

*Regional Cooperation for
Limited Area Modeling in Central Europe*



LAM-EPS activities in LACE

Clemens Wastl with contributions of LACE partners

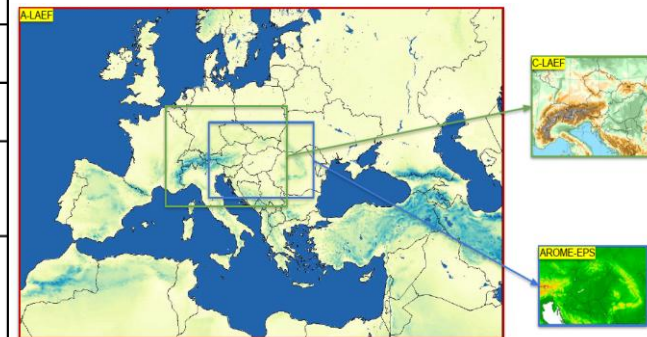


ARSO METEO
Slovenia

- **Operational Status in LACE**
- **A-LAEF: Status and Plan**
- **C-LAEF AlpeAdria: Time-step, Dynamics, Envar**
- **AROME-EPS: SPP**
- **Statistical EPS/Machine Learning**
- **Outlook and Plans**

Operational status

	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)

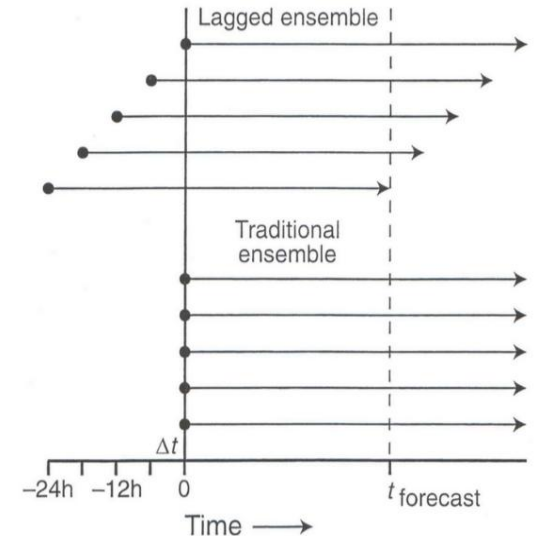


Upgrade of A-LAEF

- Operational A-LAEF is still running on cy40t1
- Upgrade delayed due to leave of main contributor
- Cy46t1 Esuite of A-LAEF running on the ECMWF HPC since summer 2025 (ctrl member)
- New ALARO-1 multiphysics scheme
- Four different physics clusters based on latest ALARO-1 developments
- Combination with SPPT for ISBA surface prognostic fields
- New clim files based on ECOCLIMAP v2.6
- Grb2 output, new parameters (precipitation type, helicity, etc.)
- Performance analysed for several case studies
- Monitoring and maintenance is spread within several LACE countries
- Further scientific and technical development taken over by Poland
- Upgraded version expected in 2026

C-LAEF AlpeAdria

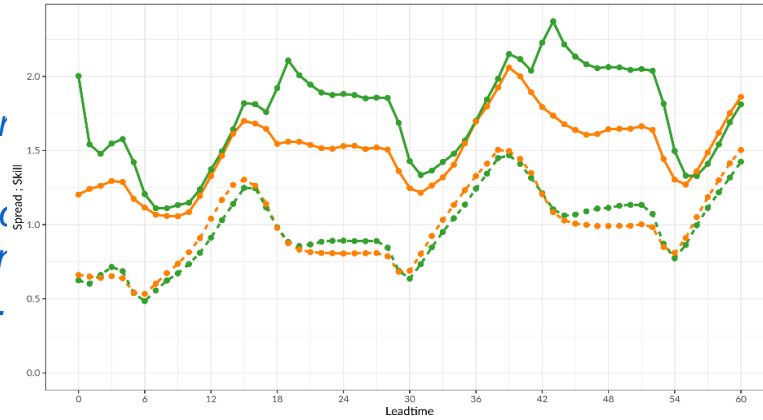
- Co-operation of Austria, Croatia and Slovenia
- Operational C-LAEF (cy43t2) on 2.5 km will be replaced by C-LAEF AlpeAdria in June 2026
- Full C-LAEF AlpeAdria test suite running (Jan/Feb 2025, Jun-Aug 2025, Nov 2025, Feb 2026)
- ECMWF HPC, 1 km, 8 runs (+60 h), 16 + 1 mems, 45 s time step
- Cy46t1, I/O server, 3h assimilation cycle, single precision
- Continuous lagged ensemble mode: 3 members + 1 control run with extended forecasting range of +69/72 h, rest is short (6 h)
- Combining members of 4 most recent runs (the oldest member is 12 h old)
 - > lagged ensemble with 16 + 1 members every 3 h
- New observations (GNSS, ceilometer, radar data), 3 FPOS domains, grb2
- SPP perturbations
- Additional control member using EnVar (cy48t3)



