WAVES TO WEATHER

Stochastic Parameterization of Processes Leading to **Convective Initiation** in Kilometer-Scale Models

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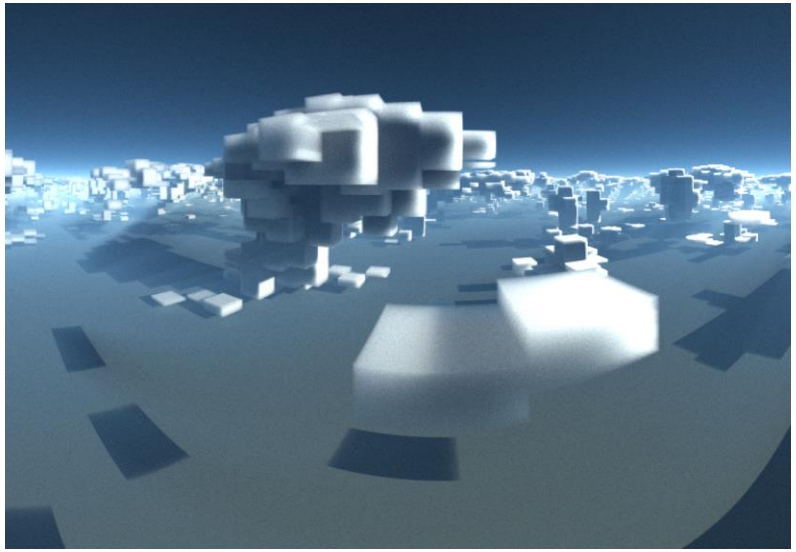
Motivation

- Recent step-change in predicting **deep convection** due to **convection-permitting models**
  - → Enable the explicit simulation of deep convective overturning circulations
  - → Are become more and more popular for different applications:
  From operational, regional NWP towards global/ensemble/climate simulations

- But still, many deficits in convective precipitation remain!
  - Onset of precipitation (Baldauf et al., 2011)
  - Lack of afternoon/evening precipitation, organization (Rasp et al., 2018)
  - …

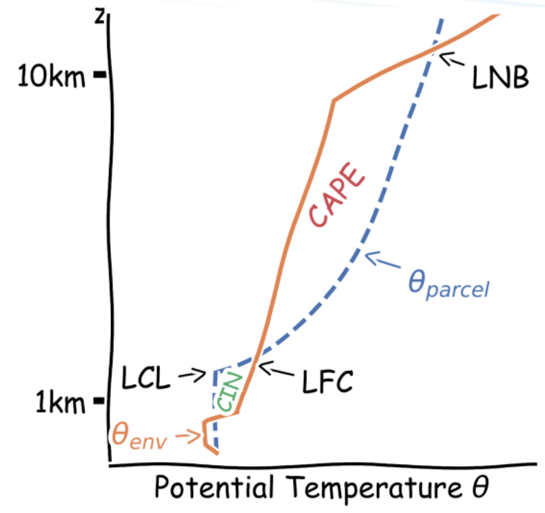
Grey Zone problem: Many processes that are closely related to convection are still subgrid-scale:
- Turbulence (entrainment, detrainment)
- Microphysics
- **Processes for convective initiation**

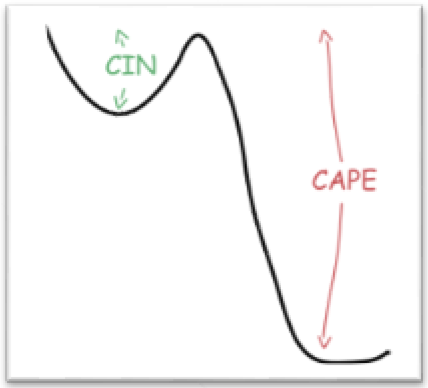
https://wiki.bildungsserver.de/klimawandel/index.php/Datei:Anvil_shaped_cumulus_panorama_edit_crop.jpg



Simulations were computed with the EULAG model using **2 km** grid sizes.
Mayer 2018, promet

Convective initiation





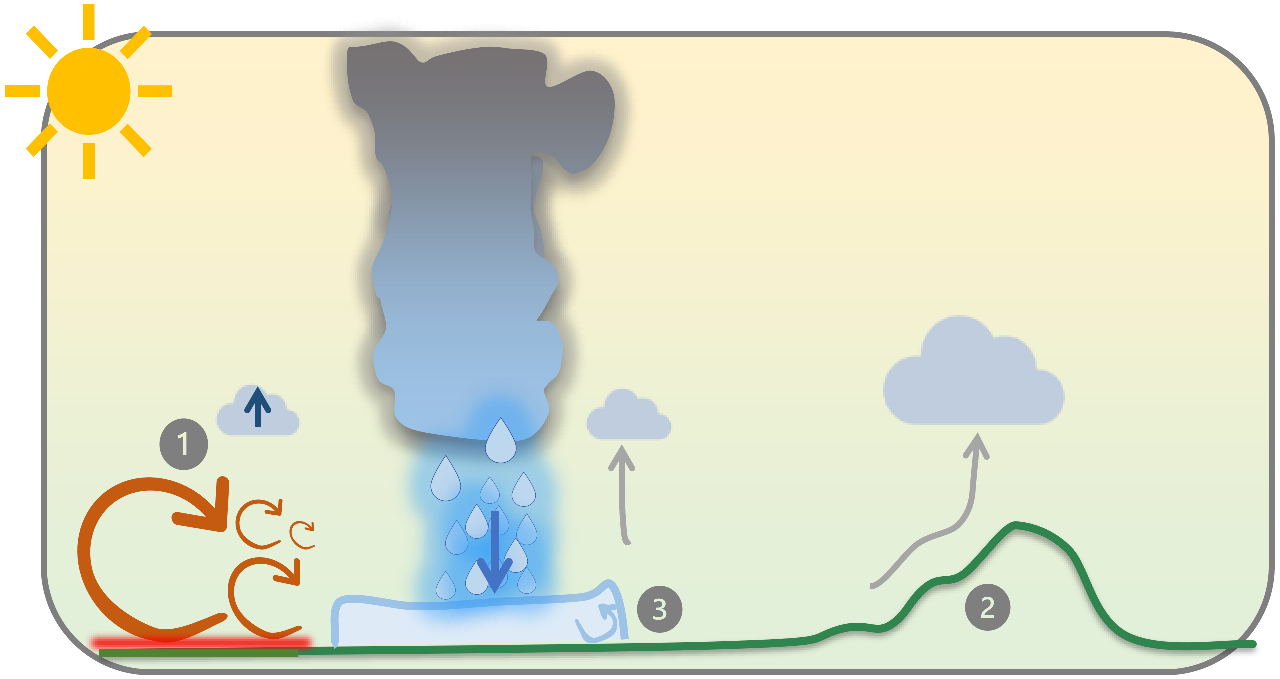
- Highly nonlinear process
- Convective Inhibition (CIN) needs to be overcome or removed for deep convection to occur!

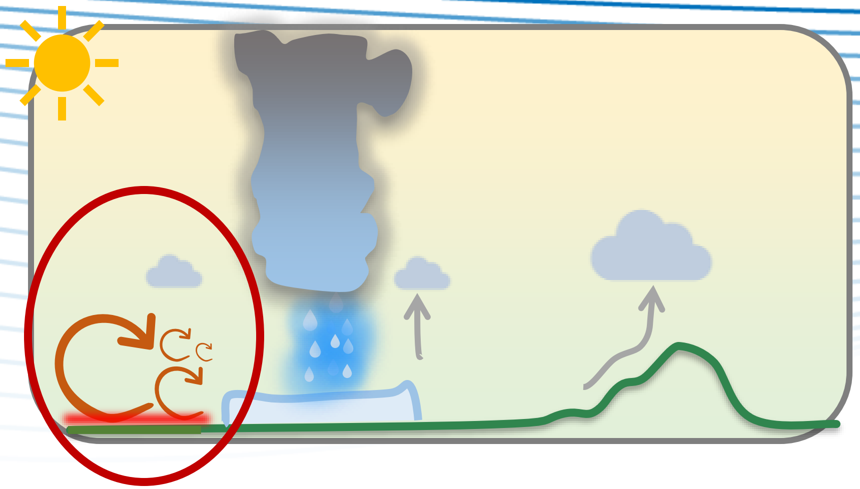
How?

