Seamless probabilistic Analysis and Prediction in very HIgh Resolution (SAPHIR)

Wang, Kann, Atencia, Awan, Dabernig, Kemetmüller, Meier, Schicker, Tüchler, Wastl and Wittmann

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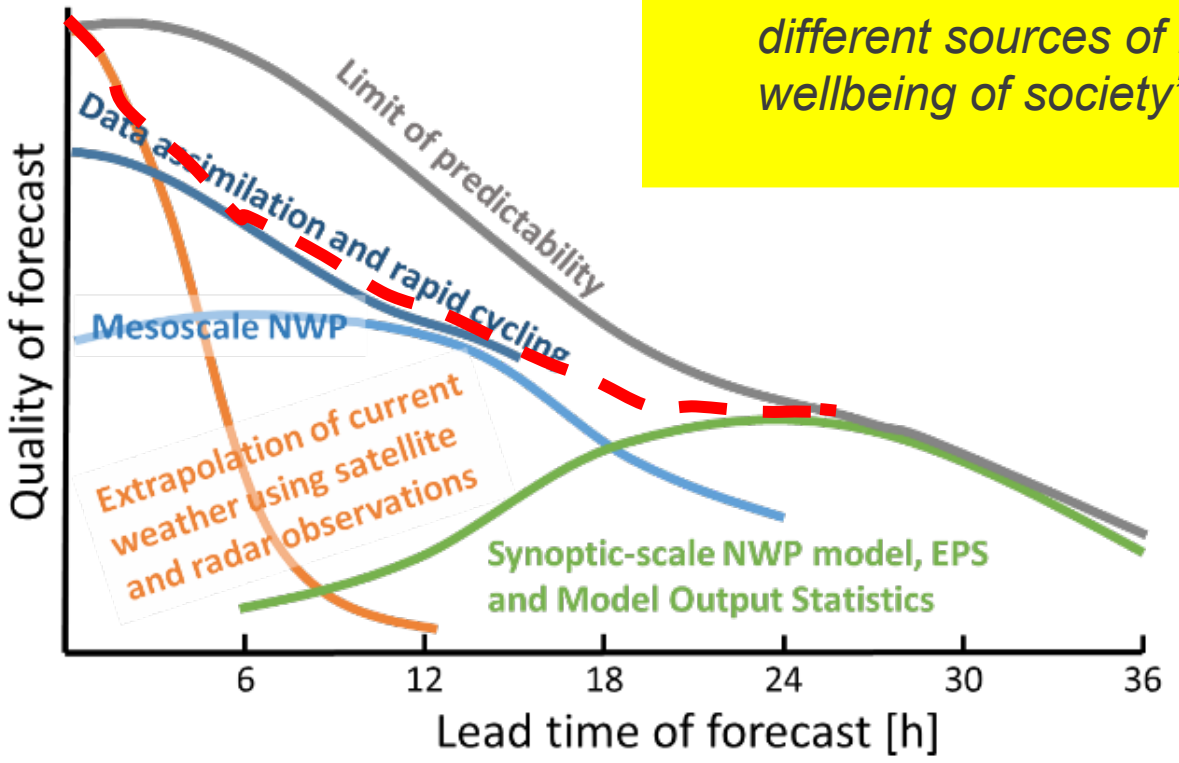
The seamless vision for forecasting

*"We are entering a new era in technological innovation and in use and **integration** of different sources of information for the wellbeing of society"*



The quality of weather forecasts defined as a function of lead time for different forecasting methods. The figure is highly schematic and the quality of forecast is a qualitative accuracy of the different performance. This figure is based on a previous one originally created by Browning (1980).

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SAPHIR goals

Radar, AWS, Satellite

High resolution GIS

Nowcasting and ensembles

Regional ensembles

Convection permitting RUC and ensembles

Global multi-models and ensembles

Integration

Blending

Calibration

Analysis and forecast

0-72h seamless: analysis, nowcasting, short range

Deterministic & probabilistic

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Expectation: output

- Seamless forecast 0-72h
- Resolution: 1km x 1km horizontal, 100m vertical up to 4km
- Update cycle: 5min – 1h
- Deterministic and probabilistic
- Application oriented: T, Q, U, V, RR (amount and type), T_{2m}, RH_{2m}, $V_{10m/100m}$, T_{surf}, cloudiness, global radiation, visibility, snowlines, wind gust, icing potential

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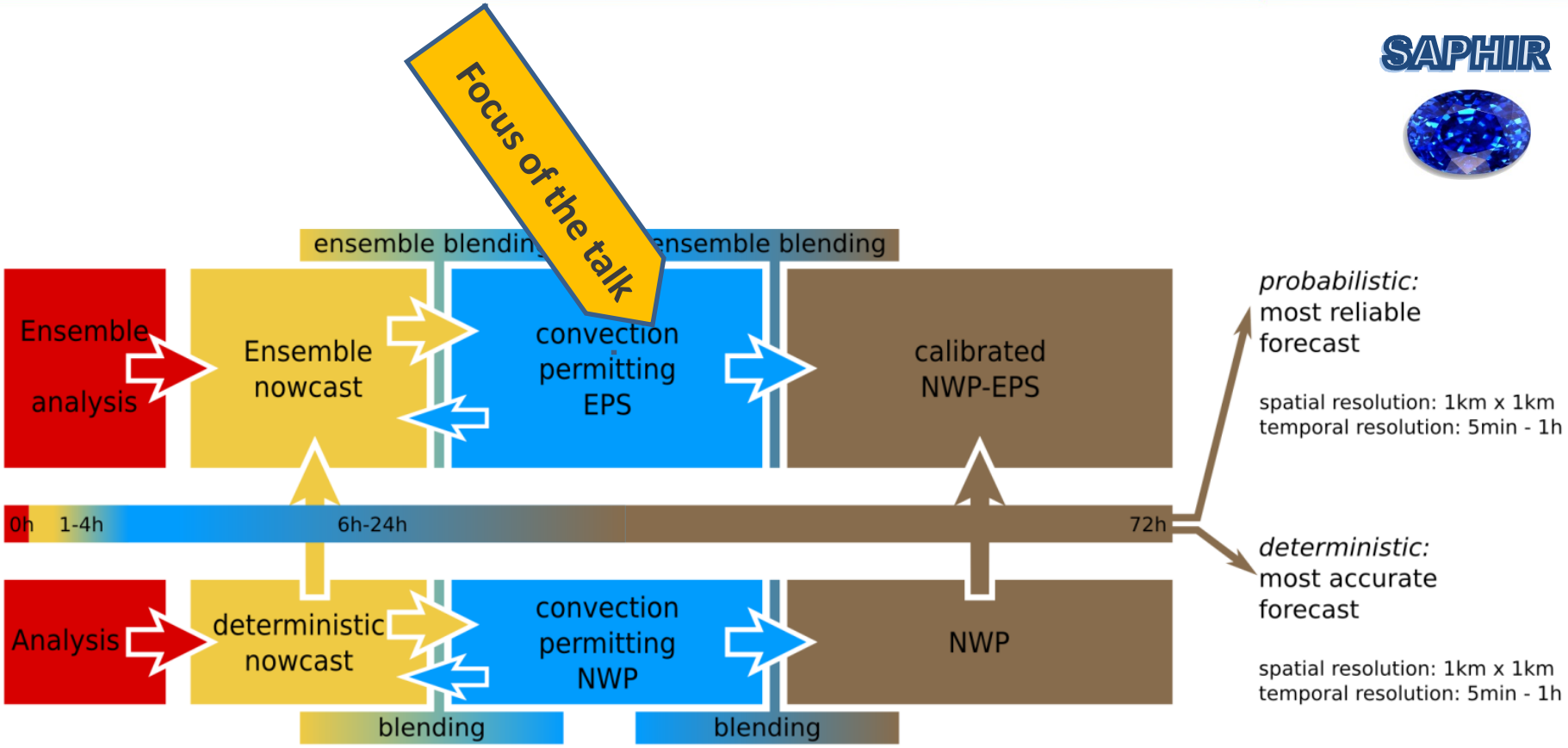
SAPHIR system design



