Implementation of the SPP scheme in ICON and first results

Zahra Parsakhoo, Chiara Marsigli, Christoph Gebhardt

With special thanks to Axel Seifert and Daniel Reinert

DWD
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Advancements in Ensemble forecasting

CPP

Classical parameter perturbation (CPP):
- Bacy → EPS run with 2 nests: 2km, 1km, 0.5km

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SPP

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Stochastic parameter perturbation(SPP):

- Implementation of SPP in ICON →
  - Test det. fc in ICON-LAM (D2)
  - Implementation for EPS
  - Test real case in ICON-LAM with single parameter perturbation →
    - ✓ microphysics
    - ✓ convection
    - ✓ land

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Stochastic parameter perturbation(SPP):

CPP vs. SPP: Key Differences

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- default or
- boundary value of the range

The value is kept fix during the run

~18 parameters

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- Spatial and temporal correlations
- Some certain properties

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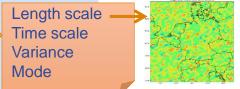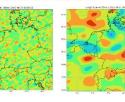The value is kept fix during the run

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~18 parameters

Seed different for each:
- parameter
- ensemble member
- initialization date
- initialization time

Length scale
Time scale
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Mode

Stochastic Pattern Generator (SPG)

SPG implementation in ICON

Stochastic Pattern Generator (SPG)

By Axel Seifert and Maleen Hanst

Merged into ICON master (June 2025)

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Coupled with microphysics

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- Sensitivity tests on SPG variance: =<0.4 model is numerically stable
- Test for ICON-LAM: real case study on 21.06.22 coupled to 2mom microphysics
  → For perturbing sedimentation velocity of graupel

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Total precipitation | 2022-06-21 | 24h fc

coupled SPP
uncoupled SPP

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↓

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- Further development for **EPS**

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Stochastic Pattern Generator (SPG)

By Axel Seifert and Maleen Hanst

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Coupled with microphysics

perturbed = unperturbed $\times$ exp(SPG)

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- Test for ICON-LAM: real case study on 21.06.22 coupled to 2mom microphysics
  → For perturbing sedimentation velocity of graupel
- Further development for EPS
- Coupled to convection → rdepths (Maximum allowed shallow convection depth)
- Coupled to land → cr_bsmin (Minimum bare soil evapotranspiration resistance)

To evaluate
- stochastic patterns and
- parameter behavior before and after SPP
(both from a technical and theoretical perspective).

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

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SPG properties (namelist):
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spg_length_scale = 50e3 [m]
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At 00 time step for one ensemble member

Overlay of all time steps for one ensemble member
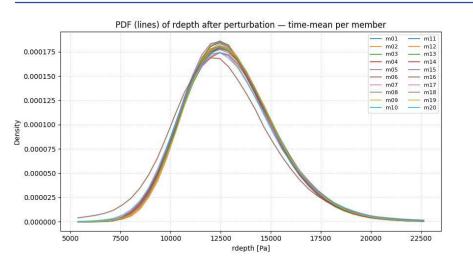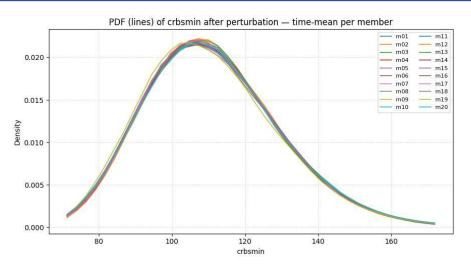
PDFs of Time-Mean Perturbed Parameters

