C-LAEF: Convection permitting Limited Area Ensemble Forecasting

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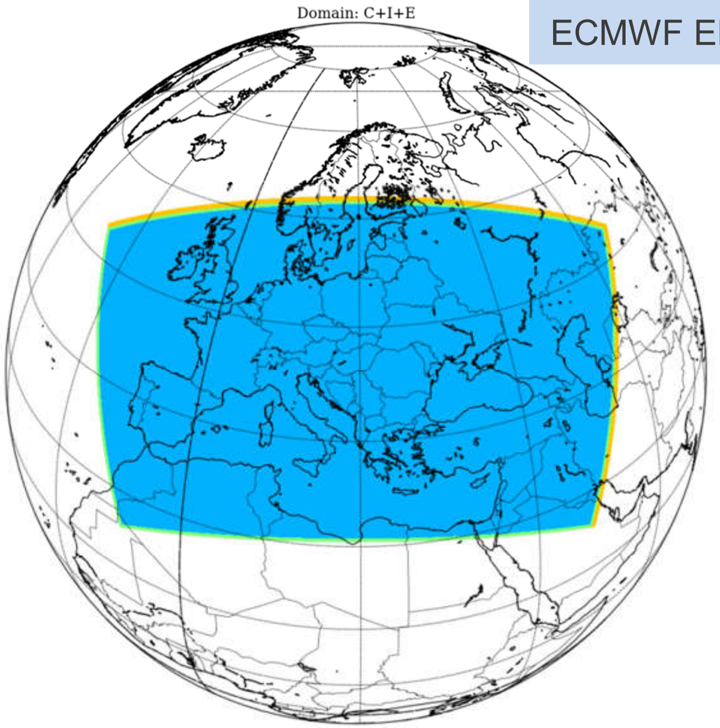
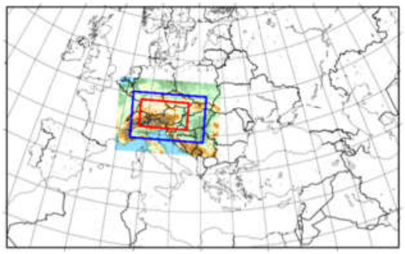
Ensemble prediction systems in Austria

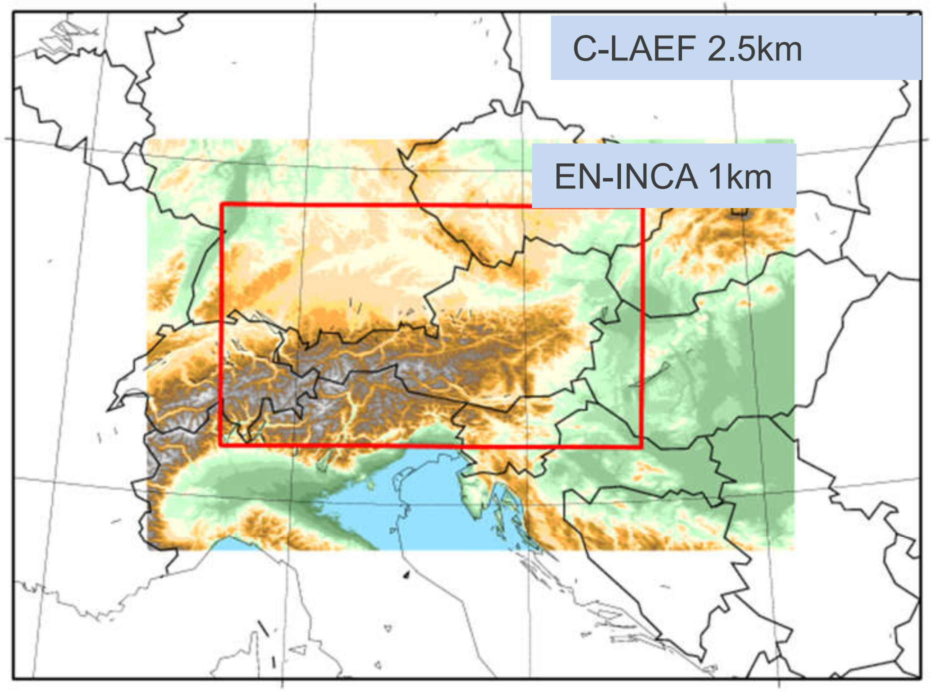
ECMWF ENS 18km



ALADIN-LAEF 11km



C-LAEF and EN-INCA



Part of the seamless system

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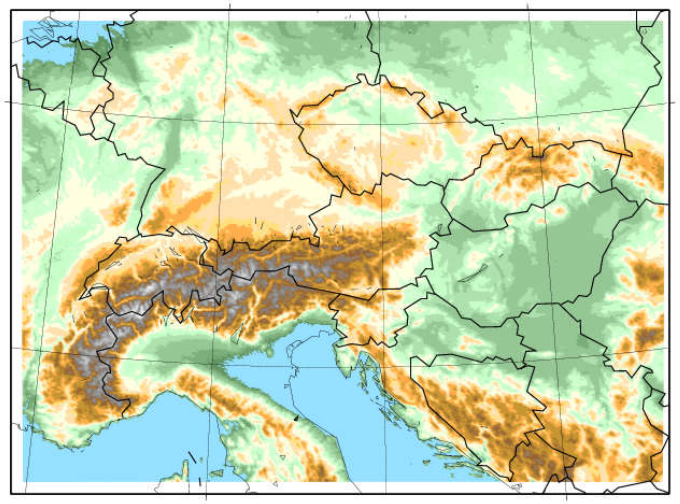
C-LAEF at ZAMG

