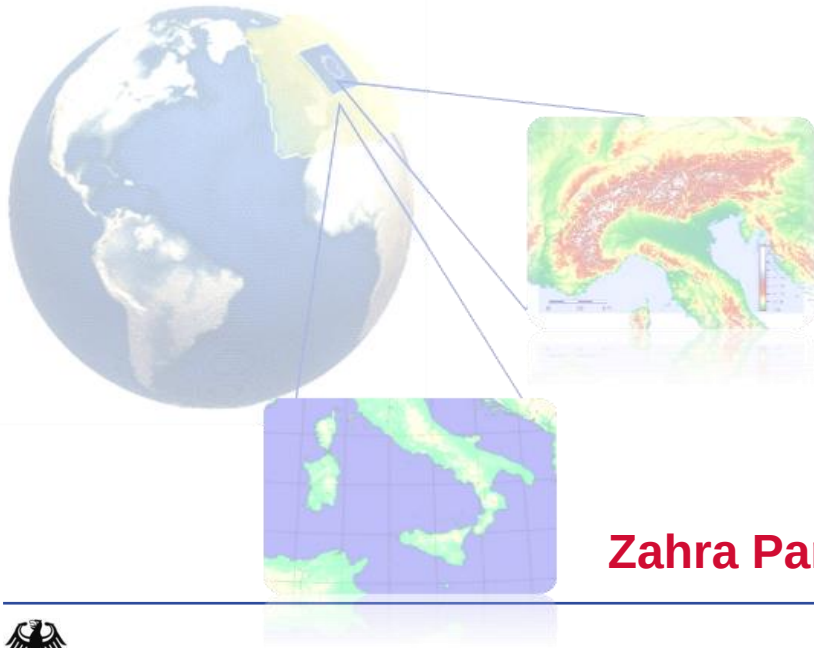


SPP development in ICON

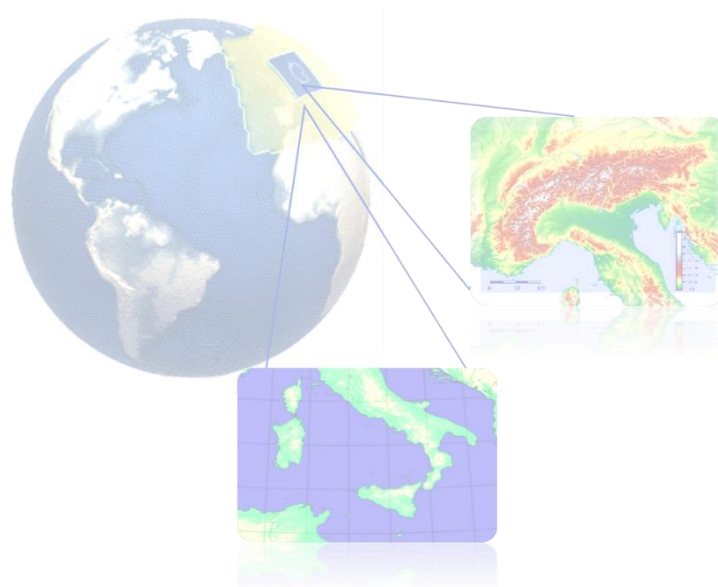


28th COSMO General Meeting

14 September 2026 | Rome, Italy

Zahra Parsakhoo, Christoph Gebhardt, Chiara Marsigli

1. **Introduction and motivation**
CPP vs. SPP: Key Differences
2. **Implementation in ICON**
Stochastic Pattern Generator (SPG)
Stochastic Parameter Perturbation (SPP)
3. **Evaluation**
Benchmarking & Experimental Results
Sensitivity analysis on SPG parameters
Analysis
4. **Summary and outlook**



CPP vs. SPP: Key Differences

Classical parameter perturbation
(CPP)



Each uncertain parameter is set to

- default or
- boundary value of the range



The value is kept **fix** during the run



~18 parameters

Stochastic parameter perturbation(SPP):



CPP vs. SPP: Key Differences

Classical parameter perturbation (CPP)

Each uncertain parameter is set to

- default or
- boundary value of the range

The value is kept **fix** during the run

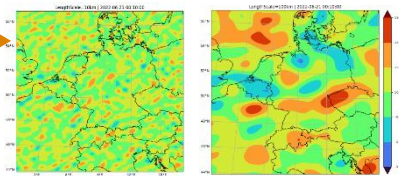
~18 parameters

Stochastic parameter perturbation(SPP):

Each uncertain parameter is perturbed by
Stochastic Pattern

- Temporally evolving via spectral space
- Spatial and temporal correlations
- Some certain properties

Length scale
Time scale
Variance
Mode



Seed different for each:

- parameter
- ensemble member
- initialization date
- initialization time

SPG implementation in ICON

**Stochastic Pattern Generator
(SPG)**



By Axel Seifert and Maleen Hanst



Deterministic forecast
Coupled with microphysics
To perturb **sedimentation velocity of graupel**

Merged into
ICON master
(June 2025)



SPG implementation in ICON

Stochastic Pattern Generator (SPG)

Merged into
ICON master
(June 2025)

By Axel Seifert and Maleen Hanst

Deterministic forecast
Coupled with microphysics

To perturb **sedimentation velocity of graupel**

$$\text{perturbed} = \text{unperturbed} \times \exp(\text{SPG})$$

ICON-LAM

SPP

- Coupled to convection → rdepths
Maximum allowed shallow convection depth
- Coupled to land → r_bsmin
Minimum bare soil evapotranspiration resistance

EPS

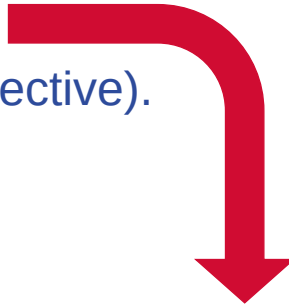


To evaluate

- role of SPG namelist parameters
- parameter behavior before and after SPP (both from a technical and theoretical perspective).

SPG properties (namelist):

```
spg_fourier_modes = .true.  
spg_length_scale = 50e3 [m]  
spg_time_scale = 3600 [s]  
spg_spec_modes = 50  
spg_variance = 0.2
```


$$\text{perturbed} = \text{unperturbed} \times \exp(\text{SPG})$$

Sensitivity analysis of SPG namelist parameter

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

Representation in Spectral space:

$$r(\mathbf{x}, t) = \sum_{m,n} \hat{r}_{mn}(t) e^{i\mathbf{k}_{mn} \cdot \mathbf{x}}$$

- $\mathbf{k}_{mn}$: wave number
- $\hat{r}_{mn}(t)$: spectral coefficients

→ Interpretation:

- 2D field = sum of waves (Fourier modes)
- Each mode evolves independently

Temporal evolution (AR(1))

$$\hat{r}_{mn}(t + \Delta t) = \phi \hat{r}_{mn}(t) + g_{mn} \varepsilon_{mn}(t)$$

with:

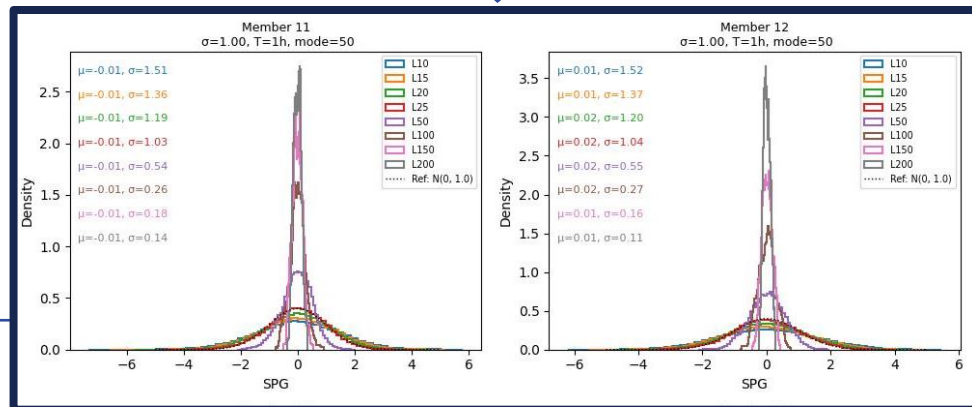
$$\phi = \exp(-\Delta t / \tau)$$

$\varepsilon_{mn}(t) \sim \mathcal{N}(0,1) \rightarrow$ random forcing (noise)

g_{mn} : noise amplitude $\rightarrow$ function of a prescribed length scale (L_x) and σ^2

SPG namelist:

spg_length_scale= 10, 15, 20, **25**, 50, 100, 150, 200
spg_time_scale= 1 [h]
spg_spec_modes= 50
spg_variance= 1.0



Sensitivity analysis of SPG namelist parameter

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

Representation in Spectral space:

$$r(\mathbf{x}, t) = \sum_{m,n} \hat{r}_{mn}(t) e^{i\mathbf{k}_{mn} \cdot \mathbf{x}}$$

- $\mathbf{k}_{mn}$: wave number
- $\hat{r}_{mn}(t)$: spectral coefficient

- Interpretation:
- 2D field
 - Each mode

Temporal evolution:

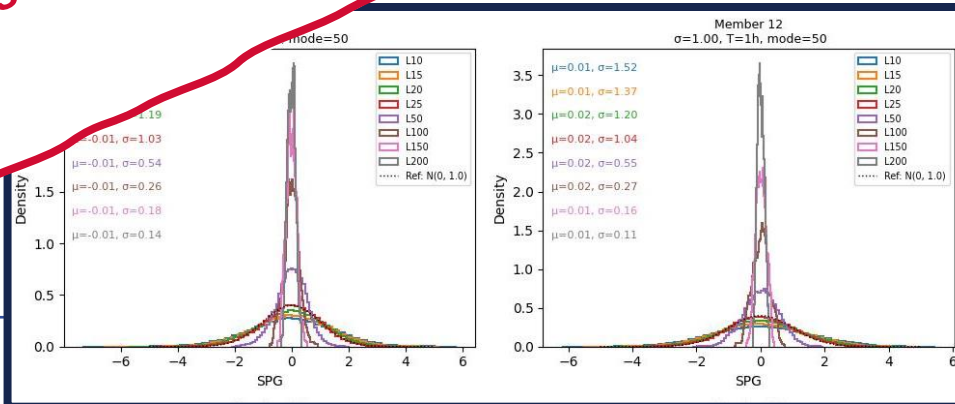
$$\hat{r}_{mn}(t + \Delta t)$$

with:

$\phi_{mn}(t) \sim \mathcal{N}(0, 1) \rightarrow$ random
 g_{mn} : noise amplitude $\rightarrow$ prescribed length
scale (L_x) and σ^2

The realized variance and structure of the SPG field depend on the interaction between the prescribed length scale and the spectral truncation and domain size. If the spectrum is not adequately resolved, the model produces biased variance

SPG parameters:
5, 50, 100, 150, 200
[h]
50
1.0

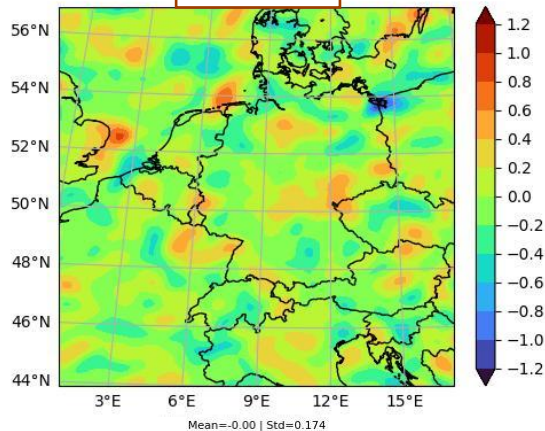


Spatial pattern and distribution of the perturbed values

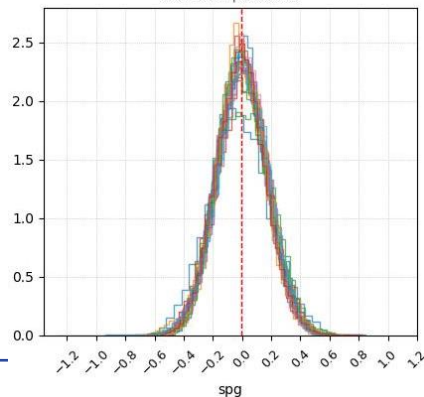
tscher Wetterdienst
ar und Klima aus einer Hand



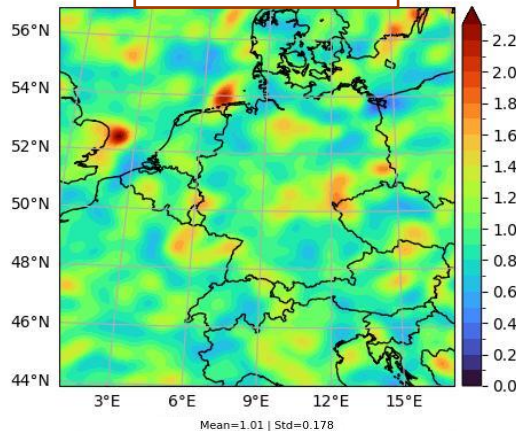
SPG



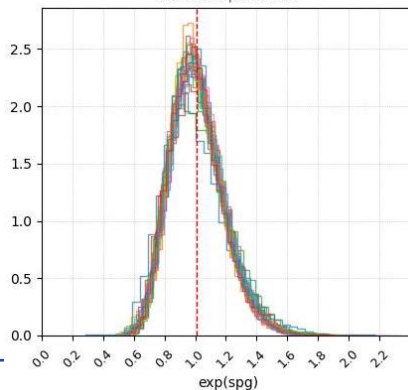
Mean=-0.00 | Std=0.174



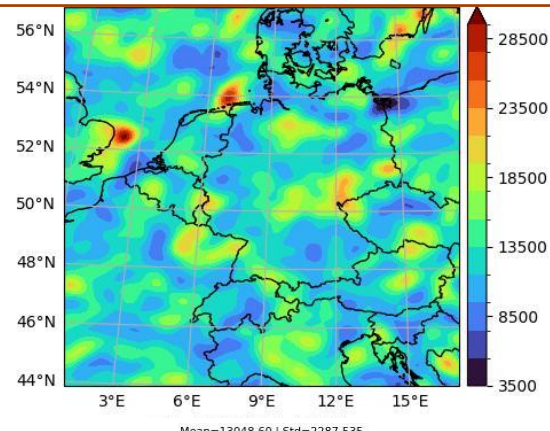
exp(SPG)



