Working Area Predictability

Progress Report

Prepared by:	Area Leader: Clemens Wastl
Period:	Jan – Jun 2023
Date:	Sep 2023

Progress summary

There is a lot of work and progress ongoing in EPS in RC LACE at the moment - colleagues from Austria, Croatia, Hungary and Slovakia are working together to improve our operational systems and to develop new methodologies in the research sector. We are currently running three operational ensemble systems (A-LAEF, C-LAEF, AROME-EPS) and they have shown a strong benefit of local ensemble systems during several severe weather situations this year (snowfall events, floodings, wind storms). We had a major upgrade of AROME-EPS (introduction of EDA) in March this year and another upgrade is planned for C-LAEF end of September (introduction of SPP). The upgrade of the common A-LAEF system to a new cycle had to be postponed because of lacking manpower.
The upgrade of the IFS systems to a new cycle and the increased resolution of the ECMWF-ENS also influenced the LACE EPSs since we are all coupling with ECMWF-ENS. The RC LACE partners agreed on a new common coupling domain and on a new setup with more vertical levels and higher resolution. Intensive testing in advance and good cooperation resulted in a smooth transition end of June without any complications.
Strong effort is currently ongoing in Austria in the development of a 1km C-LAEF ensemble system based on cy46t1 with improved data assimilation (EnVar) and run in single precision mode. An Esuite of C-LAEF 1k has been successfully tested during the summer months and first verification scores are very promising. Slovenia and Croatia have already announced their interest into this system and a possible contribution is planned (SBUs and manpower) if the domain will be extended to the south. Further expansions of C-LAEF 1k (more long runs, longer leadtimes, more members) are planned in the future based on new methodologies (e.g. continuous lagged ensemble, optimized perturbations, etc.)

The main research topics in the EPS area of RC LACE are currently the representation of model error with SPP which is under development for Hungary and ready for operations in Austria, the continuation of work on analog-based post-processing and statistical post-processing with SAMOS. Also in the area of artificial intelligence (AI) some work is ongoing on physics-informed and data-driven machine learning (ML) nowcasting.

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 OMSZ. 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 OMSZ
- ❑ 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. Some smaller problems with the file systems appeared in April and July. However due to the redundancy of these file systems (ws1 and ws2) this did not cause big problems in the production – only some small manual interventions were necessary.

The biggest change for all of our operational ensembles this year was the switch of IFS/ENS to cy48r1 in June and the increase of spatial resolution for ECMWF-ENS from O640 to O1280. Intensive testing from several RC LACE partners was done before this switch and a common setup of coupling files for RC LACE has been defined. The switch on 27 June worked smoothly without causing any problems.

Some of the topics above have been postponed because of stays that could not be realized (e.g. ENS BlendVar, upgrade of A-LAEF to cy46t1). They are still in the plan and can hopefully be realized next year. Another delay concerns the new HPC at GeoSphere Austria, which should be delivered this year. However, until now it is not yet decided which HPC will be bought, so we do not expect a new HPC before the end of 2023.

For the operational A-LAEF suite several smaller technical upgrades have been made this year so far and the performance of the system has been analyzed for several case studies showing a quite good forecast quality.

For C-LAEF, only some small technical changes and adaptations in the operational suite have been made. The planned switch from hybrid tendency/parameter perturbations to full parameter perturbations (SPP) has been postponed from May to September. Strong effort is currently ongoing in the development of a C-LAEF 1km version. First full C-LAEF 1k suite has been set up at the beginning of the summer and has been intensively verified. The performance is generally quite good with improved scores for most parameters. Problems in the vertical temperature profile could be assigned to a bug in FPOS and have been solved now.

During a 1-week stay of a Turkish colleague in Vienna in May C-LAEF has been prepared for the Turkish domain. This is not yet finished, but work is ongoing in this topic.

The operational AROME-EPS system has undergone a major upgrade in March 2023 when introducing EDA. Next step for AROME-EPS is the introduction of model perturbations (SPP) which is planned for next year.

❑ Topic 1: Switch of IFS/ENS to cy48r1 and increase of spatial resolution of ECMWF-ENS from O640 to O1280

On 27 June ECMWF models (IFS and ENS) have undergone a cycle upgrade to cy48r1 and additionally for the ECMWF-ENS system the resolution has been increased from O640 to O1280 and is now equal to the deterministic system. Since all of our ensemble systems (A-LAEF, C-LAEF, AROME-EPS) are coupled with ECMWF-ENS this also had some impact on the RC LACE ensembles. The upgrade was communicated by ECMWF already some months before and a separate dissemination of ECMWF-ENS coupling files to test the new version with new packing (Figure 1) has been set up in May. Several versions of coupling files (horizontal resolution, number of vertical levels, with/without hydrometeors, etc.) have been tested by RC LACE colleagues from Slovakia, Croatia and Austria (see dynamics and coupling report for more details). Finally we ended up with a setup of 8.5km horizontal resolution and 105L in the vertical which entered the common coupling file production at ECMWF (maintained and run by ECMWF). To consider a common RC LACE domain for C-LAEF1k, the domain of the ENS coupling files has been enlarged to the south (including whole of Croatia and Albania), compared to the previous domain.

Some results of testing the new ECMWF-ENS coupling files can be found in the following Figures 2 to 4. The differences are quite small and the results seem to be meteorologically equivalent.

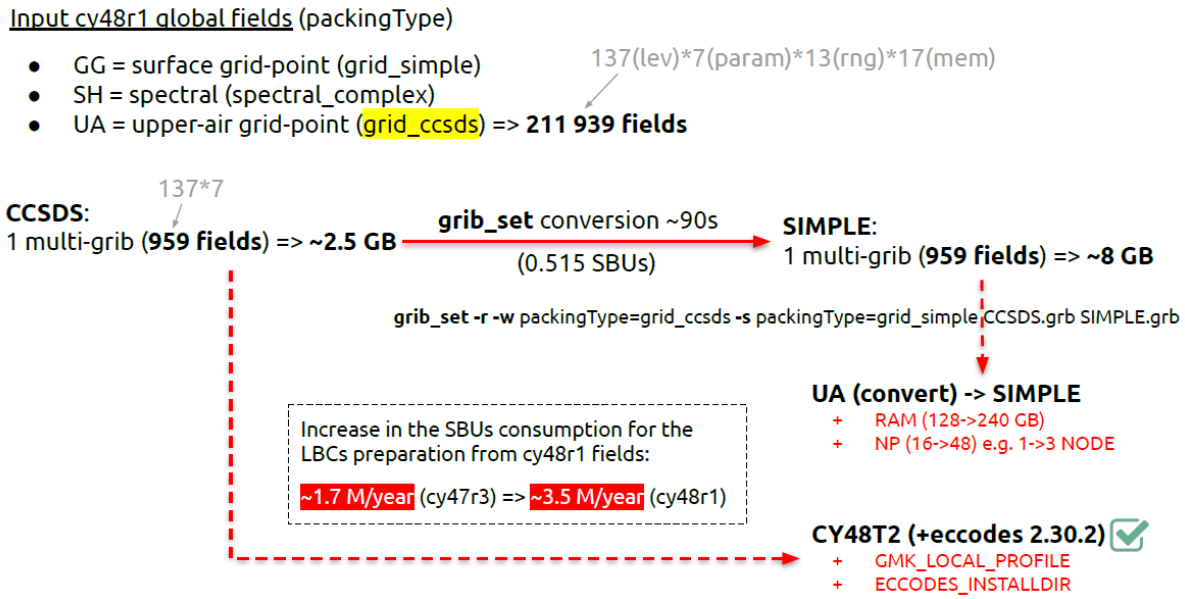

Figure 1: CCSDS packing and preparation of LBCs for A-LAEF TC2.

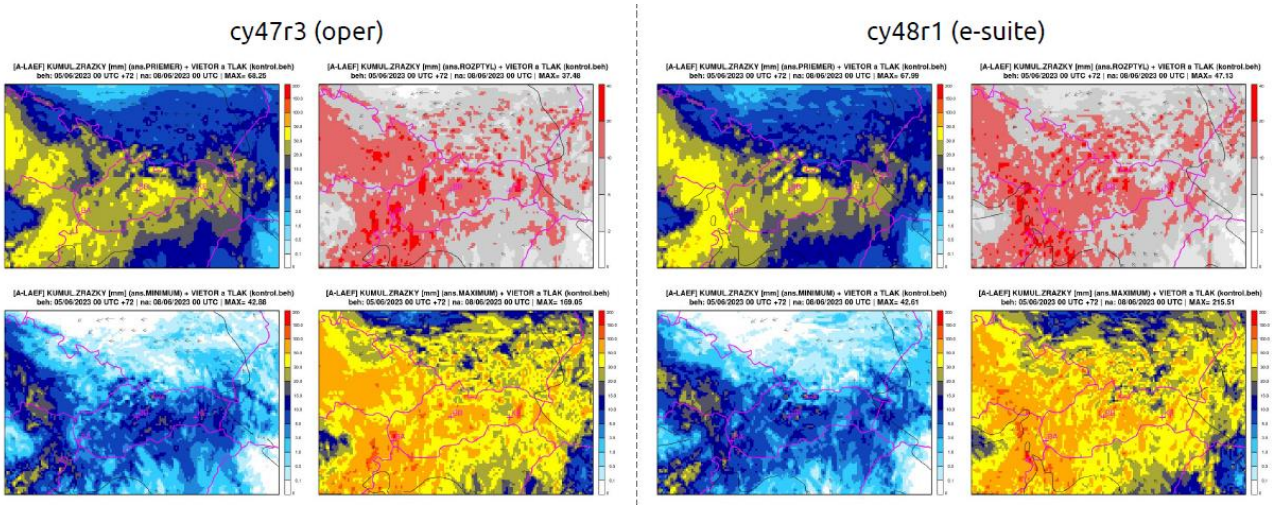

Figure 2: 24h accumulated precipitation of A-LAEF (EPS mean, spread, min, max +24h) coupled with ECMWF-ENS cy47r3 (left) and cy48r1 (right) for a test case on 5 June 2023.

