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GLObal to Regional | ICON Digital Twin

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

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

EWGLAM | Prague | 3 October 2024

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

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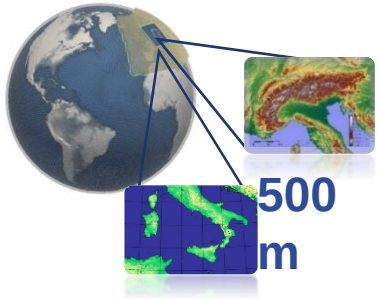
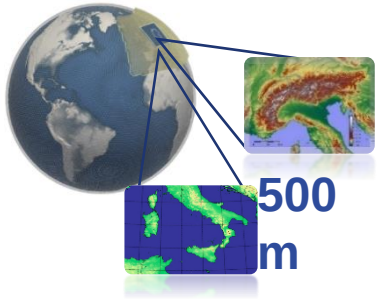
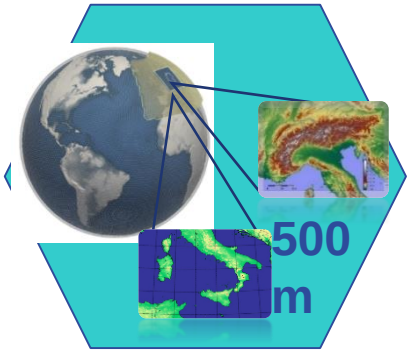


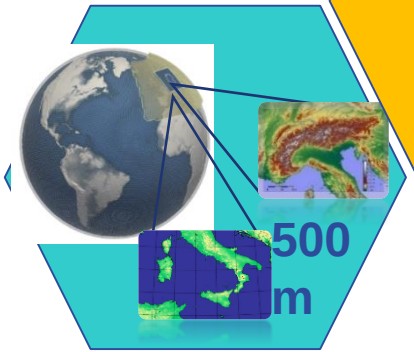
- Global storm-resolving (~3km) regional sub-km scale (500 m)
- Uncertainty estimation with ensembles
- Configurable and on-demand


500
m



Project leader:
Chiara Marsigli

system implementation and data assimilation
(Xu Xu)



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GPU capability
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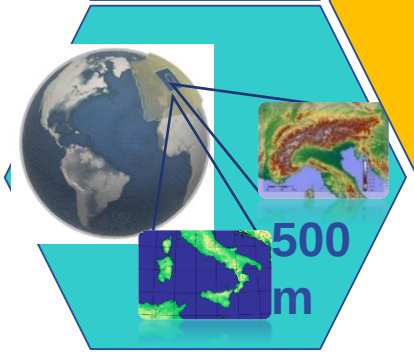

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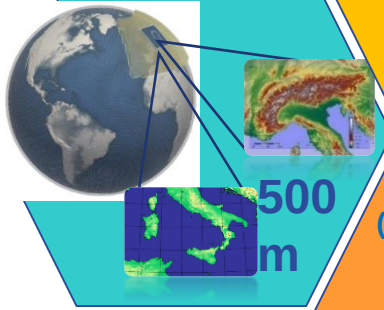
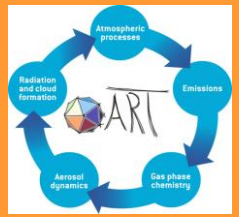
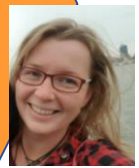


aerosol
(Katerina Kusakova)





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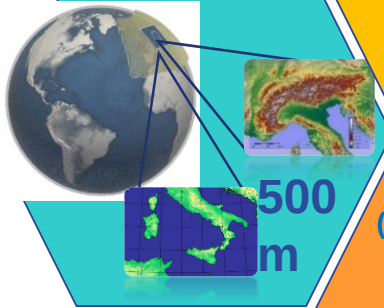

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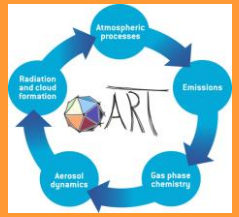

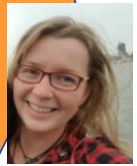

floods

Co-Design Project

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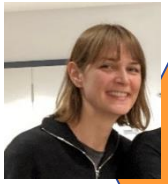

model physics for high-resolution
(Daniela Littmann)

Session “Upper-Air Physics”
Tuesday 11:00-11:20
The study of High-Resolution modelling over the complex Alpine Terrain

system implementation and data assimilation
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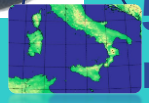

500 m

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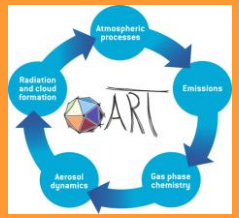

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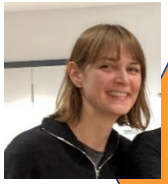

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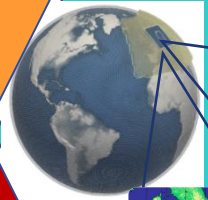

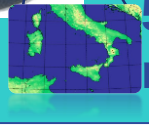

500 m

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ensembles for high-resolution

aerosol
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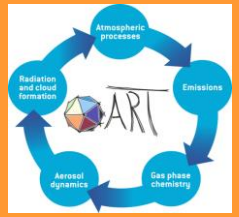

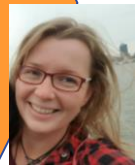

floods

Co-Design Project

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Test and development of the model perturbation

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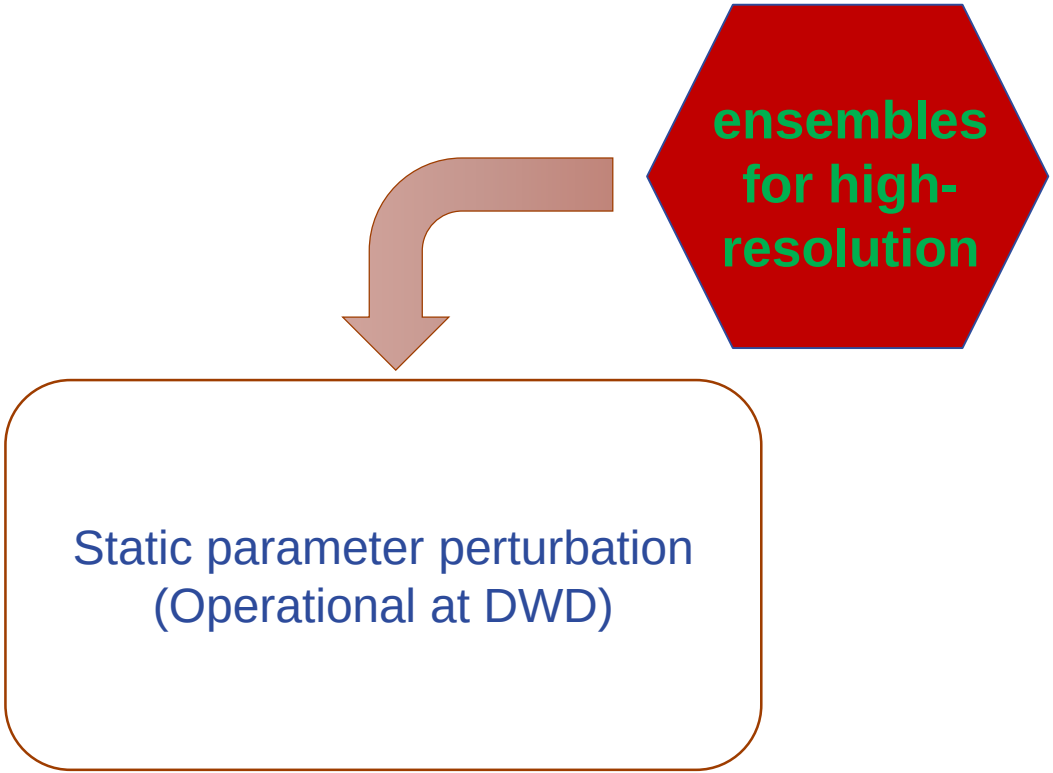

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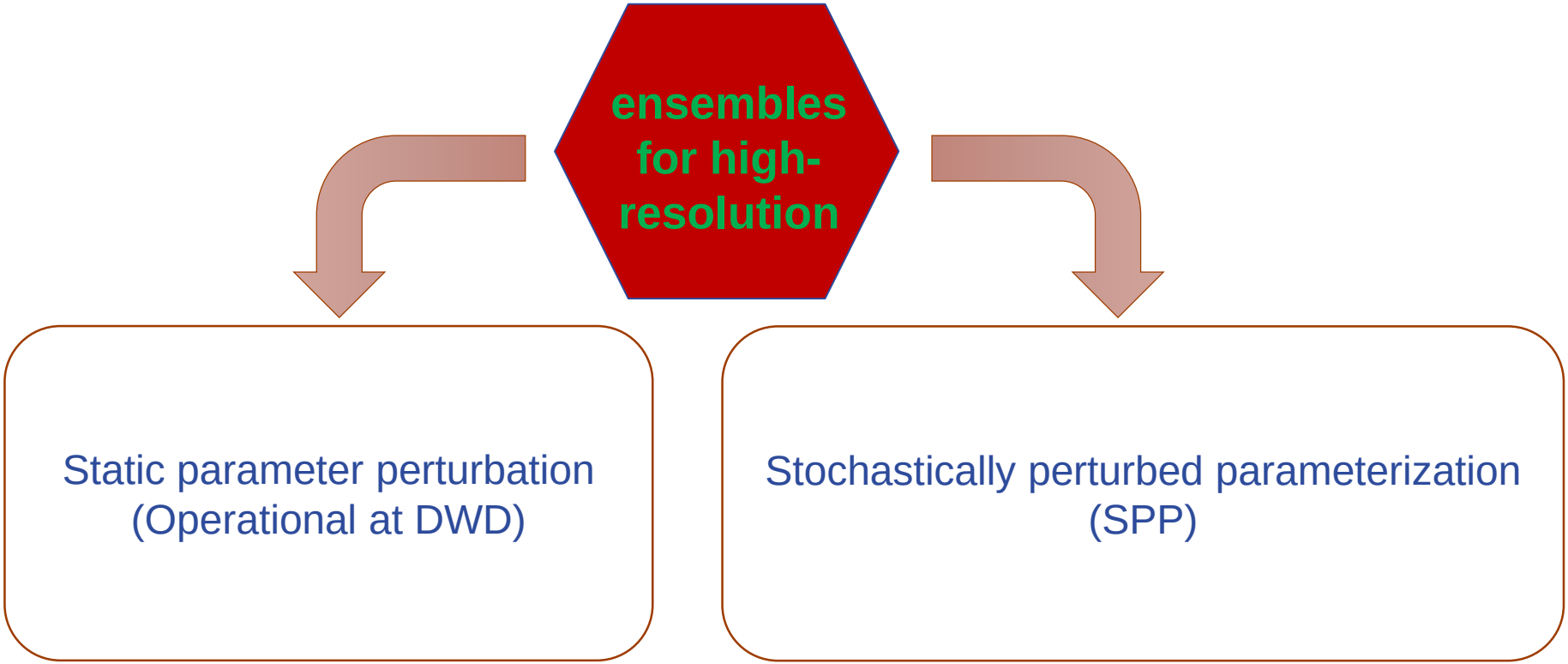
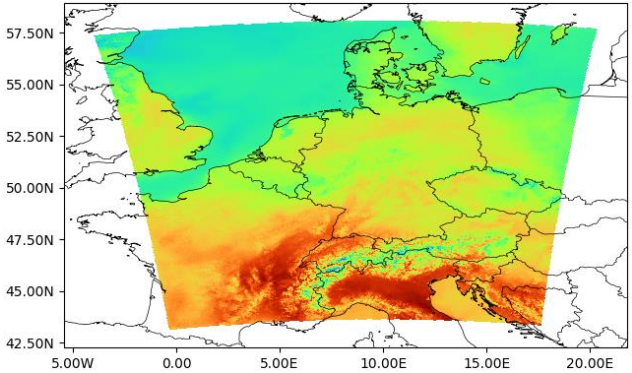


