Regional Cooperation for
Limited Area Modeling in Central Europe

LACE
nwp central europe

C-LAEF AlpeAdria
a joint convection permitting EPS for AT, CRO, SLO

Clemens Wastl with contributions of LACE partners

GeoSphere Austria · DHMZ · Czech Hydrometeorological Institute · HungaroMet Hungarian Meteorological Service · IMGW · METEO ROMANIA · SHMU · ARSO METEO Slovenia

Overview

- **EPS status in LACE**
- **C-LAEF AlpeAdria system overview**
- **Continuous lagged ensemble**
- **3DEnVar**
- **SPP & flow dependent SPP**
- **Verification results of C-LAEF AA**
- **Outlook and plans**

EPS status in LACE

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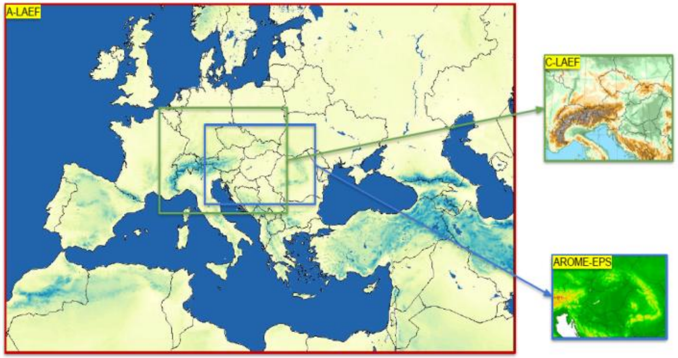
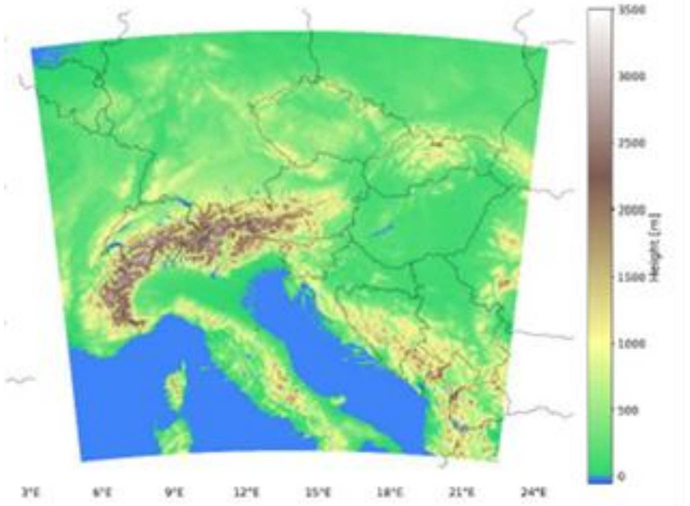
	A-LAEF	C-LAEF	AROME-EPS
CMC	ALARO	AROME	AROME
Code version	cy40t1	cy43t2	cy46t1
Horizontal resolution	4.8 km	2.5 km	2.5 km
Vertical levels	60	90	60
Runs per day	2	8	8
Forecast length	+72h (00/12 UTC)	+60h (00/12 UTC)	+48h (00/12 UTC)
Members	16+1	16+1	10+1
Assimilation cycle	yes (12h)	yes (3h)	yes (3h)
Coupling	ECMWF ENS (6h)	ECMWF ENS (1h)	ECMWF ENS (1h)
IC perturbation	ESDA [surface], spectral blending/DFI [upper-air]	ESDA [surface], EDA, Ensemble-JK [upper-air]	EDA
Model perturbation	ALARO-1 multi-physics + surface stochastic physics (SPPT)	Parameter perturbations (SPP)	-
LBC perturbation	ECMWF ENS (c903)	ECMWF ENS (c903)	ECMWF ENS (c903)



C-LAEF AlpeAdria system

- **C**onvection-permitting **L**imited **A**rea **E**nsemble **F**orecasting system for the AlpeAdria (AA) region
- Co-operation of Austria, Croatia and Slovenia to develop a joint EPS on 1km
- Based on AROME cy46t1
- Pre-operational status – operationalization planned for the beginning of 2026
- Will replace AROME (deterministic) and C-LAEF (probabilistic) on 2.5km
- Running on ECMWF HPC Atos
- Backup of Control Member on national HPCs
- 3 output domains (AT, CRO, SLO), grb2 format
- 3h assimilation cycle, 3DVar for atmosphere, OI for surface



C-LAEF AA domain.

C-LAEF AlpeAdria system

- 8 long (+60h) runs per day, 16 + 1 members
- Forecast in single precision
- New observations (GNSS, ceilometer, radar data)
- Dynamics setup based on semi-lagrangian horizontal diffusion (SLHD)
- Physics setup based on Meteo France 1 km AROME
- Quadratic truncation, 45 sec time step
- SPP perturbations (12 parameters in 5 physics parametrization schemes)
- Additional control member using EnVar (cy48t3), 32 members as input (from the latest 2 runs)
- Continuous lagged ensemble mode