PDF (lines) of rdepth after perturbation — time-mean per member

PDF (lines) of crbsmin after perturbation — time-mean per member
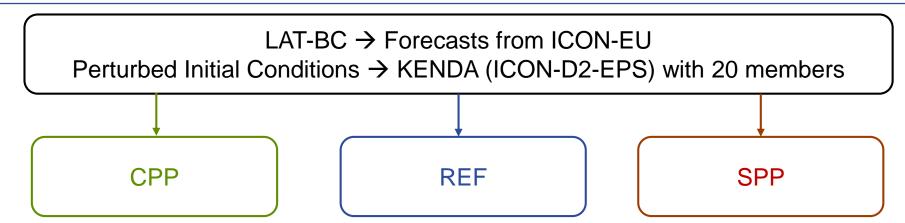
- **Time-Mean PDFs:** one member diverges for **rdepths** (slightly for **cr_bsmin**)
- **Single case** → not robust; likely not persistent across many days
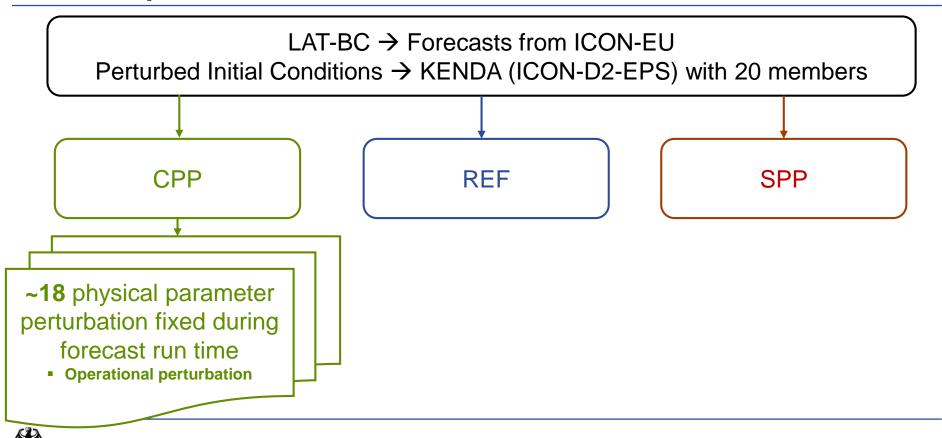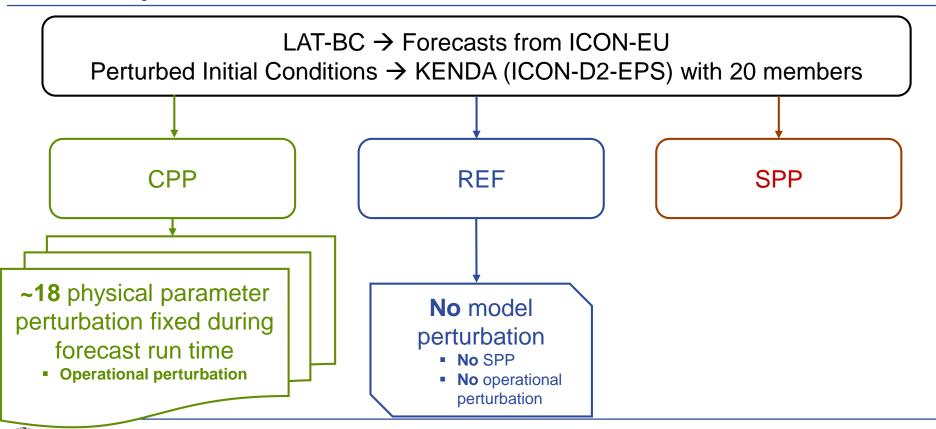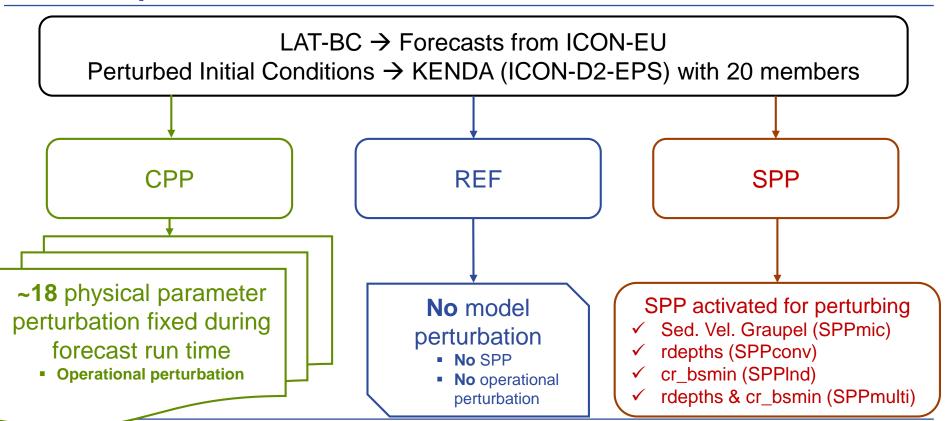
Test Setup

