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GLObal to Regional | ICON Digital Twin

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Studies of Convection-Permitting Ensemble Forecasting for ICON-D2 with a 1km Nest over the Alps

PrePEP Conference | University of Bonn | 18 March 2025

Zahra Parsakhoo
Chiara Marsigli, Christoph Gebhardt, Axel Seifert, Jan Keller

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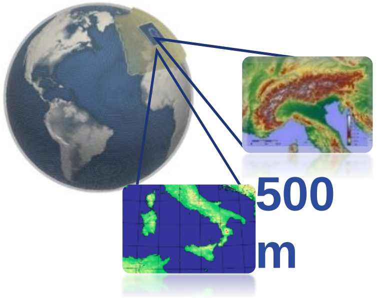

- Global storm-resolving (~3km) regional sub-km scale (500 m)
- Uncertainty estimation with ensembles
- Configurable and on-demand

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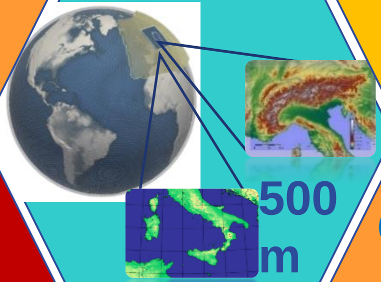
GPU capability
(Michael Krayer)

model physics for high-resolution
(Daniela Littmann)

system implementation and data assimilation
(Xu Xu)

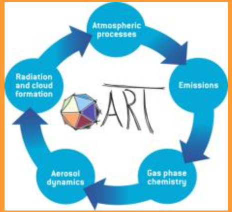
Project leader:
Chiara Marsigli

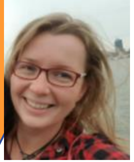


500 m

ensembles for high-resolution

aerosol
(Katerina Kusakova)





floods

Co-Design Project

ICON

Test and development of the model perturbation

ensembles for high-resolution

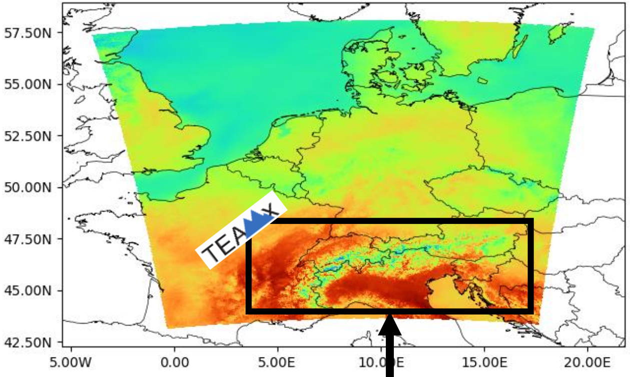
Classical parameter perturbation (CPP)
Operational at DWD

Stochastically perturbed parameterization (SPP)

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
Forecast restart	6h
Ensemble members	20
Microphysics	1mom or 2mom
Turbulence	TURBDIFF
Land	TERRA
Standard operational model perturbations	

Parent domain: ICON-D2



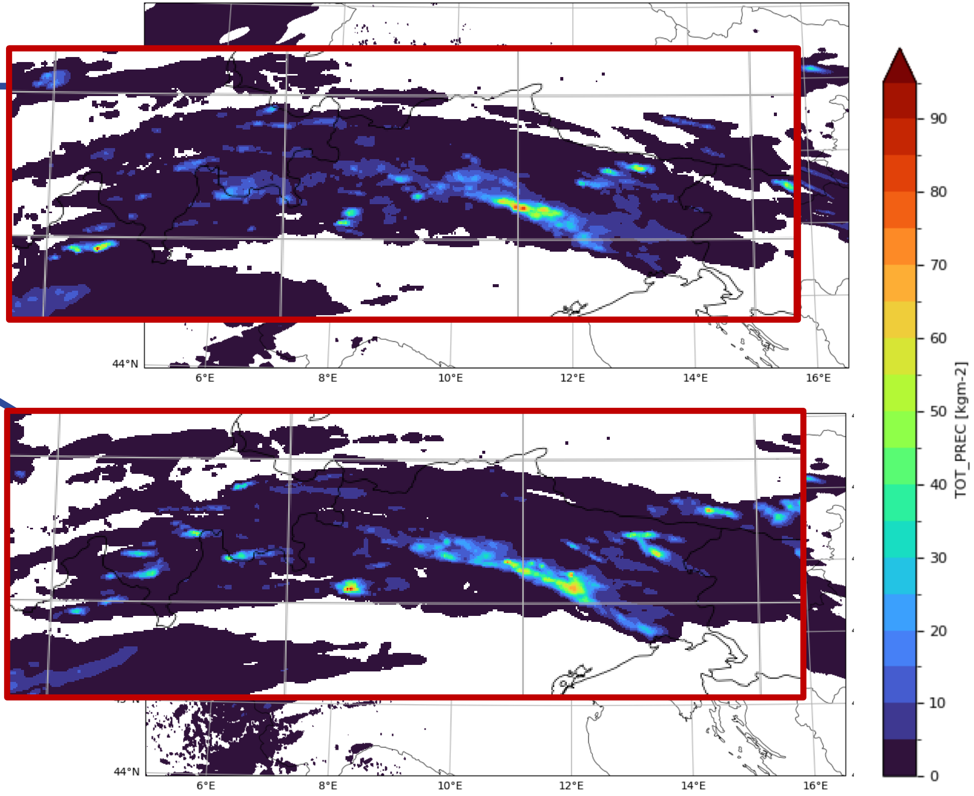
Nest domain
1km horizontal resolution

*TEAMx: https://www.teamx-programme.org/

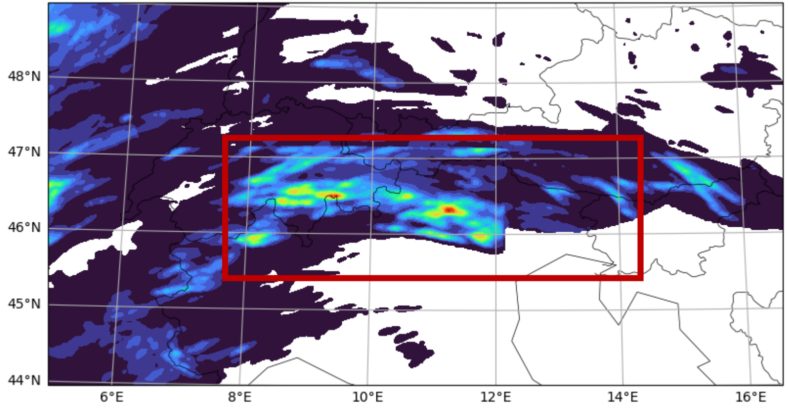
Testing the impact of convection schemes