Convection permitting Limited Area Ensemble Forecasting

AROME based; under development - not yet operational; ECMWF supercomputer

ensemble size	16 + 1
Δx / vertical levels	2.5 km / 90
coupling	ECMWF-ENS
runs per day	00/12 (+ 48 h) - 06/18 (+6h)



Initial conditions error + **Lateral boundary conditions error** + **Model error**

Initial conditions error

- Ensemble-data assimilation (EDA)
- Ensemble-data assimilation of surface variables (ESDA)
- Ensemble-Jk

Lateral boundary conditions error

- Coupling with ECMWF-ENS
- Ensemble-Jk

Model error

- Perturbation of tendencies (SPPT, pSPPT)
- Perturbation of parameters (SPP)
- Combination of pSPPT+SPP (HS)

IC and LBC perturbations in C-LAEF

- Jk blending method developed by Guidard and Fischer (2008)
- Integration of uncertainty from global EPS directly to C-LAEF data assimilation
- Combination of large scale (global EPS) with small scale (C-LAEF) perturbations
- Consistency between IC und LBC perturbations in C-LAEF

Cost function (3DVar)

$$J(x) = \underbrace{\frac{1}{2}(x - x_b)^T B^{-1}(x - x_b)}_{J_b} + \underbrace{\frac{1}{2}(y - Hx)^T R^{-1}(y - Hx)}_{J_o}$$

Cost function in Jk blending method:

$$J(x) = J_b + J_o + \underbrace{\frac{1}{2}(x - x_{ls})^T V^{-1}(x - x_{ls})}_{J_k} = J_b + J_o + J_k$$

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Physics schemes in AROME / C-LAEF

Way how tendencies of different physics schemes are processed in AROME / C-LAEF

Radiation scheme → $\frac{\delta T_1}{\delta t}$

Shallow convection scheme → $\frac{\delta T_2}{\delta t}, \frac{\delta Q_2}{\delta t}, \frac{\delta U_2, V_2}{\delta t}$

Turbulence scheme → $\frac{\delta T_3}{\delta t}, \frac{\delta Q_3}{\delta t}, \frac{\delta U_3, V_3}{\delta t}$

Microphysics scheme → $\frac{\delta T_4}{\delta t}, \frac{\delta Q_4}{\delta t}$

$$\frac{dT}{dt} = \sum_{i=1}^{4} \frac{\delta T_i}{\delta t}, \quad \frac{dQ}{dt} = \sum_{i=1}^{4} \frac{\delta Q_i}{\delta t}, etc.$$

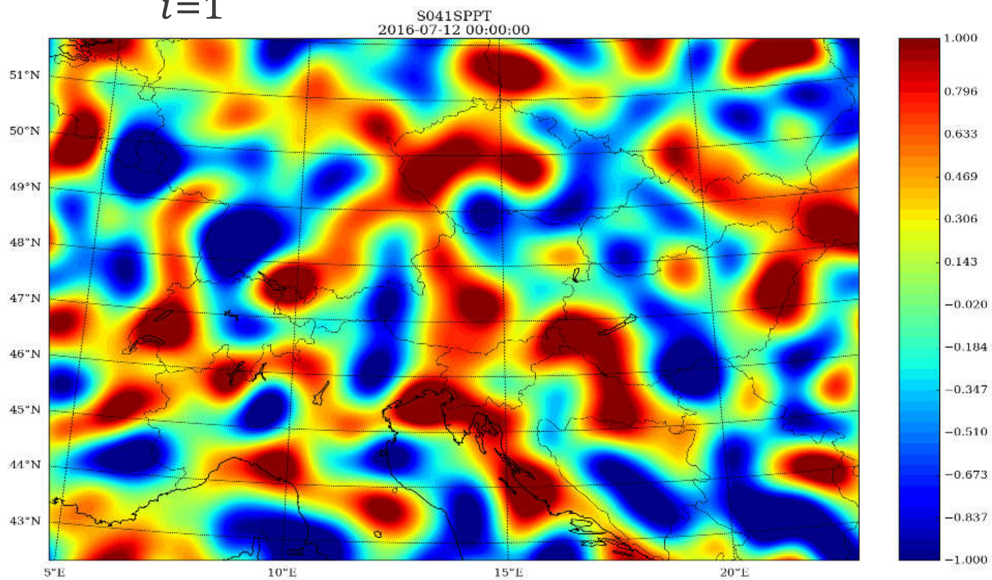
Stochastic perturbation of total model tendencies: SPPT (ECMWF)