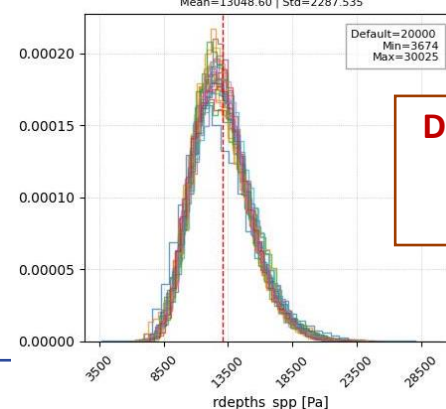
Mean=1.01 | Std=0.178



Perturbed Parameter



Mean=13048.60 | Std=2287.535



Default = 13000
Min = 3674
Max = 30025



Overlay of all time steps for one ensemble member

Test Setup “*clean*” Experiments

LAT-BC → **no** Perturbation
Initial Conditions → **no** Perturbation

CPPclean

~18 physical parameter
perturbation fixed during
forecast run time

- Operational perturbation

SPPclean

SPP activated for perturbing

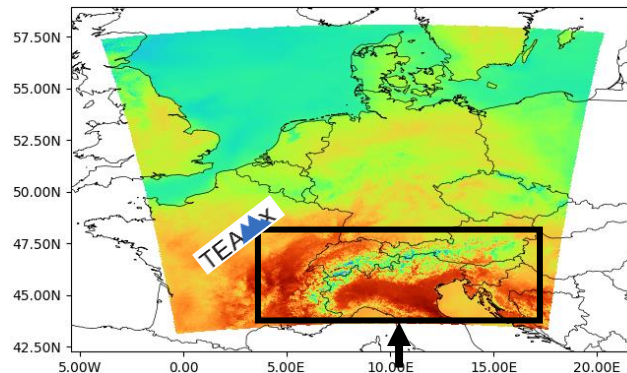
- ✓ Sed. Vel. Graupel
- ✓ rdepths
- ✓ r_bsmin



EXPERIMENTs SETUP

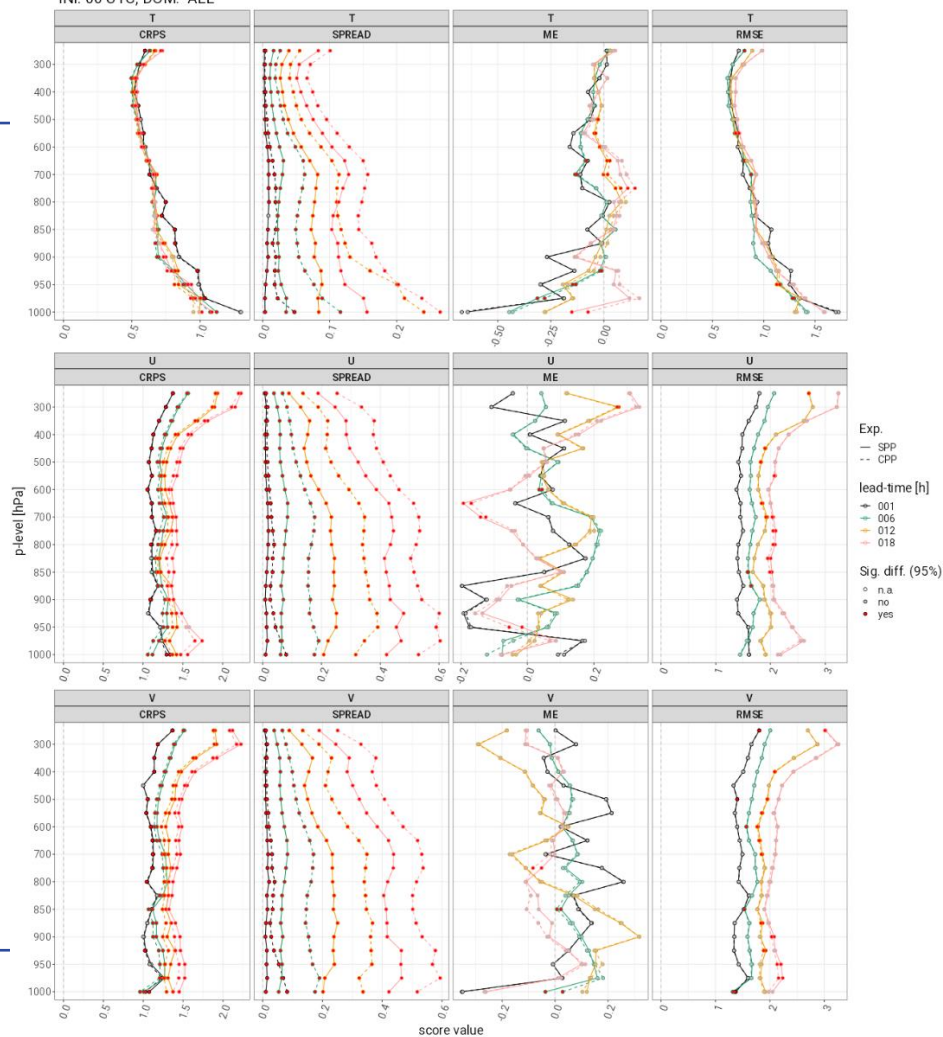
Horizontal grid resolution	2km (ICON-D2)
Upper boundary	22km
Vertical levels	65
LAT-BC	Forecasts (ICON-EU)
Forecast duration	23h starting on 2023050800- 2023051600
Ensemble members	10
Microphysics	2-moment
Turbulence	TURBDIFF
Land	TERRA

ICON-D2



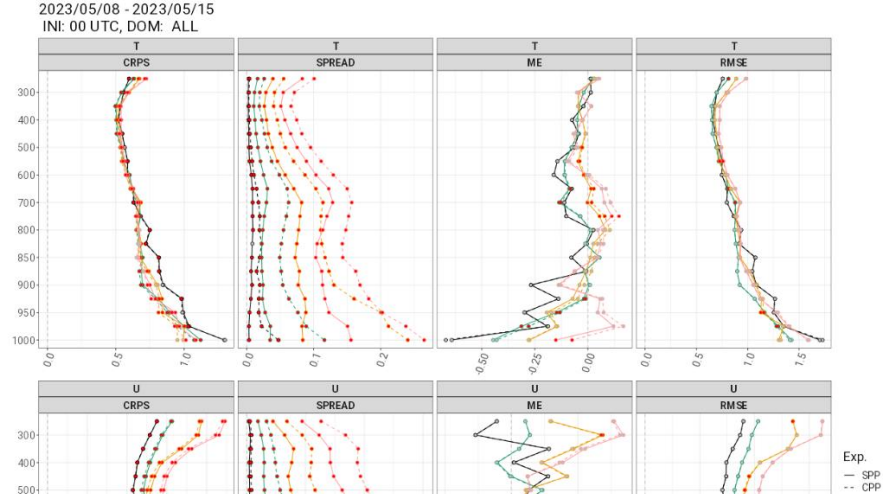
Verification

- SPP and CPP show relatively similar forecast skill.
- The main difference is seen in ensemble spread: at longer lead times, SPP exhibits smaller spread relative to CPP.