SAPHIR

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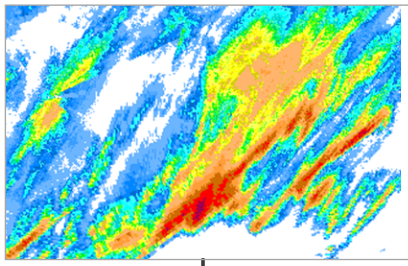
Ensemble analysis



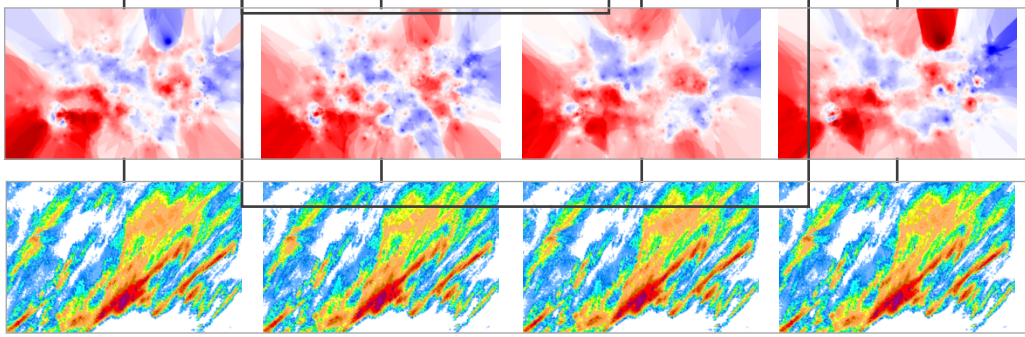
Error estimation

Estimation of error covariance matrix

Generation of perturbations by Cholesky/SV decomposition

$\mathbf{C}$

$\mathbf{C} = \mathbf{L}\mathbf{L}^{\mathrm{T}}$

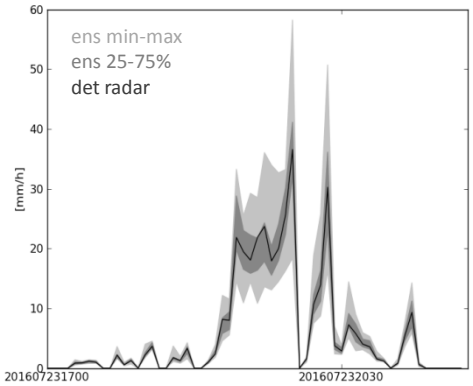


Perturbations

$\delta_{t,i} = \mu + \mathbf{L}\mathbf{y}_{t,i}$

Ensemble analysis

$$\underbrace{\Phi_{t,i}}_{\text{probabilistic}} = \underbrace{\mathbf{R}_t}_{\text{deterministic}} + \underbrace{\delta_{t,i}}_{\text{stochastic}}$$



Uncertainties in observation

Stochastic (random) perturbation, Gausssian-distributed with zero mean and standrad deviation equal to the observation error.

Uncertainties in background

Convection-Permitting EPS.

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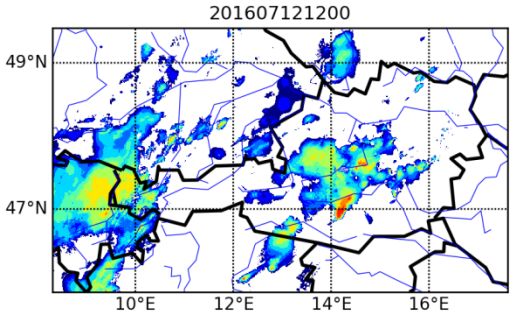
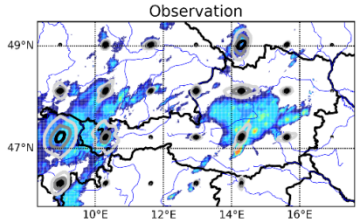
Ensemble nowcasting

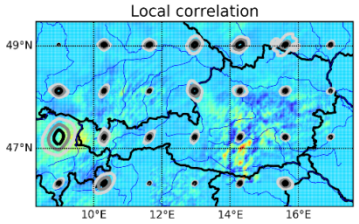
Deterministic Nowcasting = **INCA** + **AROME RUC**

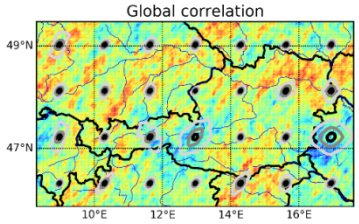
Spatial blending



$$J = [x - x_b]^T B^{-1} [x - x_b] + [x - y]^T R^{-1} [x - y]$$

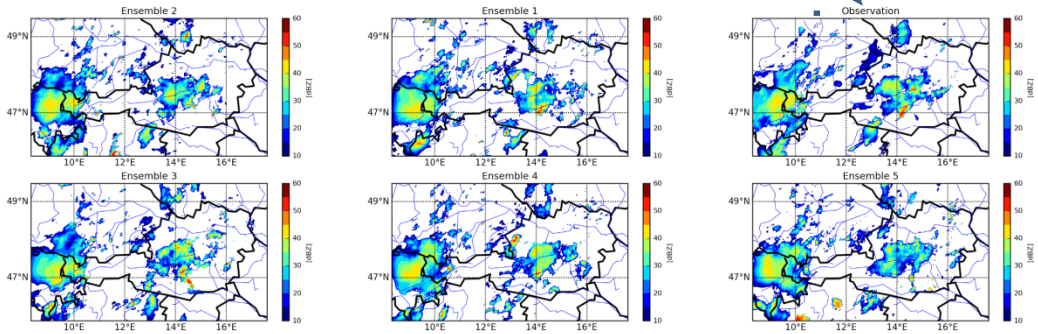






Stochastic noise is added to the INCA field using the local correlation information.