Standard SPPT: Perturbation of total model tendencies (Buizza et al., 1999; Palmer et al., 2009)

$$\frac{dT}{dt} = \sum_{i=1}^{4} \frac{\delta T_i}{\delta t} \qquad \frac{dT'}{dt} = \frac{dT}{dt} * (1 + \mathrm{P})$$

$$\frac{dQ}{dt} = \sum_{i=1}^{4} \frac{\delta Q_i}{\delta t} \qquad \frac{dQ'}{dt} = \frac{dQ}{dt} * (1 + \mathrm{P}) \ldots\ldots$$

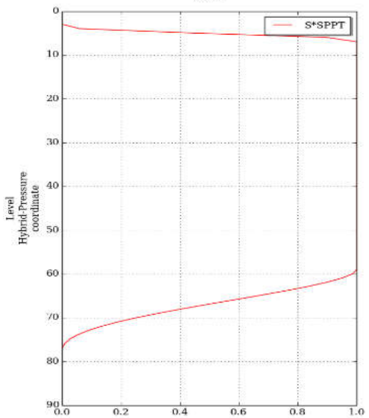
P …. stochastic pattern



Constraints:

- Energy conservation
- Tapering function ß
- Physical consistency
- Assumes same level of uncertainty for all parametrisations

$$\mathrm{P} = \mathrm{P} * \beta$$



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Stochastic perturbation of partial model tendencies: pSPPT (ZAMG)

Radiation scheme

$$\frac{\delta T_1}{\delta t} * (1 + P1)$$

Shallow convection scheme

$$\frac{\delta T_2}{\delta t} * (1 + P2), \frac{\delta Q_2}{\delta t} * (1 + \mathrm{P2}), \text{etc.}$$

Turbulence scheme

$$\frac{\delta T_3}{\delta t} * (1 + P3), \frac{\delta Q_3}{\delta t} * (1 + \mathrm{P3}), \text{etc.}$$

Microphysics scheme

$$\frac{\delta T_4}{\delta t} * (1 + P4), \quad \frac{\delta Q_4}{\delta t} * (1 + \mathrm{P4}), \text{etc.}$$

- In pSPPT the partial tendencies of T, Q, U, V are perturbed directly after each parametrization
- Influence on subsequent schemes
- Different perturbations are applied to the physics schemes
- In C-LAEF we need 4 different perturbation patterns with different temporal and horizontal scales

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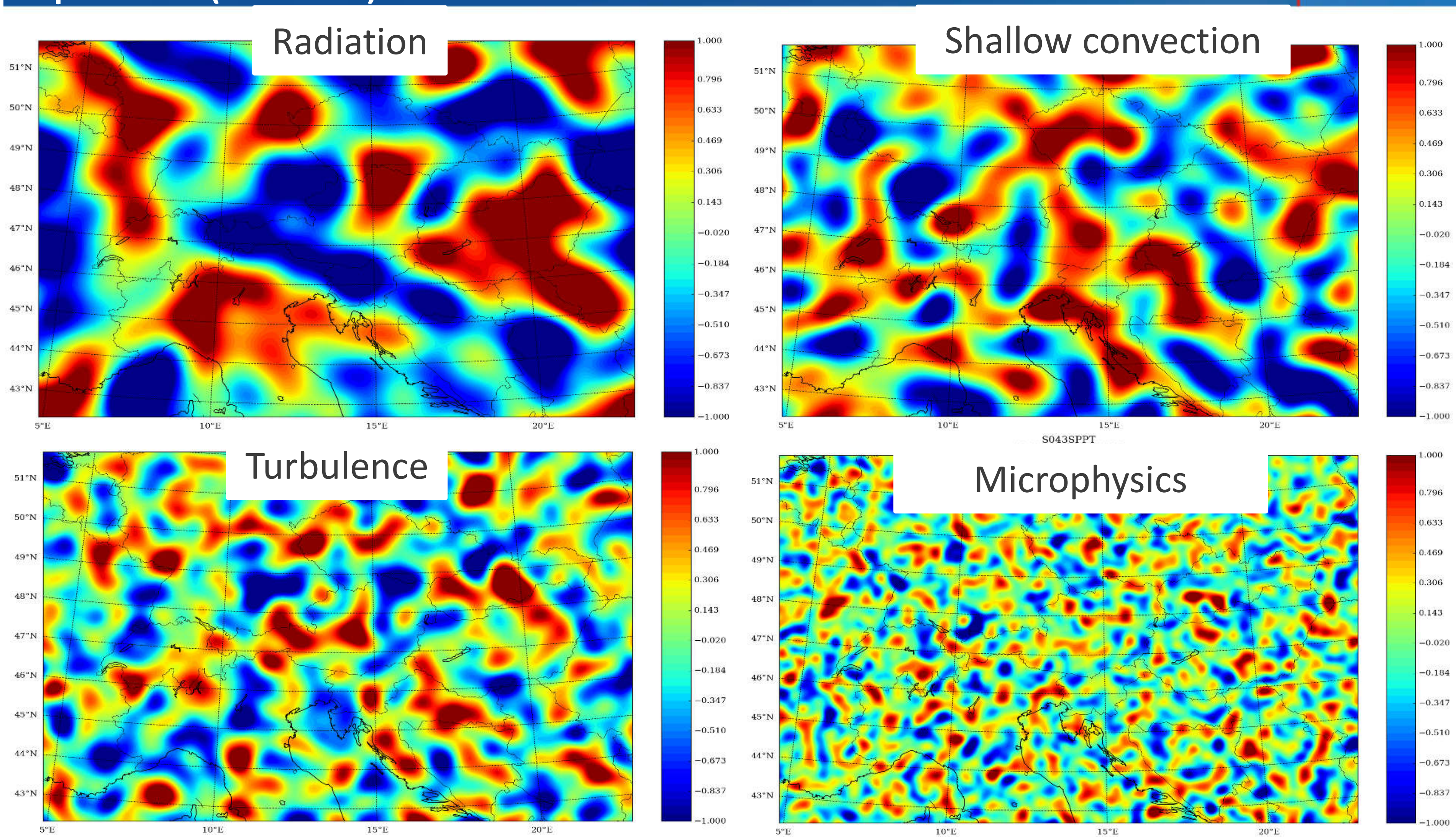
Stochastic perturbation of partial model tendencies: pSPPT (ZAMG)