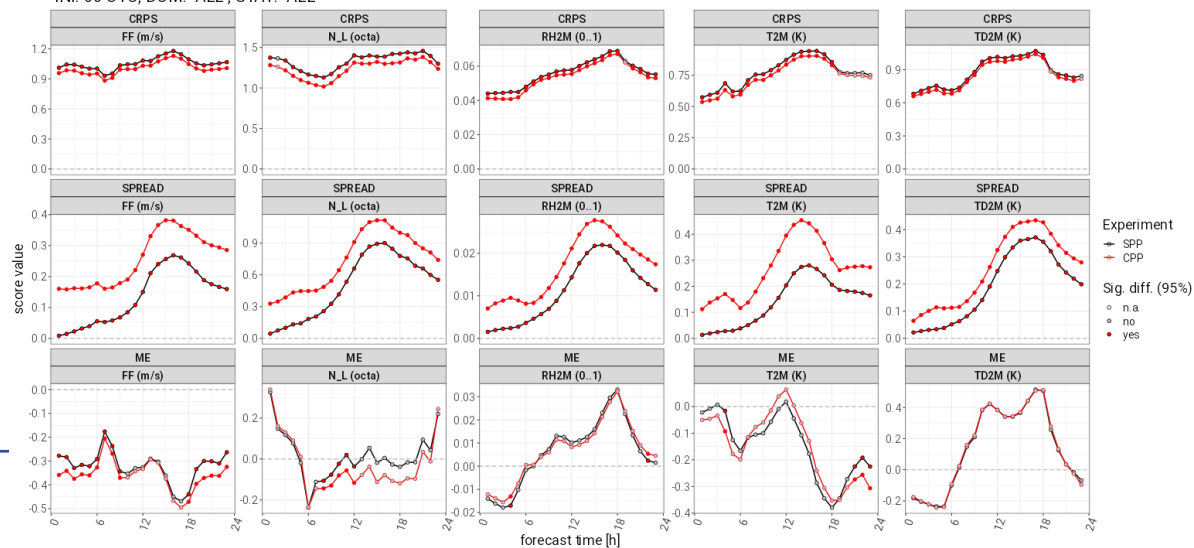


Verification

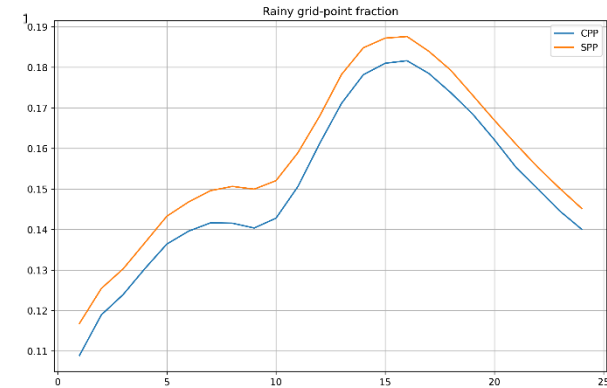
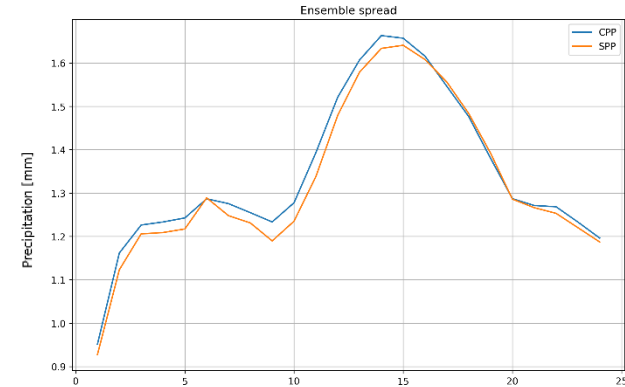
- SPP and CPP show relatively similar forecast skill.
- The main difference is seen in ensemble spread: at longer lead times, SPP exhibits smaller spread relative to CPP.