Physical processes such as the diurnal cycle of precipitation is introduced as an external forcing to the ensemble generator.



Ensemble Blending

Convection permitting Ensemble C-LAEF

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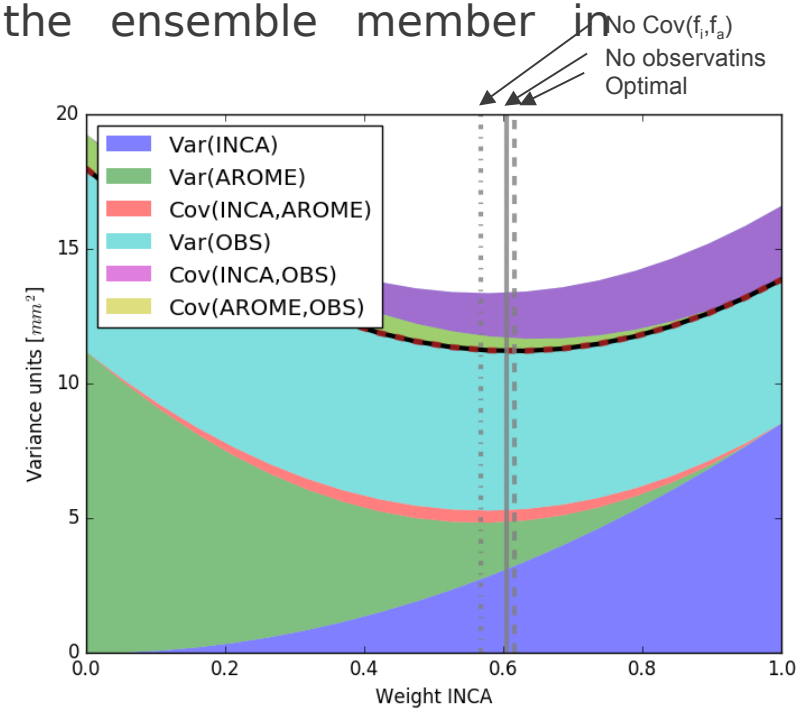
Ensemble blending

- A lead-time function based on the operational weight in the INCA nowcasting system.
- A nudging term of the weight towards/against the ensemble prediction system when there is agreement among the ensemble members (small uncertainty).
- A portion based on the quality of the ensemble member in comparison with the **latest observati** variances of both sources (and covarian

$$w_I = \frac{Var(f_A) + Cov(f_I, OBS) - Cov(f_A, OBS) - Cov(f_I, f_A)}{Var(f_I) + Var(f_A) - 2Cov(f_I, f_A)}$$



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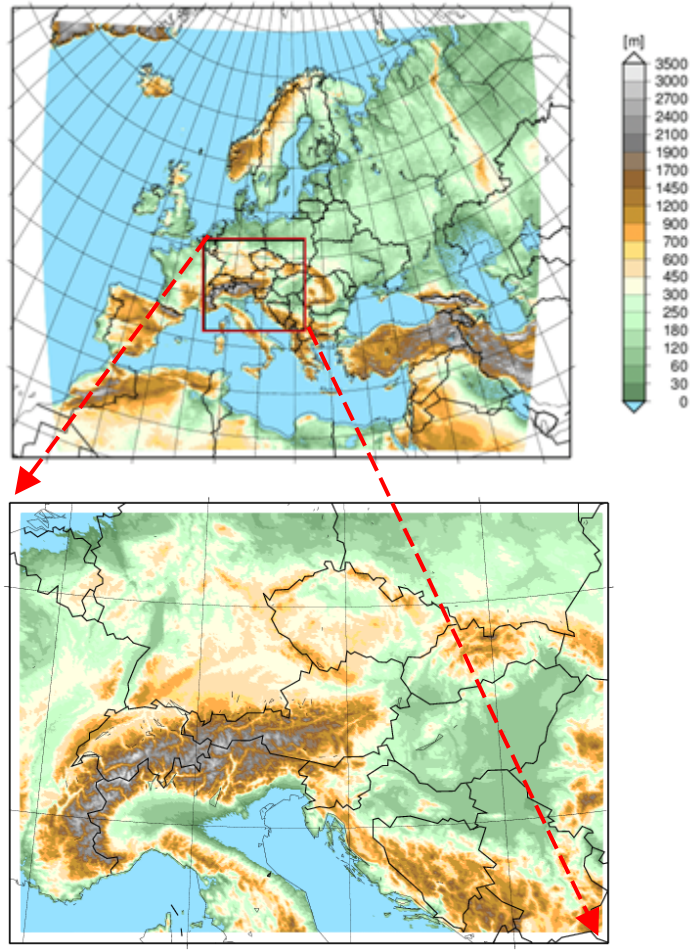
Convection-permitting ensemble prediction (C-LAEF)

C-LAEF	
Ensemble size	16 + 1
Δx /vertical levels	2.5 km / 90
Coupling	ECMWF EPS
Runs / Tag	2 / 4 runs (+ 30 h forecast)
IC/LBC perturbations	EDA + EnJk + sEDA
Model perturbations	SPPT / pSPPT / pSPPT+: ● total tendencies (SPPT) ● partial tendencies (pSPPT) ● Combination of parameter perturbations and partial tendencies (pSPPT+)