EXPERIMENTs SETUP	
Two-way nesting	
Horizontal grid resolution	2km (ICON-D2), **1km** (TeamX)
Upper boundary	22km
Vertical levels	65
LAT-BC	Forecasts (ICON-EU)
Perturbed initial conditions	KENDA (ICON-D2-EPS)
Forecast duration	24h starting on 2022062100
Forecast restart	6h
Ensemble members	20
Microphysics	1mom or 2mom
Turbulence	TURBDIFF
Land	TERRA
Standard operational model perturbations	

Parent domain: ICON-D2



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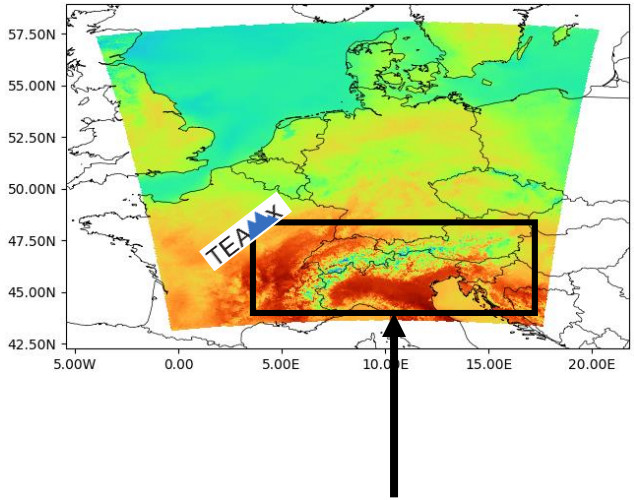


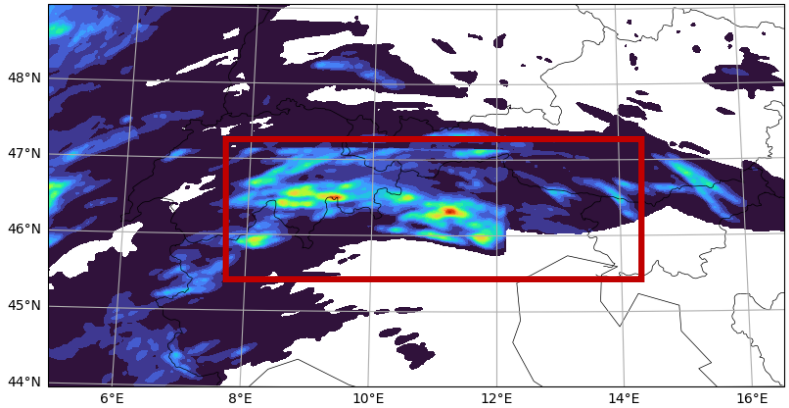
Nest domain
1km horizontal resolution

Testing the impact of convection schemes

- shallow convection only
- deep convection parameterization

  (gray-zone-tuning version)

Precipitation estimate from radar



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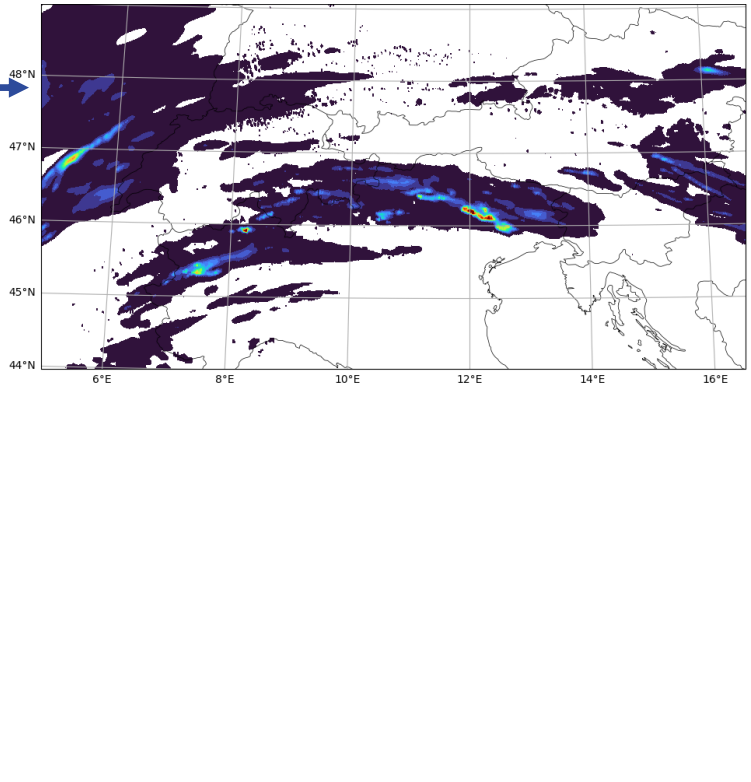

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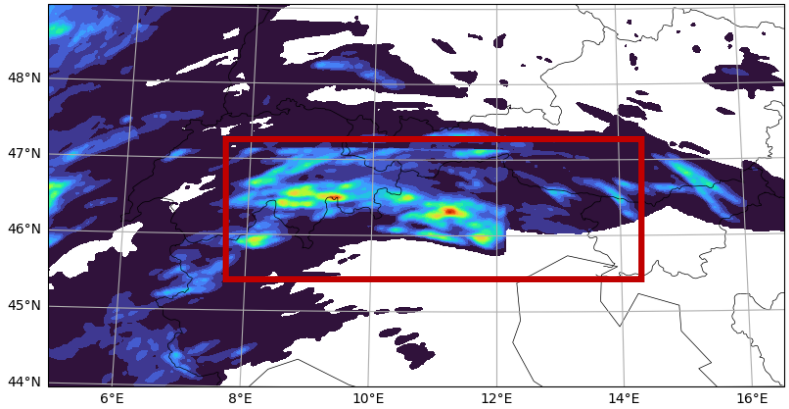

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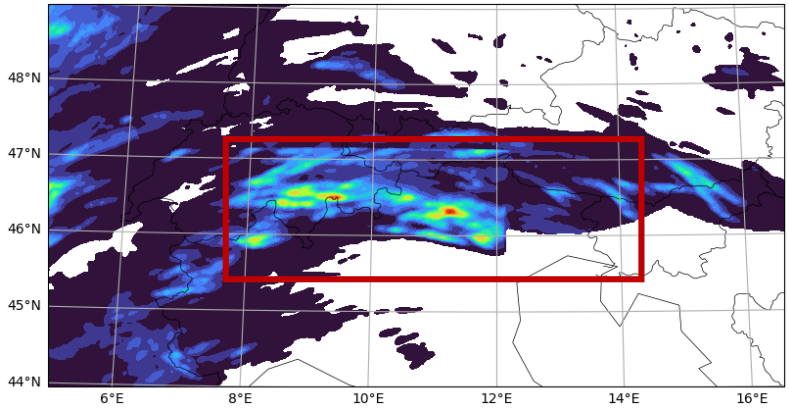

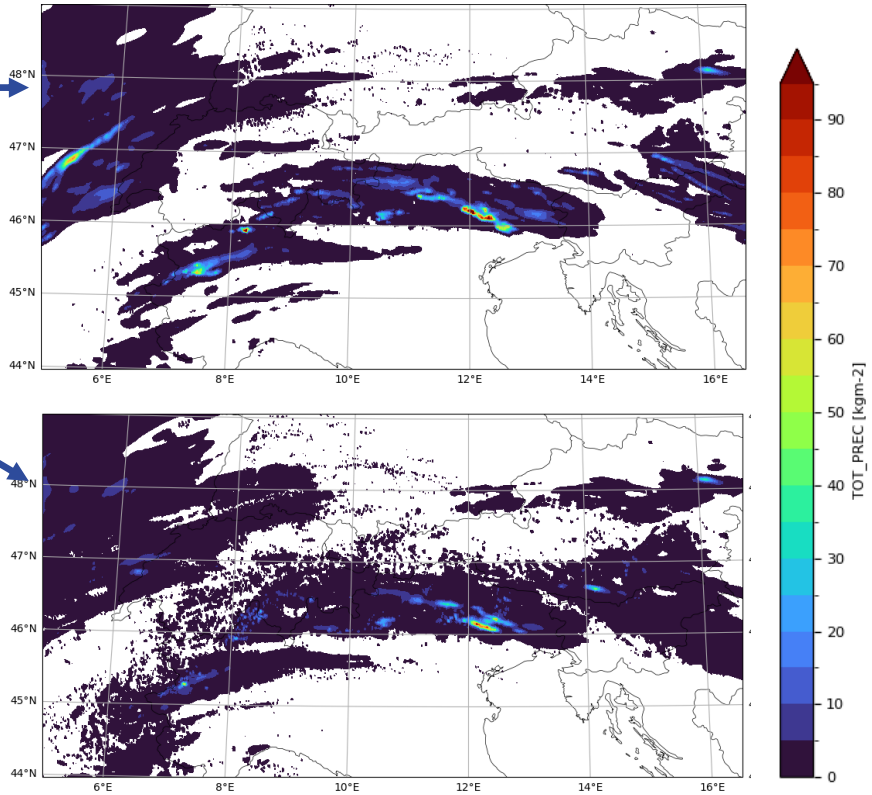

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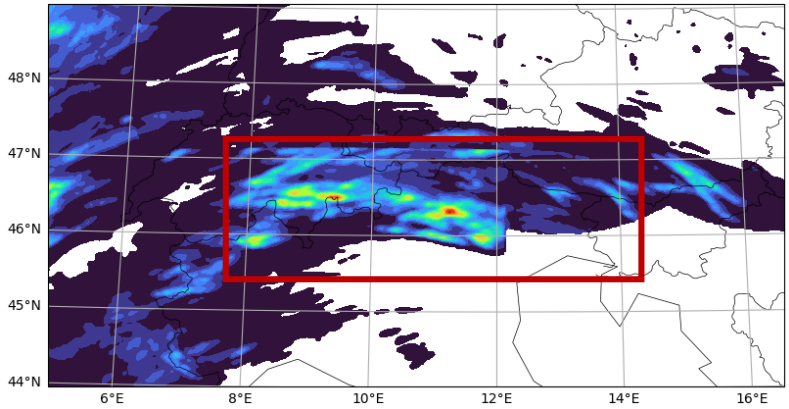