- Convergence lines, sea breezes, frontal systems, . . .

Not well resolved!

1. **Surface heating, boundary layer turbulence**
   → **PSP/PSP2**
2. **Orography**
   → **SSOSP**
3. **Convective cold pools**
   → **CPP**





WAVES TO WEATHER

PSP/PSP2: Convective initiation by Boundary layer turbulence

Publications:

- Kober, K. and Craig, G. C. (2016) Physically based stochastic perturbations (**PSP**) in the boundary layer to represent uncertainty in convective initiation. Journal of the Atmospheric Sciences, 73, 2893–2911.
- Hirt, M., Rasp, S., Blahak, U. and Craig, G. (2019) Stochastic parameterization of processes leading to convection initiation in kilometre-scale models. Monthly Weather Review

Physically based stochastic perturbations for boundary layer turbulence : PSP (Kober and Craig, 2016)

→ **Subgrid-scale variability** of turbulence needs to be included.

$$\left(\frac{\partial \phi}{\partial t}\right)_{all} = \frac{\partial \phi}{\partial t} + \underbrace{\alpha \cdot \eta \cdot \phi'}_{\text{Stochastic perturbations}}$$

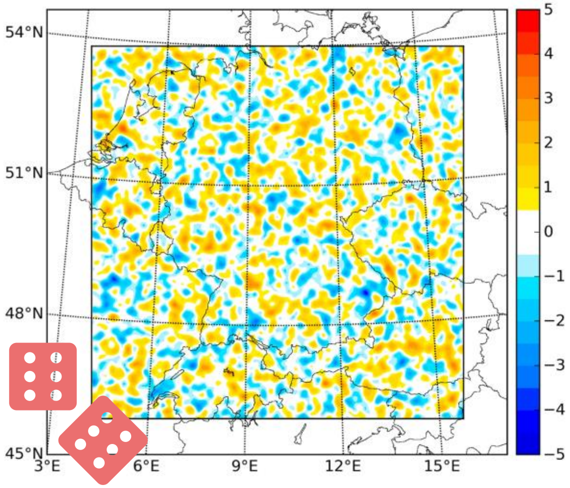
ϕ ={T, q, w}

$\eta(t,\sigma)$: Random field , regenerated every 10 min with spatial correlation σ

α: perturbation ampl., scaling factors

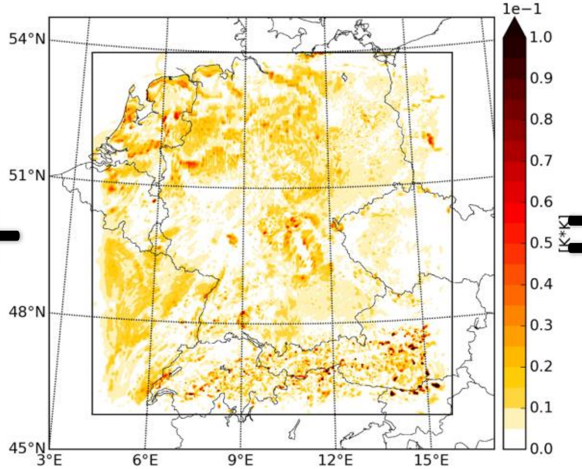
ϕ': physical scaling/subgrid-scale variance of variable ϕ

η_{sh}: gaussian random field



+

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



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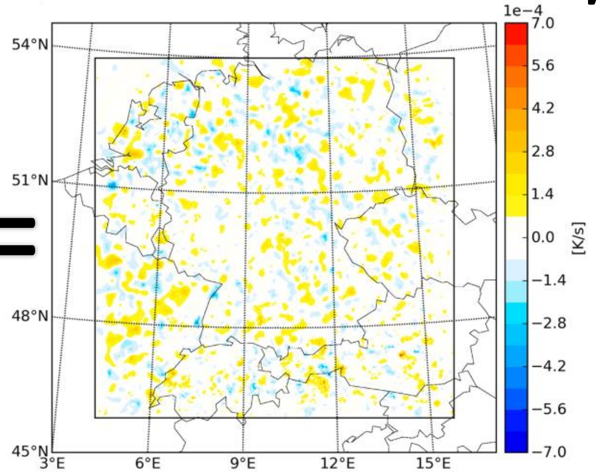
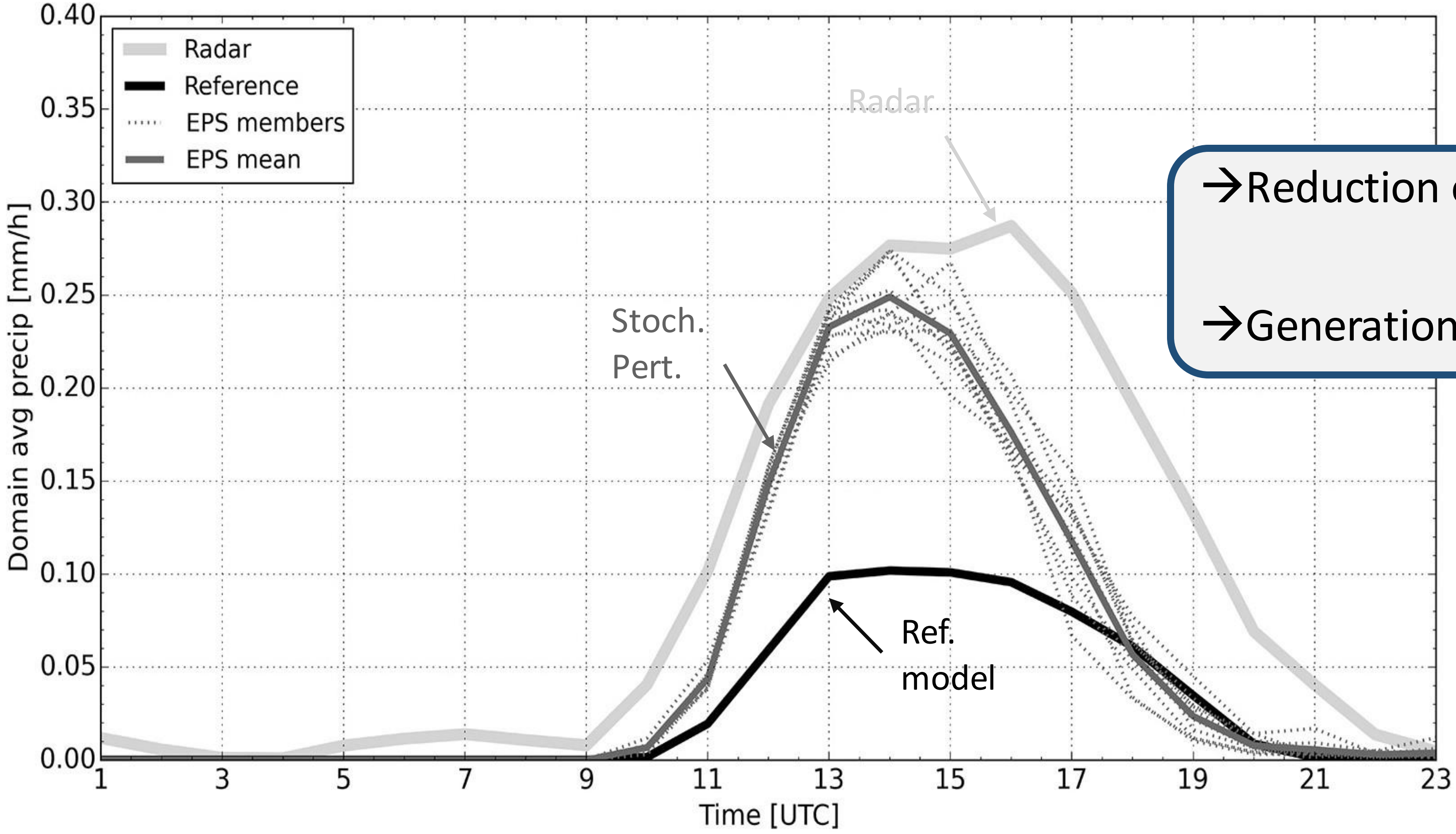


(Kober and Craig, 2016)

PSP in Kober and Craig, 2016 (JAS)

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



→Reduction of precipitation bias

→Generation of ensemble spread

(Kober and Craig, 2016)

Modifications for improved physical consistency

Hirt, M., Rasp, S., Blahak, U. and Craig, G. (2019) Stochastic parameterization of processes leading to convection initiation in kilometre-scale models. Monthly Weather Review

Autoregressive Process (Hirt et al. 2019)

Problem:

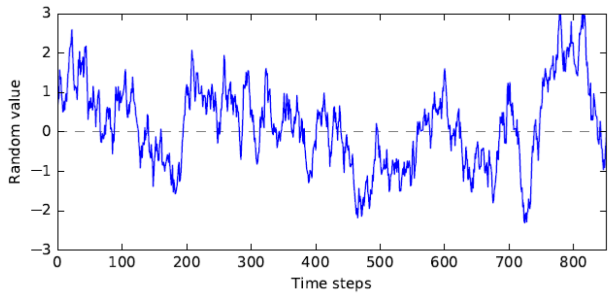
In the original version, the random field changes every 10 min: not very physical!

