LMU

LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

FAKULTÄT FÜR PHYSIK

METEOROLOGIE

MIM

How much convection do cold pools trigger?

Sophia Schäfer[1,2], Mirjam Hirt[1], Julien Savre[1] and George Craig[1]

[1]Meteorological Institute, Ludwig-Maximilians-University, Munich, Germany
[2]Deutscher Wetterdienst, Offenbach, Germany

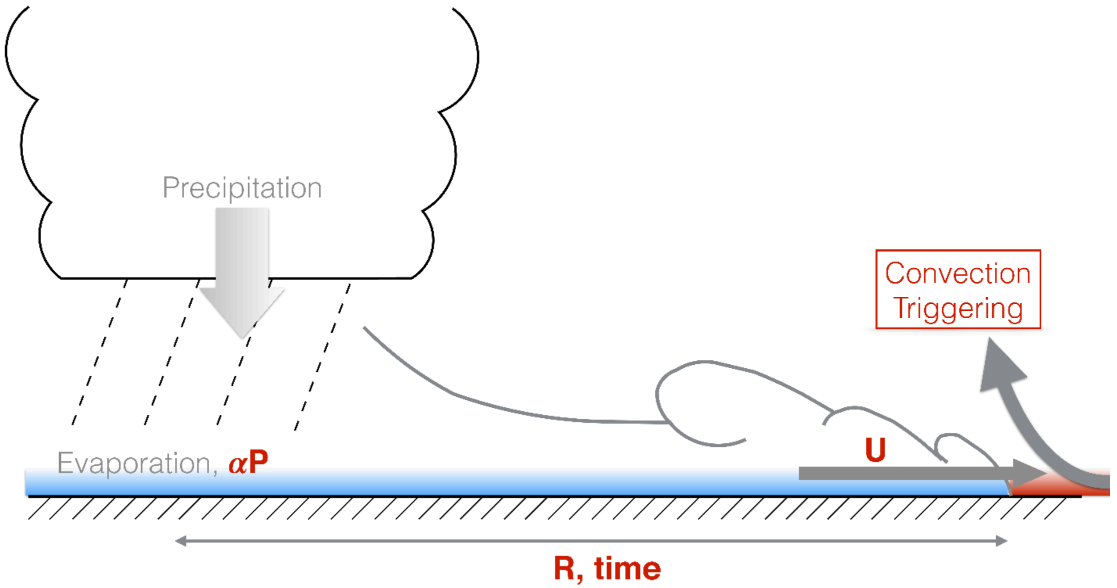
HD(CP)²

High definition clouds and precipitation for advancing climate prediction

WAVES TO WEATHER

Importance of cold pools

- Both global models with parametrised convection and km-scale models still struggle to capture organisation and diurnal cycle of convection.
- **Cold pools:** cold air from convective downdraughts expands, forms gust front at edge; mechanical lifting of warmer environmental air triggers new convection (theory of Rotunno, Klemp, Weisman 1988).



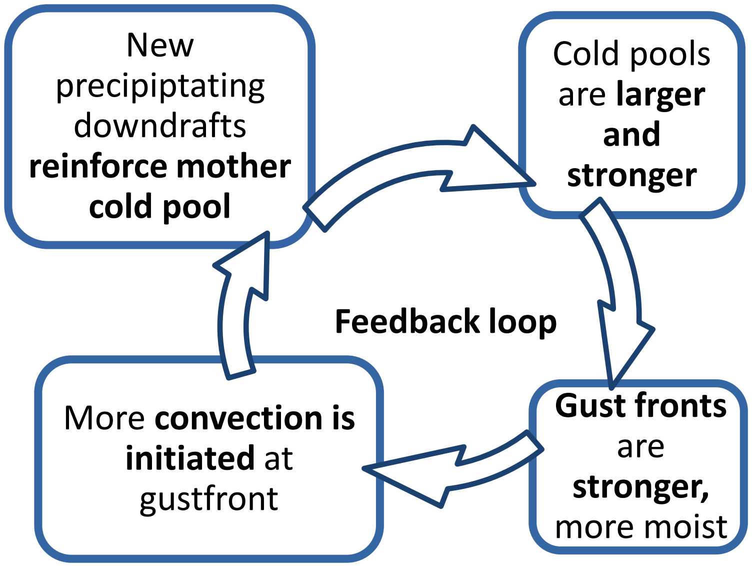
- Can also modify thermodynamics (Tompkins 2001).