1km

- shallow convection only
- deep convection parameterization (gray-zone-tuning version)

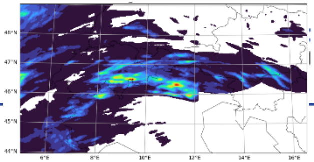


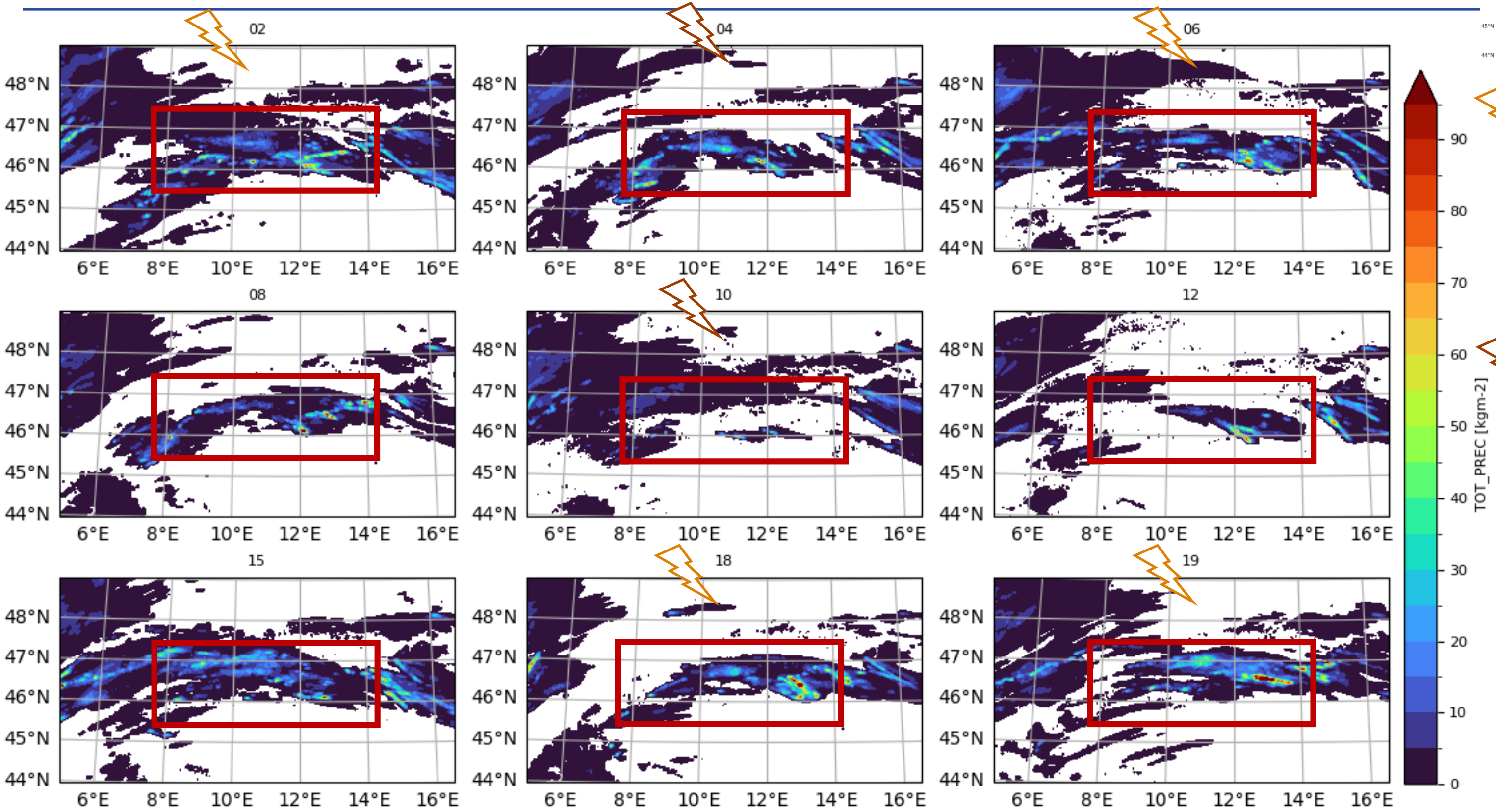
Precipitation estimate from radar



Behaviour of the ensemble members

Radar





Some members with misplaced rain

Some members with too little rain

Shallow convection only

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Summary of first part

- → Shallow-conv-only experiment forecast is slightly better in generating rain,
- → Experiments with 2mom microphysics produce more realistic clouds than 1mom,
- → In this case, there is no significant difference in precipitation between 1km and 2km in the south of Germany

→ Motivation of second part: **SPP**

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Static parameter perturbation (Operational at DWD)

- Each uncertain parameter is set to its default or to one of the limits of its perturbation range
- This is done randomly at forecast start for each member independently
- On average each uncertain parameter is perturbed in 50% of the members per forecast run

- The value is kept fix during the run

Stochastically perturbed parameterization (SPP)

- Alternatively, an uncertain parameter is perturbed with a specific temporally evolving stochastic pattern for each member
- Perturbation fields should have both spatial and temporal correlations
- All ensemble members have the same climatology, although their bias can be different from unpertubed forecast

- The value changes stochastically based on certain constraints related to the stochastic patterns properties, i.e., spatial/temporal correlation, variance

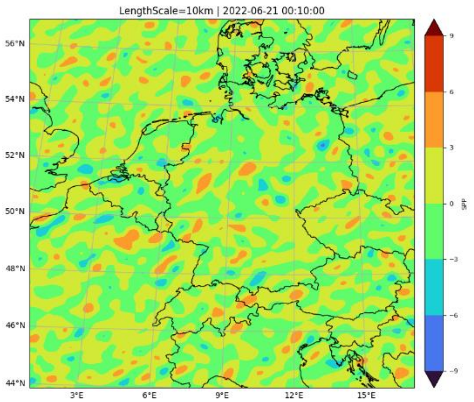
$\hat{X}_j$
Unperturbed
(det.)

