Cold pool driven convective initiation: How can we improve its representation in km-scale models?

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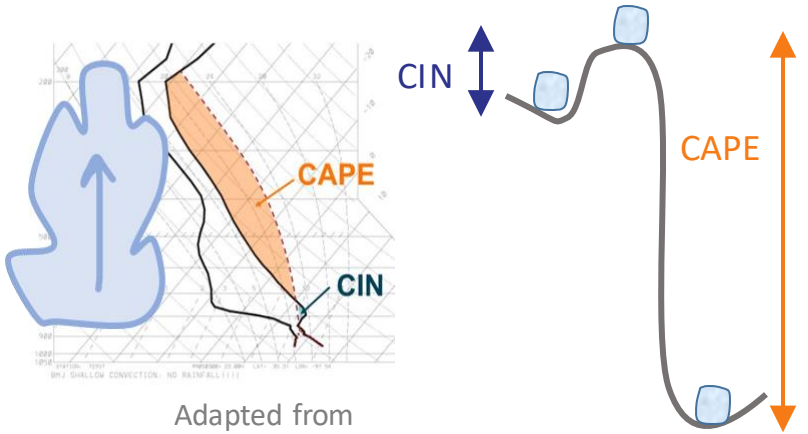
Motivation:

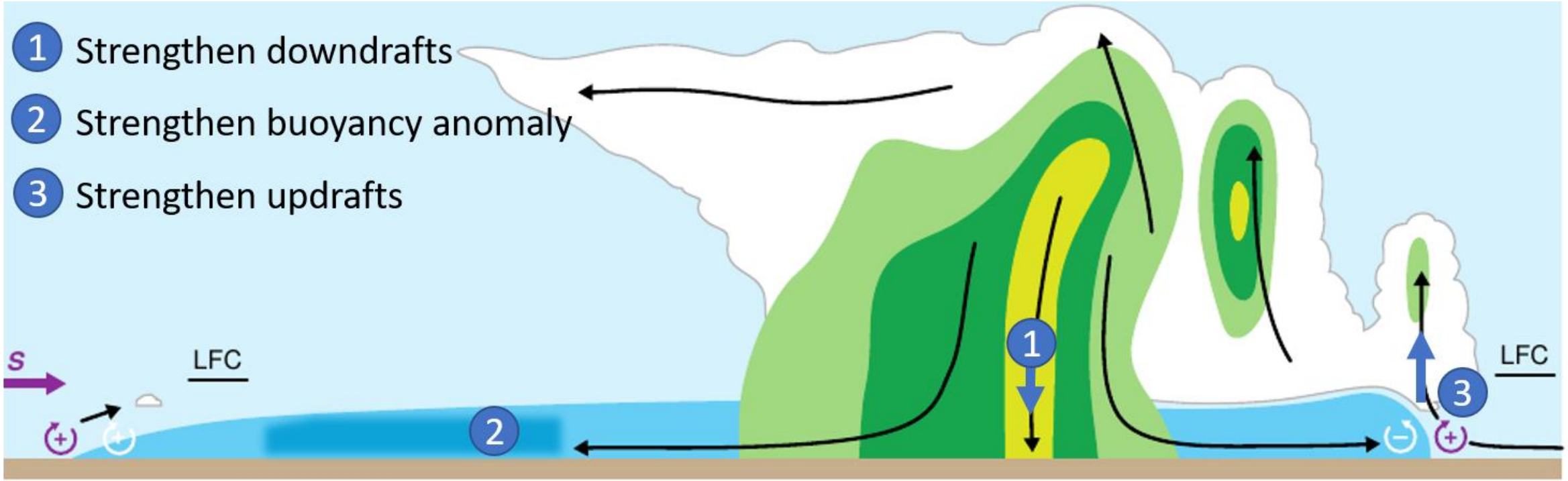
- Km-scale models are now widely used for numerical weather prediction
- Still struggle in capturing **realistic diurnal cycles** and **organization** of convection
- Partially related to **unresolved convection initiation**
- Kober and Craig, 2016 (JAS) and Hirt et al. 2019 (MWR): **Physically based stochastic perturbations (PSP)** for PBL turbulence
- But **organization** and **evening precipitation** is not addressed



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

→ Parameterization to account for Cold pool driven convection initiation?

CPP: cold pool perturbations

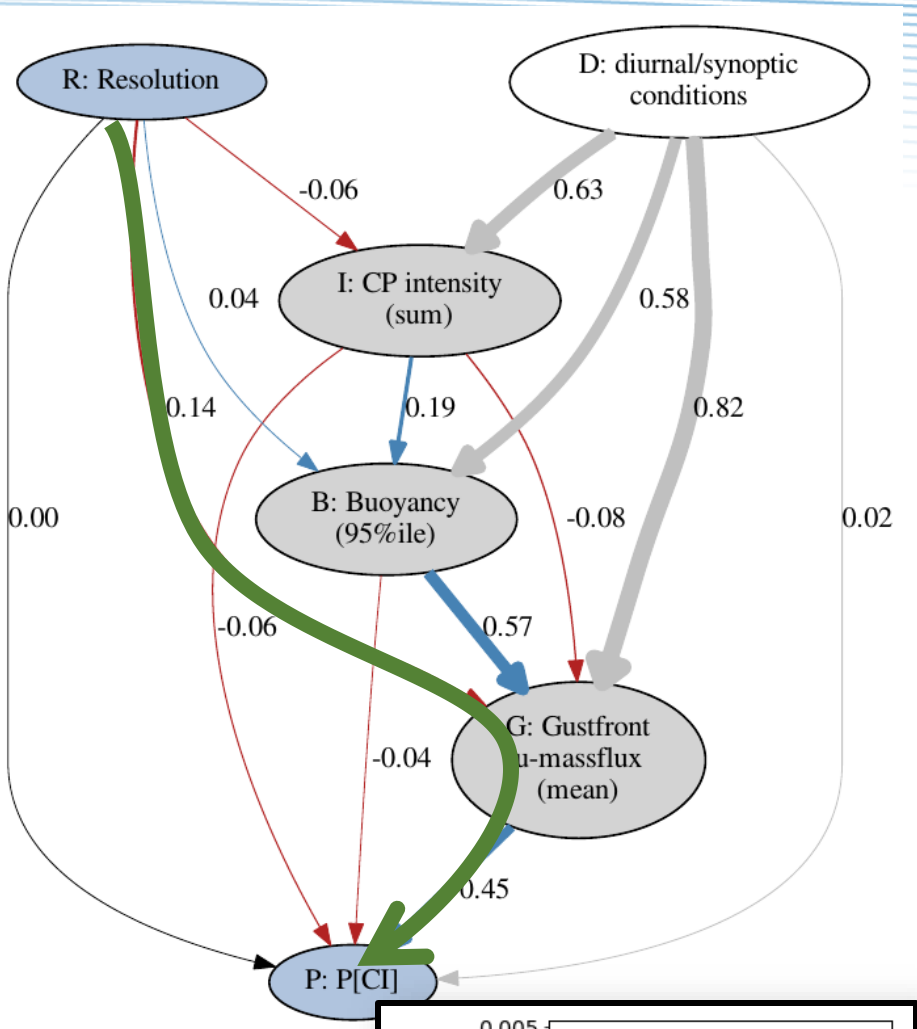


From Markowski and Richardson (2011), modified

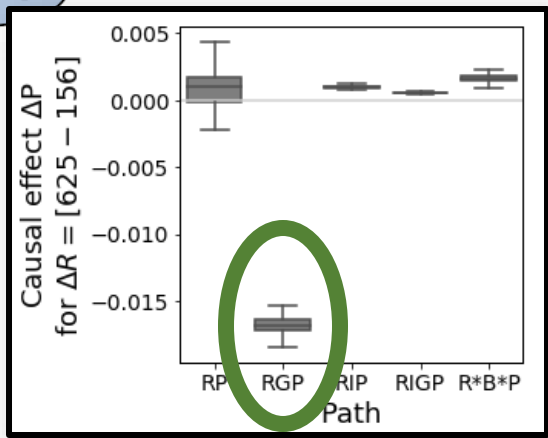
Summary Hirt et al. 2020, QJRMS (accepted):

- Cold pools are **more frequent**, **smaller** and **less intense** in lower resolutions (156m – 612m; HDCP2 ICON-LEM simulations).
- Their **gust fronts** are **weaker** and **trigger less** new convection in lower resolutions.
- **Causal graph analysis**: RGB path dominates!

