Working Area Predictability

Progress Report

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Period:	Jul – Dec 2023
Date:	Mar 2024

Progress summary

The three operational ensemble systems in RC LACE (A-LAEF, C-LAEF, AROME-EPS) have undergone some major upgrades in 2023. For A-LAEF the upgrade to cy46t1 has been prepared including some adaptations in the multiphysics scheme and an upgraded upper-air spectral blending by digital filter, for C-LAEF the model error representation has been changed to a pure parameter perturbation scheme (SPP) and in AROME-EPS an EDA scheme with sEKF has been introduced to represent initial condition uncertainties.
Beside this, a lot of research is currently ongoing in the EPS area in RC LACE. For the common A-LAEF system a lot of work has been spent on the before mentioned adaptation in the multiphysics scheme which is based on the latest ALARO-1 code developments in cy46t1. Therefore different tunings and parametrizations in two physics clusters have been intensively tested and verified. Furthermore, to enhance the model uncertainty simulation in A-LAEF, the stochastic perturbation of ISBA surface prognostic fields has been implemented and validated.
Austria, Slovenia and Croatia have committed to strengthen their cooperation in the EPS area by developing a common 1km EPS based on the Austrian C-LAEF system. This system includes besides an upgrade in resolution and cycle (cy46t1) also an improved atmospheric data assimilation system (based in EnVar), new observations (radar, GNSS, ceilometers, etc.), an upgraded dynamics/physics setup and a flow dependent model error representation. To expand the C-LAEF 1k system (more runs, longer leadtimes, more members) a lagged ensemble approach is under development. All of these features are currently tested on the ECMWF HPC. The plan is to finish the tests until the end of 2024 and to go operational with the common C-LAEF 1k system in 2025.
In Hungary, the main research focus in 2023 was put on the development and implementation of a model error representation scheme based on SPP. The technical work could be finished during two remote stays, currently a lot of tuning, optimization and intensive verification is ongoing to be ready for a final operationalisation.
In the statistical EPS and user-oriented approaches area, the work on analog-based post-processing and statistical post-processing with SAMOS has been continued. Also the use of artificial intelligence (AI) methodologies in post-processing and nowcasting has been has been forced in 2023.

Scientific and technical main activities and achievements, major events

S1 Subject: Preparation, evolution and migration

Description and objectives: Maintain and monitor the operational suites of A-LAEF and C-LAEF running on ECMWF's HPC and the AROME-EPS running at the HPC at HungaroMet. Migration and implementations to new HPCs, operational upgrades, new cycles, optimizations and tunings.

The originally planned topics for 2023 were:

- ❑ A-LAEF and C-LAEF: Maintenance/monitoring of operational EPSs on ECMWF's HPC in Bologna, upgrades
- ❑ A-LAEF: Upgrade of the upper-air IC uncertainty simulation by ENS BlendVar
- ❑ A-LAEF: Development of an ALARO-based convection-permitting EPS coupled to the regional ensemble A-LAEF, running at new SHMU HPC
- ❑ C-LAEF: Operationalization of SPP scheme in C-LAEF
- ❑ C-LAEF: Upgrade of C-LAEF to 1km – test suites, optimizations, verification, single precision
- ❑ C-LAEF: New HPC at GeoSphere Austria – migration, first tests for C-LAEF 1km
- ❑ C-LAEF: Adaptation of C-LAEF to Turkish Domain
- ❑ AROME-EPS: Optimization and tuning of convection-permitting ensemble system on HPC at HungaroMet
- ❑ AROME-EPS: Introduction of EDA in operational AROME-EPS

The operational suites on the new ECMWF HPC in Bologna (A-LAEF and C-LAEF) are generally running very smoothly and stable. The only worth mentioning event in 2023 was a complete power outage at the ECMWF computing facilities in Bologna on 16 November 2023 site which caused a complete shutdown of all ECMWF services. Therefore also the two operational ensemble systems in LACE were not available for several hours (two runs were affected).

Some of the topics above have been postponed because of stays that could not be realized on time. E.g. the big upgrade of the common A-LAEF EPS to cy46t1 has been postponed to January 2024, but all the preparatory work (e.g. setup of Esuite, implementation of upper-air spectral blending, upgrade of multiphysics, etc.) falls into this reporting period. The upgrade of the upper-air IC uncertainty simulation by ENS BlendVar in A-LAEF has also been postponed, because of missing resources and other priorities. Another delay concerns the new HPC at GeoSphere Austria, which should have been delivered at the end of 2023. However, the tender and the application process took much longer than foreseen – the new HPC is now expected to be available in Q3 2024.

For C-LAEF, the upgrade of the stochastic model error representation to SPP has been realized in September 2023 after some extensive testing. Strong effort is currently ongoing in the development of a C-LAEF 1km EPS. First full C-LAEF 1k suite has been set up in summer 2023 and it has been running continuously until end of 2023. Intensive verification showed a general quite good performance, but also some deficiencies arose which need to be fixed before a final operationalization (e.g. problems with hanging jobs in single precision, dry bias at the beginning, etc.). Intensive cooperation between the LACE countries Austria, Slovenia and Croatia has been initiated with the scope of a common C-LAEF 1k system in the future.

The setup of C-LAEF for Turkey has been initialized during a 1-week stay of a Turkish colleague in Vienna in May. This work has been continued at the Turkish meteorological service in autumn 2023. The current status (February 2024): C-LAEF for Turkey is running continuously in a test phase on Atos and they want to make it operational soon. The model resolution is 1.7 km with 72 vertical levels. Lead time of 24 hours and the domain is the same as the operational AROME model.

The operational AROME-EPS system has undergone a major upgrade in March 2023 when introducing EDA and sEKF. In the second half of 2023 the focus was put on the introduction of a model perturbation scheme (SPP). This has been realized in course of two 2-weeks remote stays.

Additionally, a cooperation with the Spanish development team for gSREPS ensemble system was established. LACE helped them with the ALARO NH configuration on cy46t1 running on Atos HPCF, and with the preparation of new CLIMfiles for their 2.5 km domain.

❑ Topic 1: Upgrade of A-LAEF on ECMWF's HPC

Upgrade of upper-air spectral blending by digital filter:

The A-LAEF e-suite on Atos@ECMWF was prepared, including the upgrade of upper-air spectral blending by digital filter (DFI) to cy46t1. DFI within the blending procedure was tuned and validated in order to reproduce the operational configuration as much as possible.

The conclusions for the blending upgrade:

- small discrepancy between cy40t1 (oper) and cy46t1 (new) below level 30 (total levels 60), see Figure 1
- differences getting smaller near the lowest model level
- most obvious deviation observed for specific humidity and temperature above sea
- differences in surface pressure field less than 0.02 hPa (not shown)
- central Europe (land) mostly without significant differences (case sensitive)
- generally reasonable change between the cycles (taking into account the modified physics)

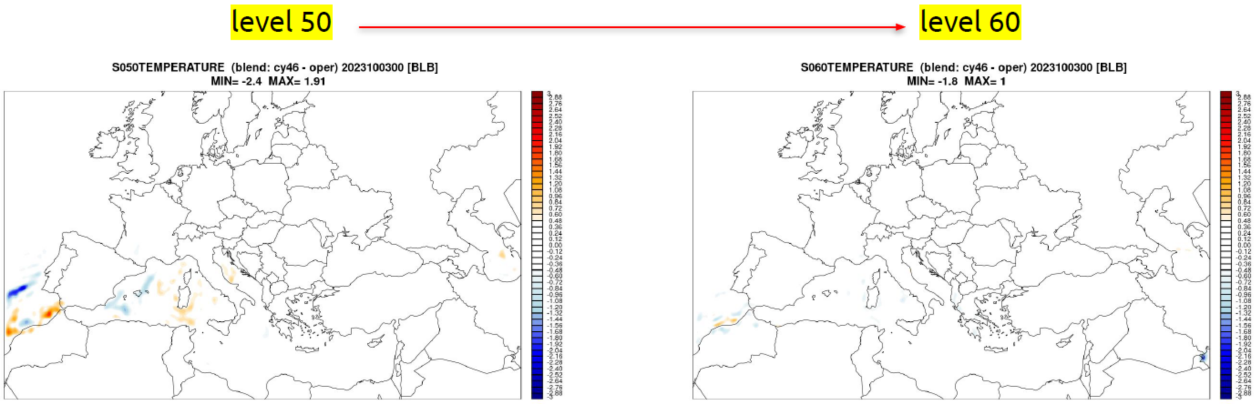


Figure 1: Differences of temperature at level 50 (left) and level 60 (right) between new DFI blending on cy46t1 and the operational cy40t1 blending in A-LAEF.

Upgrade of 001 to cy46t1

The operational A-LAEF suite is still running on cy40t1 – the planned upgrade to cy43t2 or cy46t1 has been postponed in the past years several times due to missing resources. This topic has been finally tackled in the second half of 2023 by setting up a cy46t1 Esuite of A-LAEF on the ECMWF HPC. This suite also includes inline grib production (grib version 2) which replaces the previously used external GL tool. Therefore, the grib2 tables within a local concept for newly defined LACE center (id 249) were prepared, to be used in A-LAEF inline grib encoding. When verifying the cy46t1 Esuite and comparing it to the operational cy40t1 version of A-LAEF, an issue with 2m realtive humidity over the sea arose (Figure 2).

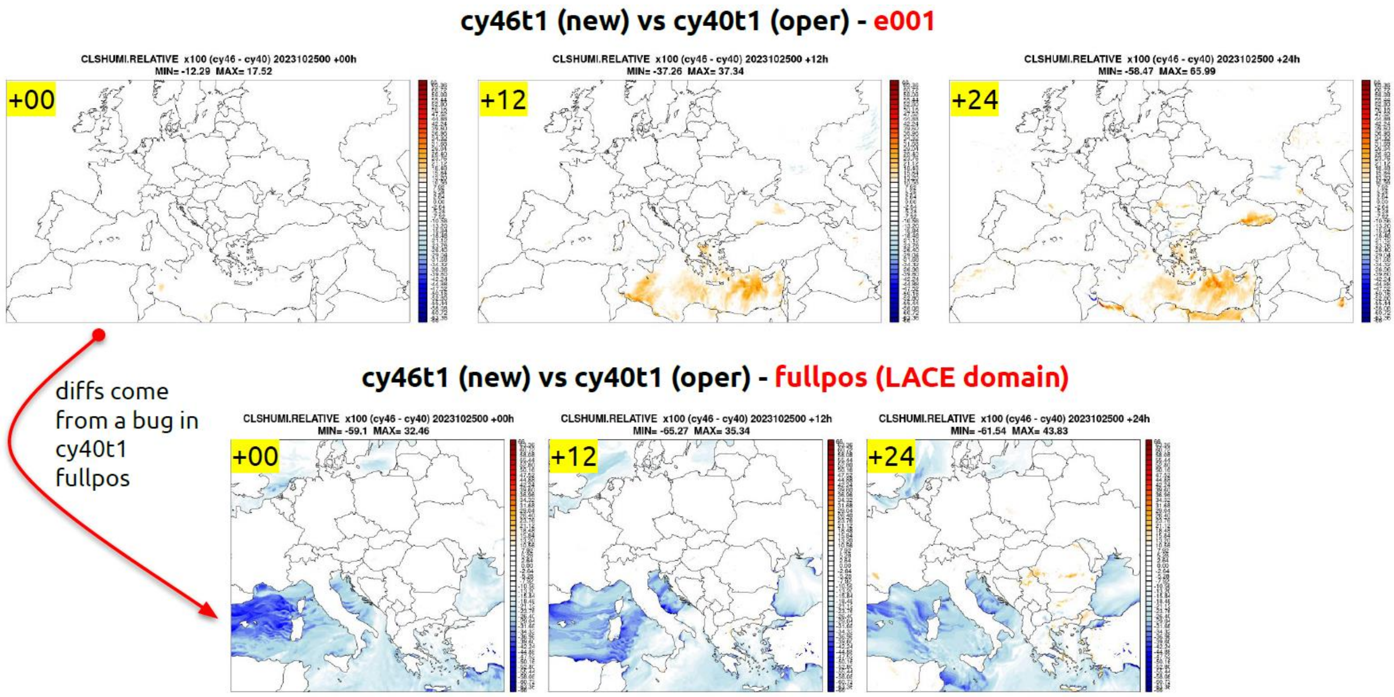


Figure 2: Differences of 2m relative humidity between cy46t1 Esuite and operational cy40t1 A-LAEF for 001 output (top) and fullpos output (bottom) for different lead times.

