
ZAMG
Zentralanstalt für Meteorologie und Geodynamik

**Workshop on model uncertainty**
# C-LAEF – status and development of model error representation

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## C-LAEF operational status

The Convection-permitting Limited-Area Ensemble Forecasting System (C-LAEF) is the operational LAMEPS system of ZAMG since November 2019 (Wastl et al 2021). It has the same horizontal and vertical resolution (2.5km/90 level) as the main deterministic NWP model of ZAMG (AROME-Aut). After a major system upgrade in December 2021 C-LAEF runs 8 times per day, with two long runs with lead times of +60h/+48h, where the control run has the identical setup as AROME-Aut and serves also as backup for the deterministic forecast. The system consists of 16 perturbed member that consider uncertainties in initial conditions, lateral boundary conditions, surface fields and in the model itself. Fig.1 shows the domain and topography of C-LAEF while Table 1 summarizes the technical setup of C-LAEF and its deterministic counterpart AROME-Aut.

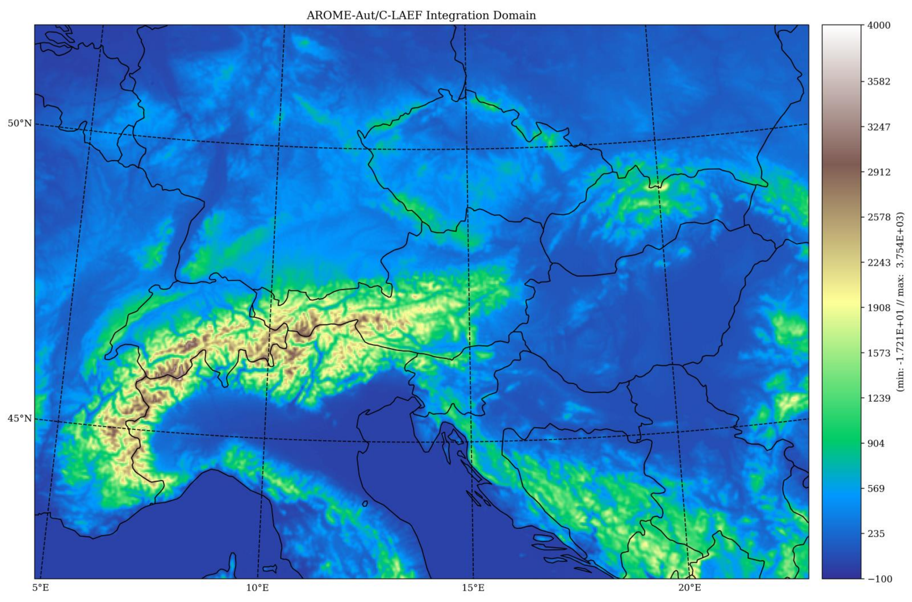


**Figure 1**: Integration domain of AROME-Aut/C-LAEF

| | AROME-Aut | C-LAEF |
|---|---|---|
| Model version | cy43t2bf11 | cy43t2bf11 |
| Resolution | 2.5km | 2.5km |
| Area | Alpine area (600x432) | Alpine area (600x432) |
| Members | 1 | 16 + 1 |
| Levels (lowest/highest) | 90<br>(5m / 35km) | 90<br>(5m / 35km) |
| Starting times | 00, 03, ... 21 UTC | 00, 03, ... 21 UTC |
| Forecast range | 60 hours | 60 hours / 48 hours |
| Time step | 60s | 60s |
| Output Frequency | 1h 2D/3D | 1h 2D/3D |
| Orography / physiography | GMTED2010<br>ECOCLIMAP 1 | GMTED2010<br>ECOCLIMAP 1 |
| LBC model | ECMWF HRES | ECMWF ENS |
| LBC update | 1h | 1h |
| Surface scheme | SURFEX 8.0 | SURFEX 8.0 |
| Initial conditions (3D / Surf.) | 3DVAR / OI | Ens 3DVAR+Jk / Ens OI |
| Cycle interval | 3 hours | 3 hours |
| Assimilation Window | -90min-+90min | -90min-+90min |
| B-Matrix | C-LAEF EDA climatologic | C-LAEF EDA climatologic |
| Hardware | HPE Apollo 8600 (ZAMG) | Cray XC40 (ECMWF) |