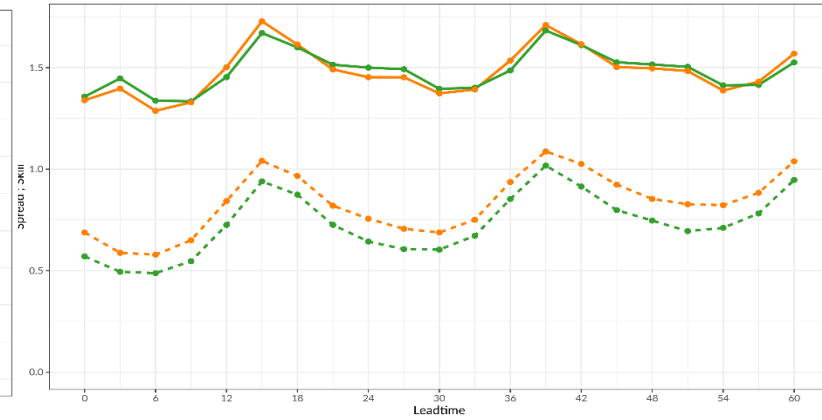
Warner et al., 2011

C-LAEF AlpeAdria

Spread Skill : 00:00 03 Jul 2025 - 00:00 20 Aug 2025
97 stations



Spread Skill : 00:00 03 Jul 2025 - 00:00 20 Aug 2025
100 stations

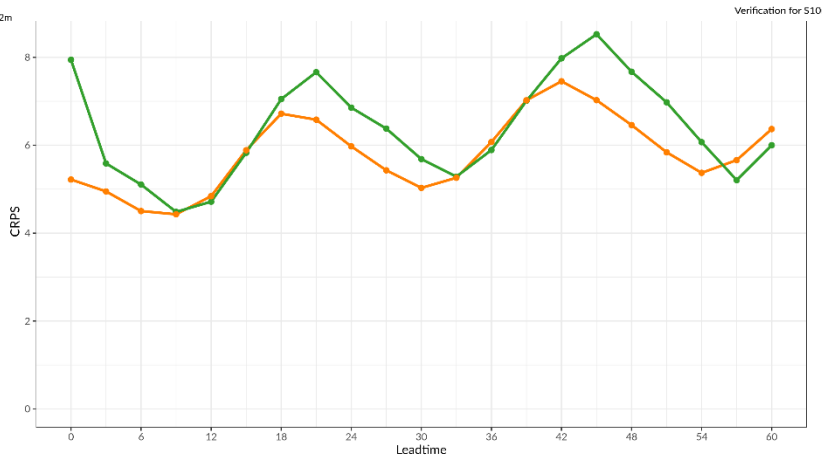
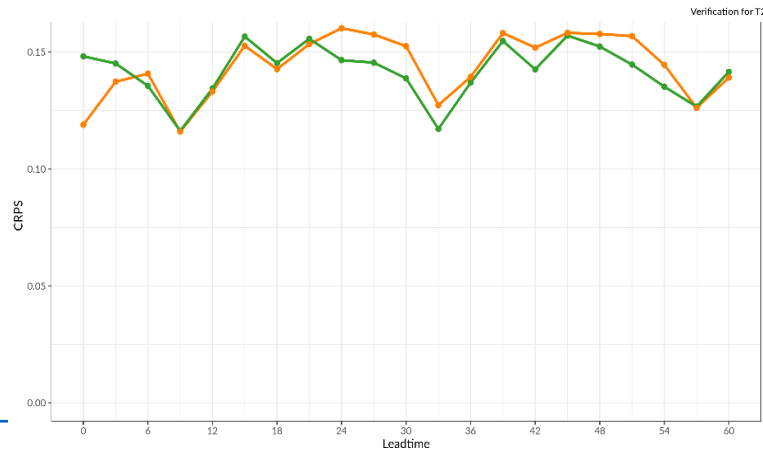


— CLAEF_1k_flat — CLAEF_OPER_flat — rmse - - spread

— CLAEF_1k_flat — CLAEF_OPER_flat — rmse - - spread

Spread/skill of 2m temperatur (left) and 10m wind speed (right) for C-LAEF (green) and C-LAEF AlpeAdria (orange) in the summer test period 2025.