It turned out that the big differences between the operational A-LAEF and the cy46t1 Esuite come from a fullpos bug in the operational cy40t1 suite. The 2m relative humidity over sea is always 100% in the operational A-LAEF (Figure 3).

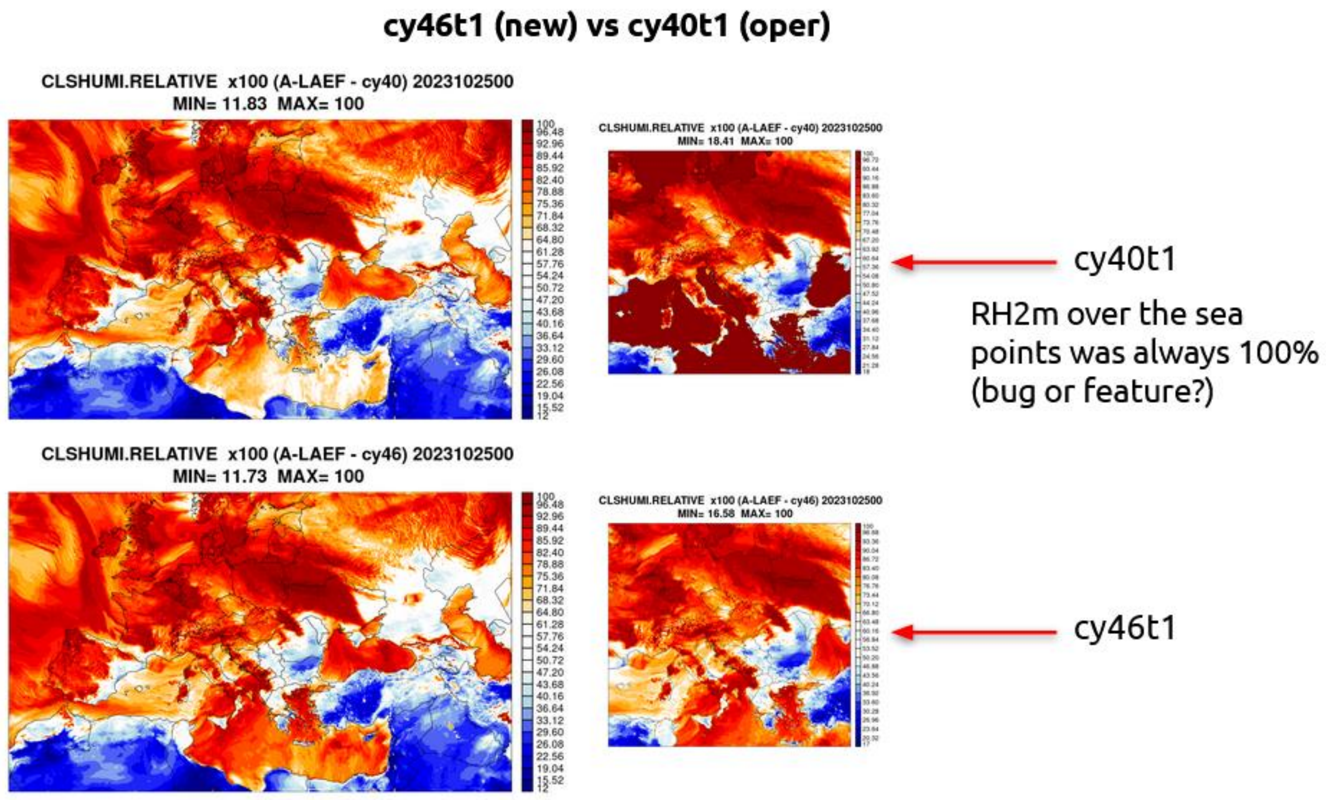


Figure 3: 2m relative humidity of A-LAEF oper (cy40t1, top) and A-LAEF Esuite (cy46t1, bottom) for a test case in October 2023.

New ALARO-1 physics clusters for A-LAEF cy46t1:

The upgrade of A-LAEF multiphysics based on the latest ALARO-1 code development at cy46t1 has been initiated at the end of 2023. However, the main work was done during a 2-week LACE stay of Martin Bellus (supervised by Jan Mašek) in Prague in January 2024, so more details will follow in the next EPS report.

To start with, two physics clusters were prepared derived from CZ operational and double suite, involved different tunings and parameterizations. Their ability to produce distinct weather scenarios was verified (Figure 4). In the next step, these two clusters will be expanded by other two using a different mixing length parameterization (the code for EL1 was not ready during the stay).

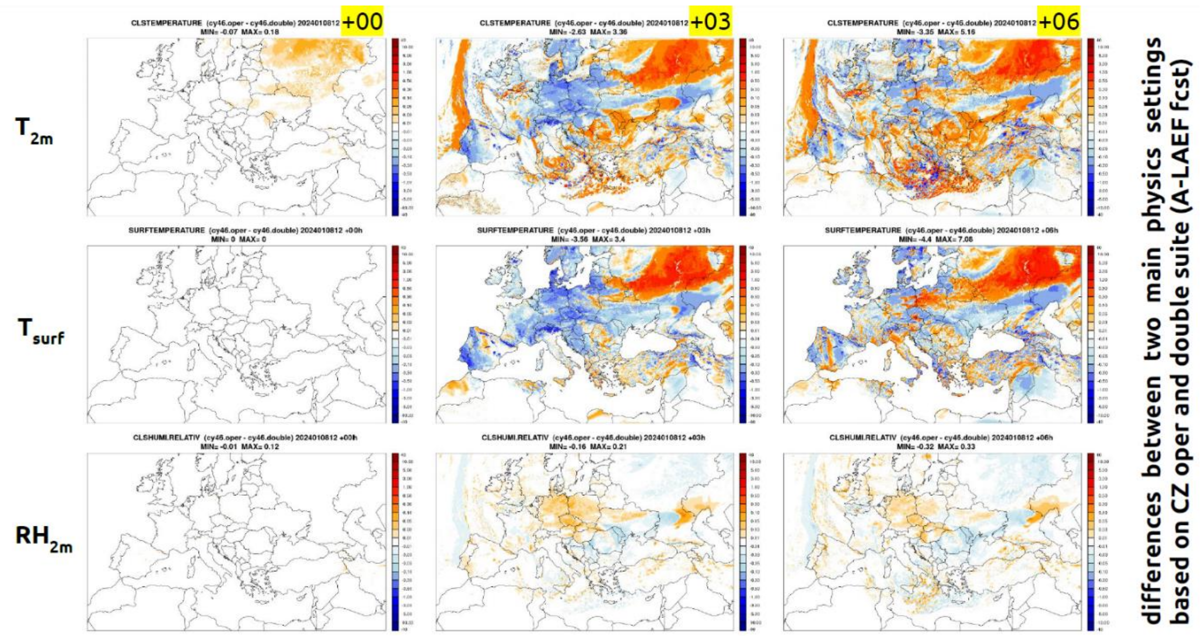


Figure 4: Differences for 2m temperature (top), surface temperature (middle) and 2m relative humidity (bottom) between two main physics settings based on CZ operational and double suite (A-LAEF) for different lead times.

New CLIM files:

New CLIM files for the A-LAEF domain were prepared with the updated physiographic fields including their low spectral truncation version for blending (Figure 5). This contributes to a further improvement of surface fields representation.

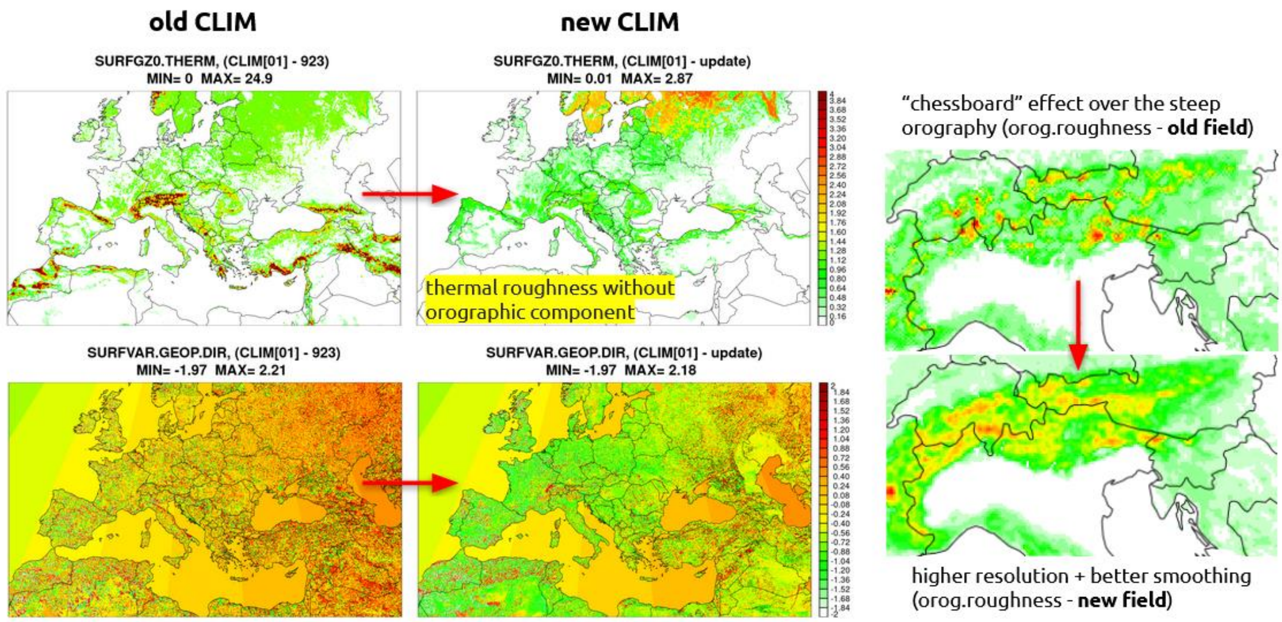


Figure 5: Comparison of old and new CLIM files for A-LAEF.

Implementation of precipitation types in A-LAEF cy46t1

The new cy46t1 code used in A-LAEF system (Esuite) already includes prognostic graupels, diagnostics of 16 distinct precipitation types, flashes, but also a wet snow and its accretion on high voltage wires (by André Simon). Regarding the probabilistic products, new maps for precipitation types were prepared and tested during a freezing rain event in south-western part of Slovakia (Figures 6 and 7).