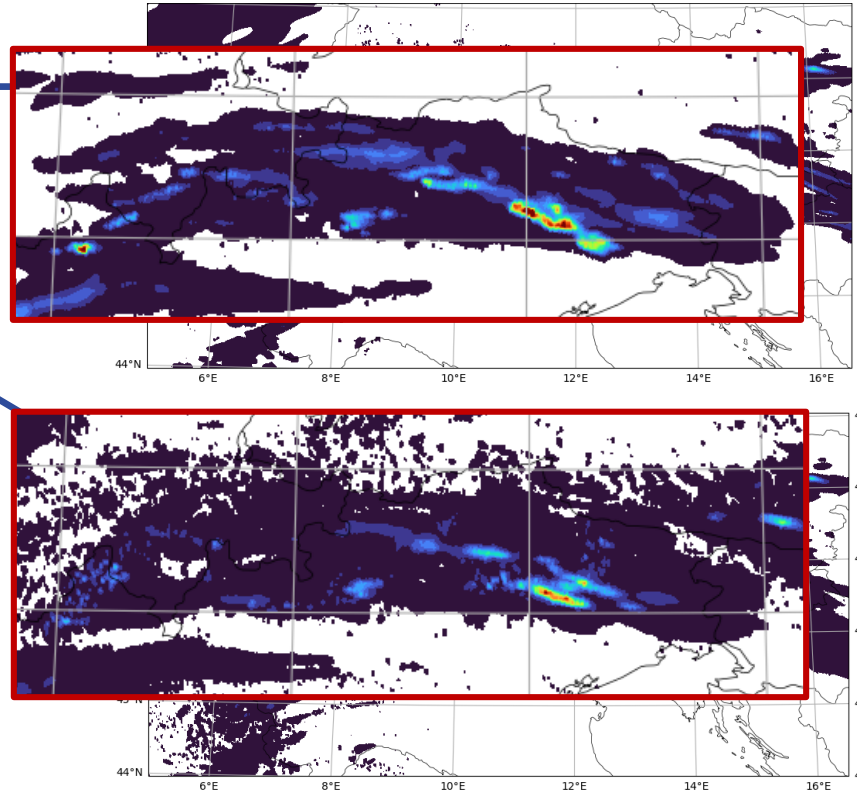

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1km

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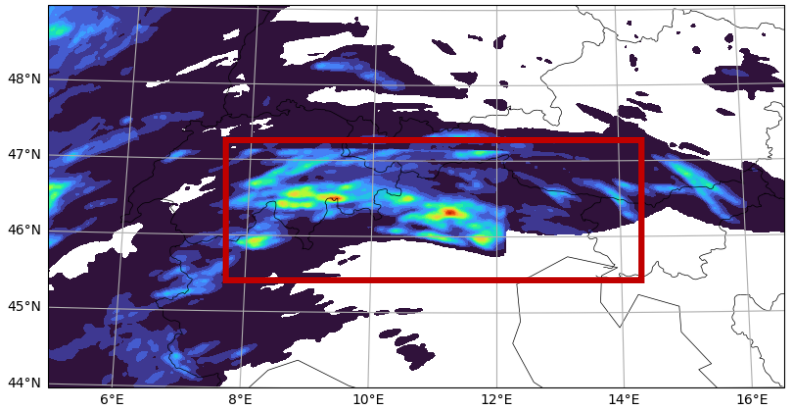
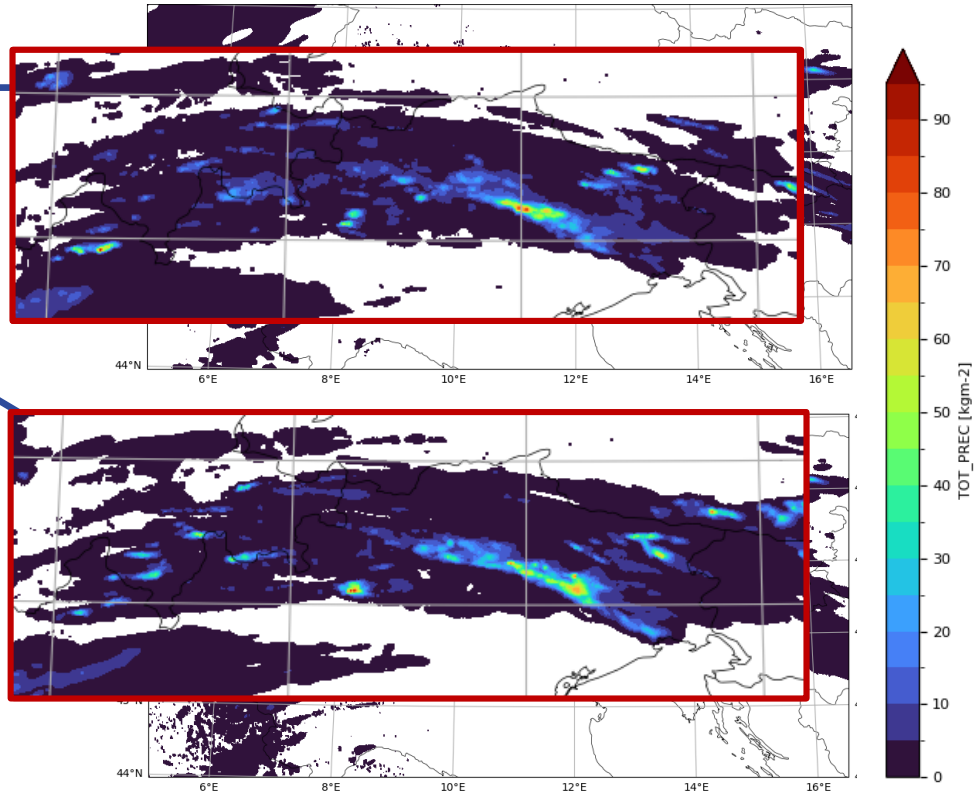
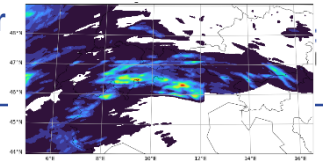
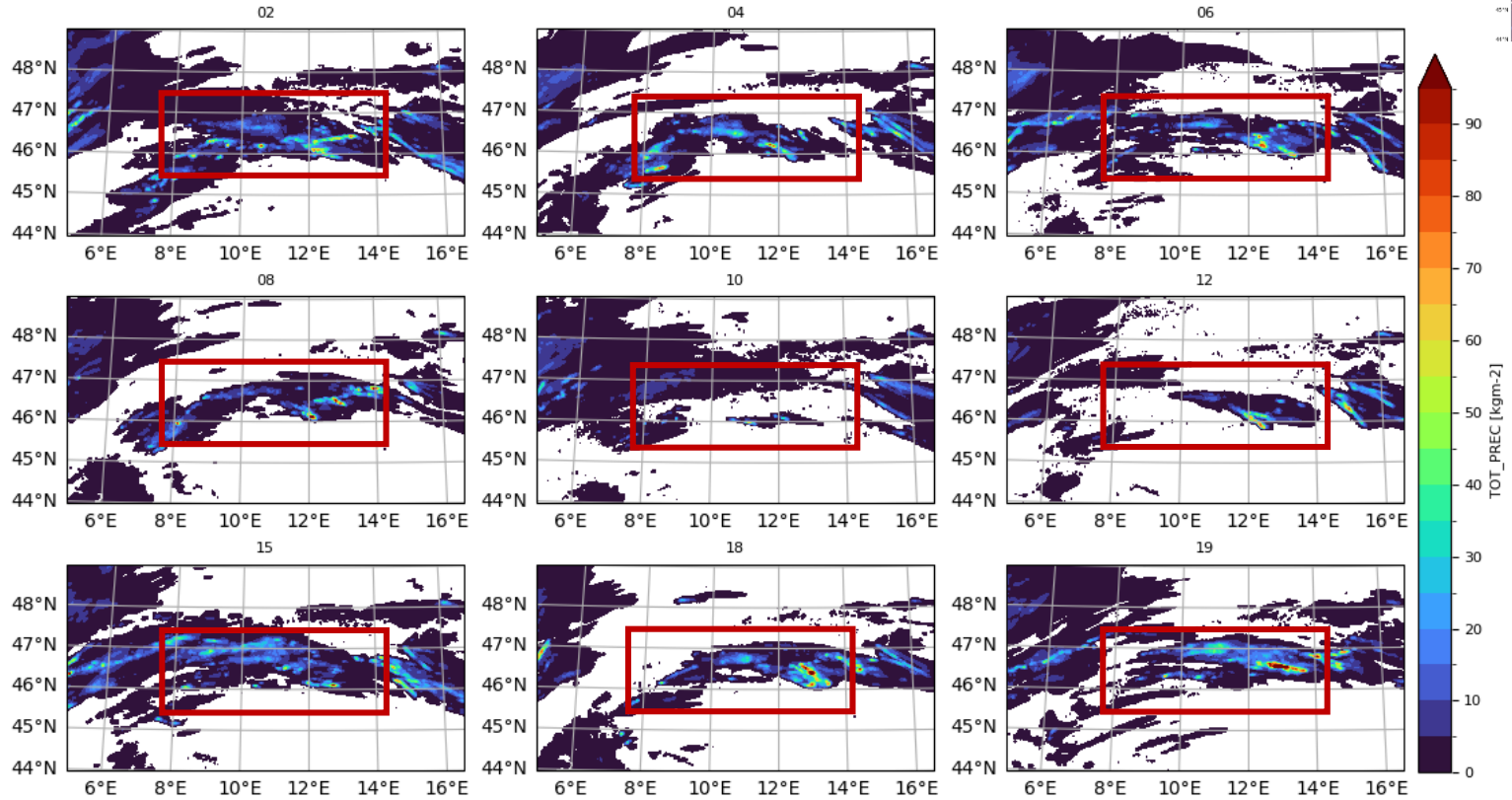




Behaviour of the ensemble members

Radar





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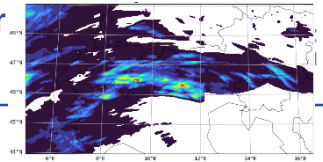

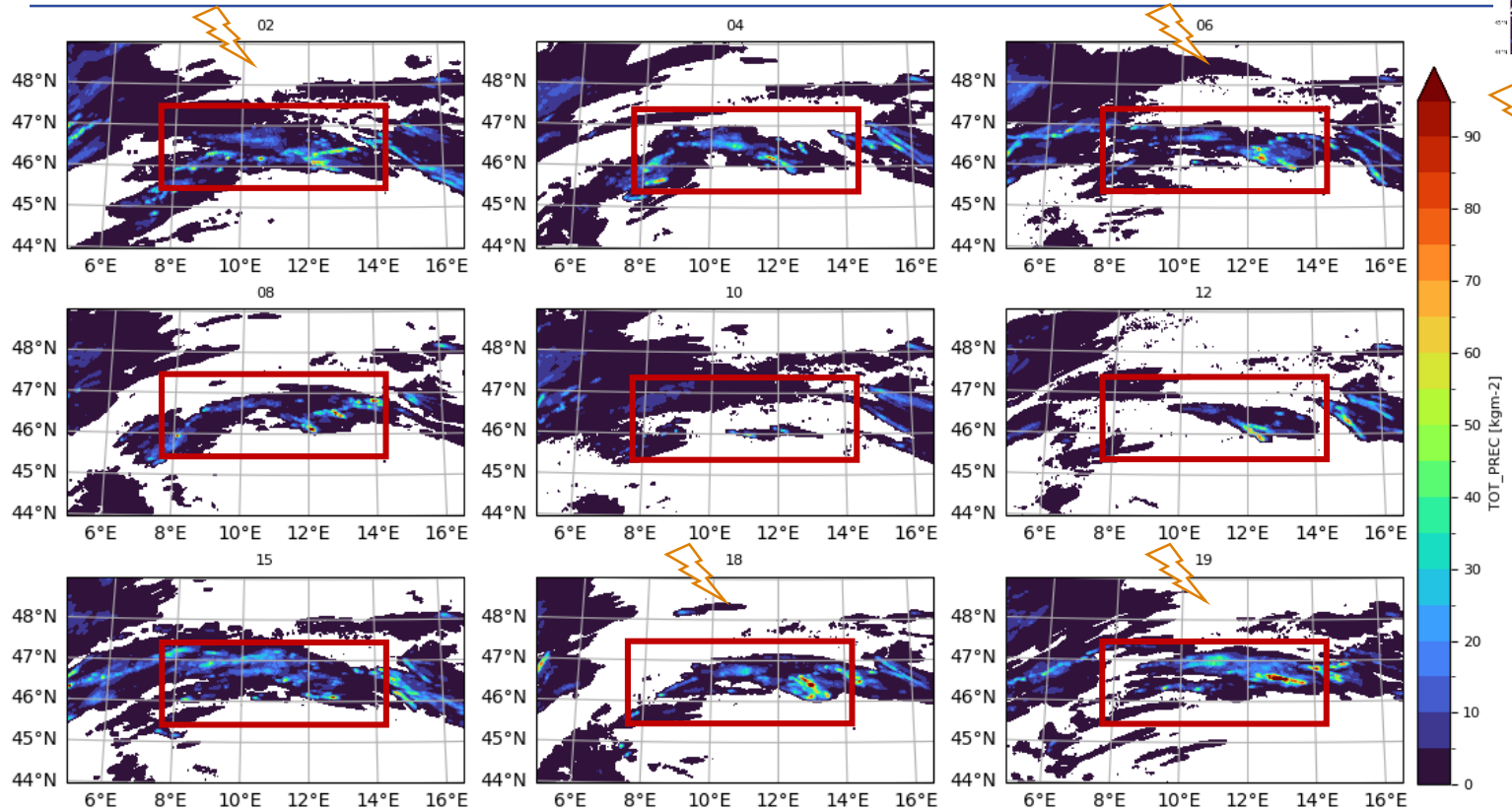

Some members with misplaced rain

Shallow convection only

Behaviour of the ensemble members

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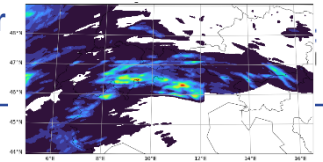