CRPS of total cloudiness (left) and 2 m relativ humidity (right) for C-LAEF (orange) and C-LAEF AlpeAdria (green) in the summer test period.

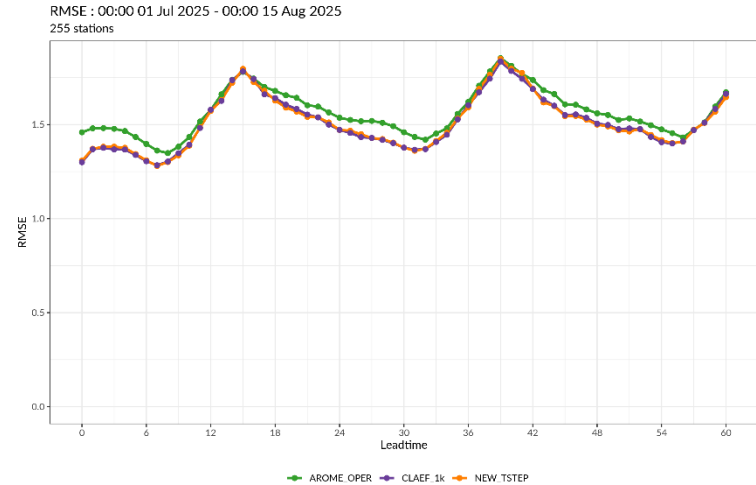
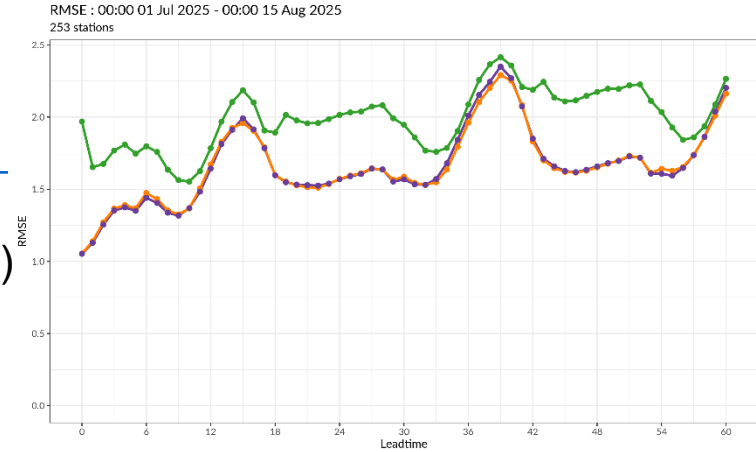