→ **Increased triggering** probability close to / after existing convection.

Questions

- **How much convection do cold pools trigger (compared to environment) and on which cold pool properties does this depend?**
- *Are other factors like spatial pattern of cold pools important?*

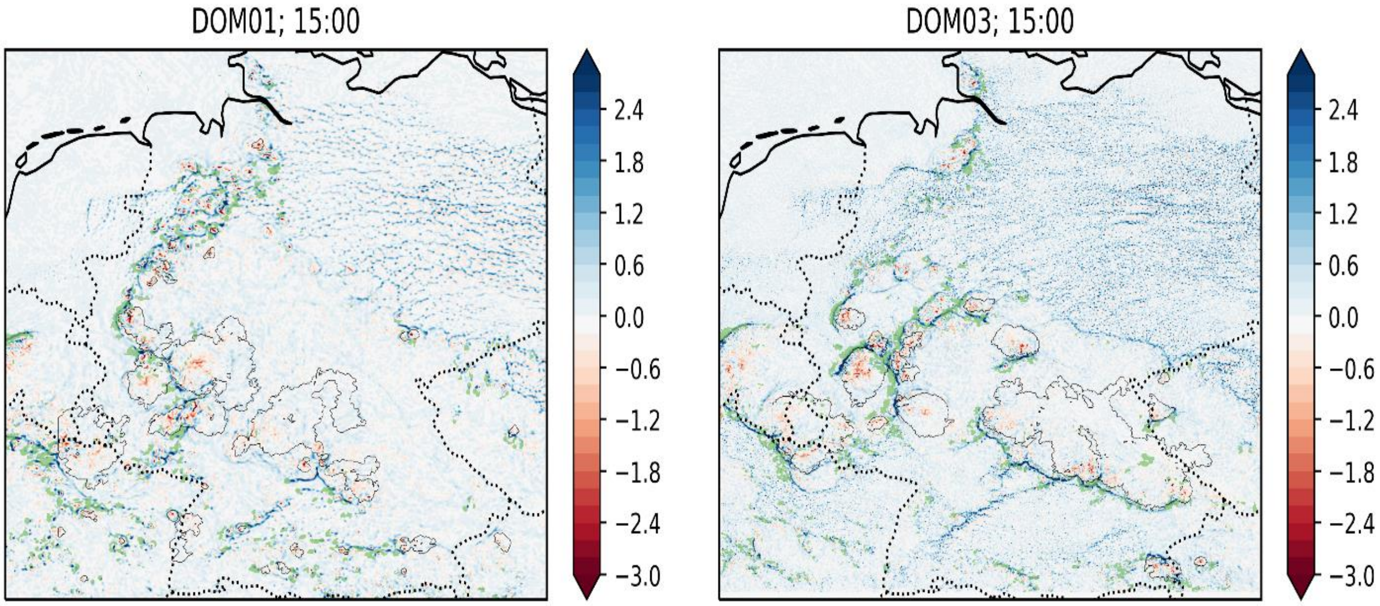
  Most triggering where 2 gust fronts collide (Feng et al. 2015)?
- **How do cold pool properties depend on parent convection ?**
- **How do differences in triggering subsequently change cold pools (feedback loop)?**
- **How can we parametrise the effect of cold pools on global and km-scale models?**
- *Does this improve convection?*