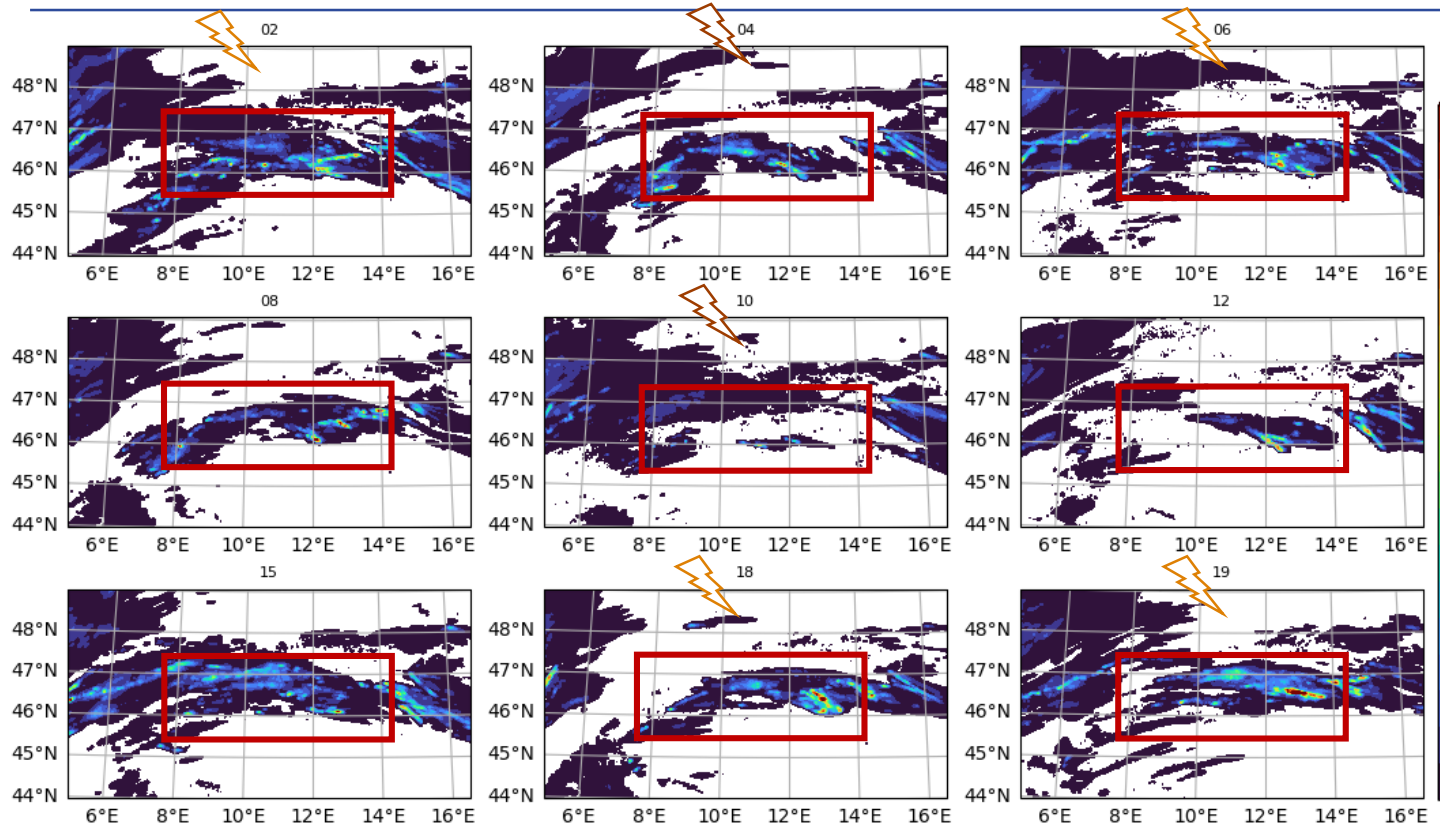

Some members with misplaced rain

Some members with too little rain

Shallow convection only

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

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**

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

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

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- 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

t:

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

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

t:

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

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

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

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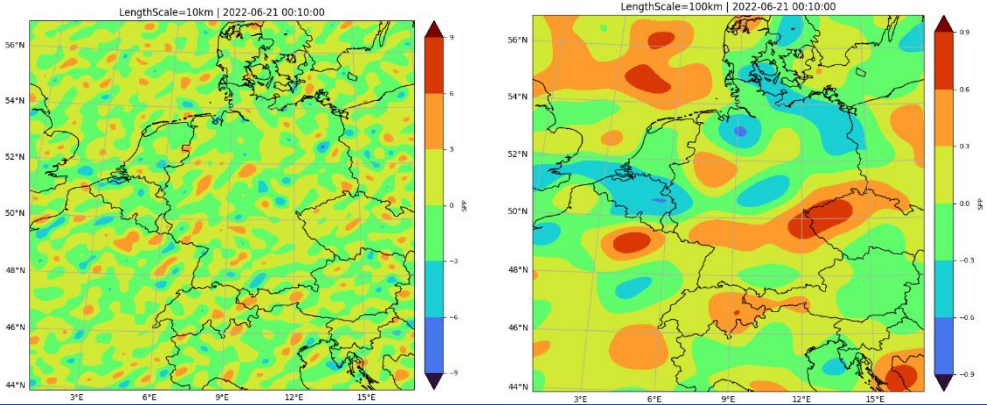

Pattern properties:
- ✓ Length scale
- ✓ Time scale
- ✓ Modes
- ✓ Variance

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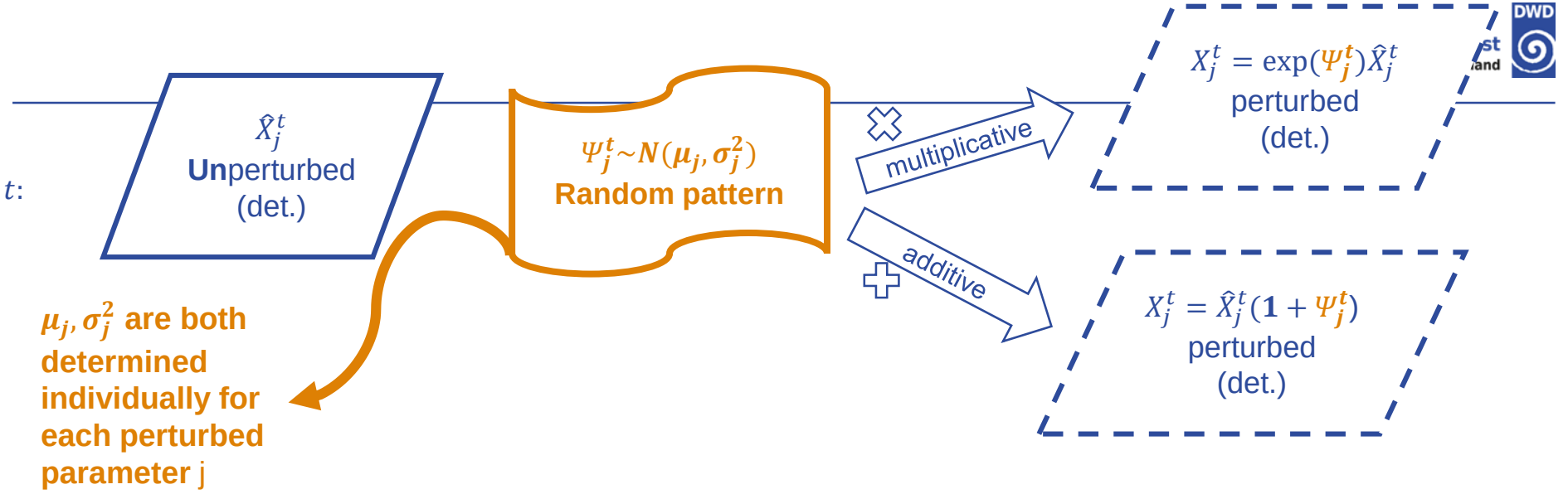

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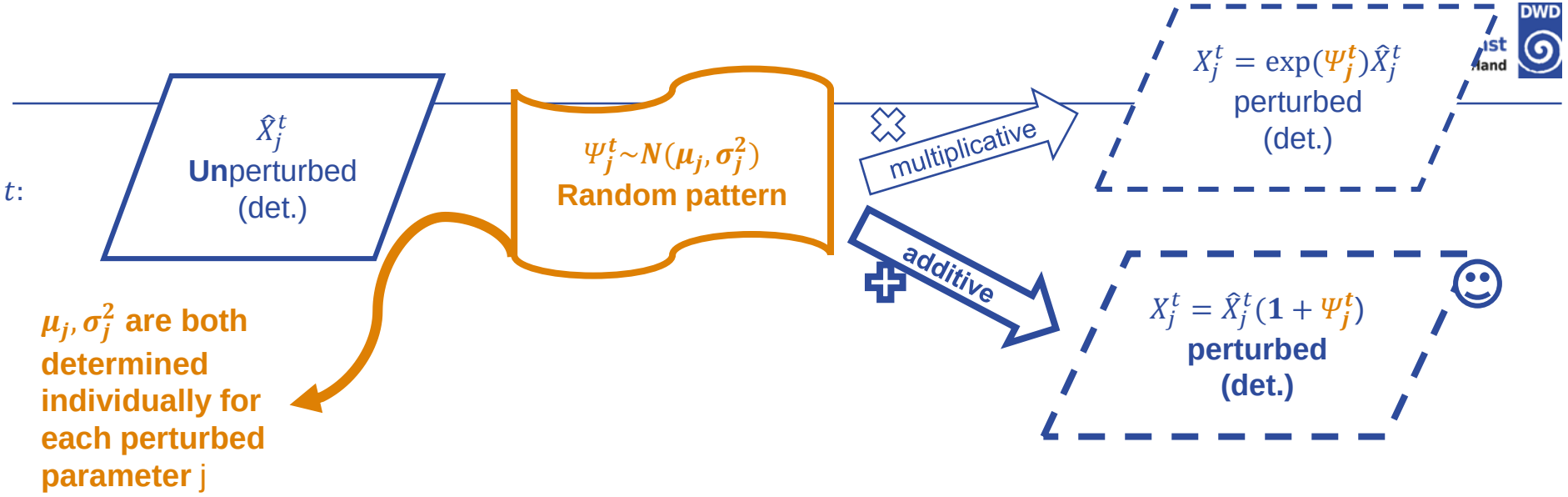

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t:

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

Ψ_j^t
Random pattern

$X_j^t = \hat{X}_j^t(\mathbf{1} + \Psi_j^t)$

X_j^t by Ψ_j^t
perturbed
(det.)

