Physically based stochastic perturbations (PSP)

Parameterizing boundary layer variability and subgrid scale orography

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Physically based stochastic perturbations

Motivation:

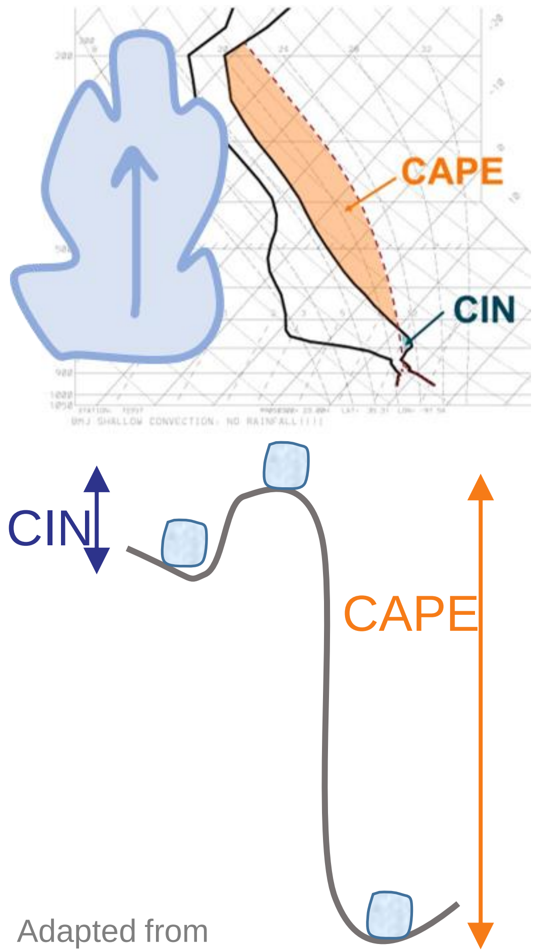
- Convection permitting models
- **Subgrid-scale processes** responsible for triggering convection

→ Parameterize the effect in a stochastic way: stochastic perturbations

1. **Subgrid-scale variability of boundary layer turbulence (Kober & Craig, 2016): Modifications**
2. **Subgrid-scale orographic lifting**

Goal:

Improve probabilistic precipitation forecasts based on physical processes



Adapted from http://slideplayer.fr/slide/3284387/

PSP for boundary layer variability

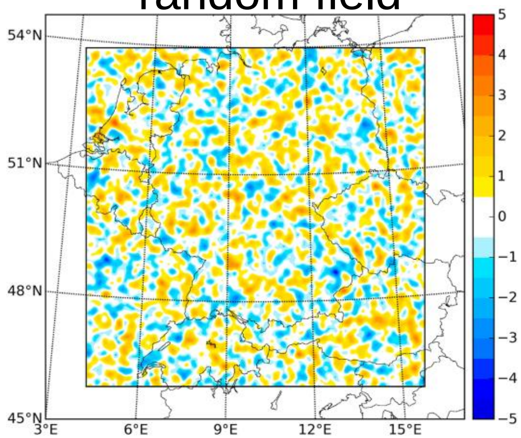
(Kober and Craig, 2016; modifications)

Boundary Layer Scheme (Kober and Craig, 2016)

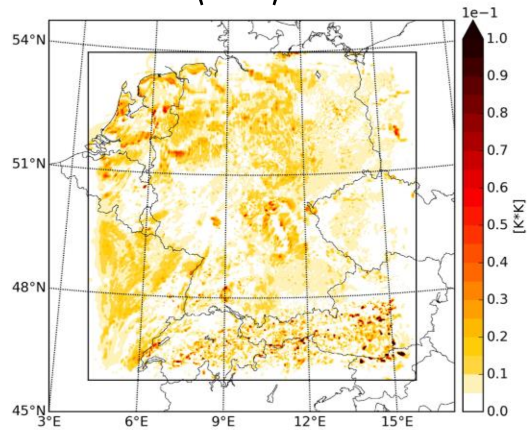
Perturbation of T, q and w according to boundary layer turbulence variance

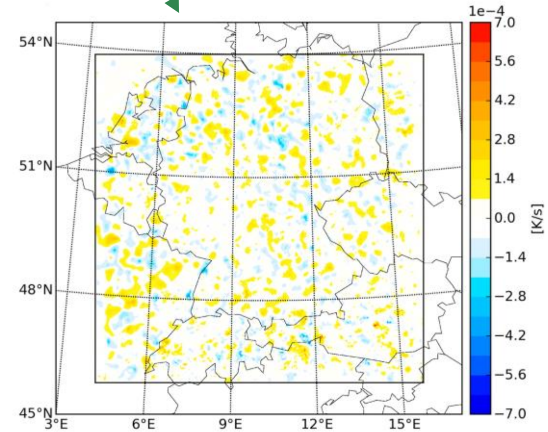
$$\left(\frac{\partial T}{\partial t}\right)_{sh} = \frac{\partial T}{\partial t} + \alpha_{sh}\,\frac{l_{eddy}}{\tau_{eddy}\Delta x_{eff}} \cdot \eta_{sh} \cdot \langle T^2 \rangle^{0.5}$$