Continuous lagged ensemble

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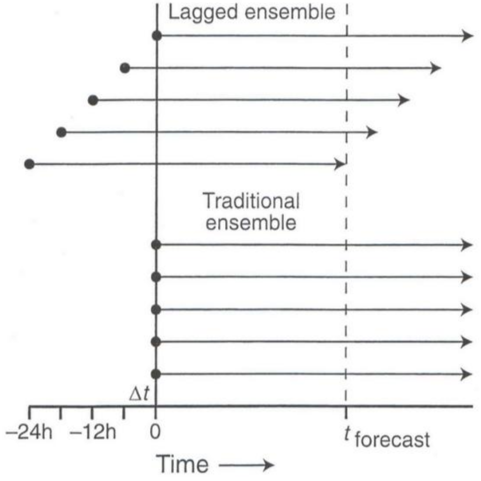
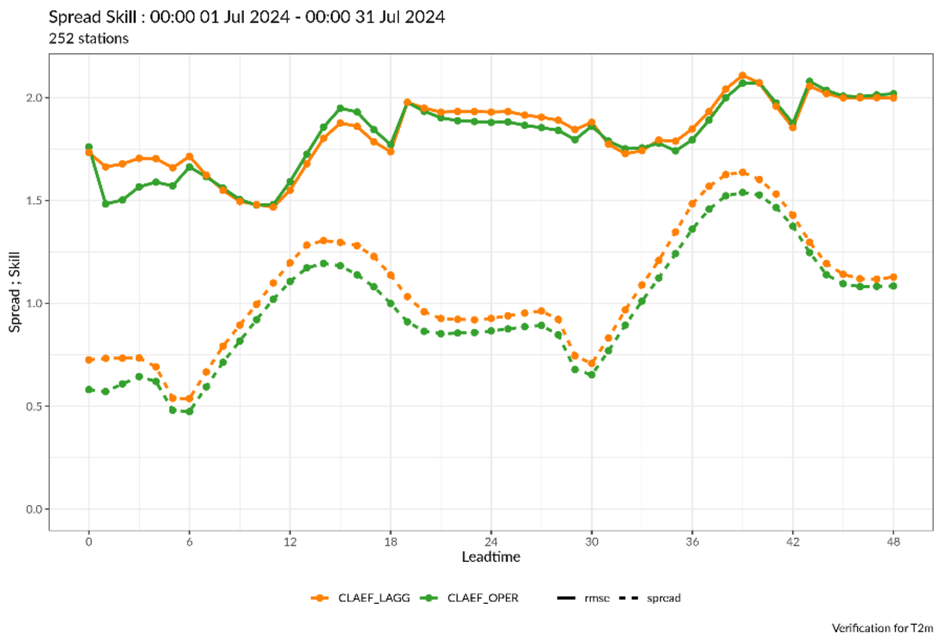
- To expand the C-LAEF AA system (more runs, longer leadtimes, more members) a continuous lagged ensemble approach has been implemented
- 4 members (alternating) + 1 control run of C-LAEF AA are running every 3h with an extended forecasting range of +69 h
- Rest of the members is short with +6 h lead time (for EnVar assimilation)
- Combining the members of the 4 most recent runs (the oldest members are 9 h old) a lagged ensemble with 16 +1 members can be created every 3 h

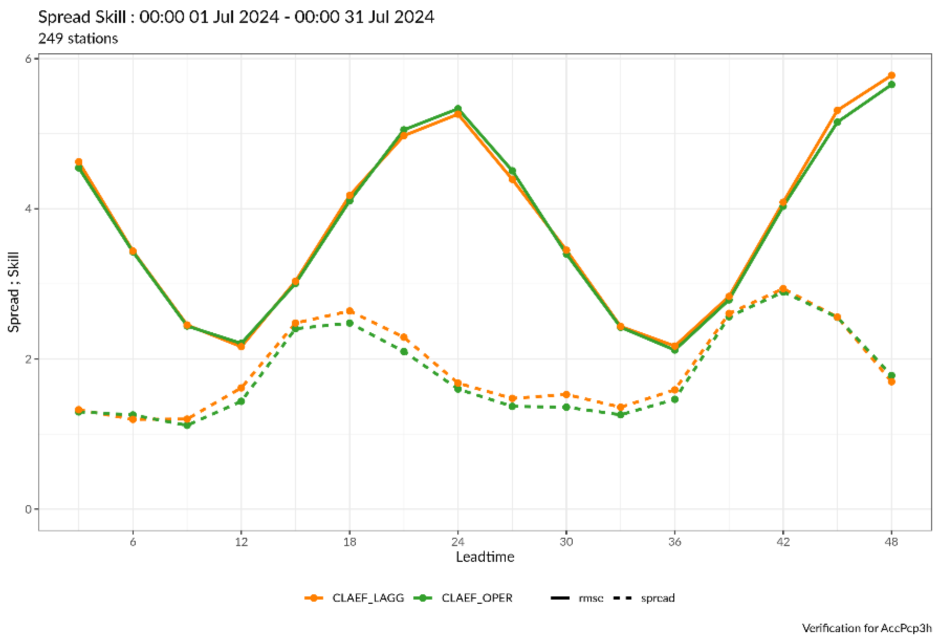


Warner et al., 2011

- Significant reduction of computational costs
- Lagged ensemble has been tested for a winter (February 2024) and summer (July 2024) period and compared with classical EPS approach
- Scores of the lagged ensemble are equal or even better than for the classical ensemble (increase of spread), only for T2m at the beginning worse, no clustering

Continuous lagged ensemble





Ensemble spread (dashed) and RMSE (full) of 2m temperature (left) and 3h accumulated precipitation (right) for C-LAEF AA lagged (orange) and C-LAEF AA classical (green) for a test period in July 2024.

Uncertainty representation

Initial conditions error

- Ensemble-data assimilation (EDA)
- Ensemble-data assimilation of surface variables (sEDA)
- Ensemble-JK