Cold pool analysis: Data

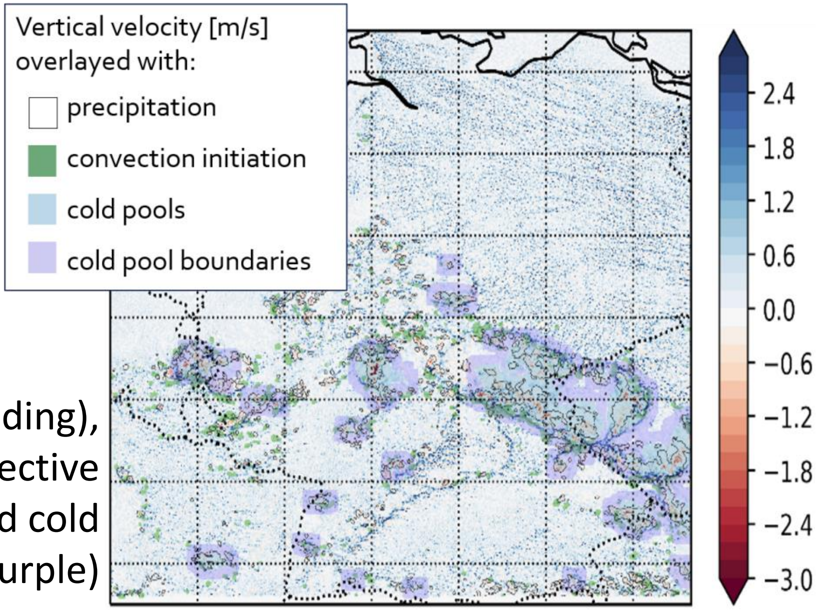
- High-resolution HD(CP)² ICON-LEM-DE simulations over Germany, weather / clouds evaluated against observations (Heinze et al., 2017)
- Grid spacing: 625m, 312m and 156m (output on 1.5 km grid)
- Selected convective days with different forcings:
  05.07.2015, 29.05.2016, 06.06.2016, 01.08.2016
- New precipitation forms along cold pool edges

Vertical velocity (shaded) and cold pools (black contours) for 06.06.2016 15 UTC, and precipitation initiation between 15:20 and 15:40 UTC (green contours). DOM01 is at 625m, DOM03 at 156m.