2023/05/08 01UTC - 2023/05/15 23UTC
INI: 00 UTC, DOM: ALL, STAT: ALL

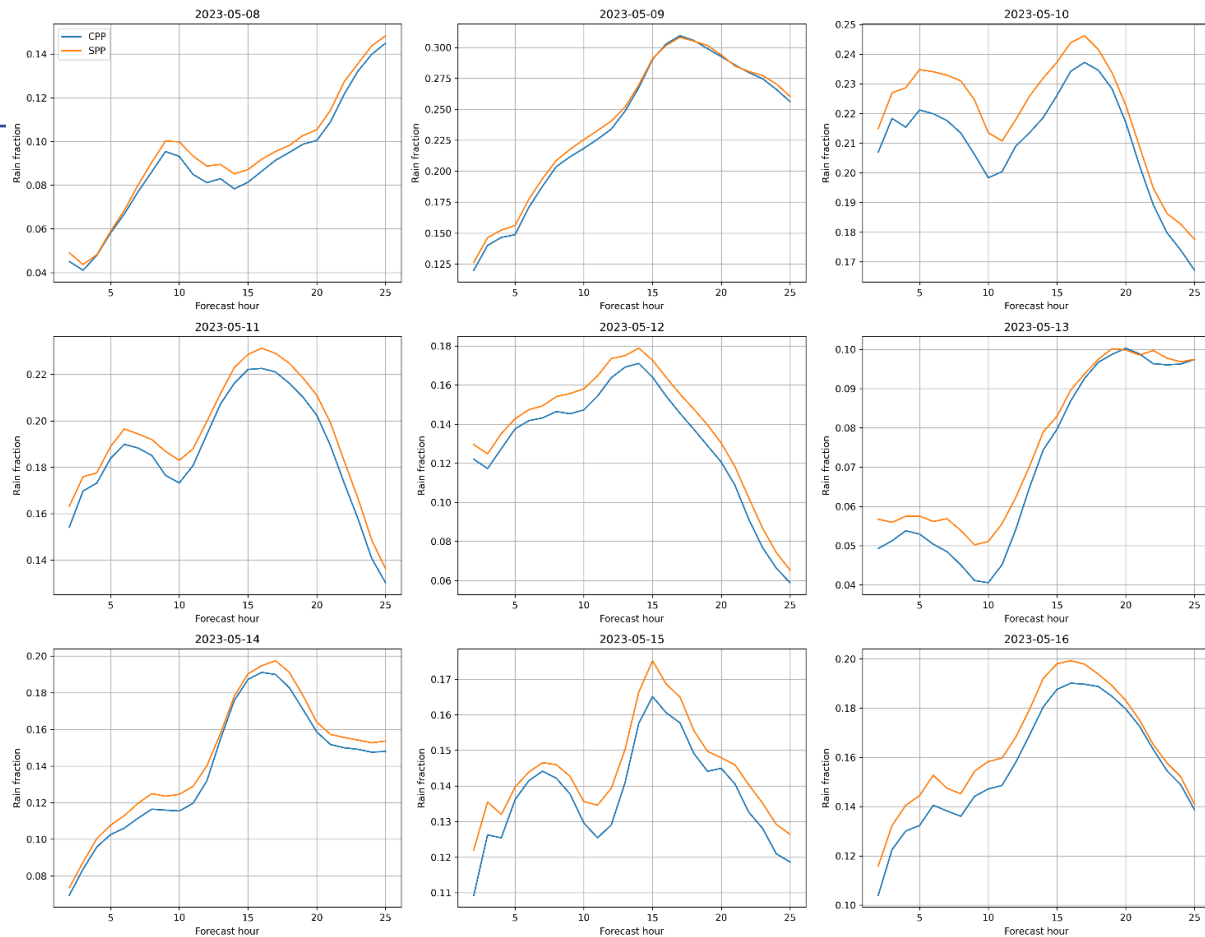


- SPP and CPP show small differences in domain-averaged ensemble spread for hourly precipitation.
- Domain-averaged spread → masks local ensemble sensitivity
- SPP slightly increases rainy-grid fraction.