via spectral space

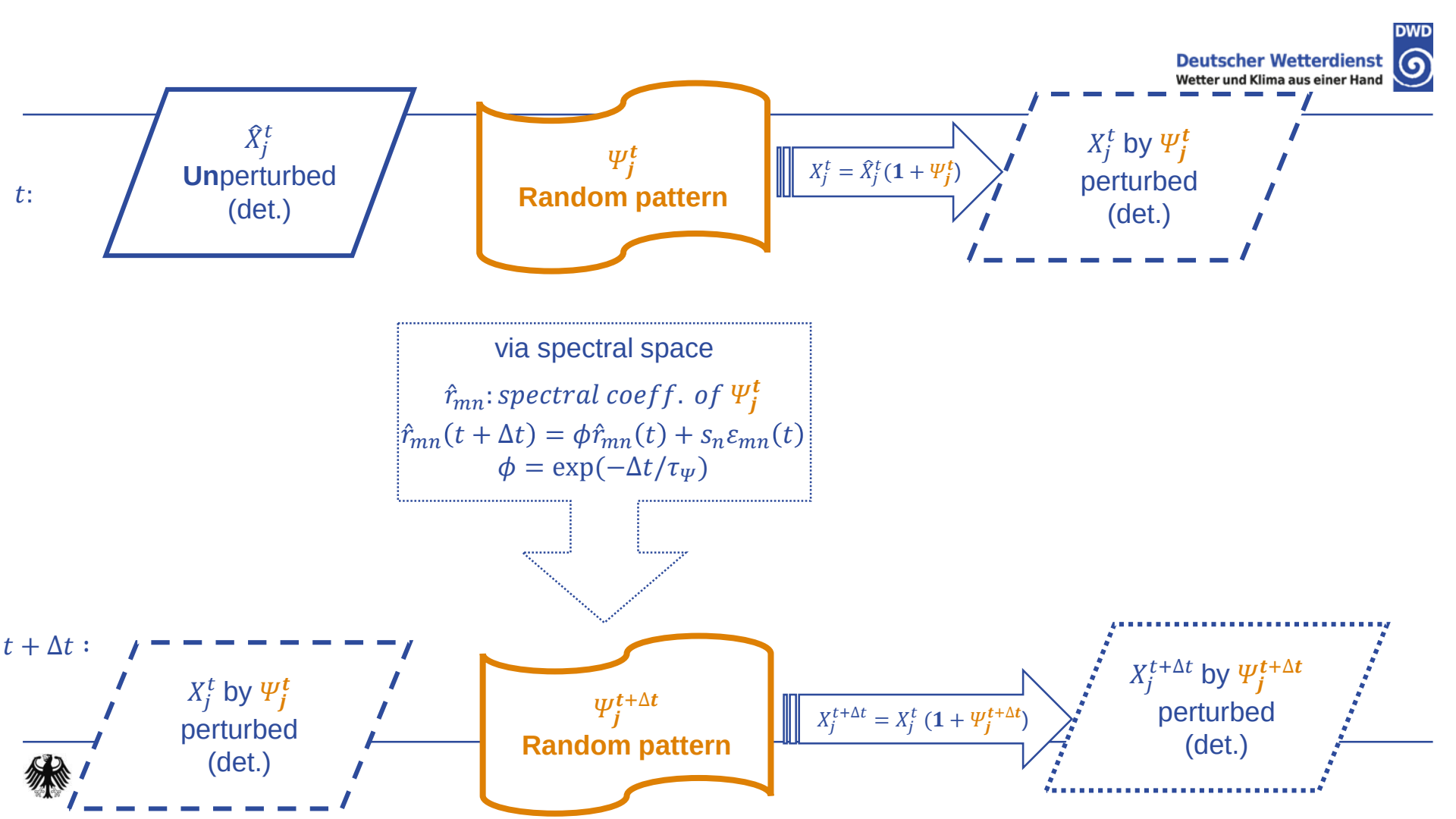
$\hat{r}_{mn}: spectral\ coeff.\ of\ \Psi_j^t$

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

$\phi = \exp(-\Delta t / \tau_\Psi)$

$t + \Delta t$:

$\Psi_j^{t+\Delta t}$
Random pattern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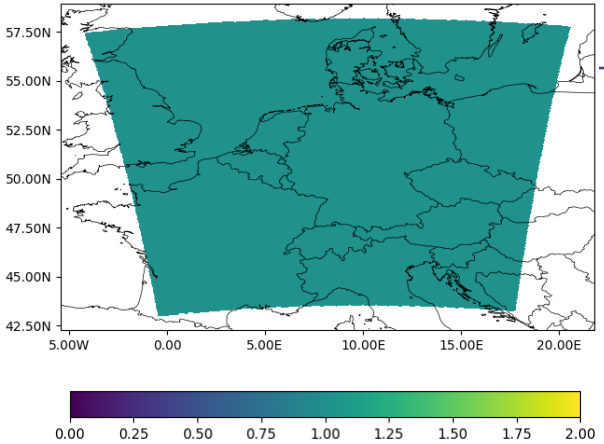
$t + \Delta t$:
X_j^t by Ψ_j^t
perturbed
(det.)
$\Psi_j^{t+\Delta t}$
Random pattern
$X_j^{t+\Delta t} = X_j^t\ (1 + \Psi_j^{t+\Delta t})$
$X_j^{t+\Delta t}$ by $\Psi_j^{t+\Delta t}$
perturbed
(det.)

Unperturbed parameter: $\hat{X}_j^t$



Ψ_j^t
Random pattern

X_j^t by Ψ_j^t
perturbed
(det.)

via spectral space
at $t + \Delta t$

$t + \Delta t$:

X_j^t by Ψ_j^t
perturbed
(det.)

$\Psi_j^{t+\Delta t}$
Random pattern

$X_j^{t+\Delta t}$ by $\Psi_j^{t+\Delta t}$
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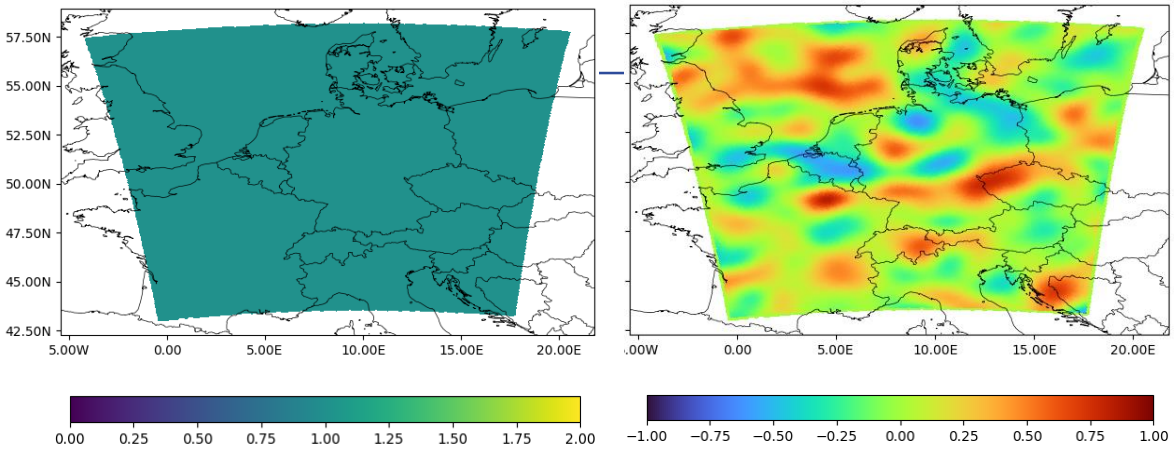
Unperturbed parameter: $\hat{X}_j^t$

Stochastic pattern: Ψ_j^t



X_j^t by Ψ_j^t perturbed (det.)

via spectral space at $t + \Delta t$

$t + \Delta t$:

X_j^t by Ψ_j^t perturbed (det.)

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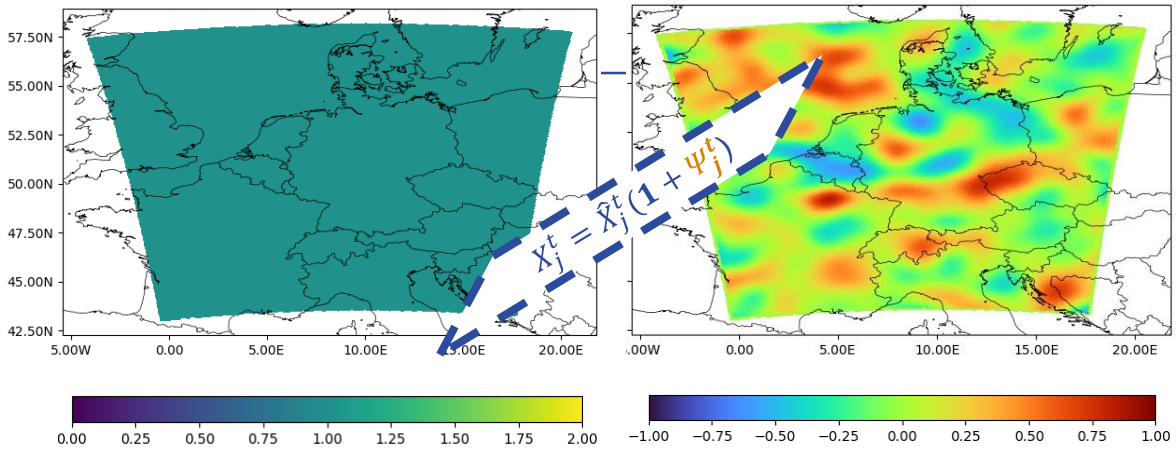

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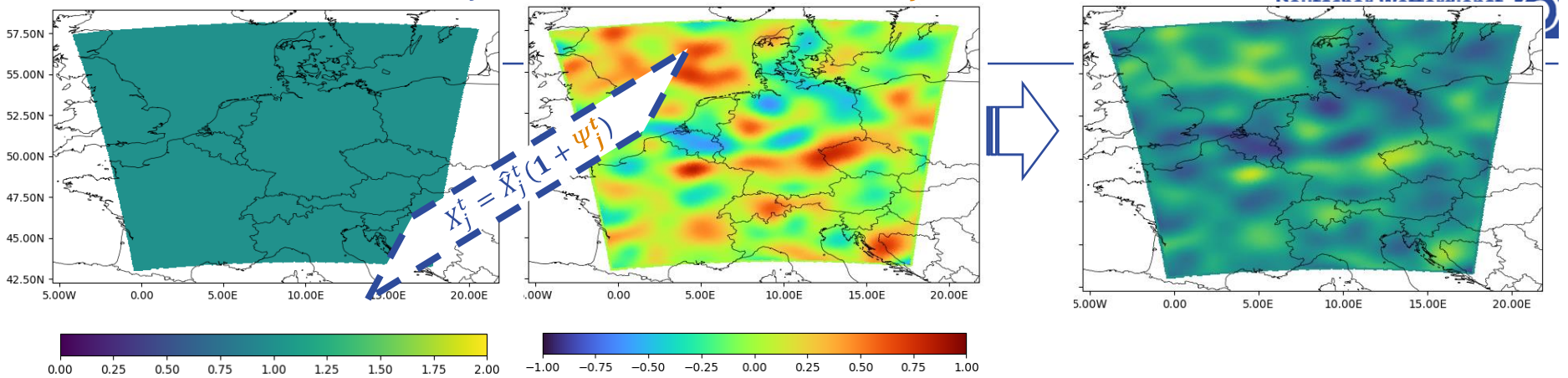