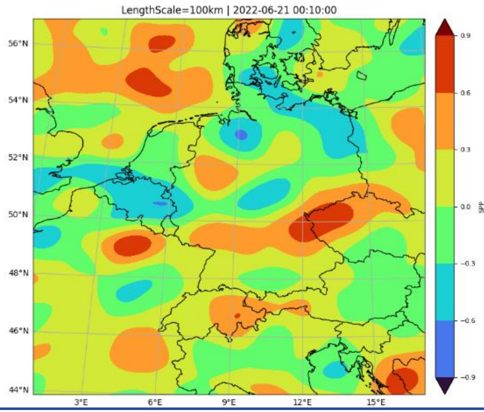
$\Psi_j \sim N(\mu_j, \sigma_j^2)$
Random pattern

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

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

μ_j, σ_j^2 are both determined individually for each perturbed parameter j





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

Ref: Ollinaho et. al. 2016, Frogner et al. 2021, and Tsiringakis et. al. 2024

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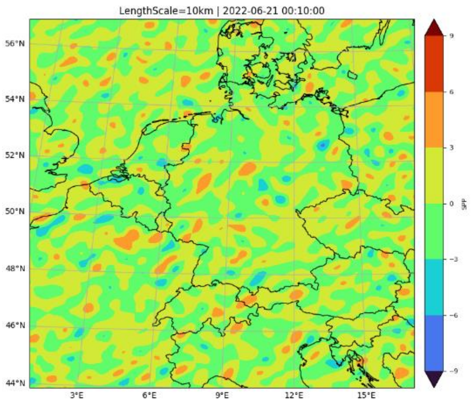

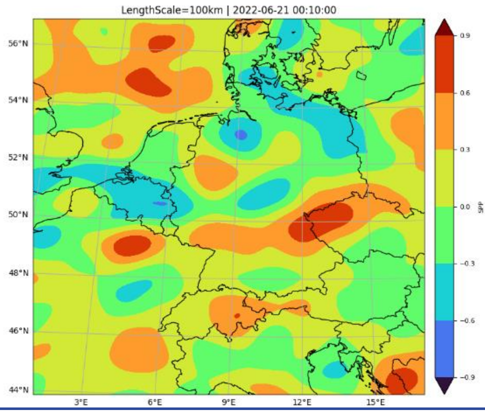

Pattern properties:
- ✓ Length scale
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- ✓ Variance

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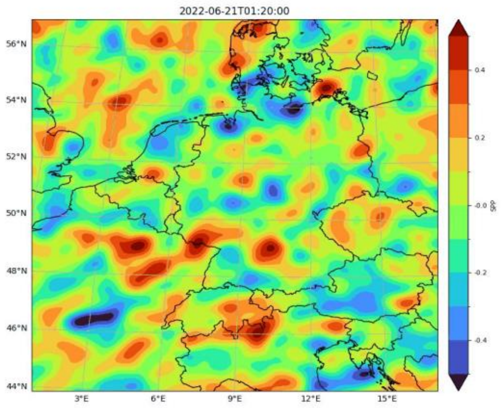
SPG in ICON implemented by Axel Seifert and Maleen Hanst

SPG properties:

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



Sensitivity tests for SPG 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

Test on a real case

Deterministic forecast

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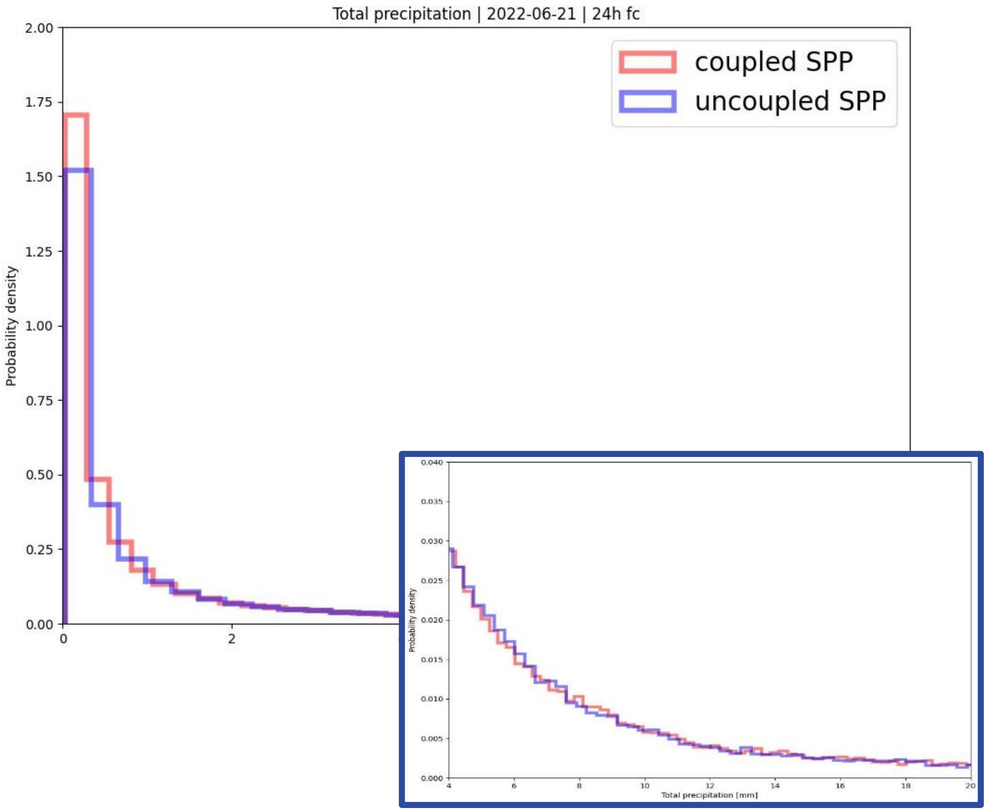
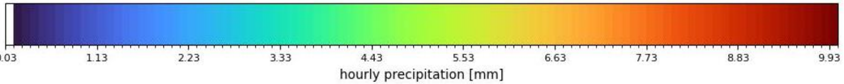
Test: Coupled SPP with 2mom microphysics scheme