**Table 1**: Setup of operational AROME-Aut/C-LAEF

## Initial and lateral boundary condition perturbations

The ECMWF-ENS system provides the lateral boundary conditions for C-LAEF. The 16 perturbed member of C-LAEF are coupled with the first 16 member of ECMWF-ENS not taking the other members into account. For the initial perturbations a combination of Ensemble Data Assimilation (EDA), EDA of surface variables (sEDA) and Jk is implemented. EDA/sEDA are implemented such that the first guess from the particular member is used and observations are randomly perturbed before entering the assimilation scheme. Fig. 2 shows the workflow of the implemented EDA/sEDA.
Uncertainties from ECMWF-ENS are integrated in the 3D-Var system of C-LAEF by the Jk blending method developed by Guidard and Fischer (2008). With this method large scale perturbations from the coarser global EPS system are combined with small scale perturbations from C-LAEF assimilation cycle without introducing inconsistencies between the different scales (Keresturi et al., 2019).

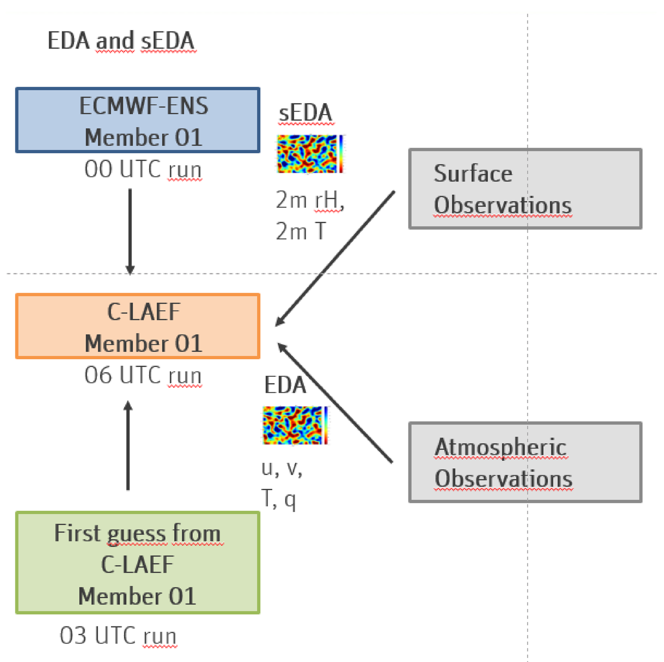


**Figure 2**: Schematic workflow for initial condition perturbations in C-LAEF

## Surface perturbations

Between surface analysis and forecast start a number of surface fields are stochastically perturbed. Seasonal/constant surface fields – e. g. leaf area index, vegetation index - are taken from the unperturbed control run and are perturbed with seperate random numbers in the members. Prognostic surface fields (e. g. soil moisture, soil temperature, snow depth) are perturbed after surface analysis using different seed numbers for every member allowing independent cycling for every field.