LAT-BC → Forecasts from ICON-EU
Perturbed Initial Conditions → KENDA (ICON-D2-EPS) with 20 members

CPP

REF

SPP

~18 physical parameter perturbation fixed during forecast run time
- **Operational perturbation**

No model perturbation
- **No** SPP
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SPP activated for perturbing
- ✓ Sed. Vel. Graupel (SPPmic)
- ✓ rdepths (SPPconv)
- ✓ cr_bsmin (SPPlnd)
- ✓ rdepths & cr_bsmin (SPPmulti)

EXPERIMENTs SETUP

Two-way nesting	
Horizontal grid resolution	2km (ICON-D2)
Upper boundary	22km
Vertical levels	65
LAT-BC	Forecasts (ICON-EU)
Perturbed initial conditions	KENDA (ICON-D2-EPS)
Forecast duration	24h starting on 2022062100
Forecast restart	6h
Ensemble members	20
Microphysics	2mom
Turbulence	TURBDIFF
Land	TERRA

ICON-D2

Domain of analysis

Statistical Analysis

Box-Whisker plot:
- The larger distribution (wider min-max range) observed in CPP indicates a higher level of perturbations.
- The medians across the different experiments are very similar, showing consistency.

Statistical Analysis

Spatial Mean Hourly Precipitation (Excluding < 0.03 mm)

Thunderstorm started!

Box-Whisker plot:
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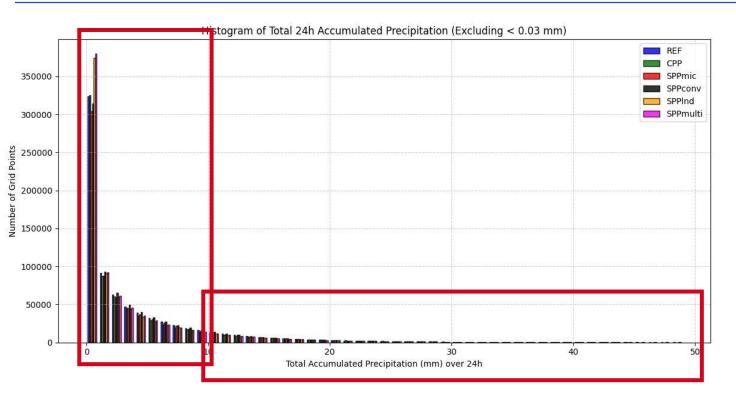
Start of rain: larger spread in hourly precipitation for all EXPs.

Statistical Analysis

Histogram of Total 24h Accumulated Precipitation (Excluding < 0.03 mm)