Solution:

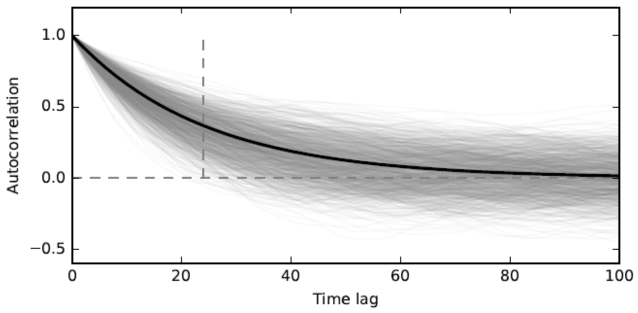
Continously modifying η at every time step, but temporally correlated via an autoregressive process:

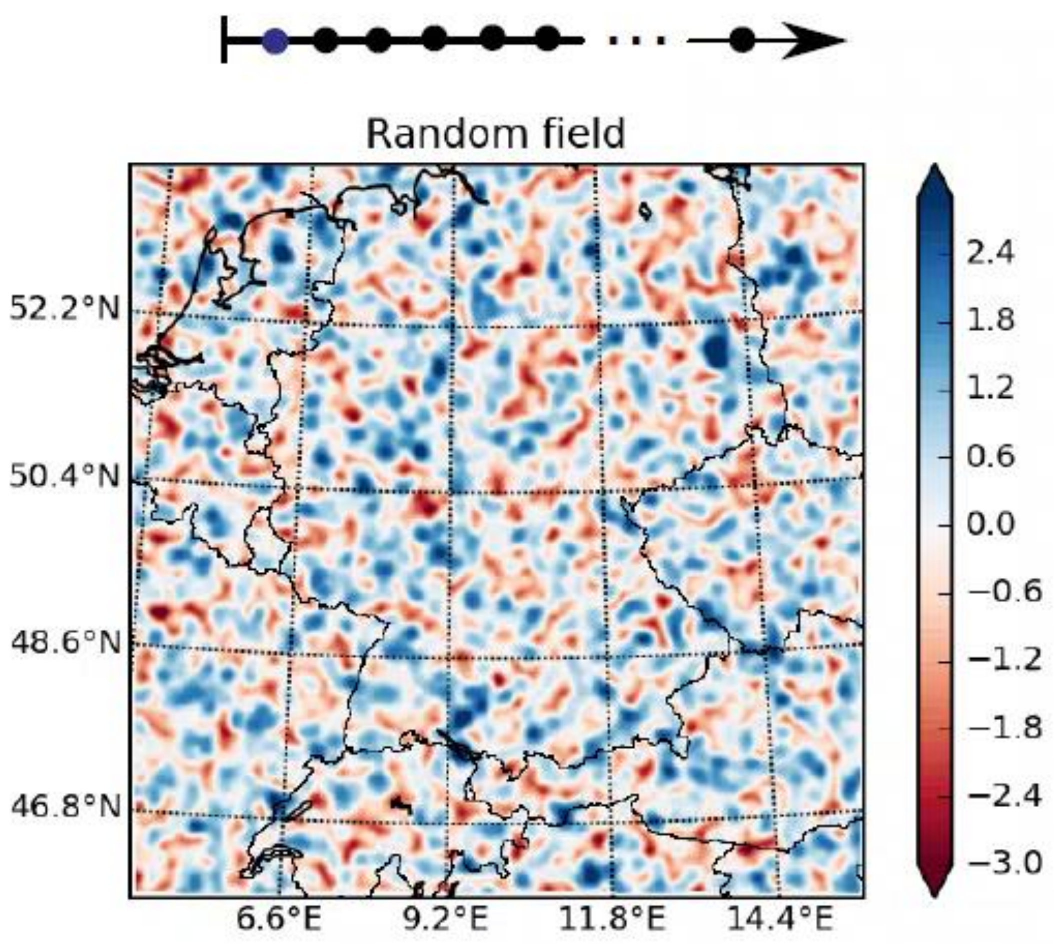
$$\eta_t = \sigma_t \cdot \eta_{t-1} + \epsilon_t$$

Timeseries at one grid point:



Autocorrelation:

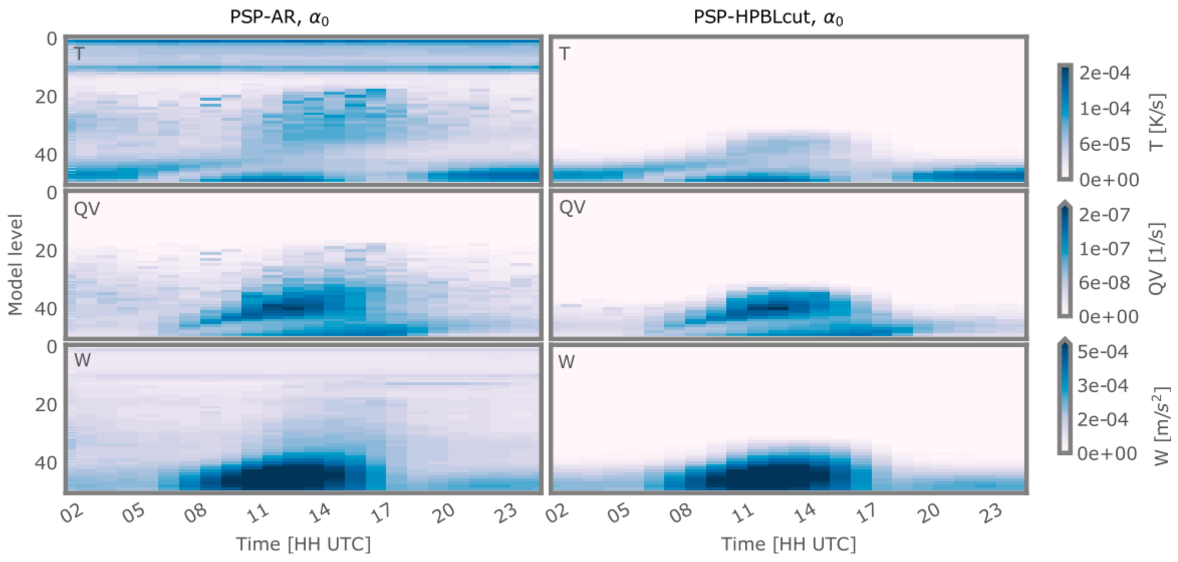


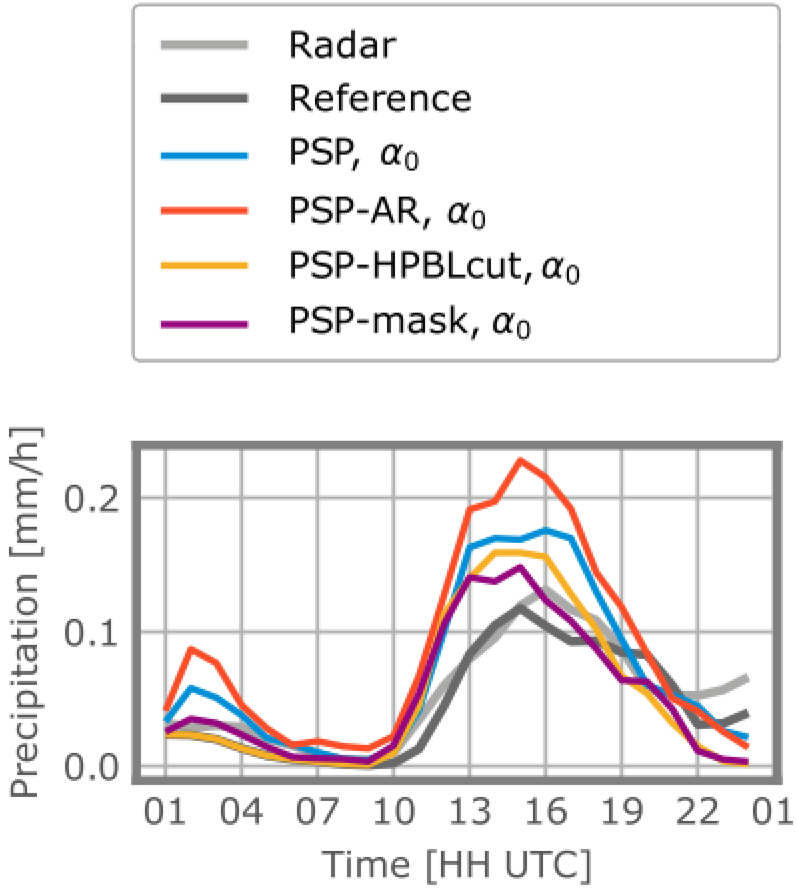


Constraining to PBL (Hirt et al. 2019)

Problem:
Nighttime and tropospheric perturbations are not physical.

Solution:
Perturbations are switched off outside the boundary layer.
→ Reduce impact of perturbations at night
→ Scheme developed for buoyant turbulence, not shear (vertically correlated perturbations)





3d-nondivergent Perturbations (Hirt et al. 2019)

Problem:

W perturbations are virtually ineffective due to dissipation via pressure perturbations.

Solution:

Perturbing also u & v in a 3d-nondivergent manner, depending on w perturbations:

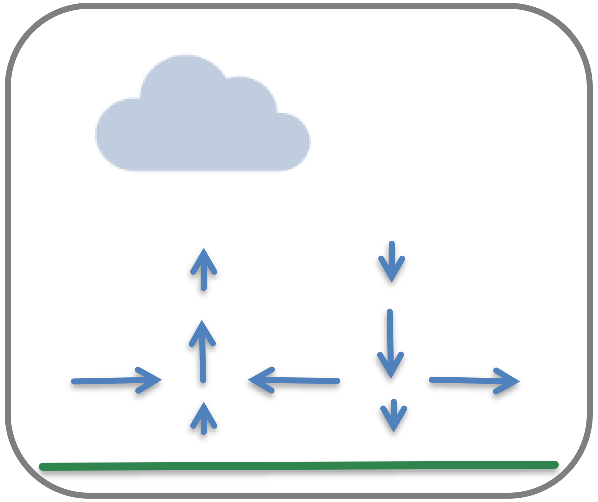
- 3d non-divergence:

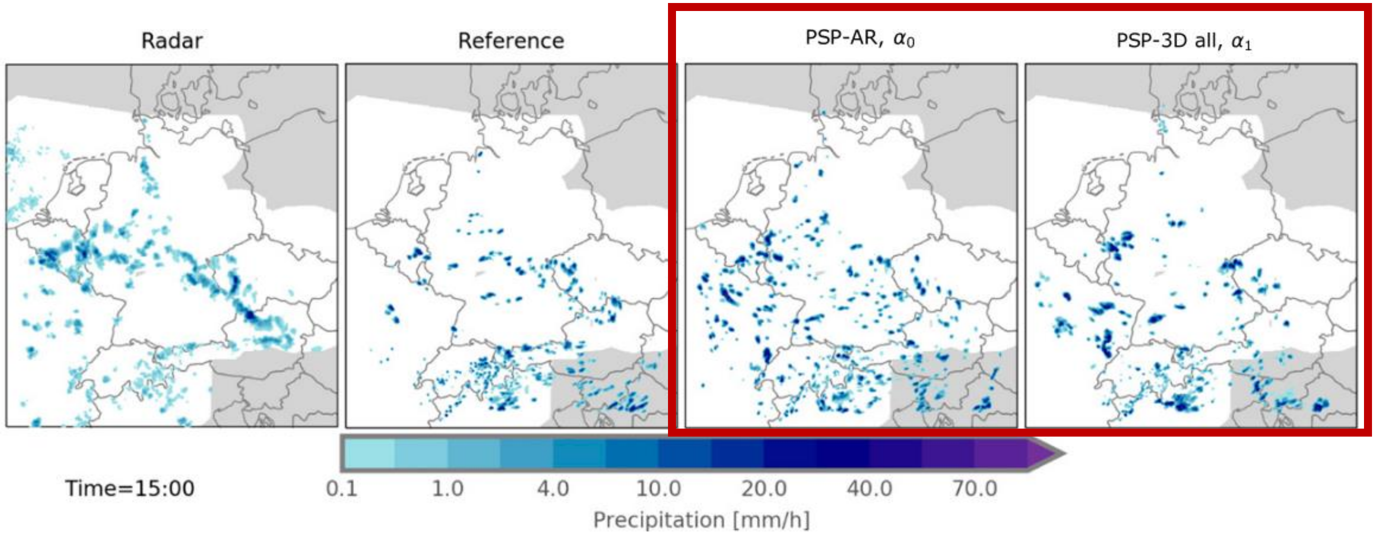
$$-\frac{\partial w}{\partial z} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}$$

- Solving velocity potential ϕ:

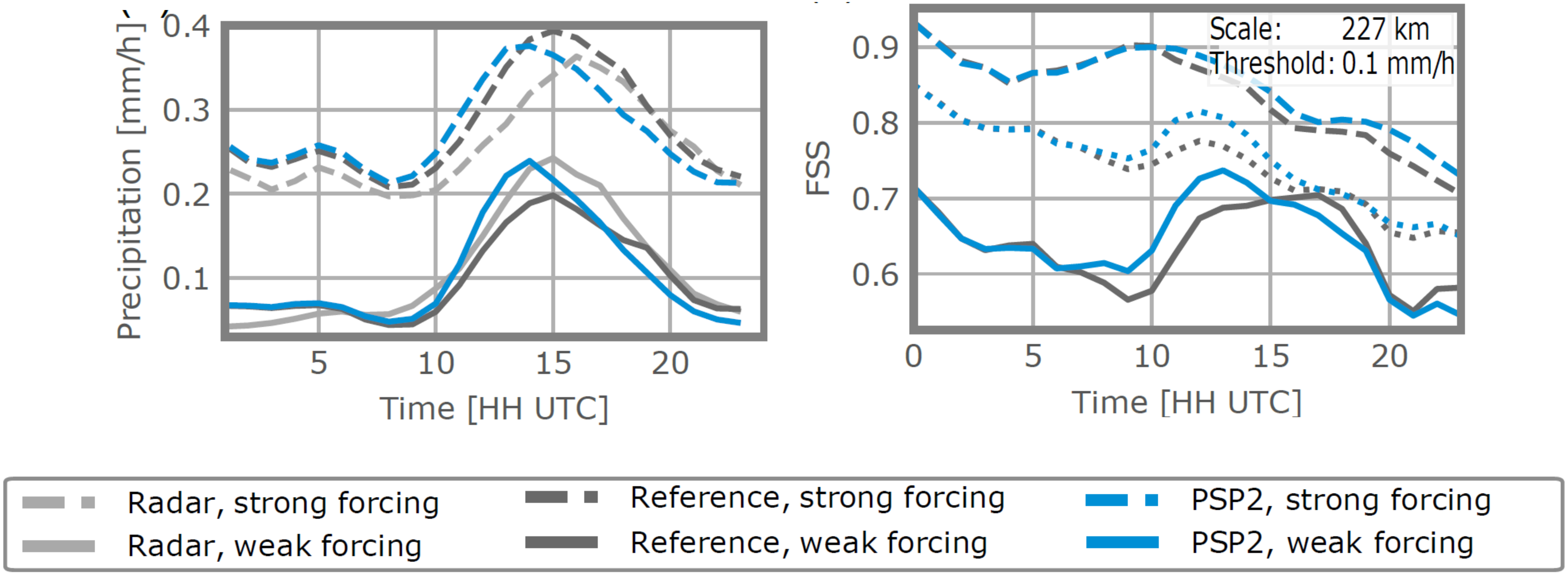
$$\nabla^2 \phi = -\frac{\partial \omega}{\partial z}$$