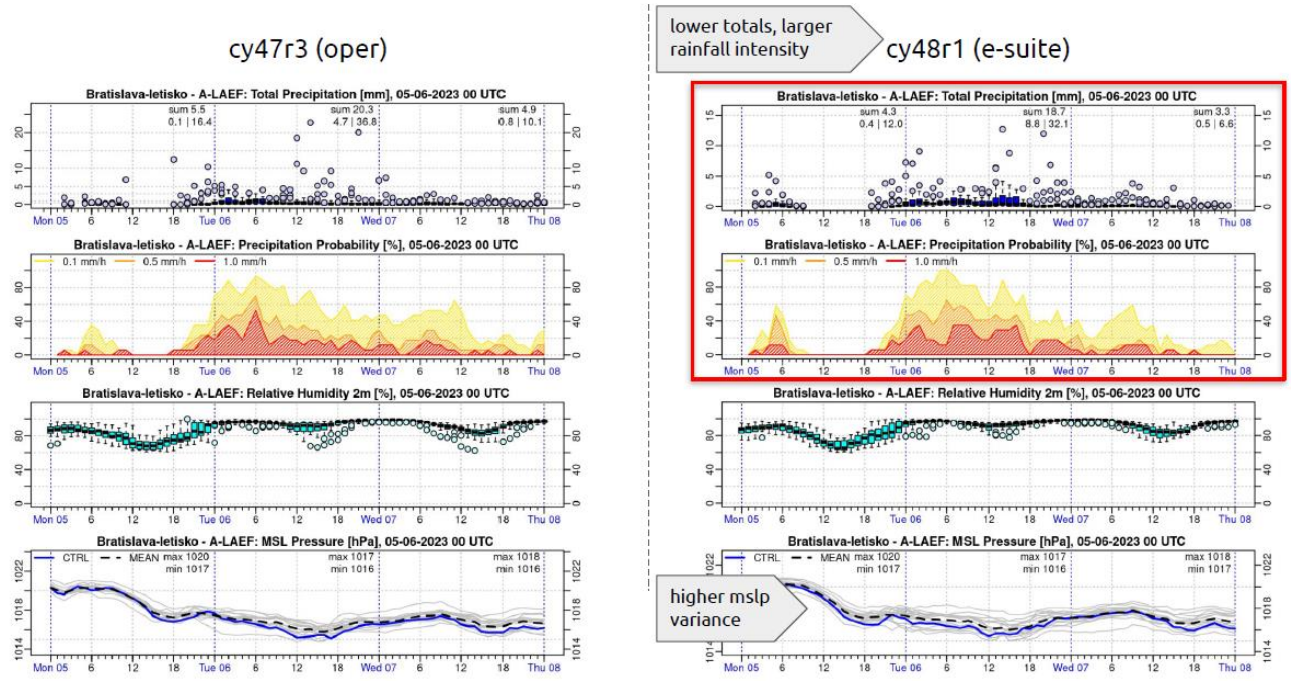

Figure 3: EPSgram of A-LAEF coupled with ECMWF-ENS cy47r3 (left) and cy48r1 (right) for a test case on 5 June 2023.

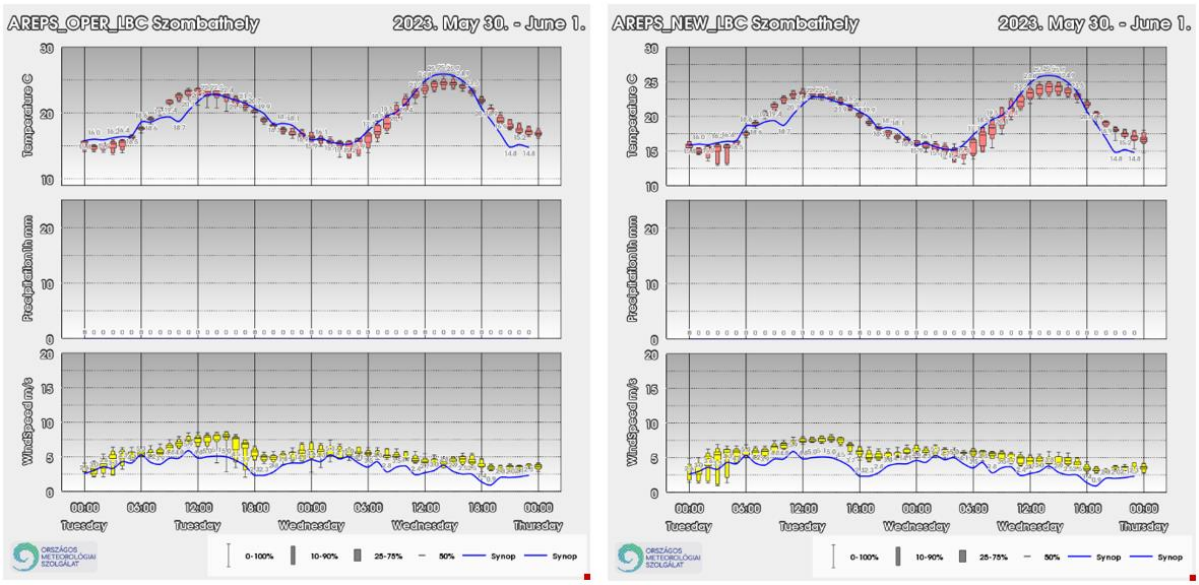

Figure 4: EPSgram of AROME-EPS coupled with ECMWF-ENS cy47r3 (left) and cy48r1 (right) for a test case on 30 May 2023.

- **Topic 2: A-LAEF and C-LAEF: Maintenance/monitoring of operational EPSs on ECMWF's HPC in Bologna, upgrades**

A-LAEF:

No major upgrades have been made for A-LAEF so far in 2023. The planned upgrade to cy46t1 (or cy48) has been postponed once more. Only some small technical upgrades and adaptations listed below have been made on Atos HPC:

- technical upgrades of A-LAEF TC2 suite at ECMWF (jobs' memory/time management, SMS notifications, etc.)
- recompilation of cy48t2 master (used for c903) with the CCSDS support (ecCodes 2.30.2)
- more reliable dissemination of A-LAEF products via ECPDS for SK, CZ and Turkey (added transferred file size check)
- found and reported a bug in grib_set tool for new ecCodes 2.30.0 (CCSDS encoding/decoding discrepancy)
- development of parallel A-LAEF ecflow suite under sk2 user for testing the upgrades and modifications
- development of tool for statistical processing of data read from A-LAEF multi-GRIBs via R-package

Furthermore, the visualization tools for A-LAEF EPSgrams have been modified and EPS downstream products for hydrology have been generated.

This year was so far very challenging in respect of extreme weather events (snowfall, storm events, floodings) and therefore a lot of case studies for testing the A-LAEF performance are available. In the following the results of three case studies are depicted where A-LAEF could show the benefit of a LAM ensemble system:

- Heavy snowfall in Balkan on 25-27 February, 2023
- Storm Juliette near the Balearic Islands on 27-28 February, 2023
- Floods in Italy on 16 May, 2023

Case 1: Heavy snowfall in Balkan on February 25-27, 2023

The abrupt onset of winter conditions in the Balkans came after a period of unseasonably warm weather, causing:

- a large amount of fresh snow
- strong wind (causing snow drifts)
- traffic connection cut off
- interrupted electricity supply
- big temperature differences (2-22°C in Serbia)

These extreme weather changes were well captured by the A-LAEF forecasting system (Figures 5 and 6).

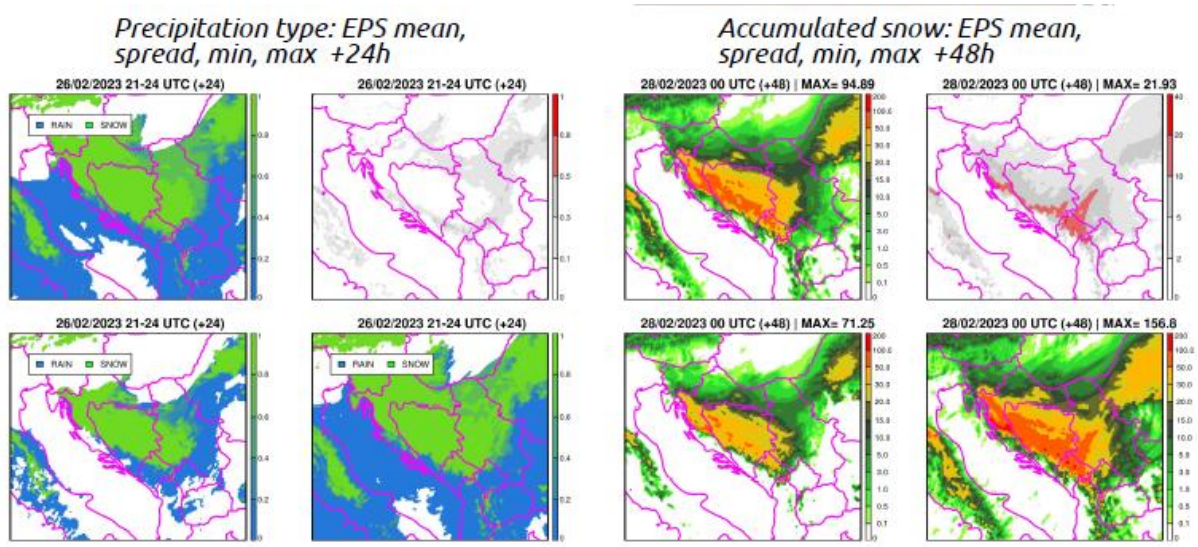

Figure 5: Precipitation type (EPS mean, spread, min, max +24h) on the left and accumulated snow (EPS mean, spread, min, max +48h Wind) on the right for A-LAEF 28 February 00 UTC run.