- Assumes same level of uncertainty for all parametrisations ✓
- Physical consistency ✓

- Energy conservation ✗
- Tapering function ß (turbulence) ✓ ✗

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Stochastic physics in C-LAEF: Hybrid system (HS)

- Stochastic perturbation of model tendencies showed promising results, especially pSPPT, still some restrictions
- → Stochastic perturbation of key parameters (SPP, Ollinaho et al., 2017) at process level in the turbulence scheme (see table)
- Hybrid system (HS): Combination of pSPPT with parameter perturbation in turbulence

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

$$\alpha_{i'} = \exp(P) * \alpha_i$$

Parameters in the turbulence scheme which are stochastically perturbed.

- Energy conservation ✓ ✗
- Tapering function ✓

→

- Surface EDA, perturbation of surface variables

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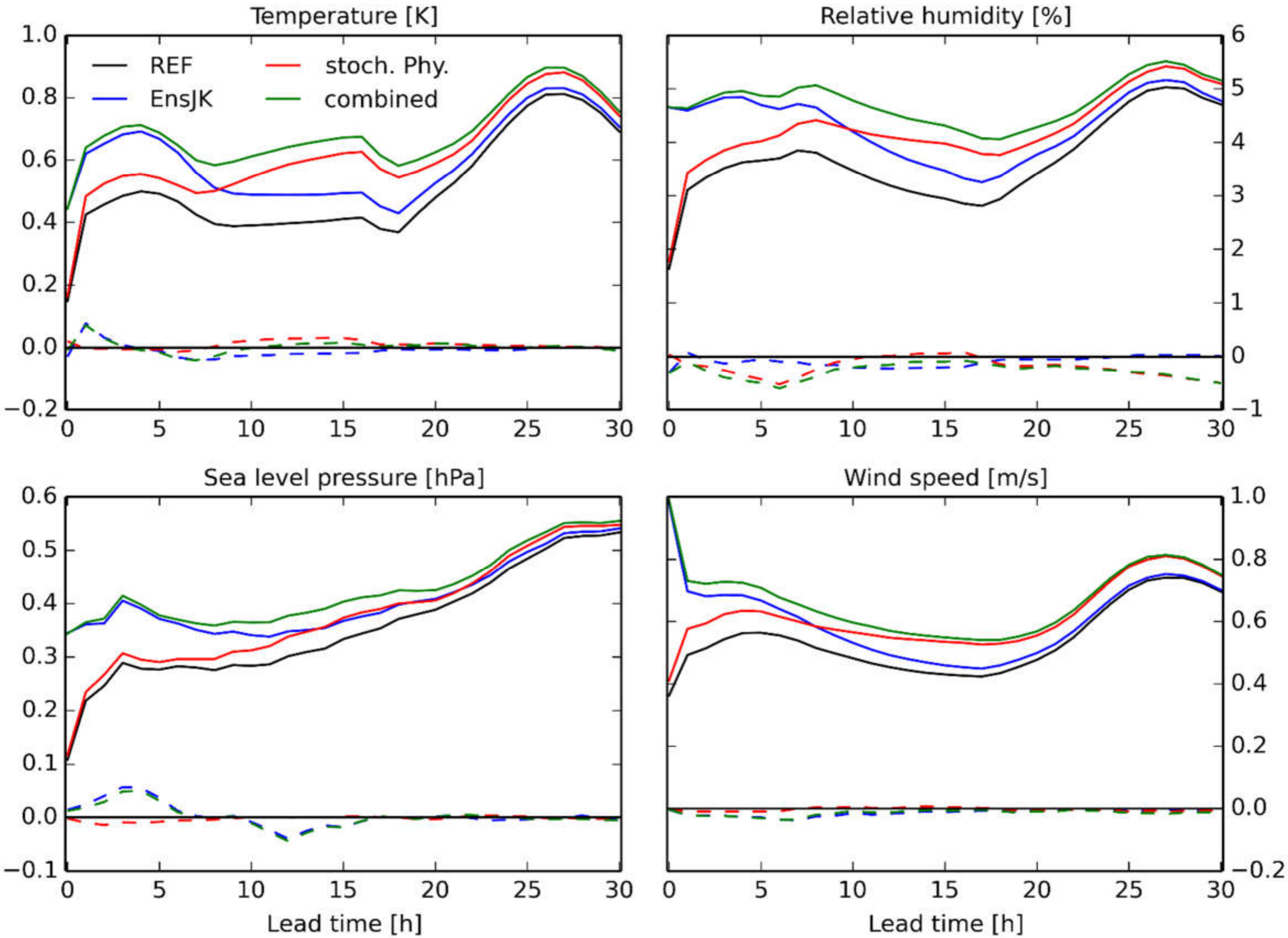
Results of summer test period