→**Develop perturbations to strengthen cold pool gust fronts**



Probability of convective initiation



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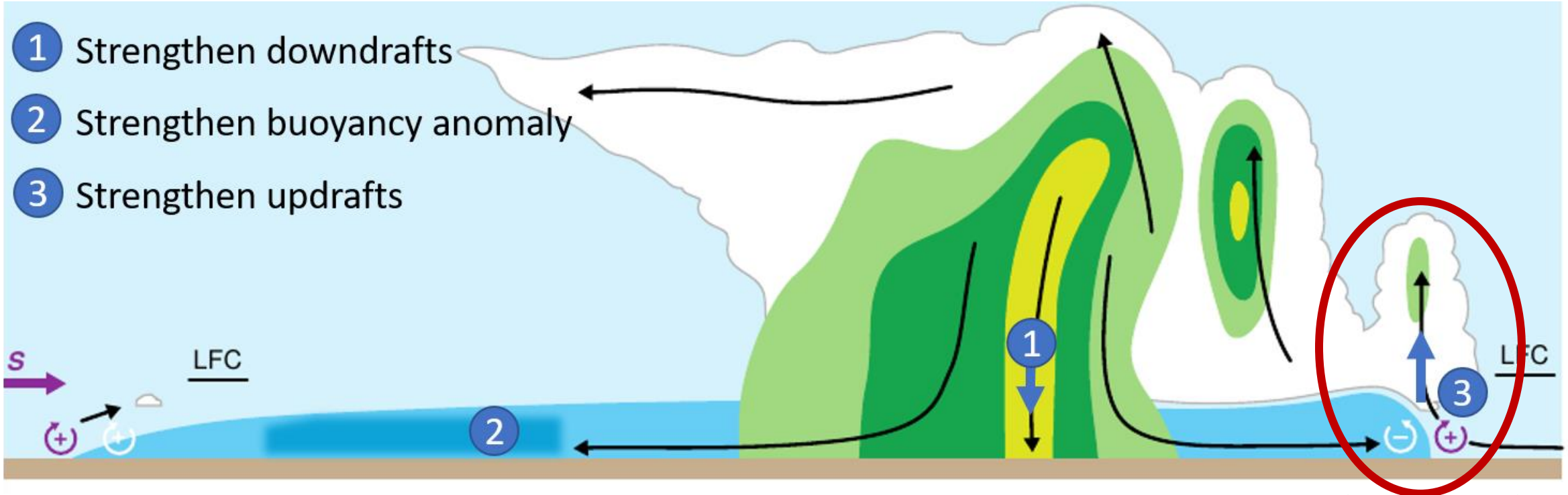
CPP: cold pool perturbations



From Markowski and Richardson (2011), modified

Design of the Cold Pool Perturbations (CPP)

Theoretical explanation:

- Vorticity – Streamfunction system (xz-plane, inviscous, Boussinesque-approximated)
- Dimensional analysis

$$\rightarrow \quad \mathbf{W} = \sqrt{\frac{\mathbf{BH}}{\mathbf{1}+\frac{\mathbf{L^2}}{\mathbf{H^2}}}}$$

L: horizontal length scale (limited by Δx)

H: vertical length scale

Fully **resolved case**: L/H=1

$$\rightarrow \quad \mathbf{w_0} = \sqrt{\frac{\mathbf{BH}}{\mathbf{2}}}$$

Similar relationships have also been derived for:

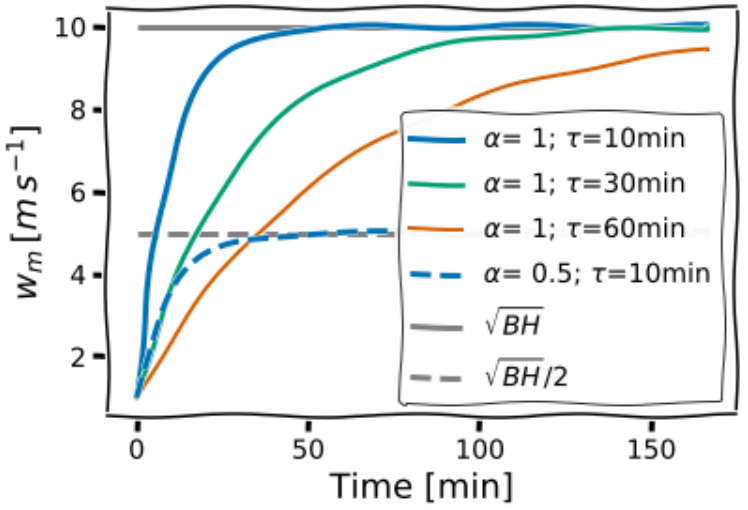
- the horizontal propagation speed of a density current ($\mathrm{U} = \sqrt{2\mathrm{BH}}$)
- Rising warm bubbles (resolution dependency)
  - Jeevanjee 2017, JAMES
  - Morrison 2015, JAS
  - Pauluis and Garner 2006, JAS
  - Weisman et al. 1997, MWR

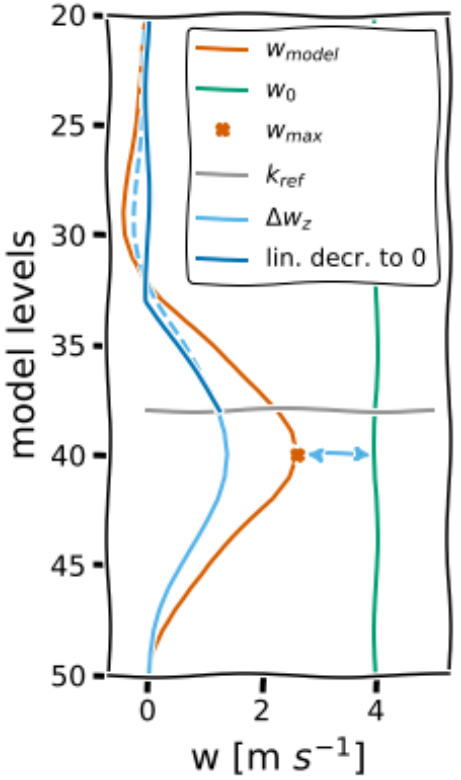
CPP Basic design

- Nudging gust front vertical velocity towards $\mathbf{w_0} = \sqrt{\mathbf{BH}/\mathbf{2}}$

$$\left.\frac{\partial w}{\partial t}\right|_{cp} = \frac{w_0 - w}{\tau_{cp}}$$

- Details:
  - Estimation of $\sqrt{BH}$ $\left(B = \frac{|\nabla\overline{\theta_v}|}{\theta_v} \cdot g\ 5\Delta x, H = 200m\right)$
  - $\boldsymbol{\alpha_{cp}}$ for tuning w_0
  - Vertical profile from model → w_{max}
  - Identifying cold pool gust fronts in the model
  - Time scale τ_{cp} = 10-30 min
  - u, v are perturbed in 3d-non-div. way (see Hirt et al. 2019, MWR)

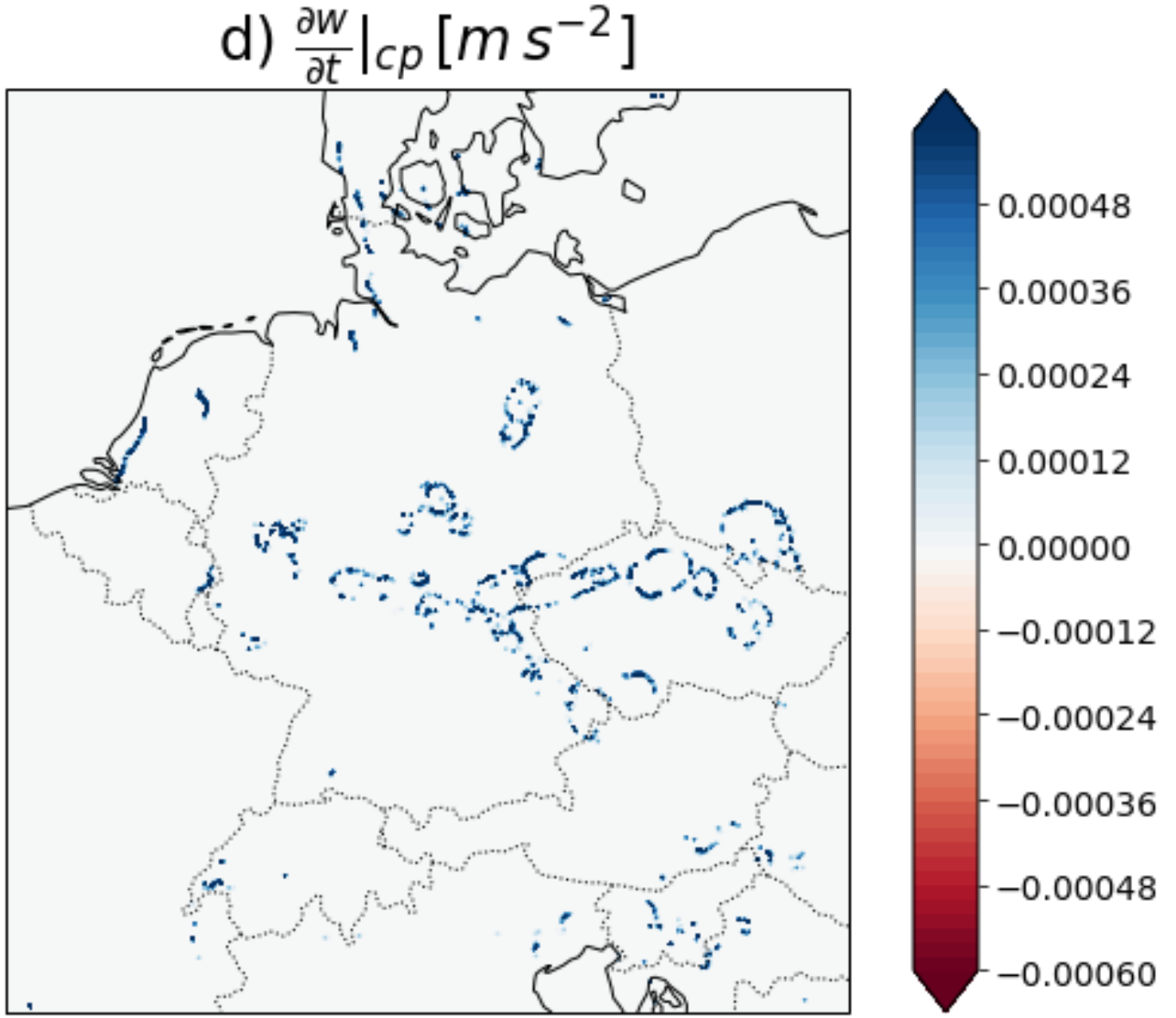




$$\left.\frac{\partial w}{\partial t}\right|_{cp} = \frac{1}{\tau_{cp}} \frac{\left(\boldsymbol{\alpha_{cp}}\sqrt{BH} - w_{max}\right)}{w_{max}} \cdot w(z)$$