Cold pool analysis: Methods

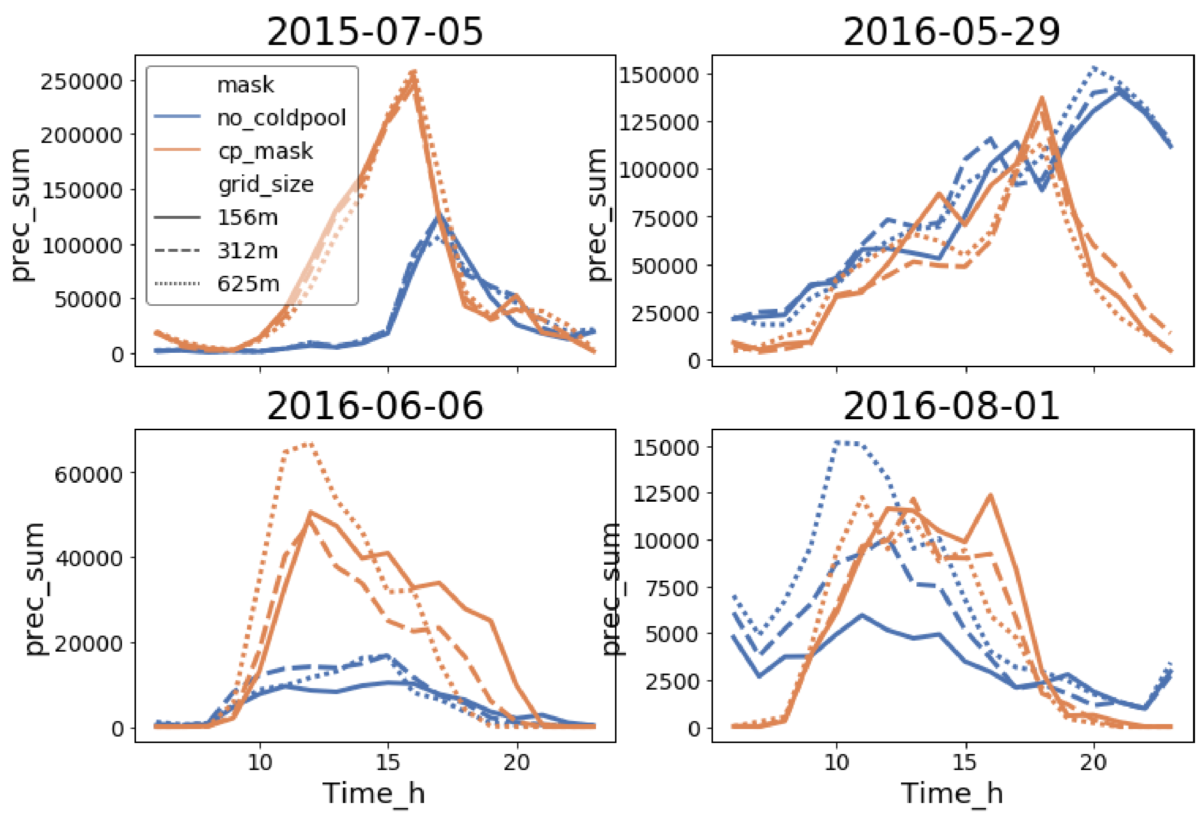
- **Cold pool labeling:** Cold pools = connected regions with low-level virtual potential temperature perturbation $\theta_v' <$ -2K, maximum precipitation > 10 mm/h (following Rieke Heinze)
- Identify **cold pool edges:** ~30km zone around labeled cold pools
- **Tracked** through time with IRT algorithm (Moseley et al., 2019)
- **Convection initiation (CI)**: determined by fast growing cloud water content
- **Triggering** probability $= \frac{\#\, gridpoints\ of\ CI}{\#\, total\ gridpoints}$
- Analyse up- / downdraughts, intensity = integrated θ_v -perturbation, precipitation,… per cold pool / edge



Vertical velocity (red / blue shading), precipitation (black contours), convective initiation (green), cold pools (blue) and cold pool edges (purple)

Results: Triggering

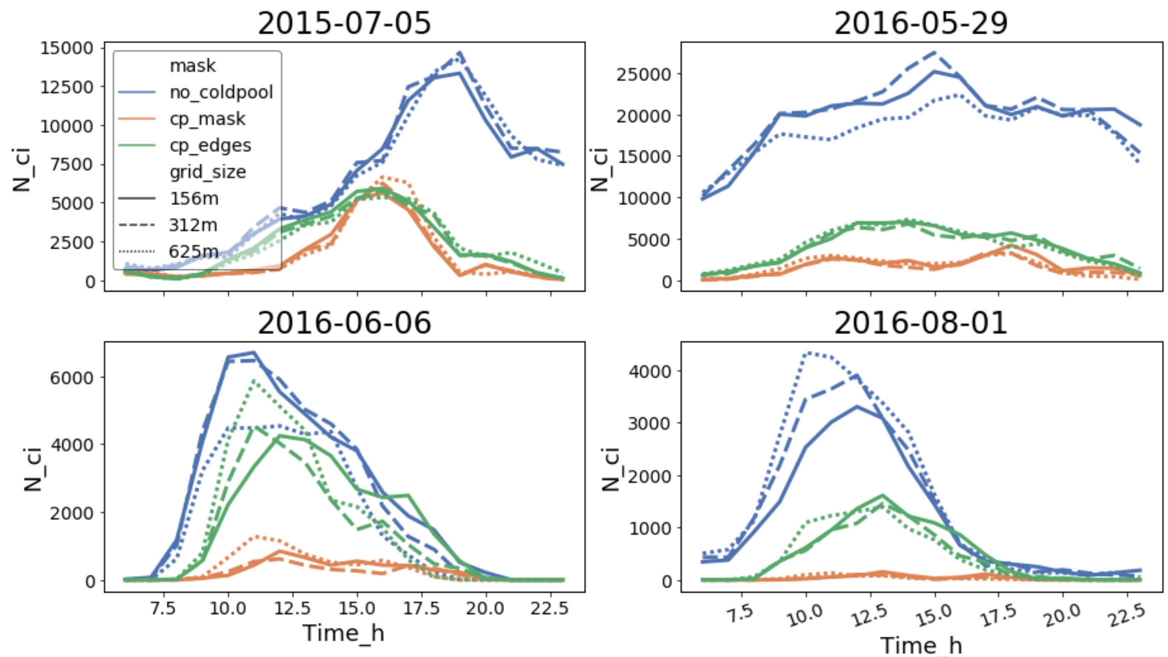
- Up to 80% (in both weak forcing) of new precipitation triggers in cold pools or cold pool edges, ca. 30 min earlier
- Cold pool triggering resolution-dependent (especially in weak forcing)