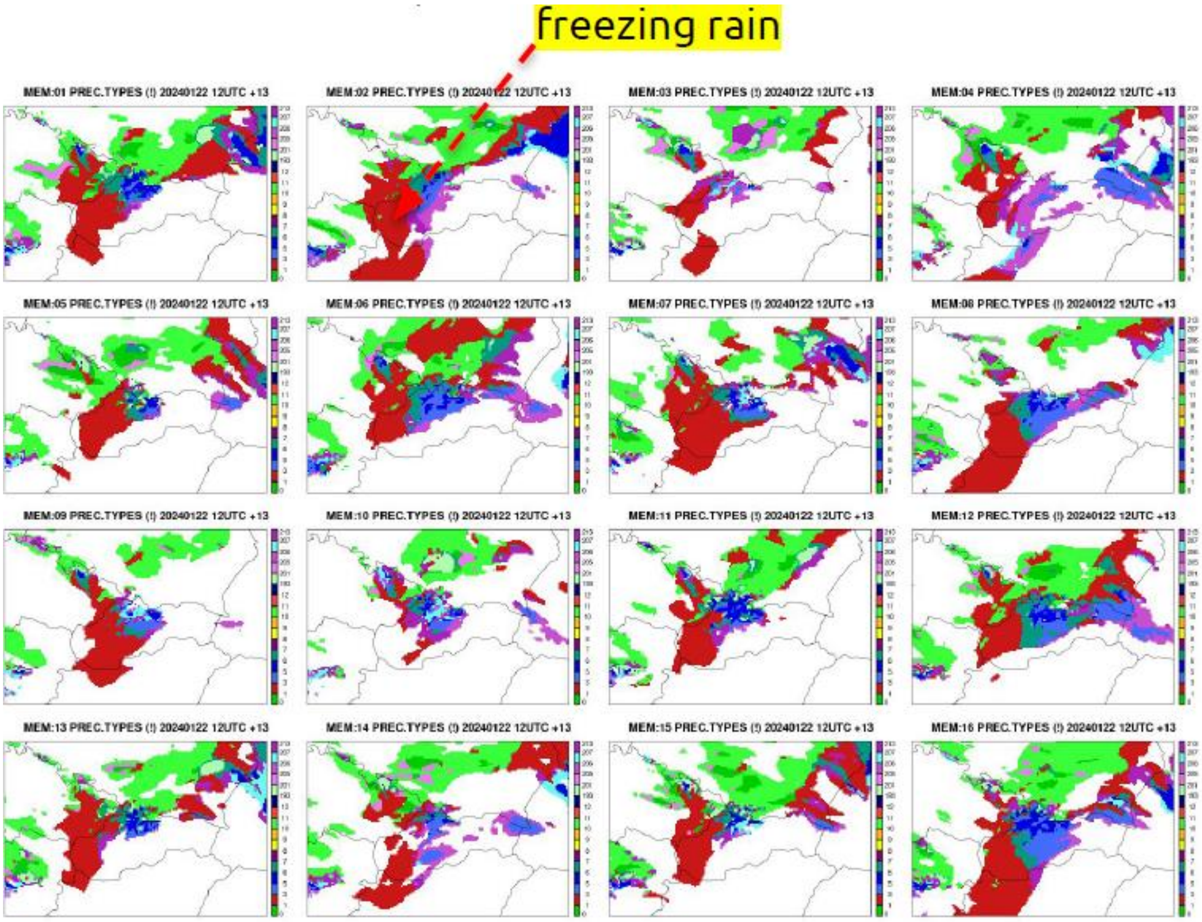


Figure 6: Precipitation types for all 16 perturbed A-LAEF members for a freezing rain event on January 23, 2024 in Bratislava.

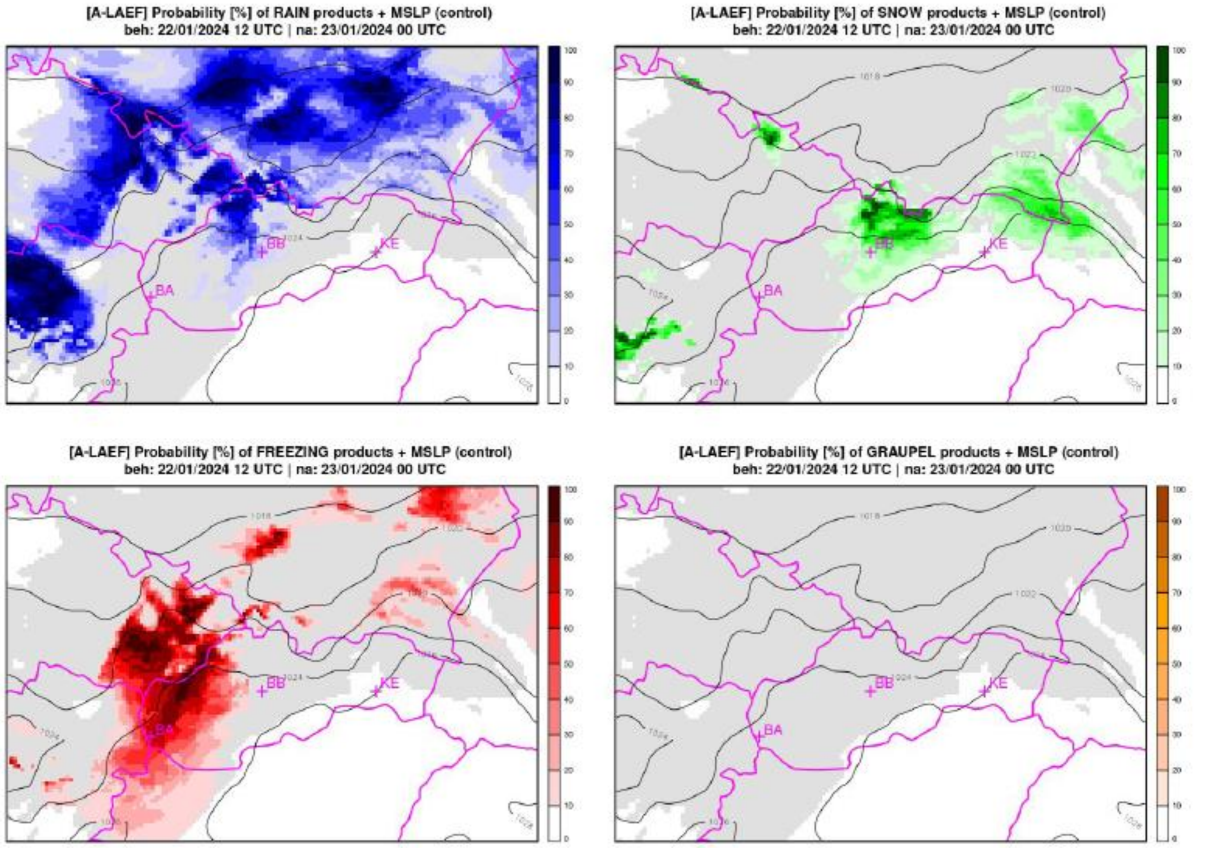


Figure 7: New A-LAEF probability maps for precipitation types rain, snow, freezing rain and graupel for the test case on January 23, 2024 in Bratislava.

- **Topic 2: Operationalization of SPP in C-LAEF**

The model error representation in the operational C-LAEF EPS has been changed from 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 a pure parameter perturbation scheme (SPP - stochastically perturbed parametrizations; Ollinaho et al., 2017) with a C-LAEF upgrade in September 2023. The idea was to increase the physical consistency in the model error perturbation scheme. In SPP uncertain parameters are directly perturbed in the physics parametrizations with some random noise generated by a pattern generator (SPG, Tsyrulnikov and Gayfulin, 2017). A first version of the SPP scheme has already been implemented in a C-LAEF Esuite in 2022 (see EPS report of 2022). This first version includes a set of 13 stochastically perturbed parameters - 11 of those parameters are listed in the following Table 2. Additionally, 2 microphysics parameters are perturbed which are controlling the sublimation of graupel and snow hydrometeors (ZRDEPGRED, ZRDEPSRED). They have been added because of too strong orographic precipitation influence on the precipitation field in the operational C-LAEF (too much precipitation on the mountains and in the luv, too less in the valleys and in the lee). By stochastically perturbing these parameters, the precipitation field in the Alps could be improved significantly.

Table 1: Parameters which are perturbed stochastically in the new SPP scheme operationalized in C-LAEF in September 2023 (in yellow boxes).

Scheme	Parameter	Physical meaning	Default	Range
Radiation	RSWINHF	Shortwave inhomogeneity factor	1	0.6 - 1
	RLWINHF	Longwave inhomogeneity factor	1	0.6 - 1
Microphysic	RCRIAUTI	Snow Autoconversion threshold	0.2e-3	0.2e-4 - 0.25e-3
	RCRIAUTC	Rain Autoconversion threshold	1e-3	0.4e-3 - 1e-3
	VSIGQSAT	Constant for subgrid condensation	0.02	0 - 0.1
Turbulence	XLINI	Minimum mixing length	0	0 - 0.2
	XCTD	Constant for dissipation	1.2	0.98 - 1.2
	XCTP	Constant for T-P correlations	4.65	1.035 - 22.22
	XCEP	Constant for V-P correlations	2.11	0.225 - 4.0
	XCED	Constant for dissipation of TKE	0.85	0.4 - 2
	XPHI_LIM	Threshold value for Sc^{-1} and Pr^{-1}	3	1 - 4.5
	XCET	Constant for transport of TKE	0.4	0.072 - 1.512
Diffusion	SLHDEPSH	Strength of SLHD	0.060	0.01 - 0.09
	SLHDKMIN	Diffusion function minimum	0	-1 - 1
	SLHDKMAX	Diffusion function maximum	6	4 - 12
Surface	XRIMAX	Critical Richardson Number	0.2	0 - 0.2
	XFRACZ0	Coefficient of orographic drag	5	2 - 10
	XCMF	Closure coefficient at bottom level	0.065	0 - 0.1
Convection	XABUO	Coefficient of the buoyancy	1	0.7 - 1.5
	XBDETR	Coefficient of the detrainment	1e-6	0 - 1
	XENTR_DRY	Coefficient for dry entrainment	0.55	0.1 - 0.699

In 2023 a lot of tuning considering the perturbation scales and ranges has been made based on verification results from the test cycles in 2022 (summer and winter period). SPP was originally planned to be put into operations in May 2023, but due to the paternity leave of the main contributor Clemens Wastl, it has been realized not before September 2023. In April/May 2023 another parallel C-LAEF suite (16 members) with SPP model perturbations has been running – verification results can be found in Figures 8 and 9. The scores are comparable to the operational C-LAEF, but SPP is a bit cheaper (5%), more flexible (better tuning) and it is physically more consistent. Furthermore the SPP scheme has been implemented and tested in the new C-LAEF 1k suite which is running continuously as an Esuite since May 2023.

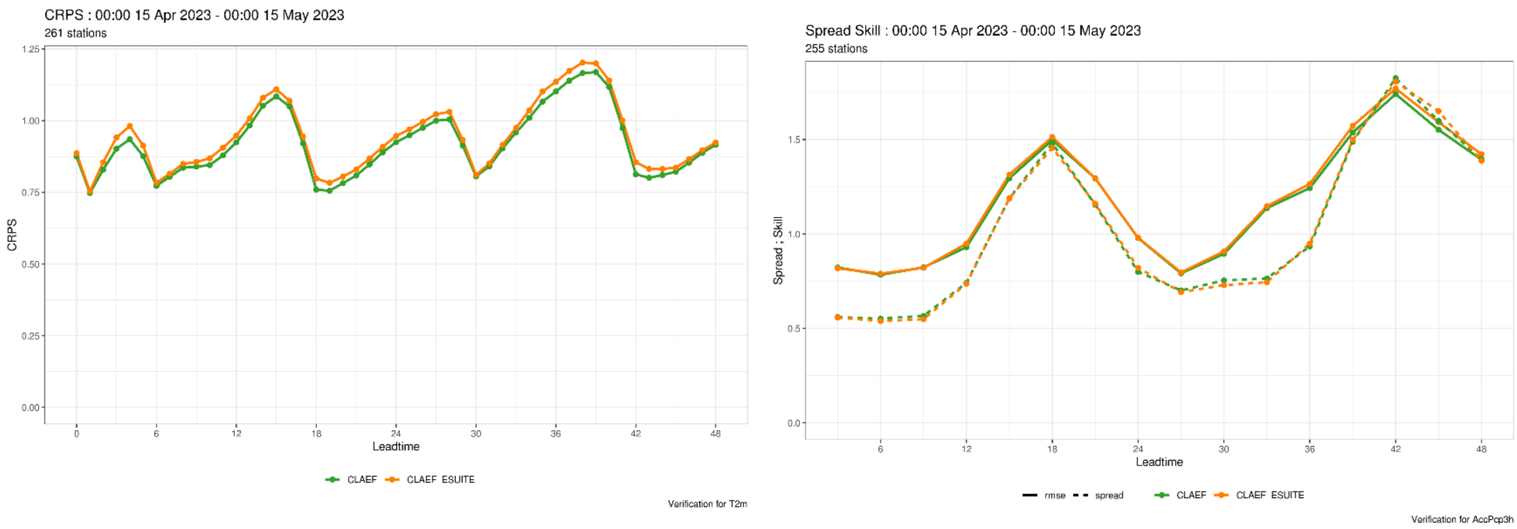


Figure 8: Comparison of C-LAEF with hybrid stochastic perturbation scheme (green) and C-LAEF Esuite with new SPP scheme (orange) for the period 15 April – 15 May 2023. CRPS for 2m temperature (left) and spread (dashed) skill (full) for 3h accumulated precipitation.