η_{sh}: gaussian random field



$\langle T^2 \rangle^{0.5}$





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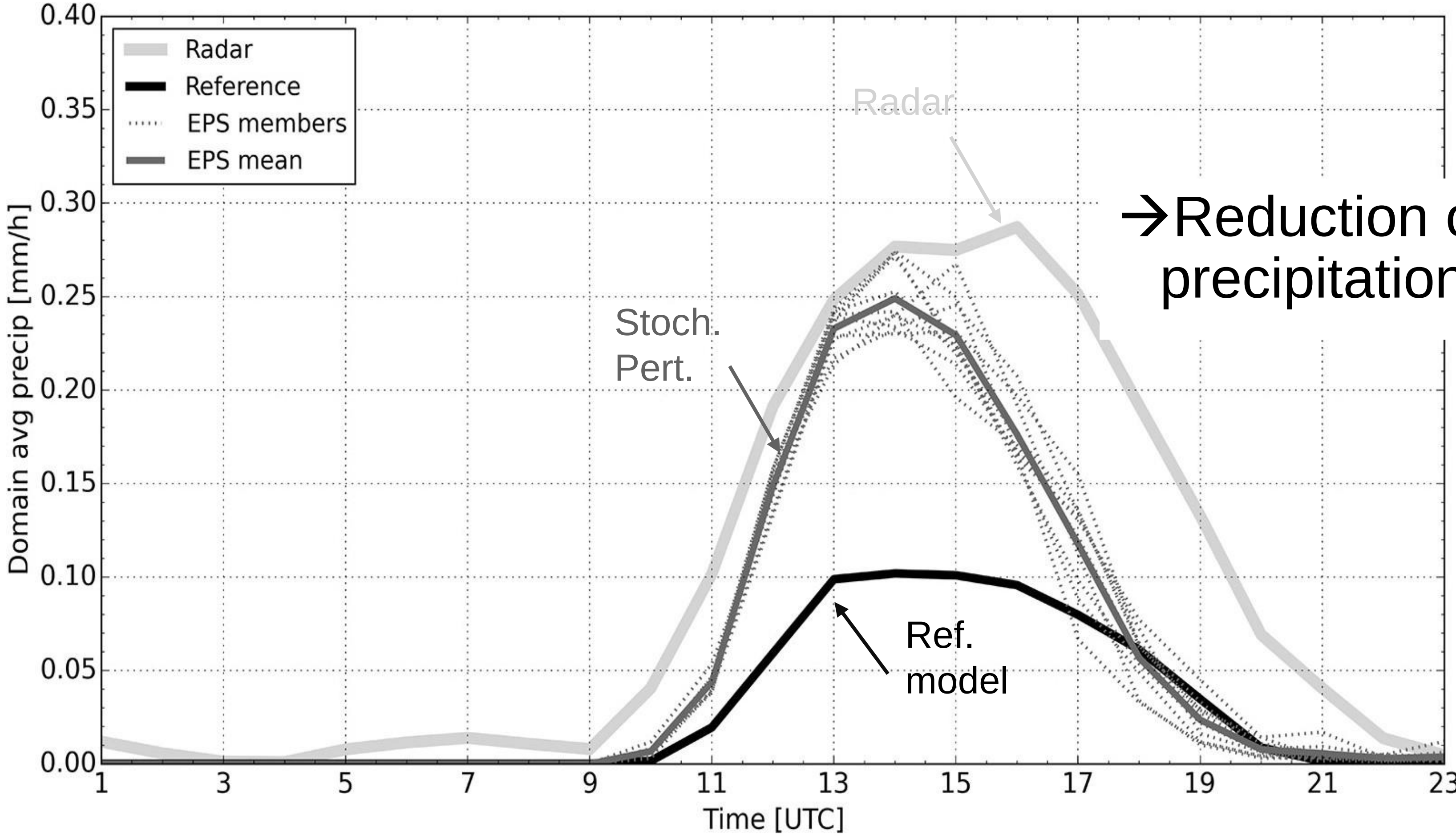
Boundary Layer Scheme (Kober and Craig, 2016)

Domain averaged (Germany) precipitation for 01/07/2009:



→Reduction of precipitation bias

Modifications to the Boundary Layer Scheme

- Autoregressive Process (AR): continously modifying η at every time step, but temporally correlated:

$$\eta_t = \sigma_t \cdot \eta_{t-1} + \epsilon_t$$

- Perturbing also u & v in a 3d-nondivergent manner, depending on w perturbations:
  - 3d non-divergence: $-\frac{\partial w}{\partial z} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}$
  - Solving velocity potential ϕ: $\nabla^2 \phi = -\frac{\partial \omega}{\partial z}$

- Constraining the perturbations to the boundary layer (HPBLcut)
  →Reduce impact of perturbations at night
  →Scheme developed for buoyant turbulence, not shear