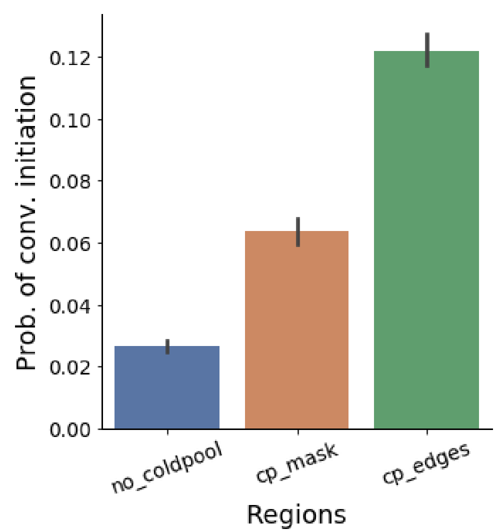
Convective precipitation timelines for all grid spacings, inside cold pools and without cold pools. Very strong forcing on 05.07.2015, very weak forcing on 06.06.2016

Results: Triggering

- Much convection triggering outside cold pools, but leads to less precipitation – does not develop into deep convection?
- Probability of triggering highest in cold pool edges
- On which parameters does triggering depend?



Convective triggering timelines inside cold pools, in cold pool edges and without cold pools.

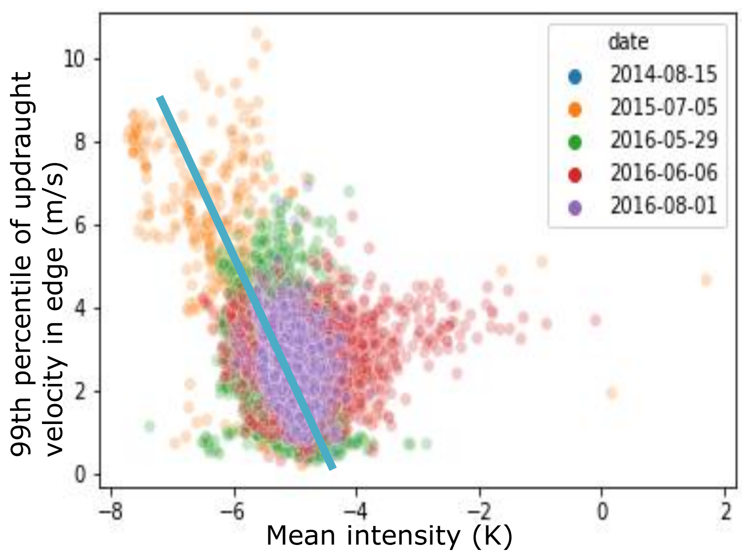


Probability of triggering (all days) inside cold pools, in cold pool edges and without cold pools.