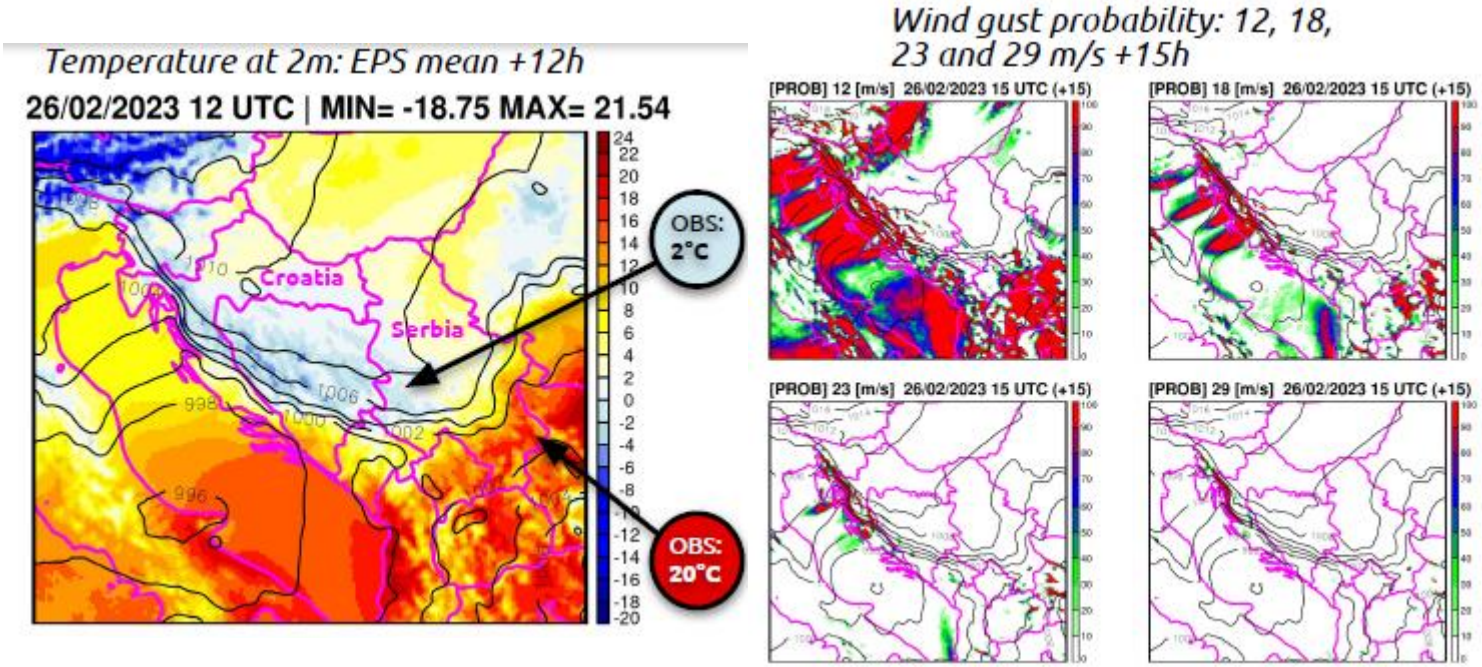

Figure 6: EPS mean of temperature at 2m (left) and wind gust probability for different thresholds (right) for A-LAEF 26 February 12/15 UTC run.

Case 2: Storm Juliette near Balearic Isl. - Feb 27-28, 2023

Wind gusts exceeding 100 km/h caused power cuts in various parts of the Mallorca island (with a peak gust of 119 km/h measured on 28 February at Capdepera station). Strong wind was accompanied by outbreak of cold weather and snow in coastal municipalities such as Felanitx, Manacor and Santanyi. The red alert for snow has been extended to the noon of 28 February. The A-LAEF ensemble system nicely captured the significant depression and the trajectory of its movement south of Sardinia to the coast of Italy, together with snowfall on Mallorca island (up to 70 cm) and strong gusty winds.

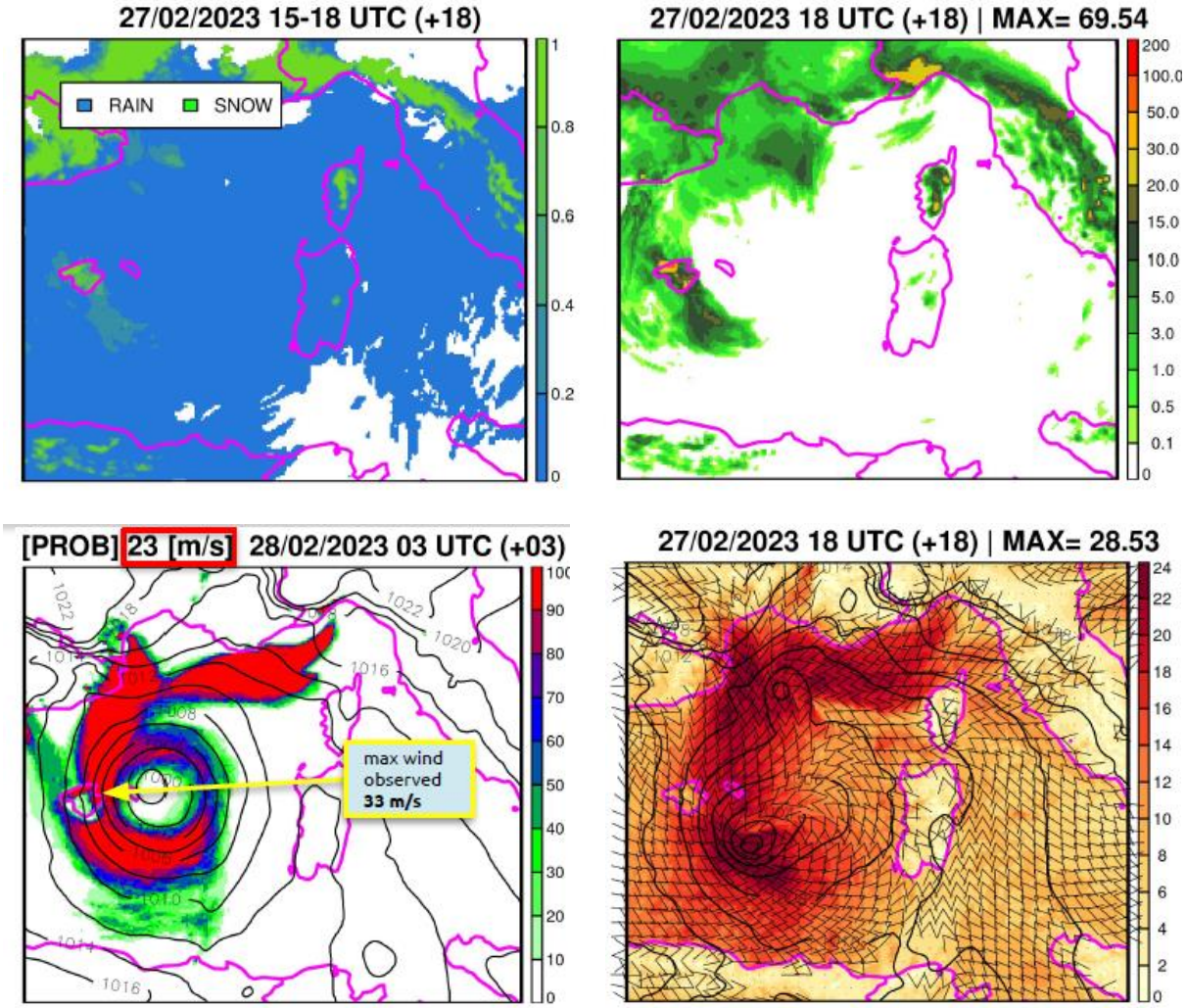

Figure 7: A-LAEF EPS mean of precipitation type (upper left), accumulated precipitation amount (upper right), probability of wind gusts > 23m/s (lower left) and maximum wind speed (lower right) for this test case end of February 2023.

