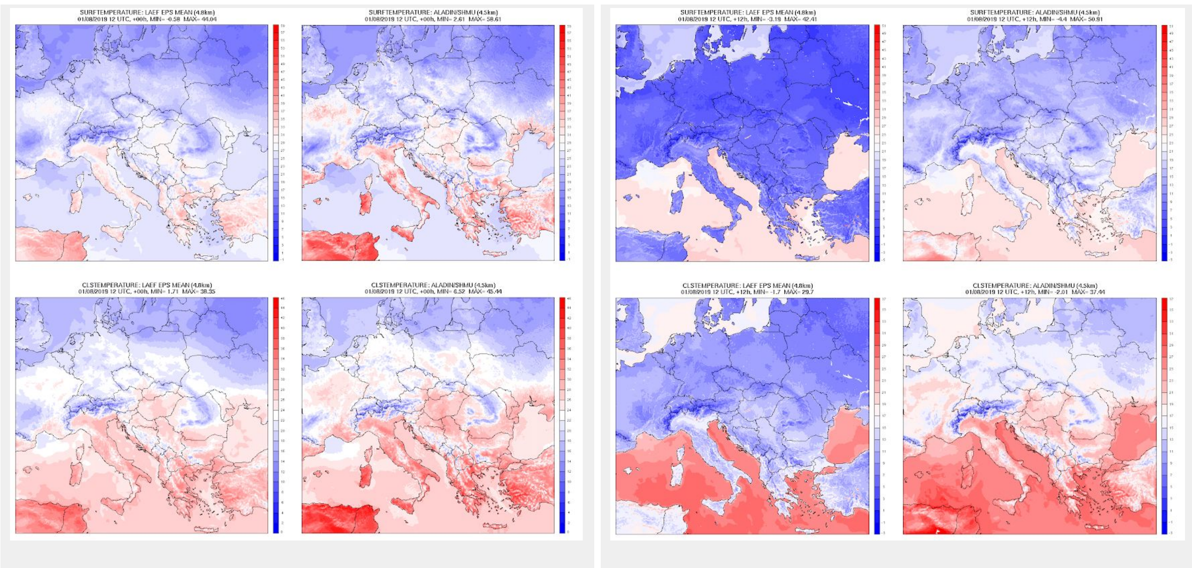

*Figure 1: The surface (top) and screen level (bottom) temperature for A-LAEF ensemble mean (left) and ALADIN/SHMU reference coupled to ARPEGE model (right). Left panel is the analysis, right panel is 12h forecast.*

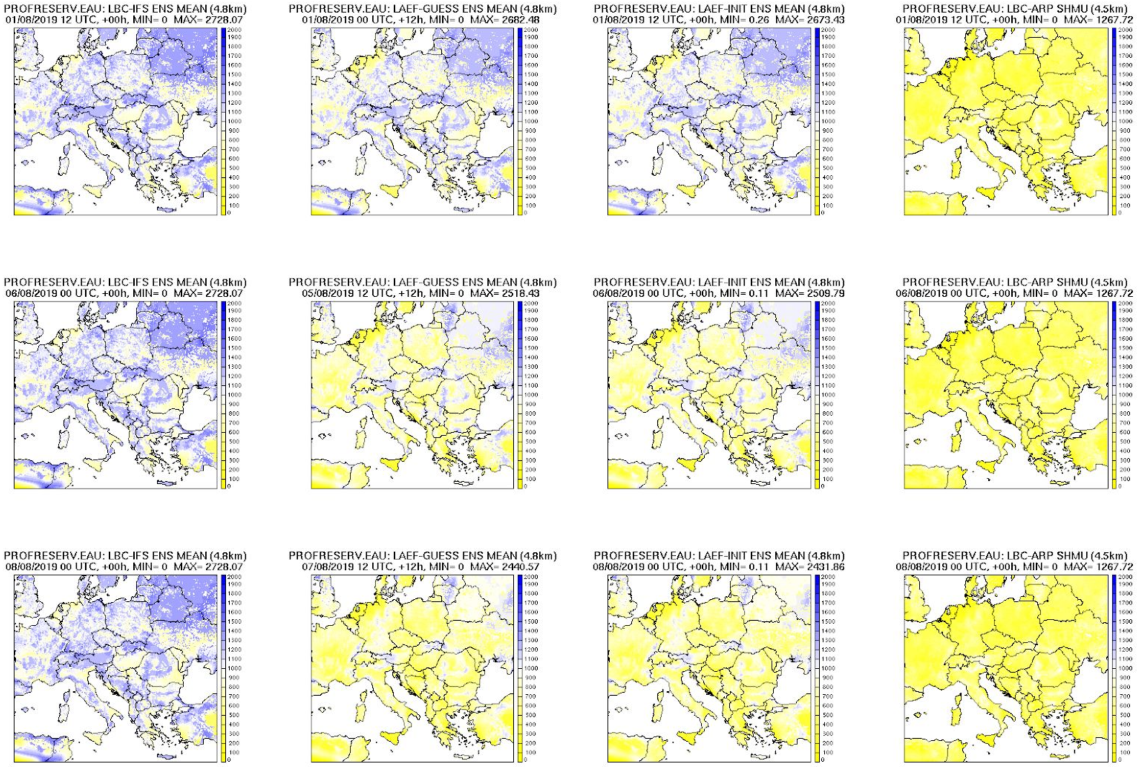


*Figure 2: From left to right: the soil moisture for IFS - ENS mean (LBC), A-LAEF (first guess +12h), A-LAEF analysis (INIT file) and ALADIN/SHMU LBC (ARPEGE model reference). From top to bottom: beginning of the assimilation cycle, fields after the 6 and 10 assimilation loops, respectively.*

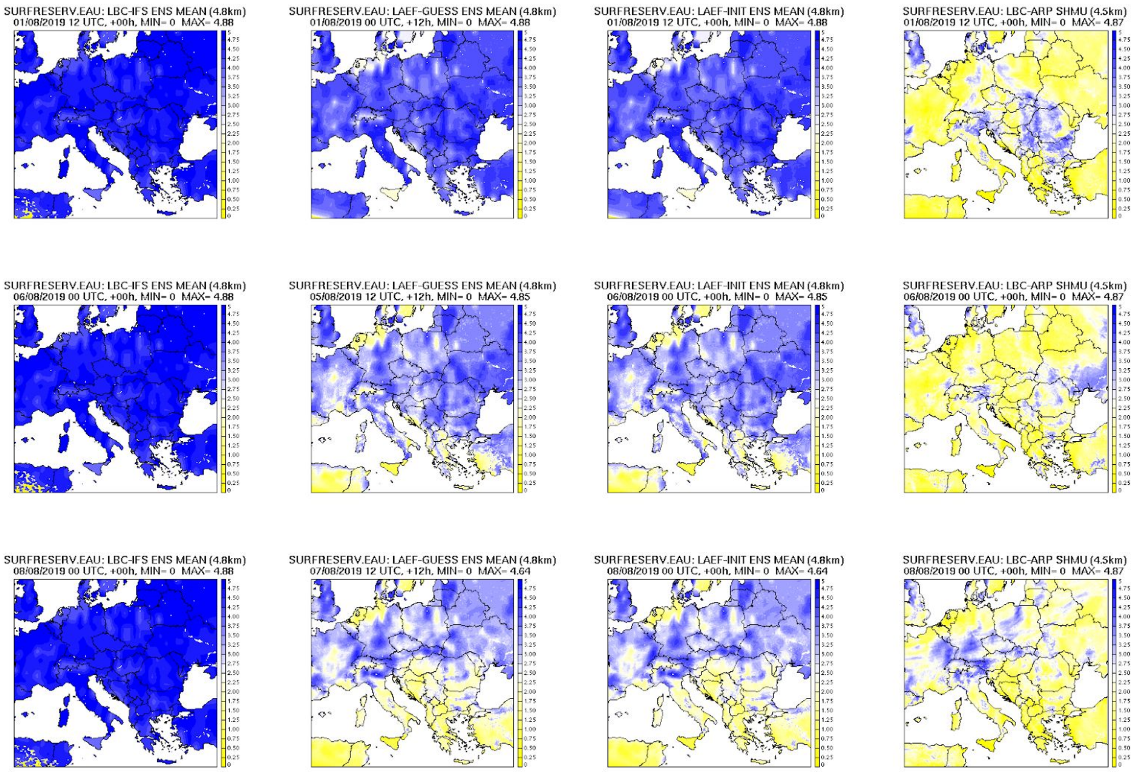


*Figure 3: Exactly the same as in figure 1 but this time for the surface moisture.*

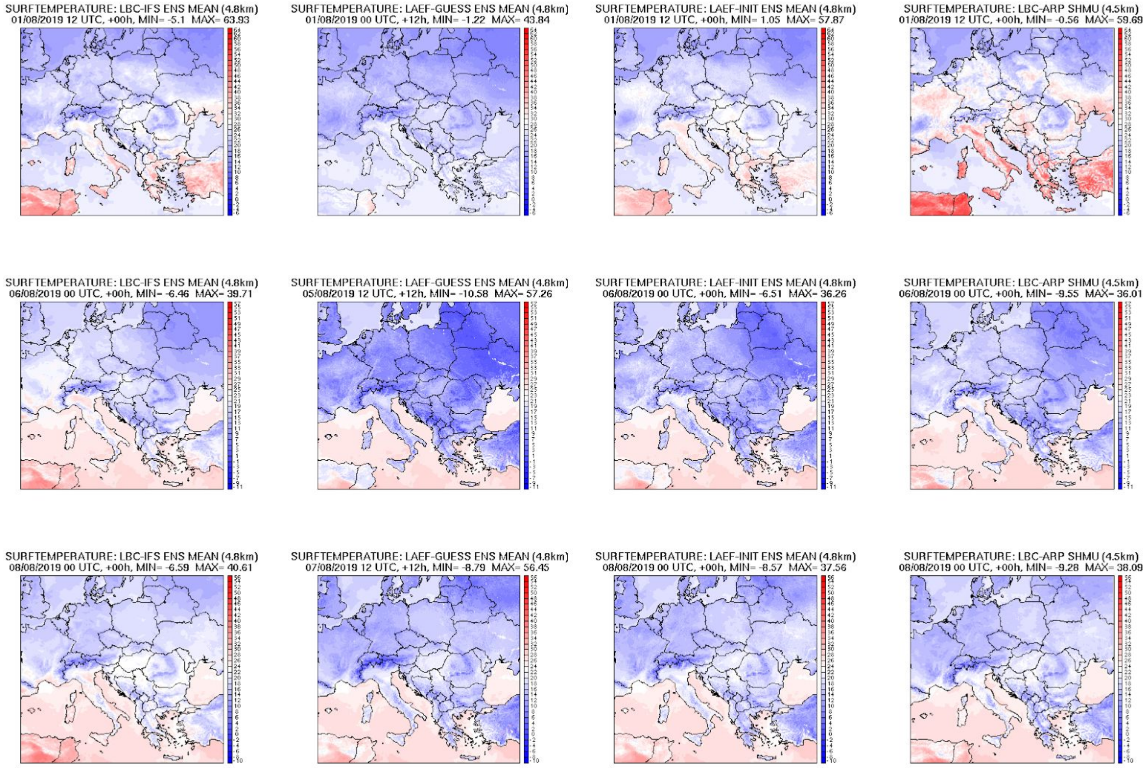

*Figure 4: From left to right: the surface temperature for IFS - ENS mean (LBC), A-LAEF (first guess +12h), A-LAEF analysis (INIT file) and ALADIN/SHMU LBC (ARPEGE model reference). From top to bottom: beginning of the assimilation cycle, fields after the 6 and 10 assimilation loops, respectively.*

As a result the moisture increments in CANARI assimilation procedure were forced to zero. Obviously, that had the fatal consequences in given coupling configuration. Such potentially dangerous behavior of surface assimilation, where the optimum coefficients for soil moisture analysis are modulated or switched off depending on the presence of several meteorological fields like precipitation, cloudiness, surface evaporation, etc. was already discovered in 2013 (see Belluš, "Time Consistent versus Space Consistent coupling and the revision of the Ensemble of surface Data Assimilations by CANARI in ALADIN/LAEF", Report on stay at ZAMG). Nevertheless, this issue was reintroduced again with its full "potential" (see figures 1) until we reinvented the solution (see figures 2, 3 and 4 - bottom row).

- **coupling**

The A-LAEF system is coupled to the global ECMWF EPS. The perturbed lateral boundary conditions are retrieved from the first 16 ENS members with a coupling frequency of 6h to account for the uncertainties at the domain boundaries. However, it is technically not a trivial task to prepare LBC files from ECMWF global gribs. We aimed for the processing of global data on native cubic octahedral grid, since we didn't want to follow the old path which require downscaling and several spatial interpolations. Therefore, new 903 configuration was implemented (cy46). The input global ECMWF gribs were retrieved from MARS database during the testing period. That worked nicely, but it is not meant for the operational applications. The switch for ECPDS stream was planned since October, but it turned out that two of 52 input parameters were not available in current ECPDS dissemination management (logarithm of surface roughness length for heat - param 234 and standard deviation of filtered subgrid orography - param 74). All those fields are mandatory for the initialization of the IFS model in configuration 903.

It was promised that the refactored ECPDS management tool will contain missing parameters 234 and 74 at the beginning of 2020. It does, however it introduced another issue when A-LAEF precipitation forecasts were suddenly deteriorated (see figure 5). Quick investigation revealed that the specific humidity at the model levels wasn't correct in the ECPDS local dissemination stream (see figure 6). That led to the moisture deficit in the atmosphere and reduced or missing precipitation. Fortunately, the surface assimilation cycle wasn't affected by this error (see figure 7).