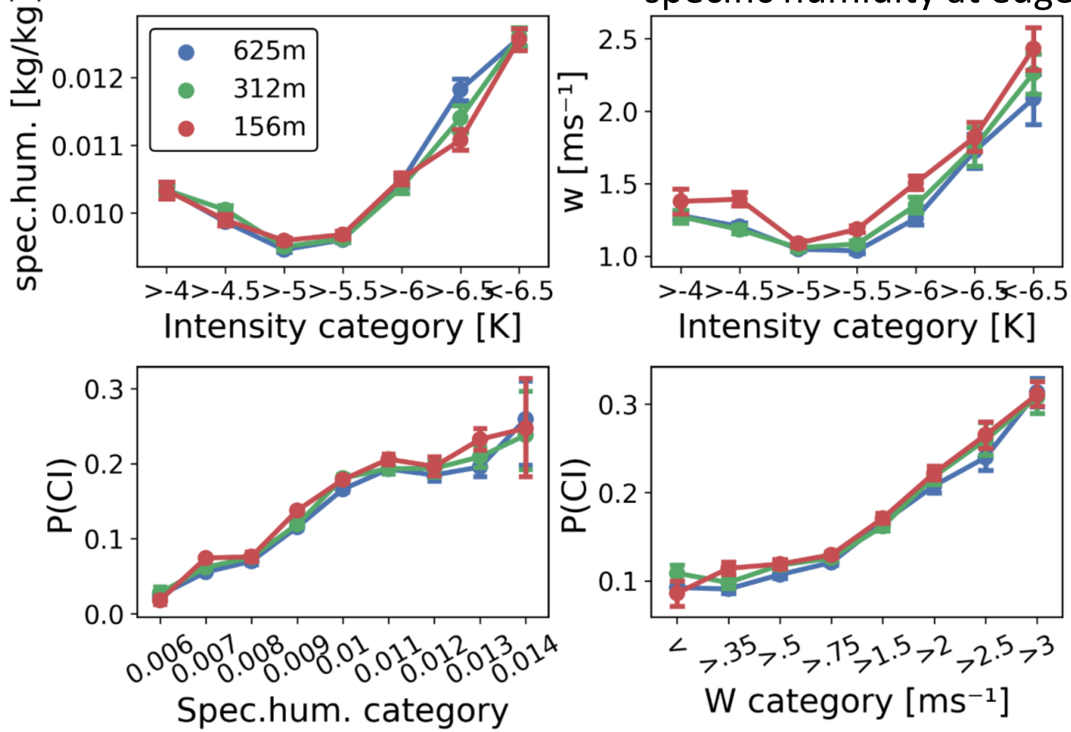
Cold pool variables

- **Triggering probability** strongly correlates to **peak updraught velocity** at edge; they correlate with **specific humidity** at edge and with **cold pool intensity** for large, strong cold pools.
- Considerable scatter for smaller cold pools.
- Updraught velocity higher at 156m grid spacing (for same intensity)

99th percentile updraught velocity in cold pool edge versus mean cold pool intensity

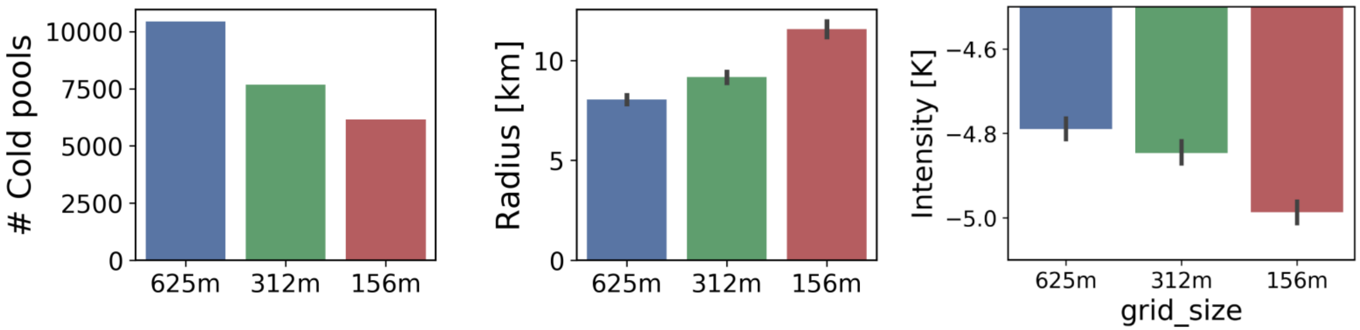


Correlations between cold pool intensity and triggering probability and 95th percentiles of updraught velocity and specific humidity at edge