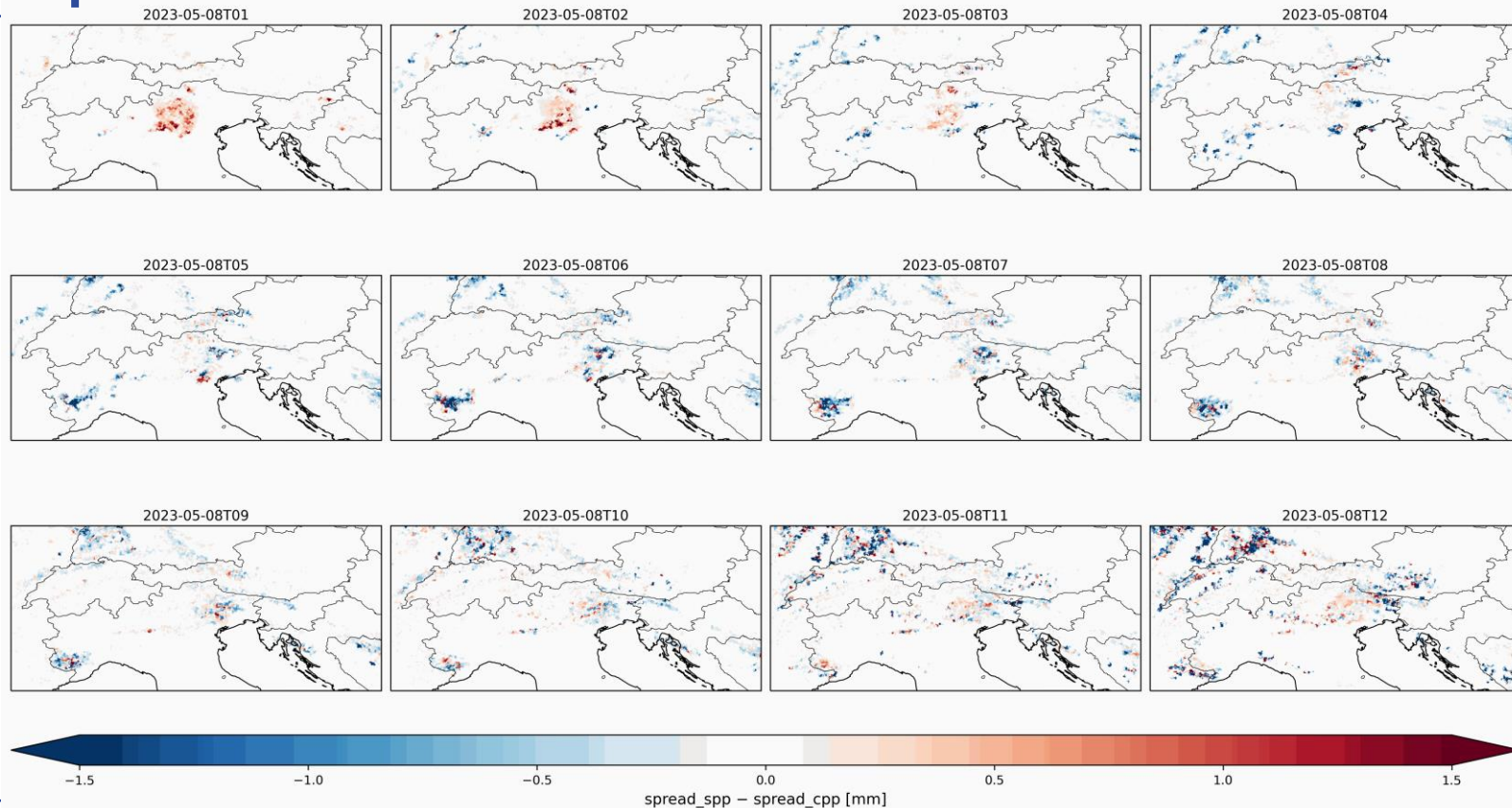
Rain fraction

- SPP increases slightly the spatial occurrence of precipitation



Ens-Spread-Difference

Spread difference: 2023-05-08
Forecast-time indices 1-12



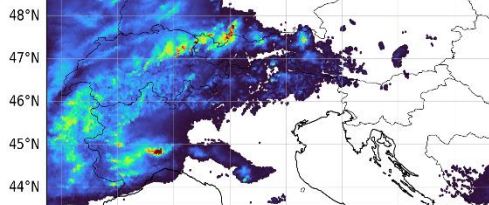
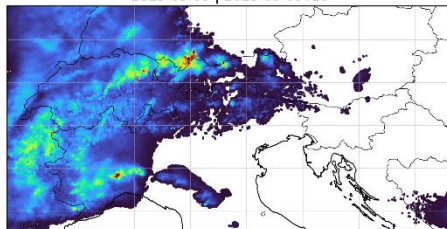
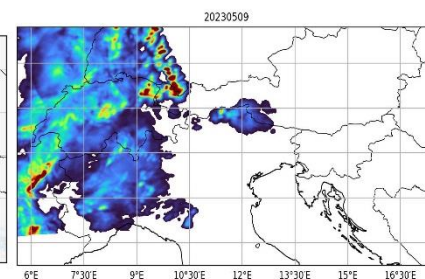
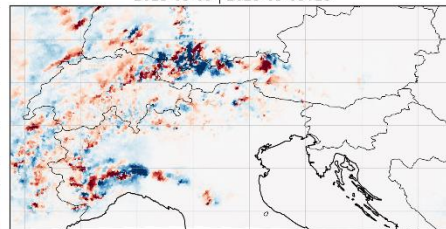
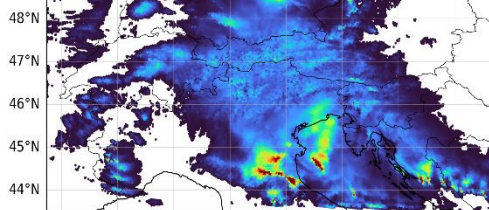
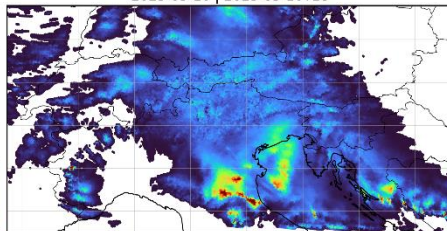
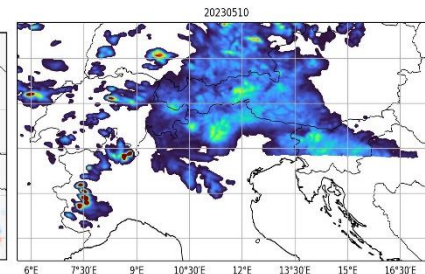
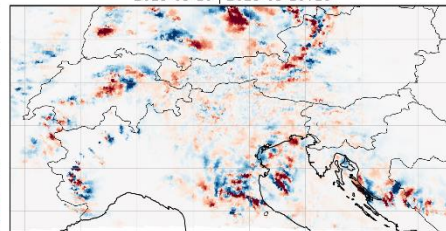
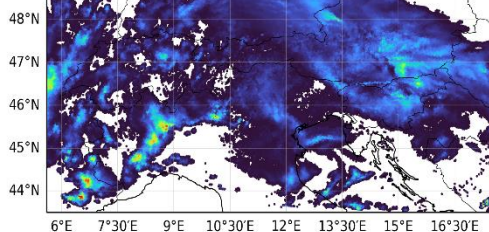
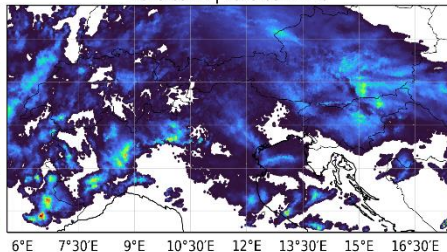
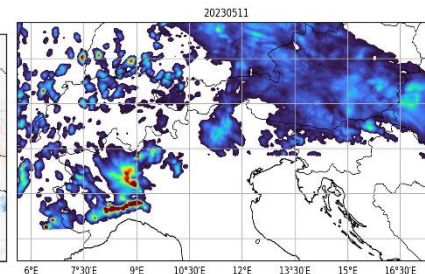
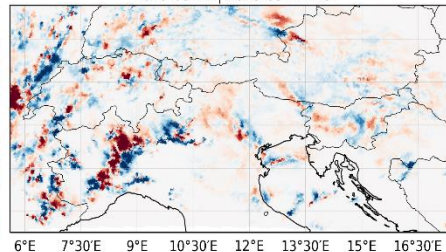
18UTC

SPP

CPP

SPP-CPP

RADAR

SPP Ensemble Mean
2023-05-09 | 2023-05-09T18CPP Ensemble Mean
2023-05-09 | 2023-05-09T18SPP - CPP Ensemble Mean
2023-05-09 | 2023-05-09T18SPP Ensemble Mean
2023-05-10 | 2023-05-10T18CPP Ensemble Mean
2023-05-10 | 2023-05-10T18SPP - CPP Ensemble Mean
2023-05-10 | 2023-05-10T18SPP Ensemble Mean
2023-05-11 | 2023-05-11T18CPP Ensemble Mean
2023-05-11 | 2023-05-11T18SPP - CPP Ensemble Mean
2023-05-11 | 2023-05-11T18

Hourly Precipitation



SPP-CPP



- SPG Implementation is done by Axel Seifert (since June 2025 is merged in ICON-Master),
- Tuning SPG in ICON-LAM-D2: Optimize values for SPG parameters (e.g., length scale, wave mode, temporal scale) for perturbing physical parameters.
- SPP successfully implemented in ICON-LAM for three parameters (sed. vel. graupel, rdepths and r_bsmin) and SPPmulti (sed. vel. Graupel & rdepths & r_bsmin) successfully with ICON-LAM.
- SPP maintains forecast skill comparable to CPP.
- SPP increased rainy-grid fraction while keeping the overall precipitation behavior comparable to CPP
- Results are promising but preliminary → more cases and targeted parameter perturbations are required to assess robustness and optimize ensemble spread.

- **Implementation:**
 - Add spg_call_interval in spg namelist
 - Test other physical uncertain parameters (Any suggestion!?)
 - Combine with Adaptive Parameter Tuning (by Günther Zängl)
- More case studies
- Refining SPP for Higher Resolution: Focus on 1 km resolution for the GLORI Alpine region.
- Nest: First test uncoupled at 500 m resolution, then fully coupled with SPP.

- **Implementation:**
 - Add spg_call_interval in spg namelist
 - Test other physical uncertain parameters (Any suggestion!?)
 - Combine with Adaptive Parameter Tuning (by Günther Zängl)
- More case studies
- Refining SPP for Higher Resolution: Focus on 1 km resolution for the GLORI Alpine region.
- Nest: First test uncoupled at 500 m resolution, then fully coupled with SPP.

- **Implementation:**
 - Add spg_call_interval in spg namelist
 - Test other physical uncertain parameters (Any suggestion!?)
 - Combine with Adaptive Parameter Tuning (by Günther Zängl)
- More case studies
- Refining SPP for Higher Resolution: Focus on 1 km resolution for the GLORI Alpine region.
- Nest: First test uncoupled at 500 m resolution, then fully coupled with SPP.