Ensemble spread (solid) and RMSE (dashed) for surface parameters in July 2016.
RMSE is given as difference to the reference run.

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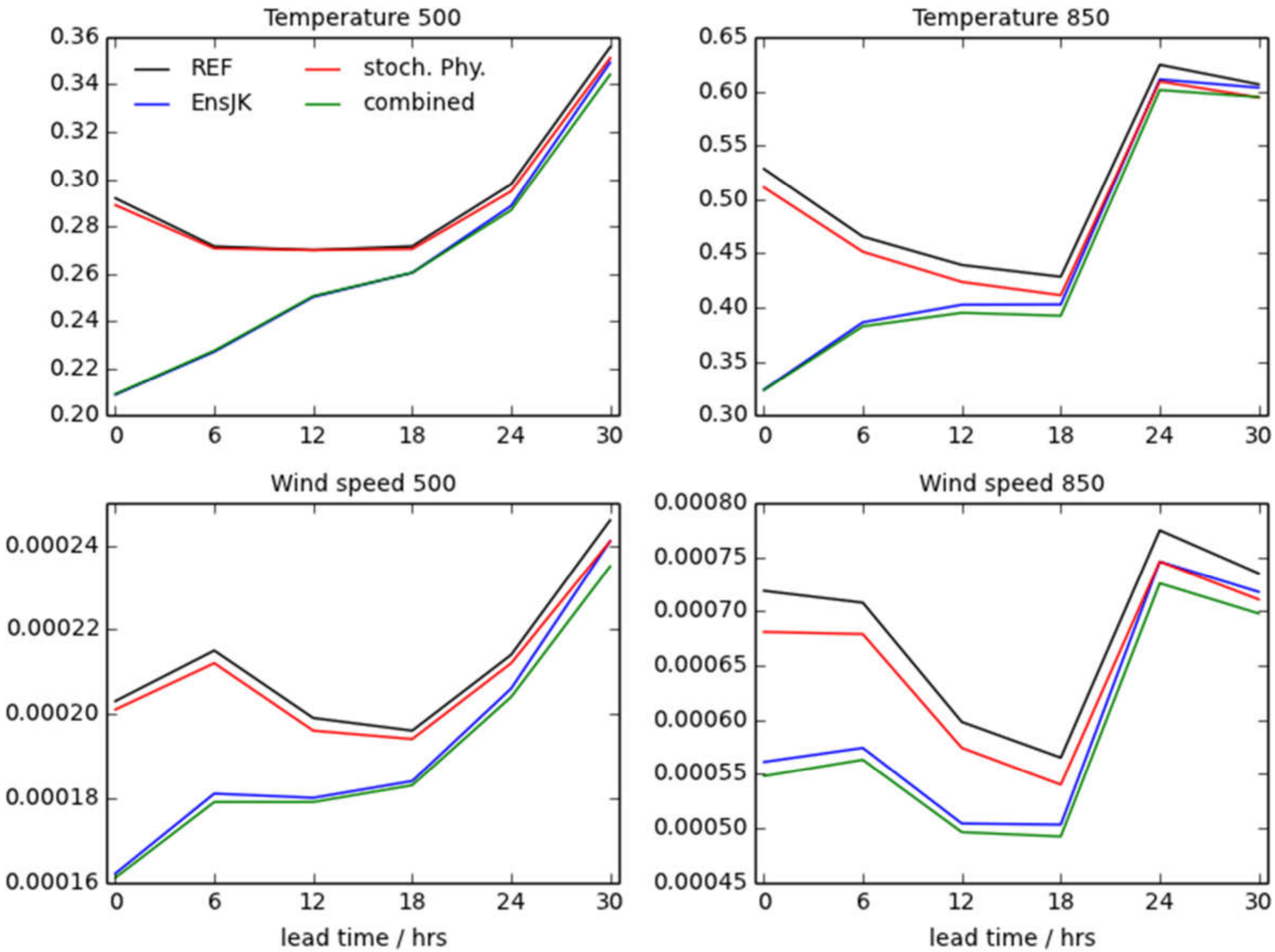
Results of summer test period



CRPS for temperature and wind speed at 500 hPa and 850 hPa in July 2016.