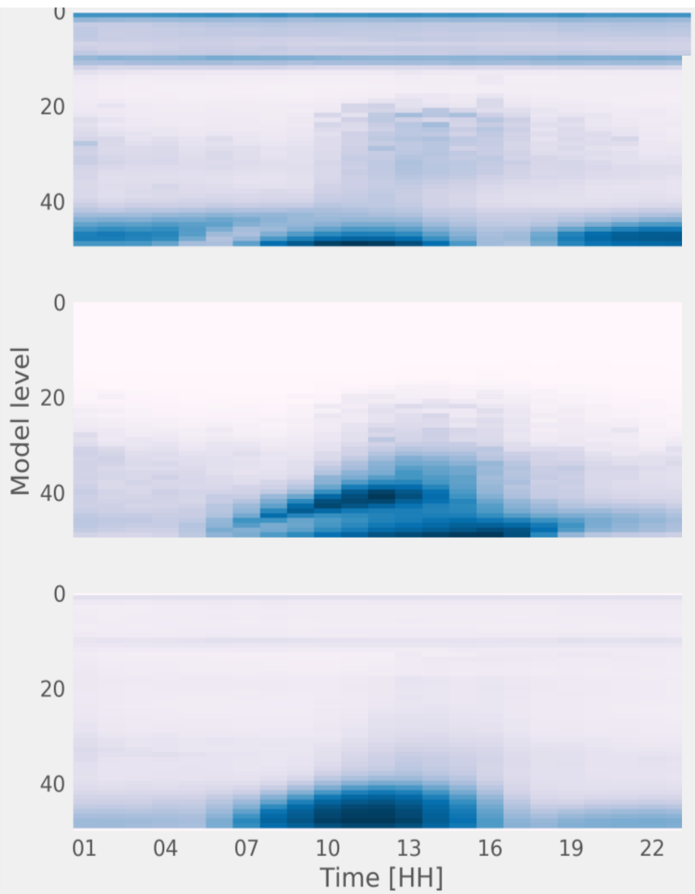
Effect of HPBL-cut

Convection permitting 2.8km resolution COSMO model during weak synoptic forcing (June 6th, 2016)

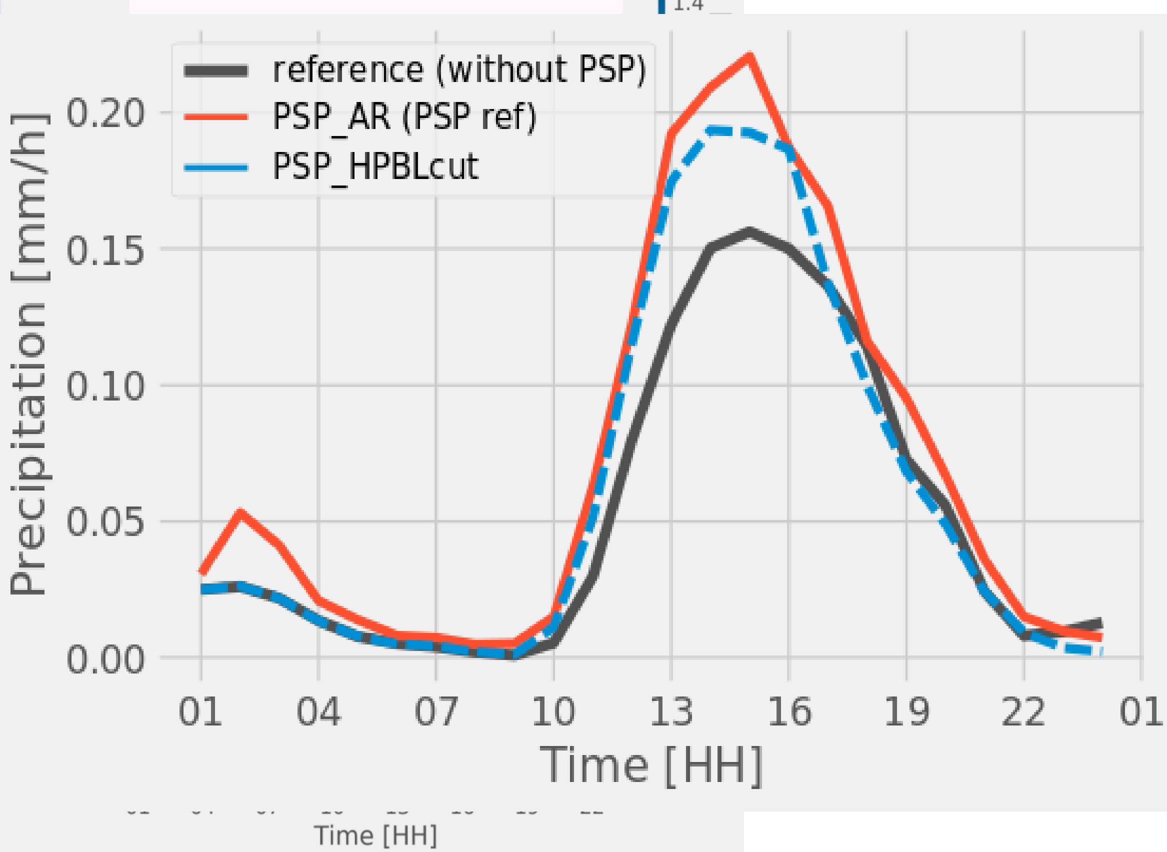
Standard deviation of perturbations:

AR-process only

With HPBLcut



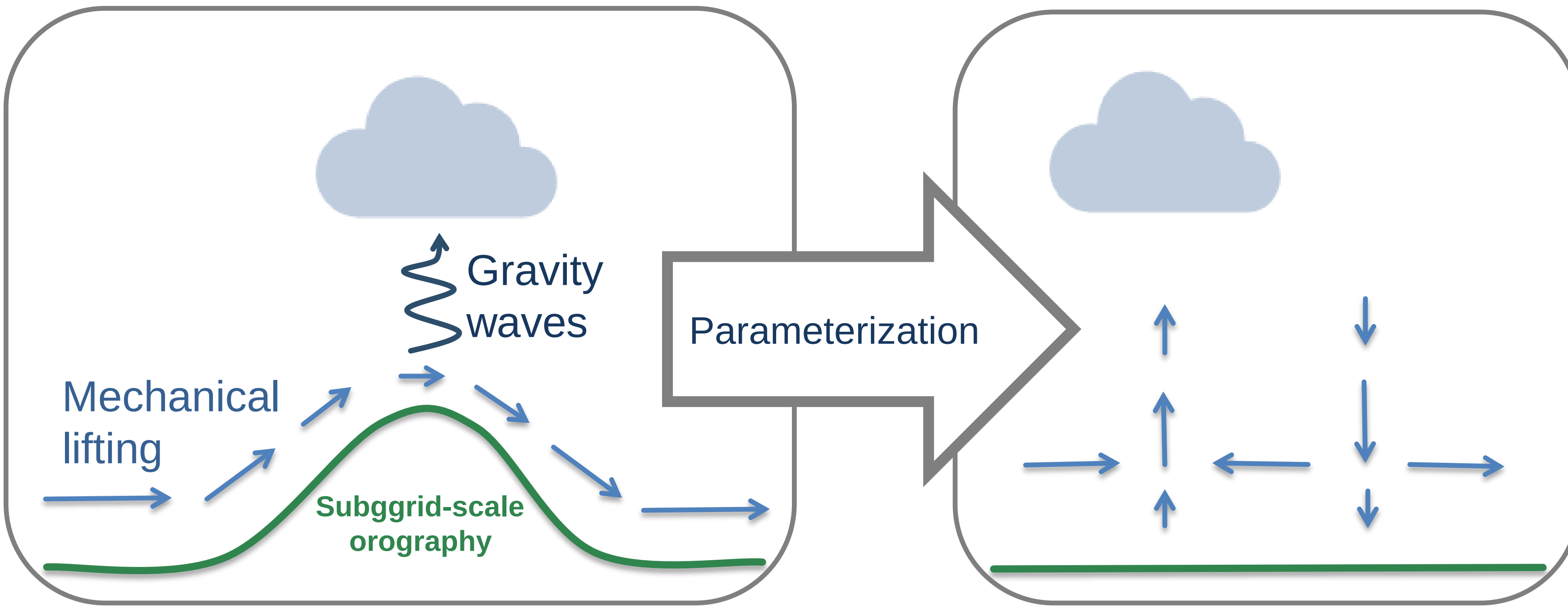
Accumulated precipitation time series



PSP for
Subgrid scale orography

Physical process for subgrid-scale orography perturbations

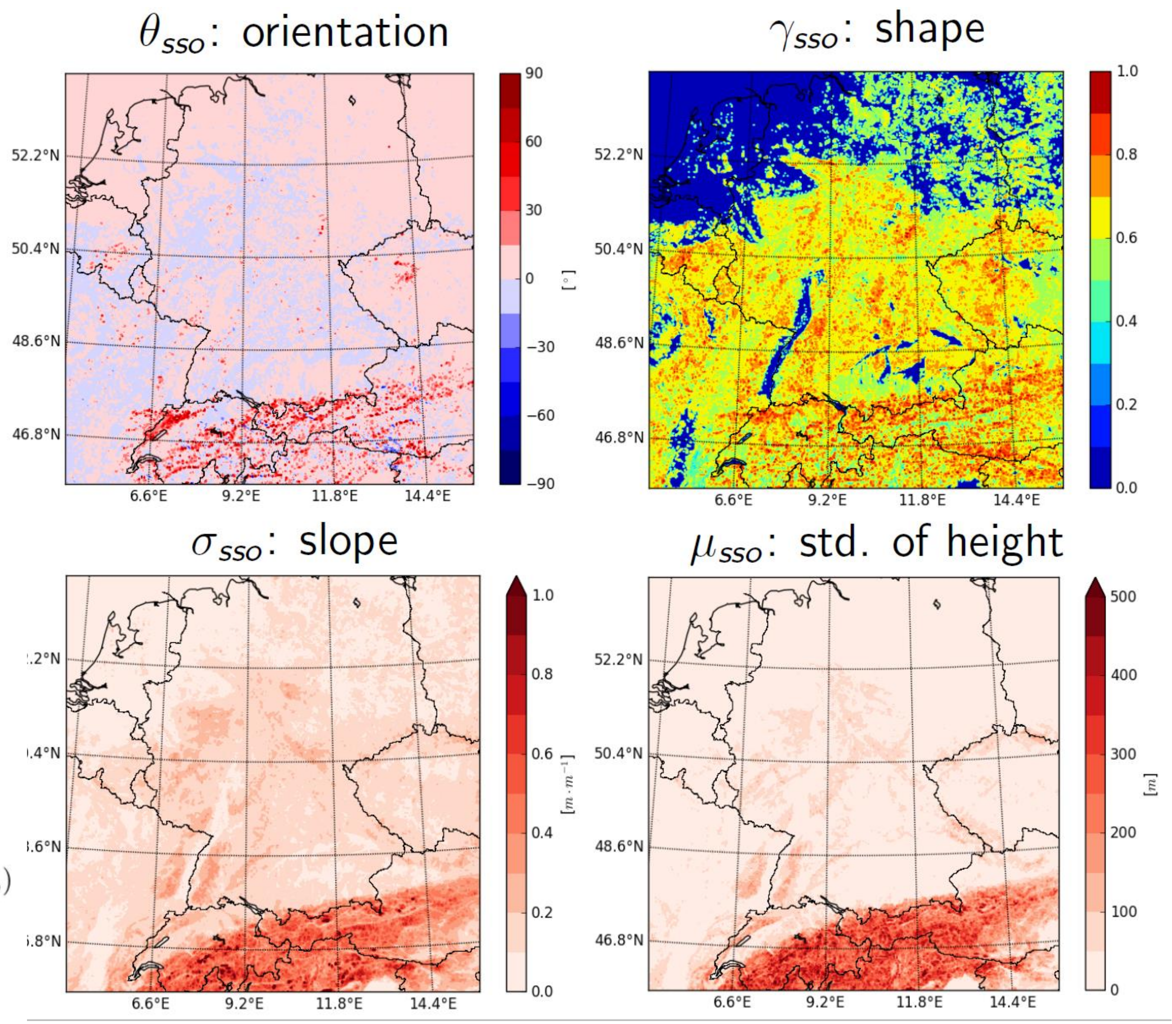
- Orographic lifting & gravity waves
- Enhanced vertical velocities
- Triggering of convection