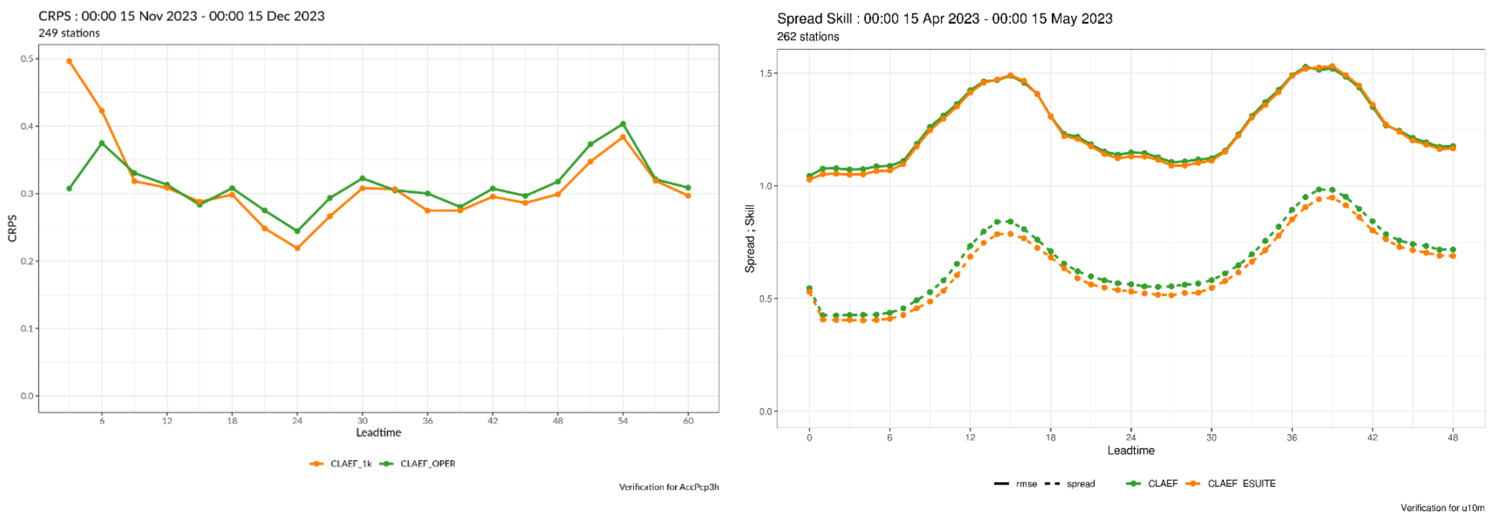


Figure 9: Comparison of C-LAEF with hybrid stochastic perturbation scheme (green) and C-LAEF Esuite with new SPP scheme (orange) for the period 15 April – 15 May 2023. CRPS for 2m relative humidity (left) and spread (dashed) skill (full) for 10m wind speed (right).

❑ Topic 3: Upgrade of C-LAEF to 1km – test suites, optimizations, verification, single precision

Strong effort in Austria is currently ongoing in upgrading the operational C-LAEF system to 1km and cy46t1. After extensive tests with AROME on 1km resolution on ECMWF ATOS-HPC in 2022 a C-LAEF 1k Esuite (based on the operational C-LAEF ecflow suite) with 1km horizontal resolution and built on cy46t1 was set up for summer 2023. The integration domain is almost identical to the operational C-LAEF domain (Figure 10).

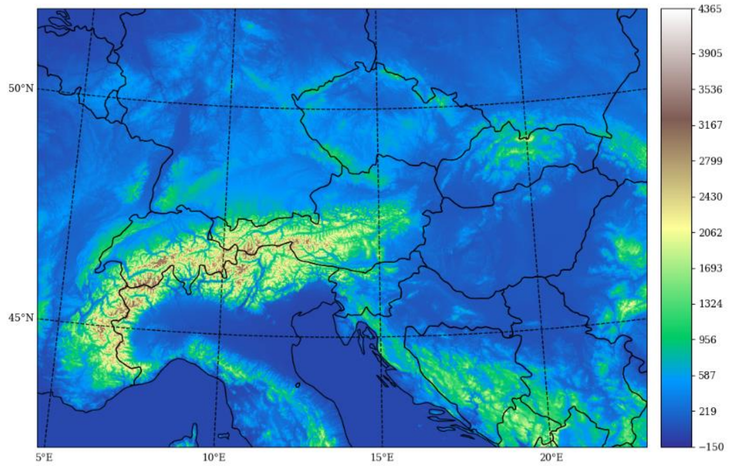


Figure 10: C-LAEF 1k domain.

The C-LAEF 1k ensemble consists of 16+1 member, where the 16 perturbed member are coupled with the first 16 ECMWF-ENS member, whereas the control run is coupled with the IFS deterministic run. We implemented a 3-hourly assimilation cycle with one long run per day, which is the 00 UTC run with a forecast range of +60h, while the other 7 runs only run up to 3 hours.

The perturbation methods include the SPP scheme for model perturbations, Ensemble-JK, EDA and surface EDA for initial condition perturbations and an external surface perturbation scheme (pertsurf).

As a result of the extensive testing of 1km AROME runs, single precision is used for configuration 001 including the usage of the I/O-server. The computing resources on ATOS for the 1km Esuite sum up to approximately 1.4 Mio SBU per day. The Esuite was initialized mid of May 2023 and is running relatively stable since mid of June. Since end of June the grib-files are shared with Slovenian colleagues. Epsgrams for selected places are also shared with Slovenian and Croatian colleagues.

A number of bug fixes and new features were implemented in the second half of 2023 where the most important are:

- Addition of ceilometer observations in 3D-Var (Austrian stations only)
- Switch off CANOPY scheme
- Fixes in SPP scheme
- Updated B-Matrix
- Additional Member using EnVAR -> all members switched from spectral to grid point output

Since beginning of February 2024 the C-LAEF 1k Esuite is stopped, except for the control run, to save computational resources.

The performance of C-LAEF 1k is monitored continuously using HARP verification software. The following verification scores were calculated for approx. 250 stations over Austria for the period from 15 November 2023 to 15 December 2023 (Figure 11). The overall performance of C-LAEF 1k is quite satisfying although some issues were observed during daily monitoring and more detailed analysis. Overall for 2m temperature and 10m Wind speed C-LAEF 1k outperforms the current operational system. For station based verification of 3hourly precipitation the scores are rather neutral with a large degradation in the first forecast hours. This is currently under evaluation and is most likely related to issues with the B-Matrix.

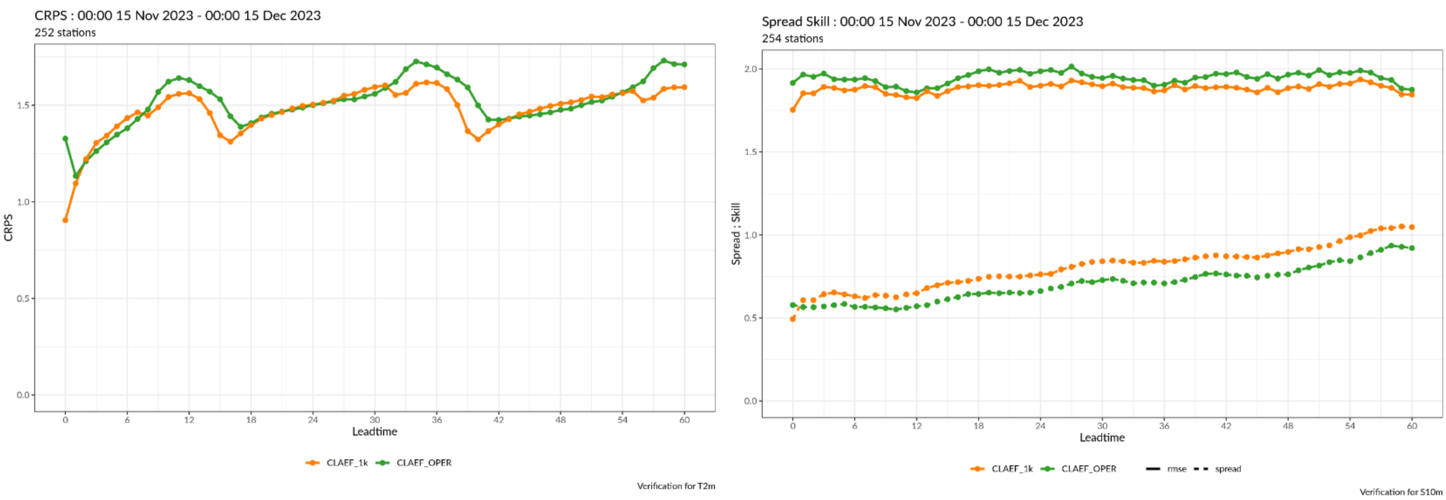


Figure 11: CRPS of 2m temperature (left), spread skill of 10m wind speed (right) of C-LAEF 1k (orange) and C-LAEF oper (green) for a verification period in November/December 2023.

An additional control member was implemented into the C-LAEF1k suite using EnVar for testing purposes. The current EnVar setup uses in total 48 member as input, 16 member from previous forecast, 16 member from last 00 UTC run, and 16 member from last available ECMWF-ENS. This setup has certainly some caveats as it mixes members with different resolutions from ECMWF-ENS and C-LAEF 1k. In addition some input member might be quite old, since e. g. for the 3 UTC run, input from 00 UTC of the same day and from 00 UTC of the previous day are used. However this is due to the current setup of only 3h forecast range for all init times except 00 UTC. The overall performance of the EnVar setup was in general comparable to the other C-LAEF 1k members. Significant differences were observed in humidity and precipitation where the EnVar Member lacks the overestimation of precipitation in the first forecast hours. However the EnVar setting appears to be too dry compared to observations (Figure 12). Further investigations are ongoing.

To expand the C-LAEF 1k system in the future (more runs, longer leadtimes, more members) a lagged ensemble approach is currently under development.

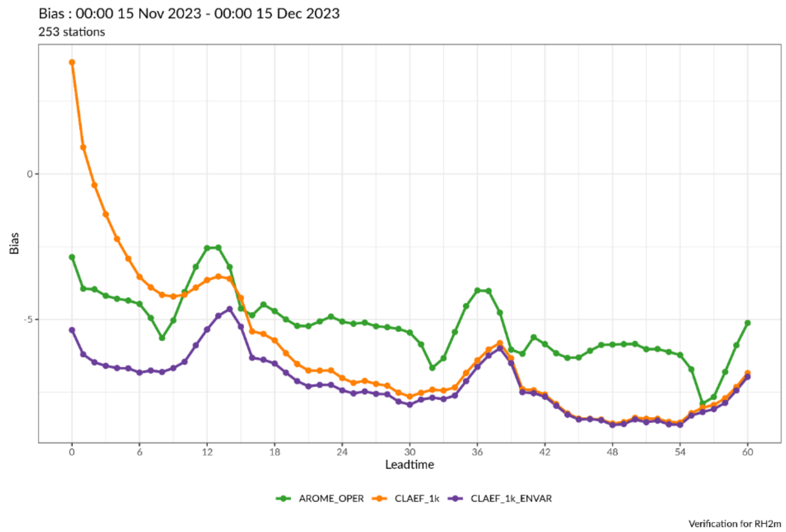


Figure 12: BIAS of 2m relative humidity of AROME operational (green), C-LAEF 1k control member (orange) and C-LAEF 1k EnVar member (purple) for a verification period in November/December 2023.

- ❑ **Topic 4: Adaptation of C-LAEF to other domains**

To increase the usage of C-LAEF it is planned to provide the C-LAEF system (scripts, source code, namelists, etc.) to other meteorological services. Turkey has already announced its interest in a high resolution EPS a few years ago. After several postponements of an ACCORD stay it could be finally realized in May 2023. Mustafa Basran from the Turkish Meteorological Service spent one week in Vienna to adapt C-LAEF for the huge Turkish domain. A lot of preparatory work has already been made before - scripts, source code and namelists have been provided to the Turkish colleagues and the B-Matrix for the assimilation has already been calculated. The one week period was a bit too short to fully implement C-LAEF for Turkey, but a first test suite with pure downscaling has been set up on the Atos HPC. The continuation of this work is planned, but has been postponed because of missing resources in the Turkish team.