Horizontal constraints to select gust fronts

- $|\nabla\theta_v| >$ threshold
- $w_{max} >$ threshold
- SSO < threshold
- $(w_0 - w_{max}) > 0$



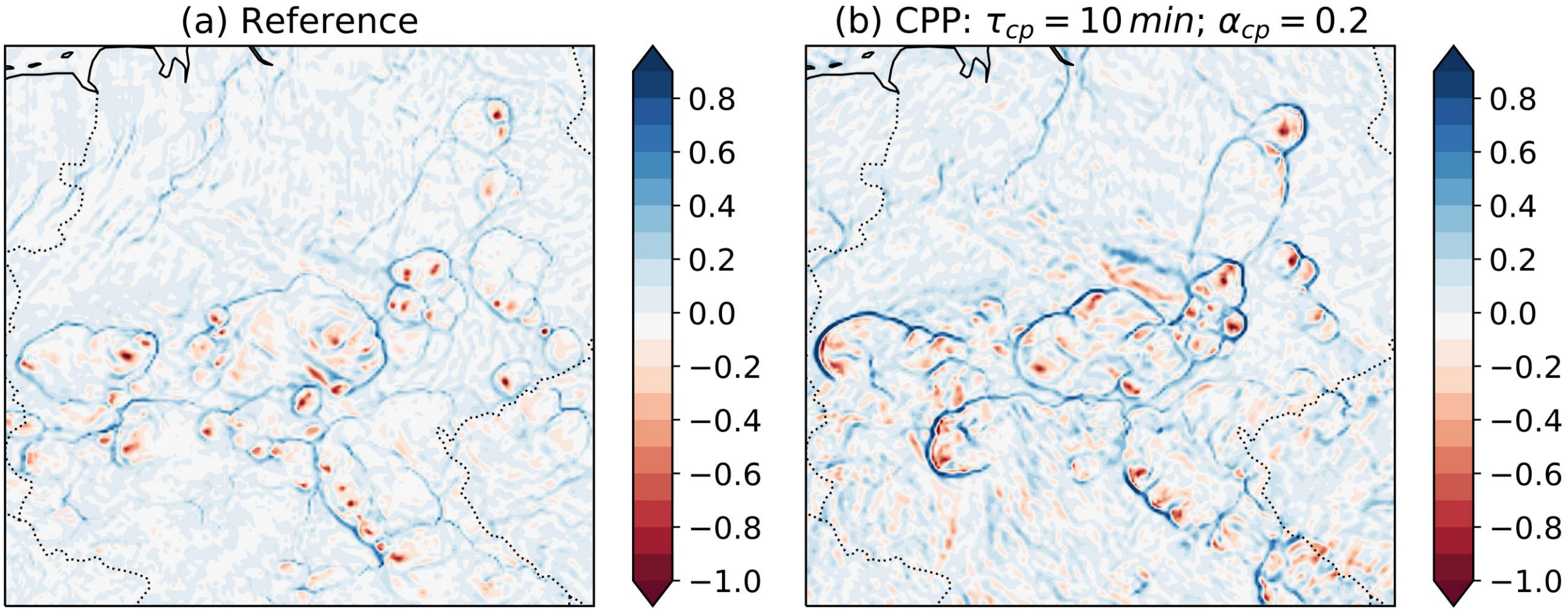
Simulations and model setup

- **COSMO-DE**, $\Delta x = 2.8\,\mathrm{km}$, operational setup (except tur_len=500)
- Test case: **5 June 2016** with many cold pools
- Longer evaluation period: **29 May -7 June 2016**
- 24 h, deterministic simulations

WAVES TO WEATHER

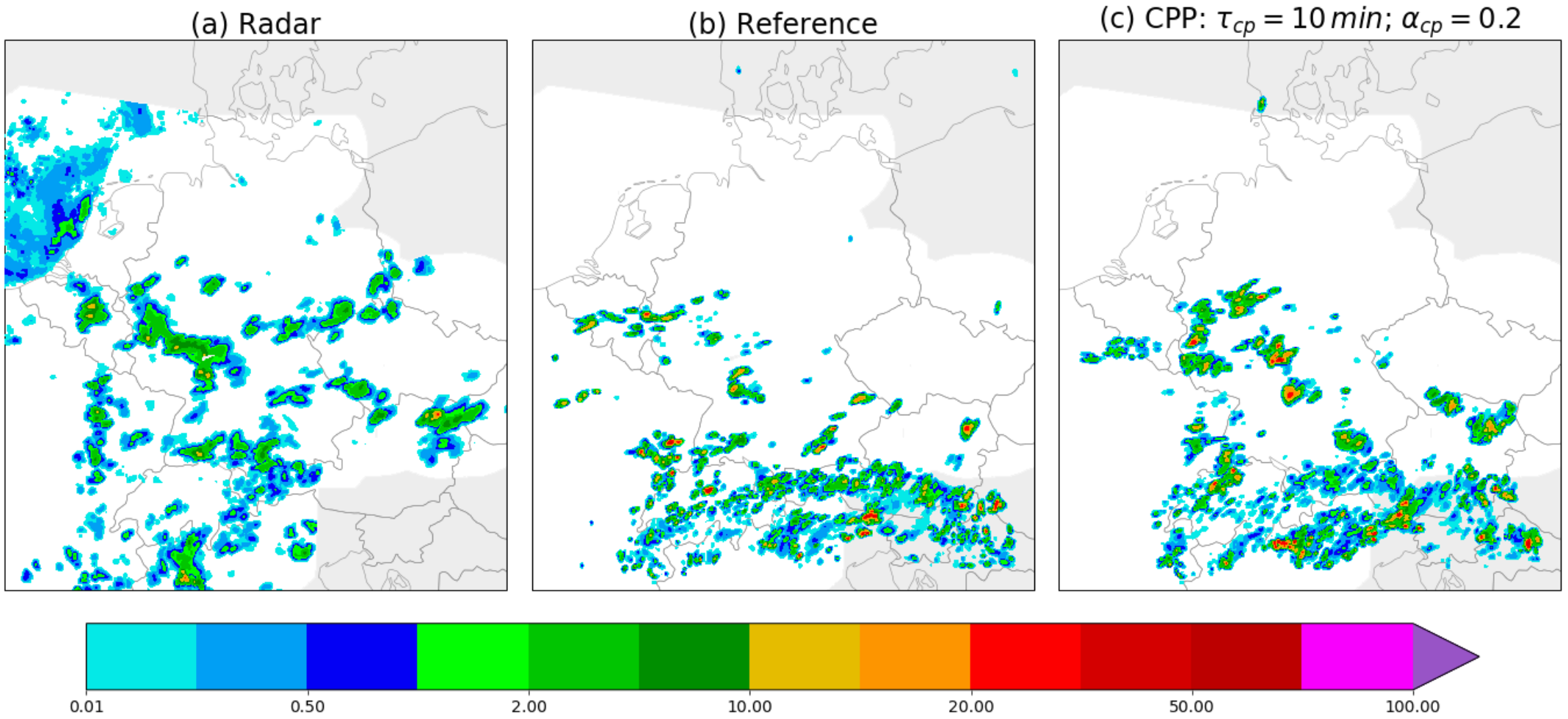
Impact of cold pool perturbations (CPP)

Vertical velocity [m/s]