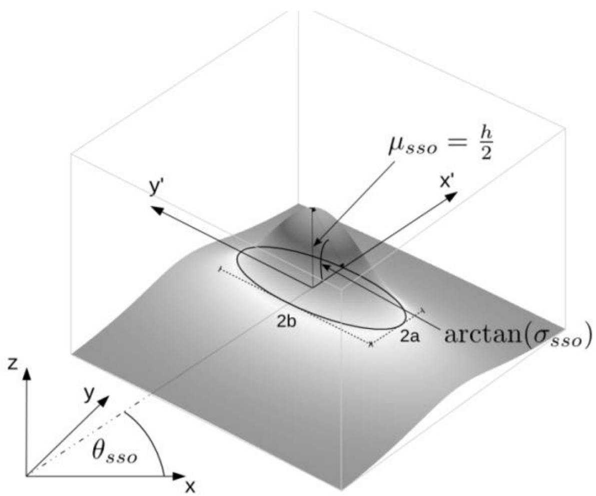


Subgrid-scale orography

30m resolution ASTER dataset

→ upscaled on model grid to yield SSO information



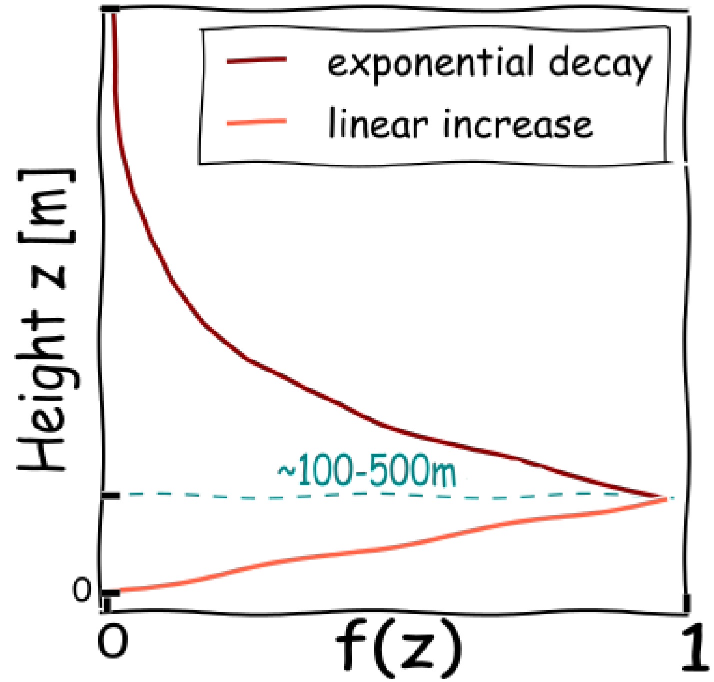


SSO perturbations: vertical velocity

$$\left(\frac{\partial w}{\partial t}\right)_{all} = \frac{\partial w}{\partial t} + \underbrace{\frac{\alpha_{sso}}{\tau} \cdot \eta \cdot w'}_{\text{Stochastic perturbations}}$$

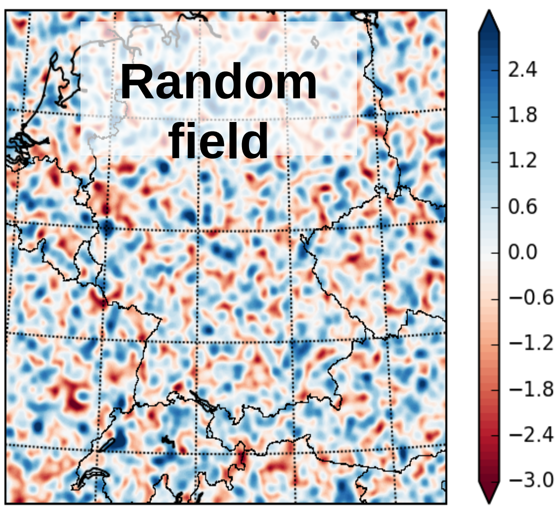
- $\boldsymbol{\eta(\tau,\sigma)}$: Random field with AR process (τ) and spatial correlation σ
- $\boldsymbol{\alpha_{sso}}$: perturbation amplitude
- $\boldsymbol{w'(SSO, N_z^2, \vec{v}_h)}$: physical scaling