Case 3: Floods in Italy on 16 May 2023

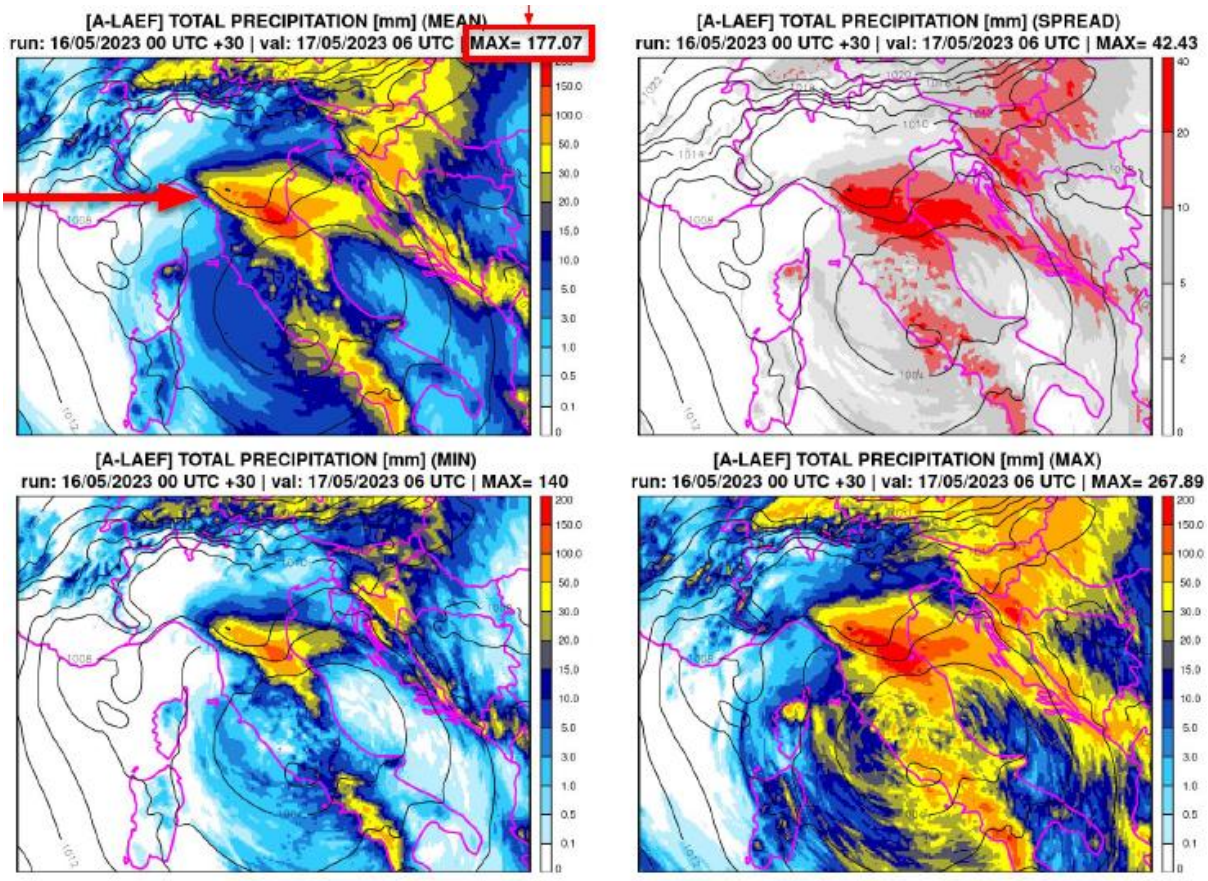

Figure 8: 24h accumulated precipitation from 06 UTC on 16 May to 06 UTC on 17 May 2023. Ensemble mean (upper left), ensemble spread (upper right), ensemble minimum (lower left) and maximum (lower right) based on A-LAEF 00 UTC run on 16 May.

Floods and landslides in the Emilia-Romagna (IT) region have caused eight deaths on 16 May and forced thousands to evacuate their homes. More than twenty rivers and streams overflowed their banks and caused flooding in 37 villages. Authorities reported 250 landslides, including 120 severe landslides in 48 municipalities. Heavy rainfall was well captured both with respect to the location and amount, even by the A-LAEF ensemble mean.

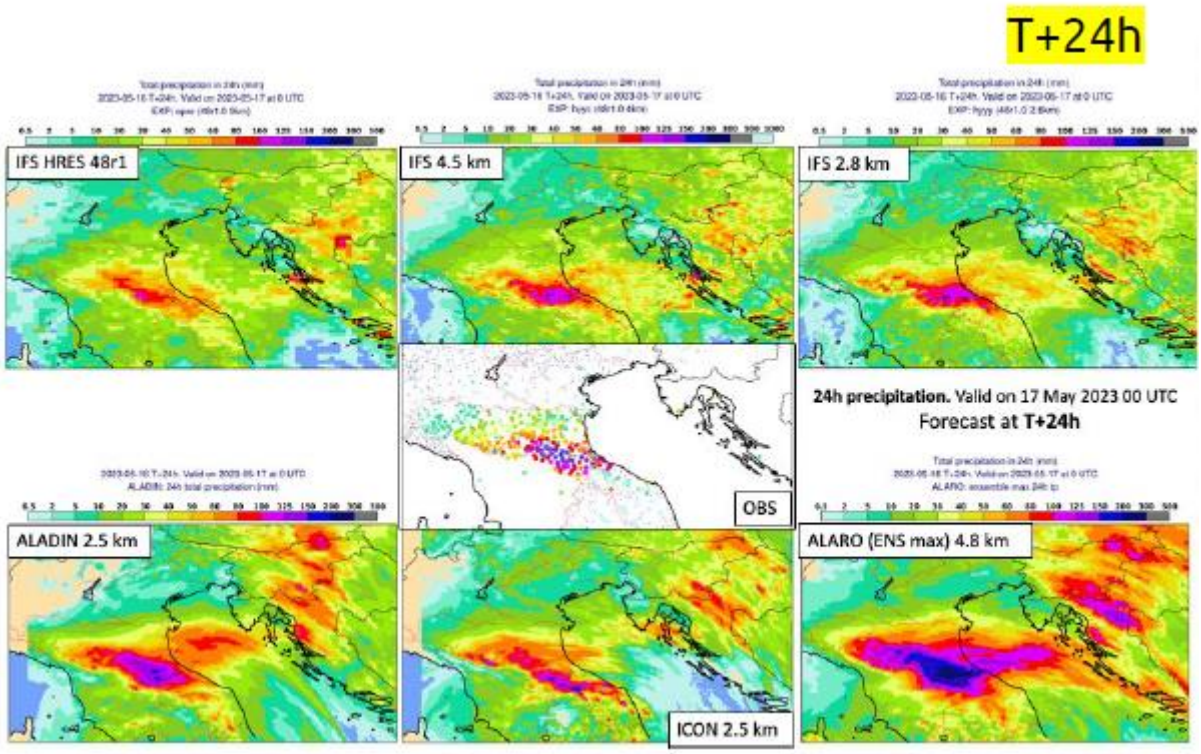

Figure 9: Comparison of 24h accumulated precipitation (00+24h) simulated by different models for this case.

Figure 9 shows a comparison of different models/resolutions for 24h accumulated precipitation forecasts. We can see the current IFS HRES and two experiments with the IFS at 4.5 and 2.8 km resolutions on the top. At the bottom, we compare ALADIN 2.5 km NH (ARSO), ICON 2.5 km, and the ensemble maximum of A-LAEF 4.8 km (ALARO). The first thing to notice is the much larger general precipitation in Italy and Croatia by the Limited Area Models (bottom images) compared to ECMWF global model. One of the main reasons is probably that even with the increased resolution of the IFS, the deep convection parametrization is still activated. The IFS improves with the resolution, but still underestimates the maximum amounts registered over Italy. IFS at 4.5 and 2.8 km are pure research experiments to test the effect of horizontal resolution, but without any other adjustment. For a true benefit from increasing resolution, some other components of the IFS should have been modified too (which was not the case here).

Higher precipitation amounts forecasted by A-LAEF EPS seems to be related to the specific parameterization schemes, since the different schemes and their tunings are used to simulate model uncertainty. Some schemes are obviously more sensitive to such extreme precipitation events, however, the final outcome is the combined effect of the cluster physics settings and stochastic perturbations of physics tendencies in each time step. In this situation and T+30h lead time, the maximum of the ensemble was 241 mm/24h, while the minimum was "only" 140 mm/24h. Looking into the individual physics clusters (Table 1), the maximum average comes from the first one. The differences between EPS min and max were about the same for T+54h lead time, but the individual clusters had more variability between each other, while the maximum

average was again obtained by cluster one 194.4 mm/24h and the second highest was cluster 3 with 160.5 mm/24h (not shown).