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Stochastic physics

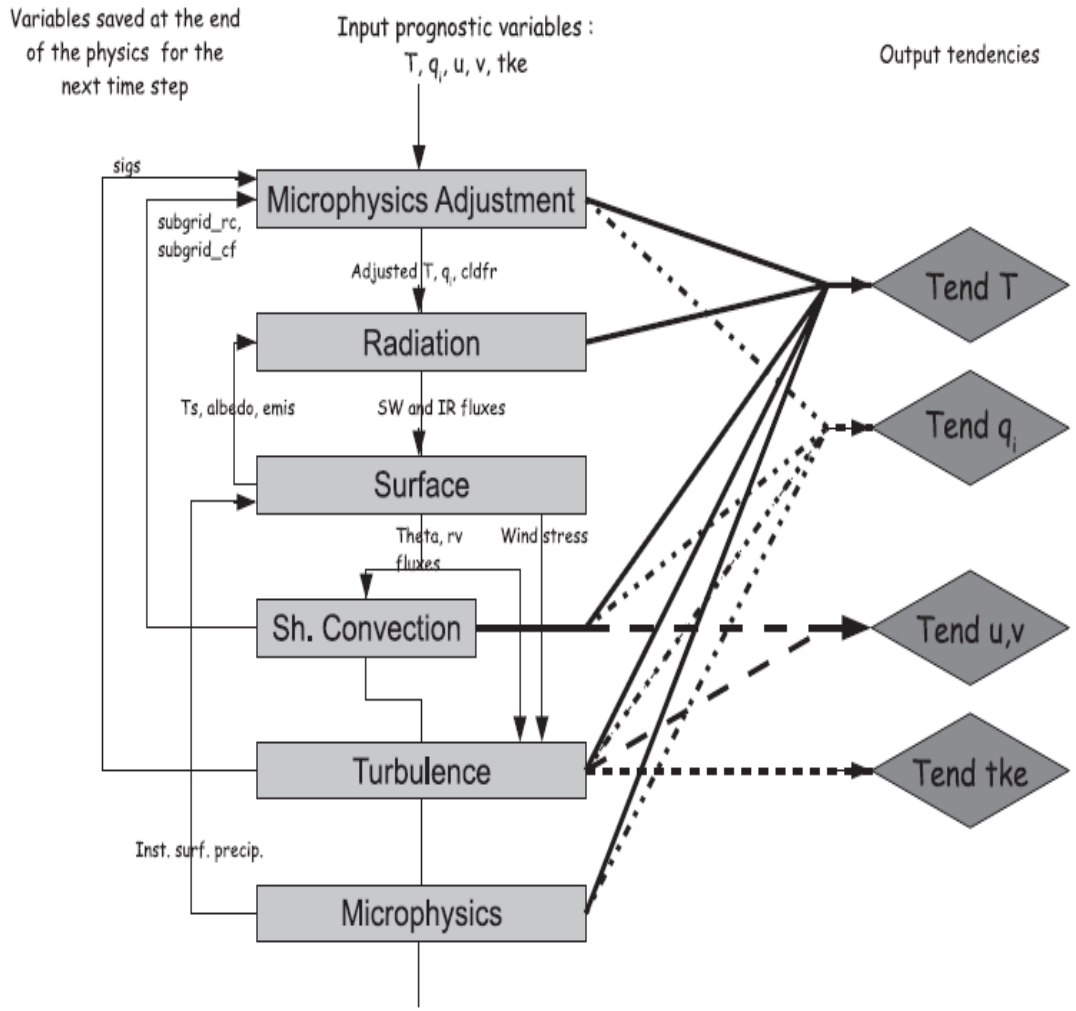
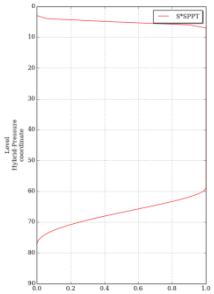


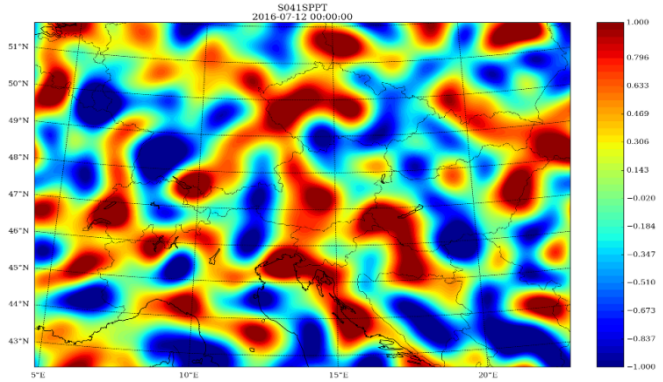
FIG. 2. AROME physics schematic.

Standard SPPT (ECMWF):
Perturbation of total tendencies

$$\frac{dT}{dt} = \sum_{i=1}^{4} \frac{\delta T_i}{\delta t}$$



$$\frac{dT'}{dt} = \frac{dT}{dt} * (1 + \mathrm{P}) \quad \& \quad \mathrm{P} = \mathrm{P} * \alpha$$



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Standard SPPT (ECMWF)

Physically consistent relationship between different variables ?

Same level of uncertainty for all the physical processes ?

Respectation of the conservation laws, e.g. energy, mositure budget at the surface?

Tapering function?

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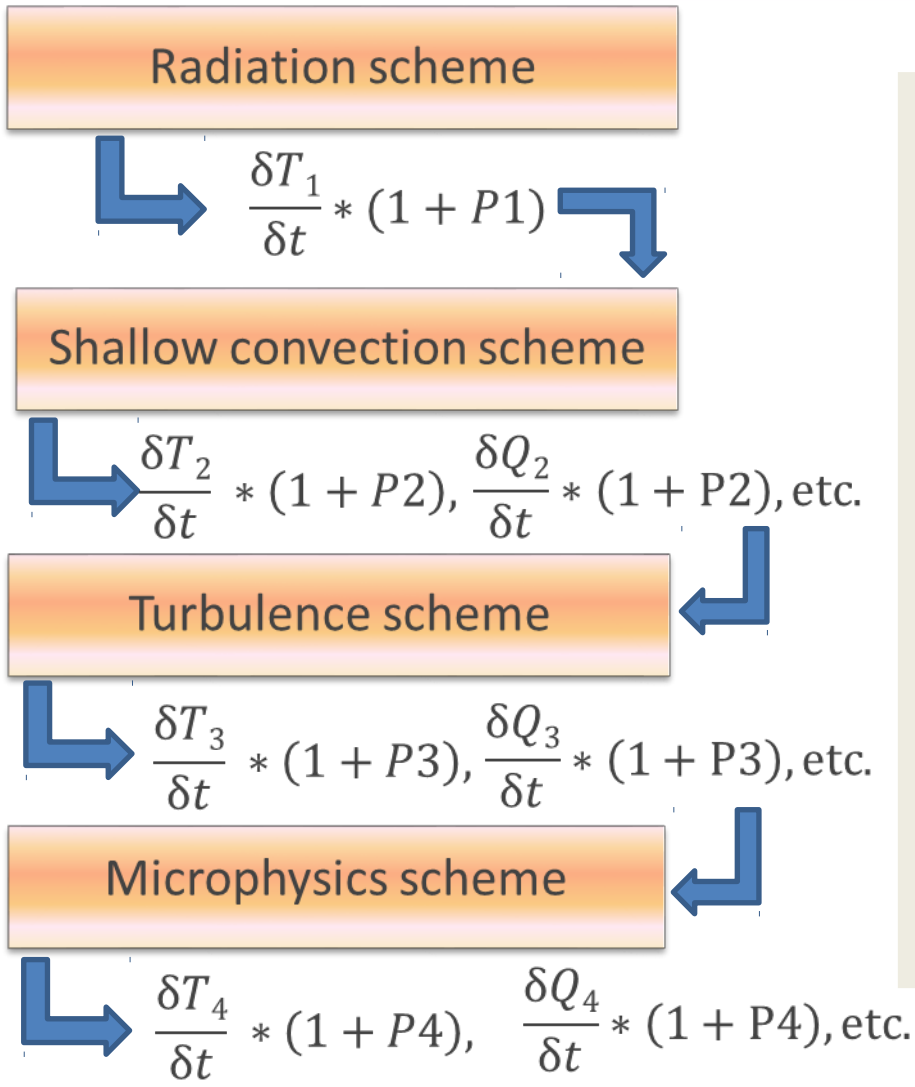
Stochastic perturbation of partial tendencies: pSPPT (ZAMG)