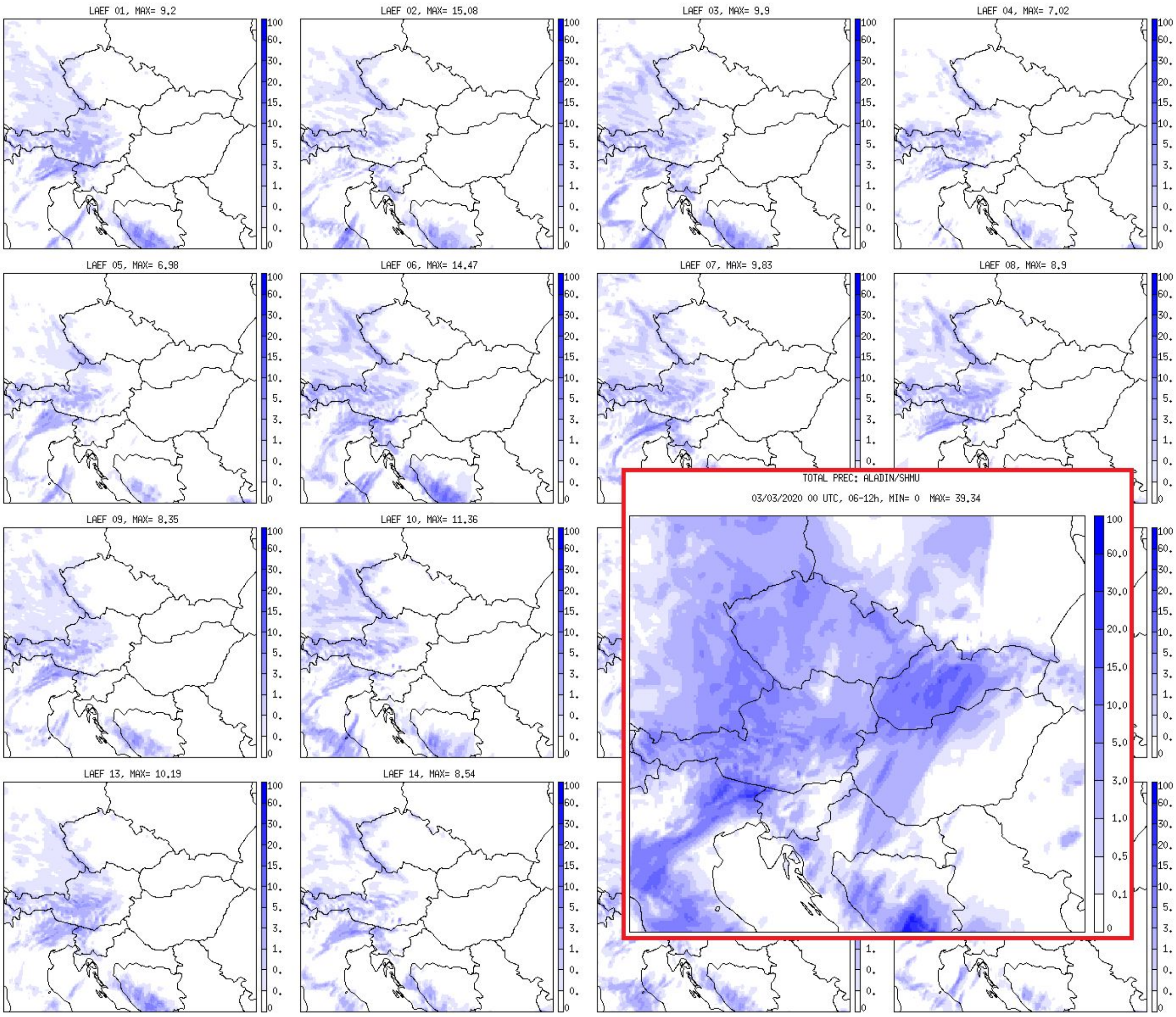


*Figure 5: 6-hourly accumulated precipitation forecast for A-LAEF ensemble members and the same for ALADIN/SHMU deterministic model. There was rain in reality over Slovakia.*

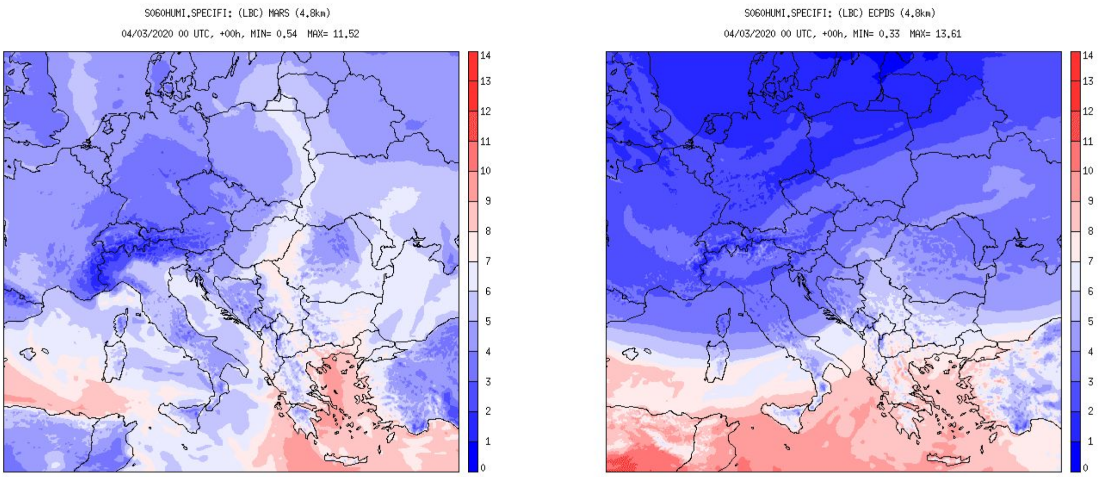


*Figure 6: Specific humidity at the lowest model level in LBCs obtained from MARS input fields (left) and ECPDS (right).*

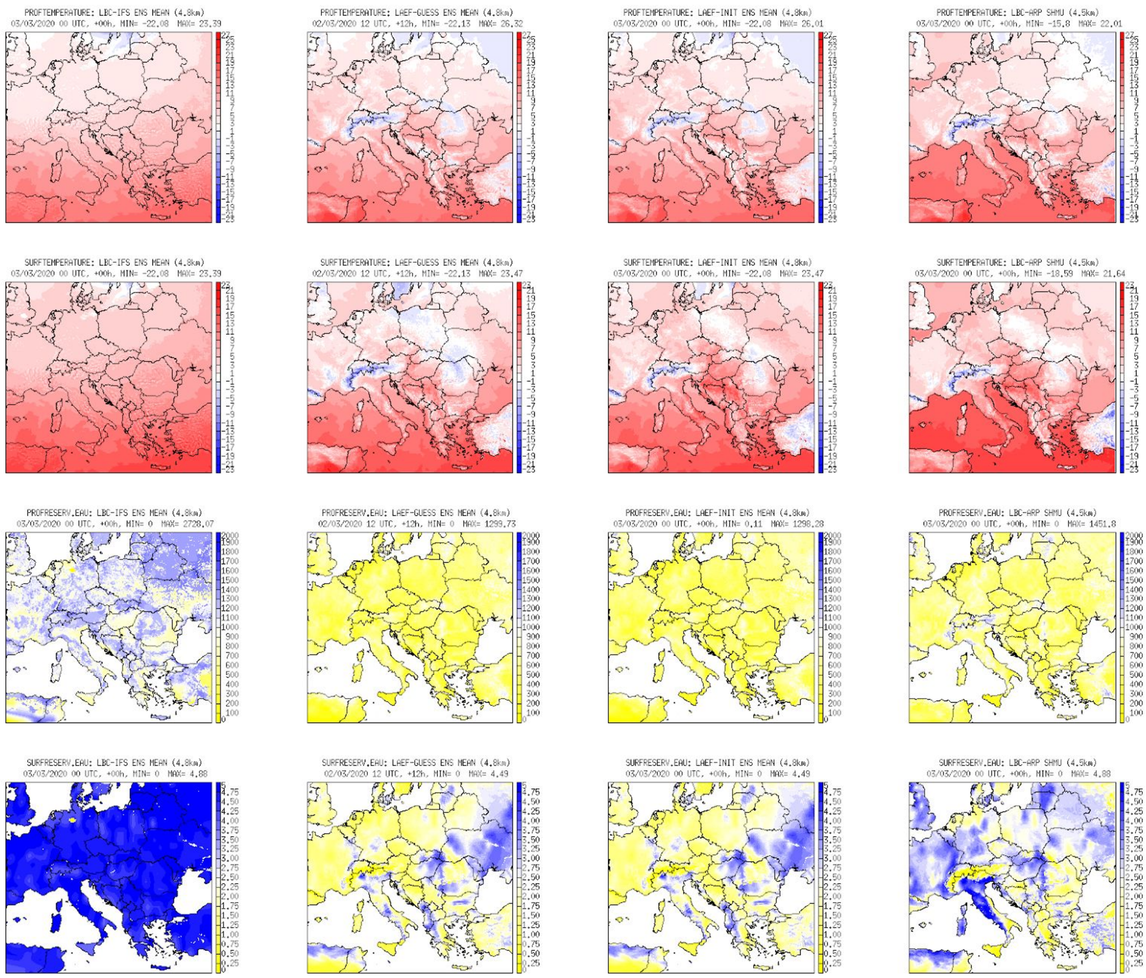

*Figure 7: Soil and surface temperature (first 2 rows) and moisture (last 2 rows). From left to right: IFS - ENS mean (LBC), A-LAEF mean (first guess +12h), A-LAEF mean analysis (INIT file) and ALADIN/SHMU LBC (ARPEGE model reference).*

The problem was solved shortly after reporting it to the ECMWF (see figure 8). The issue was related to the accuracy of disseminated fields in ECPDS stream where 12 bits per value was used instead of 16. Since the specific humidity is coded like very small numbers [kg/kg], it was affected the most and with fatal consequences.

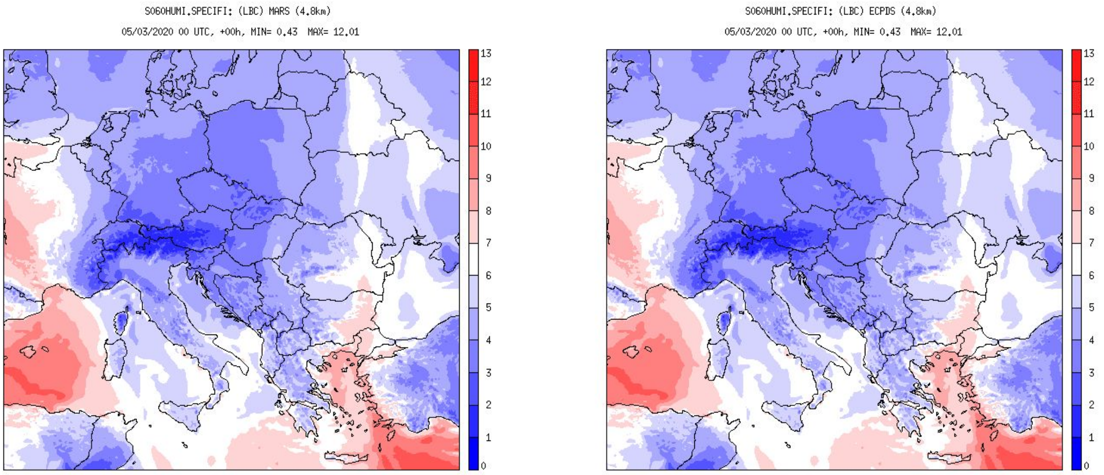


*Figure 8: Specific humidity at the lowest model level in LBCs obtained from MARS input fields (left) and ECPDS (right) after the correction of accuracy in disseminated fields.*

- **Topic 2: A-LAEF preoperational runs (case studies)**

After intensive validation of the assimilation cycle in A-LAEF and solving the issues concerning the RH2m increments and therefore solving the cold bias problem, it was finally time for some case studies.

- **Turkey - Flash floods of 17 August 2019**

Heavy rainfall affected several districts of Istanbul (particularly Fatih, Kartal and Bakirkoy) on 17 August causing widespread flash floods. According to media reports, one person died in Fatih District, some houses have been damaged and several streets were flooded leading to significant transport disruptions. Despite unpleasant consequences, this mesoscale convective system was a good case for testing the skills of new A-LAEF system. In the following figures one can see the global synoptic analysis of the situation by MetOffice (figure 9, left), MSG satellite image (figure 9, right) and corresponding A-LAEF forecast (figure 10).