— CLAEF_1k_flat — CLAEF_OPER_flat

— CLAEF_1k_flat — CLAEF_OPER_flat

C-LAEF AlpeAdria - Tstep

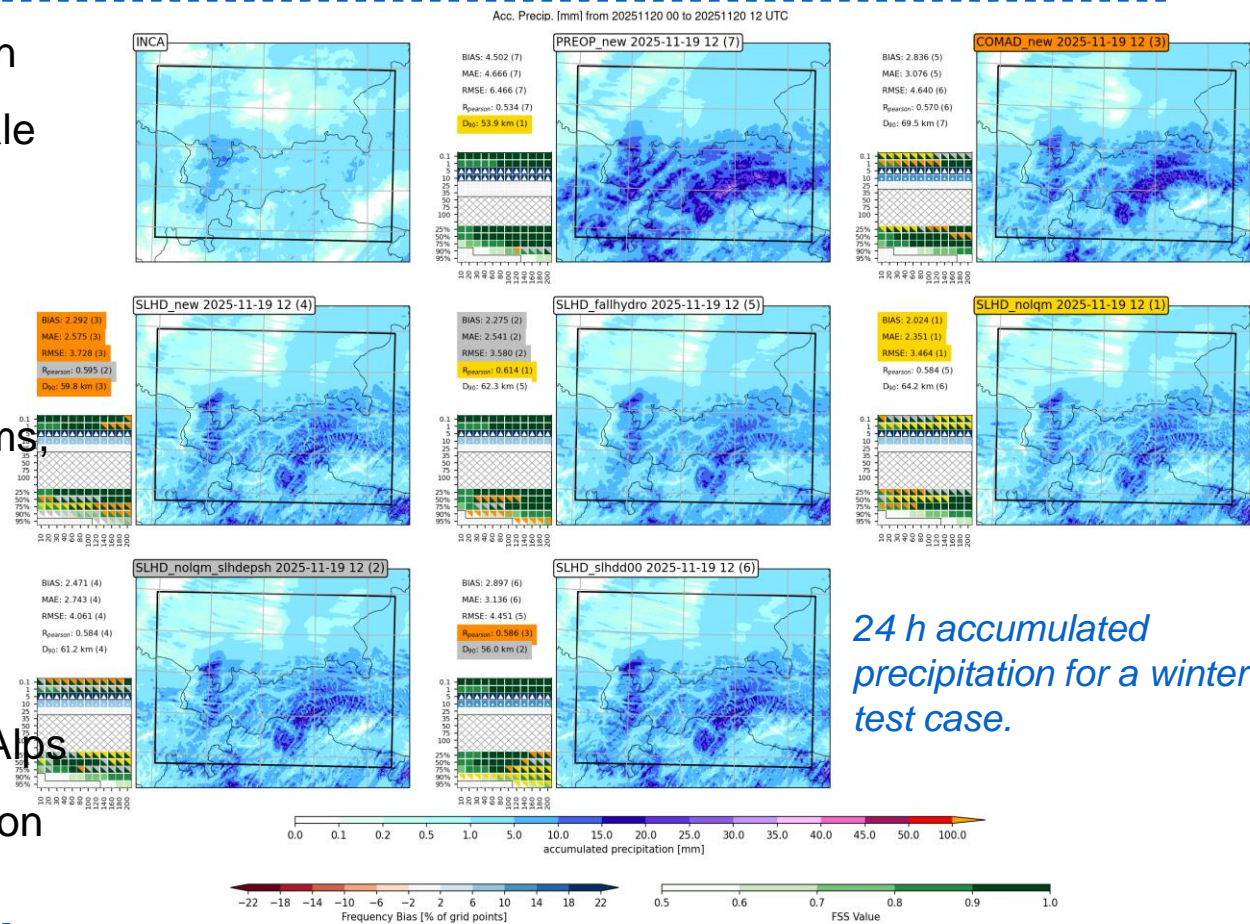
- C-LAEF AlpeAdria is a very expensive system (1 km, EPS every 3 h)
- Limited resources (SBUs) -> quadratic truncation, Tstep of 60 sec
- Tested with 1 member during the summer period
- Scores ok, no degradation, no stability issues
- In autumn increased Smilags, stability issues – first crashes
- Investigation of spectral norms, etc. has shown that Tstep of 60 sec is too long - moved back to 45 s in January 2026
- Still some smilags in case of windy situations
- Single grid points with unrealistic precipitation amounts
- Test runs with 30 s solved that problems (not affordable)



Verification for 510m
RMSE of T 2m and 10 m wind speed for C-LAEF oper (2.5 km, green), C-LAEF AA with tstep=45 s (purple) and C-LAEF AA with tstep=60 s (orange) for summer 2025.

CLAEF AlpeAdria: Dynamics

- Precipitation overestimation in the Alps in C-LAEF AlpeAdria in course of large scale events – too strong orographic impact
- Physics adaptations (VSIQGSAT, SUBGCOND, etc.) with minor impact
- Reduce Tstep to 30 sec – improved norms, less small scale patterns in vertical wind speed, not affordable
- Comad reduces precipitation efficiently, removes convective precipitation in the Alps
- Tuning of SLHD settings, spectral diffusion currently ongoing



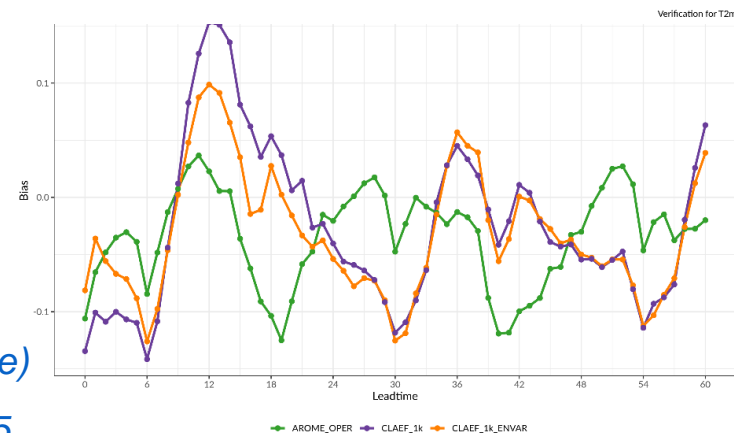
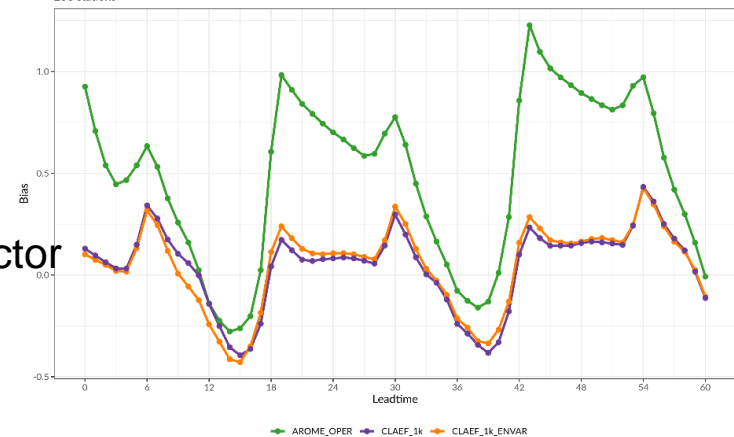
24 h accumulated precipitation for a winter test case.