- 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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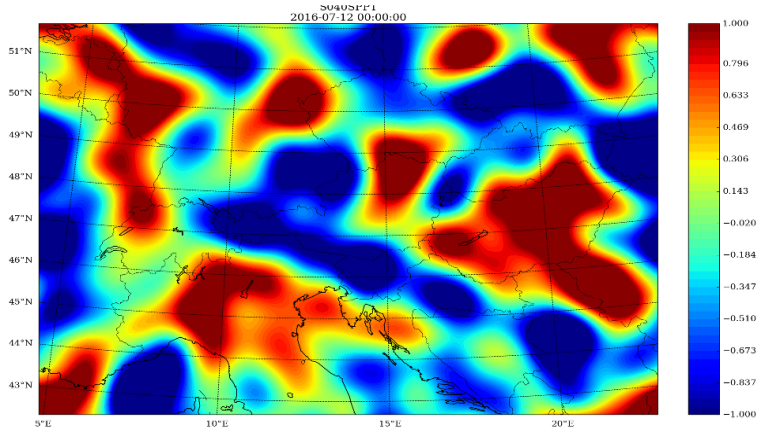
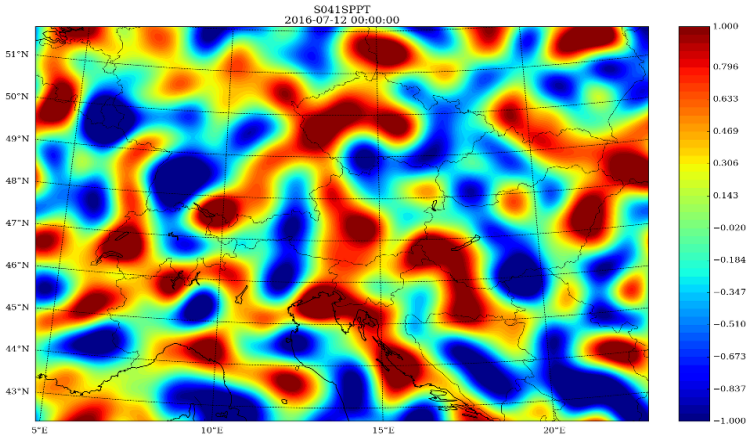
Stochastic patterns in pSPPT

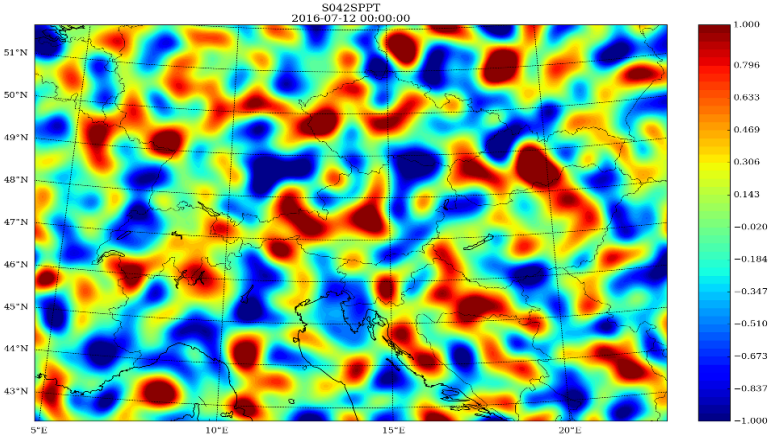
Radiation



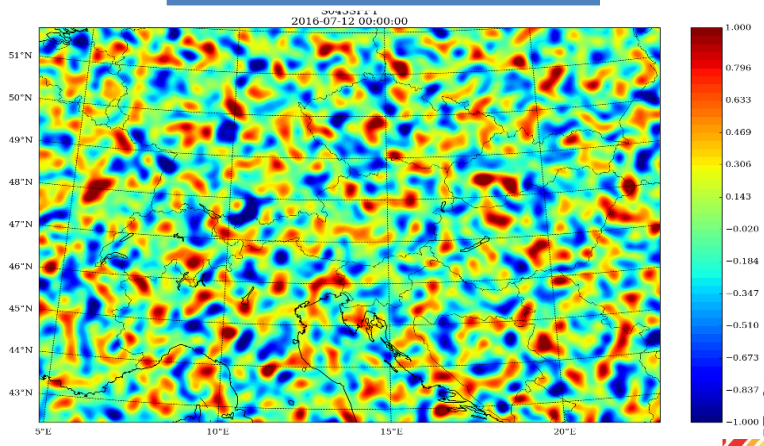
Shallow convection



Turbulence



Microphysics



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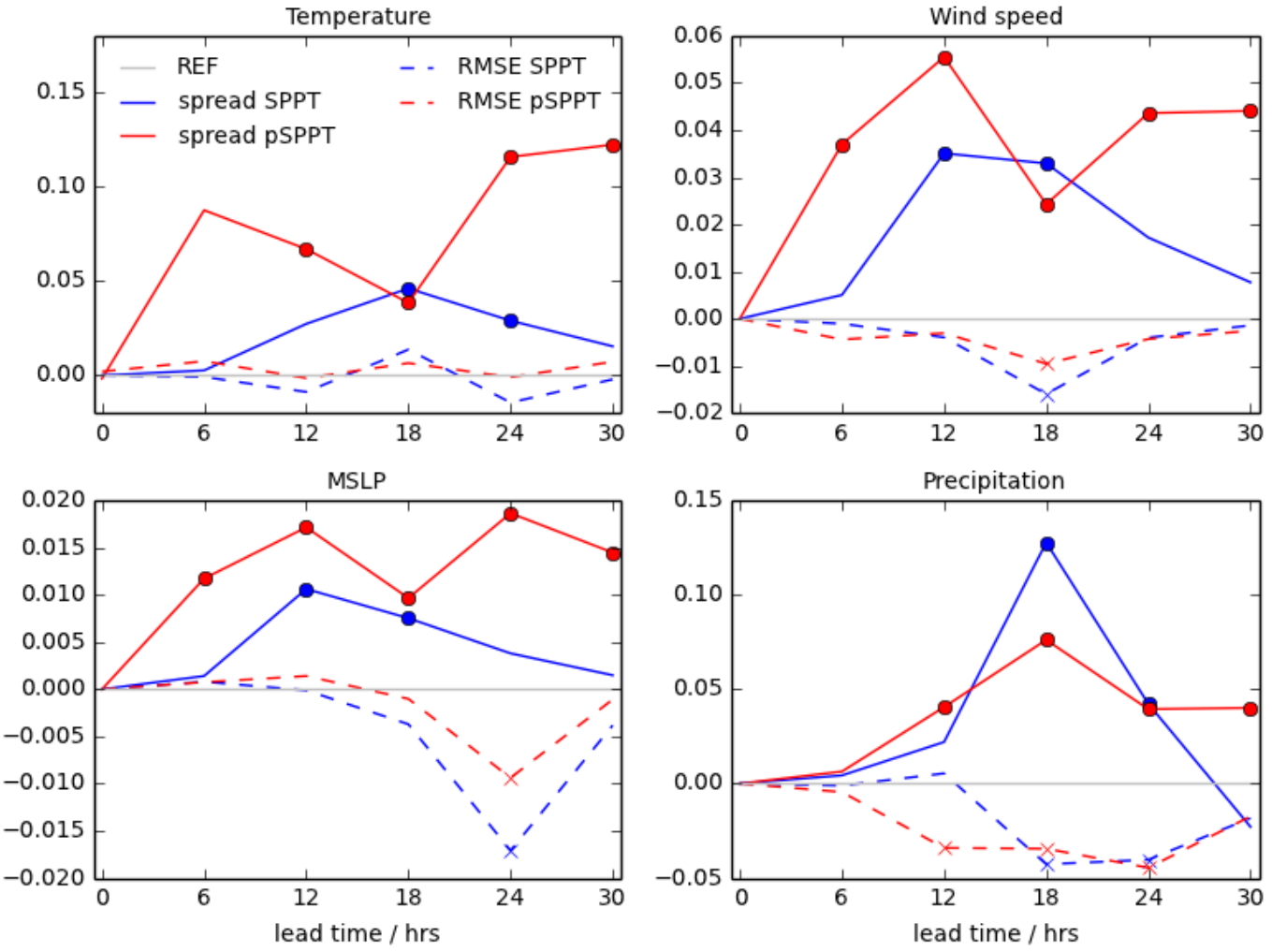
Results