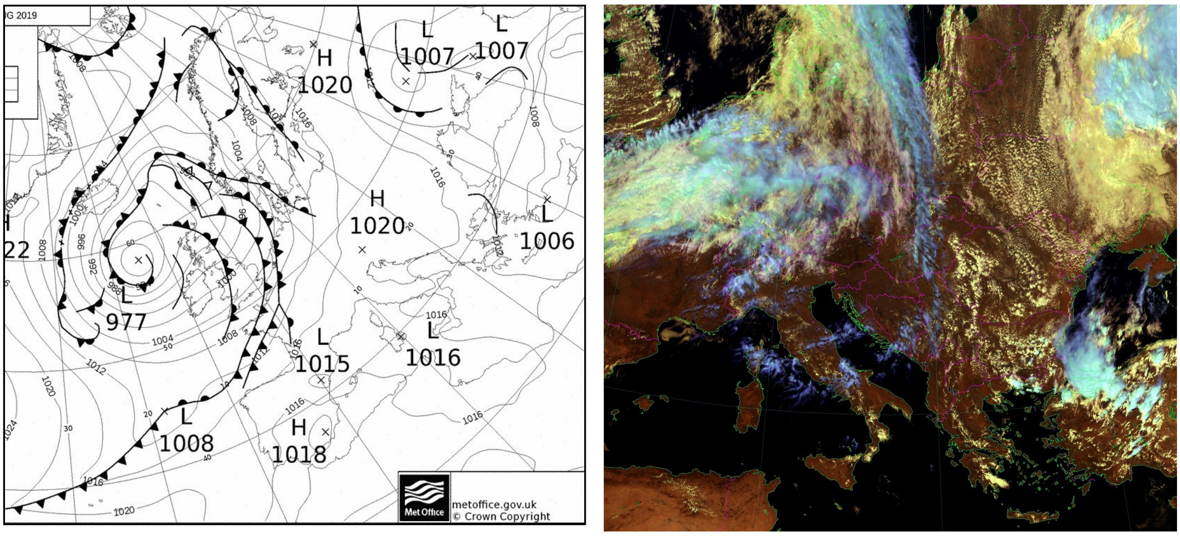


*Figure 9: Synoptic analysis chart by MetOffice from August 17, valid at 6 UTC (left) and MSG satellite image from August 17, 12 UTC (right).*

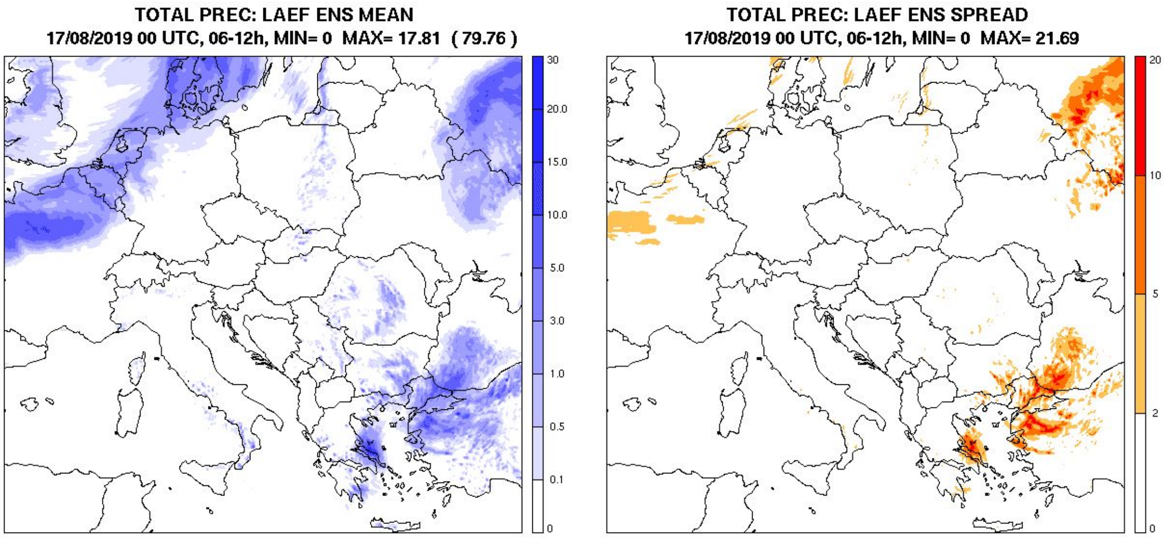


*Figure 10: A-LAEF total precipitation forecast for August 17, 6-12 UTC represented by the ensemble mean (left) and ensemble spread (right).*

It is clear, that the ensemble mean and spread of total precipitation very well correspond to the flash flood event over Istanbul. The importance of a probabilistic forecast in such situations is nicely demonstrated by figure 11, where all 16 perturbed A-LAEF members are shown. While the large-scale frontal precipitation over the north-westerly Europe is captured without any doubts by each member (high predictability), the convective mesoscale system over Istanbul is well predicted only by several members. There are also some members where the event is completely missing (low predictability). If one of those was the only deterministic forecast, the extreme weather event could have been missed.

Furthermore, a beautiful demonstration of new ALARO-1 physics capability can be seen in figure 12, where the A-LAEF ensemble mean of total cloudiness for August 17, 12 UTC is compared to the corresponding MSG image. It is beyond the expectations, how closely the different cloud types and patterns match to each other for this 12h forecast and reality!

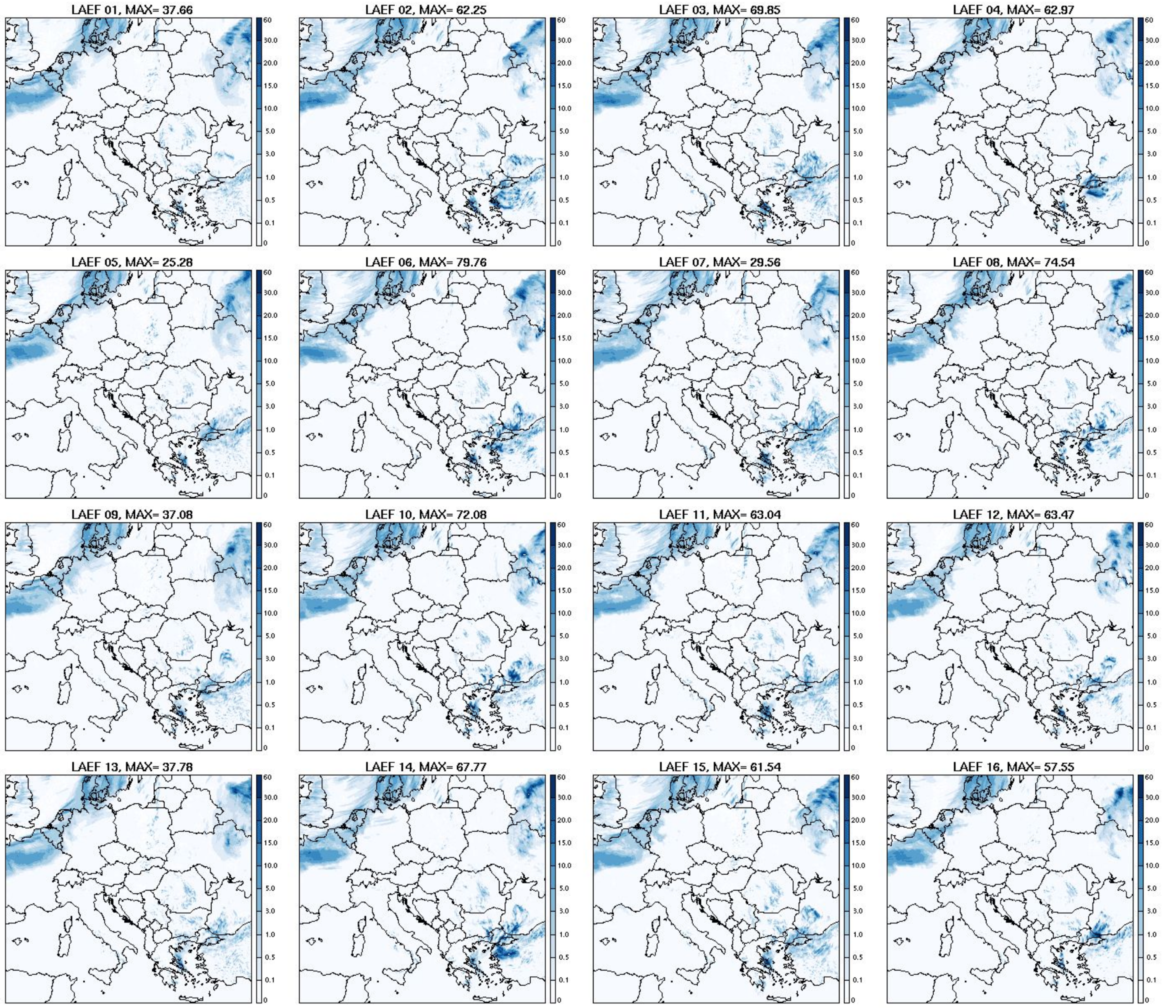


*Figure 11: All 16 perturbed A-LAEF members and their total precipitation forecast for August 17, 6-12 UTC.*

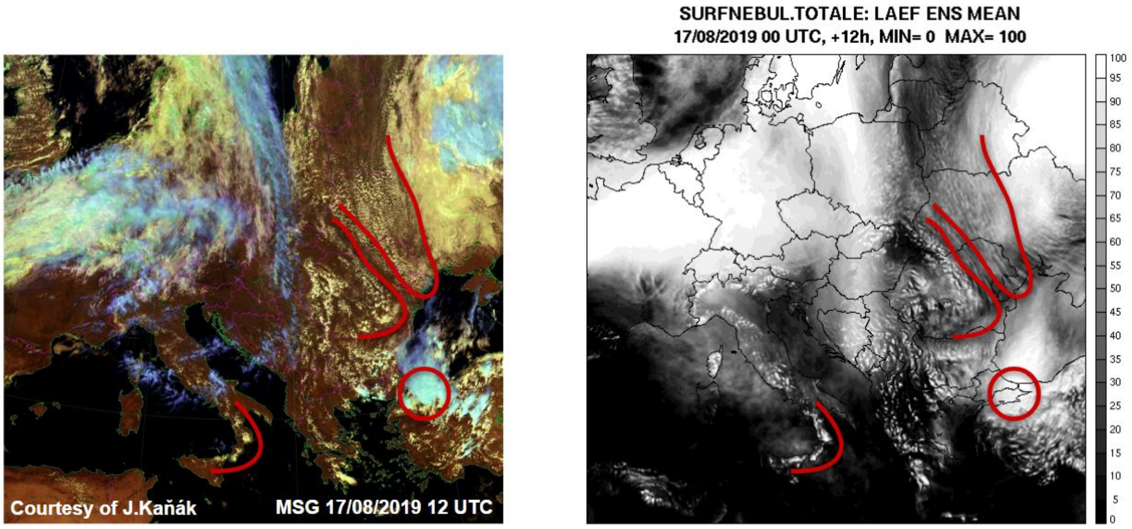


*Figure 12: A-LAEF total cloudiness ensemble mean 12h forecast valid on August 17, 12 UTC (right) and corresponding MSG satellite image (left).*

- **Central Europe - Night storm of 24 August 2019**

Another nice example of A-LAEF capabilities is being the night storm event which happened on August 24 over Central Europe, especially in Bratislava. During the night hours the southwestern part of Slovakia was hit by strong thunderstorms. The total number of lightning strikes was about 15,000 with about 15 to 50 millimeters of rainfall. Several thunderbolts also hit the 30-meters flagpole, which had been erected in front of Parliament by Andrej Danko, President of the Slovak Parliament (see embedded photo).

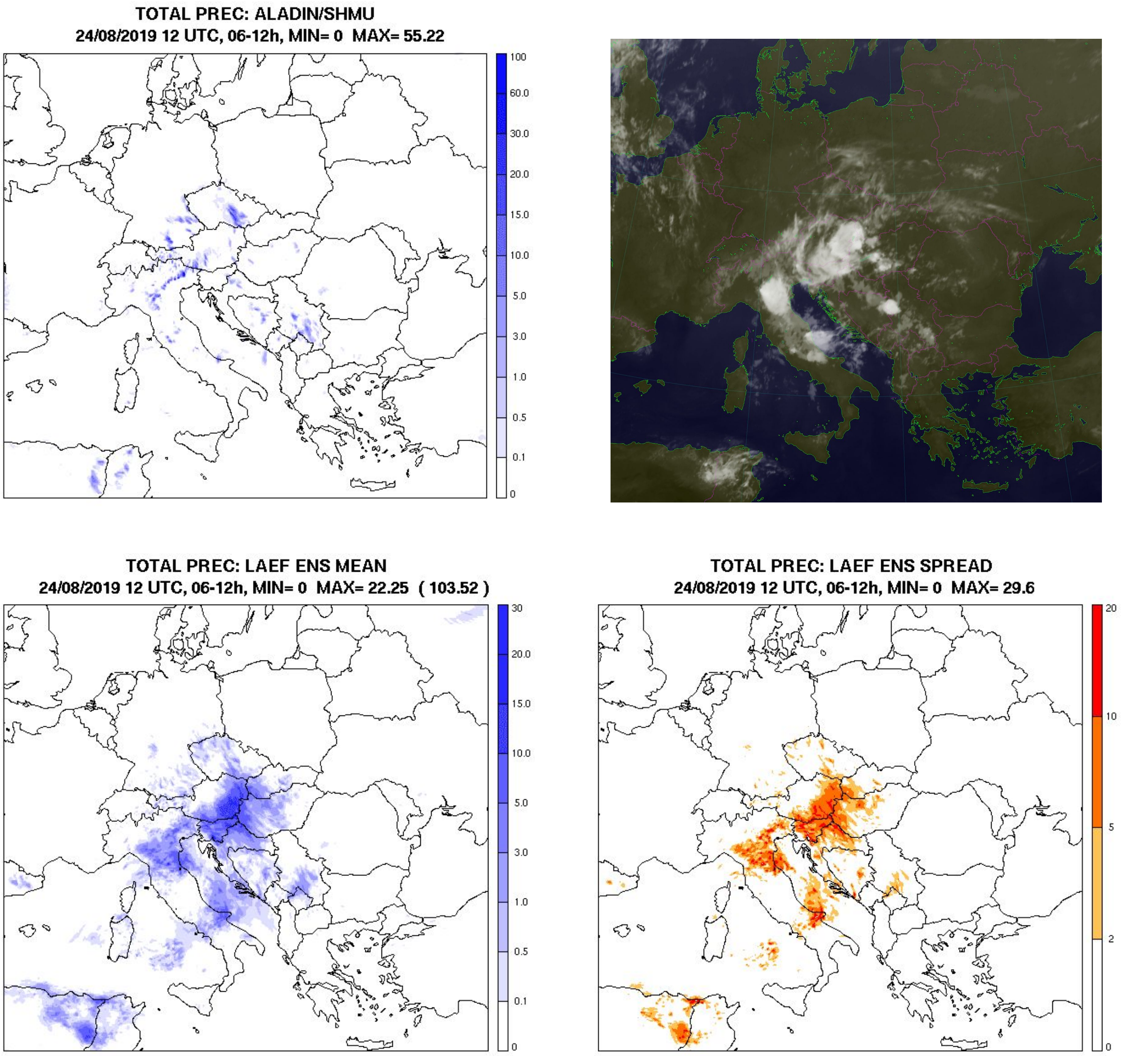


*Figure 13: Total precipitation - deterministic forecast of ALADIN/SHMU 4.5 km (top left), A-LAEF 4.8 km ensemble mean (bottom left) and spread (bottom right) and corresponding infrared MSG image (top right).*

*Thunderbolt strikes the flagpole near Bratislava castle. (photo by Adam Kováč, 2019.08.24/25)*

Although, the deterministic ALADIN/SHMU forecast from August 24, 12 UTC was completely missing this convective precipitation event during the night hours, A-LAEF ensemble for the same network time captured the case nicely (see figure 13).