❑ Topic 5: AROME-EPS: Introduction of EDA in operational AROME-EPS

The introduction of EDA in the operational AROME-EPS in Hungary has been planned for several years, but due to intensive testing and optimizations it has been postponed. A parallel suite of AROME-EPS with EDA has been set up and tested during winter and summer periods in 2022. Verification has shown that EDA has strong impact especially in first forecast hours of AROME-EPS. Furthemore, the impact of EDA is significantly stronger in summer than in winter. Most positive effect could be found for wind speed and gusts, small improvements for temperture and precipitation and rather neutral impact on relative humidity. More details and verification results can be found in the EPS report of 2022.

After this intensive testing phase EDA finally became operational in the second half of March 2023.

Efforts: 13.75 PM (planned 21.5 PM total in 2023)

Contributors: Martin Belluš and Maria Derkova (SHMU), Katalin Jávorné-Radnóczi and Gabriella Tóth (HungaroMet), Clemens Wastl, Florian Weidle, Florian Weidle, Christoph Wittmann (GeoSphere Austria)

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

Planned stays:

1. Martin Bellus (4 weeks at GeoSphere Austria) – A-LAEF upgrade – cancelled; instead Martin Bellus went for 2 weeks to Prague in January 2024 to work on the multiphysics upgrade of A-LAEF
2. Mustafa Başaran (1 week at GeoSphere Austria) - ACCORD stay - set-up of C-LAEF for Turkish domain – held from 8 – 12 May 2023

Status: Ongoing; some delays and shifts in this topic due to postponed stays and missing manpower.

S2 Action/Subject/Deliverable: Model perturbations

Description and objectives: Research and development concerning model perturbations in the three EPSs within RC LACE. Study ways to represent uncertainty in the atmospheric models itself and how to best incorporate this into the models.

The originally planned topics for 2023 were:

- ❑ A-LAEF: Stochastic perturbation of fluxes instead of tendencies in order to preserve the energy balance in a perturbed model.
- ❑ C-LAEF: Improvement of stochastic parameter perturbations (SPP) with special focus on convective hazards (e.g. processes in microphysics); make SPP cheaper (not perturbing every time-step)
- ❑ C-LAEF: Development of flow-dependent model perturbations
- ❑ AROME-EPS: Add model perturbations to AROME-EPS at HungaroMet. Work on SPPT, SPP

The A-LAEF topic (stochastic perturbation of fluxes instead of tendencies) is delayed because Martin Bellus could not arrange a stay on this topic in Vienna this year. He worked instead on an enhanced model uncertainty simulation by stochastically perturbing ISBA surface prognostic fields.

A lot of work in S2 in 2023 has been spent on the improvement of the model error representation by using SPP in C-LAEF and AROME-EPS. While the scheme has already been operationalized in Austria (September 2023, see S1), it has been tested experimentally in Hungary. Gabriella Tóth from HungaroMet made two 2-weeks remote stays (May and October 2023) where she implemented the SPP code and the SPG pattern generator into the AROME-EPS system.

The work on flow-dependent model perturbations has also proceeded very well in 2023. During his stay in Vienna in October 2023 Endi Keresturi from Croatia implemented a complete flow-dependent SPP scheme which is currently tested in an Esuite at GeoSphere Austria.

❑ Topic 1: Stochastic perturbation of ISBA surface prognostic fields

To enhance the model uncertainty simulation in A-LAEF, the stochastic perturbation of ISBA surface prognostic fields has been implemented into cy46t1. The output of a stochastic pattern generator has been used to perturb physics tendencies in ISBA (Figure 13).

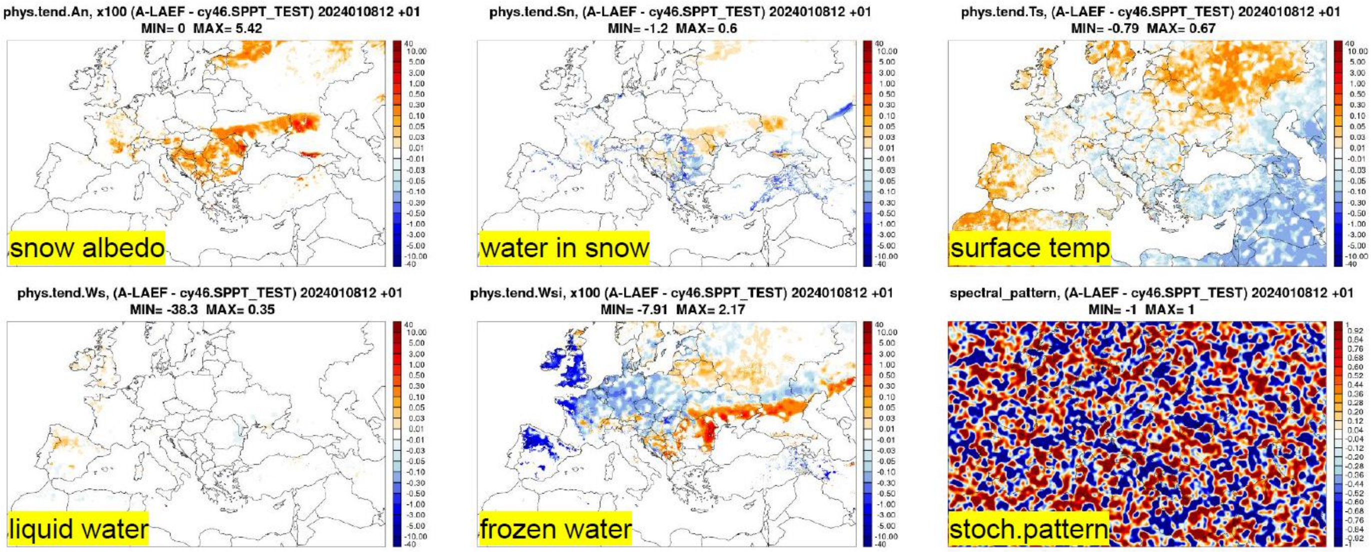


Figure 13: Perturbed physics tendencies for selected ISBA fields in A-LAEF.

- ❑ **Topic 2: Development of flow-dependent model perturbations**

SPP scheme is a widely used perturbation scheme to represent model uncertainties but it is purely stochastic - the perturbations are applied completely randomly without any consideration of the weather/flow situation. The idea in this subject is to develop a kind of intelligent perturbation scheme which applies perturbations especially in areas where most impact can be expected (frontal zones, convective areas, etc.). The work has been initiated in 2022 and has been continued during a stay of Endi Keresturi at GeoSphere Austria in October 2023. SPP FD (for flow dependent) has been implemented in the new C-LAEF 1k configuration of GeoSphere Austria on cy46t1 with a horizontal resolution of 1 km. Changes to the code made during the previous stay were phased to cy46t1. In total, there are 6 physics schemes that are affected by SPP in C-LAEF (see Table 1 in S1). Flow-dependent perturbations have been implemented to all physics schemes and all parameters. There are 11 namelist switches for 12 parameters which are perturbed.

Following Ollinaho et al. (2017), in C-LAEF, SPP-perturbed parameters $\hat{P}$ are obtained by equation 1:

$$\hat{P} = P\, e^{c+w\varphi} \quad (1)$$

Where P is the original constant parameter, ϕ is normally distributed stochastic perturbation pattern and c and w are some constants. This results in a log-normal distribution for $\hat{P}$ which has a nice consequence that perturbed parameters will not change the sign. The stochastic perturbation pattern ϕ varies in space and time independently for each parameter and ensemble member. After the perturbations are applied according to (1), each parameter is clipped to remain inside its physical limits. Additionally, impact of ϕ can be tuned for each parameter separately by adjusting c, w or its clipping values. Increasing (decreasing) w will increase (decrease) the magnitude of the applied perturbations and increasing (decreasing) c will move the log-normal distribution to the right (left) resulting in shifting all the perturbations in positive (negative) direction.

In SPP FD the pattern generator is not changed, but the existing pattern is modified by some weights. The idea is to diagnose which areas in the model are the most unstable for each parameter and then to modify the pattern so that it perturbs more in those areas, i.e., to amplify perturbations. The weights are then added to the perturbation field as w in (1), i.e., they multiply the pattern. From (1), we see that in the areas where w=1, nothing will happen and where w>1 (w<1), the perturbations will be amplified (attenuated). This means that we the weights are satisfying this condition (because we want to amplify perturbations): w ϵ [1, Wmax] where Wmax is some arbitrary number. The question is how to find which areas of the domain to target, i.e., how to determine the magnitude and the spatial distribution of weights? The approach taken is rather pragmatic – for each of 12 parameters a particular model variable will be used to diagnose sensible areas for that parameter. For microphysics, we have chosen a cloud fraction field since microphysics governs the cloud particle formation, growth, and dissipation. The two radiation parameters are also closely related to clouds, so the same cloud fraction field is used. For three turbulence and one shallow convection parameters, TKE field was chosen since all of them are related to turbulence and for the final orographic drag parameter a 10 m wind speed is used because wind is a measure of the atmospheric flow near the surface. The fields used as weights are transform to [1, Wmax]. Cloud fraction is already between 0 and 1 so it is almost ready to be used as weights. First, as this field is given for all model levels separately, it needs to be summed up over all model levels. Then, this new field w' is slightly modified:

$$w = MIN[(w'Nl \times N) + 1, Wmax] \quad (2)$$

Where Ni is the number of vertical levels in the model, N is some arbitrary real number and w are the final weights. The division by Nl is done to normalize the values (go to 0-1) because Nl is the maximum value in w'. We multiply by a factor of N=1.5 to increase the impact. 1 is added to ensure that minimum value is 1. Lastly, MIN ensures that no value is bigger than Wmax.

TKE field is given for all levels and has unbounded values greater than 0. This means that we need to calculate the maximum TKE value (TKEmax) over all levels and the whole domain to normalize it. This is not a trivial task since the physics part of the model is heavily parallelized and information is not shared between the processors and the calculation of maximum value requires that we have information from all processors. Nevertheless, the problem was eventually solved (calculating TKEmax every timestep by using gpnorm_gfl.F90 routine and then using mpl_send/mpl_recv to share the value between the different MPI tasks) and the maximum value of TKE was obtained. For wind field, the same procedure as for TKE is implemented.

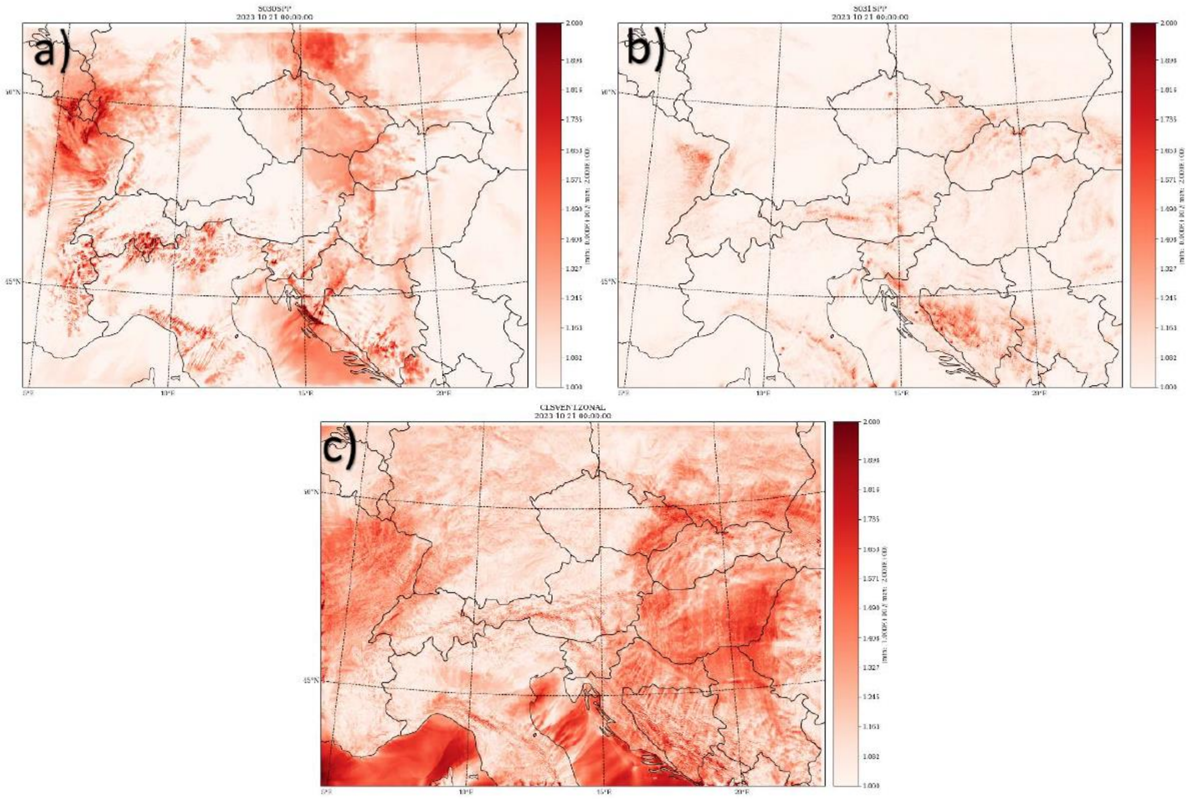


Figure 14: Example of flow-dependent weights obtained from a) cloud fraction, b) TKE and c) 10 m wind speed for ensemble member 2 valid at 21. 10. 2023 at 00 UTC.