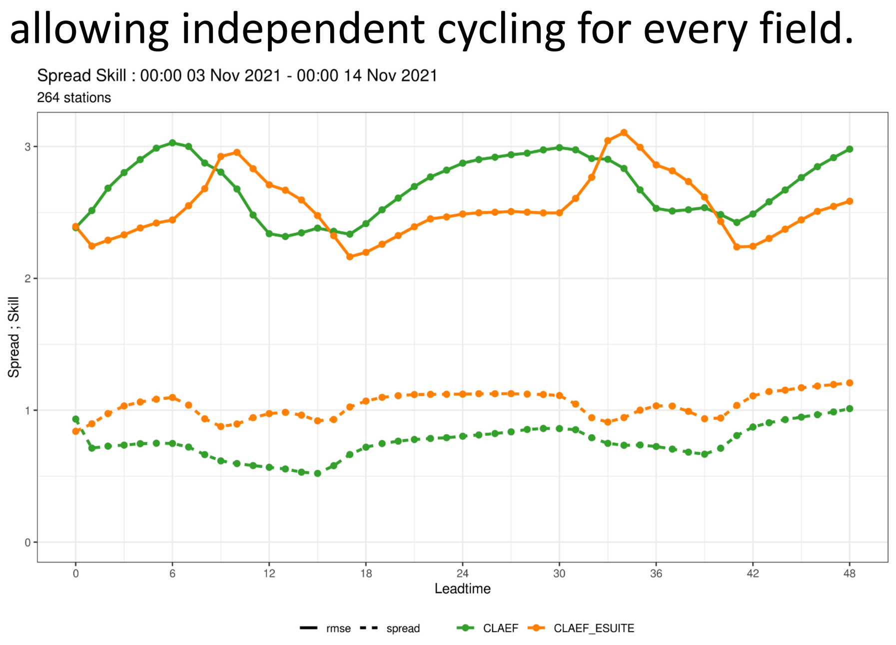


**Figure 3:** Spread and RMSE of T2m of C-LAEF with (orange) and without (green) surface perturbations

| Parameter name | Std. dev. | Perturbation type |
|---|---|---|
| Vegetation index | 0.1 | Multiplicative |
| Vegetation heat coefficient | 0.1 | Multiplicative |
| Leaf area index | 0.2 | Multiplicative |
| Land albedo (all wavelengths) | 0.1 | Multiplicative |
| Land roughness length | 0.2 | Multiplicative |
| Soil/sea surface temperature (K) | 1.5 | Additive |
| Soil moisture | 0.1 | Multiplicative |
| Snow depth | 0.5 | Multiplicative |
| Sea surface fluxes | 0.2 | Multiplicative |

**Table 2**: List of surface parameters randomly perturbed before model integration

References:
- Guidard, V. and Fischer, C., 2008: Introducing the coupling information in a limited-area variational assimilation. QJRMS, 134, 723–735.
- Keresturi et al., 2019: Improving initial condition perturbations in a convection-permitting ensemble prediction system , QJRMS, doi:10.1002/qj.3473
- Ollinaho et al. 2017: Towards process-level representation of model uncertainties: stochastically perturbed parametrizations in the ECMWF ensemble, QJRMS, doi:10.1002/qj.293
- Palmer et al 2009: Stochastic parametrization and model uncertainty. Technical Report, ECMWF Technical Memo. 598, 42 pp. Available at: http://www.ecmwf.int/publications/
- Wastl et al., 2021: C-LAEF: Convection-permitting Limited-Area Ensemble Forecasting system. QJRMS, 147, 1431– 1451
- Wastl et al., 2019: A hybrid stochastically perturbed parametrization scheme in a convection-permitting ensemble, Mon. Wea. Rev. 147, 2217-2230

## Stochastic physics – a hybrid system

In C-LAEF stochastic physics are implemented as a combination of a tendency and a parameter perturbation scheme (Wastl et al. 2019). The model tendencies of T, Q, U and V are perturbed after each parameterization scheme (shallow convection, microphysics, and radiation). This allows to use different perturbation patterns for each parameterization with different temporal and horizontal scales targeted to the specific process (see Fig. 4).

| Parameter | Range | Description |
|---|---|---|
| XLINI | 0 – 0.1 | Minimum BL89 mixing length |
| XCTD | 0.98 – 1.2 | Constant for dissipation of potential temperature and mixing ratio |
| XCTP | 2.325 – 4.65 | Constant for temperature-vapor pressure correlation |
| XCEP | 1.055 – 4.0 | Constant for wind-pressure correlation |
| XCED | 0.7 – 0.85 | Constant for dissipation of total kinetic energy (TKE) |
| XALPSBL | 3.75 – 4.65 | Value related to the TKE universal function within the surface boundary layer |

**Table 3**: List of parameters in the turbulence scheme that are stochastically perturbed

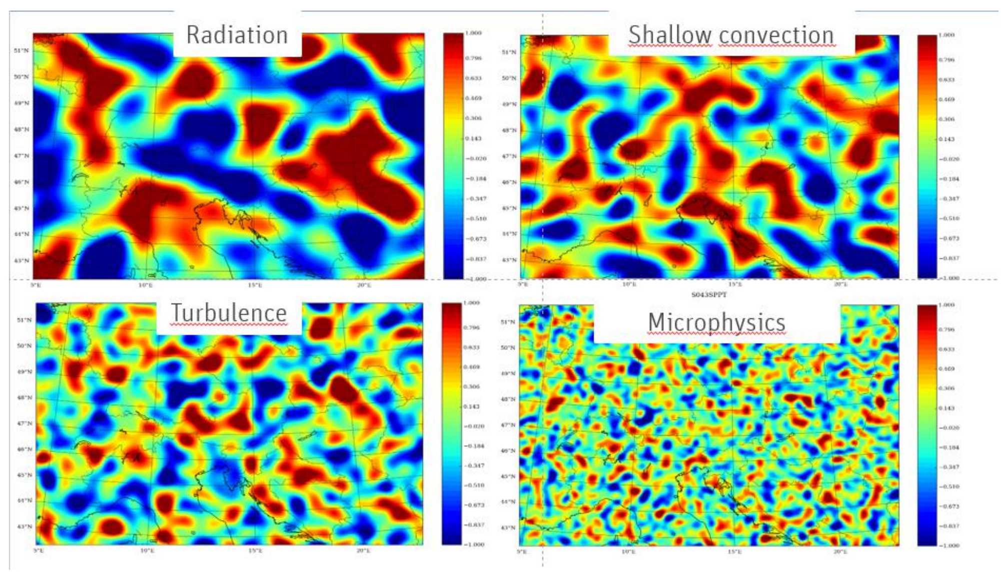


**Figure 4**: Example of perturbation patterns for different parameterization schemes

However the perturbation of partial model tendencies has some drawbacks with energy conservation and tapering function, especially in the turbulence scheme. This can be solved by directly perturbing uncertain key parameters (SPP - Ollinaho et al., 2017; see Table 3) at process level in the turbulence scheme.