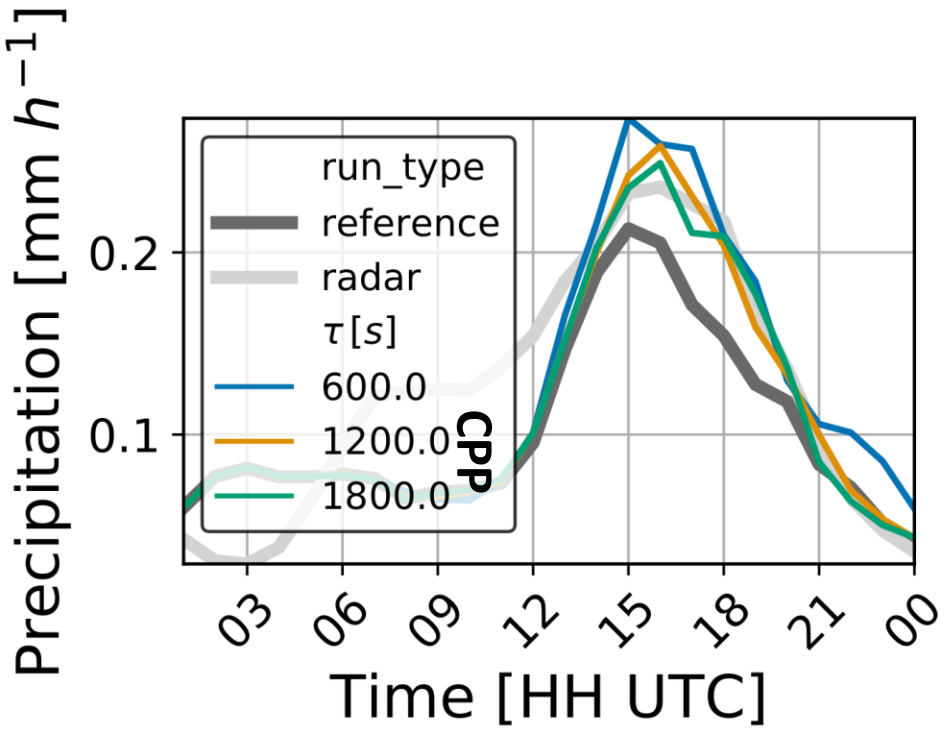


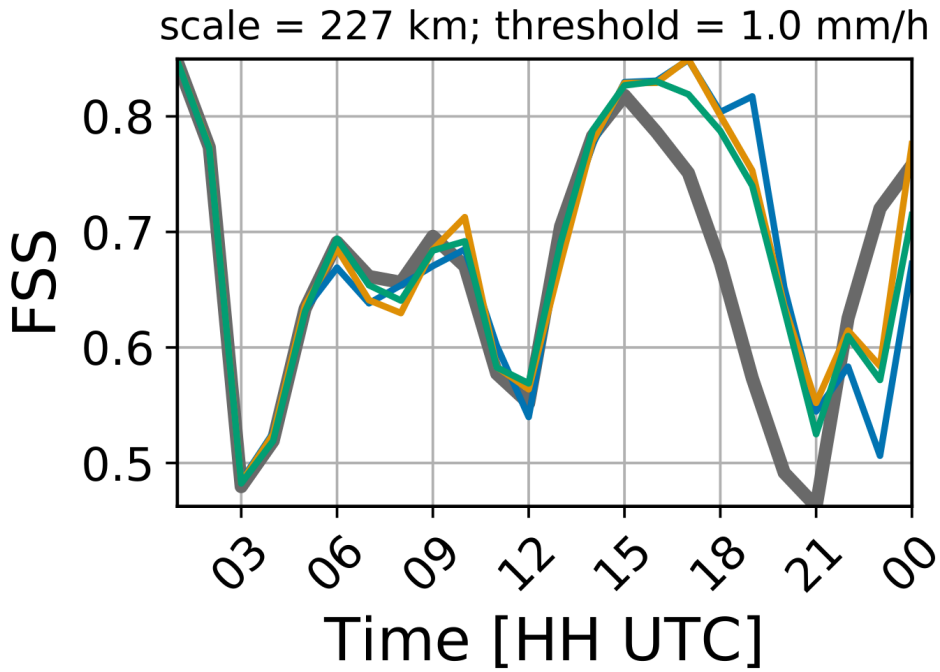
5th level above surface, 15 UTC
5 June 2016, 15:00 UTC

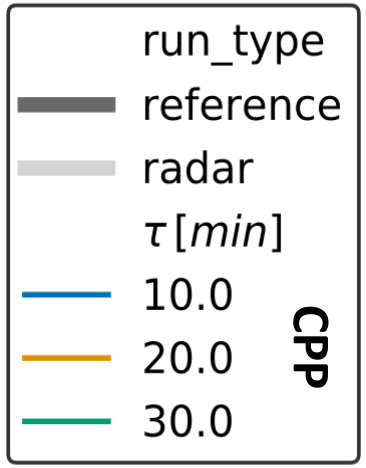
Precipitation [mm/h]