Lateral boundary conditions error

- Coupling with ECMWF-ENS

Surface uncertainties

- Surface perturbation scheme

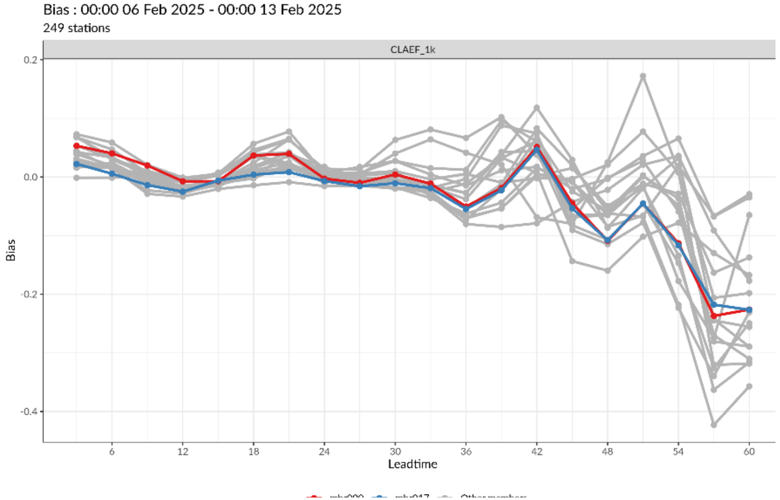
Model error

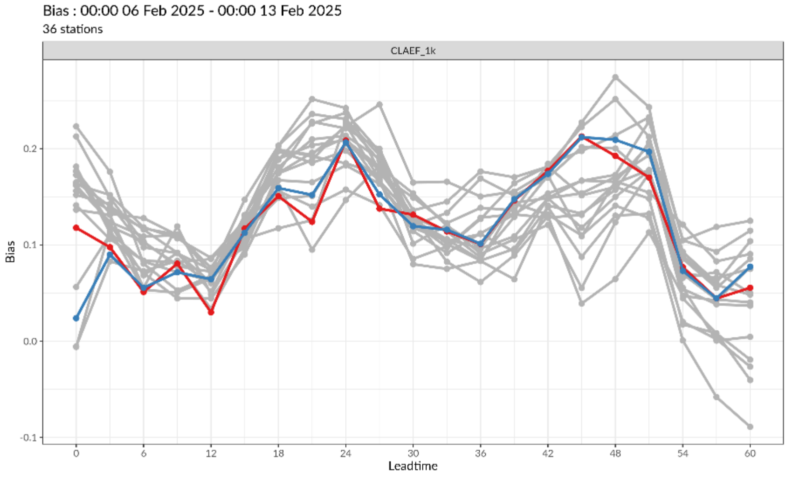
- Stochastic physics: SPP

3D EnVar

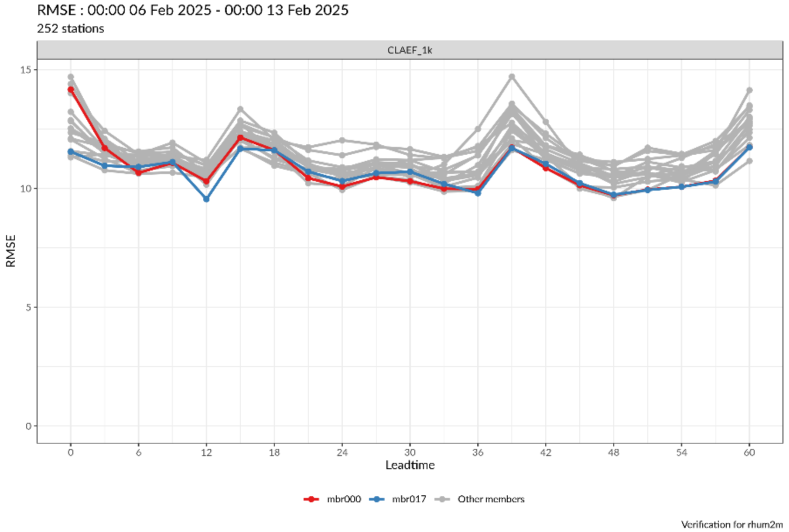
- The goal is to increase the flow dependency in C-LAEF AA (assimilation, integration)
- Replace 3DVar (static B-Matrix) in C-LAEF AA with 3DEnVar (flow dependent)
- Some stability problems at the beginning (a lot of tuning necessary)
- EnVar based member (cy48t3) has been added to the C-LAEF AA suite since October 2024 as second control
- 3DEnVar uses 32 member as input, 16 members from t -3 h and 16 members from t –6 h
- Verification shows promising results
- Bias reduction especially in the first 6h
- For some convective cases, the 3DEnVar member did not perform well – detailed investigation before operationalization

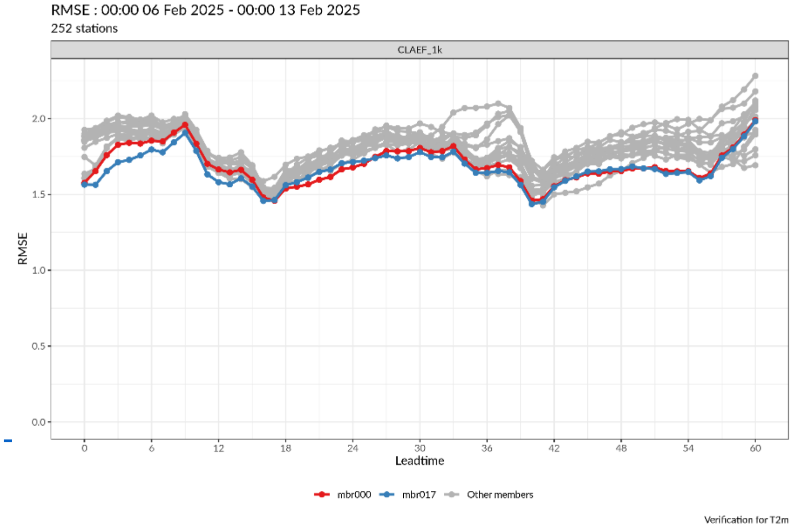
3D EnVar





BIAS of 3 h accumulated precipitation (left) and total cloud cover (right) for all members of C-LAEF A during the test period in winter 2025. The 3Dvar member is given in red, the 3DEnvar member in blue.





RMSE of 2m relative humidity (left) and temperature (right) for all members of C-LAEF AA during the test period in winter 2025.