Resolution dependence

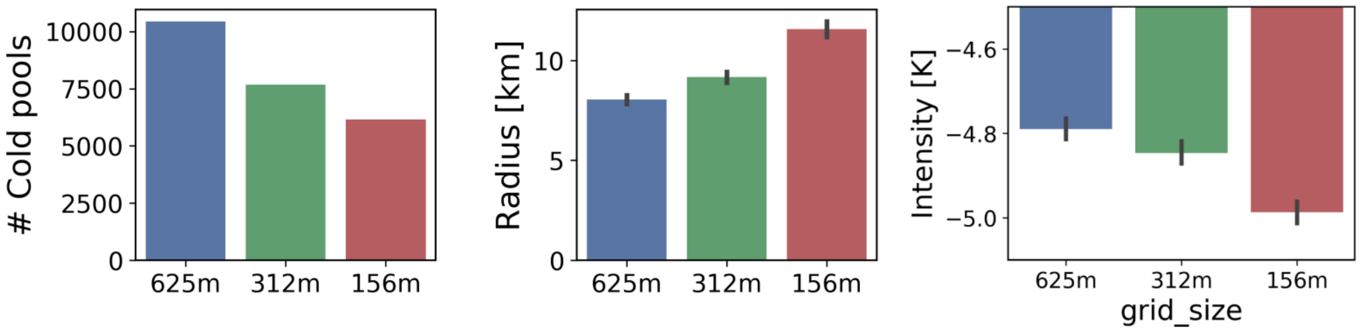
- Coarser models have **more cold pools**, but they are **smaller, less intense**, **grow slower** and **die sooner**.