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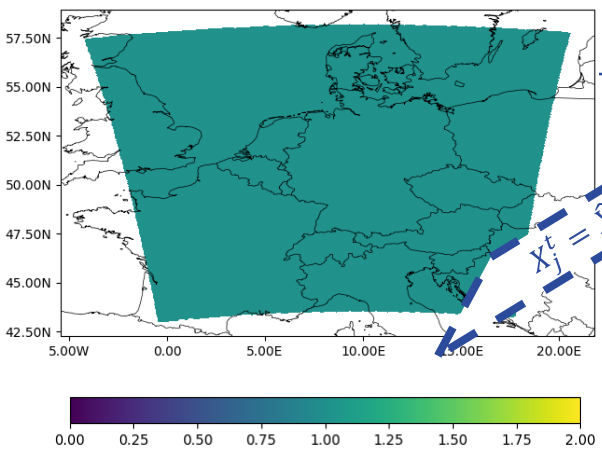
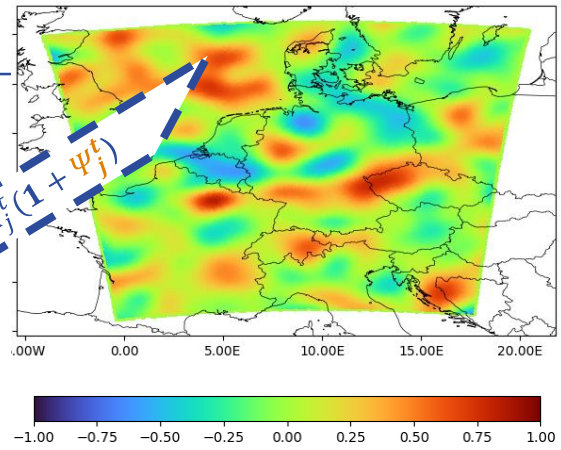
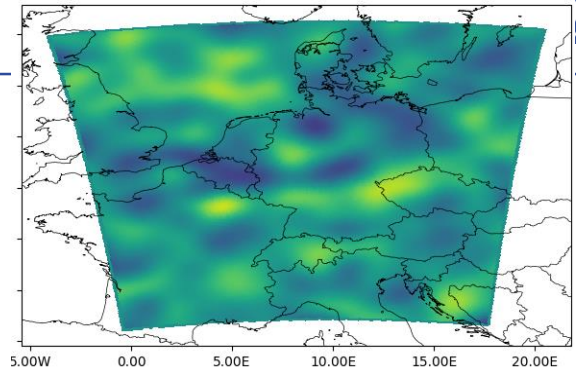


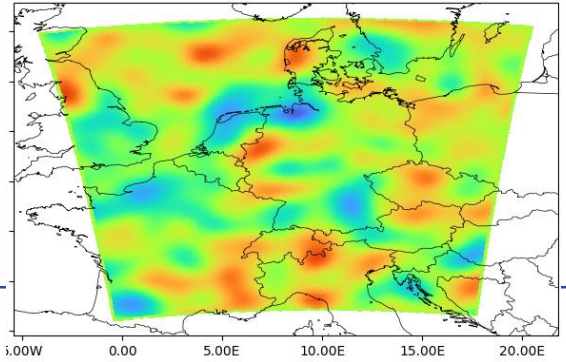
$$X_j^t = \hat{X}_j^t(1 + \Psi_j^t)$$





via spectral space at $t + \Delta t$

$\Psi_j^{t+\Delta t}$



$t + \Delta t$:

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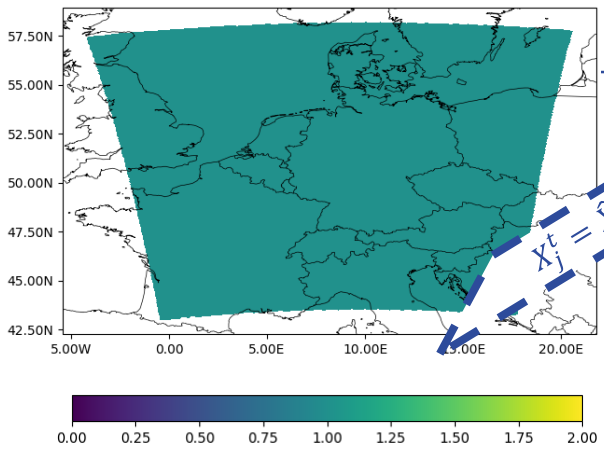
$X_j^{t+\Delta t}$ by $\Psi_j^{t+\Delta t}$ perturbed (det.)

Unperturbed parameter: $\hat{X}_j^t$

Stochastic pattern: Ψ_j^t

Perturbed parameter at t: X_j^t



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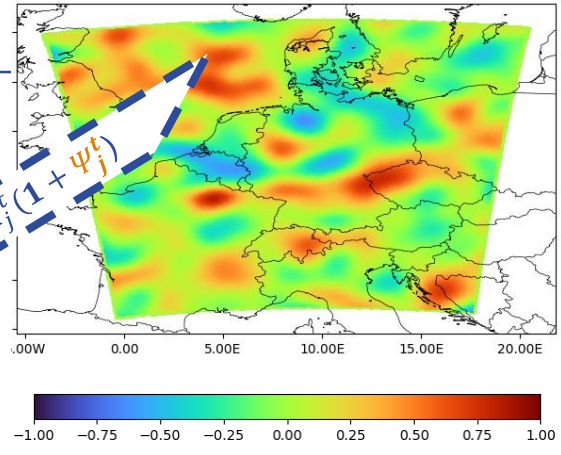
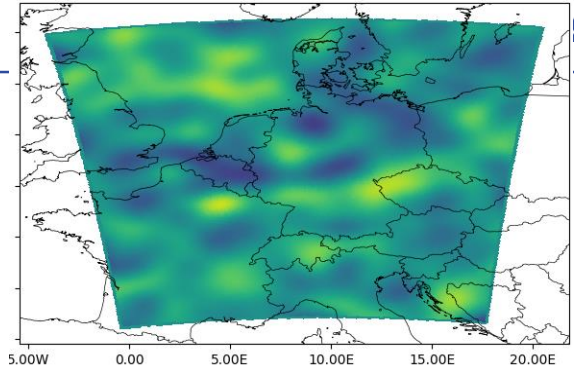
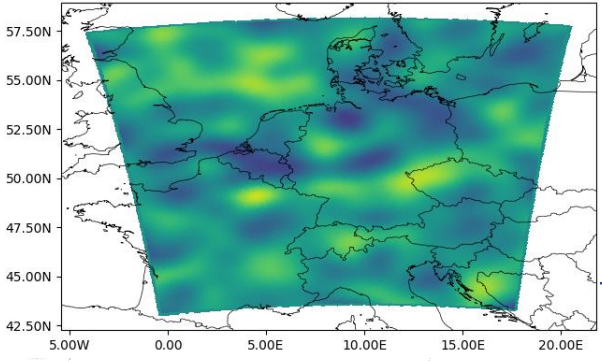


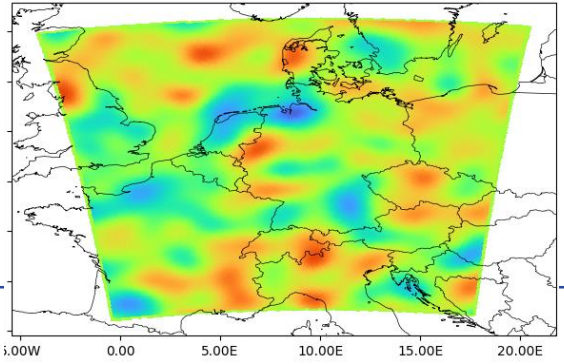


via spectral space at $t + \Delta t$

$\Psi_j^{t+\Delta t}$

Perturbed parameter at t: X_j^t





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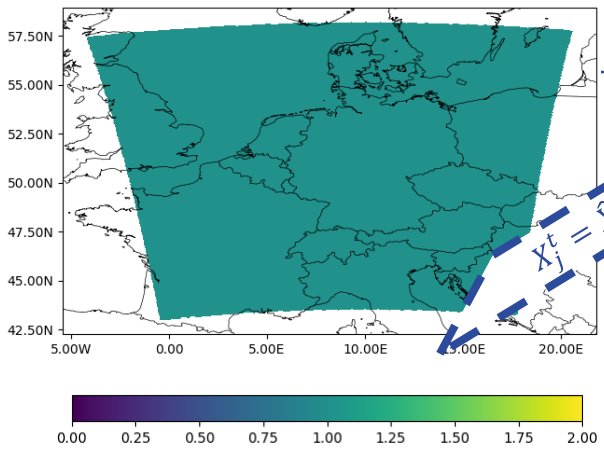

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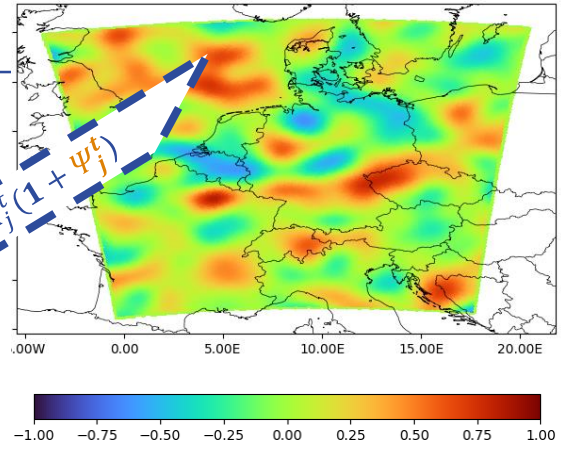
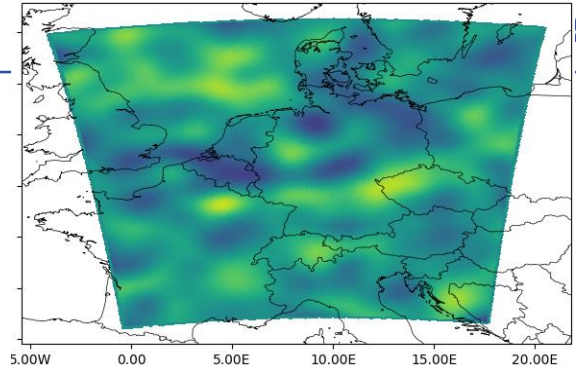
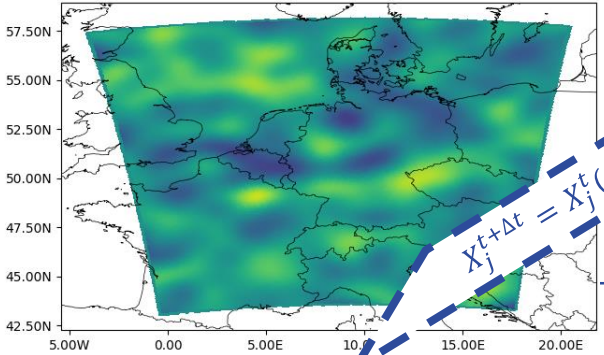




via spectral space
at $t + \Delta t$

$\Psi_j^{t+\Delta t}$

Perturbed parameter at t: X_j^t



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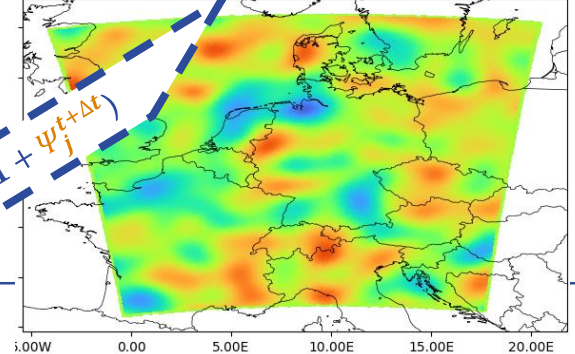