SPP

- Model error representation in C-LAEF AA is done by stochastically perturbed parameterization (SPP)
- Stochastic pattern created by SPG pattern generator
- 12 perturbed parameters in radiation, microphysics, turbulence, surface and shallow convection parameterization
- A lot of tuning to find optimal settings
- Work on extending this parameter list – dynamics, SURFEX

Scheme	Parameter	Description
Microphysics	ZRDEPSRED	Snow reduction factor
	ZRDEPGRED	Graupel reduction factor
	RCRIAUTI	Snow autoconversion threshold
	RCRIAUTIC	Rain autoconversion threshold
	VSIGQSAT	Saturation limit sensitivity
Radiation	RSWINHF	Short-wave cloud thickness inhomogeneity factor
	RLWINHF	Long-wave cloud thickness inhomogeneity factor
Turbulence	XCTP	Constant for temperature and vapour pressure correlations
	XCEP	Constant for wind and pressure correlations
	XCED	Constant for dissipation of TKE
Shallow convection	XCMF	Closure coefficient at bottom level for convective mass flux
Surface	XFRACZ0	Coefficient of orographic drag

Parameters which are perturbed stochastically in the SPP scheme implemented in C-LAEF AA.

Flow dependent SPP

- SPP scheme is purely stochastic: the perturbations are applied completely randomly without any consideration of the weather/flow situation
- This is in contrast to SPPT, which puts more weight to areas with high total tendencies; but this respects only total net tendencies – possibility of zeroing out the tendencies from different parametrizations
- Idea to develop a kind of intelligent parameter perturbation scheme which applies perturbations especially in areas where most impact can be expected
- First preparatory work in summer 2022
- Stays of Endi Keresturi in Vienna 2022, 2023, 2024

Flow dependent SPP

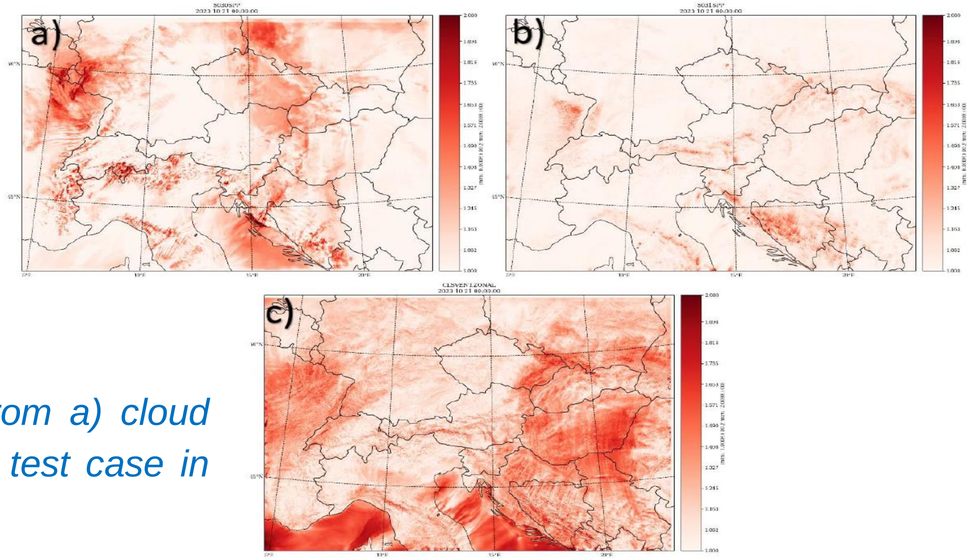
- Pattern generator is not changed, but the existing pattern is modified by some weights
- Modify perturbed parameter (P^) by adapting w $\hat{P} = P\, e^{c+w\varphi}$
- Weights are transformed to [1, Wmax] $w = MIN[(w'Nl \times N)+1, Wmax]$
- How to find/diagnose possible areas of interest?

Pragmatic approach – for each of the 12 parameters a particular model variable is used:

Cloud fraction for microphysics and radiation;

TKE for turbulence and shallow convection;

10m wind speed for SURFEX



Example of flow-dependent weights obtained from a) cloud fraction, b) TKE and c) 10 m wind speed for a test case in October 2023.