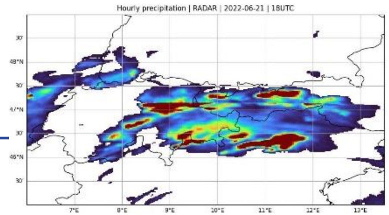
For perturbing the sedimentation velocity of graupel

24h run
ICON-LAM: D2 domain
21st of June 2022



Hourly precipitation



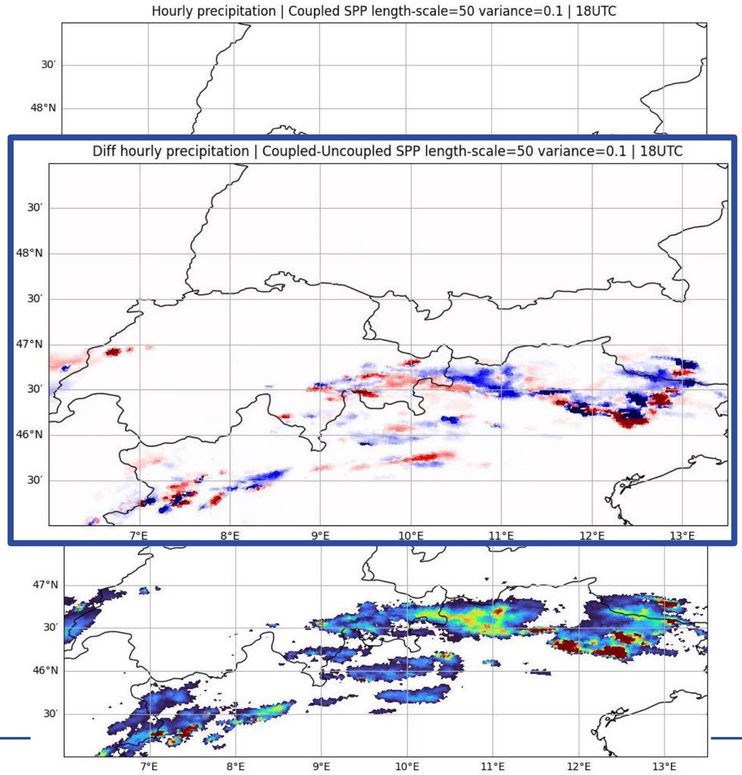


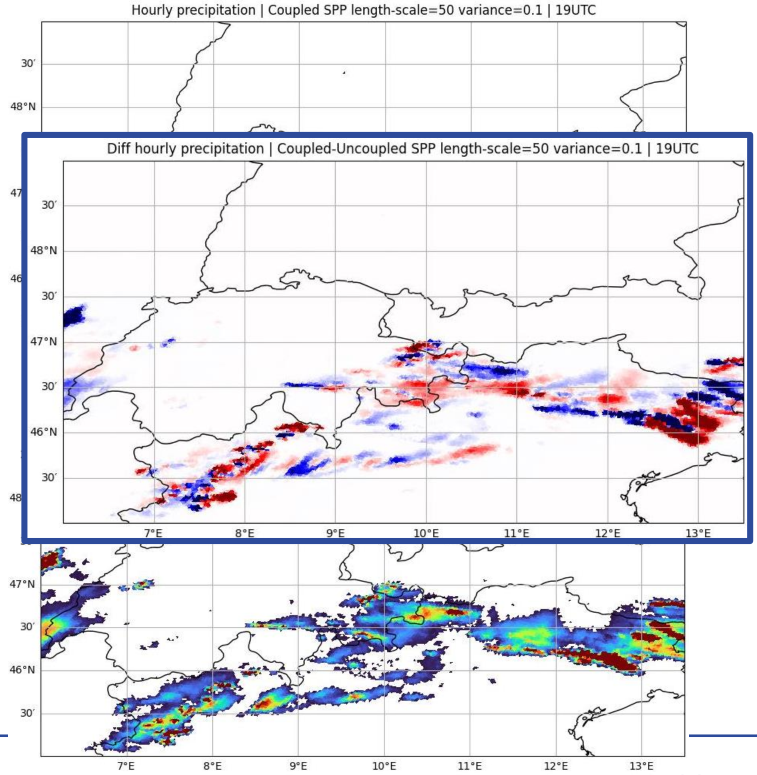
18UTC

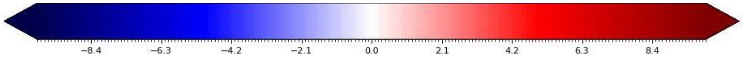
19UTC

coupled SPP

uncoupled SPP







Test on a real case *Ensemble forecast*

Test: Coupled SPP with 2mom microphysics scheme

For perturbing the sedimentation velocity of graupel

24h run
ICON-LAM-**EPS**: D2 domain
21st of June 2022

Implementation of SPP ICON-D2-*EPS* ✓