Statistical significant

Promising results!

Ensemble spread (solid) and RMSE (dashed) of 2m-T, 10m-wind speed, MSLP and precipitation relative to REF for July 2016.

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Partial pSPPT (ZAMG)

Physically consistent relationship between different variables √ √

Same level of uncertainty for all the physical processes √

Respectation of the conservation laws, e.g. energy, mositure budget at the surface? x

Tapering function still needs be applied for tubulence! x

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A combined stochastic physics: pSPPT + SPP

- Stochastic perturbation of key parameters (SPP, Ollinaho et al., 2017) at process level in the turbulence scheme (see table)
- Combination of pSPPT with parameter perturbation SPP 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.

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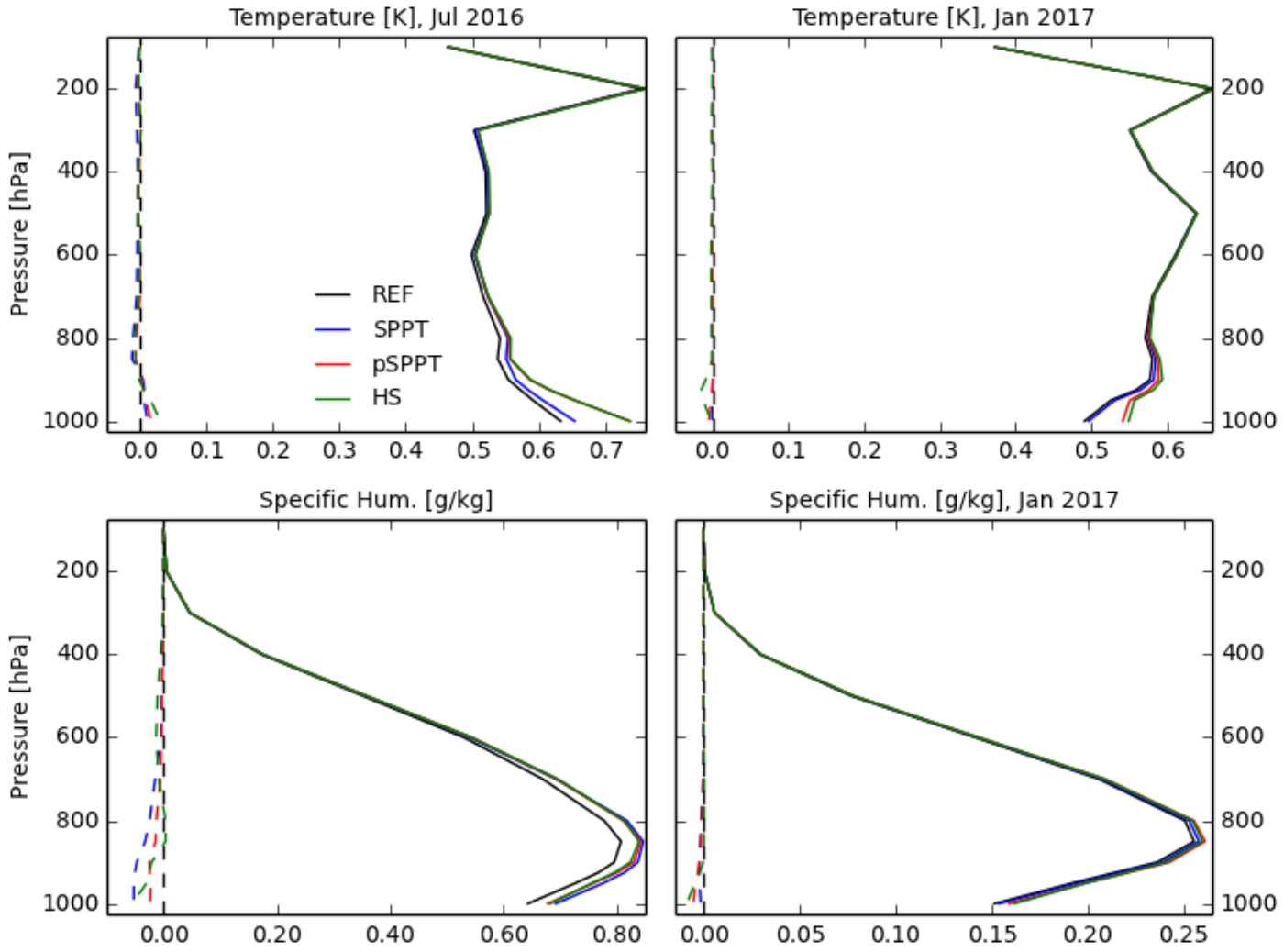
Results: pSPPT + SPP



Average vertical profiles of temperature and specific humidity in July 2016 and January 2017. Ensemble spread (solid), RMSE difference to REF (dashed).