SPP FD has been tested for 2 selected case studies in 2023 with all 17 members of C-LAEF 1k and an integration duration of 60h. To see the impact of flow dependency, 4 experiments have been run. **NO_SPP** – reference experiment where no SPP perturbations are used. **SPP** – standard SPP configuration is used. **SPP_FD** – flow dependent perturbations are used and *Wmax*=2. **SPP_FD2** - flow dependent perturbations are used and Wmax=3. The last one was performed to assess the impact of additionally increasing the flow dependent weights' magnitude.

The first case study is a strong-wind event from 19 October 2023. Figure 15 shows domain averaged spread for three SPP experiments with respect to NO_SPP and for different surface variables averaged over two model runs. It is clearly visible that SPP_FD has more spread for each variable during the whole integration. The same is true for SPP_FD2 which has more spread than SPP_FD. The reduction of spread in all SPP experiments and in the differences between them is visible at the end of model integration. This is explained by the fact that the weather situation is calmer by that time. SPP FD does not change the mean state of the model.

Figure 16 shows ensemble mean bias, RMSE/spread and spread/RMSE ratio for 10m wind speed and for all experiments averaged for 253 stations in Austria (similar results for 2m temperature and humidity). SPP increases already present biases in the model, and impact of flow dependency is in the same direction, but minimal. RMSE and spread scores reveal that impact of standard SPP on spread is positive and impact on RMSE is slightly negative. However, impact on spread is more positive than negative impact on RMSE, meaning that spread/RMSE ratio is better. SPP FD increase spread slightly and increase RMSE slightly less when compared to SPP. The overall impact is similar as in SPP vs NO_SPP - spread/RMSE ratio is slightly better than in the standard SPP.

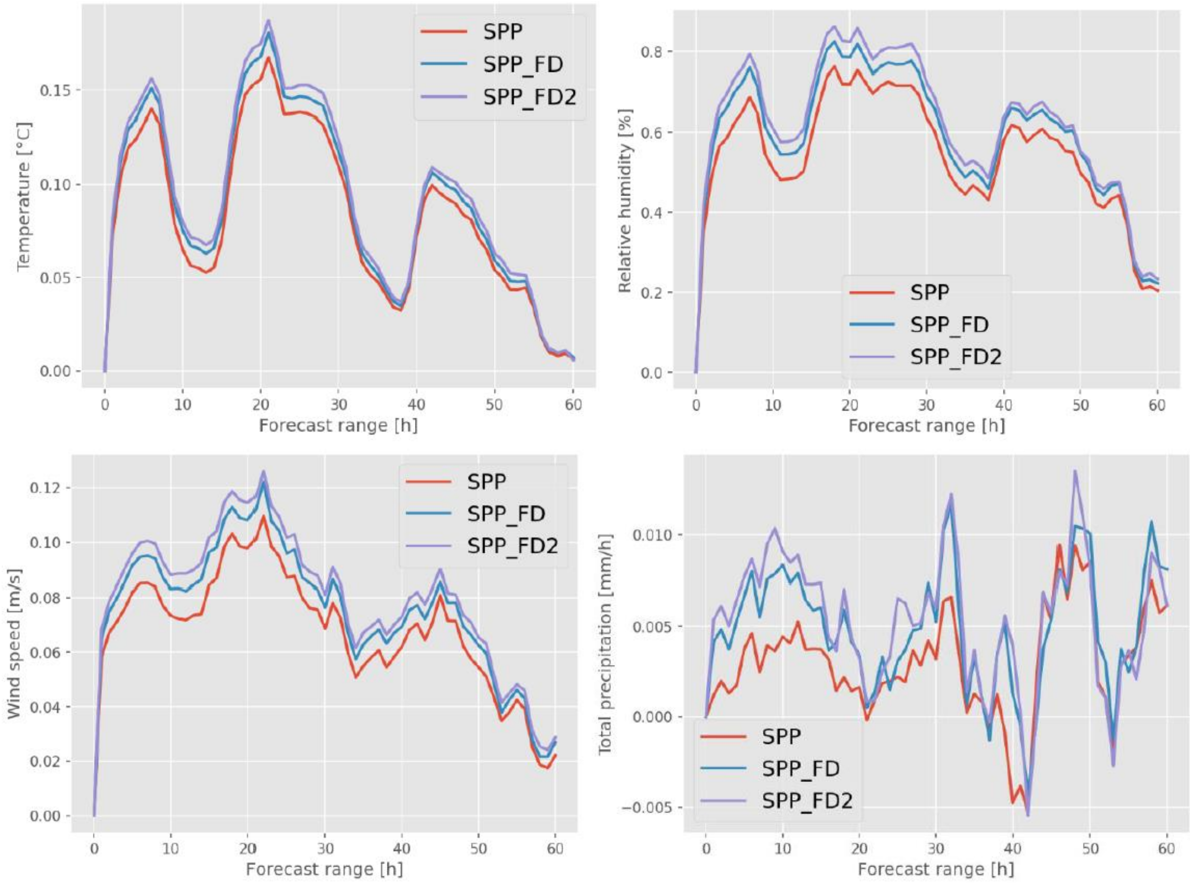
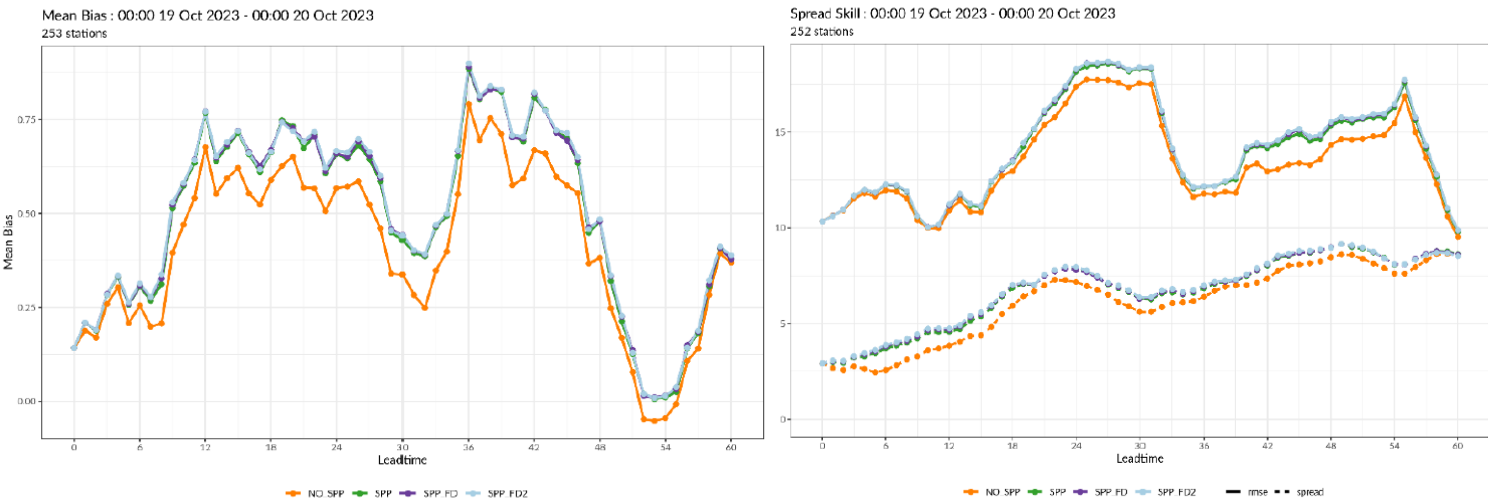


Figure 15: Domain averaged spread (19 October 2023) for three SPP experiments with respect to NO_SPP for 2m temp., 2m rel. hum., 10m wind and total precipitation.

The second case study is a high-precipitation event from 3. - 5. August 2023. Like before, domain averaged spread is higher for SPP_FD2 experiment for all variables and almost all lead times (Figure 17).

In conclusion it can be said that SPP FD behaves expectedly, meaning that in the targeted regions perturbations are amplified and the differences “move” with the weather. Spread is increased for all variables and for almost all lead times. Impact is smaller for higher vertical levels as we move away from the ground, but this is expected. Effect on precipitation forecast over Austria in large-scale flow forcing case (October) is almost negligible but is more noticeable in a summer convection case. Still, differences remain visible mostly in precipitation quantity and not in spatial distribution. Verification performed on October case reveal that impact of flow dependency is slightly positive on ensemble spread and less negative on RMSE meaning that RMSE and spread ratio is improved. Overall, the new method acts in the desired direction.

Next, a more comprehensive verification is needed. This includes a long-term evaluation and a few additional case studies (both winter and summer). Currently a Esuite with SPP FD is running at the ECMWF HPC.



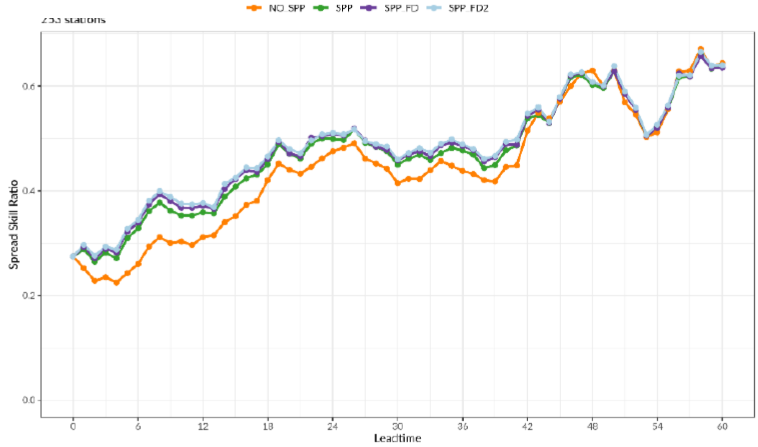


Figure 16: BIAS (upper left), RMSE/spread (upper right) and spread/skill ratio (bottom) for 10m wind speed on 19 October 2023 for the four experiments.