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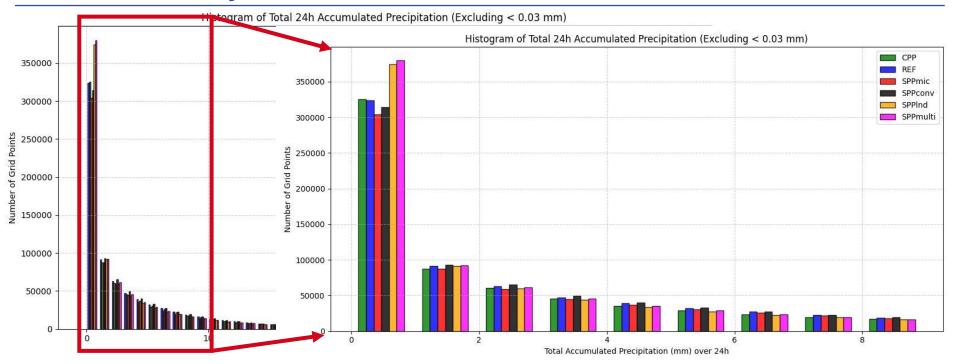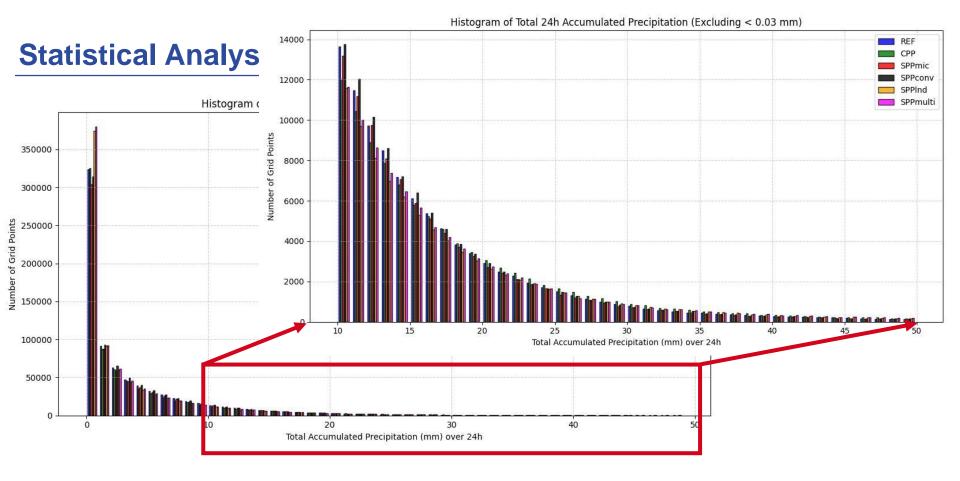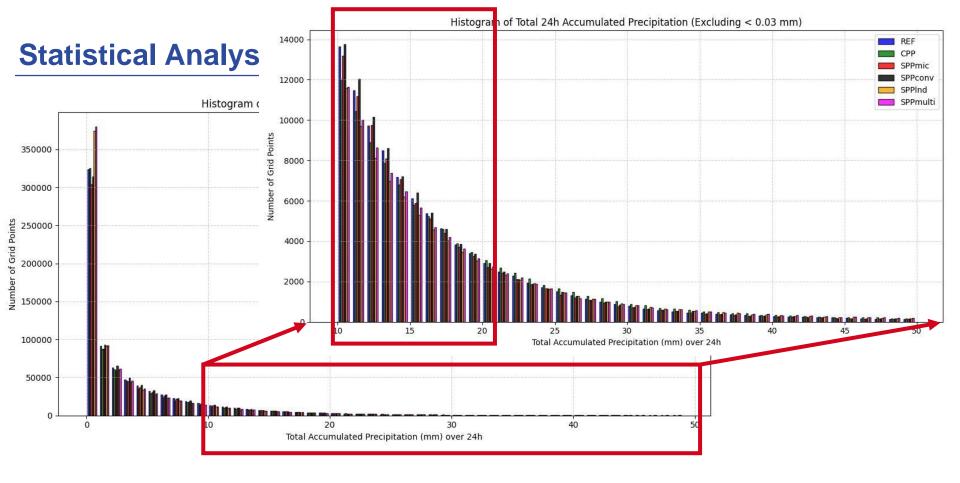
The difference is too small. However, for small values, SPPlnd has larger impact on rain

Statistical Analys

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Statistical Analys

For larger values, SPPconv has a bit more impact on precipitation

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Histogram of Total 24h Accumulated Precipitation (Excluding < 0.03 mm)

At tail, SPPlnd has a bit more impact on precipitation

Hourly precipitation at 18UTC
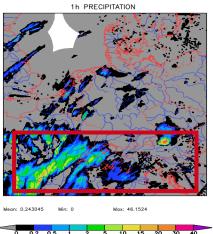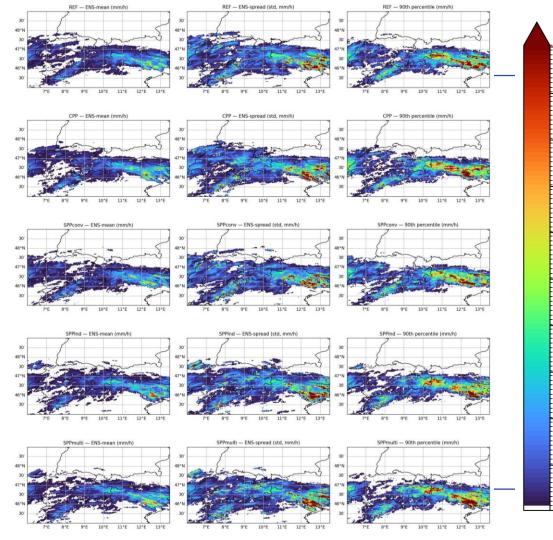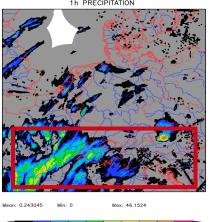
Radar German composite: ICON-D2