→ More clustered, less scattered.
→ computationally expensive, more unstable



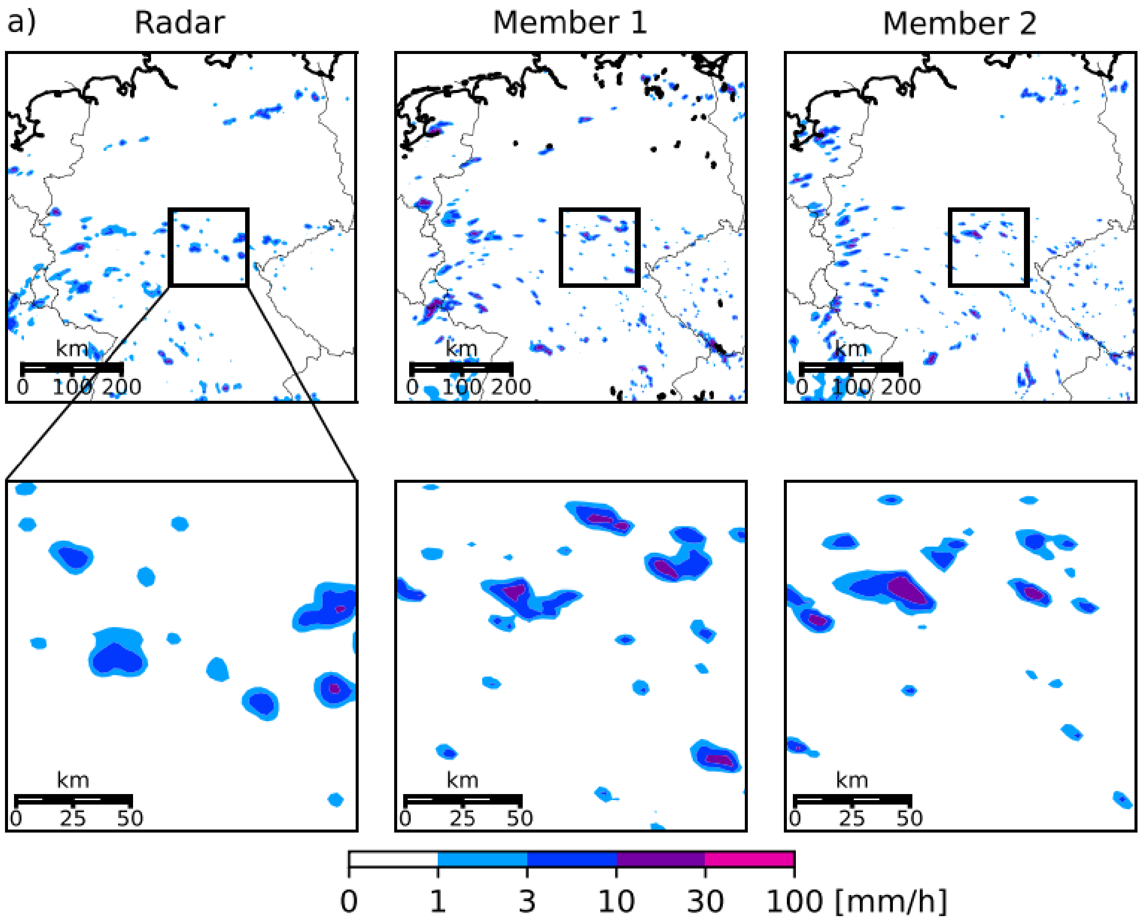


PSP2: PSP AR + HPBLcut + w2uv,
simulate longer period: 29.05- 07.06.2016
COSMO-DE



Applications of the PSP Scheme

- Different realizations given the same macroscale/synoptic condition to test Craig and Cohen Theory *(Rasp et al. 2018, JAS)*
- Ensemble spread *(Keil et al. 2019, QJRMS)*
- Model error representation for DA (*Zeng et al. 2020, MWR)*
- PSP in ICON
  - Implementation (F. Jakub)
  - Application in large ensembles (I. Chen, C. Keil)



(Rasp et al. 2018, JAS)

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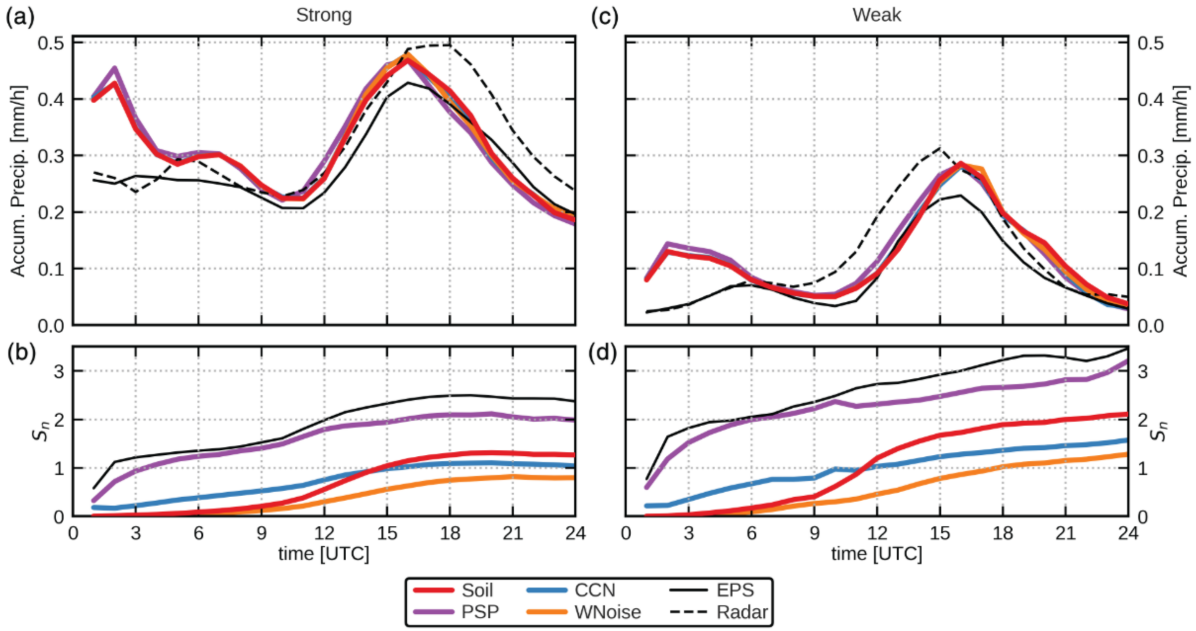

(Keil et al. 2019, QJRMS)

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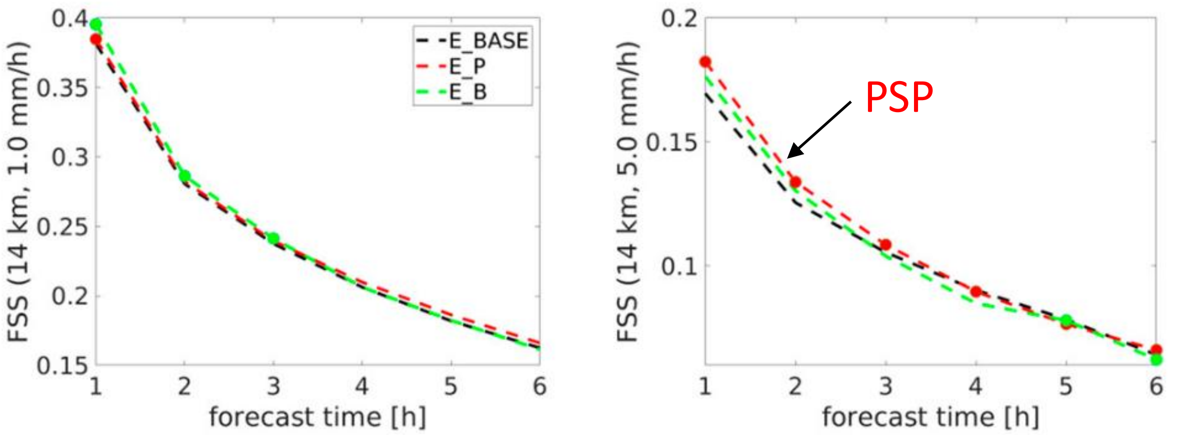