Flow dependent SPP

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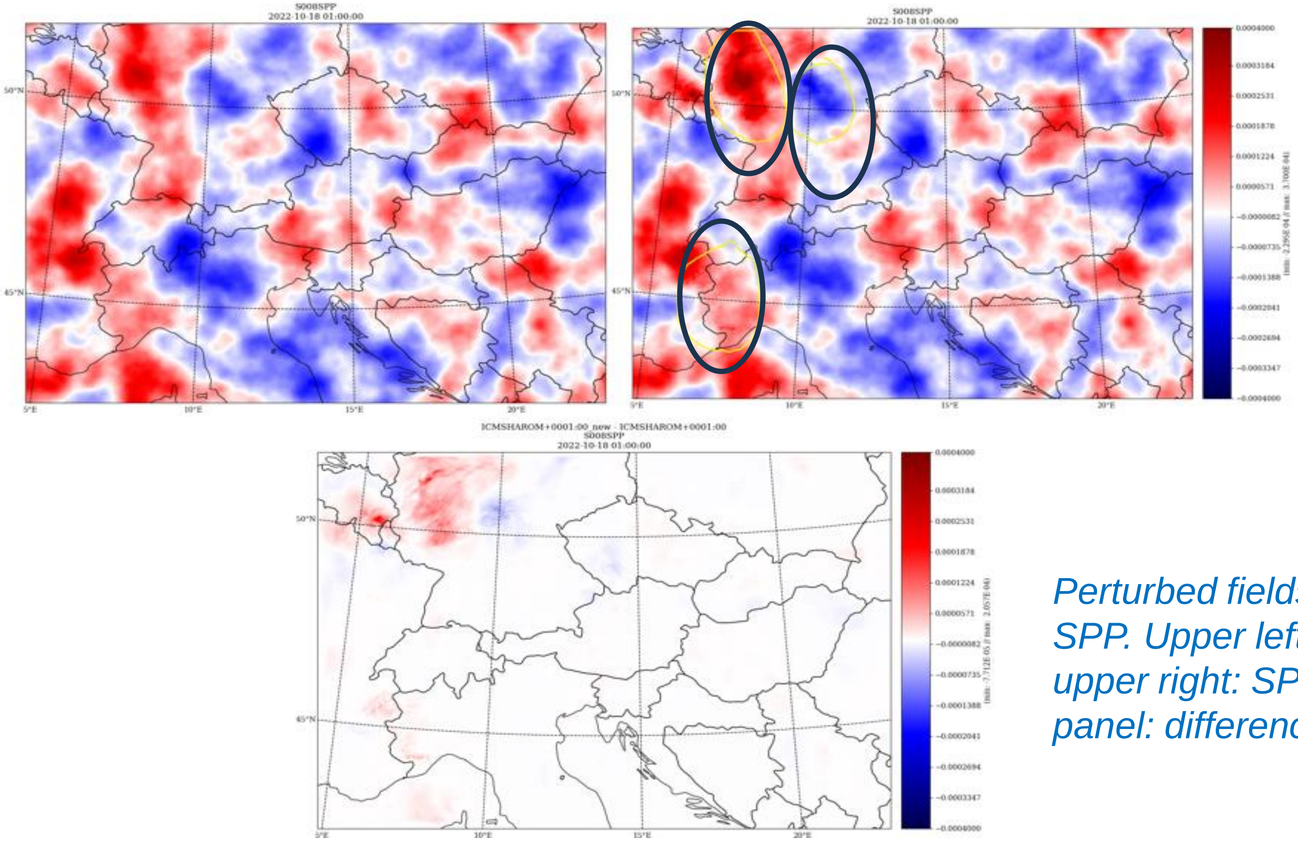
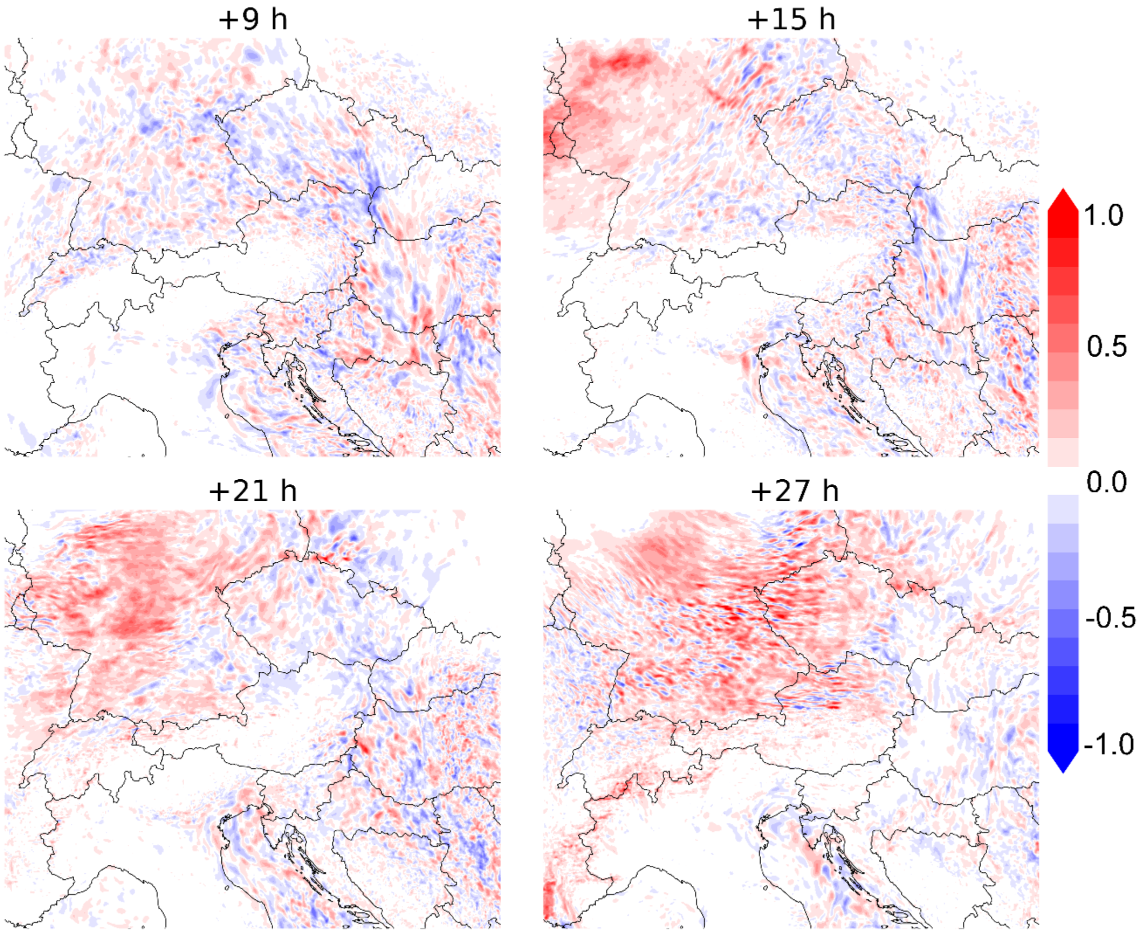


Perturbed fields of a microphysics parameter in SPP. Upper left: SPP without flow dependency, upper right: SPP with flow dependency, lower panel: difference.

Flow dependent SPP



6-hourly evolution of ensemble spread differences FDSPP – SPP for wind speed at 925 hPa [m/s] for a test case in February 2024.