Precipitation - diurnal cycle

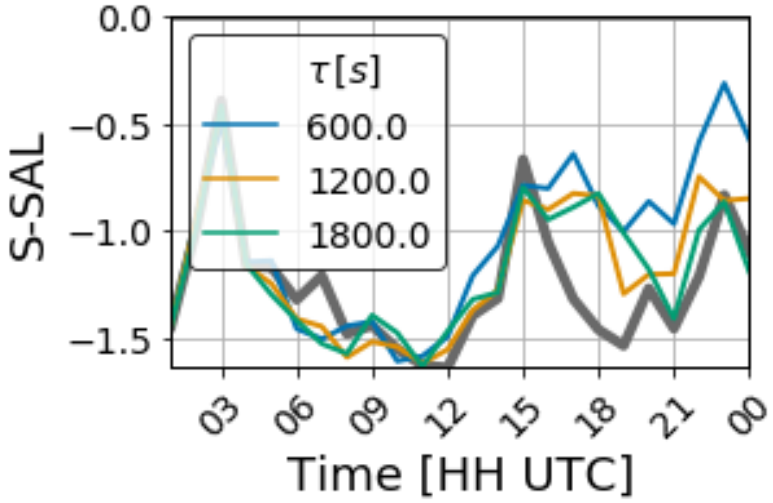


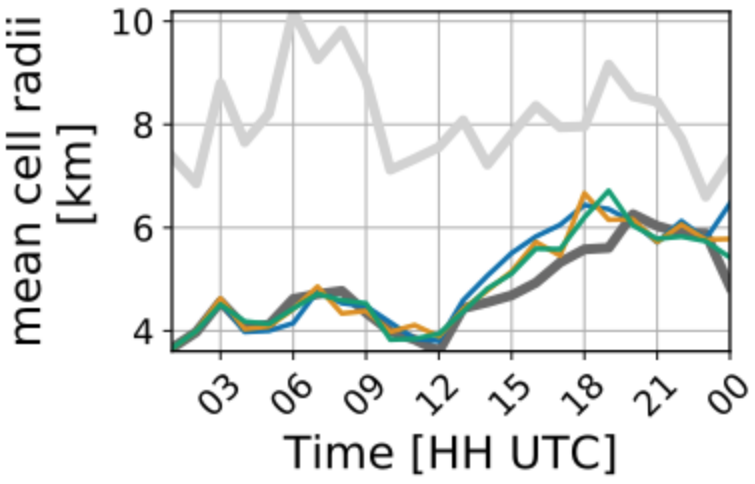


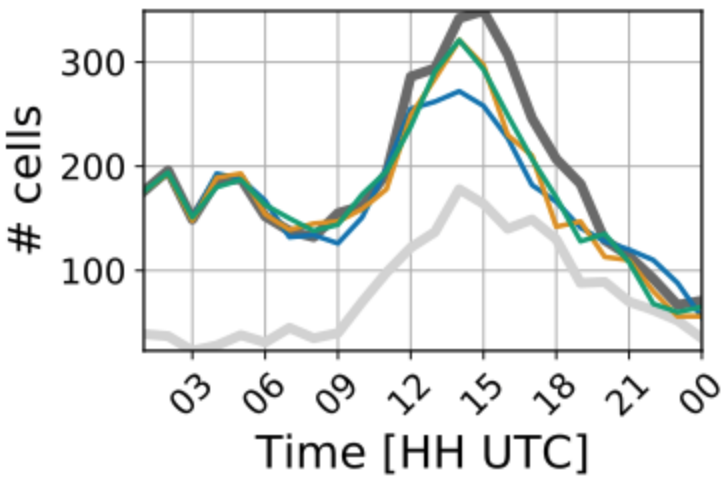


5 June 2016

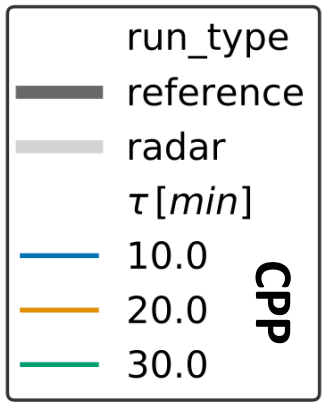
Precipitation - organization



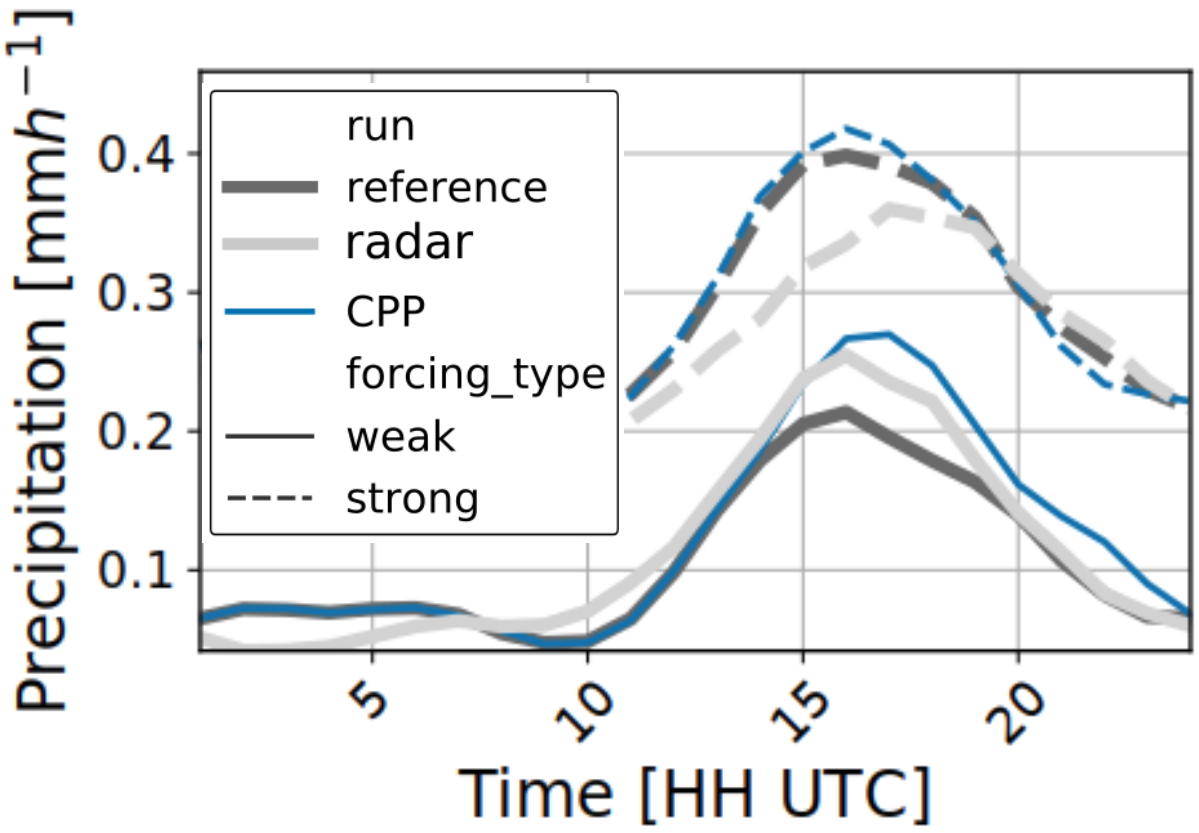


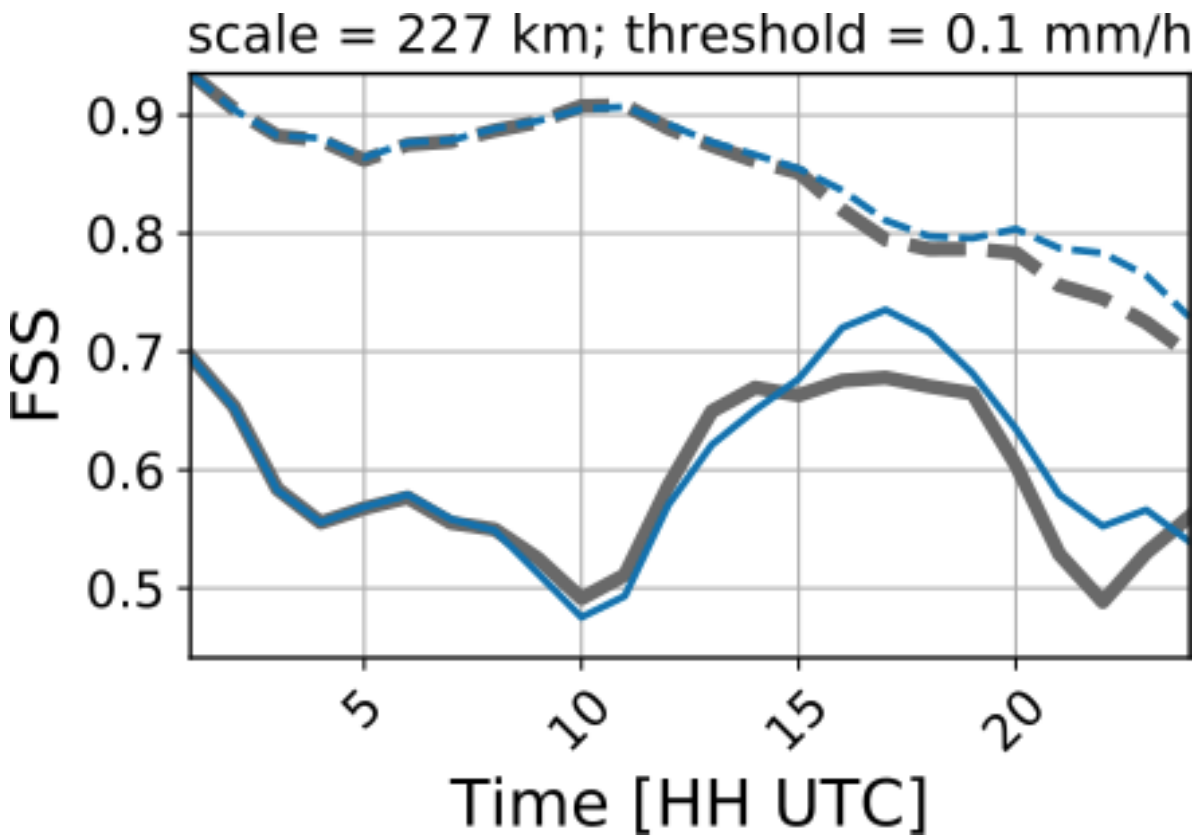


- S-SAL is improved (more wide, less peaked)
- Cell get bigger and less frequent
- Area based metrics: indirect measures for organization
- Distance based metrics (RDF; I-org): Interpretation more difficult



10 day period

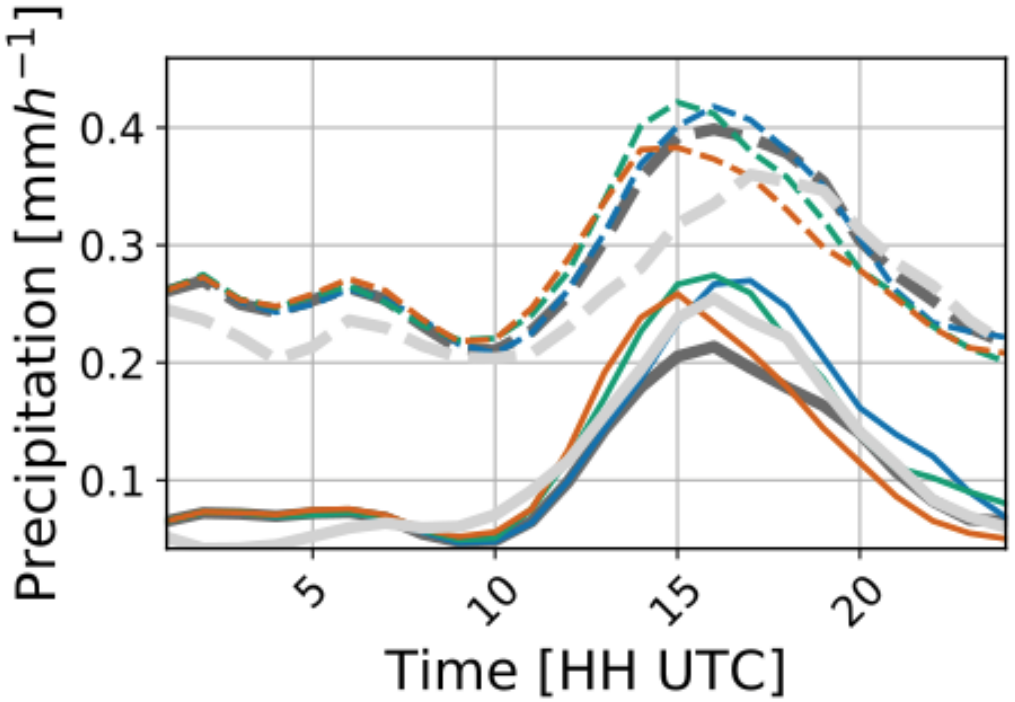


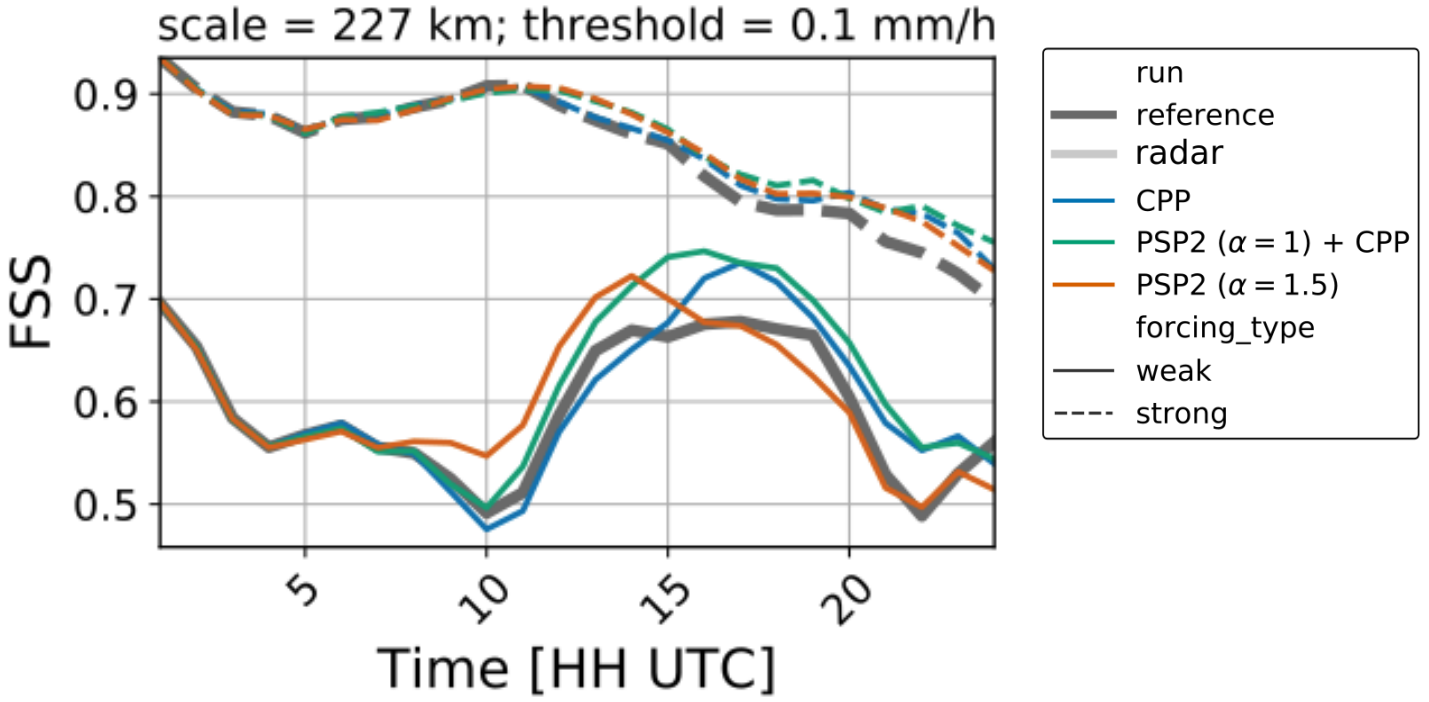


CPP + PSP2: “effects add up”