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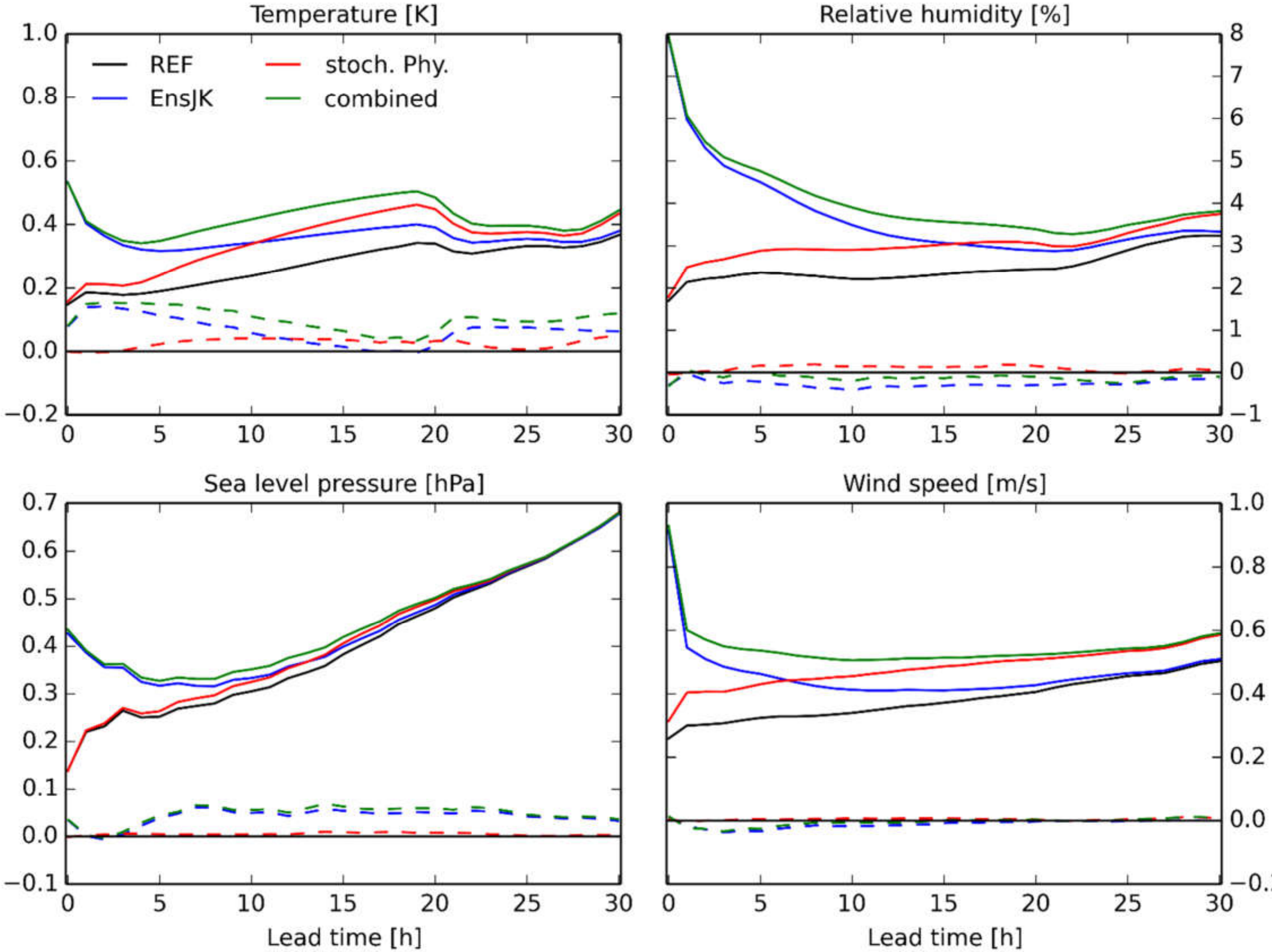
Results of winter test period



Ensemble spread (solid) and RMSE (dashed) for surface parameters in January 2017. RMSE is given as difference to the reference run.