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Radar German composite: ICON-D2
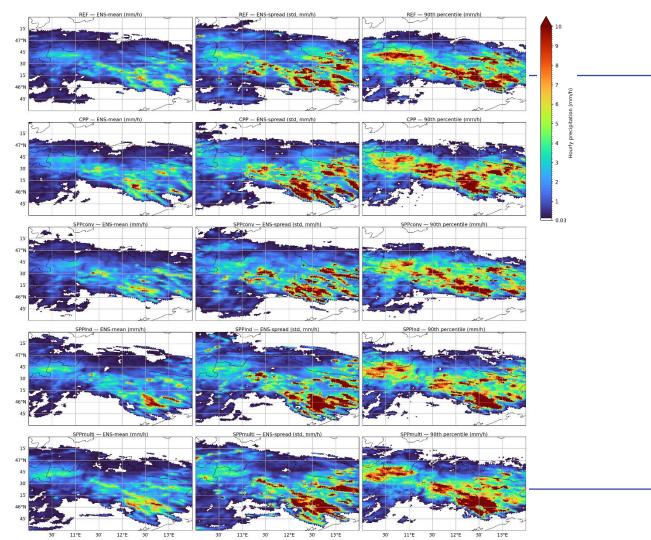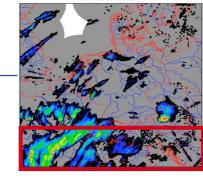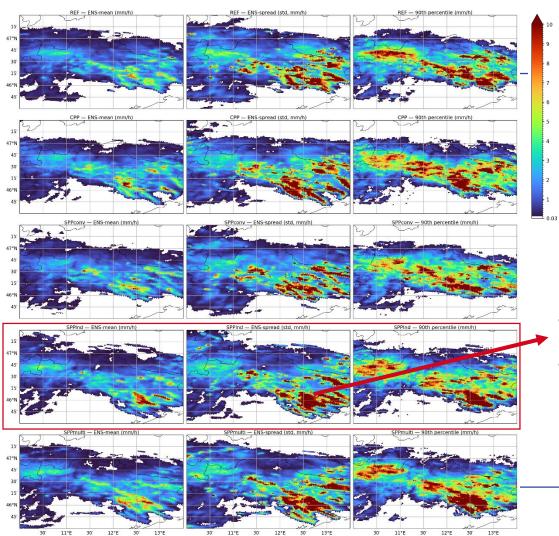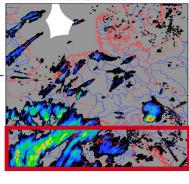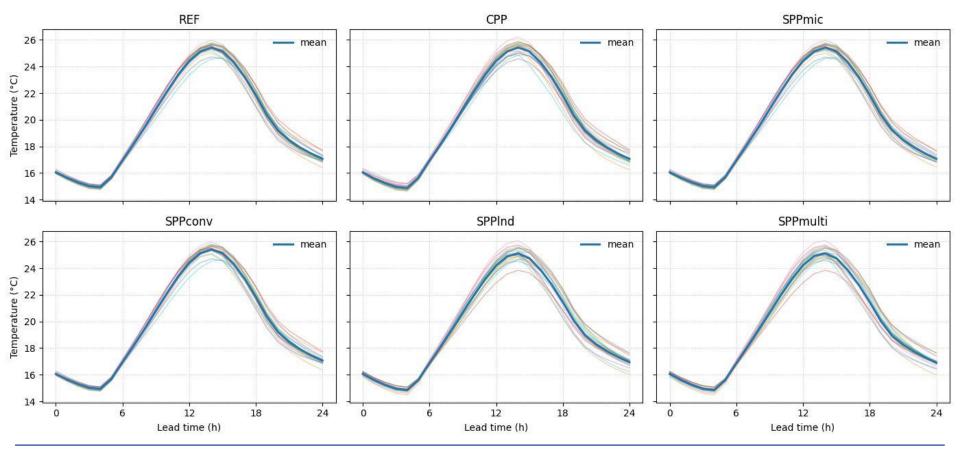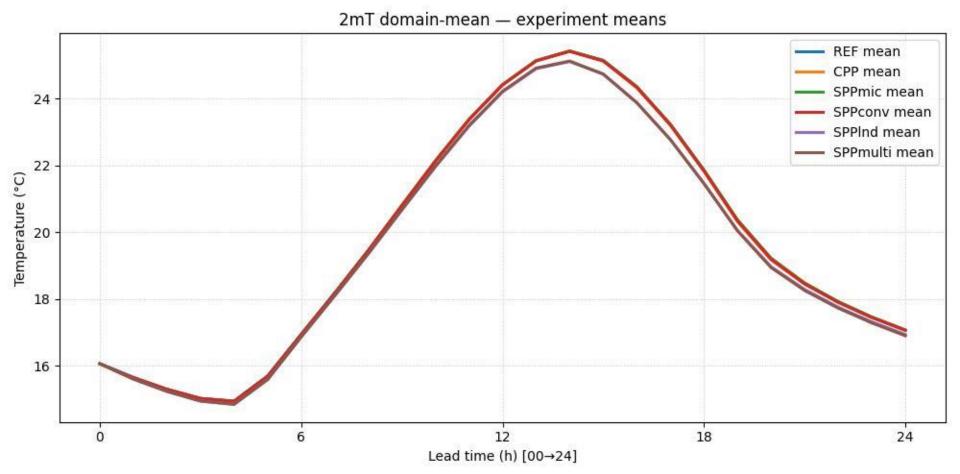
- **SPPInd:** pronounced local mean increase near the Adriatic (high precip).
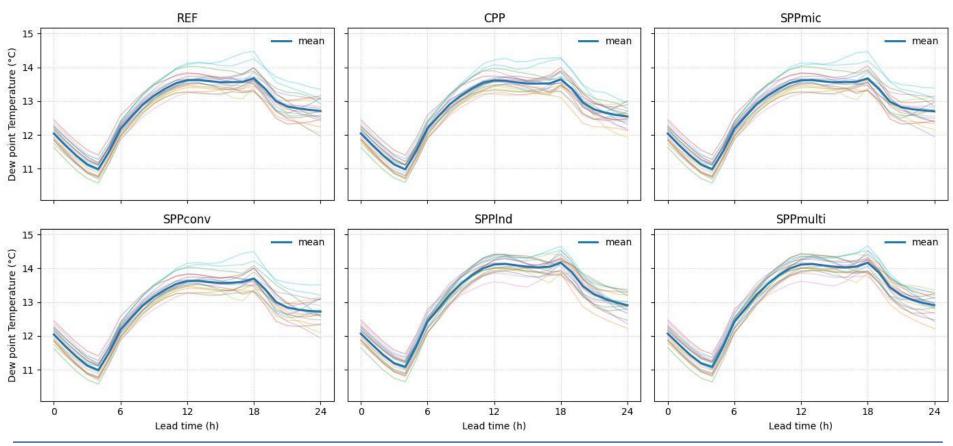- based on a single case → not robust; needs more cases to confirm