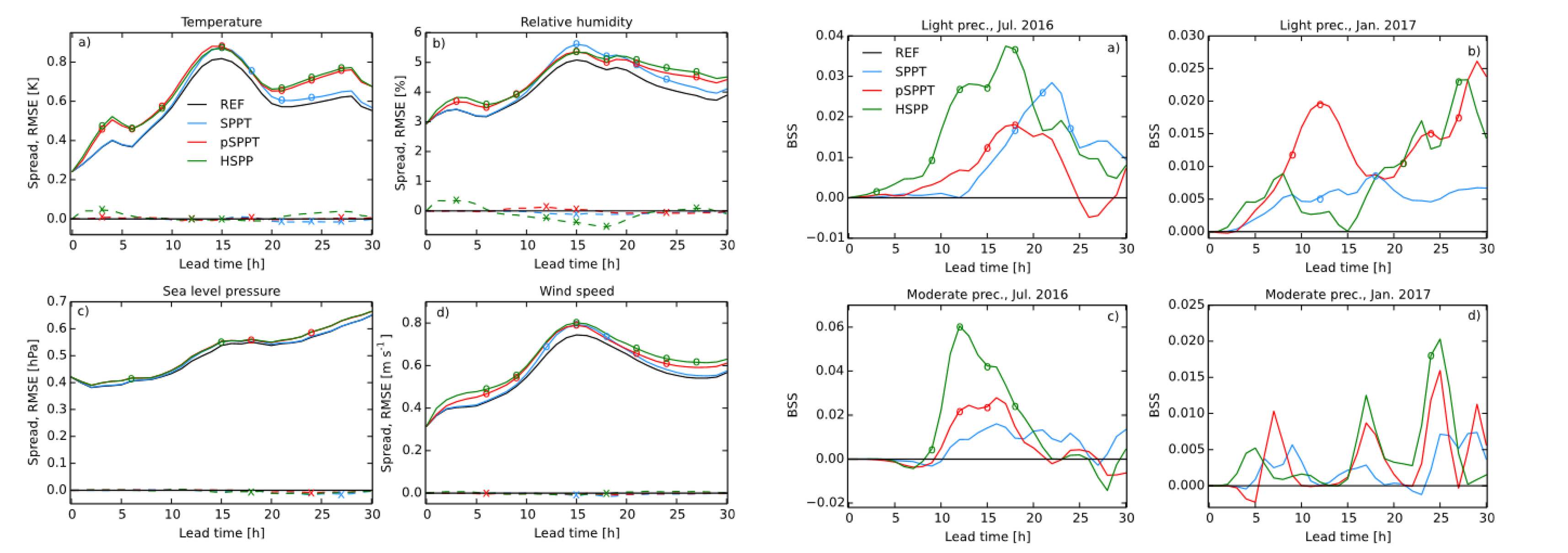


**Figure 5**: REF – no perturbations, SPPT – original SPPT (Palmer et al. 2009), pSPPT – perturbation of partial model tendencies, HSPP – combination of pSPPT and paramter perturbation. Left: Spread (absolute)/RMSE (relative to REF) for 2m Temperature, 2m RH, MSLP, 10m Wind valid for July 2016; Right: Brier Skill Score for light (upper row) and moderate rain (lower row)., left colum for July 2016, right for Jan 2017 (all Figures from Wastl et al. 2019).

## Current research

There is ongoing work to extend the stochastic parameter perturbations of key parameters at process level to all physics parametrizations (SPP). It is planned to enhance the number of perturbed parameter in the future.
Case studies have been carried out where specific processes that are known to be uncertain or causing problems in forecasts are perturbed. Fig. 6 shows a case where operational C-LAEF shows too strong orographic effects over the Alpine ridge. Perturbation and bias reduction of sublimation of snow/graupel in the microphysics scheme can reduce the orographic induced effect.