Flow dependent SPP

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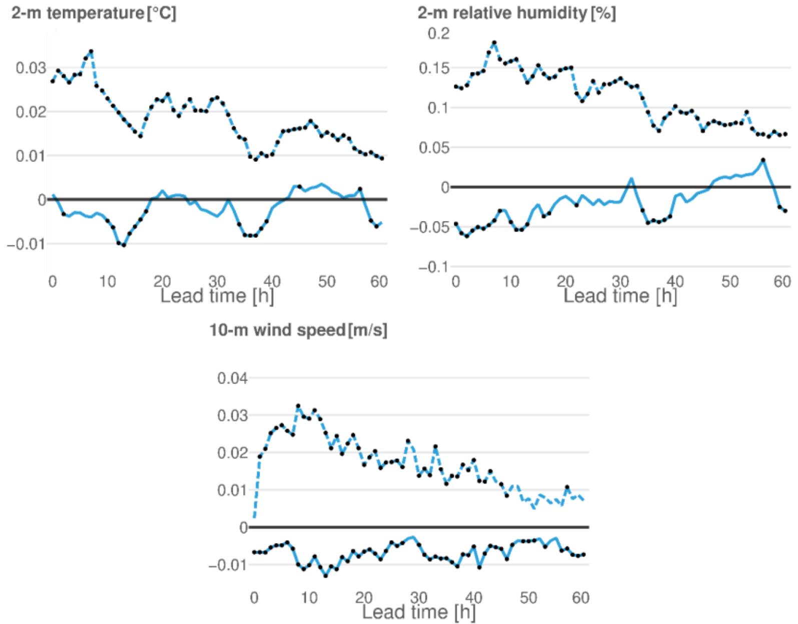
- Tested for case studies, long term verification for winter (February 2024) and summer (June 2024)
- Results for February are generally positive - ensemble spread is significantly increased for all variables and all lead times, impact on RMSE is neutral/slightly positive, CRPS improved
- Results for June are more neutral, almost no increase in spread, RMSE decrease for wind
- SPP not properly tuned for convective season (small impact of SPP in summer vs. winter)



RMSE of the ensemble mean (solid) and spread (dashed) of flow dependent SPP relative to SPP for February 2024. Lead times with statistically significant differences are marked with black bullets.

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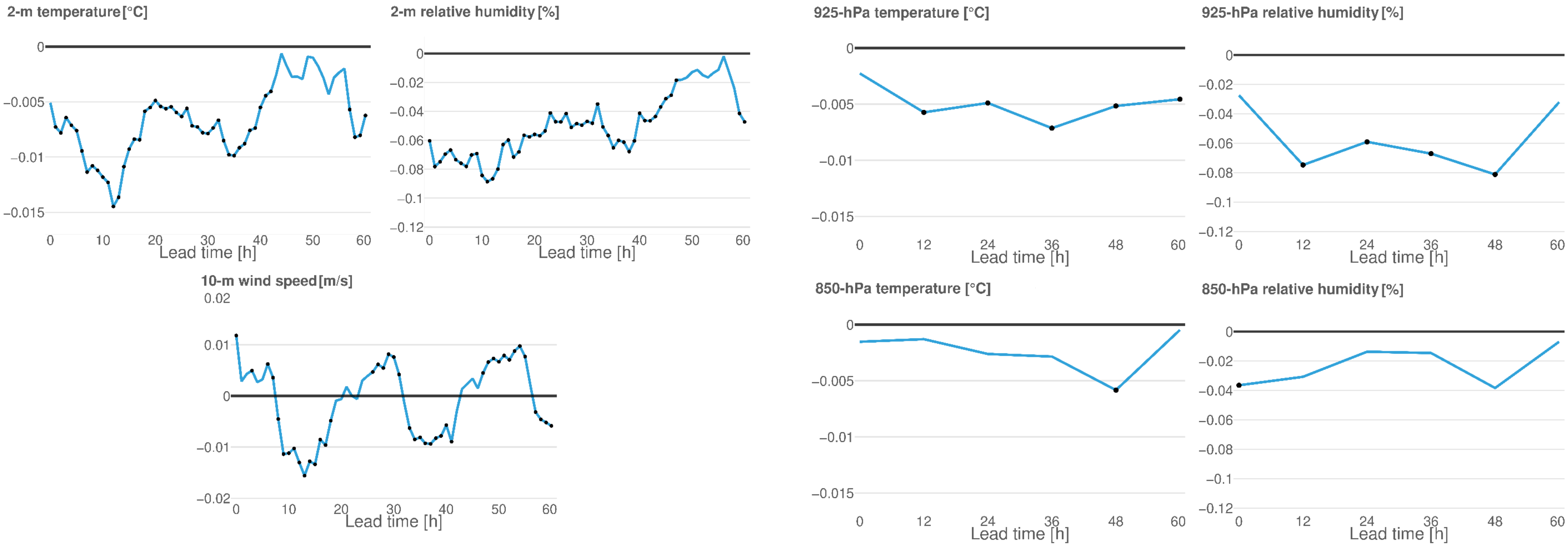
Flow dependent SPP



CRPS of flow dependent SPP relative to SPP for February 2024. Lead times with statistically significant differences are marked with black bullets.