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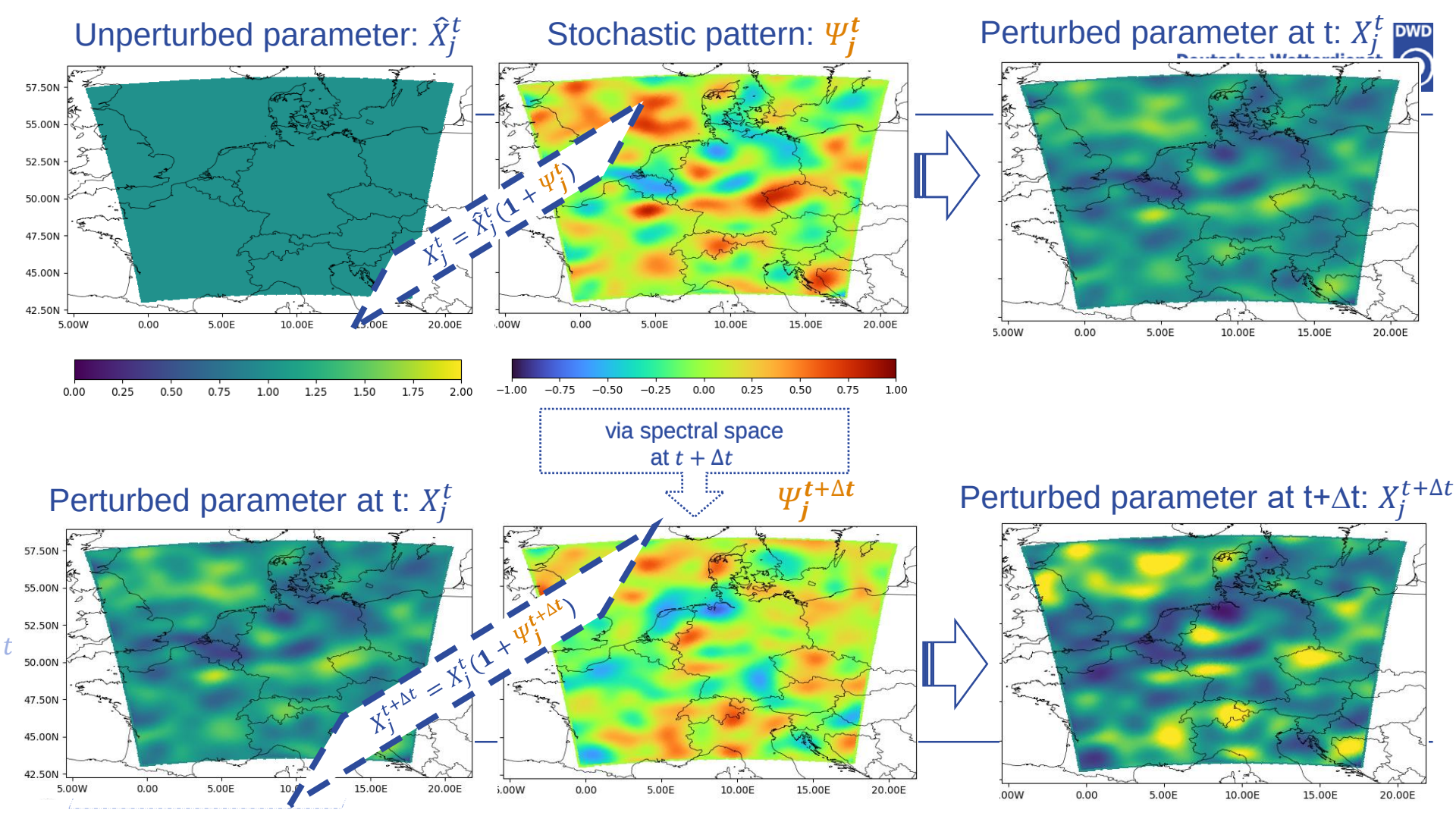
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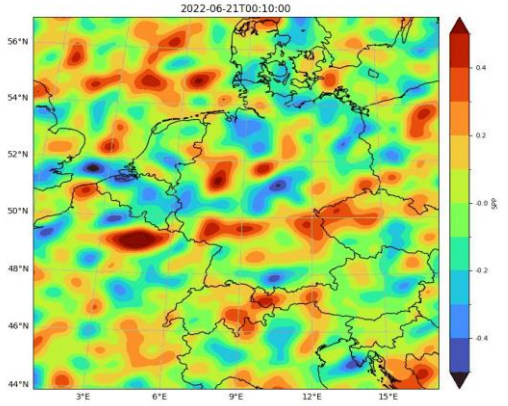
t
57.50N
55.00N
52.50N
50.00N
47.50N
45.00N
42.50N
5.00W
0.00
5.00E
10.00E
15.00E
20.00E
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
−1.00 −0.75 −0.50 −0.25 0.00 0.25 0.50 0.75 1.00
DWD

SPP in ICON implemented by Axel Seifert and Maleen Hanst

SPP properties:

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



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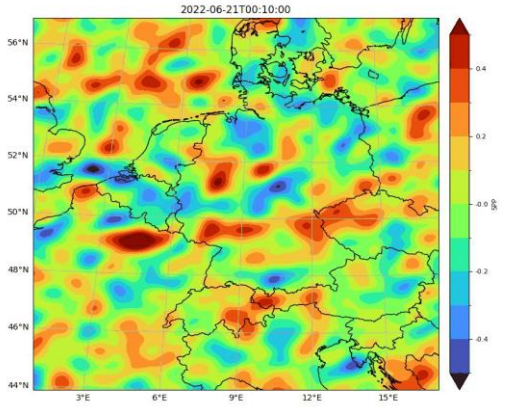

Sensitivity tests for SPP variance

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

Test on a real case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

Test: Coupled SPP with 2mom microphysics scheme

Test on a real case

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For perturbing the sedimentation velocity of graupel

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

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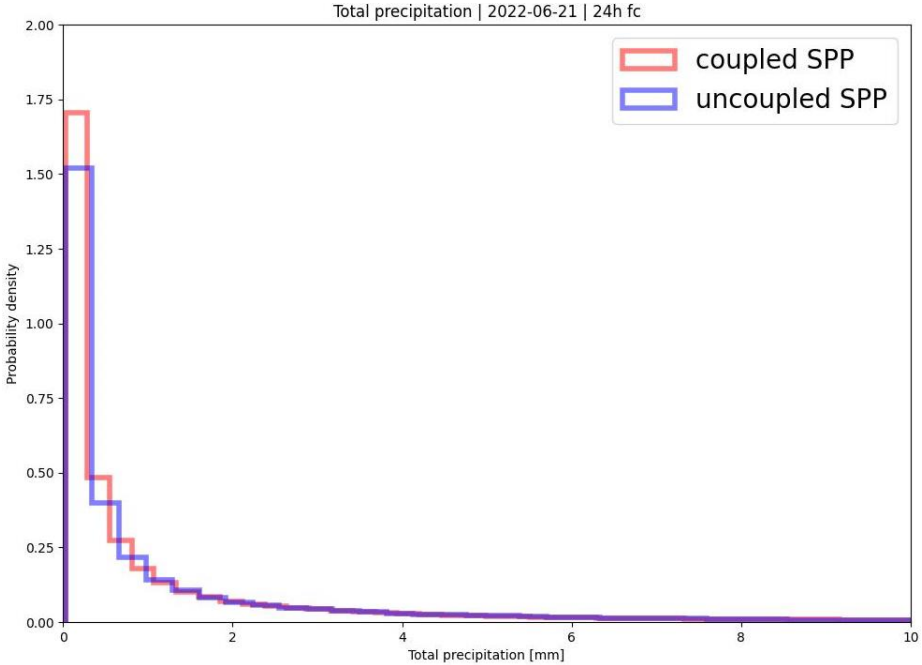

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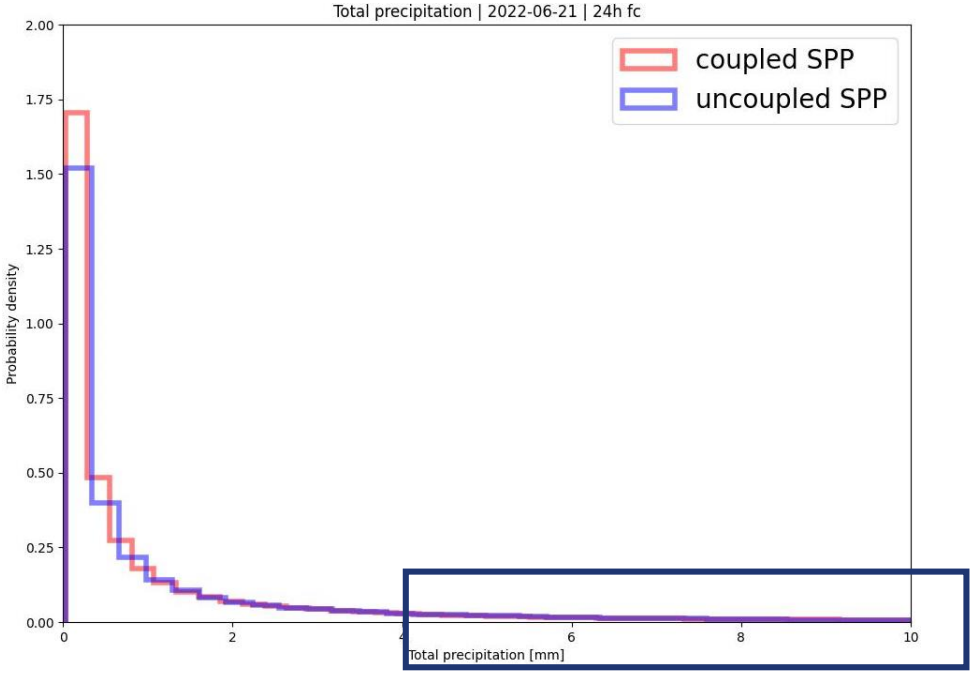

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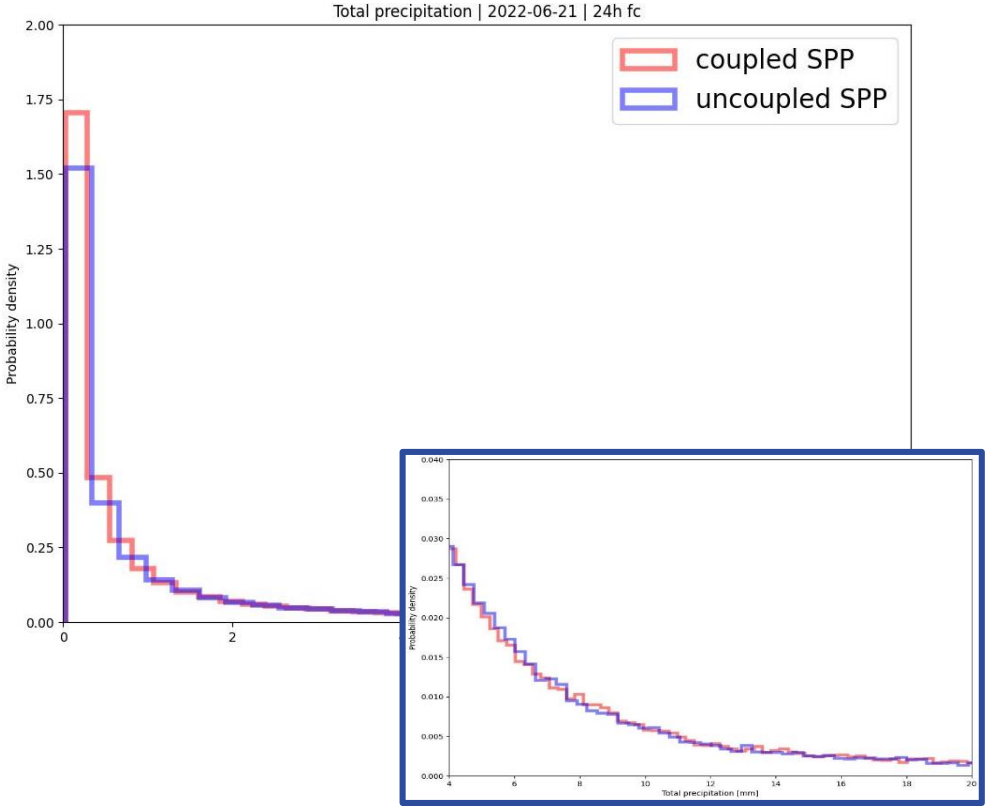
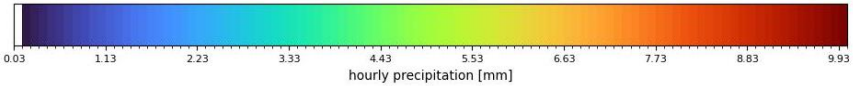
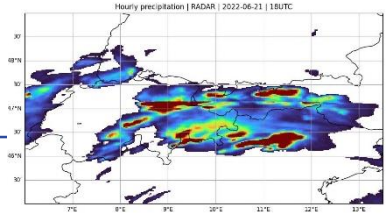