- **Topic 3: Analog-based post-processing method (continuation work)**

Iris worked on the analog-based post-processing method applied to a NWP model output for point forecasts. It is the continuation of work carried out during the two previous stays at ZAMG, where the basic algorithm in Python was written and the usability of the analog method was investigated for Austria territory. The method was already tested using the AROME deterministic model for 2015-2017 period and corresponding observations from local 265 TAWES sites.

The analog-based method uses historical data within the specified training period for which both the NWP model and the verifying observation are available. The analog-based method uses one consistent grid-point, which is usually the closest one to the measurement site. The best-matching historical forecasts to the current prediction (analogs) may originate in any past date within the training period. The quality of the analog is evaluated by the predefined metric. Analogs are found independently for every forecast time and location, narrowing the search within particular time of the day by a time window. The verifying observations of the best-matching analogs are then the members of the analog ensemble.

Now, two different modifications to the analog-based post-processing method were tested:

- Firstly, for the **deterministic analog forecast**, the time window to search the analogs was extended and the results for modified analog-based post-processing method were compared against previously developed analog-based post-processing method and against AROME deterministic model forecasts. The time window for analog search can be now shifted maintaining the same width. This has shown some potential, however the improvement over the former method is not statistically significant.

- Secondly, for the **probabilistic analog forecast**, several different configurations of LAEF ensemble forecast have been used as input and tested (see figures 14 and 15). These were the LAEF wind speed ensemble forecast used as 17 predictors (AN_Ws); ensemble means of LAEF forecast for wind speed, wind direction, 2m temperature, 2m relative humidity, MSLP and precipitation used as 6 predictors (AN_Me); the same as previous but with additional ensemble spreads used as 12 predictors (AN_St); all LAEF members for the wind speed, wind direction, 2m temperature, 2m relative humidity, MSLP and precipitation counting 6×17 predictors (AN_Al); and finally the most demanding member-by-member approach where 6 predictors were used, but the search algorithm was applied 17 times for each forecast (AN_11). The raw LAEF wind speed forecasts for 17 members were used as a reference (LA_Ws).

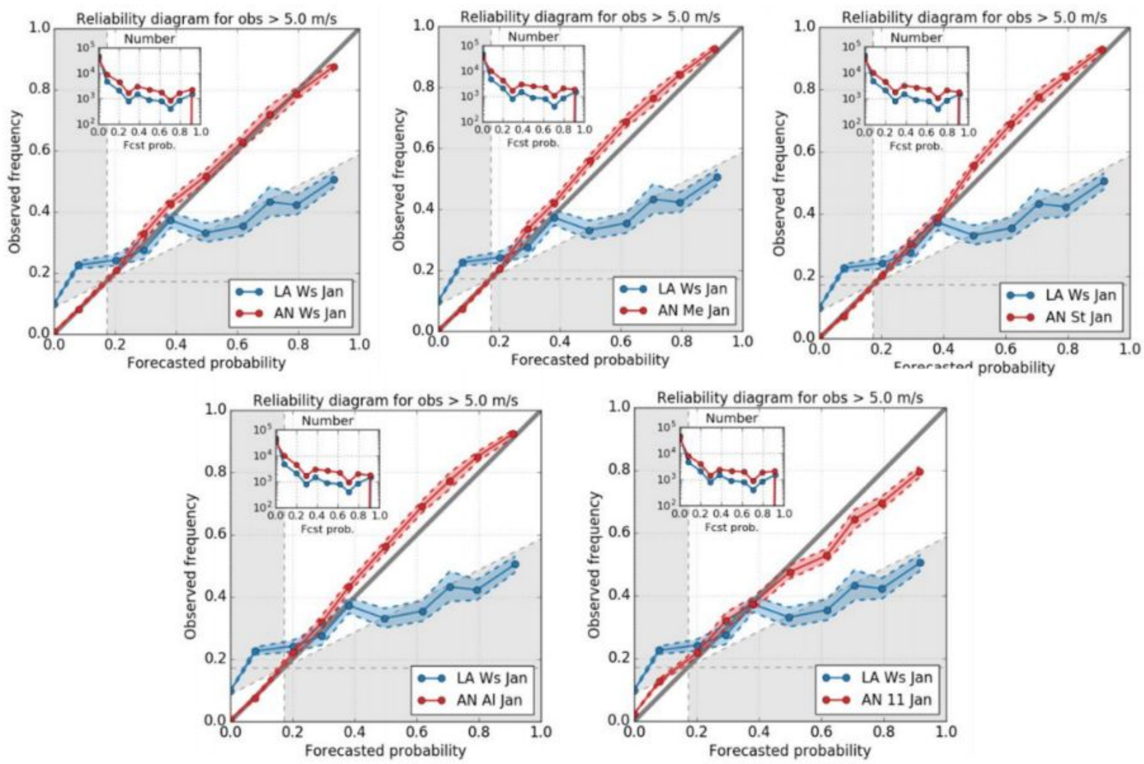


*Figure 14: Reliability diagrams for five different analog forecasts compared to LAEF raw forecast (LA_Ws) during January 2017 at all tested stations. The dashed lines show 95% confidence interval.*

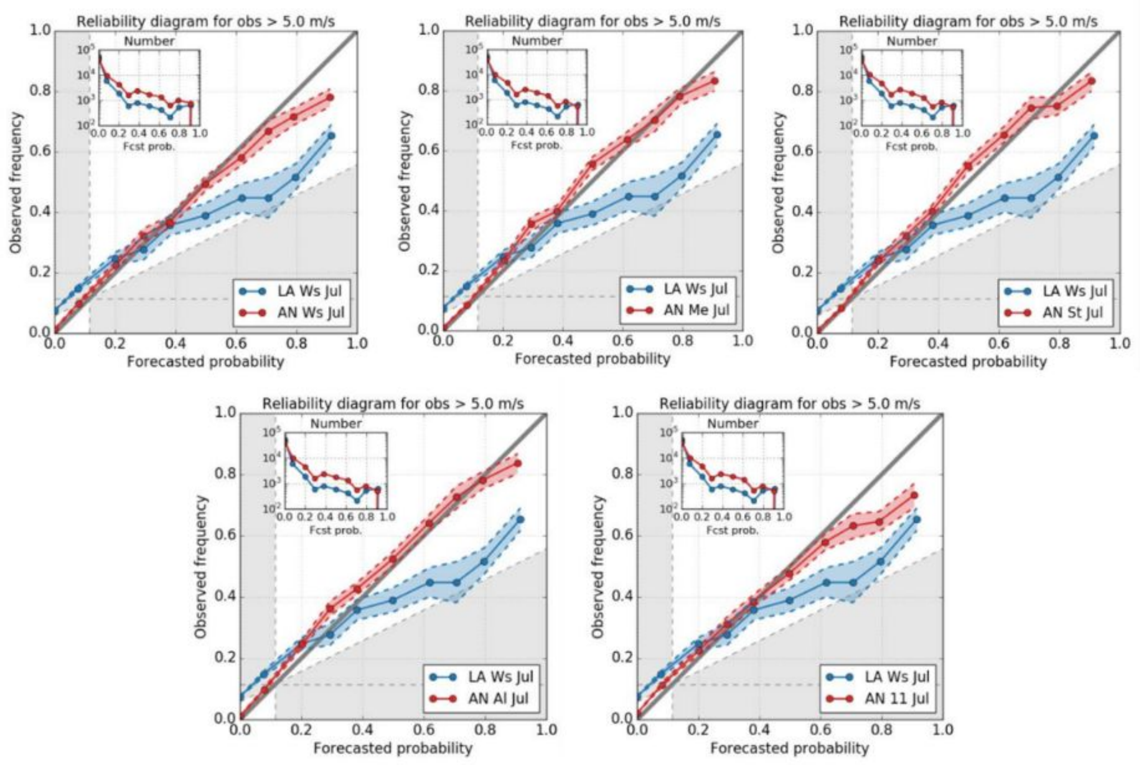


*Figure 15: Reliability diagrams for five different analog forecasts compared to LAEF raw forecast (LA_Ws) during July 2017 at all tested stations. The dashed lines show 95% confidence interval.*

It was shown that using only one predictor variable as input (wind speed LAEF ensemble) already improves the forecast skills and lowers the systematic error of the ensemble mean. Even better results are achieved when using more than one predictor variable. We can also conclude that there is no need to use the full input spectrum of a raw probabilistic model, i.e. all LAEF members as predictors. Using basic information of an input ensemble, such as ensemble mean and standard deviation, improves the forecast skills the most.

- **analog method on the grid**

The work further continued during Iris' second stay at ZAMG at the end of the year. This time they started to develop the algorithms that would allow testing the implementation of the analog method on the gridded forecasts. The first step was to search through available literature regarding gridded forecast post-processing. The main issue is how to compare historical forecasts on the grid with the current one. It is possible to use a point-by-point approach (as done before) on every grid point. However, even though this is a good starting point, it is to be expected that it will produce noisy results. Alternatively, one can compare an average error on the entire field and use the mean value to choose the most similar (entire) fields. More complicated approaches include additional methods in order to simplify the information. It was decided to start with the benchmark experiments, i.e. grid point-by-point approach and field-wise comparison.

The algorithms for the analog search were modified in order to use the grid-point values or the field comparison. Even though these algorithms work at the moment, they are extremely slow, making it impossible to verify the results before further optimization. Moreover, it was necessary to split the process in order to run it without memory issues. At this moment, instead of the observed value, the algorithm is actually 'forecasting' the timestamp of the most similar forecasts. In the future work, probably during the next stay, the algorithms will be further optimized in order to produce some viable results.

**Efforts:** 9 PM (2 PM LACE stay)

**Contributors:** Martin Belluš (SHMU), Iris Odak Plenković (DHMZ)

**Documentation**: Reports on stays; papers for publication in scientific journals

**Status:** Ongoing

**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 operational suite under ecFlow

As it was already mentioned, the old common RC LACE's ensemble system ALADIN-LAEF is going to be soon replaced by more sophisticated A-LAEF system. Its first preoperational version is running at ECMWF's HPCF regularly twice a day for 00 and 12 UTC network times since the end of July 2019 with many upgrades since then (see figure 16). The most important changes against the former ALADIN-LAEF system being the higher resolution (4.8 km / 60 levels on linear grid), new ALARO-1 perturbed physics on cy40t1, internal perturbation of OBS within ESDA, combination of ALARO-1 multi-physics with stochastic perturbation of physics tendencies, coupling files preparation directly from ECMWF ENS fields utilizing new 903 configuration on cy46 and complete rebuild of the system from scratch within the ecFlow environment using Perl and Python scripts.

The current configuration of A-LAEF is shown in the following figure. There are three essential families: *admin* to make an easy switch between the computational clusters (SCHOSTs) and file systems (STHOSTs); *RUN_00* and *RUN_12* for 00 and 12 UTC cycles respectively (starting daily at 00:30 and 12:30 UTC). Each of the last two contains four other families for processing input data from ECPDS dissemination stream (*ecpds*), fetching observations from OPLACE (*getobs*), running the ensemble (*main*) and final processing like cleaning and mirroring the data (*closure*). The family *main* has further subfamilies for each ensemble member (*MEM_<nn>*) involving preparation of the coupling files via c903 (task *getlbc*), surface data assimilation (task *canari*), upper-air spectral blending by DFI (task *blend*), model integration (task *laeff*) and for production of GRIB files (task *make_gribs*).