- With $w' = w_0 \cdot \underbrace{f(z)}$
- w_0 : gravity wave scaling



Stochastic perturbations (vertical velocity)

$$\left(\frac{\partial w}{\partial t}\right)_{sso} = \frac{\alpha_{sso}}{\tau} \cdot \eta_{sso} \cdot w'(sso, N_z^2, \vec{v}_h)$$



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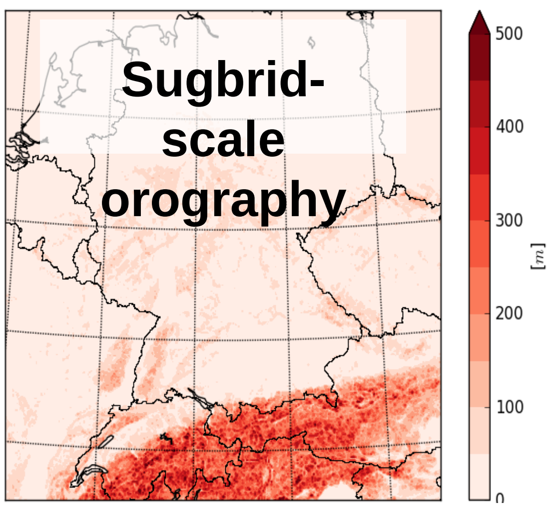

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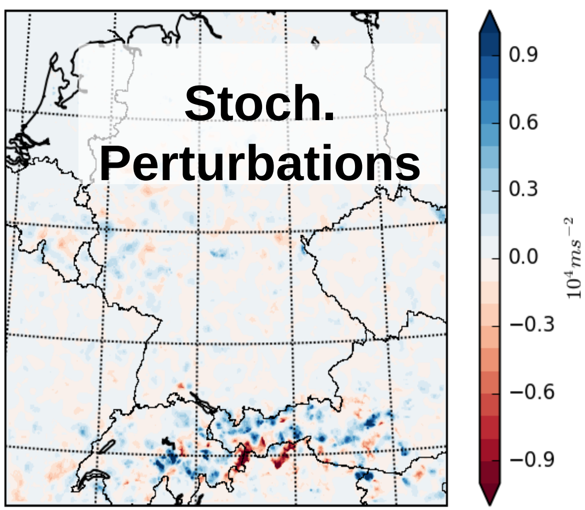


SSO perturbations: horizontal velocities

u & v perturbations are derived from w perturbations:

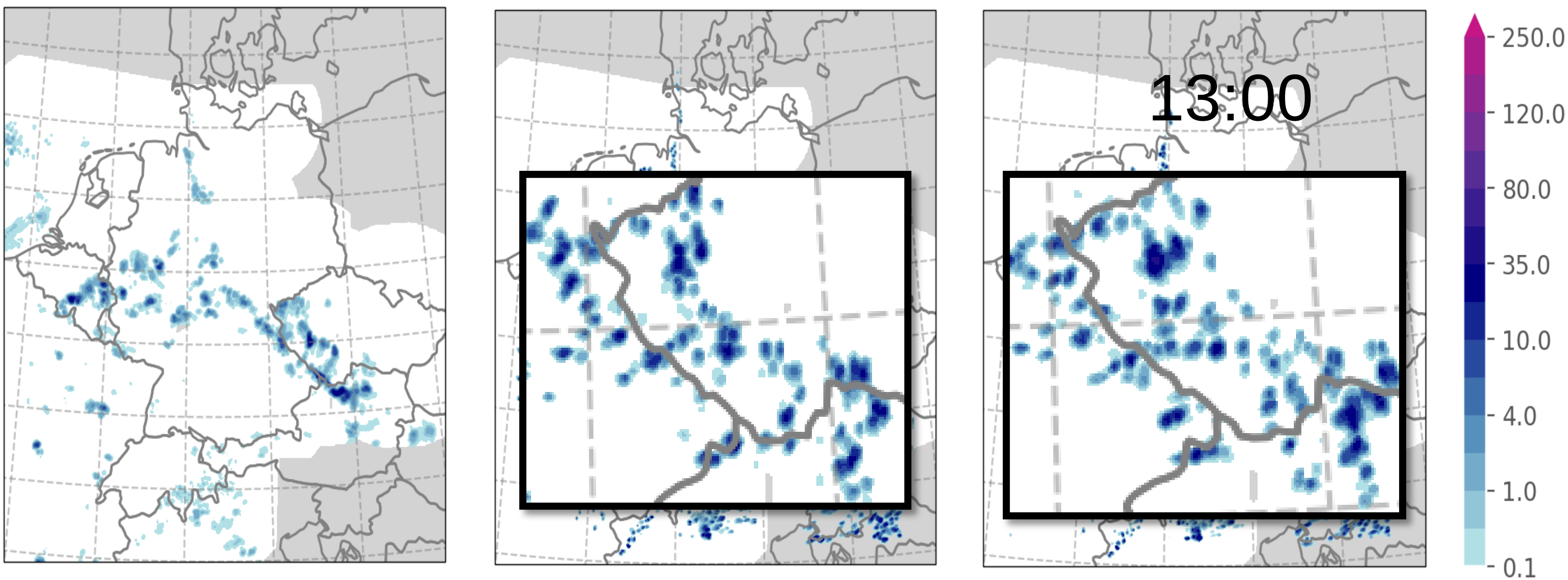
- 3d non-divergence: $$-\frac{\partial w}{\partial z} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}$$
- Solving velocity potential ϕ: $\nabla^2\phi = -\frac{\partial \omega}{\partial z}$
- Deriving u, v from ϕ