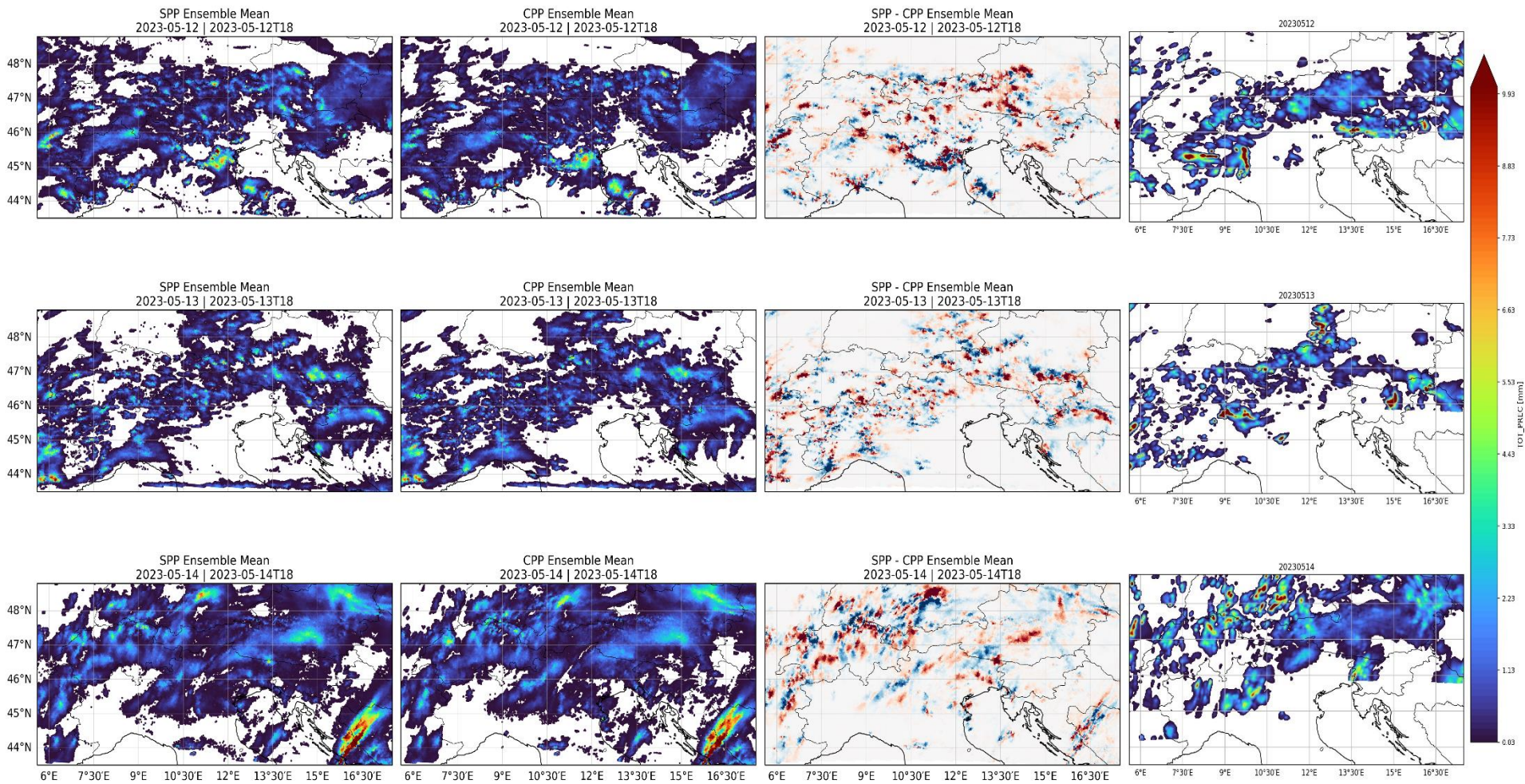


Thank you!

Backup slides



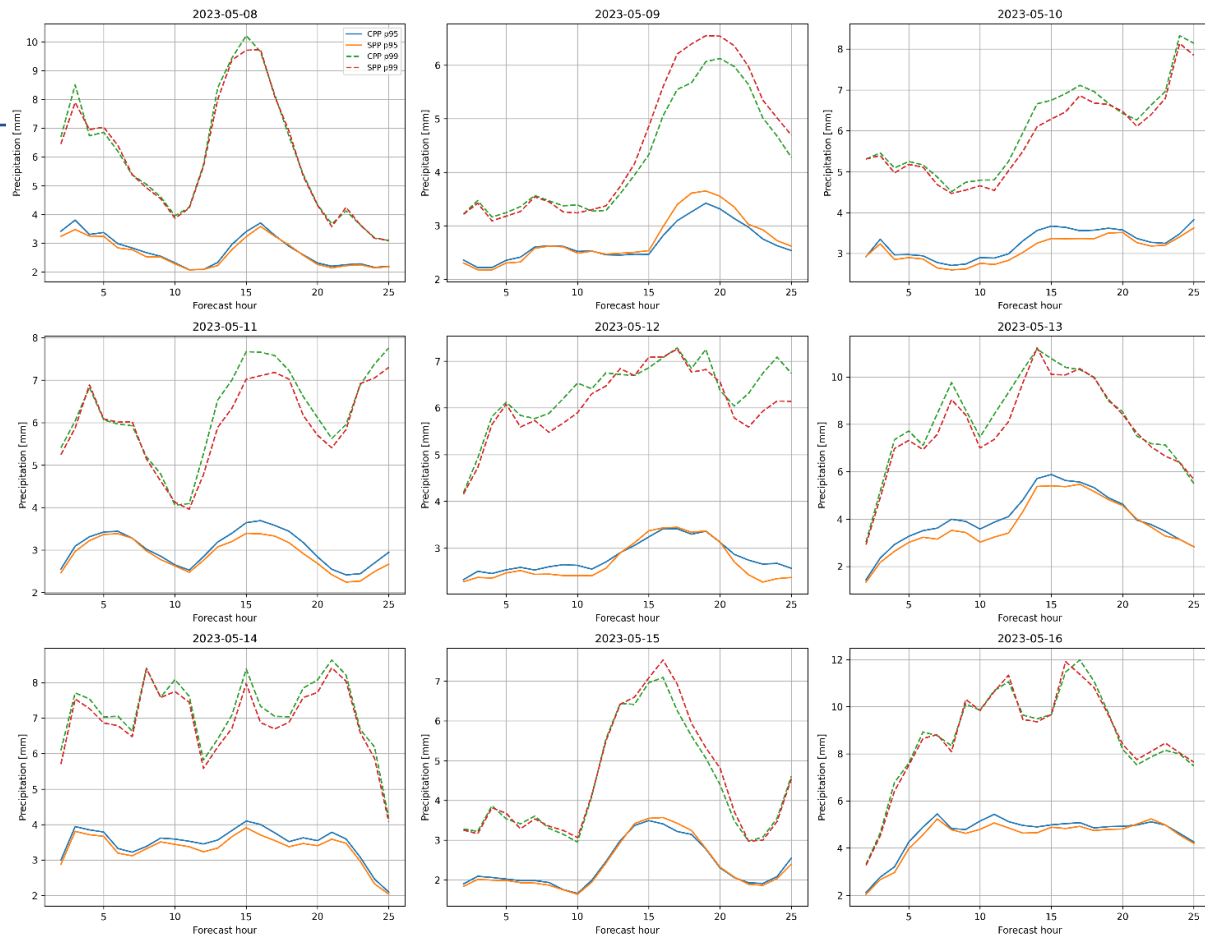
Radar Composite at 18 UTC | 12-14 May 2023



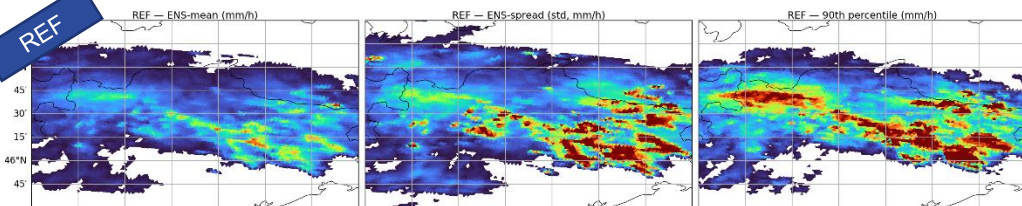
P95/P99 | EnsMean

Increased precipitation coverage does not lead to systematic inflation of heavy precipitation