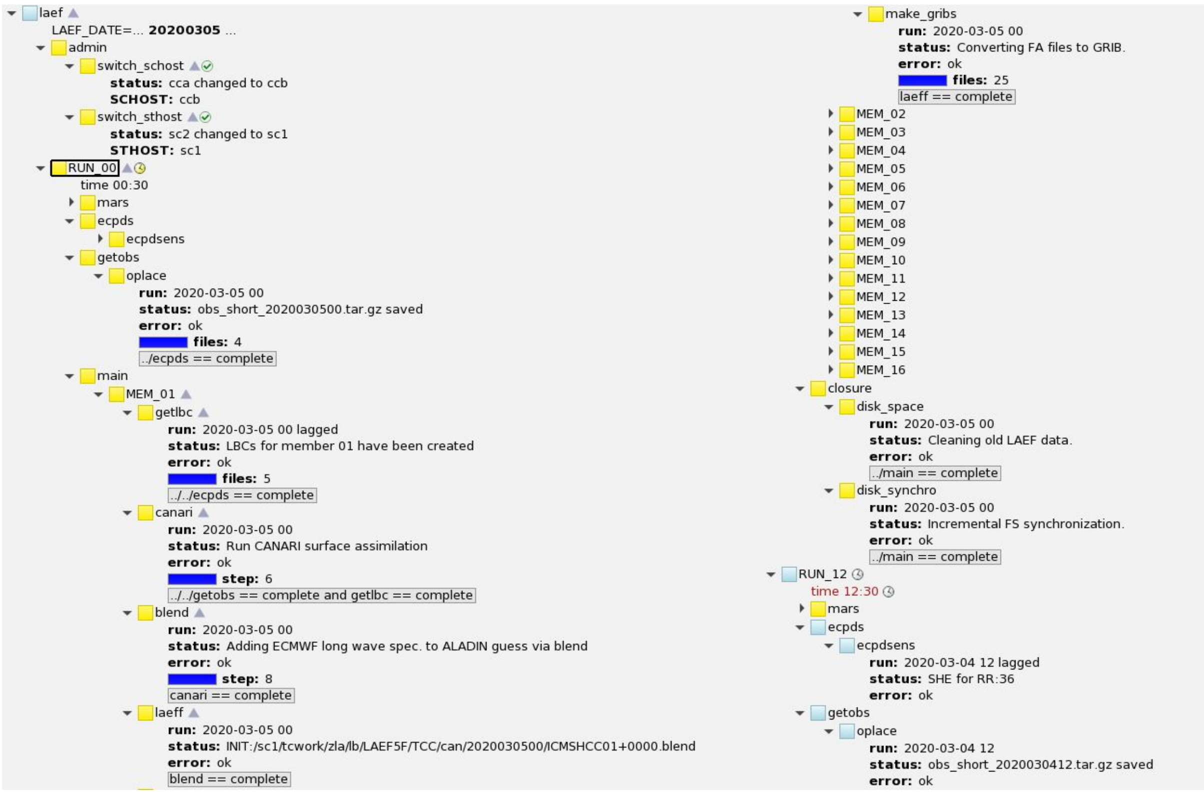


*Figure 16: User interface (ecFlow) for new A-LAEF suite under RC LACE's TC user.*

Among the many modifications and improvements of A-LAEF suite during the last period, this is the list of the most important ones:

- The suite was moved to the ecgb-vecf virtual machine.
- New admin family was added containing 2 tasks for easy switch between the computational clusters (cca/ccb) and/or tcwork file systems (sc1/sc2).
- New task was added to mirror the necessary files (binaries, namelists, clim files, ...current 12h first guesses) between the sc1/sc2 file systems. It uses *rsync* for an incremental file transfer, so in everyday reality just the current 12h forecasts are mirrored to the "backup" FS (everything else is static).
- Task which cleans the old production data (older than 3 days) was upgraded in order to clean the "backup" FS as well.
- New task to convert FA files to GRIBs (the final products) was added and the list of post-processed fields has been slightly changed to meet requirements.
- Start of the 00/12 suite has been shifted to 00:30 UTC and 12:30 UTC respectively (suite was switched to the time-lagged coupling mode controlled by variable CNF_LAGGED). Outputs are available in “real-time”.
- The ECPDS dissemination stream was implemented instead of MARS database for the IFS ENS input parameters.
- Manual pages have been added for each ecFlow task.
- Technical documentation of A-LAEF TC2 suite was prepared (see Appendix).

**Efforts:** 3.5 PM

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

**Documentation**: LAEF flow charts, presentations, reports

**Status:** New scripts development for ecFlow; A-LAEF suite implementation under TC environment; permanent 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 at OMSZ and ZAMG institutes.

- **Topic 1: EPS related development at OMSZ**

At OMSZ, a non-hydrostatic convection-permitting system AROME-EPS is being developed and tested at new HPC. Similarly to the operational ALARO-EPS, new system runs once per day coupled to 18 UTC run of ECMWF ENS (TEFRCL=3h). In this lagged mode the forecast from 00 UTC is produced for +48h. The ensemble comprises 11 members, but covers a smaller domain (Carpathian Basin) with the horizontal grid spacing of 2.5 km (see figure 17). 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 3-hourly assimilation cycle. The upper-air fields are downscaled from boundary conditions.

AROME-EPS configuration at OMSZ:

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

Forecasters can still use both ALARO-EPS and AROME-EPS (declared as operational since February 4$^{th}$ 2020). It is also planned to create more visual outputs and a more comprehensive ensemble verification as before.

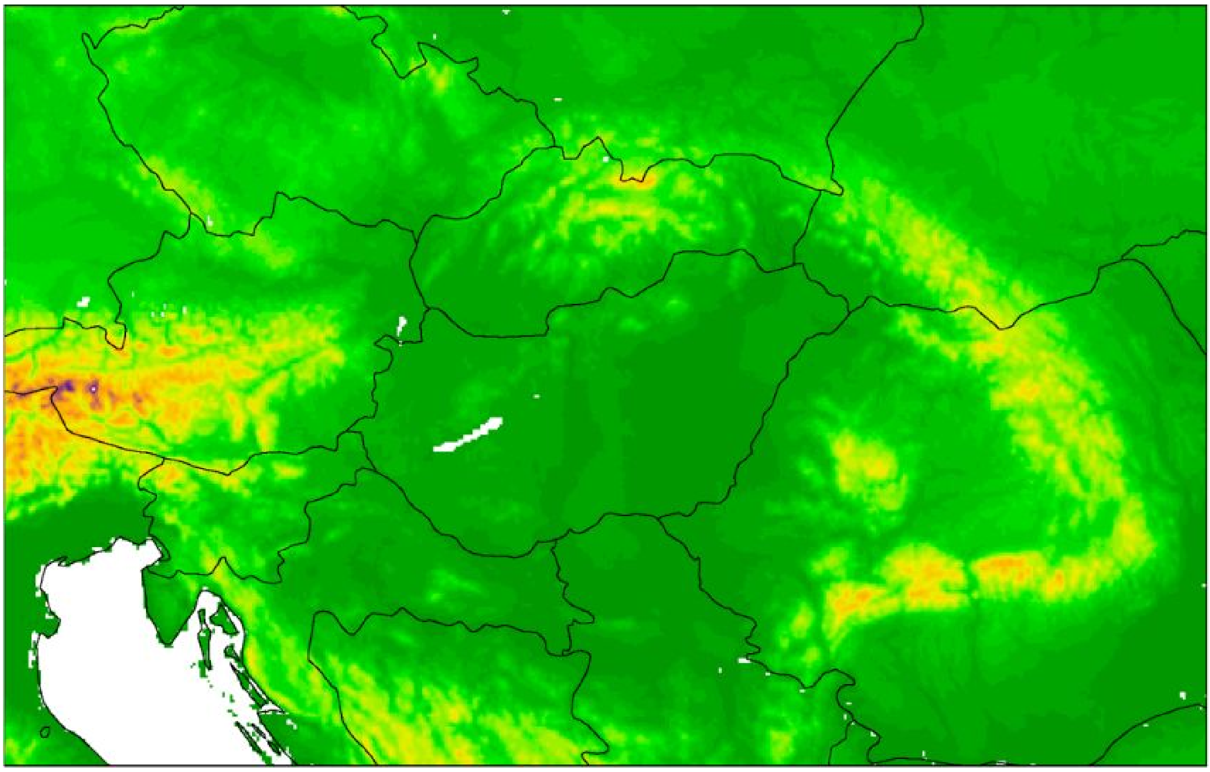

*Figure 17: Integration domain of the operational AROME/HU and AROME-EPS.*

The AROME-EPS results can be accessed by forecasters through HAWK visualization system since the end of May 2019. Comparison of both AROME-EPS and ALARO-EPS was made for May-June period (see figure 18), where also heavy precipitation events occurred. While geopotential, wind and cloud parameters have been clearly improved in AROME-EPS over ALARO-EPS forecast, humidity, temperature and precipitation fields have variable quality.

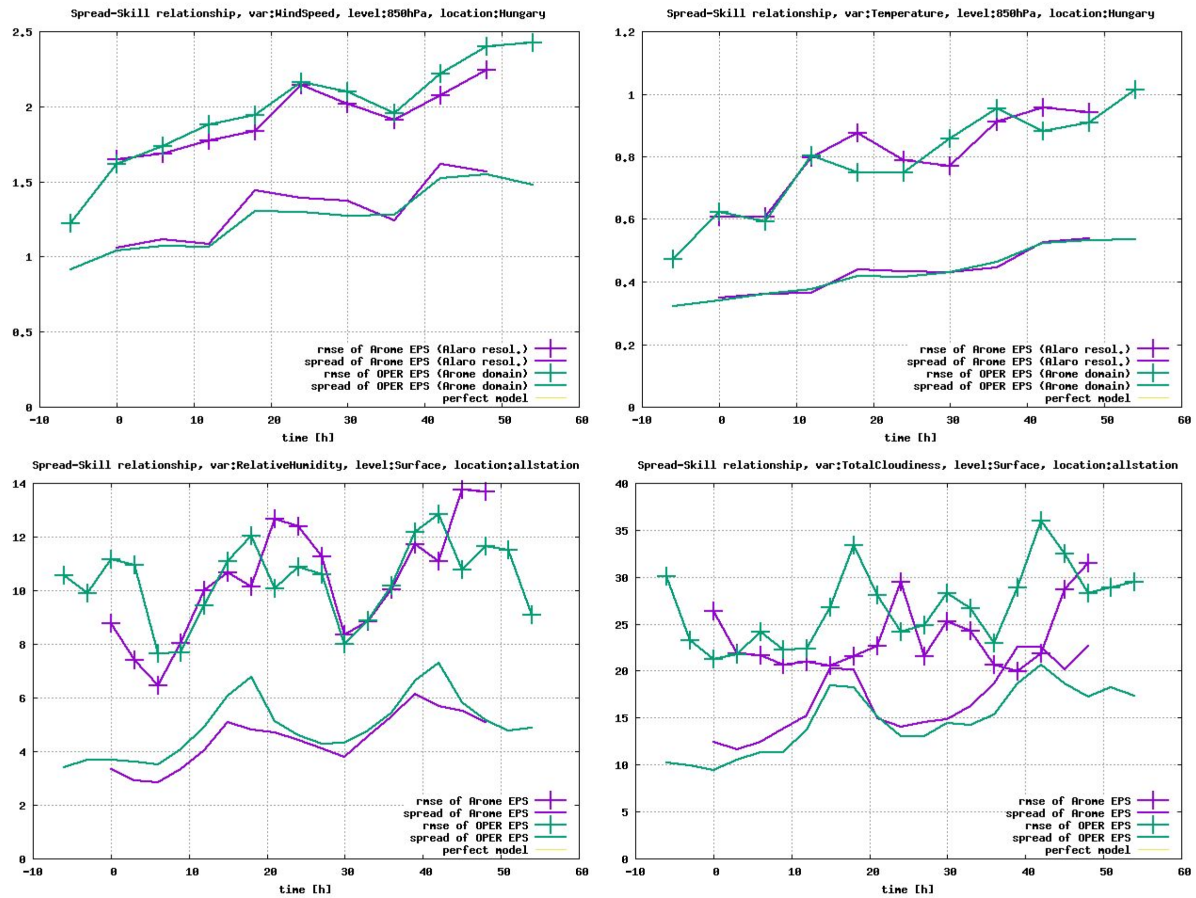


*Figure 18: Verification of AROME-EPS vs ALARO-EPS for 850 hPa wind speed (upper left) and temperature (upper right), and for surface relative humidity (bottom left) and total cloudiness (bottom right). Upper-air parameters (top) are verified against ECMWF analysis, while surface fields (bottom) are checked against the surface observations of Hungarian network.*

- **AROME-EDA experiments – first run and conclusions**

The AROME-EDA test runs were executed for period from May 28 till June 19, 2019 when heavy rainfall (exceeding 30 mm/day) occurred for 5 days in Hungary. The main characteristics of AROME-EDA are similar to those of AROME-EPS suite: 48h forecast (from 00 UTC) after 10 days of spin-up; ECMWF ENS coupling with 3-hourly coupling frequency; 2.5 km / 60 vertical levels; AROME/HU domain (see figure 17); 10 ensemble members + control forecast; 3-hourly assimilation cycle (identical to the operational deterministic AROME) with surface OI and 3D-Var upper-air analysis; AROME cy40. OBS perturbation was executed offline before the surface assimilation and after the screening by routine “pertcma” written by A. Storto. A perturbation scale was added to multiply all the perturbations. Conventional and GNSS ZTD measurements were assimilated, like in AROME/HU. Three experiments were conducted: without the OBS perturbation, without upscaling of OBS perturbation and with the OBS perturbation scaled by factor 1.4. Verification was made focusing on the control member. Figure 19 shows that RMSE values of AROME-EDA control forecast are very close to those of AROME/HU. 3D-Var assimilation introduces lower RMSE values for 2m temperature and 10m wind, but higher RMSE values are obtained for 2m humidity both for AROME-EDA and AROME/HU with respect to AROME-EPS. Quality of AROME-EPS forecast is overall better than ALARO-EPS control member.