CLAEF AlpeAdria: EnVar

- Work on EnVar in C-LAEF AlpeAdria ongoing
- EnVar based member (cy48t3) in C-LAEF AA as second control
- EnVar based on 32 members, 16 members (t - 3 h) and 16 (t - 6 h)
- Initially stability problems (obs perturbations) – increased inflation factor
- Crashes in 001 – solved with IAU with 15 min window
- Bad performance for some convective cases in summer –
problem in radar assimilation; not properly set NOTVAR flag;
- Perturbations lead to RH > 100% or negative in pseudo radar obs –
correction of Sigma_o in code

BIAS of 2 m temperature (up) and 10 m wind speed (down) of C-LAEF 2.5 km (green), C-LAEF AA (purple) and C-LAEF AA with EnVar (orange) in summer 2025.

Bias : 00:00 03 Jul 2025 - 00:00 15 Aug 2025
253 stations



SPP in AROME-EPS

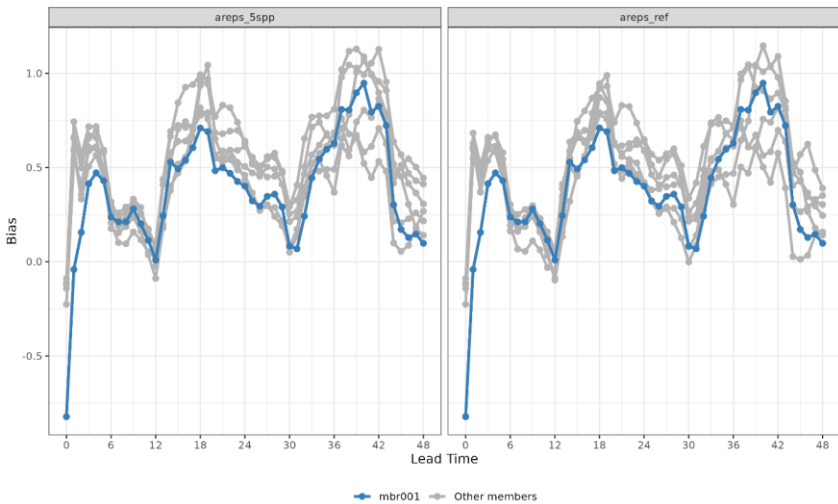
- HungaroMet is currently optimizing SPP setup - planned operationalization in AROME-EPS end of 2026
- cy46t1, starting with 10 SPP parameters (from C-LAEF)
- Test period July 2025 with 6 + 1 members
- Improvements for global radiation and MSLP, no impact on other variables
- Perturbing parameters separately has stronger effect
- Interactions between SPP parameters
- Perturbation of 5 parameters in different parameterization schemes improved scores

Name of the parameter	Description	CMPER T	Unperturbed Value
VSIGQSAT	constant for sub grid condensation	0.4	0.02
RSWINHF	short-wave inhomogeneity factor	0.05	1
RLWINHF	long-wave inhomogeneity factor	0.04	1
XCTP	constant for temperature and vapour pressure correlations	0.3	4.65
XCEP	constant for wind-pressure correlations	0.2	2.11
XCED	constant for dissipation of TKE	0.2	0.85
XCMF	closure coefficient at the bottom level	0.1	0.065
XFRACZ0	coefficient for the orographic drag	0.15	10
RCRIAUTI	snow auto conversion threshold	0.2	$1 * 10^{-3}$
RCRIAUTC	rain auto conversion threshold	0.02	$0.5 * 10^{-3}$

List of all implemented SPP parameters in AROME-EPS.