Test

Test Setup

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

CPP

~18 physical parameter perturbation fixed during forecast run time

✓ **Operational perturbation**

REF

No model perturbation

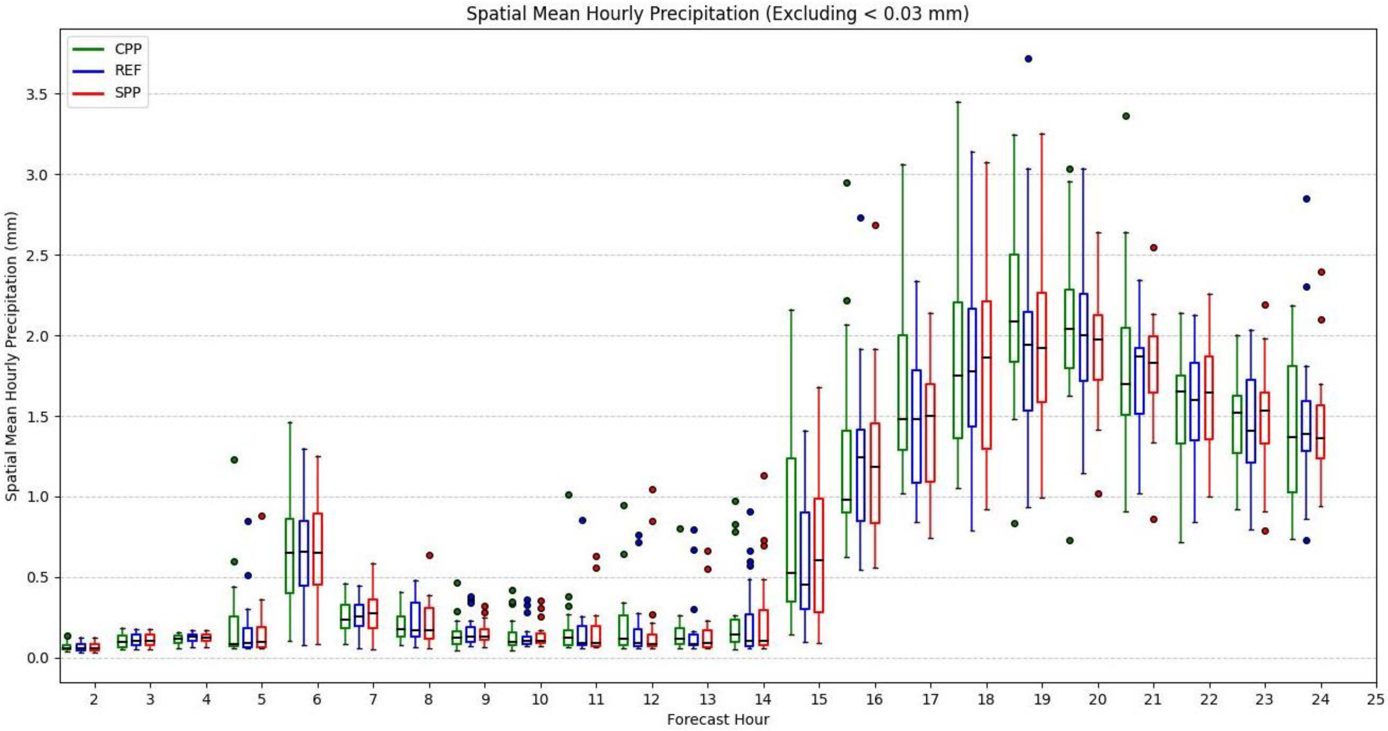
- **No** SPP
- **No** operational perturbation

SPP

SPP activated for perturbing sedimentation velocity of graupel

- **No** operational perturbation

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

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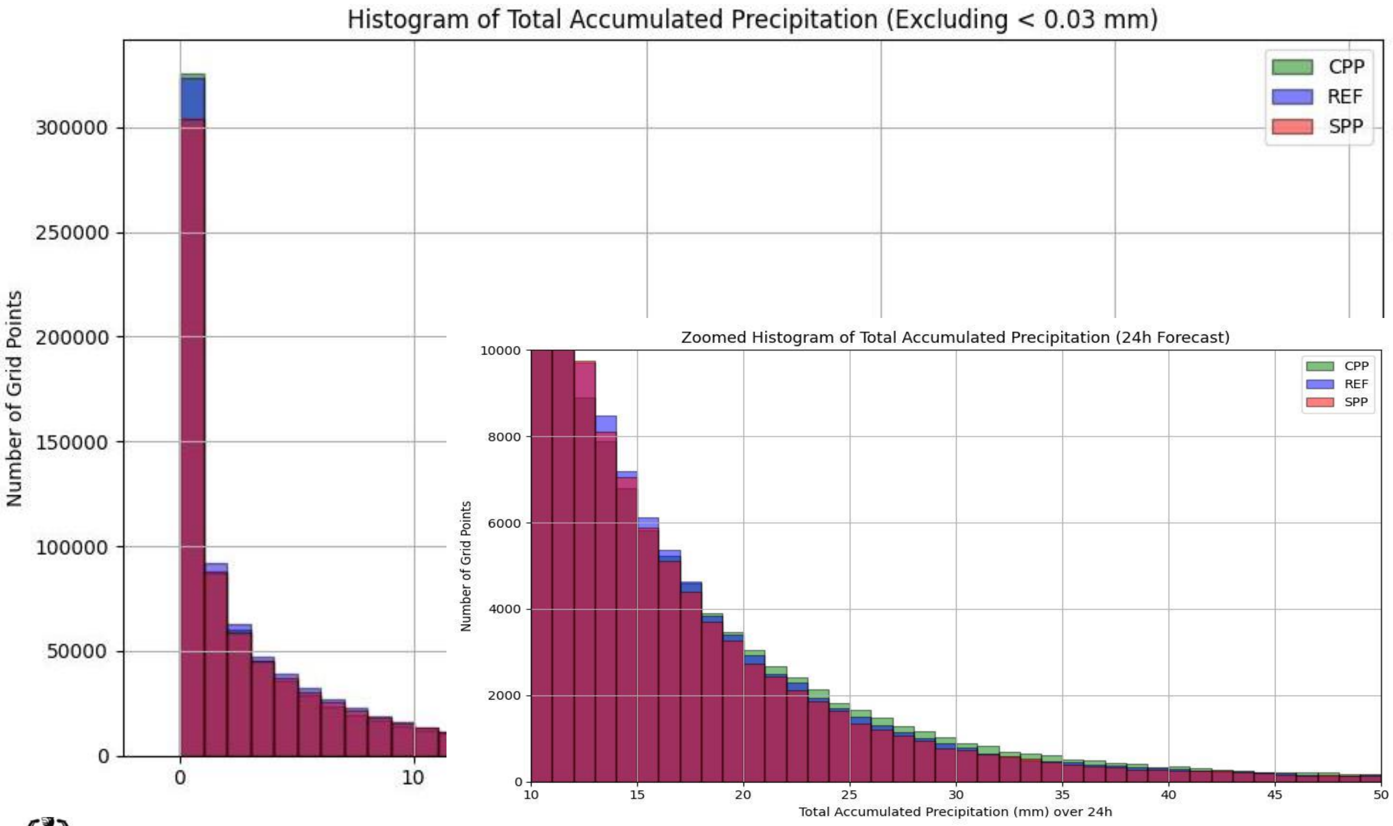

Histogram plot:

- For the smallest and largest rain bins, the CPP experiment shows higher precipitation, suggesting that more perturbations generate more rain in these extremes
- The differences among the experiments are not statistically significant

Maps of accumulated 24h rain | member 01

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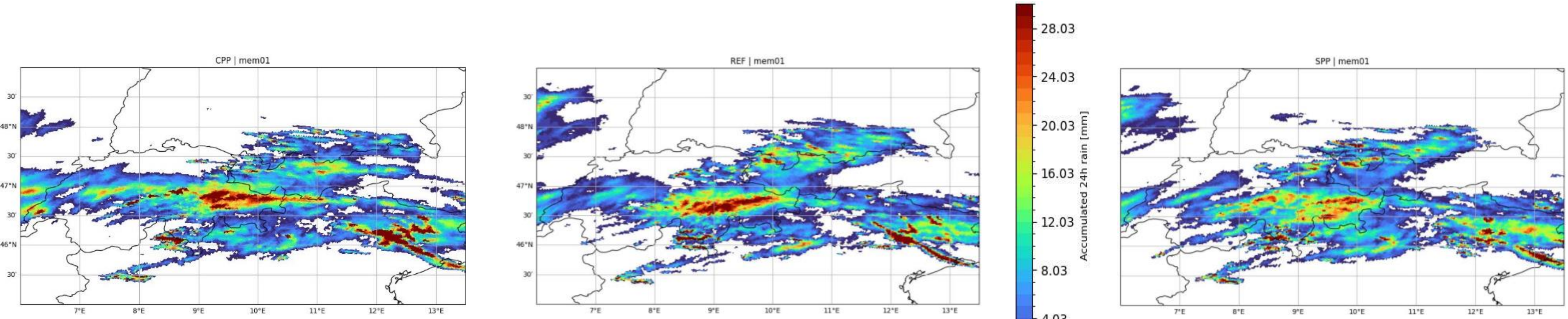

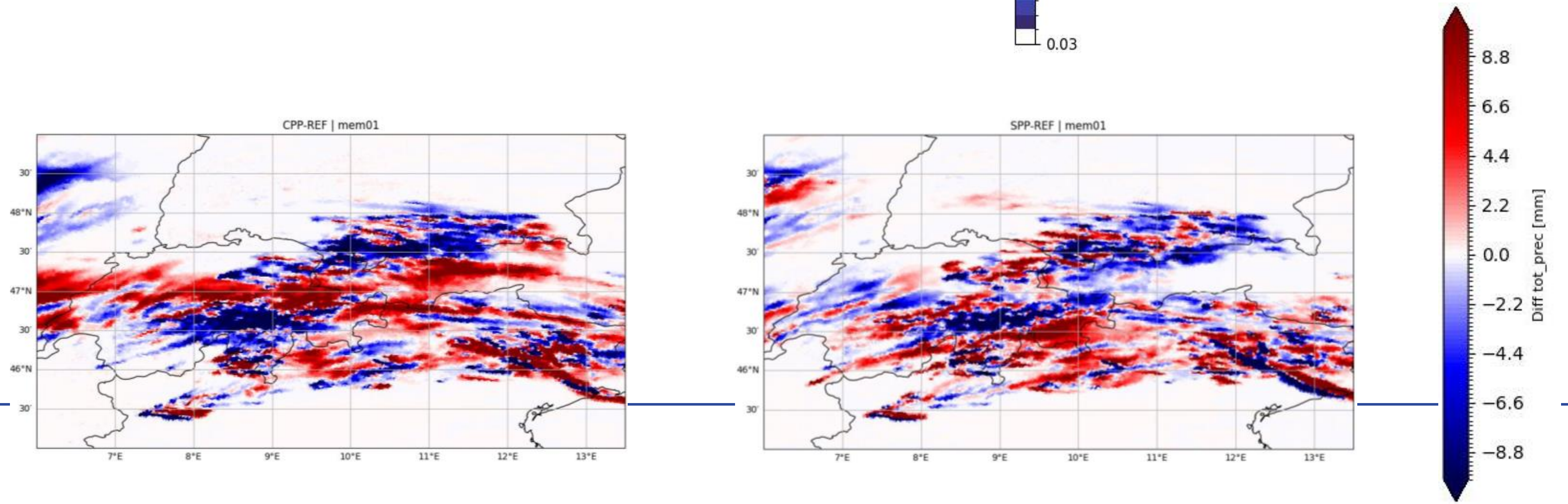

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$\boldsymbol{X_j = \exp(\Psi_j)\hat{X}_j}$
perturbed

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

Next Parameter

rdepths
(Maximum allowed shallow convection depth**)**
in convection parameterization

Outlook

- The impact of SPP on the sedimentation velocity of graupel shows reasonable behavior in this first case → No systematic differences observed in precipitation.
- A longer statistical study period is needed to confirm results
- Local analyses based on observation

Next Steps:

➔ **Implementation of SPP in ICON:**

   ➔ Couple SPP with **physics schemes** for selected parameters

   ➔ **Nest:** First test uncoupled at **500 m resolution**, then fully coupled with SPP