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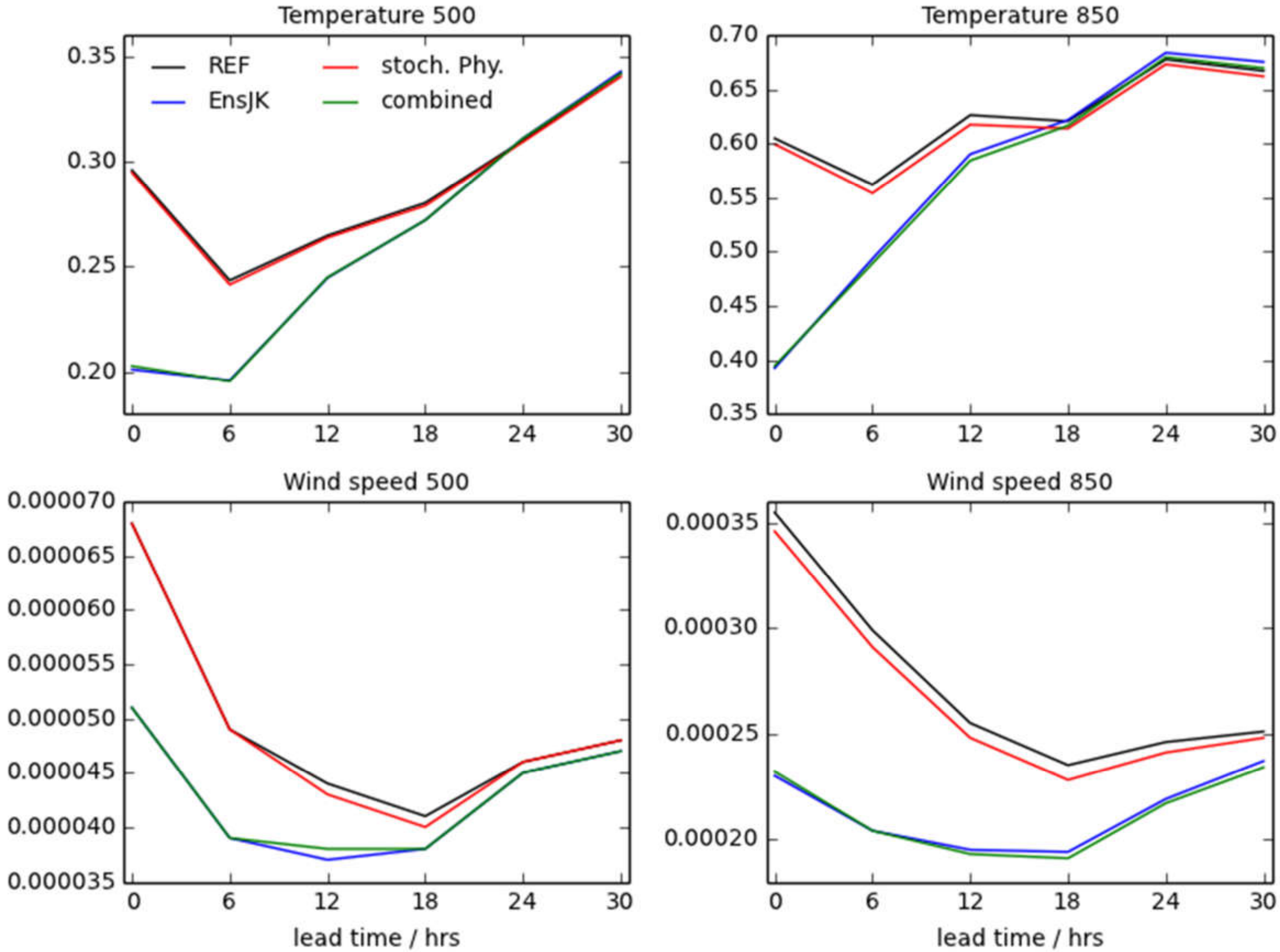
Results of winter test period



CRPS for temperature and wind speed at 500 hPa and 850 hPa in January 2017.