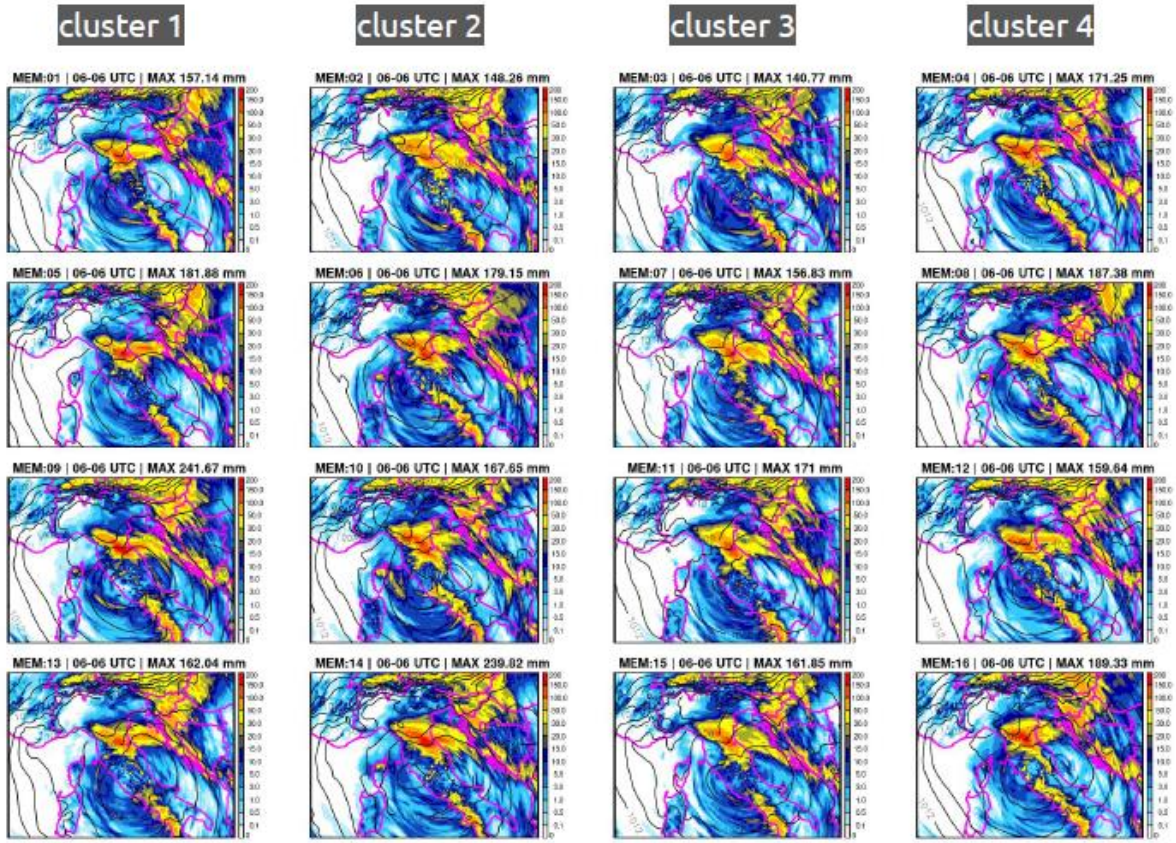

Figure 10: Physics clustering in columns (16 A-LAEF perturbed members). The differences between individual members of a cluster are due to ensemble of surface data assimilation, stochastic physics and ENS coupling.

Table 1: Impact of different physics tunings on the 24h accumulated precipitation amount of A-LAEF for this case study on 16 May 2023.

cluster	average [mm/24h]	physics tuning
1	185.7	microphysics and deep convection
2	183.7	turbulence
3	157.6	turbulence, microphysics and deep convection
4	176.9	ALARO-1 reference

C-LAEF:

No major upgrades have been made in the operational C-LAEF suite on the Atos HPC in Bologna so far in this year. The planned update of the stochastic perturbation scheme from hybrid tendency/parameter perturbations to pure parameter perturbations (SPP) has been postponed from May to September 2023. A parallel C-LAEF suite for further testing of the SPP scheme has been running in April/May 2023. Some of the verification results can be found in section 2 of this document.

- **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 11).

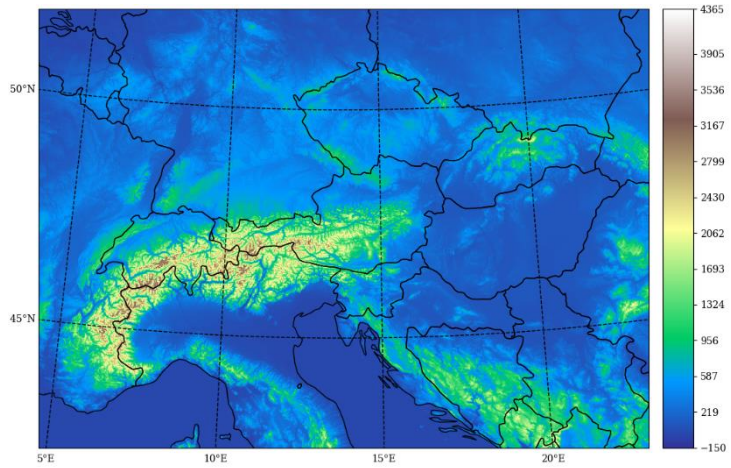

Figure 11: C-LAEF 1k domain.

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 and is running relatively stable since mid of June. Since end of June the grib-files are shared with Slovenian colleagues.

An additional control member was implemented into the C-LAEF1k suite using EnVar for testing purposes. The setup considers the perturbed member of the previous run as well as the last available 00 UTC run as input for EnVar. However this member is not yet activated since no stable setup has been found so far, leading to many model aborts.

The performance of C-LAEF 1k is monitored objectively calculating verification scores over various periods and for case studies. In general the verification results are very encouraging given that the current setup of a new cycle (cy46t1) and a new resolution of 1km. The following verification scores were calculated for approx. 250 stations over Austria.

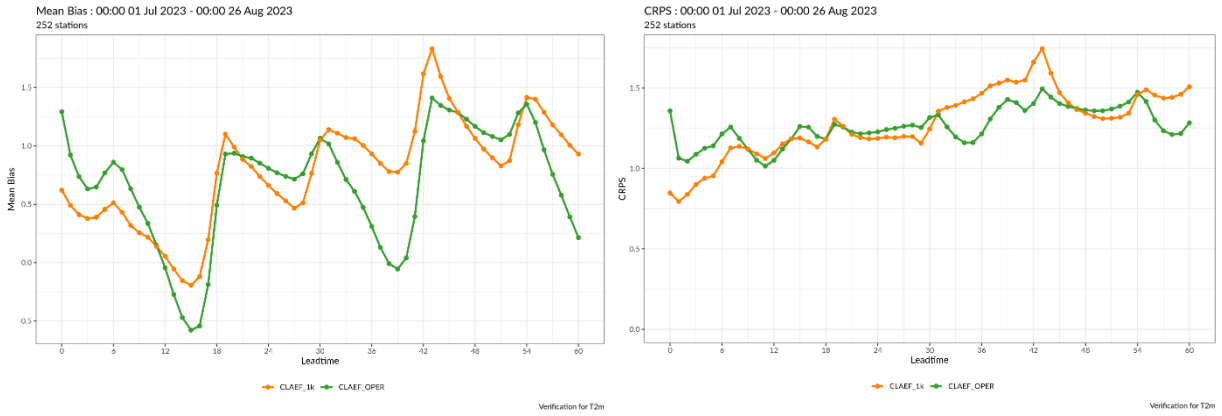

Figure 12: Ensemble mean BIAS (left) and CRPS (right) of 2m temperature for 00 UTC runs of C-LAEF OPER (green) and C-LAEF 1k (orange) for the period July and August 2023.

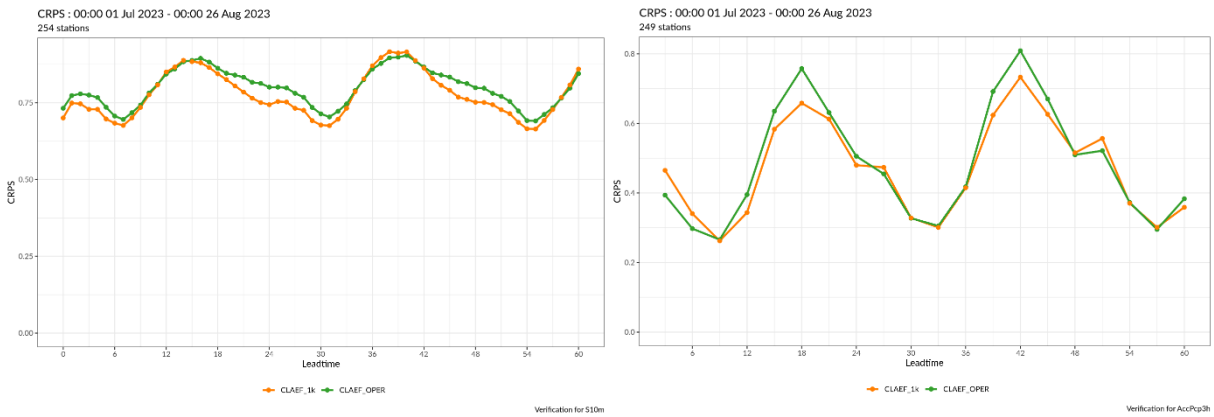

Figure 13: CRPS of 10m wind speed (left) and 3h accumulated precipitation (right) of C-LAEF OPER (green) and C-LAEF 1k (orange) for the period July and August 2023.

Upper air verification depicted a warm BIAS for C-LAEF 1k in the lower atmosphere below 700 hPa (Figure 14). It turned out that there is a bug in cy46t1 when doing inline-FullPos that was responsible for this BIAS. The bug caused that inline-FullPos wrote the virtual temperature instead of temperature at pressure levels. After this correction end of August this BIAS disappeared.