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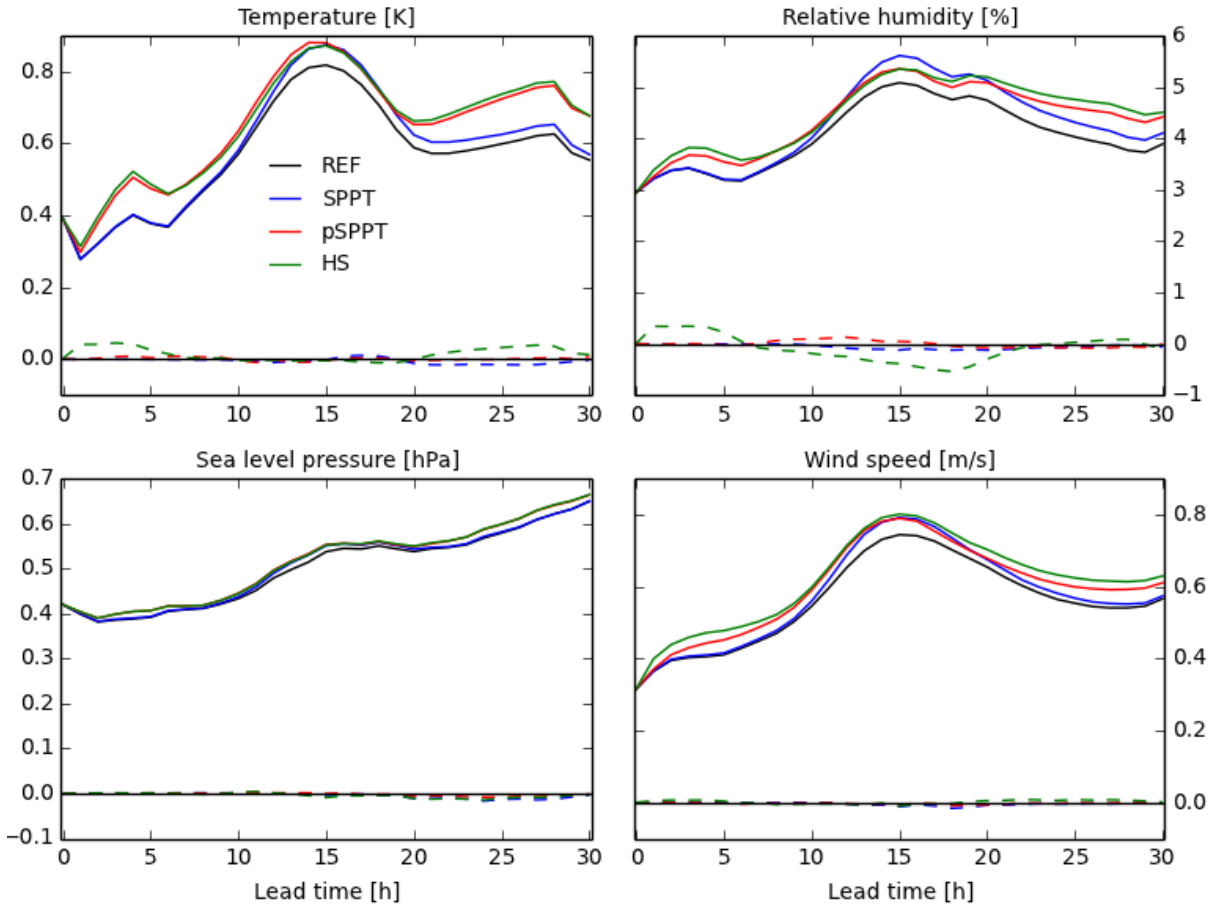
Verification: surface parameters



Ensemble spread (solid) and RMSE (dashed) for surface parameters in July 2016.
RMSE is given as difference to the reference run without stochastic physics.

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Calibration: short range ensembles

ECMWF EPS

ALADIN-LAEF

AROME

NCEP GFS

DWD ICON

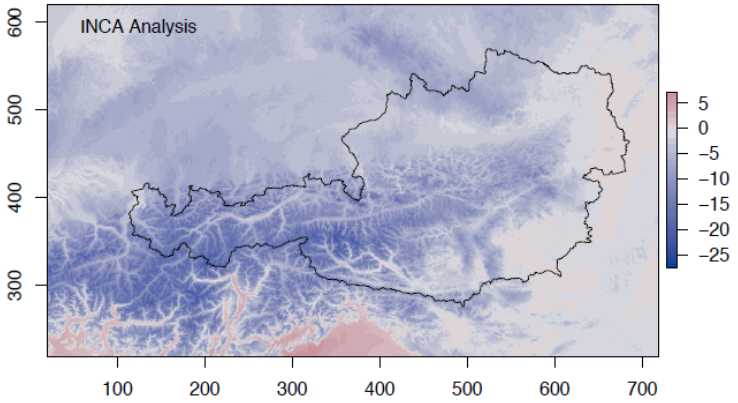
JMA

Met-Office UM

Calibration

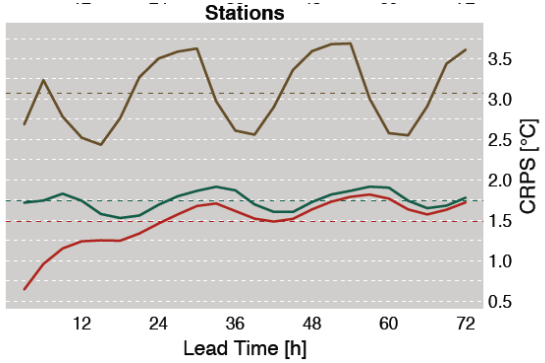
Short range ensemble forecast

Ensemble calibration

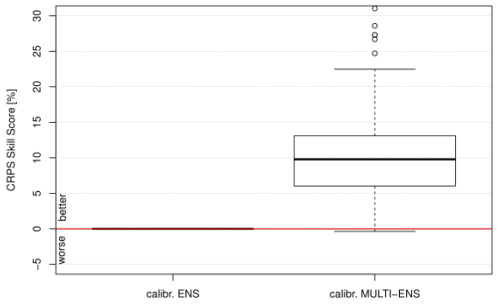


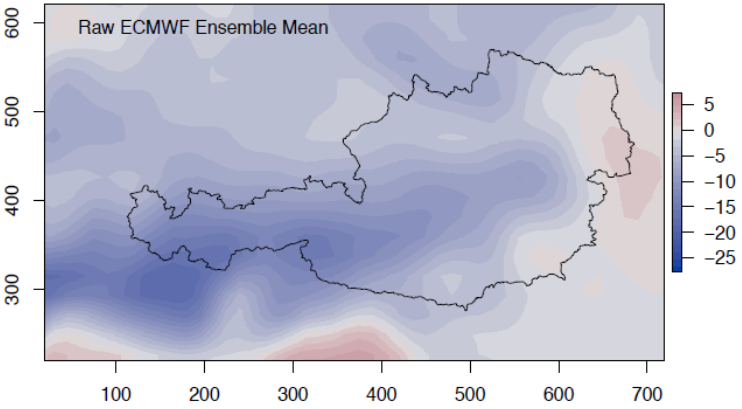
Observation

Verification

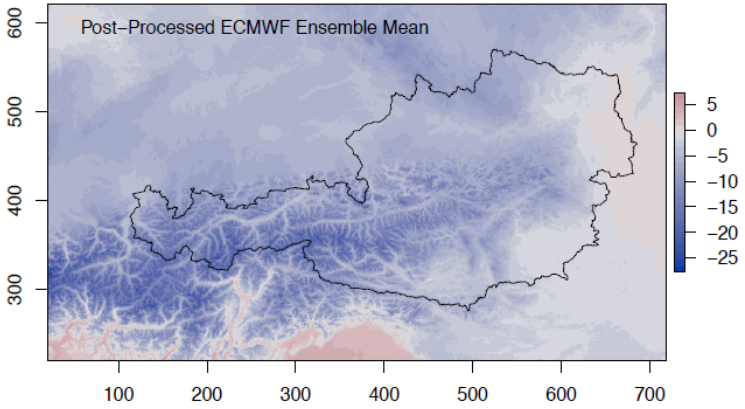


Multi-EPSs + Multi-det.