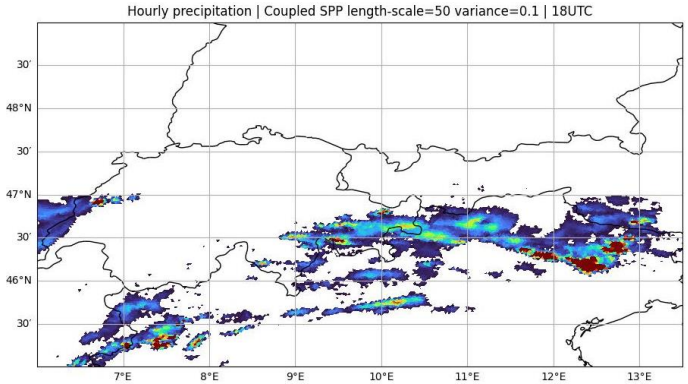
Hourly precipitation



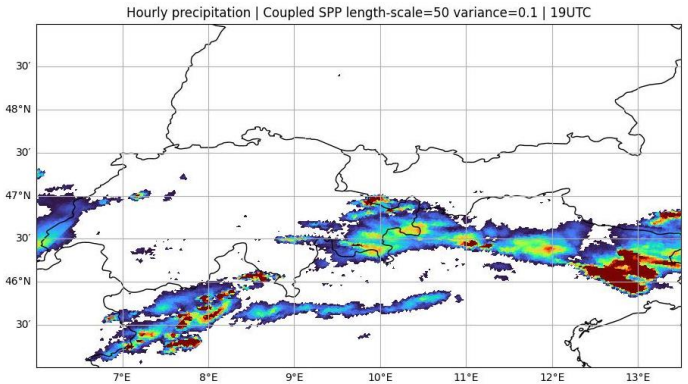


coupled SPP

18UTC



19UTC



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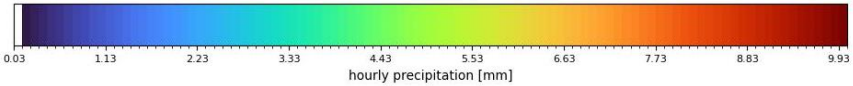
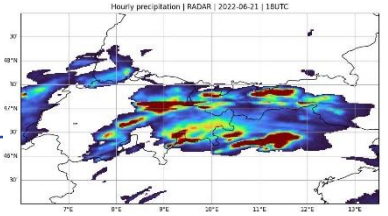


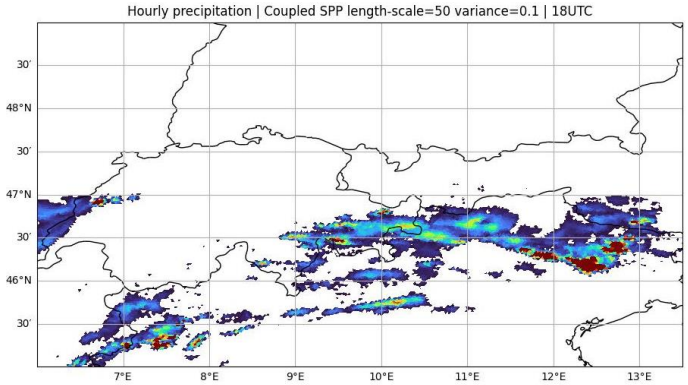


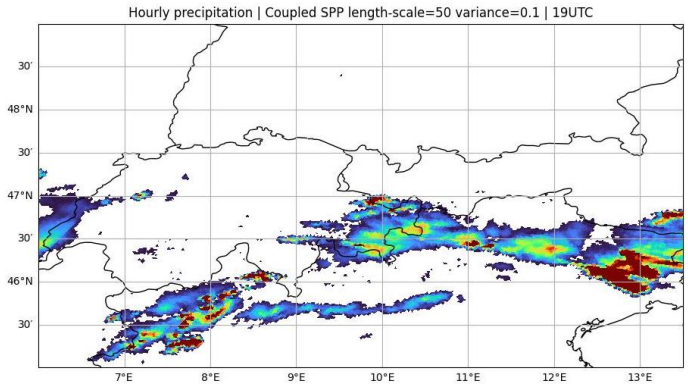
18UTC

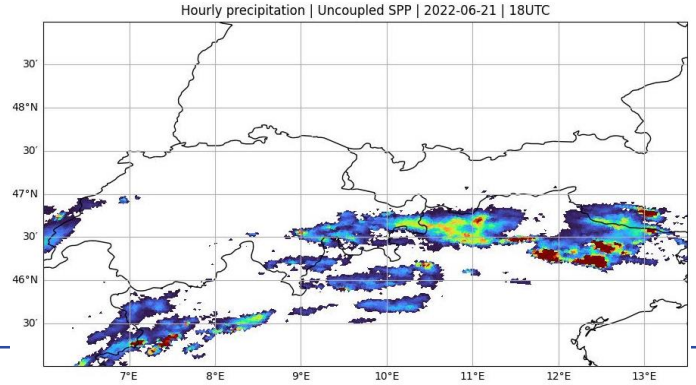
19UTC

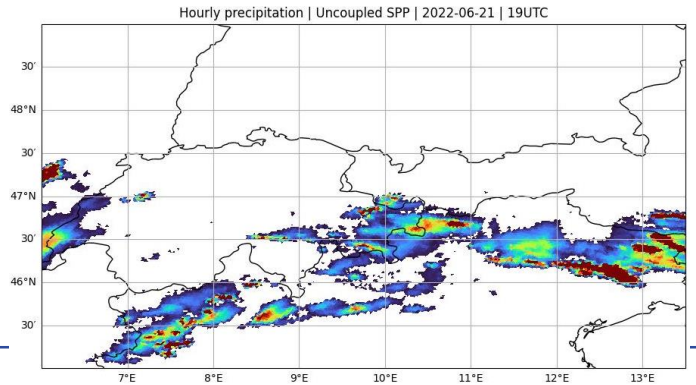
coupled SPP

uncoupled SPP









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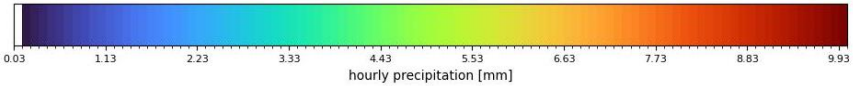

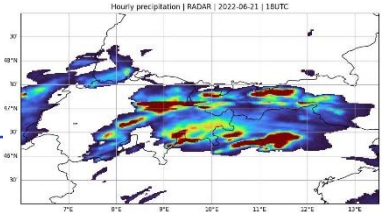

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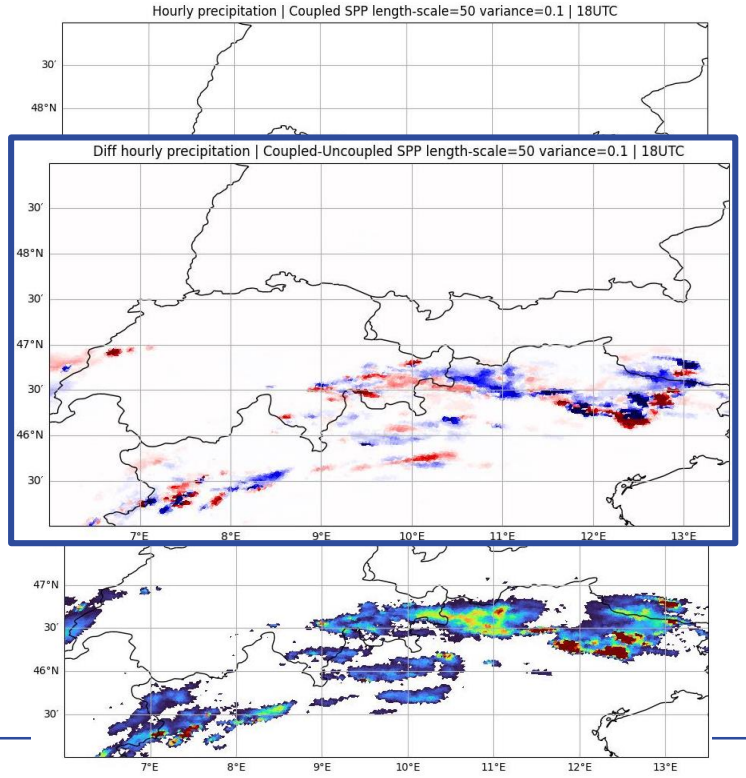

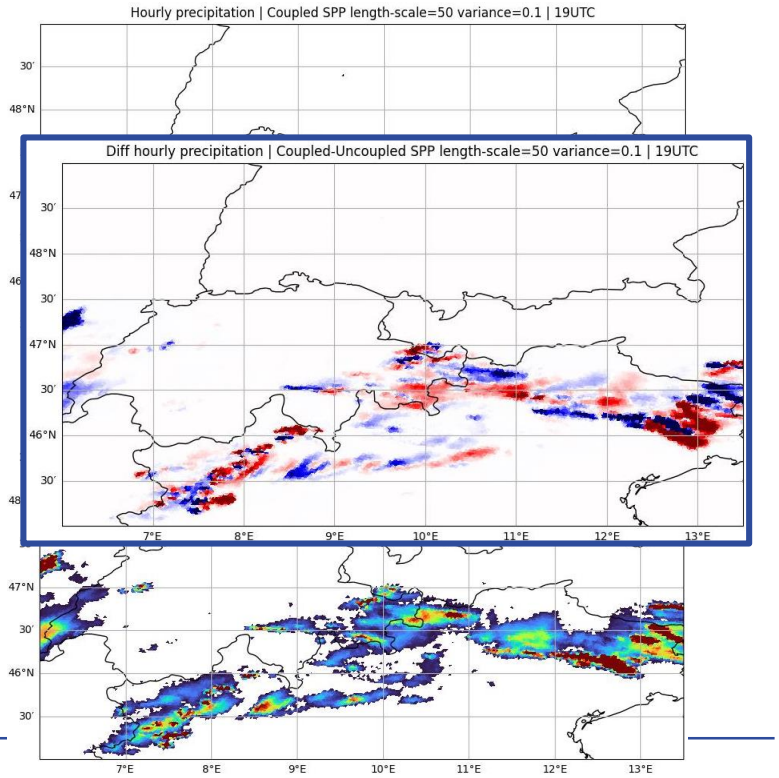

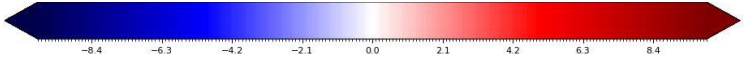

Outlook

- ➔ In this study, the impact of SPP of this parameter (Sedimentation velocity of graupel) on precipitation show reasonable behaviour → No systematic difference
- ➔ The effect should be studied over longer period statistically

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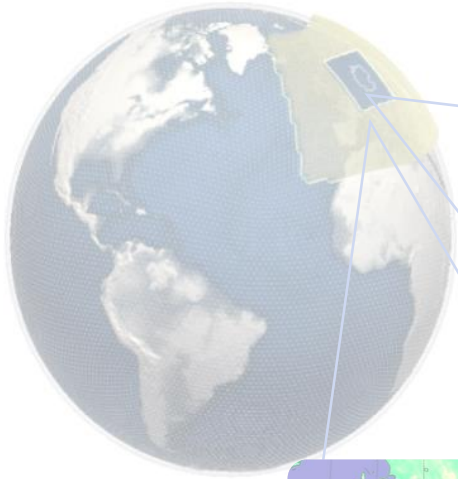
Future plans:

- Complete the implementation of SPP in ICON
  - **Ensemble**
  - Couple SPP within the physics schemes for selected parameters → we started with the microphysics parameters
- Tune SPP in ICON-LAM
  - Tests to define the optimal values of SPP parameters (i.e., lenght scale, wave mode, temporal scale) for perturbing physical parameters


Deutscher Wetterdienst



Thank you for your attention

with a picture of my GLORIous colleagues 😉