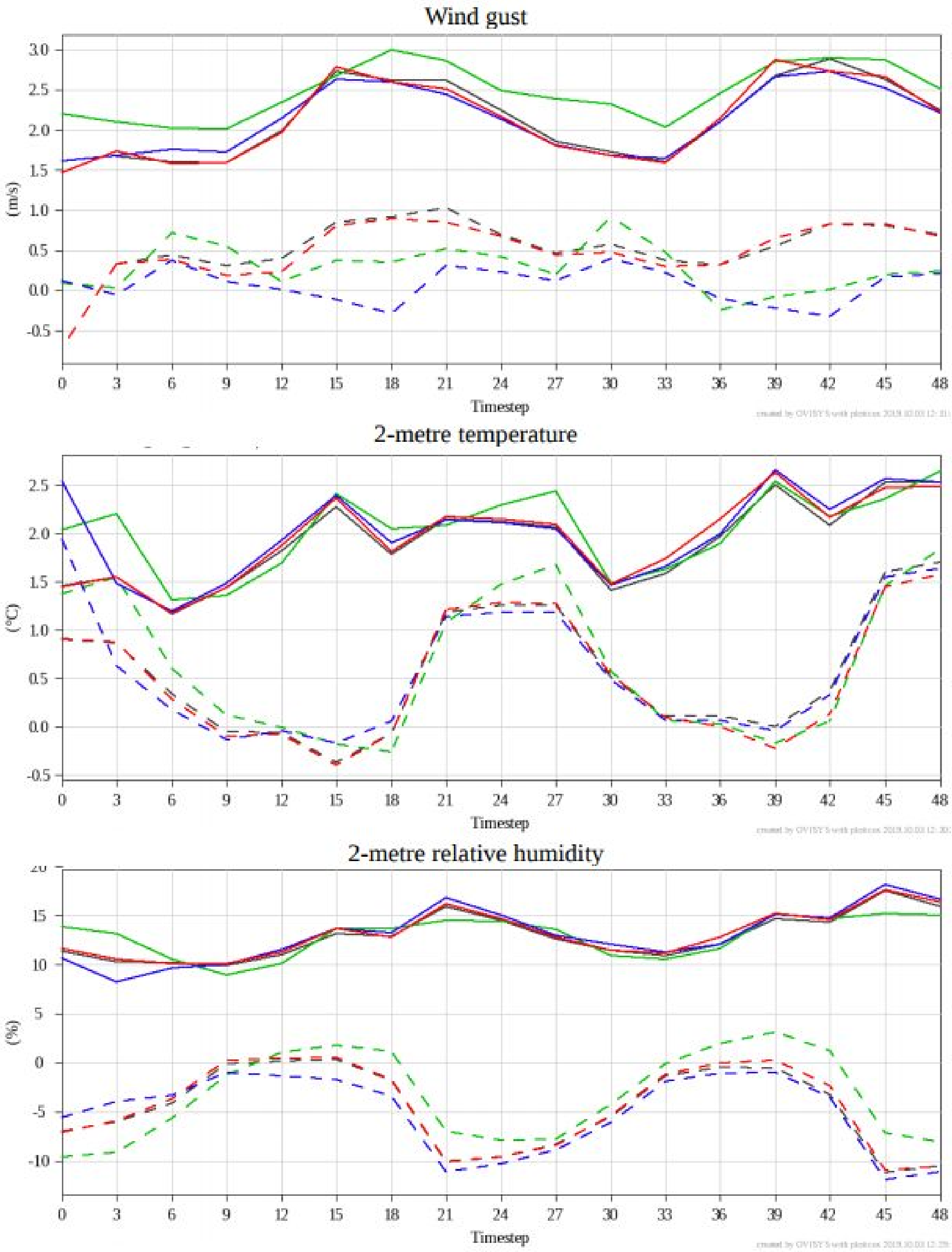


*Figure 19: RMSE (solid) and bias (dashed) of control members of AROME-EDA (red), operational ALARO-EPS (green), pre-operational AROME-EPS (blue) and operational deterministic AROME forecast (black) for wind gust (top), 2m temperature (middle) and relative humidity (bottom). Verification period: 28 May – 19 June, 2019.*

## ❑ Topic 2: EPS related development at ZAMG

At ZAMG, Convection-permitting - Limited Area Ensemble Forecasting system (C-LAEF) is being developed. It is based on non-hydrostatic AROME model with a horizontal resolution 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 tendencies perturbations in shallow convection, radiation and microphysics are combined with parameter perturbations in the turbulence scheme. After the optimization and small adaptations C-LAEF was declared as TC-2 operational suite on November 26th, 2019 with 4 runs a day (00, 06, 12 and 18 UTC). The lead times vary between +60h (00 UTC), +48h (12 UTC) and +6h (06 and 18 UTC).

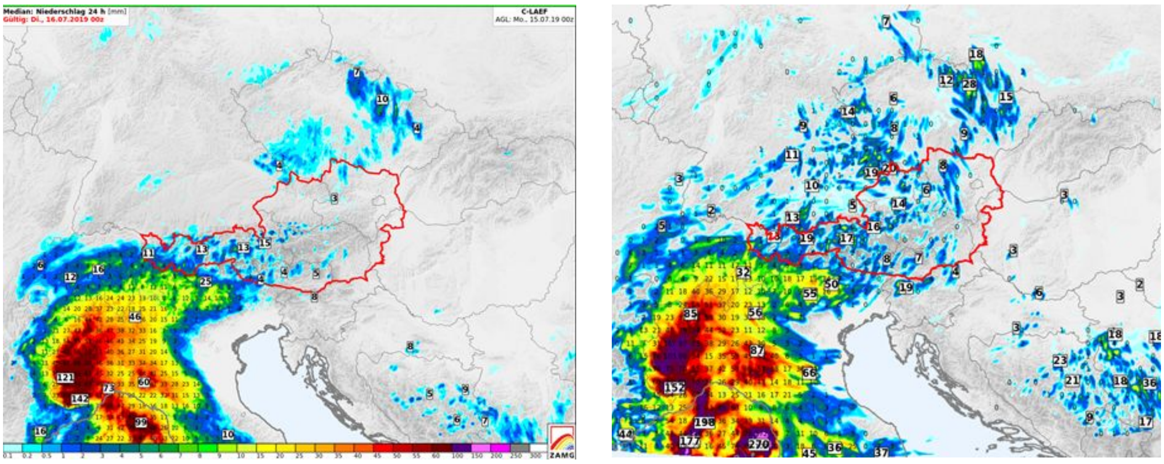

*Figure 20: 24h-accumulated precipitation forecast of C-LAEF median (left) versus deterministic AROME (right).*

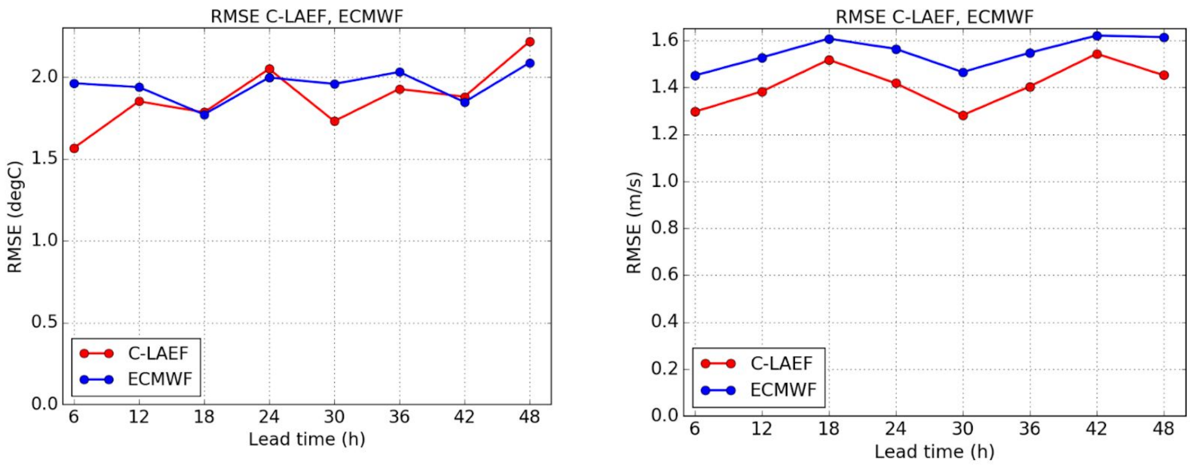


*Figure 21: RMSE of 2m temperature (left) and 10m wind speed (right) for C-LAEF mean (red) vs ECMWF ENS mean (blue), August 2019.*

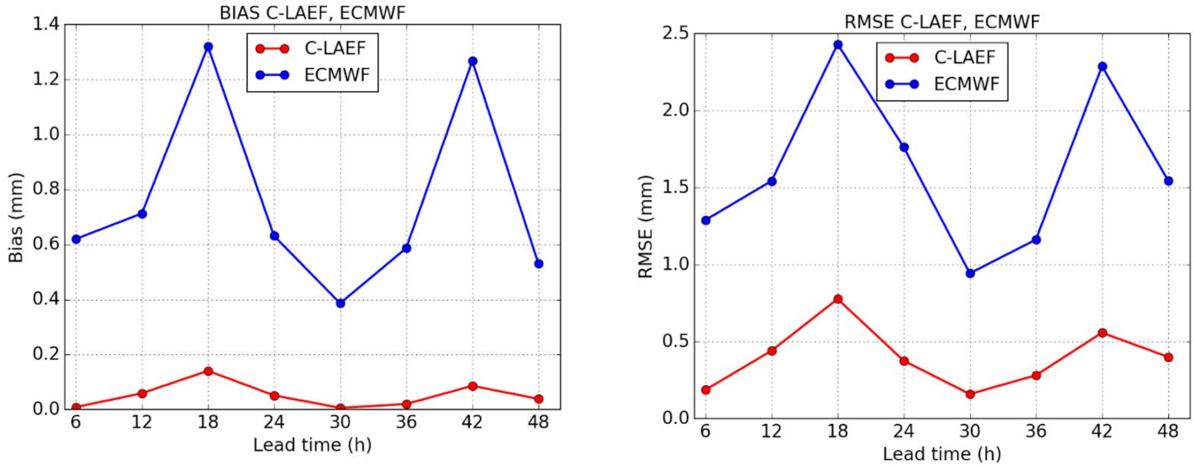


*Figure 22: BIAS (left) and RMSE (right) of precipitation forecast for C-LAEF mean (red) vs ECMWF ENS mean (blue), August 2019.*

The acceptance of AROME Austria sometimes suffers from high variability of forecasts from run to run (in particular during summer). Therefore, more consistent C-LAEF median was highly appreciated by the forecasters (see figure 20).

The "deterministic" verification scores for C-LAEF ensemble mean compared to the downscaled ECMWF ENS during August 2019 are shown in figures 21 and 22.

- **Topic 3: Adding lagged deterministic forecasts to a convection-permitting EPS**

In this study, Endi explored a possibility of extending an LAMEPS with lagged deterministic forecasts. Such setup is possible since the operational deterministic AROME system at ZAMG is configured the same (except for 3h cycling) as C-LAEF. AROME forecast range is 60h which enables to use up to 4 older AROME runs and combine them with C-LAEF to create a new 21-member ensemble, while keeping 48h forecast range. The members of such ensemble are considered to be interchangeable, and they are all equally likely.

The goal was to assess the added value of including 4 lagged AROME members to the C-LAEF ensemble. For this reason two experiments were defined:

- REF – represents C-LAEF raw ensemble (17 members)
- LAG – C-LAEF plus 4 lagged AROME runs (-3, -6, -9 and -12h)

Although it was expected to get an ensemble with exchangeable members, it was not the case due to some differences between the two models (for more details see Endi's report). However, practical benefits of this configuration were clearly visible in improved ensemble reliability, spread, and slightly higher accuracy for 10m wind speed and gusts forecasts (see figure 23).

Figure 24 shows wind speed forecast for all C-LAEF and AROME members separately and averaged over the verification period. Here we can see that C-LAEF and AROME members are clustering together, which is not what we were hoping for.

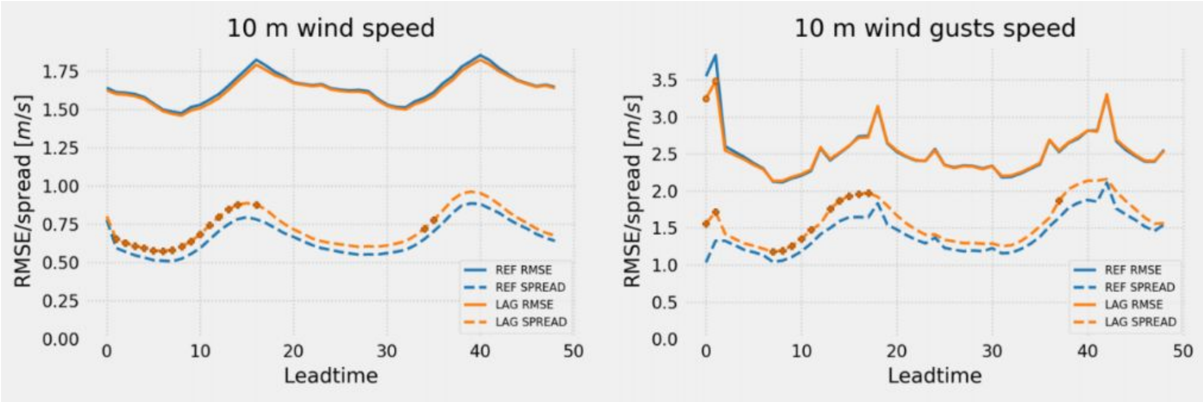


*Figure 23: RMSE of the ensemble mean and ensemble spread for wind speed (left) and wind guests (right). Forecast ranges with statistically significant differences are marked with bullets.*

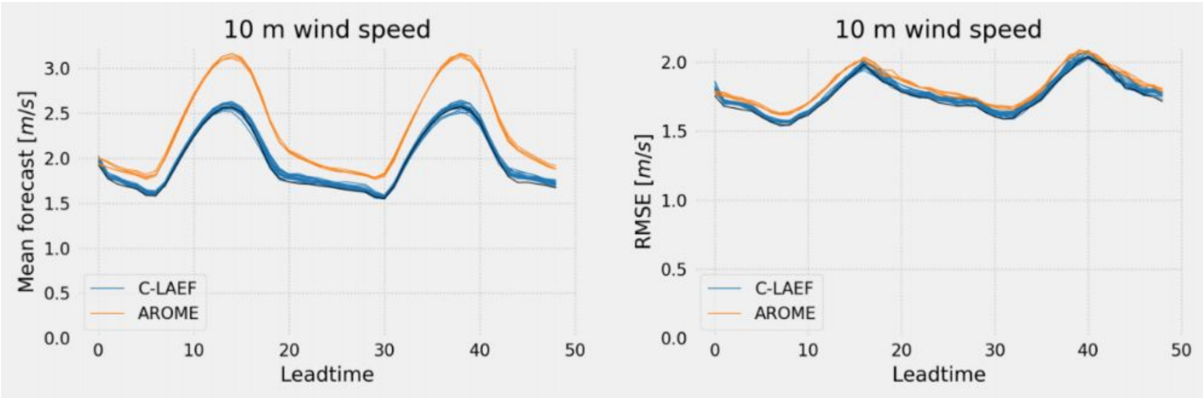


*Figure 24: C-LAEF and AROME lagged members wind speed forecast (left) and RMSE (right) averaged over the verification period.*

**Efforts:** 23.5 PM (1 PM LACE stay)

**Contributors:** Réka Suga, Mihály Szűcs, Viktória Homonnai, Katalin Jávorné-Radnóczi, Dávid Lancz (all OMSZ), Christoph Wittmann, Clemens Wastl (both ZAMG), Endi Keresturi (DHMZ)

**Documentation**: Reports on stays; papers for publication in scientific journals

**Status:** C-LAEF suite implementation under TC environment at ECMWF HPCF; AROME-EPS parallel and operational runs at OMSZ

### S4 Action/Subject/Deliverable: EPS - Verification

**Description and objectives:** A robust and reliable verification tool is very important in order to establish the quality of a weather forecasting system, either deterministic or probabilistic one. Knowing the statistical scores and limits of our forecasting system is crucial for further improvements. The huge amount of data must be processed, which requires an appropriate, optimized and flexible verification software. LAEF verification tool is being developed, maintained and used already for several years. However, distinct versions of the source code have been created in recent years under the different users. These versions may diverge from each other and involve various levels of modifications and bug fixing. Therefore, it is necessary to merge the latest development under one common library and treat the known bugs equally. Unfortunately, after the canceled stay of Simona Taşcu in 2018, also the stay of Réka Suga planned for 2019 must have been postponed to the next year for various reasons. Therefore, there is currently no evolution within this subject.