No calibration



Calibration

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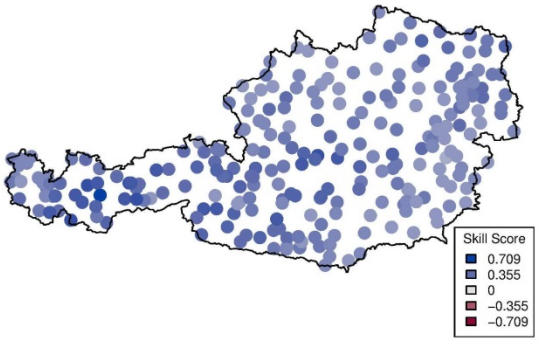
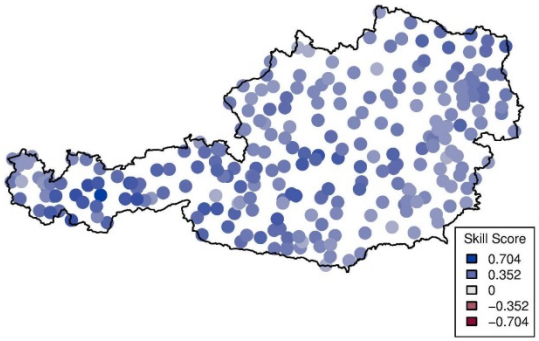
Ensemble calibration

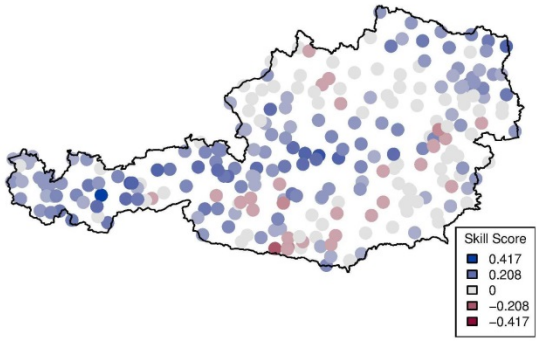
CRPS



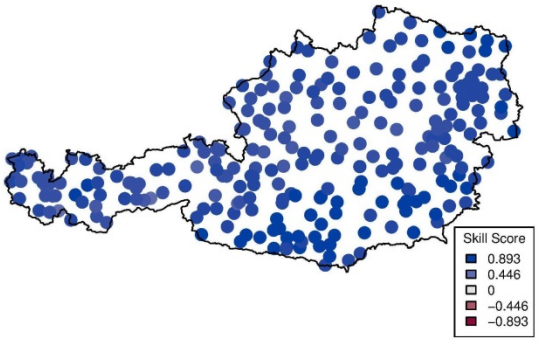
MAE



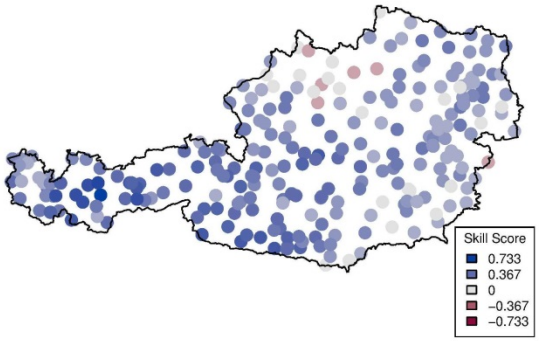
RMSE



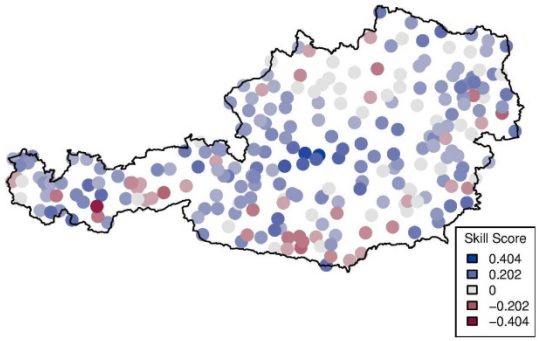
Brier Score > 0mm



Brier Score > 1mm



Brier Score > 5mm



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Conclusions & next plan

- ✓ SAPHIR has been designed, and its basic components are available.
- ✓ There are still a lot of challenges in all aspect of related science and technology.
- ✓ Other R&D activities have been started or in plan, e.g. SAPHIR at 100m resolution; extension to medium range, etc.

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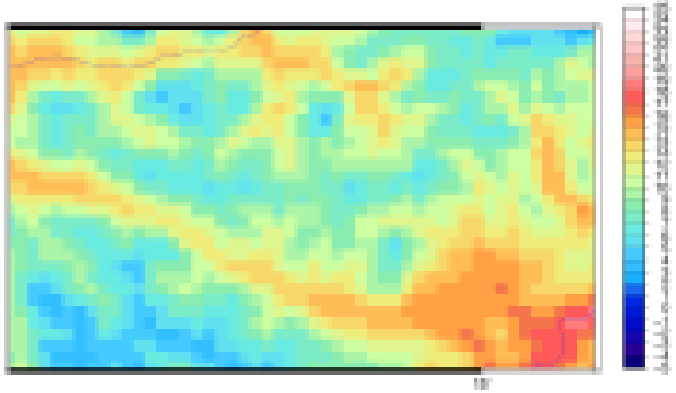
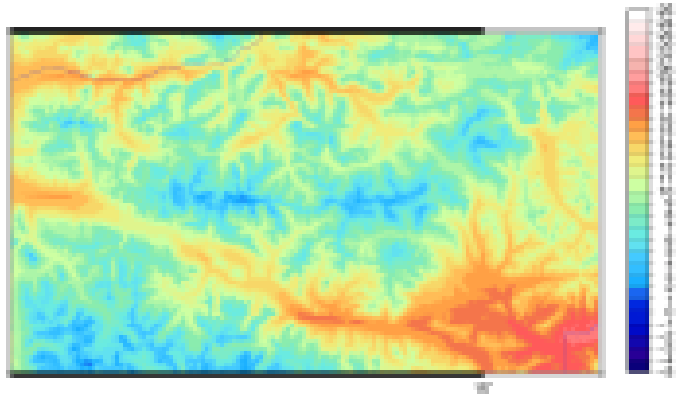


INCA 1km



INCA 100m

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