→ 3d-nondivergent perturbation fields for u, v, w

Results: Rearrangment of precipitation cells

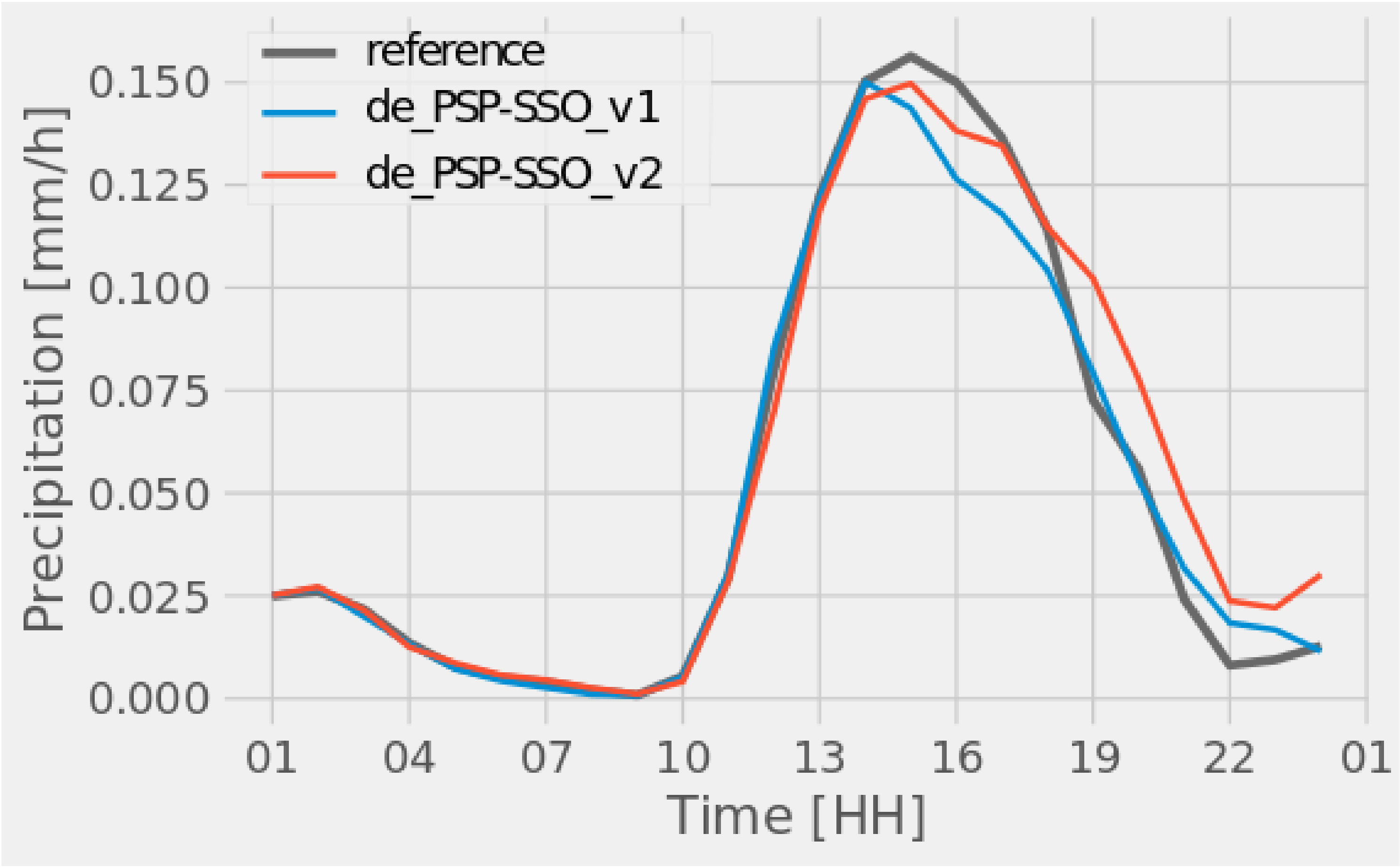
Convection permitting 2.8km resolution COSMO model during weak synoptic forcing

Radar | Ref. model | With SSO pert.