(Zeng et al. 2020, MWR)

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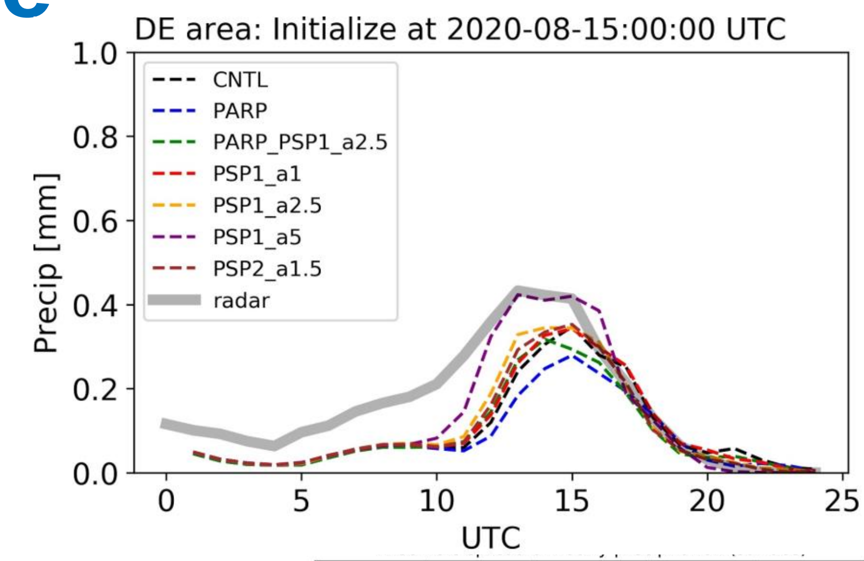
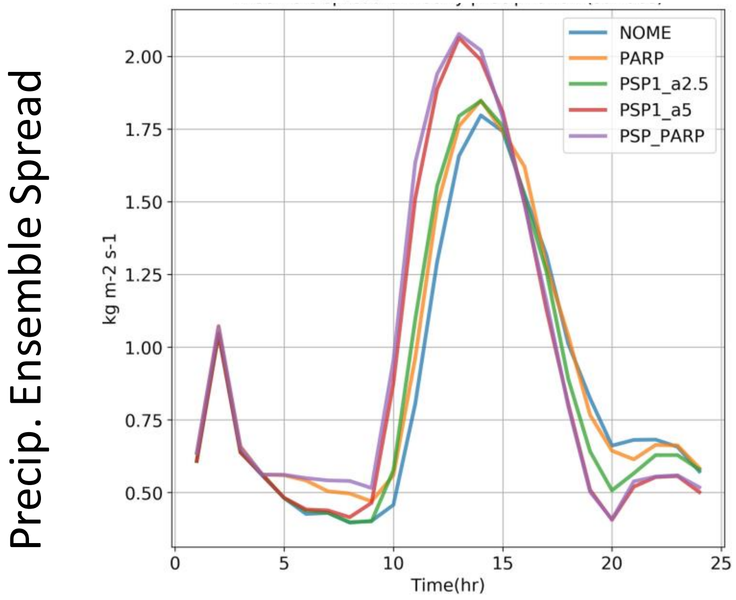
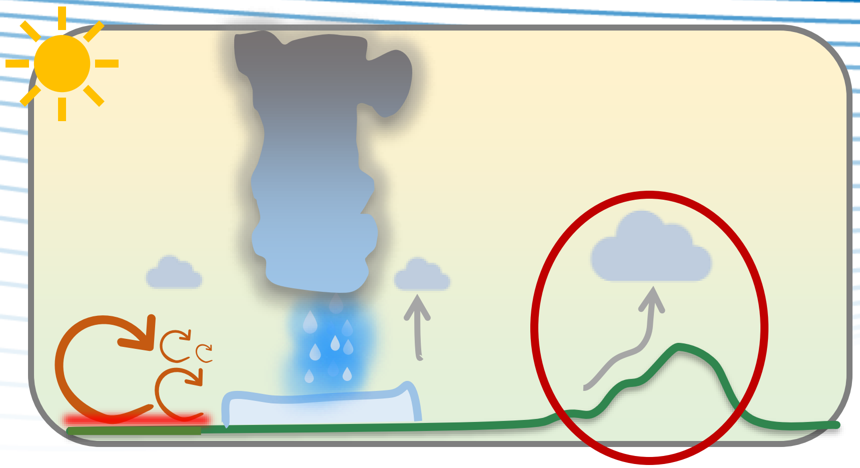




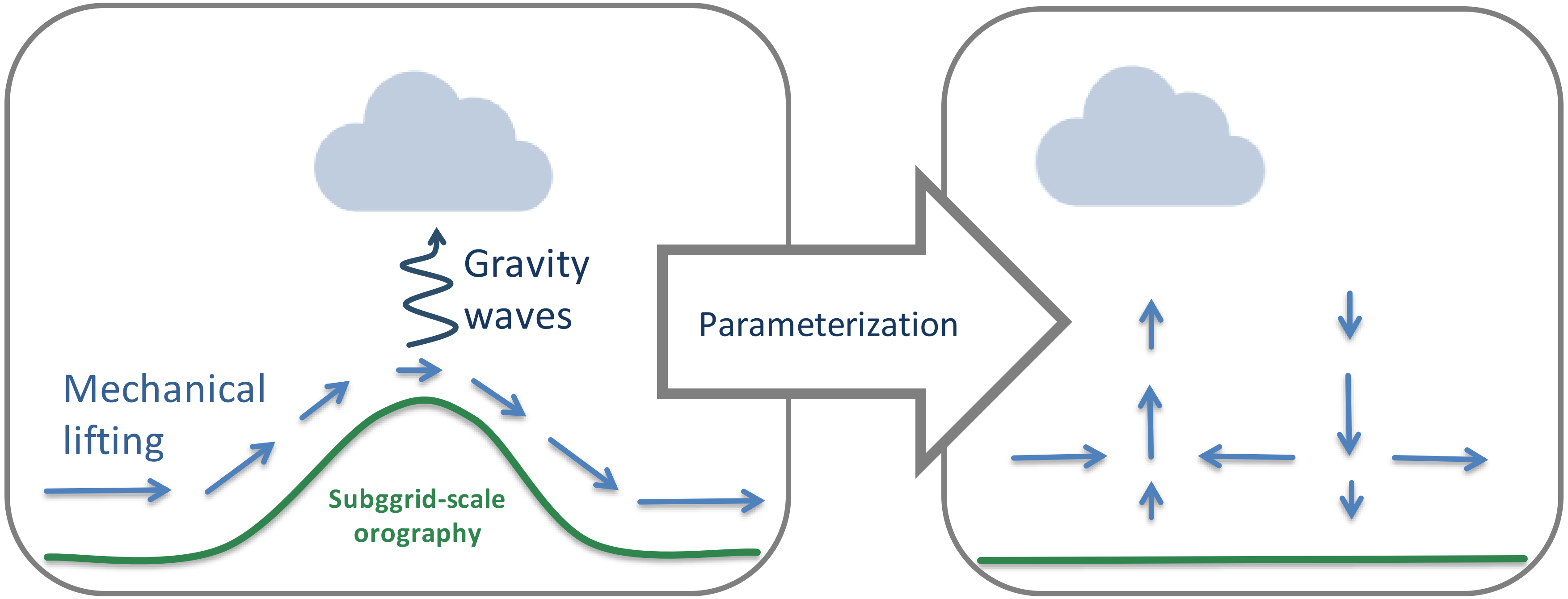
(Figures from I. Chen)