➔ Benchmarking

   ➔ **Tuning SPP in ICON-LAM-D2:** Optimize values for SPP parameters

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

Thank you for your attention

with a picture of my GLORIous colleagues 😉

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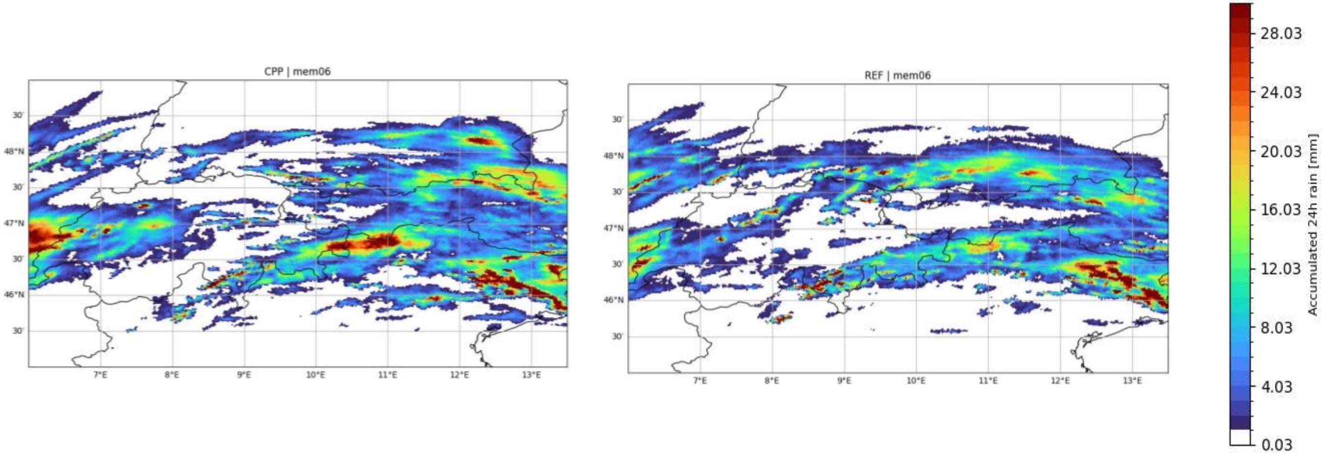
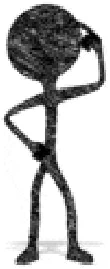
Maps of accumulated 24h rain | member 06



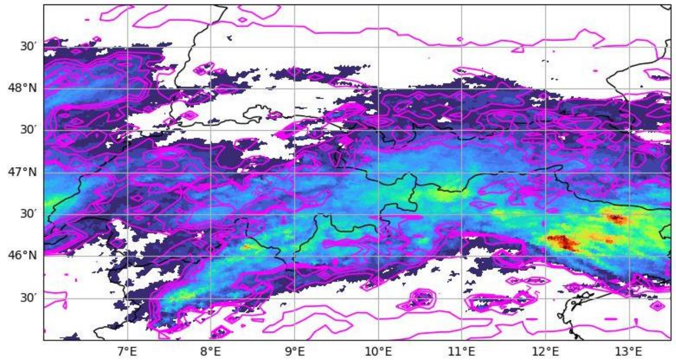
SPP | mem06

?

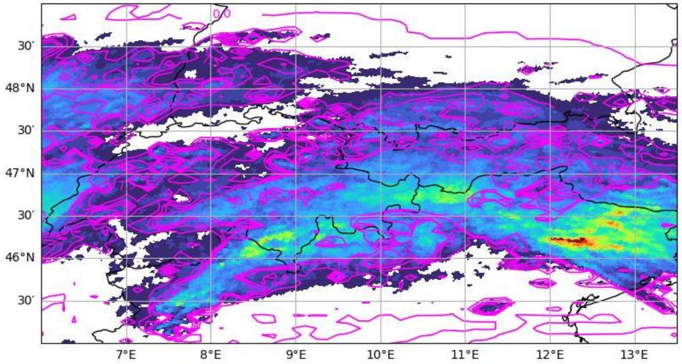


Model crashed after 7h forecast
→Numerical instability
(Divided by zero)

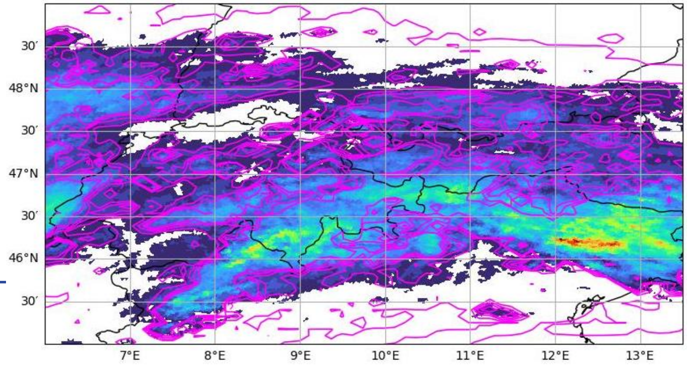
CPP Tot. Prec. | 2022-06-21 | after 24fc | Ensemble Mean and Spread Contours



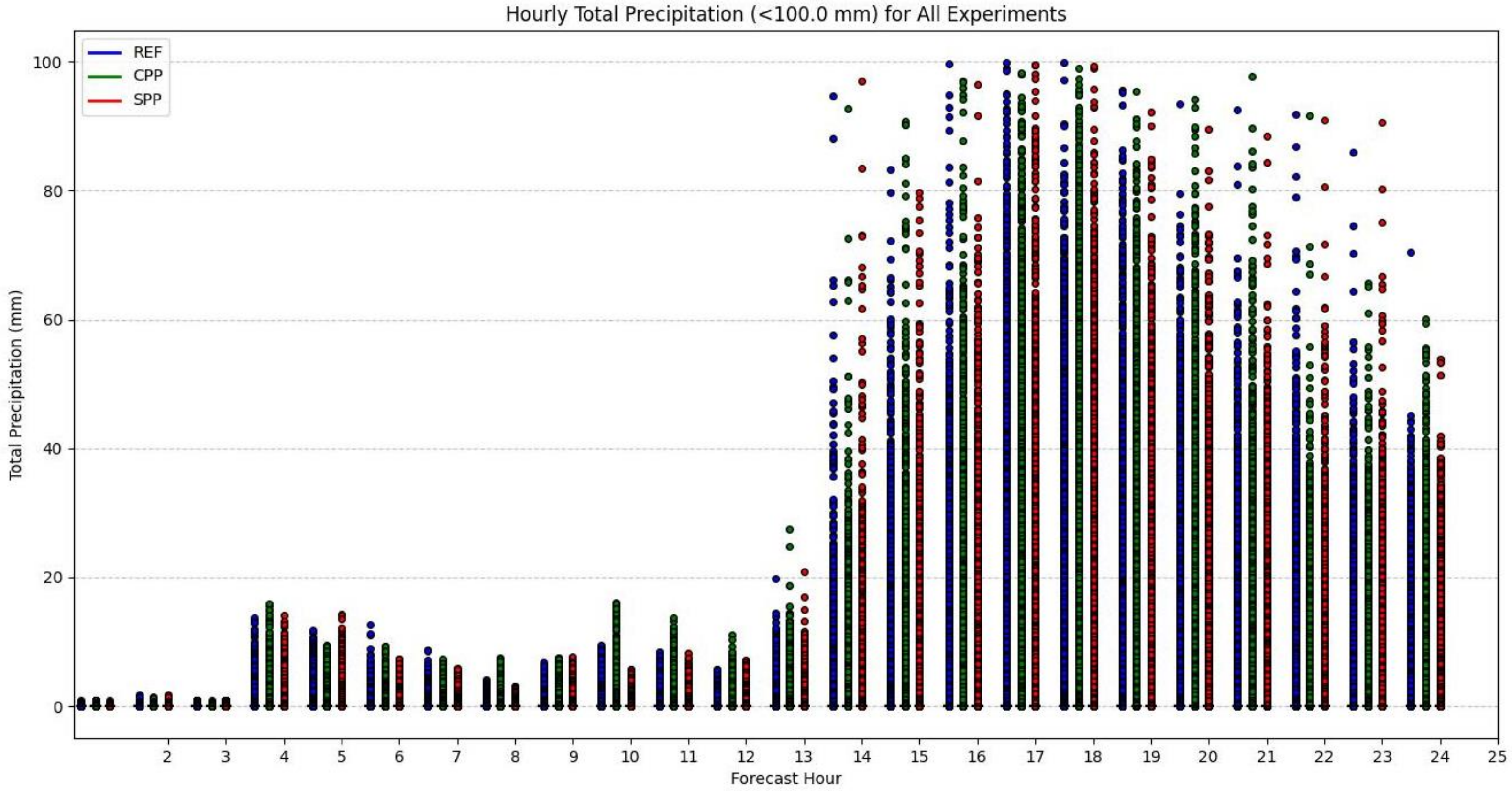
REF Tot. Prec. | 2022-06-21 | after 24fc | Ensemble Mean and Spread Contours