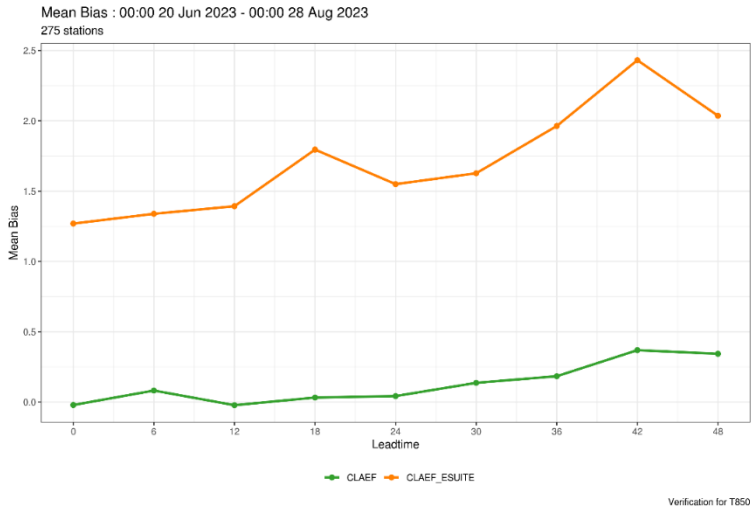

Figure 14: Ensemble mean BIAS for temperature at 850 hPa of C-LAEF OPER (green) and C-LAEF 1k (orange) before removing the bug from FullPos.

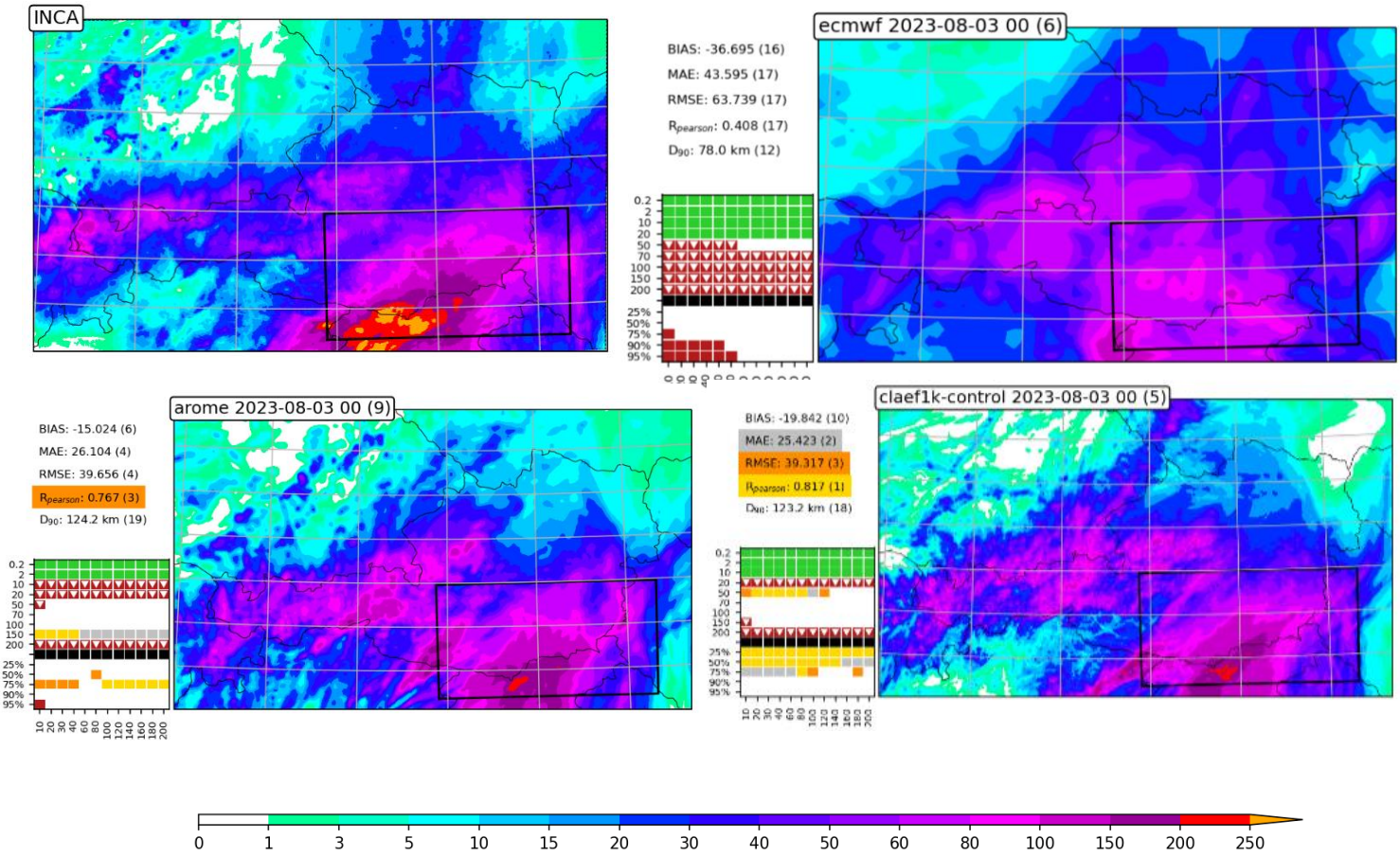

Figure 15: 48h accumulated precipitation amount (03 August 12 UTC – 05 August 12 UTC) of different models. Upper left shows INCA analysis, upper right ECMWF 00 UTC, lower left C-LAEF control 00 UTC and lower right CLAEF1k control 00 UTC of 03 August 2023.

In summer 2023 several severe weather events occurred over Austria and its surrounding countries which were used to evaluate the performance of C-LAEF 1k. Figure 15 shows a comparison of different models for a strong flooding event at the beginning of August in Slovenia and southern Austria.

ECMWF strongly underestimates the precipitation amounts, while AROME deterministic (equal to C-LAEF control) and C-LAEF1k show much higher amounts and a better localization of the precipitation maximum. Comparing the 2.5km and 1.0km version of C-LAEF reveals that that C-LAEF 1k predicts slightly lower precipitation amounts (stronger negative BIAS), but an improved fraction skill score indicates the more realistic precipitation patterns..

It is planned to keep the C-LAEF 1k suite running until the end of the year, with possible SBU-contributions from Slovenia. Apart from further adaptions to improve the performance of C-LAEF 1k the stable implementation of an EnVar Control member is of highest priority until the end of the year.

❑ 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. This work is ongoing and hopefully soon C-LAEF will be run operationally in Turkey.

❑ 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: 7.75 PM (planned 21.5 PM total in 2023)

Contributors: Martin Belluš and Maria Derkova (SHMU), Katalin Jávorné-Radnóczi and Gabriella Tóth (OMSZ), Clemens Wastl, 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
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; a lot of 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 OMSZ. Work on SPPT, SPP

The A-LAEF topic (stochastic perturbation of fluxes instead of tendencies) is delayed because Martin Bellus could not make his stay in Vienna due to personal reasons. Main work in this action in 2023 has therefore been spent on the introduction of a parameter perturbation scheme (SPP) in C-LAEF and AROME-EPS. While the scheme is ready for operations in Austria (planned in September 2023), it is still under development in Hungary. Gabriella Tóth made a 2 weeks remote stay in May where she implemented the SPP code and the SPG pattern generator into the AROME-EPS system. This work will be continued in October during another remote stay of her. The work on flow-dependent model perturbations is also planned to be continued in autumn with the stay of Endi Keresturi in Vienna.

- ❏ **Topic 1: C-LAEF - Improvement of stochastic parameter perturbations (SPP) with special focus on convective hazards (e.g. processes in microphysics)**

C-LAEF is based on the non-hydrostatic AROME model with a horizontal resolution of 2.5 km and 90 vertical levels. It has 16 perturbed members (and 1 unperturbed control run) coupled to the first 16 members of ECMWF-ENS. Model error is represented by a hybrid stochastic perturbation scheme, where perturbations of tendencies in shallow convection, radiation and microphysics are combined with parameter perturbations in the turbulence scheme.

The idea is to replace this hybrid system with a pure parameter perturbation scheme (SPP - stochastically perturbed parametrizations; Ollinaho et al., 2017), because of the increased physical consistency of this 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 report of last year). 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 2: Parameters which are perturbed stochastically in the SPP scheme currently implemented in a C-LAEF Esuite (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
Convection	XCMF	Closure coefficient at bottom level	0.065	0 - 0.1
	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 postponed to 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 16 and 17. The scores are comparable to the operational C-LAEF, but SPP is a bit cheaper (5%), more flexible (better possibilities to tune) 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.