PSP2: Stochastic perturbations to account for **subgrid variability of boundary layer turbulence**;

PSP: Kober and Craig, 2016 (JAS); PSP2: Hirt et al. 2019 (MWR)





Further analyses

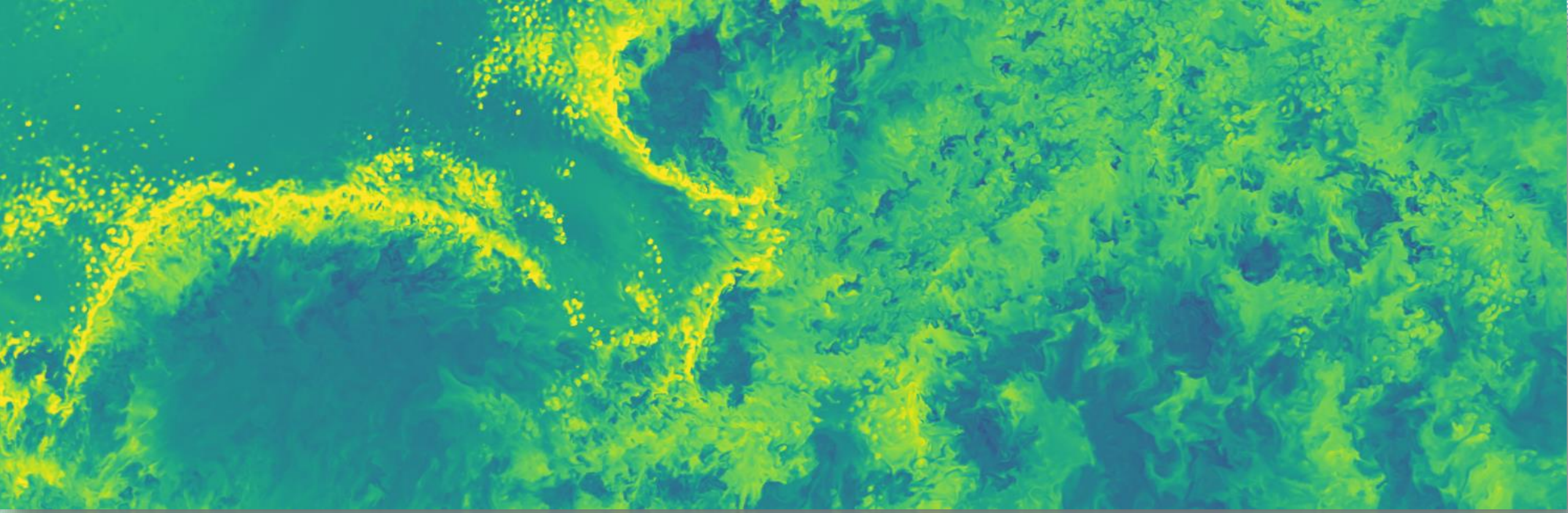
- Parameter sensitivity study
- Using 2-moment microphysics instead of single moment one
- Impact on Cold pool intensities and sizes

Summary

- CPP **strengthens cold pool gust fronts** by increasing w towards some target w_0
- **Precipitation** in afternoon/evening is strengthened and **FSS improved**
- **Organization** seems to be **improved**
- **Flow dependent** behavior
- **PSP2 + CPP**: Effects of PSP2 and CPP “add up”

Possible next steps

- Enable scale adaptivity (within km-scale range)
  - Thresholds need to be defined in a scale-adaptive way
  - Simulations with different resolutions are required
- Identify impact of CPP on other aspects, e.g. land-sea breeze
- Physically based: → retuning of other parameters may be necessary?
- Improve computational efficiency
- Implement in ICON



Thank you for your attention!

References

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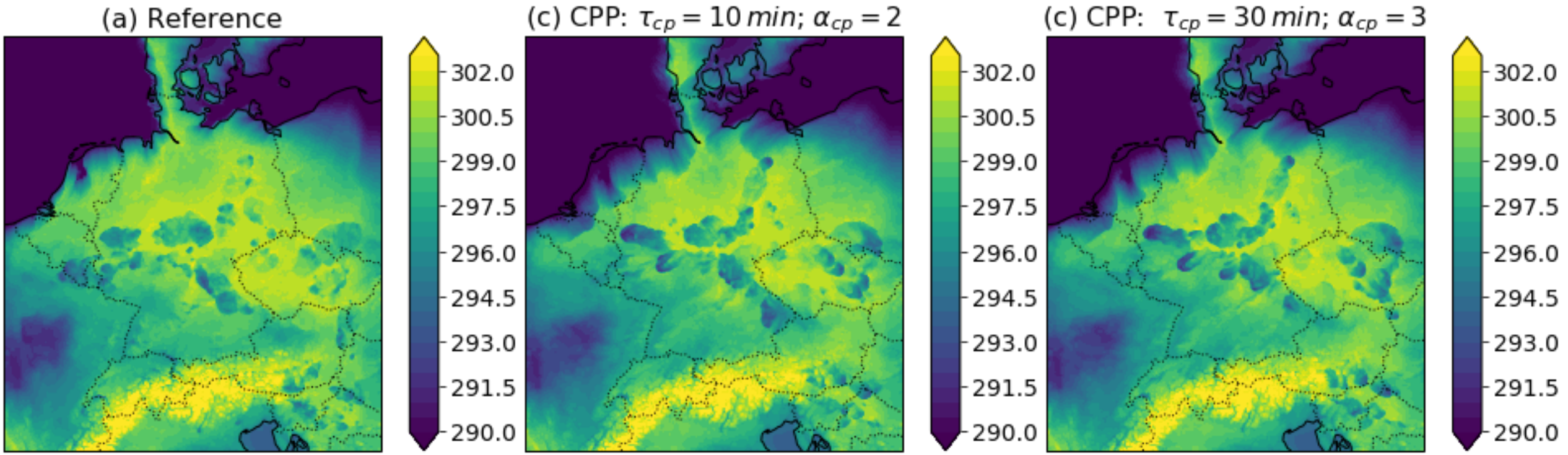
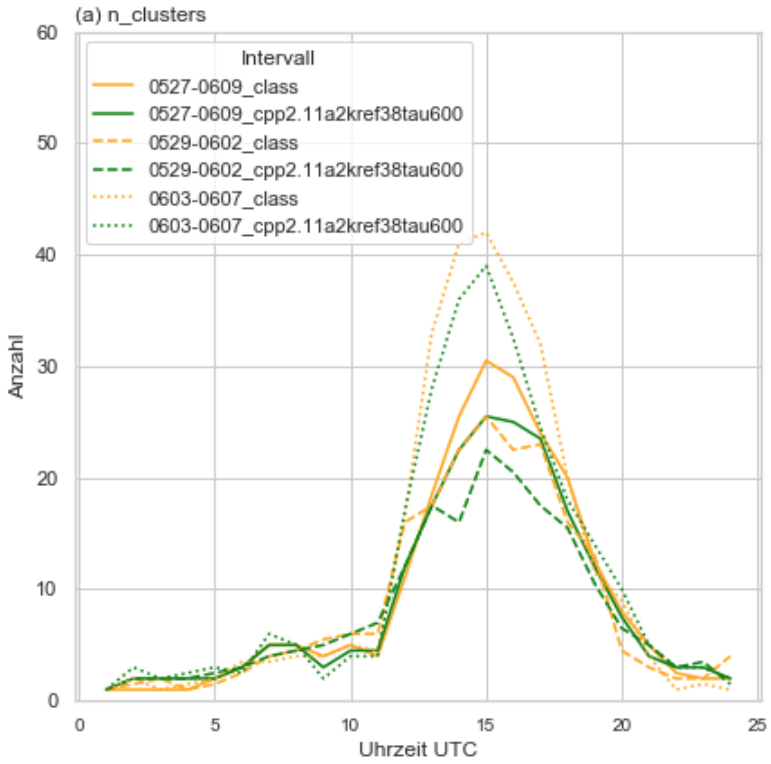
- Markowski, Paul, and Yvette Richardson. Mesoscale meteorology in midlatitudes. Vol. 2. John Wiley & Sons, 2011.