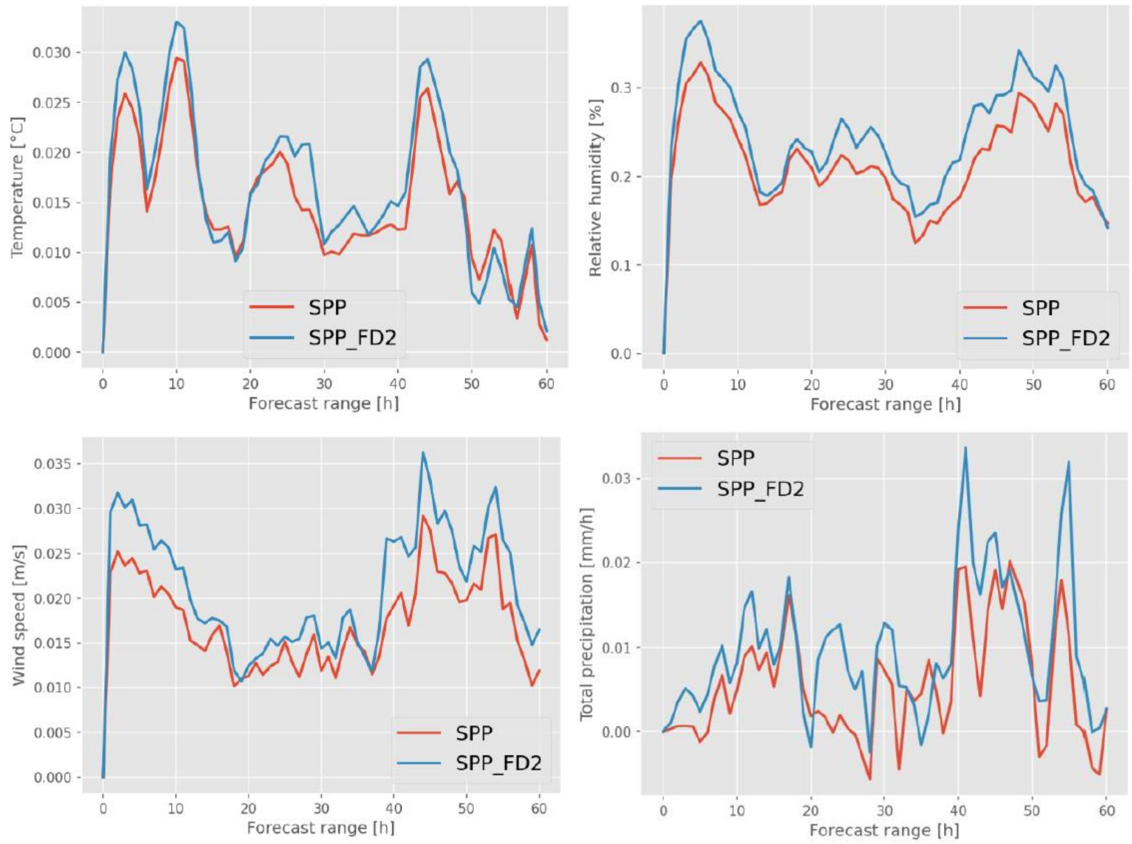


Figure 17. Domain averaged spread (19 October 2023) for three SPP experiments with respect to NO_SPP for 2m temp., 2m rel. hum., 10m wind and total precipitation.

❑ Topic 3: AROME-EPS – implementation of model perturbations (SPP)

After turning EDA in AROME-EPS into operations in March 2023, HungaroMet started working on stochastically perturbed parameterizations (SPP) to represent the model errors. GeoSphere Austria has been mentoring the first steps in the framework of a remote stay of Gabriella Tóth, which has been separated into two 2-week parts.
During the first two weeks, between 8 and 20 May 2023, she started to extend the code of AROME/HU with SPP and compile a new MASTERODB binary. In the second part of the remote stay which was held between 16 and 27 October 2023, the work was continued with the parameter perturbation tests and an experiment was run applying the chosen perturbations.

SPP allows to investigate the sensitivity of the model on the individual physical parameters by perturbing them one-by-one. During the perturbation, a spatially and temporally varying 2-dimensional stochastic pattern field was used, generated by the earlier installed stochastic pattern generator (SPG). During the local application, in consistence with the settings of the operational model, 100 km was chosen as spatial length scale, 0.5 as standard deviation of the random field, and 3600 s as temporal length scale in the pattern generator. As it was realised later, 3600 s is probably too short period for temporal length scale, which will be also reflected by the results.
10 parameters were perturbed in the first experiment, all were tested one by one during a 36-hour long test forecast run. The perturbations were following lognormal distribution. In most cases, the operational value of the parameter was set to the mean of the perturbation, only for PSIGQSAT (subgrid condensation constant) and XFRACZ0 (orographic drag coefficient) was set as median of the distribution. The unperturbed values of the parameters followed the suggestion of MeteoFrance (Wimmer et al., 2022). Only one exception was taken for the snow auto conversation threshold (RCRIAUTI), for which parameter we use a higher value operationally (RCRIAUTI=1*10-3), as the original value causes unrealistically much snow in our model. During the perturbation of RCRIAUTI, its range was shifted consistently with our operational parameter value, otherwise it would have fallen out from the originally suggested range. The individual impact of the one-by-one perturbed parameter was not spectacular.

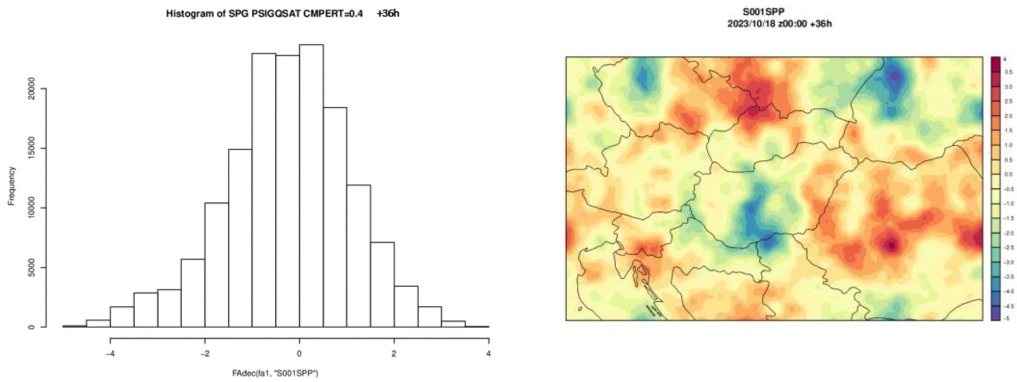


Figure 18: Probability distribution function and plot of the generated stochastic pattern field for 18 October 2023 00 UTC +36h.

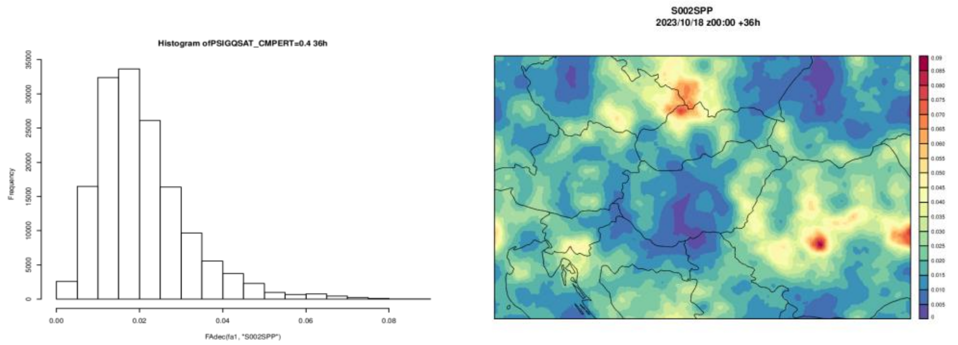


Figure 19: Probability distribution function and plot of perturbed PSIGQSAT and CMPERT=0.4 for 18 October 2023 00 UTC +36h.

The first SPP experiment was run between 01 and 14 December 2023. The initial condition was identical with the one applied in the operational AROME-EPS, SPP was not added to EDA in this experiment to see its pure effect on the forecast. Each day included a 48-hours long forecast at 00 UTC, and the EDA was cycled with 3-hourly. The first forecast was preceded by 10 days long spin up period.

According to the ensemble scores produced by this experiment, SPP mostly had neutral impact on the spread, but it caused a slight RMSE decrease in 2m temperature and relative humidity (Figure 17 a-b) On the other hand, RMSE was increasing in 10m wind speed and wind gust (Figure 17 c-d). The upper air results are mostly neutral.

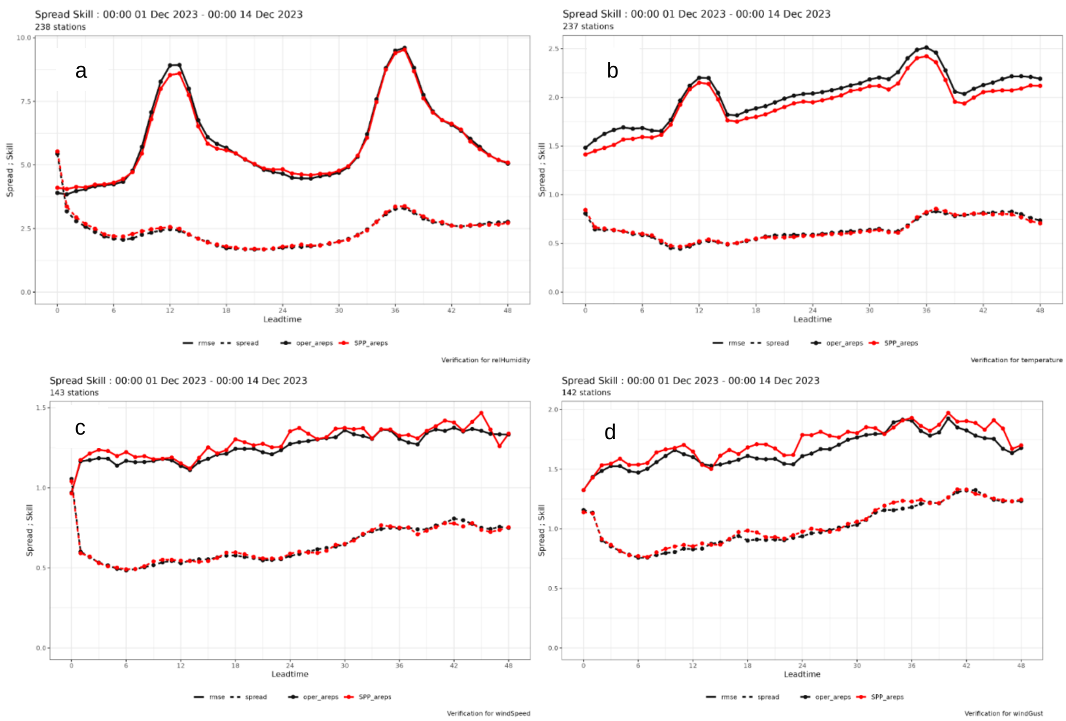


Figure 20: Spread and skill for AROME-EPS oper (black) and SPP (red) of 2m relative humidity (a), 2m temperature (b), 10m wind speed (c), 10m wind gust (d) for the period 01 to 14 December 2023.

As the results of the first experiment confirmed, the parameter perturbation is working well technically, but it still does not have the expected impact on the spread. It will be necessary to rerun the experiment with a longer temporal length scale, e.g. 6 hours instead of 1 hour. It is also important to test, how it affects the initial condition, if we apply SPP in the assimilation cycle. It would be also interesting to see results from a summertime experiment in the further steps.

Efforts: 9.25 PM (planned 5.25 PM in total in 2023)

Contributors: Martin Belluš (SHMU), Clemens Wastl (GeoSphere Austria), Endi Keresturi (DHMZ), Gabriella Tóth and Katalin Jávorné-Radnóczi (HungaroMet)

Documentation: papers published in scientific journals; convection-permitting ensemble systems for operational use (SHMU, GeoSphere Austria, HungaroMet); EPS documentation

Planned stays:

Endi Keresturi (4 weeks GeoSphere Austria) – flow dependent model perturbations (9 October – 3 November 2023)

Gabriella Tóth (4 weeks remote stay, mentored by GeoSphere Austria) – SPP in AROME-EPS: 2 weeks held from 8-19 May 2023, 2 weeks from 16-27 October 2023

Status: Ongoing; mostly in time

3 Action/Subject: Initial condition perturbations

Description and objectives: Research and development concerning initial condition perturbations in the three EPSs within RC LACE.

The originally planned topics for 2023 were:

- ❑ A-LAEF: Utilization of A-LAEF operational forecasts for flow-dependent B-matrix computation to be used in local assimilation cycles of RC LACE members.

This topic is delayed because the planned stay of Martin Bellus at GeoSphere Austria could not be arranged so far (personal reasons). Therefore also the main work in this action had to be postponed.

Efforts: 0.0 PM (planned 1.0 PM in total in 2023)

Contributors: Martin Bellus (SHMU)

Documentation: papers published in scientific journals; convection-permitting ensemble systems for operational use (SHMU, GeoSphere Austria, HungaroMet); EPS documentation

Planned stays:

1. Martin Bellus (4 weeks at GeoSphere Austria) – flow-dependent B-Matrix – postponed

Status: Ongoing. Delay because of postponed stay of Martin Bellus at GeoSphere Austria

4 Action/Subject: Surface perturbations

Description and objectives: Research and development concerning surface perturbations in the three EPSs within RC LACE.