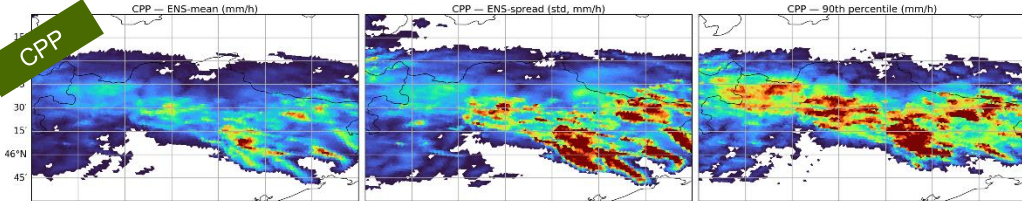
SPP rains over more grid points → but p95/p99 remain close to CPP → therefore SPP is primarily changing occurrence/coverage rather than indiscriminately amplifying rainfall.



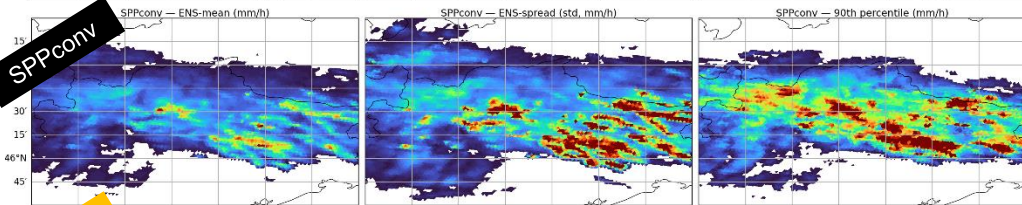
REF



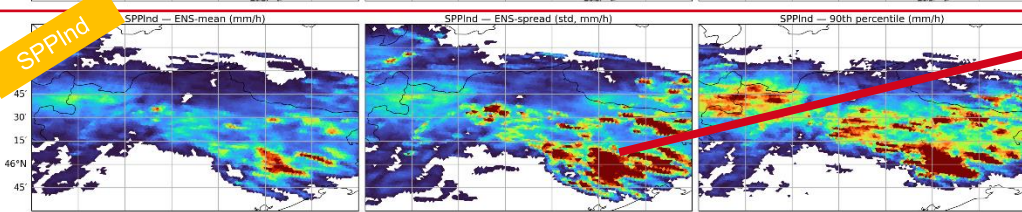
CPP



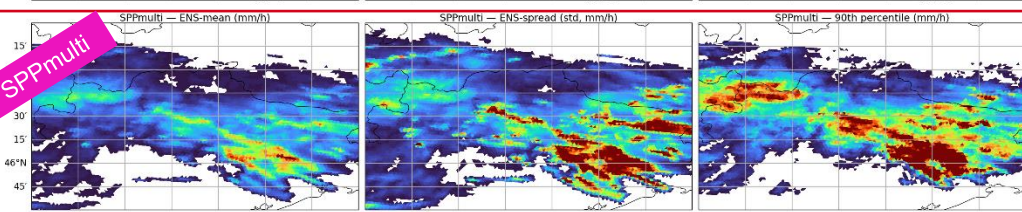
SPPconv



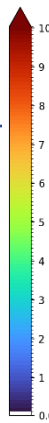
SPPInd



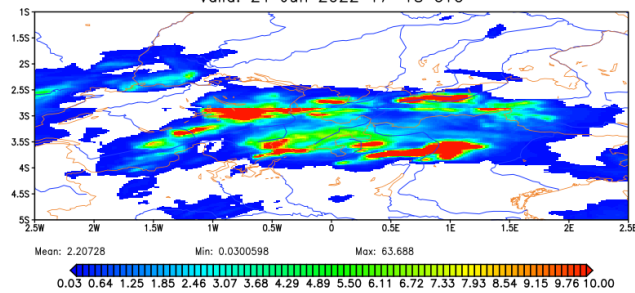
SPPmulti



Hourly precipitation (mm/h)



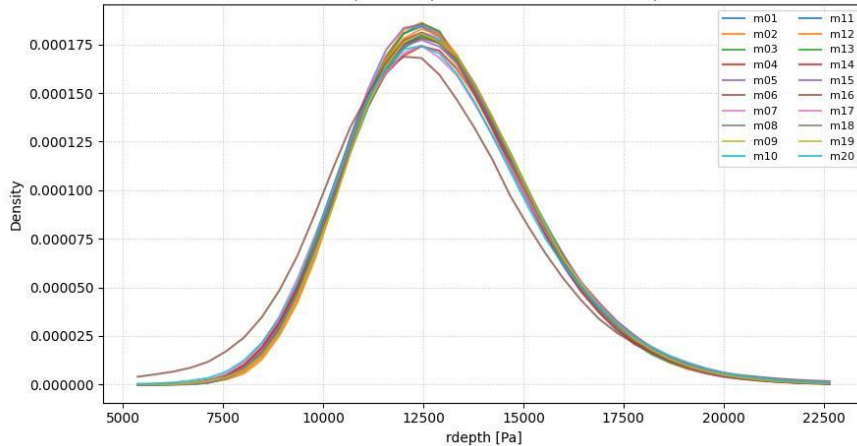
Radar Composite (Hourly Rain sum)
valid: 21 Jun 2022 17–18 UTC



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

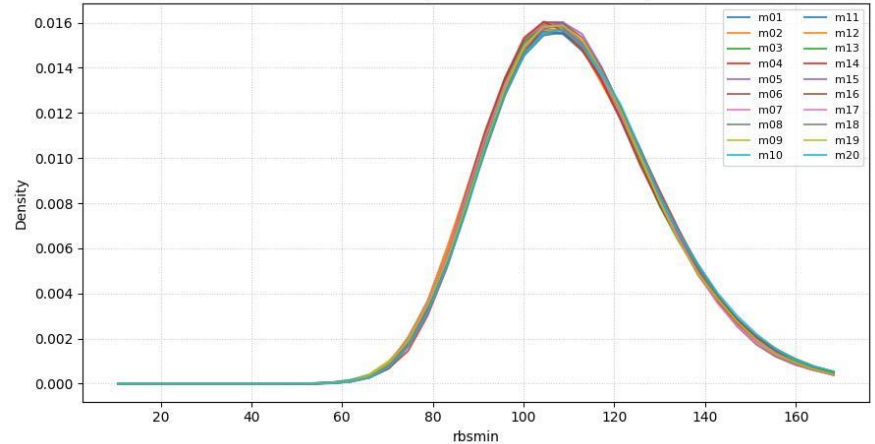
PDFs of Time-Average Perturbed Parameters

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



Maximum allowed shallow convection depths

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



Minimum bare soil evapotranspiration resistance

- **Time-Average PDFs:** one member diverges for **rdepths**
- **Single case** → not robust; likely not persistent across many days