2mT domain-mean — (all members) by experiment

- Ensemble spread in 2mTemp is negligible before noon,
- Small spread for 2 m Temp when rain started!

2mT domain-mean — experiment means
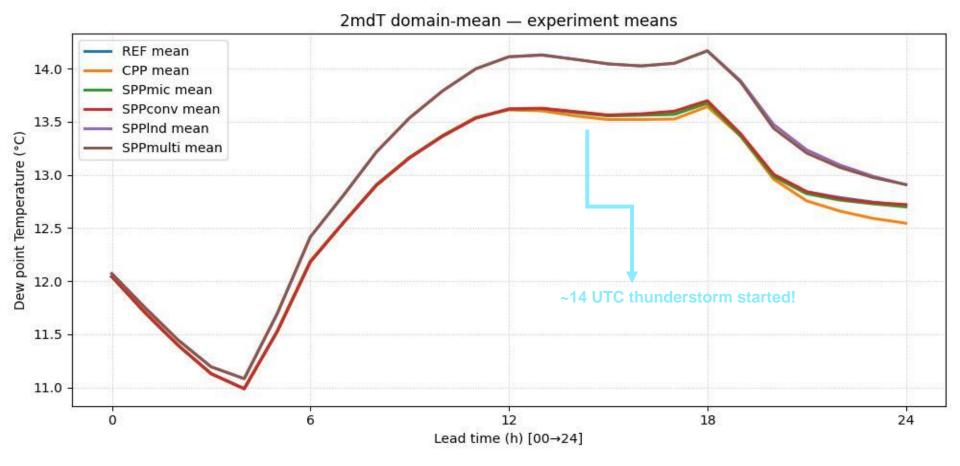
Experiments show negligible impact on 2 m TEMP.