**Efforts:** 0 PM

**Contributors:** -

**Documentation**: -

**Status:** Frozen

### 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 new A-LAEF system. Although, depending on the resource situation later in the year we might get additional 5 mio SBUs.

**Efforts:** 2 PM

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

**Documentation**: Request for a special project 2020-2022

**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.

The long awaited paper about the land surface perturbation methods used in ALADIN-LAEF system has been finally published in QJRMS. This paper is based on our former work from 2014 about the surface stochastic physics in combination with the ensemble of surface data assimilation.

The paper about ongoing ALADIN-LAEF system upgrade (A-LAEF), as the common operational RC LACE regional ensemble system, was published in ASR.

Four other papers related to the currently developed convection-permitting ensemble system C-LAEF have been published in QJRMS, GDM, MWR and MZ.

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

**Efforts:** 6 PM

**Contributors:** Yong Wang, Florian Weidle, Christoph Wittmann, Florian Meier, Clemens Wastl, (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

**Status:** New scripts development for ecFlow; A-LAEF suite implementation under TC environment; permanent maintenance tasks

### S3 Subject: AROME-EPS

**Deliverables:** Reports on LACE stays; papers submitted to scientific journals; convection-permitting ensemble system prototypes for preoperational and operational use

**Status:** C-LAEF suite implementation under TC environment at ECMWF HPCF; AROME-EPS parallel and operational runs at OMSZ

### S4 Subject: EPS - Verification

**Deliverables:** Upgrades and maintenance of LAEF Verification package; bug-fixes

**Status:** Frozen

**S5 Subject: Collaborations**

**Deliverables:** Exchange of the expertise between the other consortia or within the relevant projects

**Status:** Ongoing

**S6 Subject: Publications**

**Deliverables:** 6 papers were published (ASR, QJRMS, GMD, MWR, MZ) and 1 paper was accepted (QJRMS); 3 stay reports are available online via RC LACE portal; for more details please see the list of publications down below

**Status:** In progress

## Documents and publications

**Published papers:**

- Belluš, M., F. Weidle, C. Wittmann, Y. Wang, S. Taşku, and M. Tudor, 2019: "Aire Limitée Adaptation dynamique Développement InterNational – Limited Area Ensemble Forecasting (ALADIN-LAEF)", Adv. Sci. Res., 16, 63–68, https://doi.org/10.5194/asr-16-63-2019
- Wang, Y., M. Belluš, F. Weidle, et al., 2019: "Impact of land surface stochastic physics in ALADIN-LAEF", Quarterly Journal of the Royal Meteorological Society, 1–19, https://doi.org/10.1002/qj.3623
- Keresturi E., Y. Wang, F. Meier, F. Weidle, Ch. Wittmann, A. Atencia, 2019: "Improving initial condition perturbations in a convection permitting ensemble prediction system", published on 22 January 2019 in Quarterly Journal of the Royal Meteorological Society, DOI: 10.1002/qj.3473
- Wastl C., Y. Wang, A. Atencia and C. Wittmann, 2019: "Independent perturbations for physics parametrization tendencies in a convection-permitting ensemble (pSPPT)", published on 16 January 2019 in Geosci. Model Dev., 12, 261-273, DOI: 10.5194/gmd-12-261-2019
- Wastl C., Y. Wang, A. Atencia, C. Wittmann, 2019: "A hybrid stochastically perturbed parametrization scheme in a convection permitting ensemble", Mon. Wea. Rev., 147, 2217-2230. doi: https://doi.org/10.1175/MWR-D-18-0415.1
- Wastl C., Y. Wang, C. Wittmann: "A comparison of different stochastically perturbed parametrization tendencies schemes", Meteorologische Zeitschrift, DOI: 10.1127/metz/2019/0988

**Accepted papers:**

- Plenković, I. O., I. Schicker, M. Dabernig, K. Horvath: "Analog-based post-processing of the ALADIN-LAEF ensemble predictions in complex terrain", accepted for publication in Quarterly Journal of the Royal Meteorological Society

**Stay reports:**

- Iris Odak Plenković, 2019: Work on analog-based post-processing method, Report on stay at ZAMG, 04/02~01/03, 2019, Vienna, Austria
- Endi Keresturi, 2019: Adding lagged deterministic forecasts to a convection-permitting EPS, Report on stay at ZAMG, 24/06~19/07, 2019, Vienna, Austria
- Iris Odak Plenković, 2019: Work on analog-based post-processing method, Report on stay at ZAMG, 11/11~06/12, 2019, Vienna, Austria

## Activities of management, coordination and communication

- ALARO-1 WD, 11-13 March 2019, Bratislava, Slovakia
- 32nd LSC Meeting, 13-14 March 2019, Bratislava, Slovakia
- LACE MG Meeting, 15 March 2019, Bratislava, Slovakia
- Joint 29th ALADIN Workshop & HIRLAM All Staff Meeting 2019, 1-5 April 2019, Madrid, Spain (LACE EPS activities presented by Martin Belluš)
- 33rd LSC Meeting, 16-17 September, Prague, Czech Republic
- EMS Annual Meeting, 9-13 September 2019, Copenhagen, Denmark
- 41st EWGLAM and 26th SRNWP joined meetings, 30 Sept - 3 Oct 2019, Sofia, Bulgaria (LACE EPS activities presented by Martin Belluš)

## LACE supported stays – 3 PM in 2019

There were only three stays executed:

- Iris Odak Plenković [S1], 4 February ~ 1 March 2019, ZAMG (4 weeks)
- Endi Keresturi [S3], 24 June ~ 19 July 2019, ZAMG (4 weeks)
- Iris Odak Plenković [S1], 11 November ~ 6 December 2019, ZAMG (4 weeks)

## Summary of resources [PM] – January ~ December 2019

| Subject | Manpower | | LACE | | ALADIN | |
|---|---|---|---|---|---|---|
| | plan | realized | plan | realized | plan | realized |
| S1: Optimization of A-LAEF | 7 | 9 | 3 | 2 | | |
| S2: A-LAEF maintenance | 3 | 3.5 | 1 | | | |
| S3: AROME-EPS | 10 | 23.5 | 1 | 1 | | |
| S4: EPS – Verification | 1.5 | 0 | 1 | | | |
| S5: Collaborations | 2 | 2 | | | | |
| S6: Publications | 6 | 6 | | | | |
| Total: | 29.5 | 44 | 6 | 3 | 0 | 0 |

# A-LAEF ecFlow TC2 Suite

(technical documentation)

Martin Belluš (SHMÚ)
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October 2019, Bratislava
(updated in March 2020)

## Introduction

A meso-scale ensemble system A-LAEF (ALARO - Limited Area Ensemble Forecasting) based on ALADIN canonical model configuration ALARO (Termonia et al., 2018) has been developed in the frame of RC LACE consortium (Regional Cooperation for Limited Area modelling in Central Europe). It is focused on short range probabilistic forecast and profits from the advanced multi-scale ALARO physics (which is adapted to perform on horizontal mesh-sizes of 2-10 km). Its main purpose is to provide probabilistic forecast for the national weather services of RC LACE partners (Wang et al., 2017) who could not achieve that with their own HPC resources. It also serves as a reliable source of probabilistic information applied further into the downstream models of hydrology, energy industry and even in the nowcasting.

New A-LAEF system is a sequel to the ALADIN-LAEF (Aire Limitée Adaptation dynamique Développement InterNational - Limited Area Ensemble Forecasting), which was operational on ECMWF HPCF as TC2 application since 2011 (Wang et al., 2011).

## A-LAEF system

In A-LAEF system we use several strategies to simulate the uncertainty of the initial conditions and of the numerical model, while the perturbations at the boundaries are prescribed by the downscaled information from driving global EPS.

### a) IC perturbations

The surface and soil prognostic fields uncertainty in the initial conditions of A-LAEF system is simulated by the ensemble of surface data assimilations - ESDA (Belluš et al., 2016). Each ensemble member has its own data assimilation cycle with randomly perturbed screen-level measurements.

The uncertainty of the upper-air part of the initial conditions used in A-LAEF system is currently simulated by the upper-air spectral blending (Derková and Belluš, 2007; Wang et al., 2014). It combines the large-scale perturbations provided by the driving global ensemble (ECMWF EPS) with the small-scale perturbations coming from A-LAEF first guess within the pseudo-assimilation cycle. It is going to be replaced by so-called ENS BlendVar (ensemble of blending + 3DVar) at the Phase II.

### b) Model perturbations

The model uncertainty is simulated by the combination of ALARO multi-physics (four different setups of micro-physics, deep and shallow convection, radiation and turbulence schemes) and the stochastic perturbation of physics tendencies (Wang et al., 2019).

### c) LBC perturbations

The A-LAEF system is coupled to the global ECMWF EPS. The perturbed lateral boundary conditions are retrieved from the first 16 ENS members with a coupling frequency of 6h to account for the uncertainties at the domain boundaries.

A-LAEF system specifications can be seen in Table 1, while the integration and postprocessing domains are shown in Figure 1.

**Tab.1:** *A-LAEF system specifications.*

| | |
|---|---|
| Code version | cy40t1 |
| Horizontal resolution | 4.8 km |
| Vertical levels | 60 |
| Number of grid points | 750x1250 |
| Grid | linear |
| Time step | 180s |
| Forecast length | 72 h (00/12 UTC) |
| Members | 16+1 |
| IC perturbation | ESDA [surface], blending (Phase I) / ENS BlendVar (Phase II) [upper-air] |
| Model perturbation | ALARO-1 multi-physics + surface SPPT |
| LBC perturbation | ECMWF ENS |

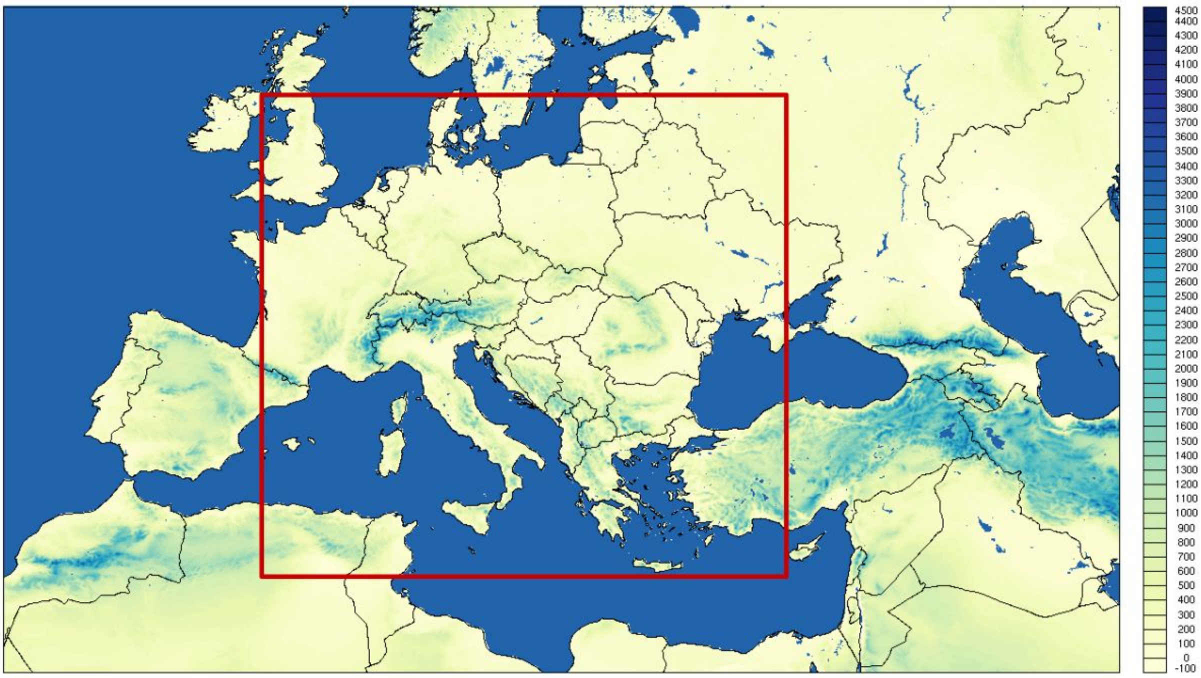

**Fig.1:** *A-LAEF integration and postprocessing domain (in red) with model orography.*

## Technical specifications

Suite definition file is generated by Python script (create_laef.py). The ECF_MICRO character used for the code preprocessing was redefined to “^” (caret). The reason is to have the least interaction with the original Perl code. The default setting for ECF_MICRO is “%” (percent), which is used for the hash associative arrays in Perl and thus is widely spread in the code. Even now, all the original caret signs (e.g. in some regular expressions) must have been exchanged by “^^” (caret caret) to avoid their substitution by ecFlow preprocessing.