Flow dependent SPP

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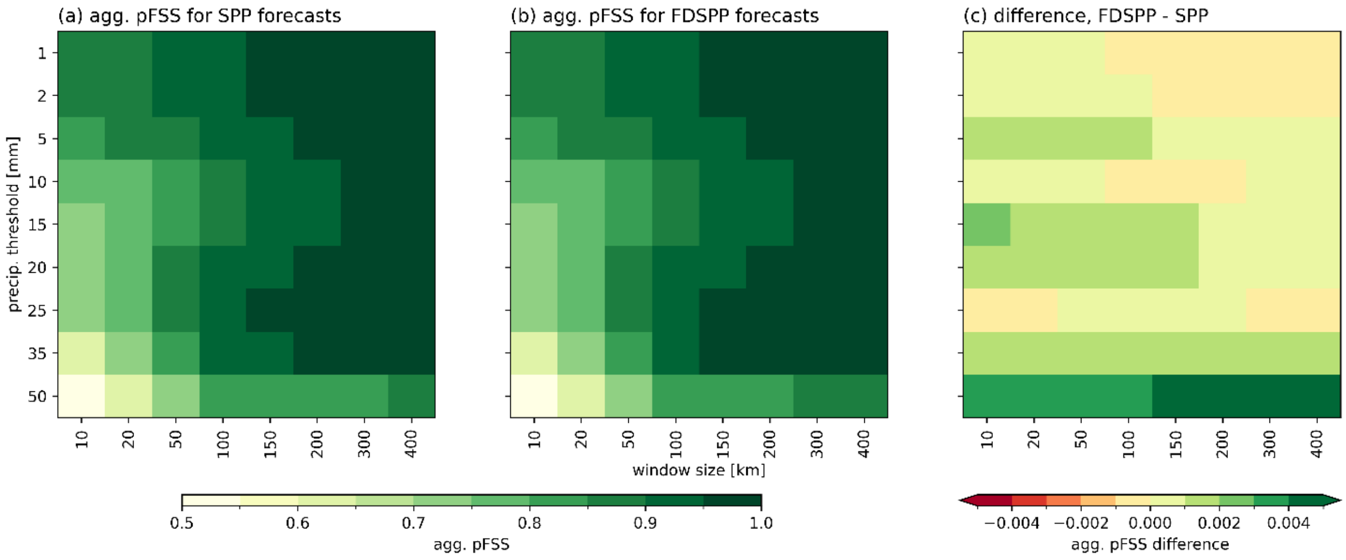
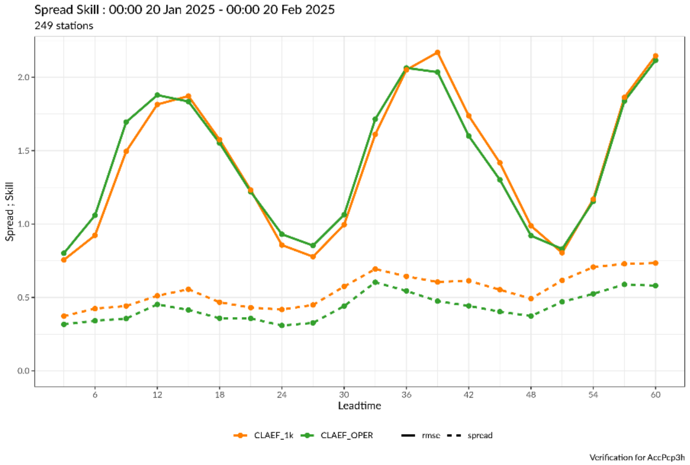


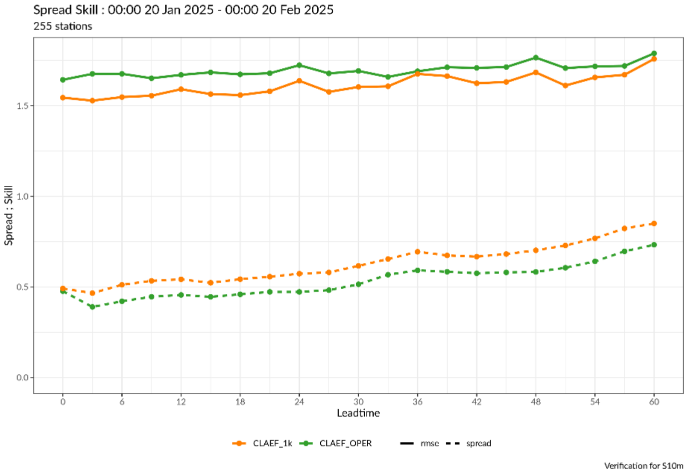
Monthly aggregated pFSS for (a) SPP, (b) flow dependent SPP and (c) flow dependent SPP – SPP. Precipitation thresholds are shown on the y-axis, while neighbourhood sizes are shown on the x-axis.

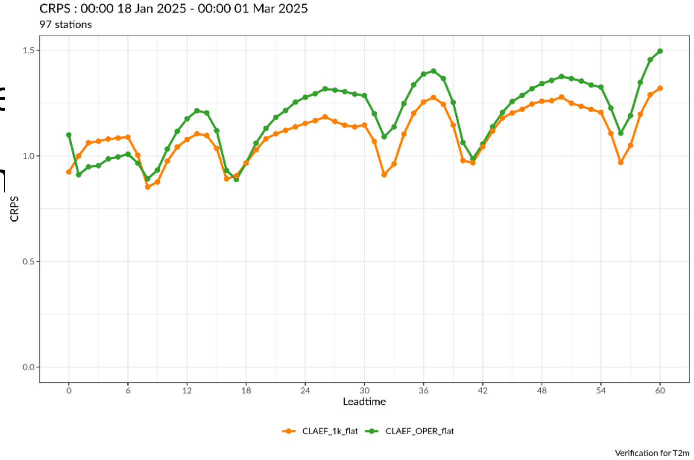
Verification winter

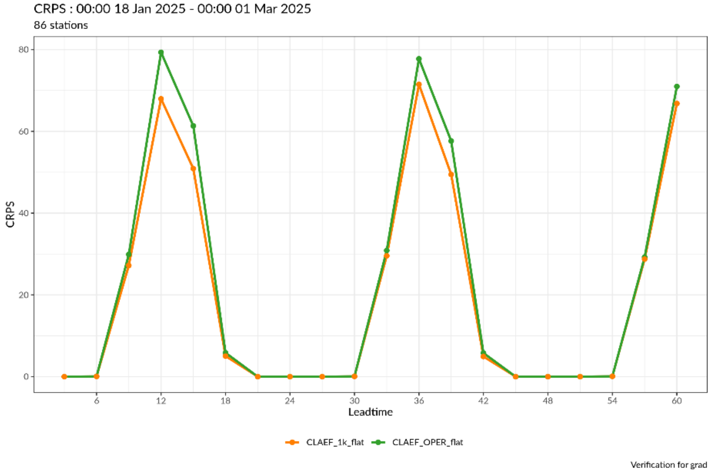
- C-LAEF AA is running in pre-operational mode since beginning of 2025
- Verification made for a winter Jan/Feb 2025) and summer (Jul/Aug 2025) period
- Good results, clear improveme compared to C-LAEF at 2.5km
- Operationalization in 2026

Spread/skill of 3h precipitation (left) and 10m wind speed (right) for C-LAEF (green) and C-LAEF AlpeAdria (orange).