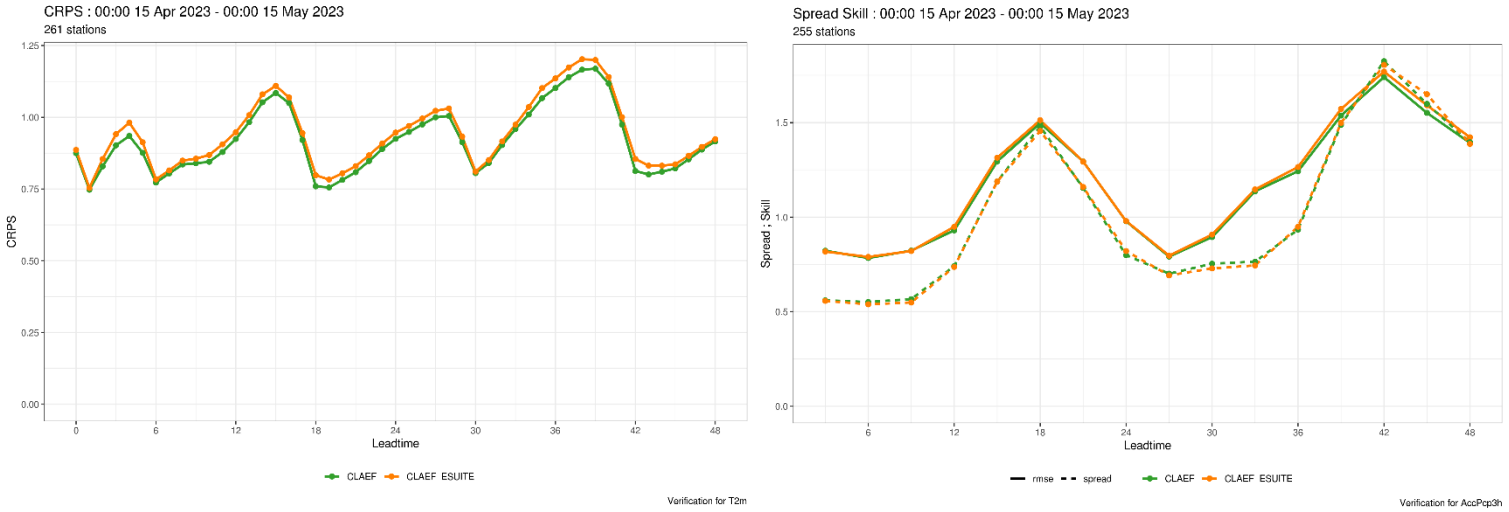

Figure 16: Comparison of C-LAEF with hybrid stochastic perturbation scheme (green) and C-LAEF Esuite with new SPP scheme (orange) for the period 15 April – 15 May 2023. CRPS for 2m temperature (left) and spread (dashed) skill (full) for 3h accumulated precipitation (right).

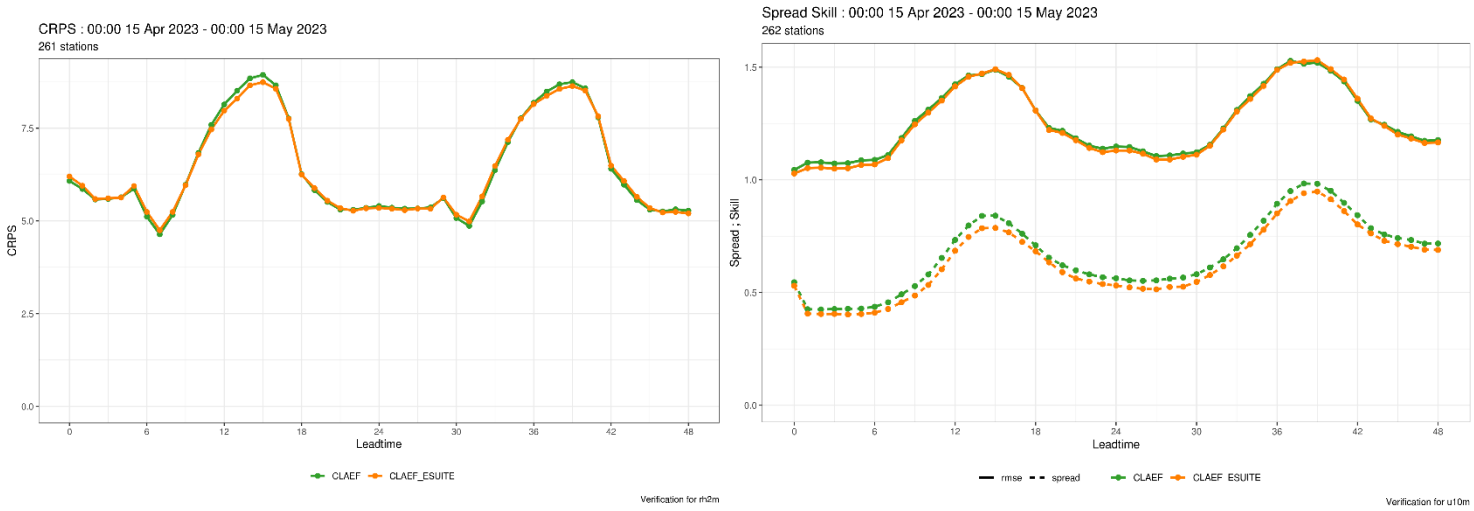

Figure 17: Comparison of C-LAEF with hybrid stochastic perturbation scheme (green) and C-LAEF Esuite with new SPP scheme (orange) for the period 15 April – 15 May 2023. CRPS for 2m relative humidity (left) and spread (dashed) skill (full) for 10m wind speed (right).

❑ Topic 2: AROME-EPS – implementation of model perturbations (SPP)

After turning EDA in AROME-EPS into operations in March 2023, OMSZ 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. So far, she has been correcting the compilation errors that are mostly related to the surface assimilation, SEKF, which is operational in AROME-EPS since March 2023. In the meantime, the stochastic pattern generator program was successfully installed on the Hungarian HPC.
The remote stay will be continued between 16 and 27 October 2023. Until then it is intended to finish the compilation of the new MASTERODB and start running the first experiments using SPP.

Efforts: 4.5 PM (planned 5.25 PM in total in 2023)

Contributors: Martin Belluš (SHMU), Clemens Wastl (GeoSphere Austria), Endi Keresturi (DHMZ), Gabriella Tóth (OMSZ)

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

Planned stays:

Endi Keresturi (4 weeks GeoSphere Austria) – flow dependent model perturbations (planned in October 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 planned 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, OMSZ); 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 will be continued during a stay at GeoSphere Austria in autumn 2023. The original contributor (Iris Odak Plenkovic) is not able to come to Vienna, but her colleague Ivan Vujec will take her spot.

Some progress has been achieved in the EPS products on the RC LACE webpage - C-LAEF is displayed now. At GeoSphere Austria new parameters (exceedance of precipitation and wind gusts) have been added to SAMOS and physics-informed and data-driven machine learning (ML) nowcasting is under development with first very promising results.

- ❏ **Topic 1: Work on statistical post-processing of EPS data at Geosphere Austria**

There is some ongoing work at GeoSphere Austria in the area of statistical post-processing of EPS data. SAMOS (standardized anomaly model output statistics) has been developed and implemented at GeoSphere Austria to improve direct model output from ensembles (EMCW-ENS, C-LAEF) especially for costumers. It has been put into operations in 2022. It has been implemented originally for 2m temperature and relative humidity, precipitation and 10m wind speed and now in 2023 wind gusts have been added. Additionally, new products containing the probability of exceedance for precipitation and wind gusts have been created (Figures 18 and 19). Verification shows that SAMOS is able to improve the BIAS of the EPSs significantly and is also able to correct the under-dispersion. SAMOS is providing spatial forecasts and offers a seamless forecast from analysis over short-range to middle-range forecasts. The training of the data is done every three hours with a rolling 45 days period in the past.

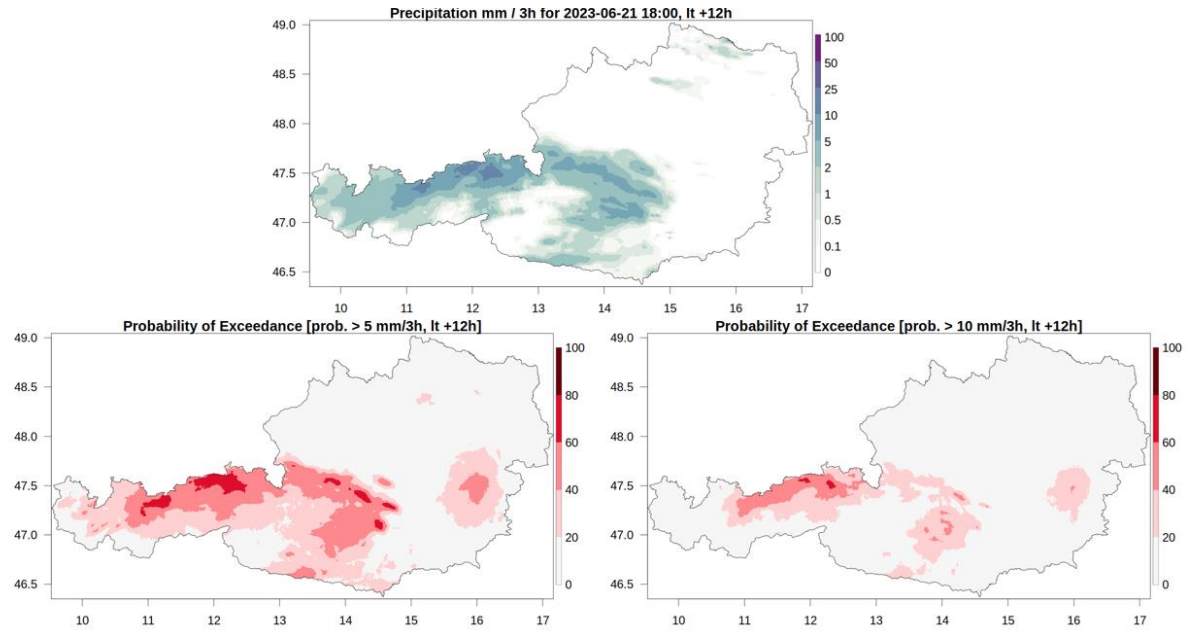

Figure 18: 3h accumulated precipitation (upper) and probability of exceedance for 5mm/3h (lower left) and 10mm/3h (lower right) from SAMOS for a test case in June 2023.