SSOSP: Convective initiation by **Subgrid-scale Orography**

Publication:
Hirt, M., Rasp, S., Blahak, U. and Craig, G. (2019) **Stochastic parameterization of processes leading to convection initiation in kilometre-scale models**. Monthly Weather Review

PSP-SSO: Subgrid scale orography



Physically based stochastic perturbations: Subgrid-scale orography

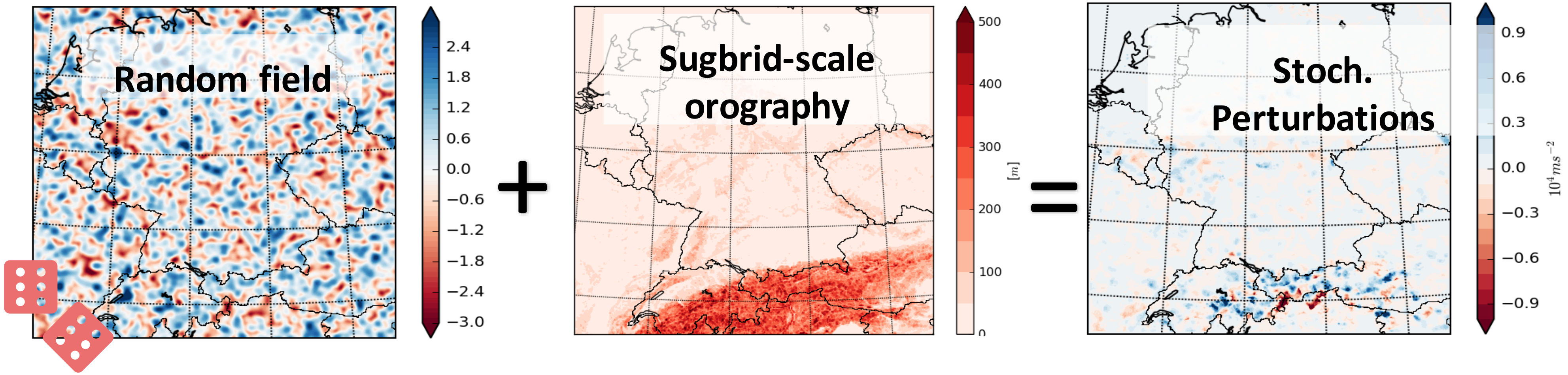
$$\left(\frac{\partial \phi}{\partial t}\right)_{all} = \frac{\partial \phi}{\partial t} + \underbrace{\alpha \cdot \eta \cdot \phi'}_{\text{Stochastic perturbations}}$$

$\boldsymbol{\eta(\tau, \sigma)}$: Random field with Autoregressive process (τ) and spatial correlation σ

$\boldsymbol{\alpha}$: perturbation ampl., scaling factors

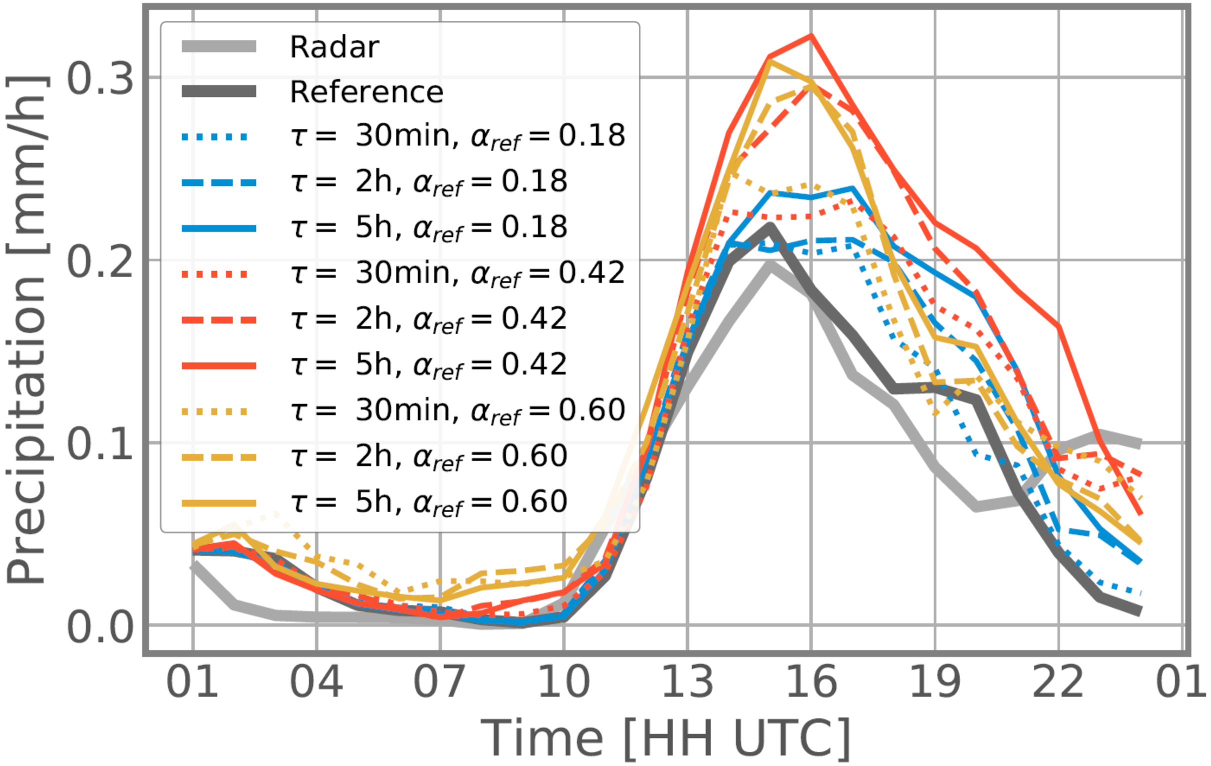
$\boldsymbol{\phi'}$: physical scaling of variable ϕ: $f(SSO, N^2, \ldots)$