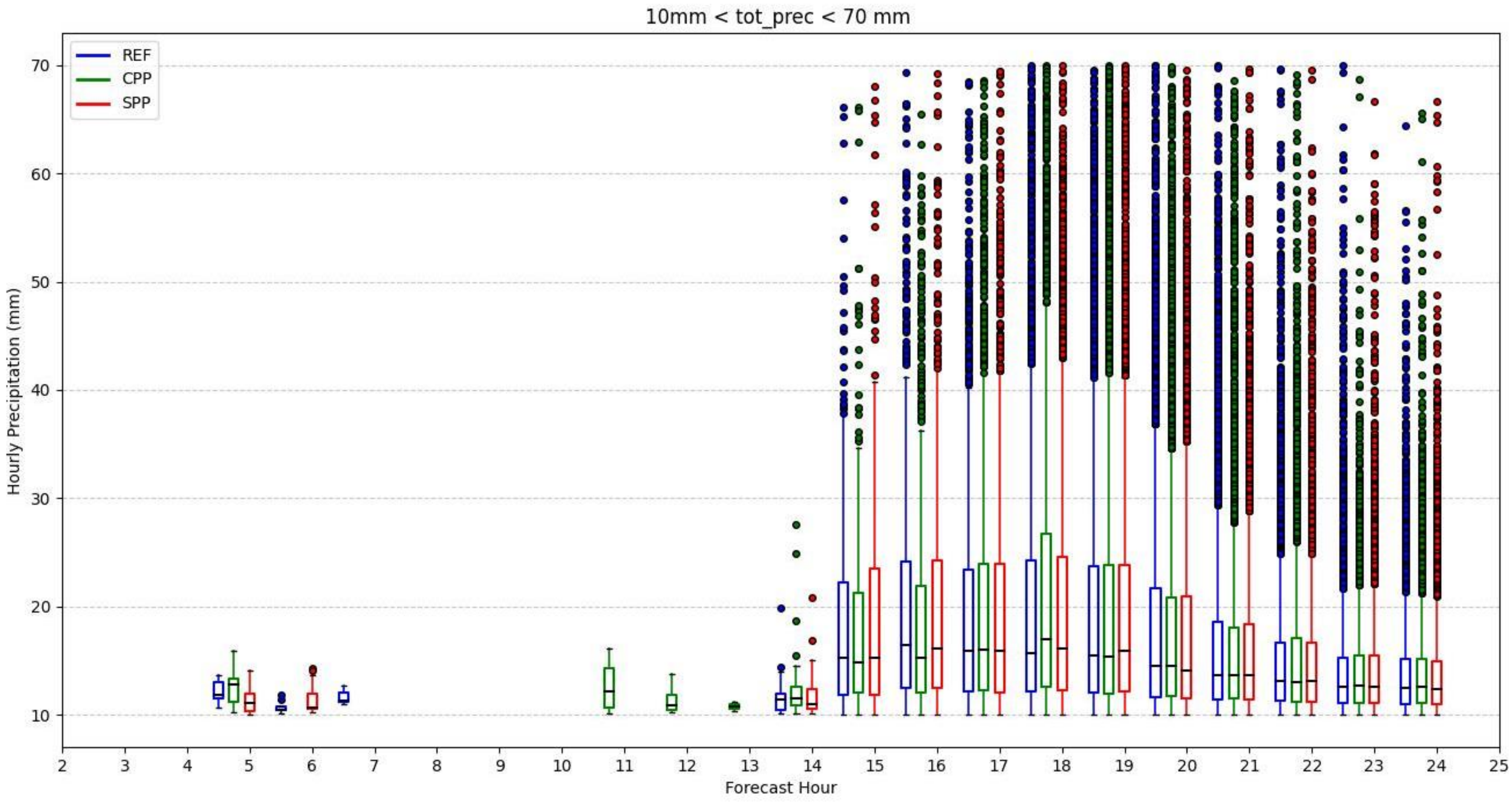


SPP Tot. Prec. | 2022-06-21 | after 24fc | Ensemble Mean and Spread Contours



Contour levels: 0.03 , 7.5, 15, 22.6 , 30.1
0.03 < ensemble mean < 30 mm


Hourly Total Precipitation (<100.0 mm) for All Experiments
REF
CPP
SPP
Total Precipitation (mm)
0
20
40
60
80
100
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
Forecast Hour


10mm < tot_prec < 70 mm
REF
CPP
SPP
Hourly Precipitation (mm)
10
20
30
40
50
60
70
Forecast Hour
2
3
4
5
6
7
8
9
10
11
12
13
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