SPP in AROME-EPS

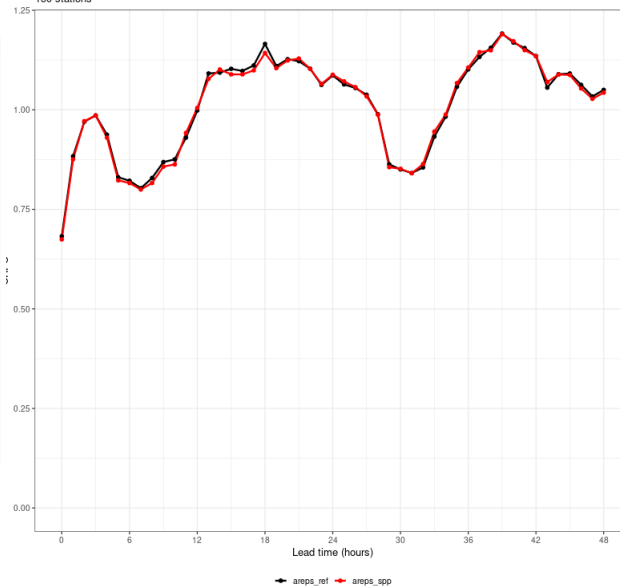
Bias :: 00:00 01 Jul 2025 - 00:00 14 Jul 2025
141 stations



Verification for windGust

Bias of 10 m wind gusts based on the control member (blue) and 6 perturbed members (grey) of AROME-EPS with 5 perturbed parameters (left) and without SPP (right) for July 2025.

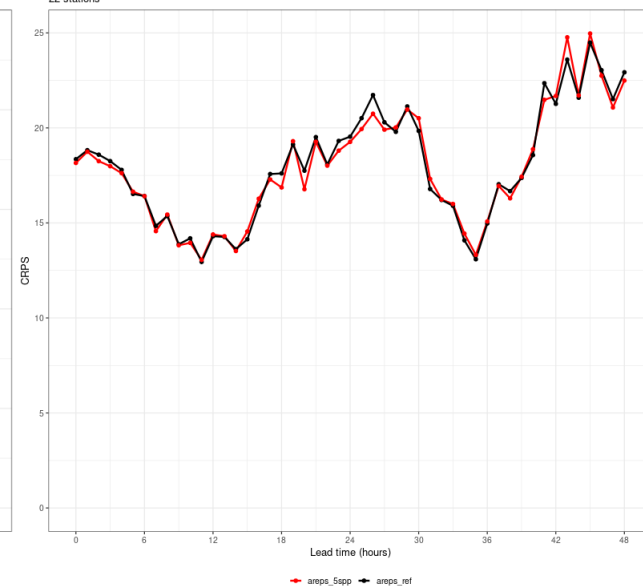
CRPS 20250701 - 20250714 for wind speed
150 stations



Verification for windSpeed

CRPS (wind speed) for the reference without SPP (black) and the experiment with 10 SPP parameters (red) for July 2025.