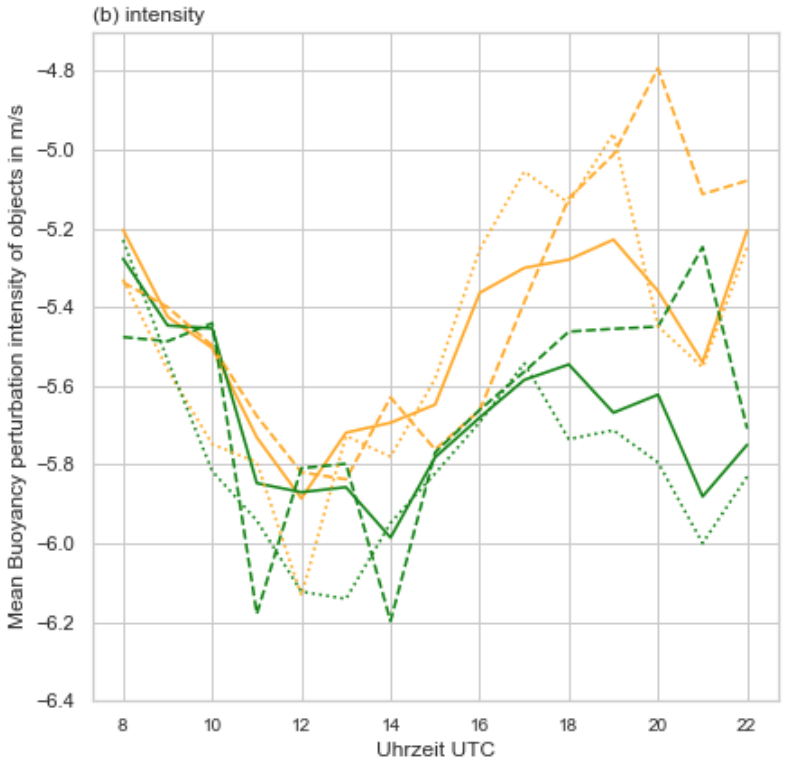
Impact of CPP: cold pools (feedback)

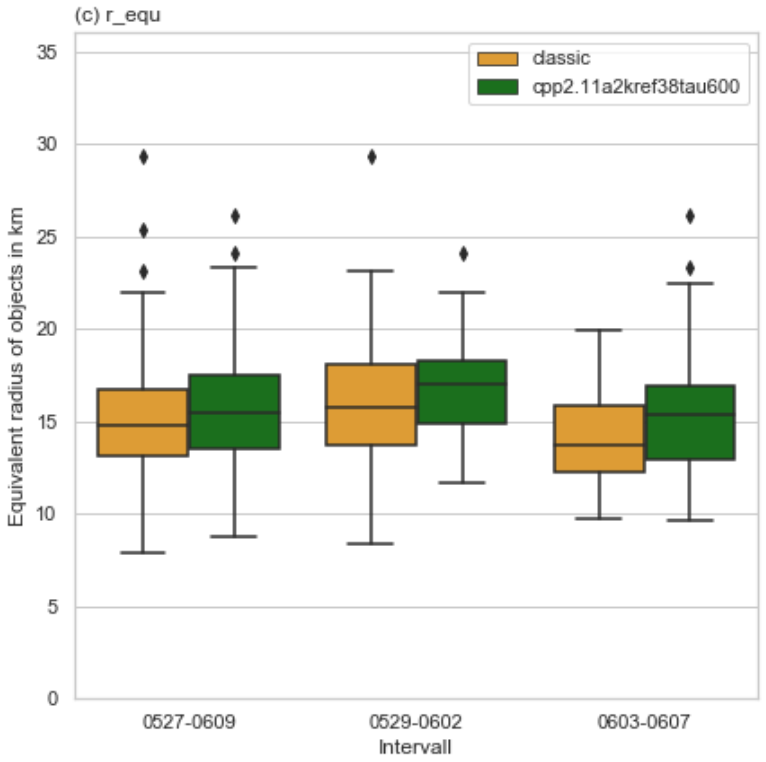
Theta-v fields; 5 June 2016



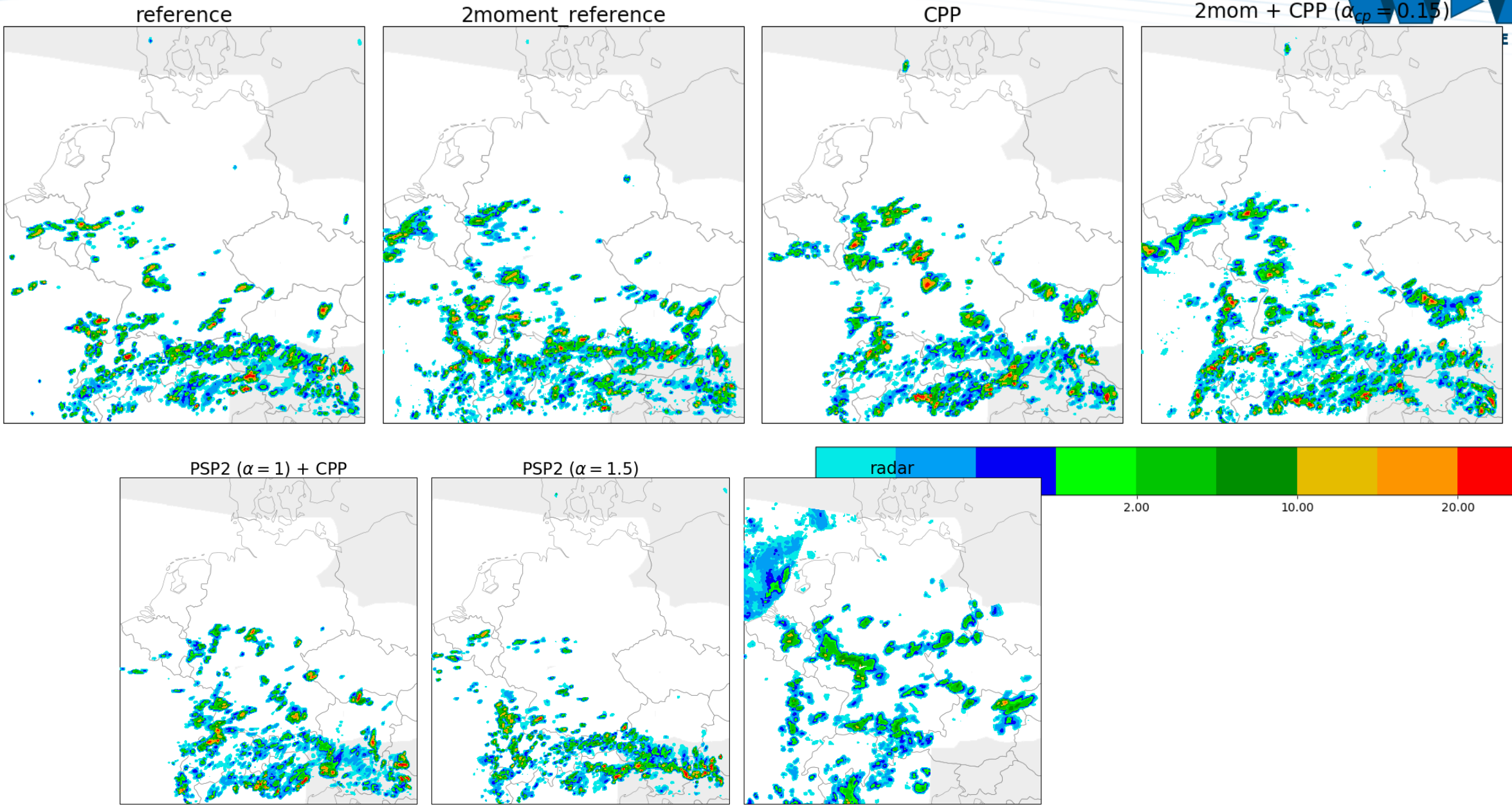
C. Sackrenz: Cold pool detection in COSMO