The “laef” suite has three essential families: “admin” to make an easy switch between the computational clusters (SCHOSTs) and file systems (STHOSTs); “RUN_00” and “RUN_12” for 00 and 12 UTC cycles respectively. Each of the last two contains four other families for processing input data (“ecpds”), fetching observations (“getobs”), running ensemble (“main”) and final processing like cleaning/mirroring and dissemination of products (“closure”). The family “main” has subfamilies for each member (“MEM_<nn>”) involving preparation of the coupling files (task “getlbc”), surface data assimilation (task “canari”), upper-air spectral blending by DFI (task “blend”), model integration (task “laeff”) and GRIBs production (task “make_gribs”).

All the ecFlow scripts (Perl application tasks, Python script to generate the “laef” suite definition file and include files) are stored on ecgate server. The “laef” suite is generated at virtual machine ecgb-vecf and also loaded into the ecFlow server running on that VM to avoid the load on the interactive node on ecgate.

**ecgate: /home/ms/laef/zla/ecf**

| | |
|---|---|
| drwxr-x---. 3 zla laef 4096 Oct 22 11:09 **app** | ecFlow tasks |
| drwxr-x---. 3 zla laef 4096 Oct 21 16:16 **def** | suite definition |
| drwxr-x---. 2 zla laef 4096 Oct 21 13:10 **include** | head, tail, pbs |
| drwxr-x---. 4 zla laef 4096 Oct  9 07:12 **laef** | suite* |

(*) auto-generated by Perl script app/link_apps_to_tasks.pl

On the other hand, the compiled binaries, namelists and input files must be located on HPCF cluster (cca/ccb), because this is where the jobs are executed under the queuing system (PBS).

**cca/ccb: /$STHOST/tcwork/zla/lb/app_LAEF5F**

| | |
|---|---|
| drwxr-x--- 3 zla laef 4096 Apr 24 11:08 **blend** | blending namelists |
| drwxr-x--- 3 zla laef 4096 Apr 24 11:11 **canari** | surface namelists |
| drwxr-x--- 3 zla laef 4096 Apr 24 11:18 **getlbc** | namelist for c903 |
| drwxr-x--- 3 zla laef 4096 Apr 24 11:18 **laeff** | e001 namelists |
| drwxr-x--- 2 zla laef 4096 Oct 22 11:42 **setup** | main laef config* |

(*) Conf_app.pm and Support.pm Perl modules

**cca/ccb: /$STHOST/tcwork/zla/lb**

| | |
|---|---|
| drwxr-xr-x 2 zla laef 4096 Oct 23 12:57 **BIN** | all executables* |
| drwxr-x--- 5 zla laef 4096 Apr 24 13:13 **CLIM** | clim files |
| drwxr-x--- 4 zla laef 4096 Oct 16 15:09 **LBC** | input from ECMWF |
| drwxr-xr-x 3 zla laef 4096 Jun 28 12:19 **LAEF5F** | A-LAEF output |
| drwxr-x--- 2 zla laef 4096 Oct  9 06:55 **bin** | Perl tools |

(*) sources and compilation: /perm/ms/at/kmxy/packs/40t1_LAEF5_FULL

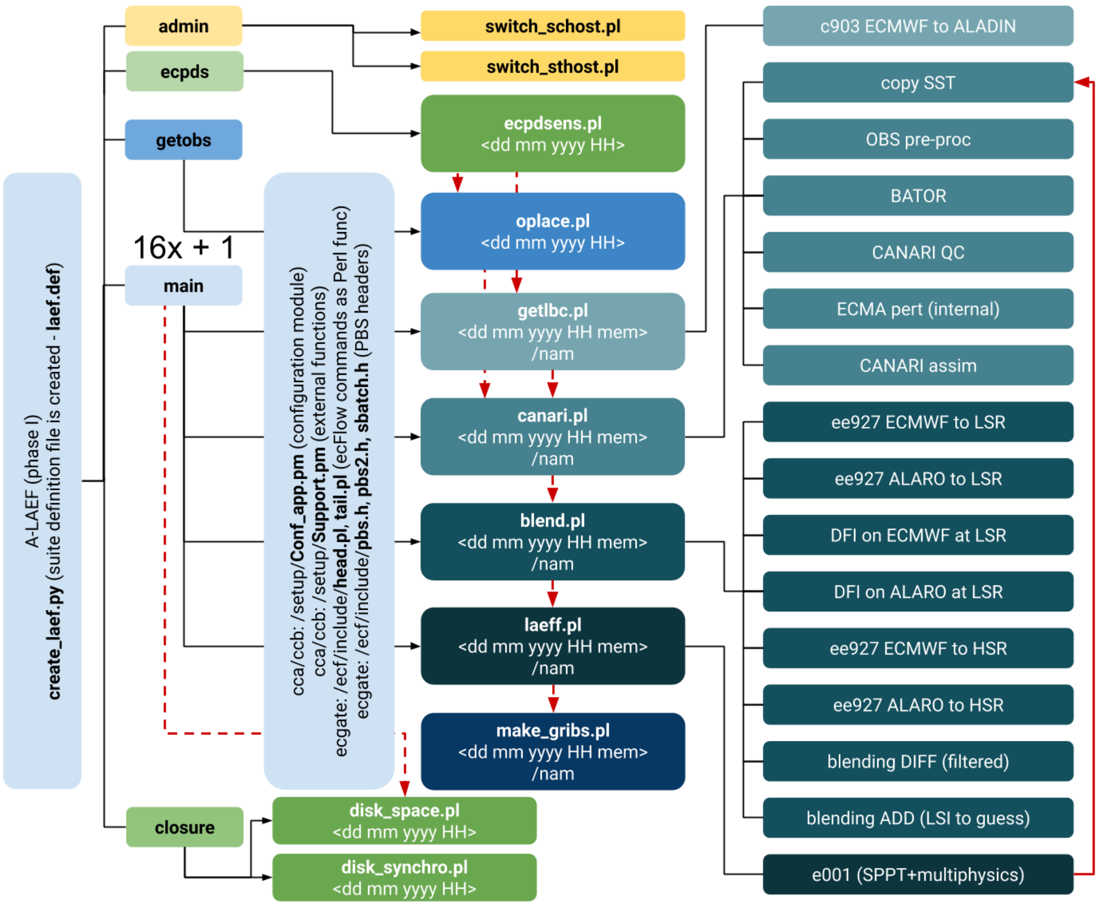


**Fig.2:** *New A-LAEF suite built under the ecFlow environment. Suite definition file is generated by Python code, while all tasks, include-files and configuration modules are written in Perl. Task dependencies are denoted by the red dashed arrows.*

**Tab.2:** *Overview of the "laef" suite requirements.*

| | | |
|---|---|---|
| 1. Run time of suite | Start time | • 00:30 UTC (RUN 00)<br>• 12:30 UTC (RUN 12) |
| | End time | • Preferably before 4:00 and 16:00 UTC. |
| | Availability requirements | • As soon as possible, but there is no deadline. |
| 2. Input data | Dependence on ECMWF forecast products | • ENS 00/12 UTC 6-hourly output to STEP=84 for the first 16 members and control run (for 12h-lagged coupling). |
| | Dependence on other data | • OPLACE obsouls* |
| | How is this transferred to ECMWF? | • ectrans<br>Gateway: ecaccess.ecmwf.int |

| | | |
|---|---|---|
| | | Host: ftp.met.hu |
| | Backup procedure? | • Not applicable. |
| 3. HPC compute resources | Number of nodes/CPUs (maximum) | • 17x(8 nodes / 288 CPUs) |
| | Times at which peak number of CPUs are needed | • For ~2 hours (01:00~03:00 UTC; 13:00~15:00 UTC). |
| 4. HPC storage resources | Input data volume | • 500 GB per cycle / 1 TB per day |
| | Output data volume | • 1 TB per cycle/ 2 TB per day |
| | Permanent storage requirements (for scripts, libraries and binaries) | • 10 GB on $TCWORK/lb |
| | Number of days of data to be stored | • 3 days of input data (3 TB)<br>• 3 days of output data (6 TB) |
| 5. Data handling storage requirements (archiving) | Data to be stored on MARS | • None |
| | Data to be stored in ECFS | • To be decided. |
| 6. Volume of data to be transferred from ECMWF to local site(s) | | • ~24 GB per cycle. |
| 7. Software requirements | ECMWF software | • ecFlow, ECaccess, ecCodes |
| | Other software | • Specific software and libraries for running ALARO CMC model chain. |

(*) observations are retrieved from OPLACE archive (operational database of RC LACE)

**Tab.3:** *Contacts.*

| | | | | |
|---|---|---|---|---|
| Emergency contact | Martin Belluš | martin.bellus@gmail.com | +421 918 412 792 | 24x7 |
| | | | | |

**Tab.4:** *Description of the "laef" suite.*

| Family | Task | Sys | Description |
|---|---|---|---|
| **admin** | switch_schost | ecgb | Switching between clusters (cca/ccb). |
| | switch_sthost | ecgb | Switching between FSs (sc1/sc2). |
| **RUN_00\|12** | | | 00 and 12 UTC runs |
| **ecpds** | ecpdsens | cca/ ccb | Processing local ECPDS stream (ENS/DET input global fields). |
| **getobs** | oplace | cca/ ccb | Fetching OBS files from OPLACE. Trigger("../ecpds == complete") |
| **main/MEM_00\|01\|..16** | getlbc | cca/ ccb | Creating LBCs for A-LAEF domain from global ENS gribs by conf 903. Trigger("../../ecpds == complete") |
| | canari | cca/ ccb | Surface assimilation using perturbed OBS by conf 701. Trigger("../../getobs == complete and getlbc == complete") |
| | blend | cca/ ccb | Upper-air spectral blending by DFI. Trigger("canari == complete") |
| | laeff | cca/ ccb | Model integration by conf e001. Trigger("blend == complete") |
| | make_gribs | cca/ ccb | Converting FA files to GRIBs. Trigger("laeff == complete") |
| **closure** | disk_space | cca/ ccb | Old data cleaning (also mirrored files). Trigger("../main == complete") |
| | disk_synchro | cca/ ccb | Incremental synchronization (mirroring). Trigger("../main == complete") |

**Tab.5:** *Location of the "laef" suite scripts and data.*

| Data | Host | Location |
|---|---|---|
| Suite scripts | ecgate | /home/ms/laef/zla/ecf/laef |
| A-LAEF executables | cca/ccb | /$STHOST/tcwork/zla/lb/BIN |
| A-LAEF namelists | cca/ccb | /$STHOST/tcwork/zla/lb/app_LAEF5F |

| | | |
|---|---|---|
| A-LAEF configuration | cca/ccb | /$STHOST/tcwork/zla/lb/app_LAEF5F/setup |
| Model climatology files | cca/ccb | /$STHOST/tcwork/zla/lb/CLIM |
| Input ENS data | cca/ccb | /$STHOST/tcwork/zla/lb/LBC/ECPDS/YYYYMMDDHH |
| A-LAEF output data | cca/ccb | /$STHOST/tcwork/zla/lb/LAEF5F/TCC |
| Job output files | cca/ccb | /$STHOST/tcwork/zla/sb/ECF/laef |

The time duration of individual A-LAEF tasks within the current preoperational implementation and expected timing for the whole suite (+72h forecast) is shown in table 6. Processes like ensemble of surface data assimilation (ESDA) and upper-air spectral blending are not dependent on the forecast length and their duration is marginal. OBS retrieval from OPLACE archive is negligible and the preparation of coupling files - although for full forecast length (+72h) - is still fast when using 903 configuration in NFPSERVER mode (with the loop on files inside). The only time demanding task here is the integration itself. Within the tested configuration involving 288 CPUs (8 nodes) the +24h forecast takes about 42 minutes. It implies that the whole 3-day forecast would take about 2 hours.

**Tab.6:** *Time duration of individual tasks within the current preoperational implementation (+24h forecast) and its extrapolation for the full forecast length (+72h).*

| Task | CPUs | +24h forecast | +72h forecast |
|---|---|---|---|
| ecpdsens | 1 | 00:08:00 | 00:22:00 |
| oplace | 1 | 00:00:30 | 00:00:30 |
| getlbc | 36 | 00:02:00 | 00:06:00 |
| canari | 288 | 00:03:00 | 00:03:00 |
| blend | 288 | 00:08:20 | 00:08:20 |
| laeff | 288 | 00:42:00 | 02:06:00 |
| make_gribs | 18 | 00:00:30 | 00:01:30 |

**Tab.7:** *Technical characteristics of the main tasks running on HPCF (not including preprocessing and postprocessing).*

| Task | CPUs | Wall (s) | Output | SBUs | Total SBUs |
|---|---|---|---|---|---|
| | values per member ([1]per 24 hour integration) | | | | 16+1 mem ([2]72h, 2x day) |
| canari | 288 | ~166 | 518 MB | ~214 | ~7280 |
| blend | 288 | ~500 | 518 MB | ~650 | ~22100 |
| laeff | 288 | ~2460 | 15 GB | ~3200[(1)] | ~326400[(2)] |
| Total SBUs consumption per year (an approximation only) | | | | | ~130 mio |

## References

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