ϕ ={u, v, w}

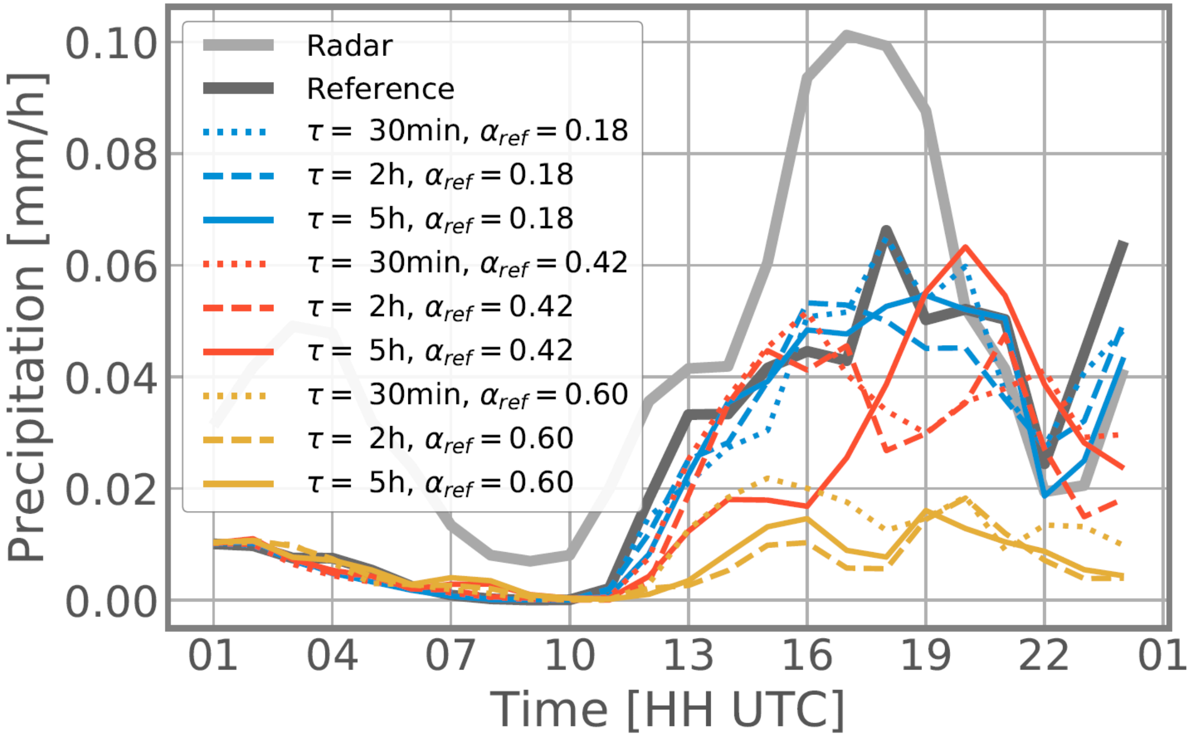


SSOSP

Orographic gridpoints

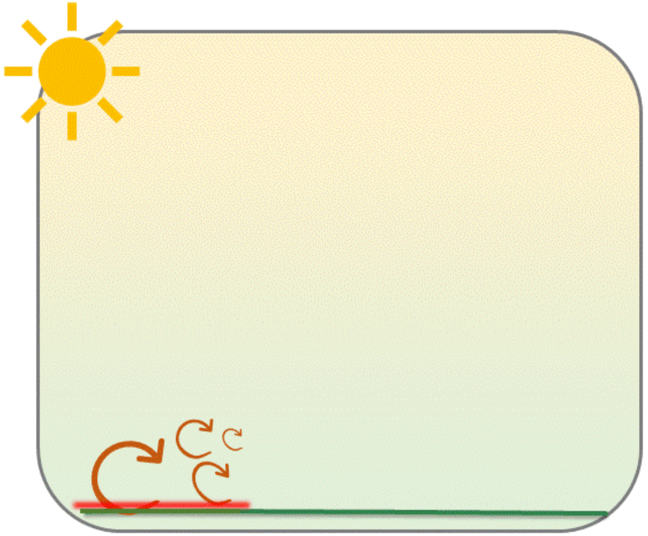


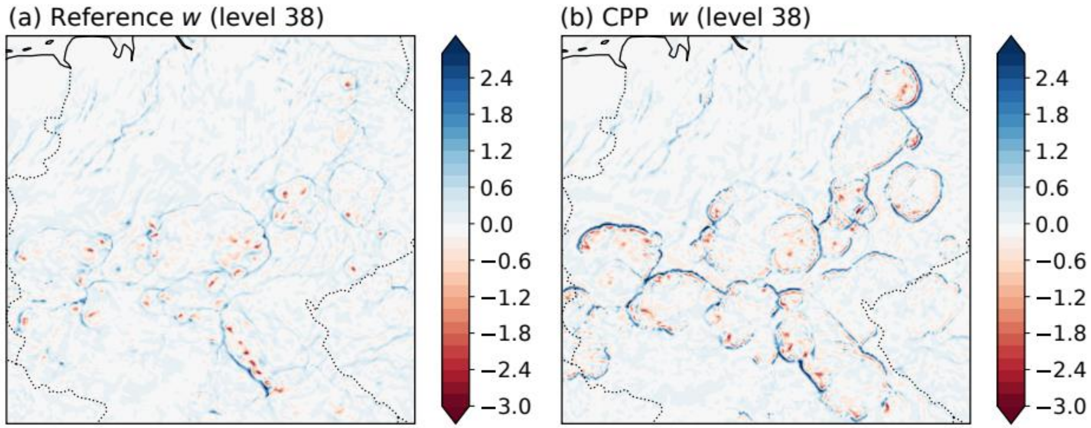
Flat gridpoints



CPP: Convective initiation by Cold Pools

(deterministic)





Hirt et al. (2020), QJRMS

Hirt and Craig (2021), QJRMS (in review)

Summary and conclusions

Summary

1. **PSP2**: Stoch. Perturbations to T, qv, w (u,v) scaled according to **boundary layer turbulence**
   - Improving physical consistency: AR-process, PBL-only, w2uv
   - Results in increased precipitation, especially under weak synoptically forced conditions
   - Ensemble spread is enhanced

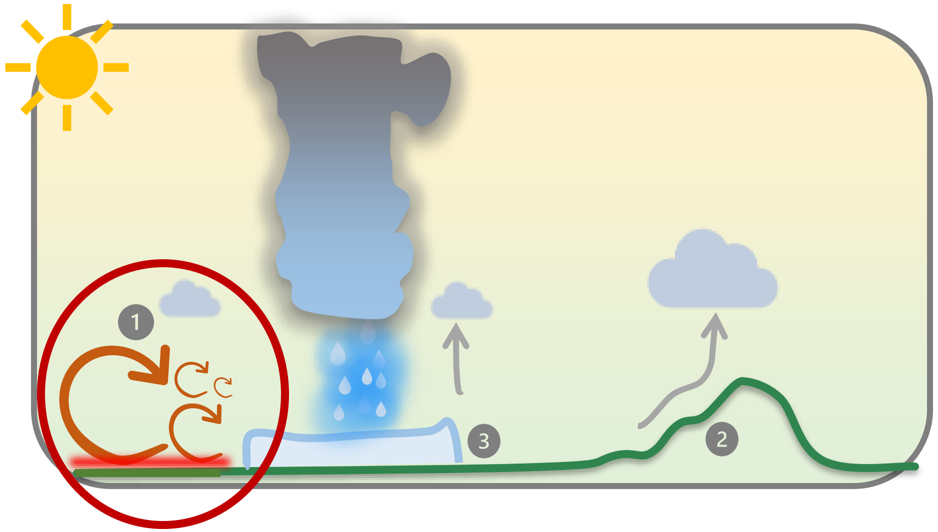
   → PSP as one component of uncertainty to generate **large ensembles** (planned)

Hirt et al., 2019, MWR

2. Representing **subgrid-scale orographic lifting** using stochastic perturbations → **SSOSP**

3. **Cold pools: CPP-Scheme** to strengthen gust fronts (*deterministic*!)

Hirt et al. (2020), QJRMS
Hirt and Craig (2021), QJRMS (in review)



By improving the representation of processes relevant for convective initiation, we can improve convective precipitation forecasts!

PSP Development:

- Kober, K. and Craig, G. C. (2016) Physically based stochastic perturbations (PSP) in the boundary layer to represent uncertainty in convective initiation. Journal of the Atmospheric Sciences, 73, 2893–2911.
- Hirt, M., Rasp, S., Blahak, U. and Craig, G. (2019) Stochastic parameterization of processes leading to convection initiation in kilometre-scale models. Monthly Weather Review.

Cold Pools:

- Hirt, M., and Craig, G. C., (2021) "A cold pool perturbation scheme to improve convective initiation in convection-permitting models", in Review

Thank you for your attention!

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References

PSP:

- Kober, K. and Craig, G. C. (2016) Physically based stochastic perturbations (PSP) in the boundary layer to represent uncertainty in convective initiation. Journal of the Atmospheric Sciences, 73, 2893–2911.
- Hirt, M., Rasp, S., Blahak, U. and Craig, G. (2019) Stochastic parameterization of processes leading to convection initiation in kilometre-scalemodels. MonthlyWeather Review.
- Keil, C., Baur, F., Bachmann, K., Rasp, S., Schneider, L., & Barthlott, C. (2019). Relative contribution of soil moisture, boundary-layer and microphysical perturbations on convective predictability in different weather regimes. *Quarterly Journal of the Royal Meteorological Society*, 1–14.
- Zeng, Y., Janji´c, T. J., De Lozar, A., Rasp, S., Blahak, U., Seifert, A., & Craig, G. C. (2020). *Comparison of methods accounting for subgrid-scale model error in convective-scale data assimilation*.
- Rasp, S., Selz, T. and Craig, G. C. (2018) Variability and clustering of midlatitude summertime convection: Testing the Craig and Cohen theory in a convection-permitting ensemble with stochastic boundary layer perturbations. Journal of the Atmospheric Sciences, 75, 691–706.

Cold Pools:

- Hirt, M., Craig, G. C., Schäfer, S. A. K., Savre, J. and Heinze, R. (2020) “Cold pool driven convective initiation: using causal graph analysis to determine what convection permitting models are missing”, Quarterly Journal of the Royal Meteorological Society.
- Hirt, M., and Craig, G. C., (2021) “A cold pool perturbation scheme to improve convective initiation in convection-permitting models”, in Review