CRPS of 2m temperature (left) and global radiation (right).

Verification summer

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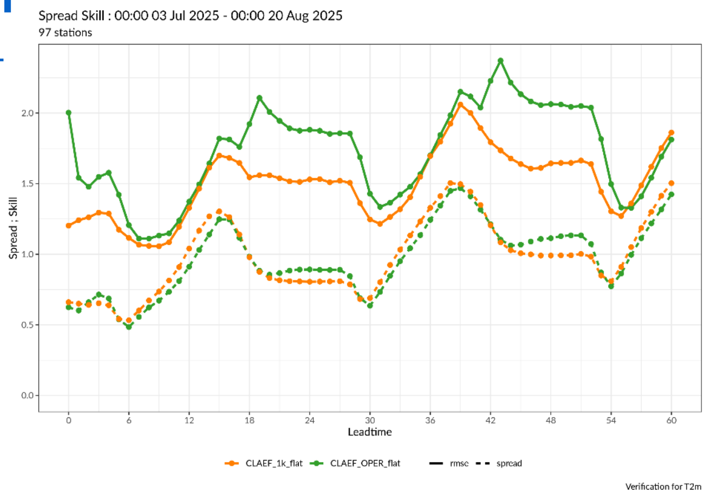
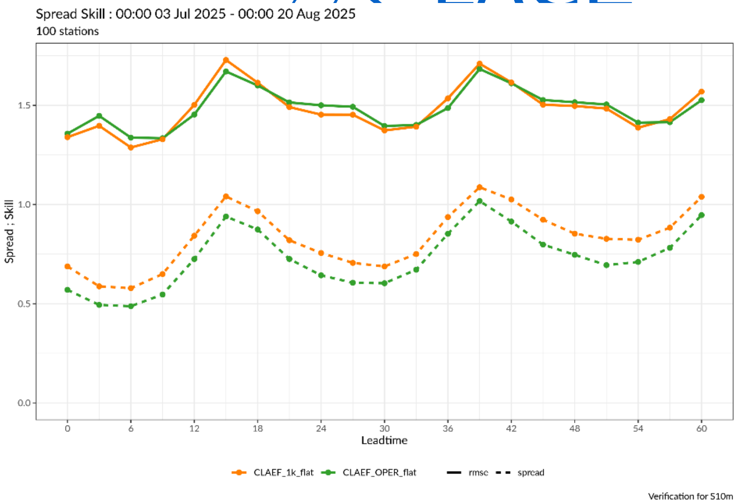
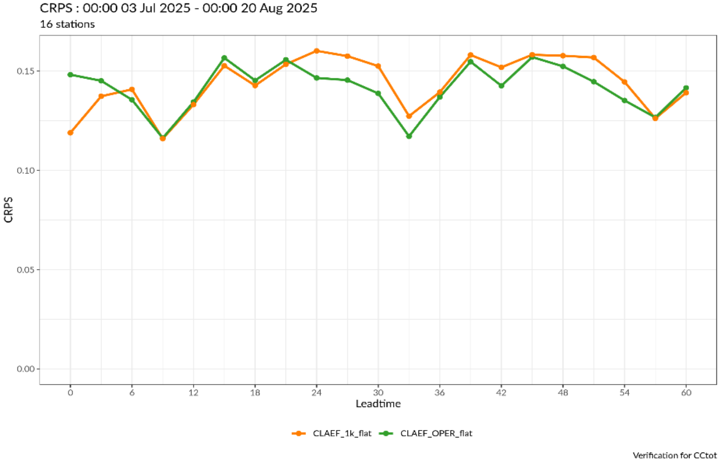
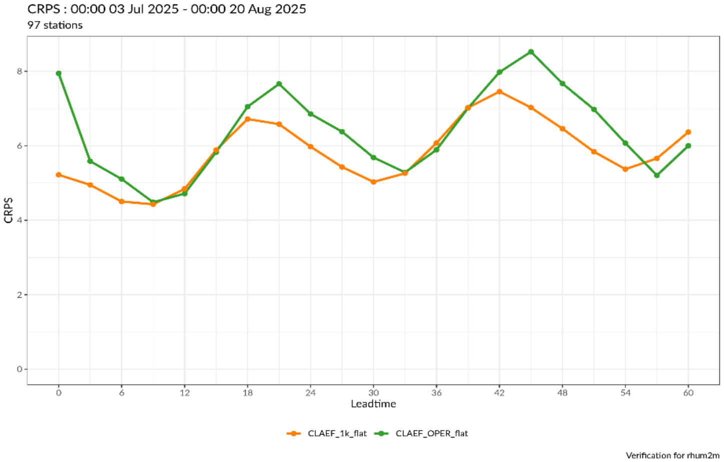
Spread/skill of 2m temperature (left) and 10m wind speed (right) for C-LAEF (green) and C-LAEF AlpeAdria (orange) in summer.





CRPS of total cloudiness (left) and 2m relative humidity (right).





Outlook & Plans

- Put C-LAEF AlpeAdria into operations in the first half of 2026
- EnVar/Hybrid EnVar (final setup, operationalisation end of 2026)
- Extend SPP scheme (dynamics)
- Improve surface perturbations (SPP in SURFEX)
- Continue research on flow-dependent SPP (include ML for identification of interesting areas)
- Generation of ensemble members by ML
- C-LAEF AlpeAdria reanalysis
- EPS on hectometric scale (Deode)