2mdT domain-mean — (all members) by experiment

Moisture spread present from initialization; rain timing isn't the driver.

2mdT domain-mean — experiment means

Legend:
- REF mean
- CPP mean
- SPPmic mean
- SPPconv mean
- SPPlnd mean
- SPPmulti mean

~14 UTC thunderstorm started!

- Early spread cancels in the ensemble mean; the remaining signal follows precipitation,
- SPPlnd is higher—consistent with the hourly precipitation map

Summary

→ SPG Implementation is done by Axel Seifert (since June2025 is merged in ICON-Master),

→ SPP Implementation has been tested for 3 parameters (sed. vel. graupel, rdepths and cr_bsmin) and multiSPP (rdepths & cr_bsmin) successfully with ICON-LAM.

- Initial tests confirm expected behavior of the SPP scheme

- Findings motivate the need for additional cases to ensure robustness

Outlook

→ **Implementation:**

- More case studies

- Test other physical uncertain parameters

- Multi-parameter perturbation

- Nest: First test uncoupled at 500 m resolution, then fully coupled with SPP.
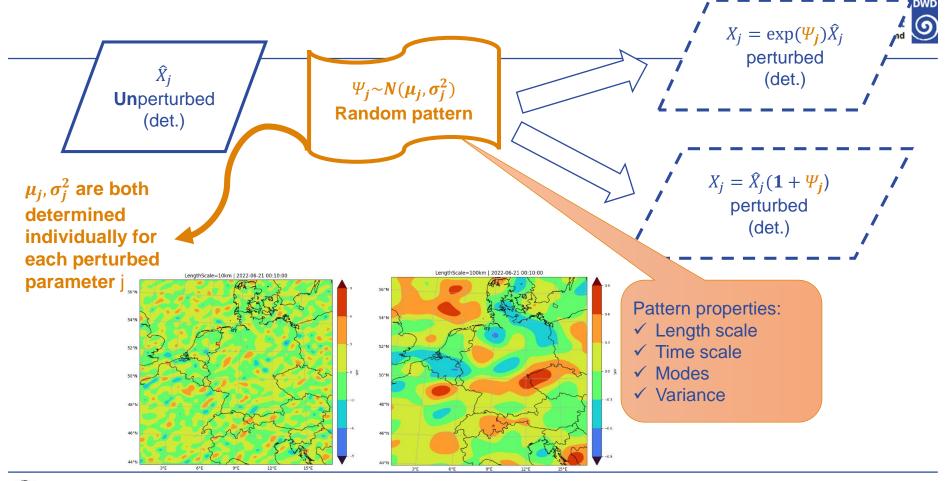
→ **Benchmarking:**

- Tuning SPG in ICON-LAM-D2: Optimize values for SPG parameters (e.g., length scale, wave mode, temporal scale) for perturbing physical parameters.

- Refining SPP for Higher Resolution: Focus on 1 km resolution for the GLORI Alpine region.

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Thank you!

Backup slides

$\hat{X}_j$
Unperturbed
(det.)

$\Psi_j \sim N(\boldsymbol{\mu_j}, \boldsymbol{\sigma_j^2})$
Random pattern

$X_j = \exp(\Psi_j)\hat{X}_j$
perturbed
(det.)

$X_j = \hat{X}_j(\mathbf{1} + \Psi_j)$
perturbed
(det.)

$\boldsymbol{\mu_j}, \boldsymbol{\sigma_j^2}$ **are both determined individually for each perturbed parameter** j

Pattern properties:
✓ Length scale
✓ Time scale
✓ Modes
✓ Variance

Ref: Ollinaho et. al. 2016, and Frogner et al. 2021

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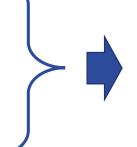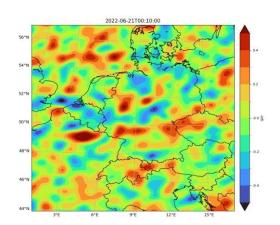
SPP properties:
- Fourier Series vs. Lagandre Polynomial
- Pattern length scale = 50km
- Pattern time scale = 1 hour
- Pattern modes = 50
- Pattern variance = 0.1