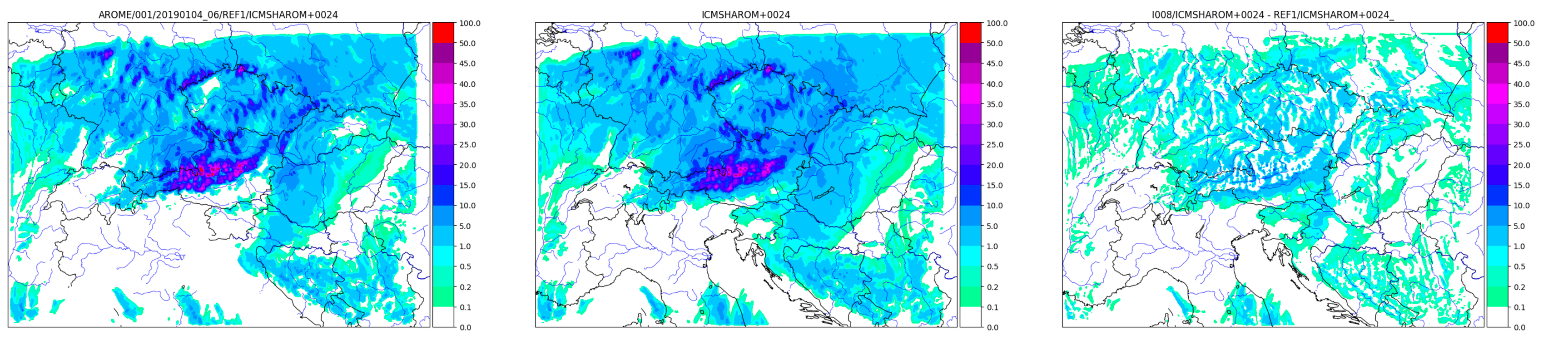

**Figure 6**: Precipitation without (left panel) and with perturbed sublimation of snow/graupel on process level (middle). Right panel shows difference between left and middle panel.

A first test period of 2 weeks in December 2021 with 13 perturbed parameters in C-LAEF indicates the need for further tuning/research. An E-suite is currently set up on the new ECMWF-HPC to further evaluate the potential of stochastic perturbed parameters.

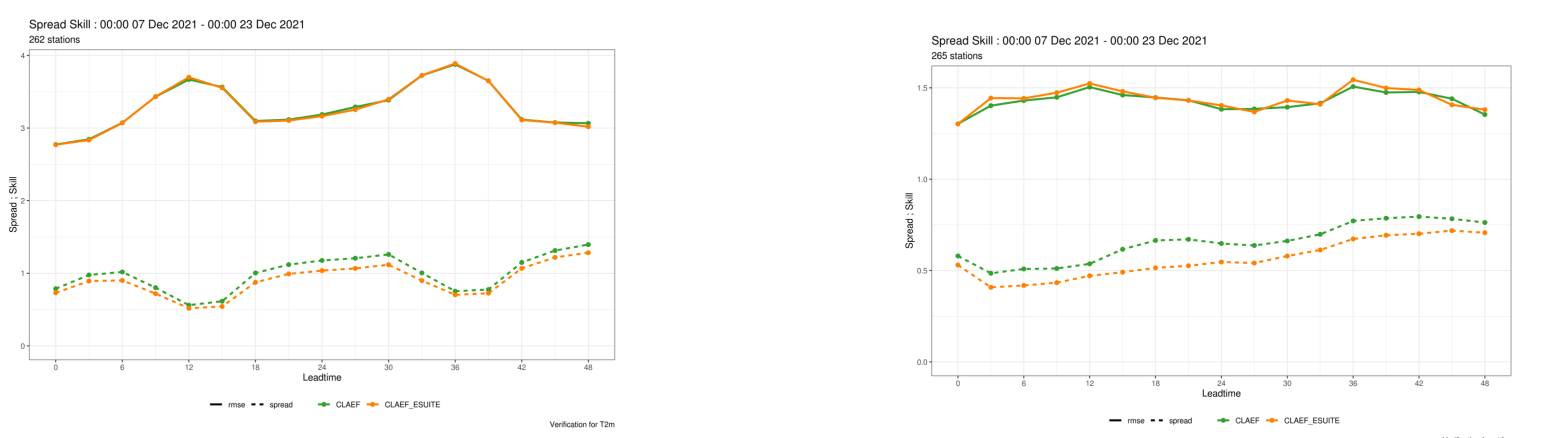

**Figure 7**: Spread skill of 2m Temperature (left) and 10m wind speed (right) for 2 week period in December 2021. Operational setup (green) and in orange C-LAEF with SPP.