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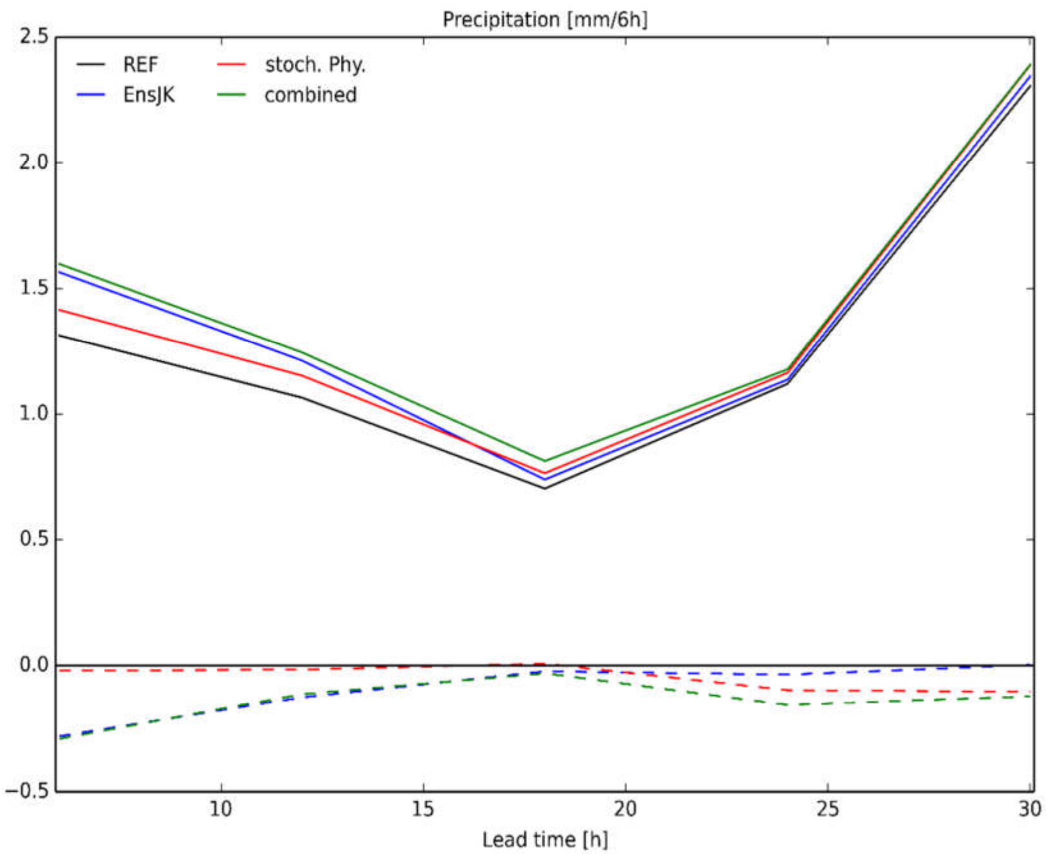
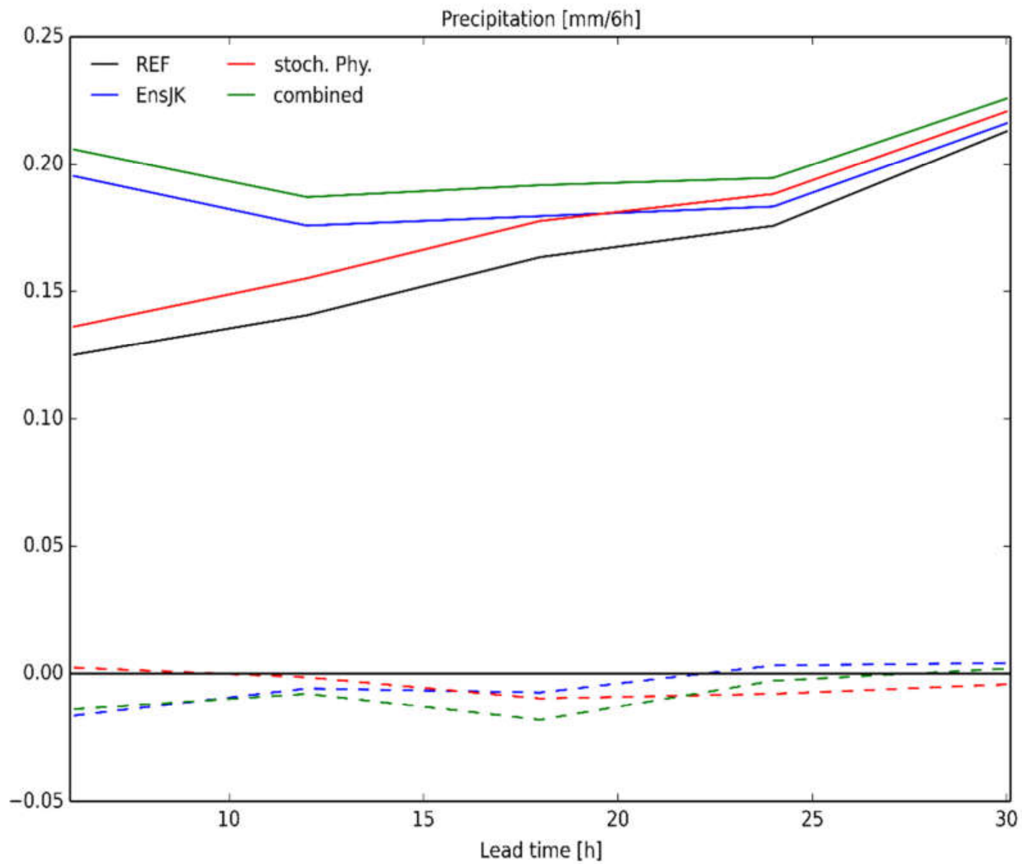
Precipitation verification





Ensemble spread (solid) and RMSE (dashed) for precipitation in July 2016 (left) and January 2017 (right). RMSE is given as difference to the reference run.

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C-LAEF: Conclusions & Outlook

- C-LAEF is an innovative convection permitting ensemble system which is currently under development at ZAMG
- C-LAEF is comprehensive and contains representation of all uncertainties in NWP (IC, LBC, model error)
- Ensemble JK significantly increases ensemble spread in the first hours
- Stochastic physics additionally increases spread and reduces RMSE during the whole forecasting range
- Combination of tendency perturbations and parameter perturbations showed best results for model error representation
- Outlook: Perturbation of surface parameters (ESDA, observation perturbation on the surface)