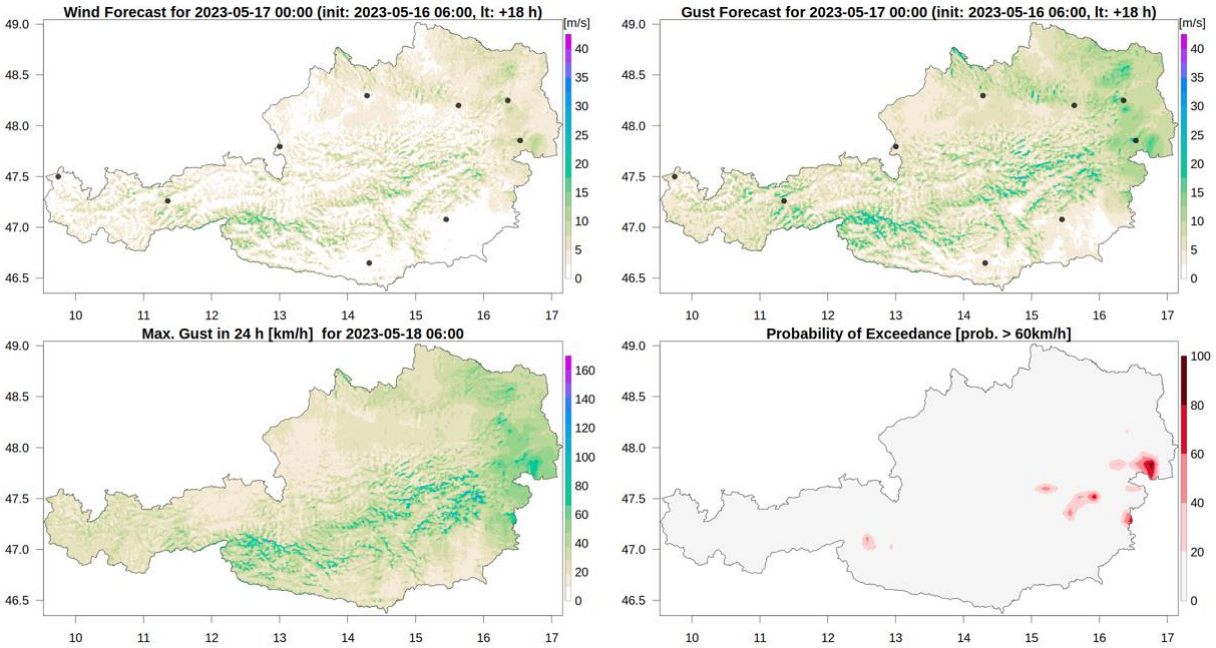

Figure 19: Wind forecast (upper left), gust forecast (upper right), max gusts in 24h (lower left) and probability of exceedance for 60km/h (lower right) from SAMOS for a test case in May 2023.

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

At GeoSphere Austria some work in the topic of machine learning (ML) is ongoing. Currently, the physics-informed nowcasting methods using MSG data (Gfäller, 2023) are adapted for on-the-fly operational purposes as well as for re-running some test cases over Austria using the pre-trained models for 15-minute predictions for the next 3 hours ahead. Once this is finalised the codes will be adapted for other regions and the code will be made available. Results for one of the models (Figure 20, random selection and not one of the better performing models) are promising for both sunny days (not shown) and overcast days.

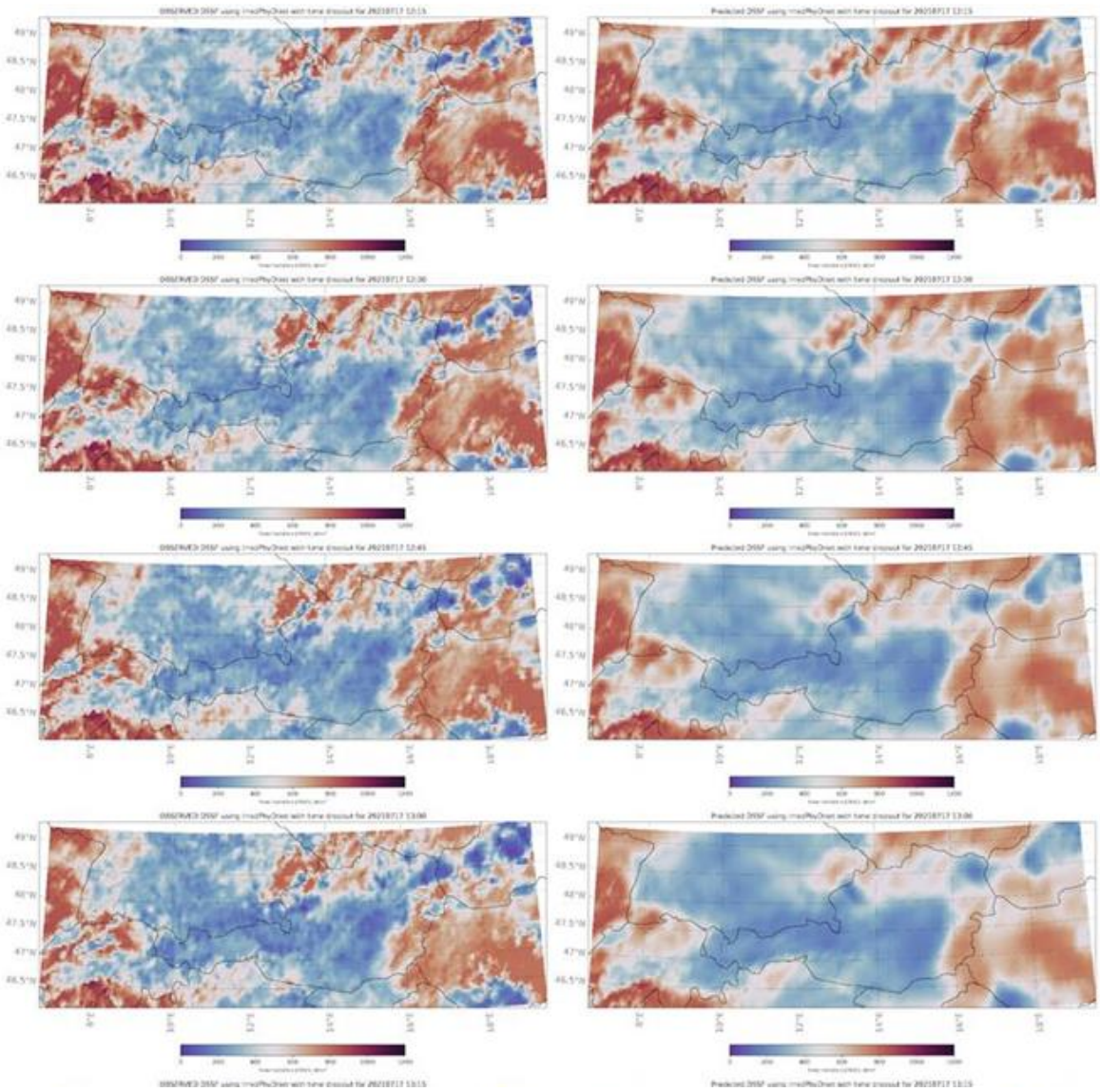

Figure 20: Observed clouds (left) and cloud output of a machine learning model (right, subset) for a test case in 2023.

Efforts: 0.25 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 (OMSZ)

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

Planned stays: Ivan Vujec (4 weeks at GeoSphere Austria; replacing Iris Odak Plenković) - analog-based post-processing methods

Status: Ongoing, on time.

7 Action/Subject: Collaboration and Publication

Description and objectives: Activities merging different areas, collaboration with other consortia, applications, projects. Publication and presentation of relevant scientific output at international workshops and in scientific journals.

It has been decided to remove this subject since there is no equivalent in the ACCORD workplan. The work planned in this subject (publications, participation in workshops, collaboration, etc.) will be distributed to the other subjects S1 – S6.

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

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 – 0.75 PM in first half of 2023

Unfortunately, due to several reasons (time, personal reasons), only two research stays could be organized in 2023 so far. There was the ACCORD stay of Musatafa Basran in Vienna (8-12 May 2023) for implementing C-LAEF for Turkey and the remote stay of Gabriella Tóth (8-19 May 2023) working on SPP in AROME-EPS. The second part of her stay is planned as remote stay as well in autumn (16-27 October 2023) where she will continue her work on SPP. In autumn another two stays are planned. One of Ivan Vujec (4 weeks at GeoSphere Austria in Vienna) who is replacing Iris Odak Plenković and who will continue her work on analog based post-processing and the other one of Endi Keresturi (1 month at GeoSphere Austria in Vienna in October/November 2023) who will continue his work on flow-dependent model perturbations. The two stays of Martin Bellus (upgrade of A-LAEF; flow-dependent B-matrix) can not take place 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	7.75	1	0	0.25	0.25
S2: Model perturbations	5.25	4.5	2	0.5	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	0.25	1	0	0	0
Total:	42	12.5	5	0.5	0.25	0.25

References

Gfäller, P. (2023): Evaluation of different techniques for solar irradiance nowcasting. Masterarbeit Universität Wien, DOI: 10.25365/thesis.73807

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