The originally planned topics for 2023 were:

- ❑ No topics planned.

There is currently no research ongoing in this topic in RC LACE. An externalized surface perturbation scheme is already used operationally in C-LAEF (pertsurf) and Hungary is planning to add such a scheme into their AROME-EPS system in 2024. However, there is some research ongoing in ACCORD on this topic where they adapt the SPP scheme to be used in surfex. So in the future this might be interesting for RC LACE as well.

Efforts: 0.0 PM (planned 0.0 PM in total in 2023)

Contributors: Documentation:

Planned stays:

Status:

5 Action/Subject: Lateral boundary condition perturbations

Description and objectives: Research and development concerning lateral boundary condition perturbations in the three EPSs within RC LACE.

The originally planned topics for 2023 were:

- ❑ No topics planned.

The coupling of the local convection-permitting EPS in Slovakia with A-LAEF has already been tested in 2022 with 903. This is planned to be used for a later operational setup of this local EPS.

Efforts: 0.0 PM (planned 0.0 PM in total in 2023)

Contributors:

Documentation:

Planned stays:

Status:

6 Action/Subject: Statistical EPS and user-oriented approaches

Description and objectives: Research and development concerning statistical calibration of EPS data to reduce systematic errors; research and development of new products; user-oriented approaches to increase the reputation of EPS

The originally planned topics for 2023 were:

- ❑ A-LAEF: Continuation work on methods for analog-based post-processing of probabilistic fields on a regular grid
- ❑ A-LAEF: Objective identification of convection objects and of severe storms in ensemble outputs using deep NN
- ❑ C-LAEF, AROME-EPS: Work on statistical post-processing of EPS data (e.g. new calibration methods)
- ❑ C-LAEF: Generation of ensemble members by deep learning algorithms
- ❑ ALL: Development of new probabilistic products to meet users requirements
- ❑ ALL: Development of decision-making criteria based on EPS for various users (e.g. hydrology, renewable energy, road safety, mountaineers, etc.)

A lot of work is currently ongoing in this topic. The work on analog-based post-processing has been continued during a stay at GeoSphere Austria in November 2023. The original contributor (Iris Odak Plenkovic) was not able to come to Vienna, but her colleague Ivan Vujec took over. He analyzed a few machine learninig (ML) techniques to improve NWP wind speed forecasts in Croatia.

At GeoSphere Austria the statistical post-processing with SAMOS has been extended to +46 days, new spatial data-driven ML nowcasting approaches have been developed for solar radiation, wind speed and precipitation and a point data-driven forecasting and post-processing ML technique has been developed for applications in the energy sector.

Some progress has also been achieved in the EPS products on the RC LACE webpage - C-LAEF is displayed now.

- **Topic 1: Analog-based post-processing of probabilistic fields on a regular grid**

In the area of analog-based post-processing of probabilistic fields on a regular grid the work of Iris Odak Plenković has been continued by her colleague Ivan Vujec who has stayed for 1 month (6 November – 1 December 2023) at GeoSphere Austria in Vienna. He analyzed a few machine learning techniques (simpler ones such as linear regression, and more complex ones such as XGBoost and Artificial Neural Networks) and tried to improve NWP forecasts for wind speed for a few locations near Zadar, Croatia.

The observations that were used are 3 different variations of the synthetic wind speed dataset. The hyperparameter optimization was a large part of the stay and still needs a bit more tuning. The analysis was performed using the Croatian NWP model ALADIN but also the IFS. The goal was to show improvements upon the baseline analog-based method. More details can be found in Ivan's stay report which should be published on the LACE webpage soon.

- **Topic 2: Physics-informed and data-driven machine learning (ML) nowcasting**

At GeoSphere Austria a lot of work has been initiated in 2023 in the area of machine learning (ML). New spatial data-driven nowcasting approaches have been developed based on various machine learning methods (NN, deep FFNN) for solar radiation, wind speed and precipitation. The training data set for the nowcasting consists of 4 years and the algorithm provides 6 hours forecast based on the past 6 hours (Figure 21). First results are very promising in that direction.

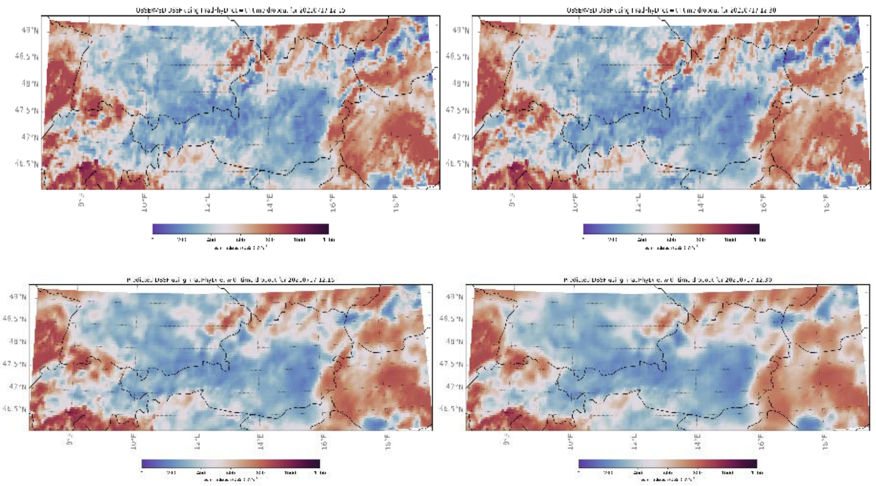


Figure 21: Observed global radiation (up) and radiation output of a pure machine learning model (bottom) for a test case in 2023.

Additionally to the spatial data-driven forecasting, also a point data-driven forecasting and post-processing machine learning technique has been developed at GeoSphere Austria. The main purpose of this model is the application in the energy sector, where point forecasts for PV production, wind power production, wind speed and temperature are provided. For PV production this is done by a random forest method combining observations of different sources trained on short available time series. For wind power production a “classical” method combining different observation sources, generating power curves from known specifications and corrections with wind atlas data generates an obs-based ensemble (Figure 22).

Furthermore, the operational statistical post-processing at GeoSphere Austria based on SAMOS (standardized anomaly model output statistics) and GMOS (gridded model output statistics) has been extended to a forecasting range of +46 days for 2m temperature and relative humidity, precipitation and 10m wind speed and gusts. Verification shows that both methods are able to improve the BIAS of the EPSs significantly and are also able to correct the under-dispersion.

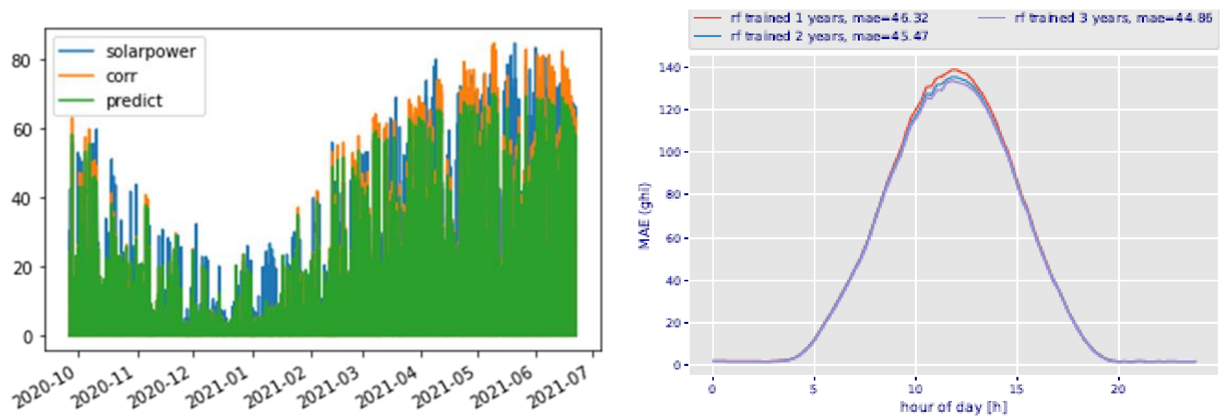


Figure 22: Left: PV power production forecast from machine learning algorithm (green is direct model output, orange is correction with wind atlas, blue is real production). Right: MAE of machine learning forecasts for global radiation at TAWES site based on different lengths of training periods.

Efforts: 10.25 PM (planned 14.25 PM in total in 2023)

Contributors: Iris Odak Plenković, Endi Keresturi, Ivan Vujec (DHMZ), Alexander Kann, Markus Dabernig, Irene Schicker (GeoSphere Austria), Martin Belluš (SHMU), Katalin Jávorné-Radnóczi (HungaroMet)

Documentation: papers published in scientific journals; convection-permitting ensemble systems for operational use (SHMU, GeoSphere Austria, HungaroMet); EPS documentation

Planned stays: Ivan Vujec (4 weeks at GeoSphere Austria; replacing Iris Odak Plenković) - analog-based post-processing methods – held from 6 November – 1 December 2023

Status: Ongoing, on time.

Activities of management, coordination and communication

- 40th LSC Meeting, 1-2 March 2023, Bratislava
- 3rd ACCORD All Staff Workshop 2023, 27 - 31 March 2023 (Tallinn), RC LACE EPS activities presented by Clemens Wastl
- 2nd ACCORD EPS working week, 24 – 28 April 2023 (Oslo)
- 41st LSC Meeting, 11-12 September 2023, Prague
- 45th EWGLAM and 30th SRNWP Meeting (Reykjavik), 25 – 28 September 2023, RC LACE EPS activities presented by Clemens Wastl

Publications

Bellus, M., A. Simon, 2023: A-LAEF migration to Bologna and extrem weather forecasts, poster at 3rd ACCORD all staff workshop, 27-31 March 2023, https://www.umr-cnrm.fr/accord/IMG/pdf/a-laef_accord_asw_2023.pdf

Szépszó G., Á. Baran, S. Baran , K. Jávorné Radnóczi , M. Kornyik, D. Tajti , 2023: Operational statistical post-processing of short-range global radiation and low-level wind forecasts (in Hungarian). Légkör 68, 3, 118–125.DOI: 10.56474/legkor.2023.3.1

Wastl C., M. Belluš and G. Szépsó, 2023: EPS research and development in RC LACE in 2022, 4th ACCORD Newsletter, https://www.umr-cnrm.fr/accord/IMG/pdf/accord-nl4.pdf

RC LACE supported stays – 3.25 PM in 2023

After almost 3 years of very low “stay activity” in RC LACE due to COVID, most of the stays could be realized in 2023. There was the ACCORD stay of Musatafa Basran (1 week at GeoSphere Austria in Vienna in May 2023) for implementing C-LAEF for Turkey, the stay of Endi Keresturi (4 weeks at GeoSphere Austria in Vienna in October/November) on flow dependent SPP for C-LAEF, the stay of Ivan Vujec (4 weeks at GeoSphere Austria in Vienna in November) on analog based post-processing, and two remote stays of Gabriella Tóth (May, October 2023) working on SPP in AROME-EPS. The two stays of Martin Bellus (upgrade of A-LAEF; flow-dependent B-matrix) have not been realized this year and are postponed to 2024.

Summary of resources [PM] – 2023

Subject	Manpower		RC LACE		ACCORD	
	plan	realized	plan	realized	plan	realized
S1: Preparation, evolution and migration	21.5	13.75	1	0	0.25	0.25
S2: Model perturbations	5.25	9.25	2	2	0	0
S3: IC perturbations	1	0	1	0	0	0
S4: Surface perturbations	0	0	0	0	0	0
S5: LBC perturbations	0	0	0	0	0	0
S6: Statistical EPS and user-oriented approaches	14.25	10.25	1	1	0	0
Total:	42	33.25	5	3	0.25	0.25

References

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.

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

Wimmer, M., Raynaud, L., Descamps, L., Berre, L. & Seity, Y. (2022) Sensitivity analysis of the convective-scale AROME model to physical and dynamical parameters. Quarterly Journal of the Royal Meteorological Society, 148, 920–942.