2022-06-21T00:10:00
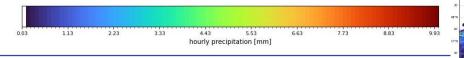
Sensitivity tests for SPP variance
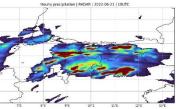
The model shows numerical instability with higher values of SPP variance:
- SPP variance = 1.0 : Model crashed
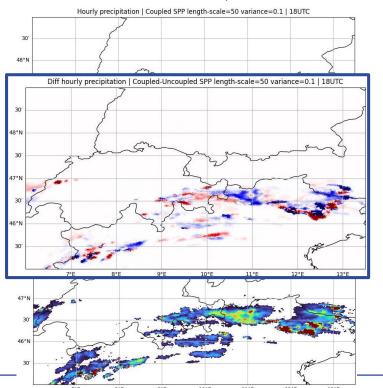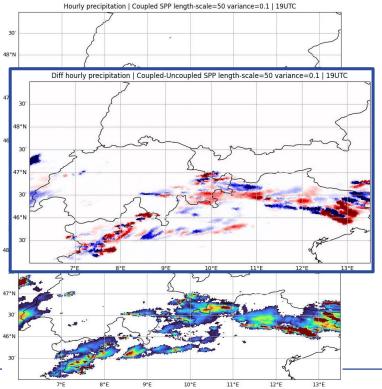- SPP variance = 0.5 : Model crashed
- SPP variance = < 0.4 : Model ran successfully

Hourly precipitation

EXPERIMENTs SETUP
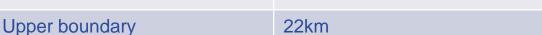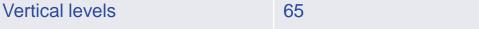
Two-way nesting	
Horizontal grid resolution	2km (ICON-D2), **1km** (TeamX)
Upper boundary	22km
Vertical levels	65
LAT-BC	Forecasts (ICON-EU)
Perturbed initial conditions	KENDA (ICON-D2-EPS)
Forecast duration	24h starting on 2022062100
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Ensemble members	20
Microphysics	1mom or 2mom
Turbulence	TURBDIFF
Land	TERRA
Standard operational model perturbations	
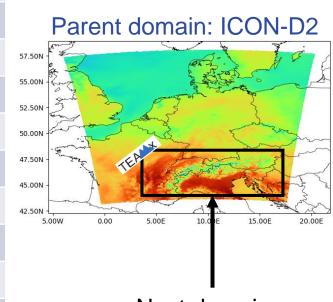
Parent domain: ICON-D2

Nest domain
1km horizontal resolution

Classical parameter perturbation (CPP):
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Case study
→ 20th June 2024
→ 24h fc
→ 2 nests over Alps (teamx)
→ 6 ensemble members

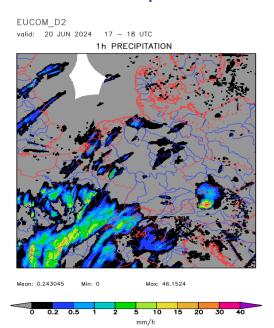Total precipitation → Deterministic fc at 18UTC for ICON-2, 1km, 0.5km

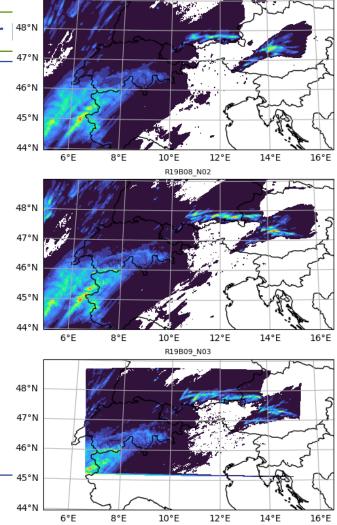# Total precipitation → Deterministic fc at 18UTC for

Radar German composite: ICON-D2

EUCOM_D2
valid: 20 JUN 2024 17 – 18 UTC

1h PRECIPITATION

Mean: 0.243045   Min: 0   Max: 46.1524

0 0.2 0.5 1 2 5 10 15 20 30 40
mm/h

Total precipitation → EPS fc at 18UTC for ICON-2, 1km, 0.5km