CRPS 20250701 - 20250714 for cloud cover
22 stations

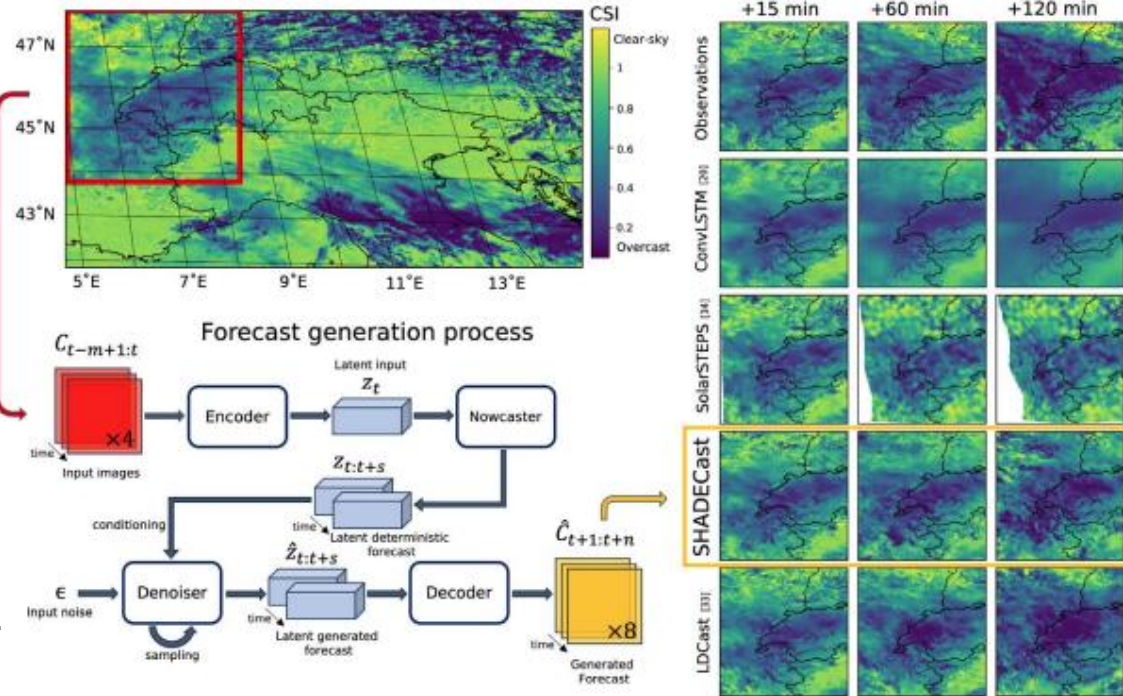


Verification for skyAllCover

CRPS (cloud cover) for the reference run without SPP (black) and the experiment with 5 SPP parameters (red).

Application of Machine Learning for EPS nowcasting

- A lot of work is ongoing in LACE in the AI area
- Strong request for accurate nowcasts for global radiation (PV) and precipitation (hydro power)
- Uncertainty of the forecasts needs to be accounted for - using EPSs as input
- Use AI models together with observations (e.g. satellite data) for improved nowcasts
- SHADECast - modular deep generative nowcasting framework for satellite-based short-term forecasting of solar radiation
- Specifically Clear-Sky Index (CSI) fields, python based



Schematic representation of the AI based nowcasts.

Statistical EPS & AI

Application of Machine Learning for EPS forecasts

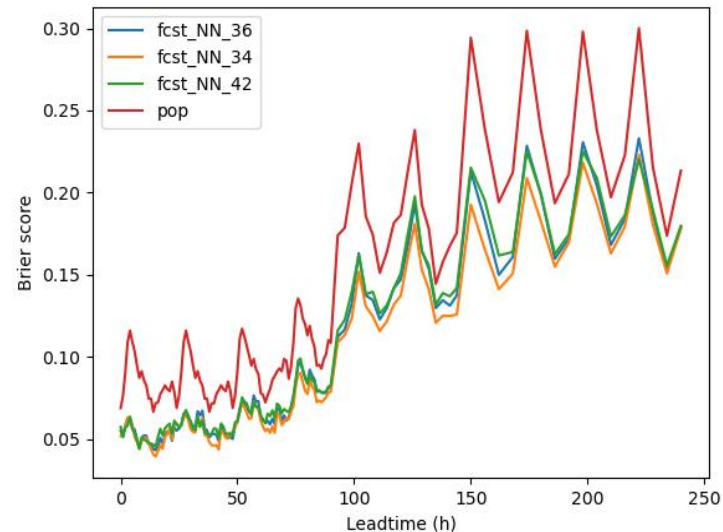
- Rain NWP postprocessing using neural networks
- Generate probabilistic rain forecasts using deterministic NWP
- Post-processing at station locations by using feed-forward neural network
- Several variations of the neural network outperform IFS-EPS

Generation of ensemble members by AI

- Technical installation and implementation of a diffusion-based model for emulating ensemble members (CorrDiff model) on the Leonardo HPC
- The training and the inference has been tested based on a mini ensemble
- The model itself is trained in a two-step process:

Pre-training with ERA5 downscaling on C-LAEF reanalysis

Finetuning with downscaling of IFS-ENS members on C-LAEF is done

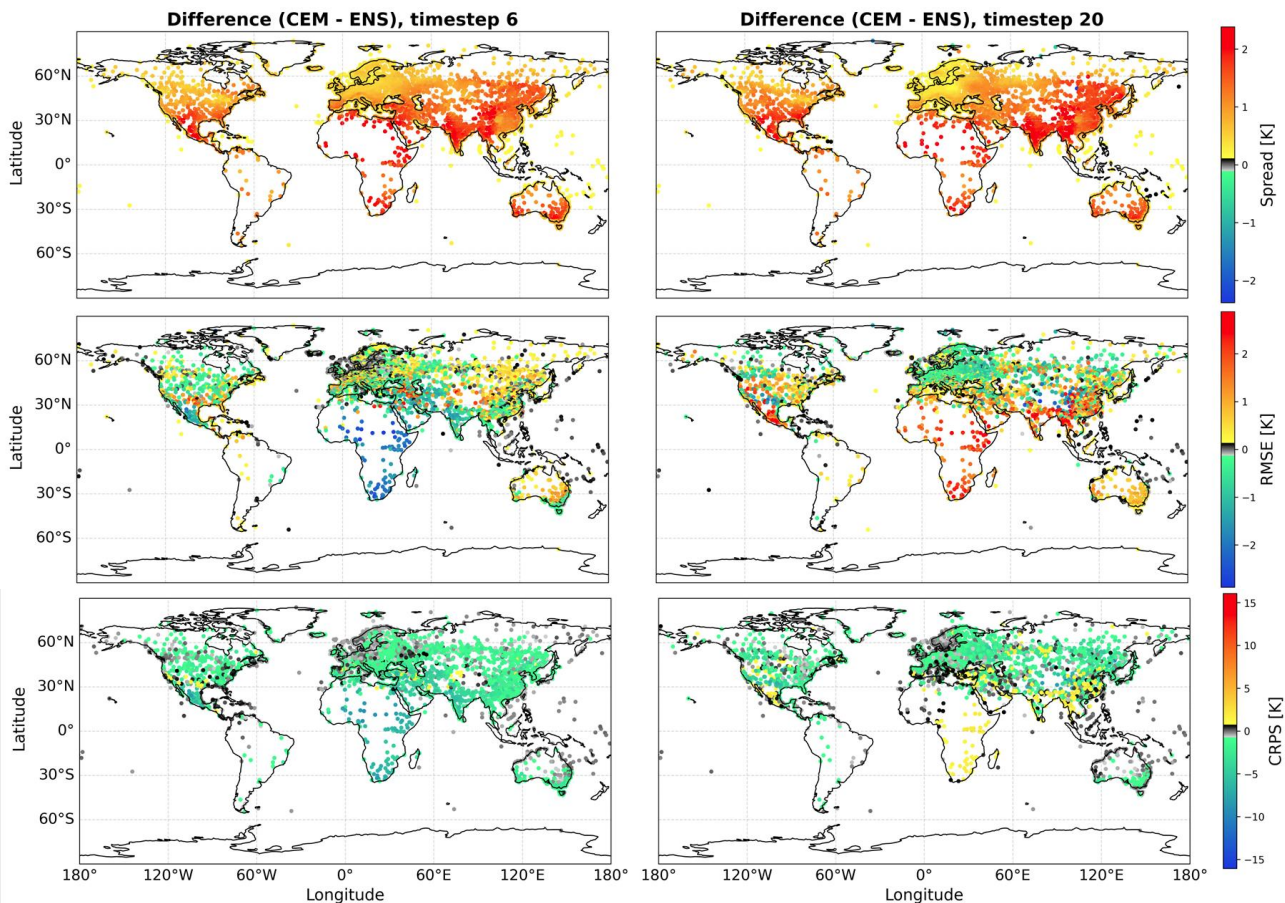


Brier score of precipitation for different postprocessing methods and IFS-EPS (red).

Cascading Ensemble Method (CEM)

- IMGW in Poland has developed a new ensemble technology CEM (Cascading Ensemble Method)
- CEM is adding new members to EPS during the forecast when uncertainties increase
- Number of ensemble members rises with the number of timesteps, for n timesteps, the final ensemble count is 2 to the n -th power
- Aim is to achieve similar or better results compared to the traditional methods, but at a lesser computational cost and less storage usage
- CEM was tested first with the data-driven global weather forecasting model FourCastNet from Nvidia (trained on ERA5)
- 20 atmospheric variables (5 on the surface), timestep of 6 hours, 0.25° spatial resolution
- CEM currently tested with ALARO in Poland

Statistical EPS



Difference (CEM – ENS) of ensemble spread, RMSE and CRPS for 2m temperature in January 2025.

Outlook & Plans

Operational Plans

A-LAEF:	Upgrade to new version (cy46t1, ALARO multiphysics)	Summer 2026
C-LAEF AlpeAdria:	New 1 km C-LAEF AlpeAdria operational	06/2026
	Flow dependency (EnVar, FD SPP)	2027
AROME-EPS:	SPP in operations	End of 2026
	SPP in SURFEX	2027

Research & Development

EnVar and Hybrid EnVar in EPS
Research on flow-dependent model perturbations (include AI)
Improved surface perturbations (SPP in SURFEX)
EPS on hectometric scale
Work on statistical post-processing of probabilistic fields
Generation of ensemble members by ML
Extension of data-driven ML ensemble methods