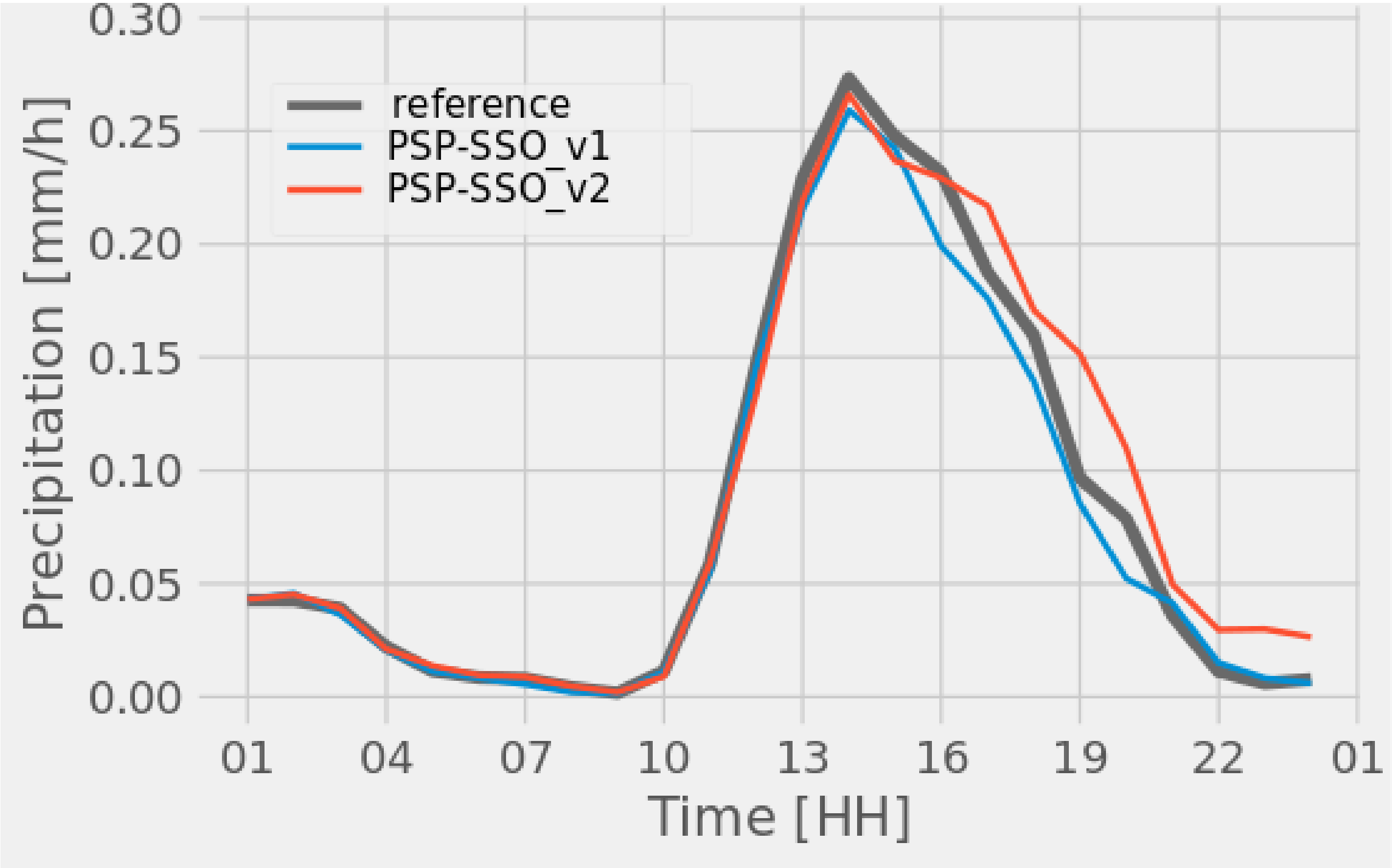
Exemplary precipitation fields for 06/06/2016 at 13:00 UTC of radar data (left) and COSMO model (middle) and COSMO model with stochastic SSO perturbations (right).

Results: No clear increase of precipitation



Hourly accumulated precipitation, 06/06/2016

Results: No clear increase of precipitation, Orographic gridpoints (SSO-Std >20m)



Hourly accumulated precipitation, 06/06/2016

Explanations

No clear precipitation increase:

- SSO is strong, where resolved orography is present
- Kirshbaum et al. 2007, Schneider et al. 2018: small scale orographic features in the presence of larger scale orography are not essential for precipitation triggering
- Enhanced mixing decreases CAPE

Summary

PSP Boundary layer variability:

- Modifications to original scheme (AR-process, w2uv, HPBLcut): improve physical consistency

PSP Subgrid scale orography:

- Perturbing u,v,w to account for mechanical lifting by subgrid-scale orography: triggering of convection
- No clear precipitation increase
- Modification of precipitation cells → spread?

Thank you for your attention!

References

- Kober, K. and G. C. Craig, 2016: Physically Based Stochastic Perturbations (PSP) in the Boundary Layer to represent uncertainty in Convective Initiation. Journal of the Atmospheric Sciences, 73 (7), 2893-2911.
- Schneider, L., Barthlott, C., Barrett, A. I., & Hoose, C. The precipitation response to variable terrain forcing over low-mountain ranges in different weather regimes. Quarterly Journal of the Royal Meteorological Society.
- Kirshbaum, D. J., Rotunno, R., & Bryan, G. H. (2007). The Spacing of Orographic Rainbands Triggered by Small-Scale Topography. Journal of the Atmospheric Sciences, 64(12), 4222–4245.