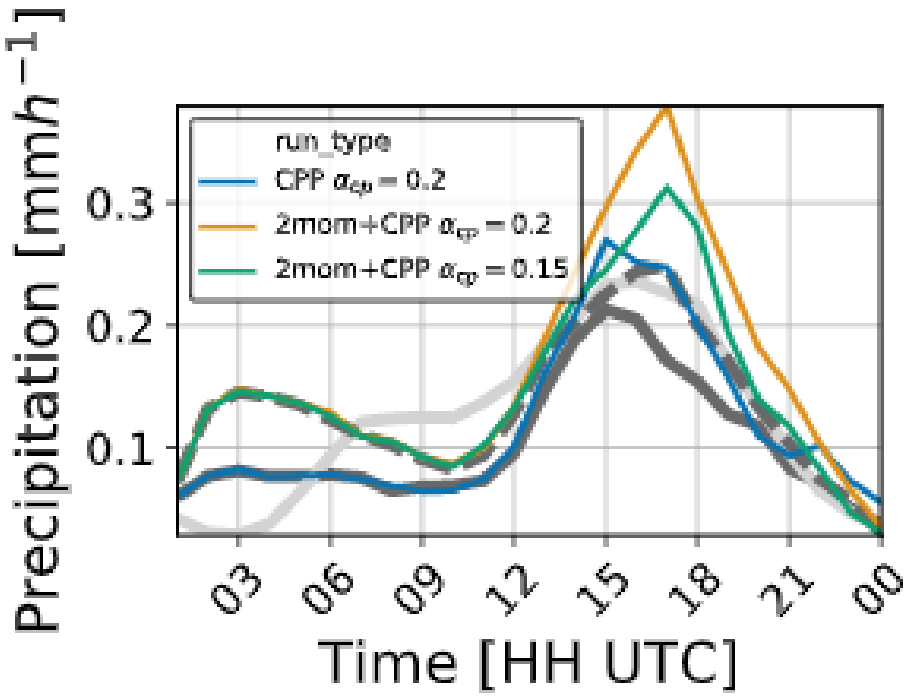


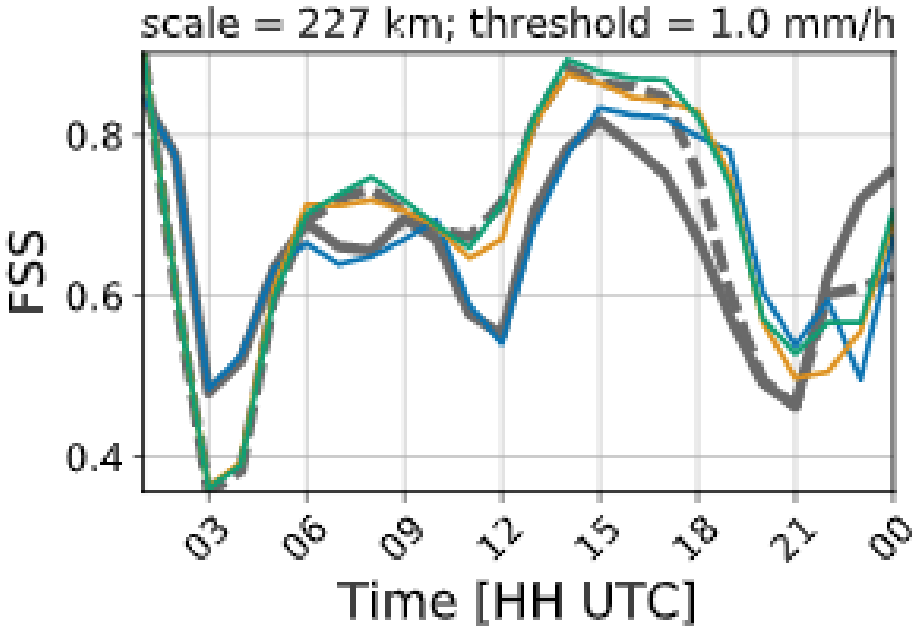


With **CPP** (green), there are **less cold pools**, they **are more intense** and **bigger**.


reference
2moment_reference
CPP
2mom + CPP ($\alpha_{cp} = 0.15$)
PSP2 ($\alpha = 1$) + CPP
PSP2 ($\alpha = 1.5$)
radar
2.00
10.00
20.00

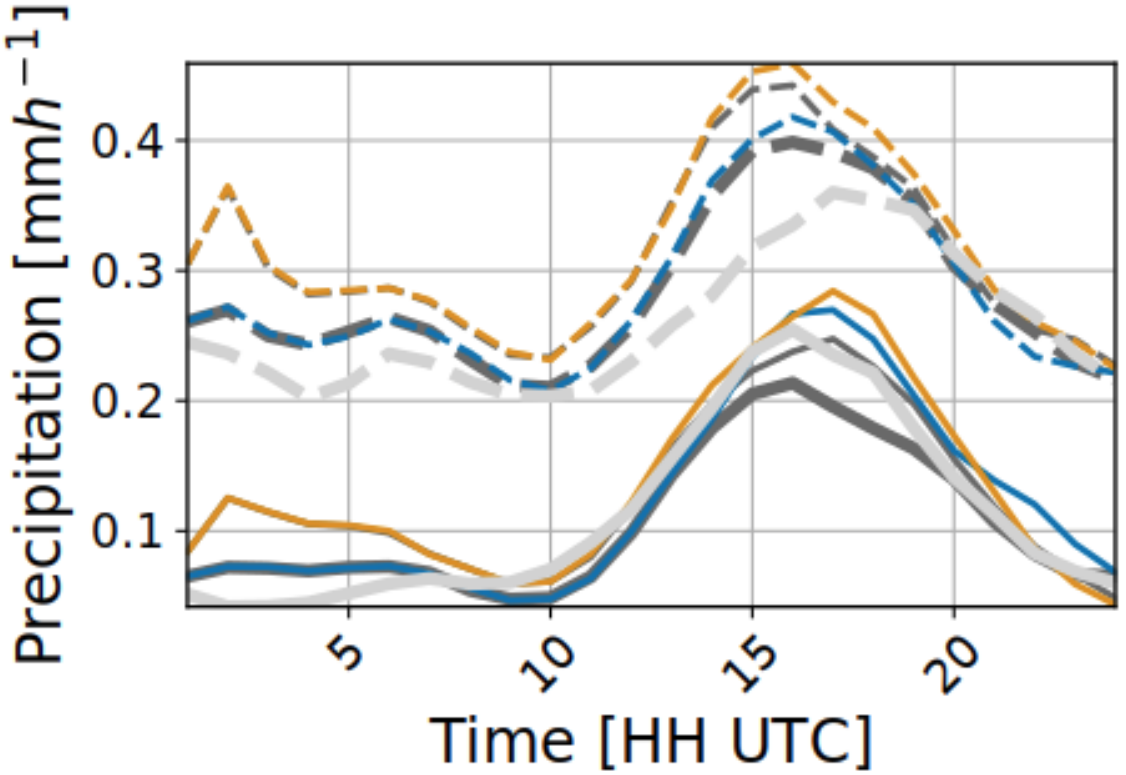
5 June 2020

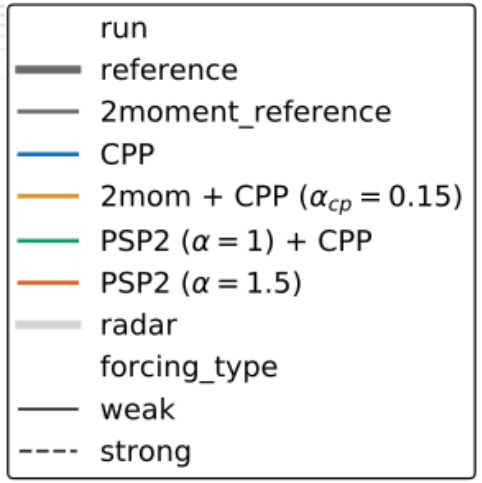


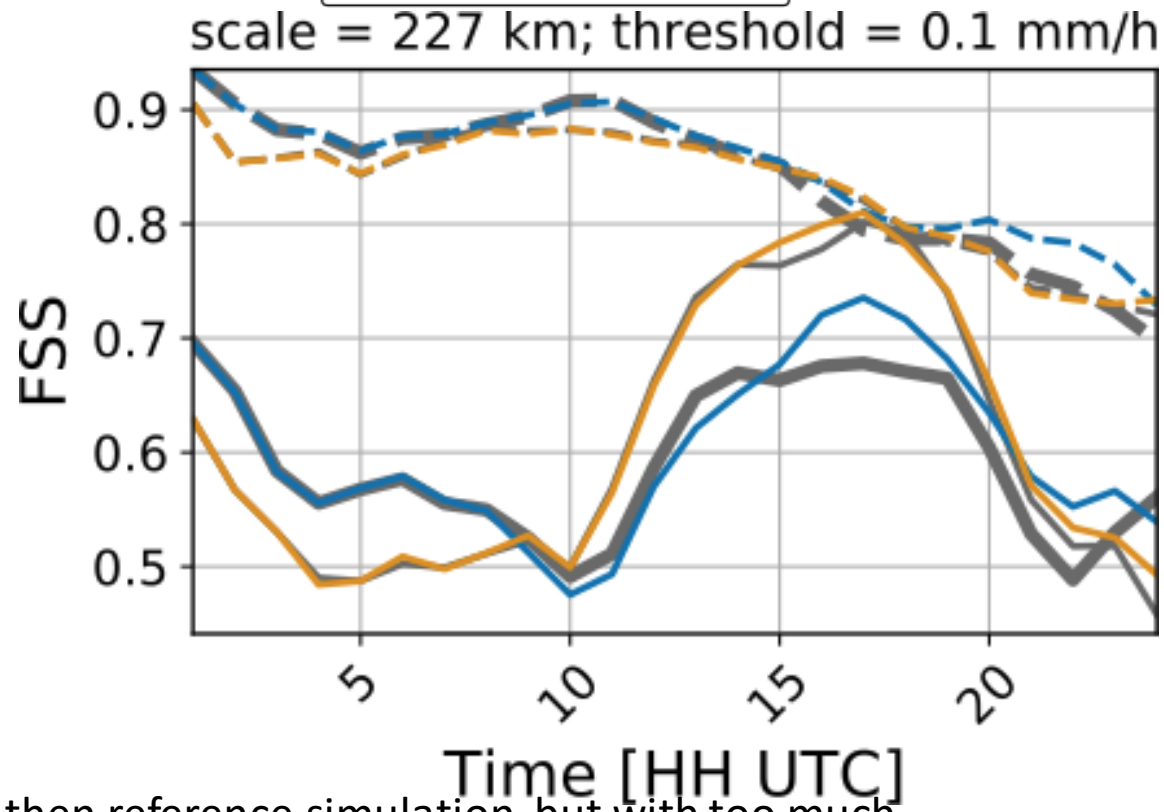


- We use itype_gscp=2483 (typical cloud condensation nuclei amount for continental conditions over Central Europe of 1700 **cm-3**
- 2mom is already doing better
- Qualitative behavior of CPP is similar
-

10 days: Impact of CPP + 2mom: 2mom already quite strong, additional impact of CPP is small







Two moment scheme is already better then reference simulation, but with too much precipitation for weakly forced days (biases that motivated CPP are not that strong any