Dependence of cold pool number, size and intensity on grid spacing

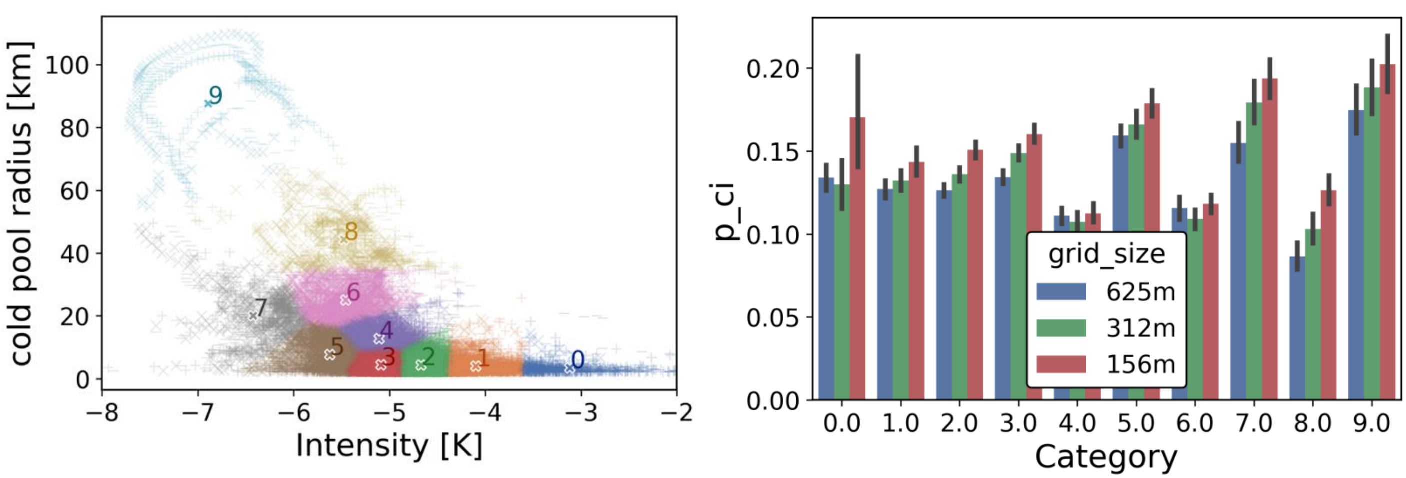
Resolution dependence

- Coarser models have **more cold pools**, but they are **smaller, less intense**, **grow slower** and **die sooner**.



Dependence of cold pool number, size and intensity on grid spacing

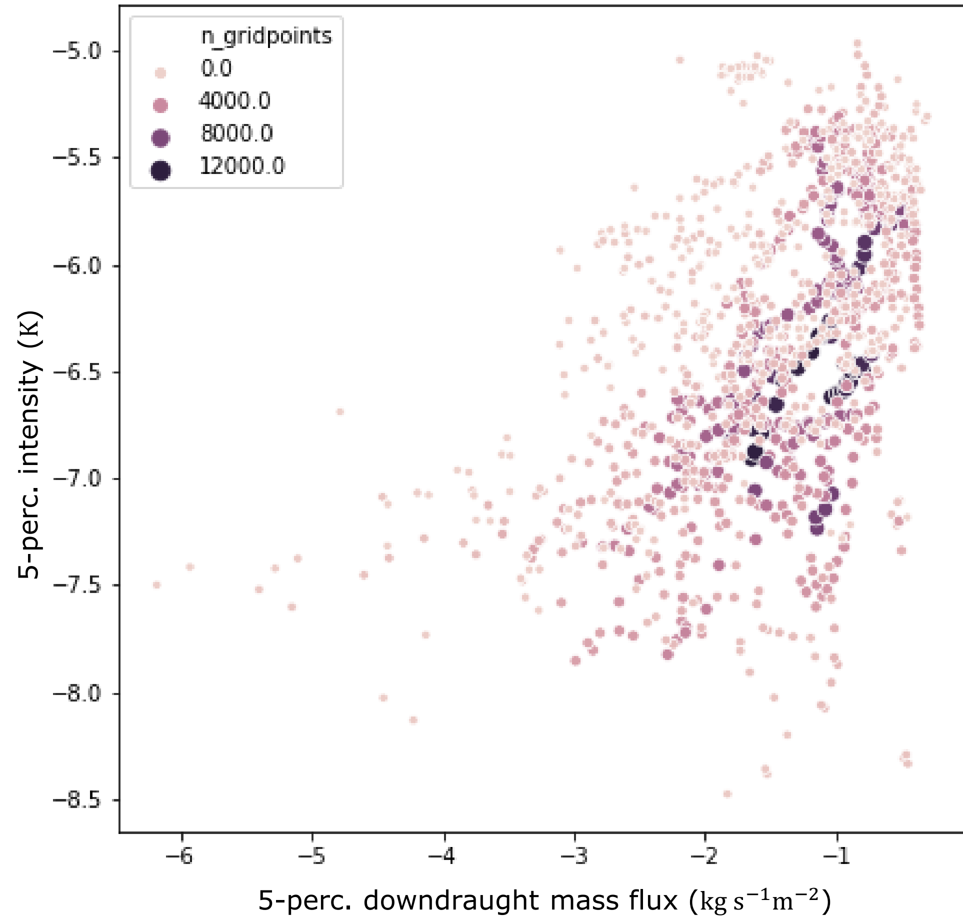
- When binned by cold pool size and intensity, **triggering** probability, horizontal convergence, **updraught** velocity and mass flux **increase with resolution**; **humidity nearly constant** in each category.



Cold pool categories by size and intensity and triggering probability per category by grid spacing

What controls cold pool intensity?

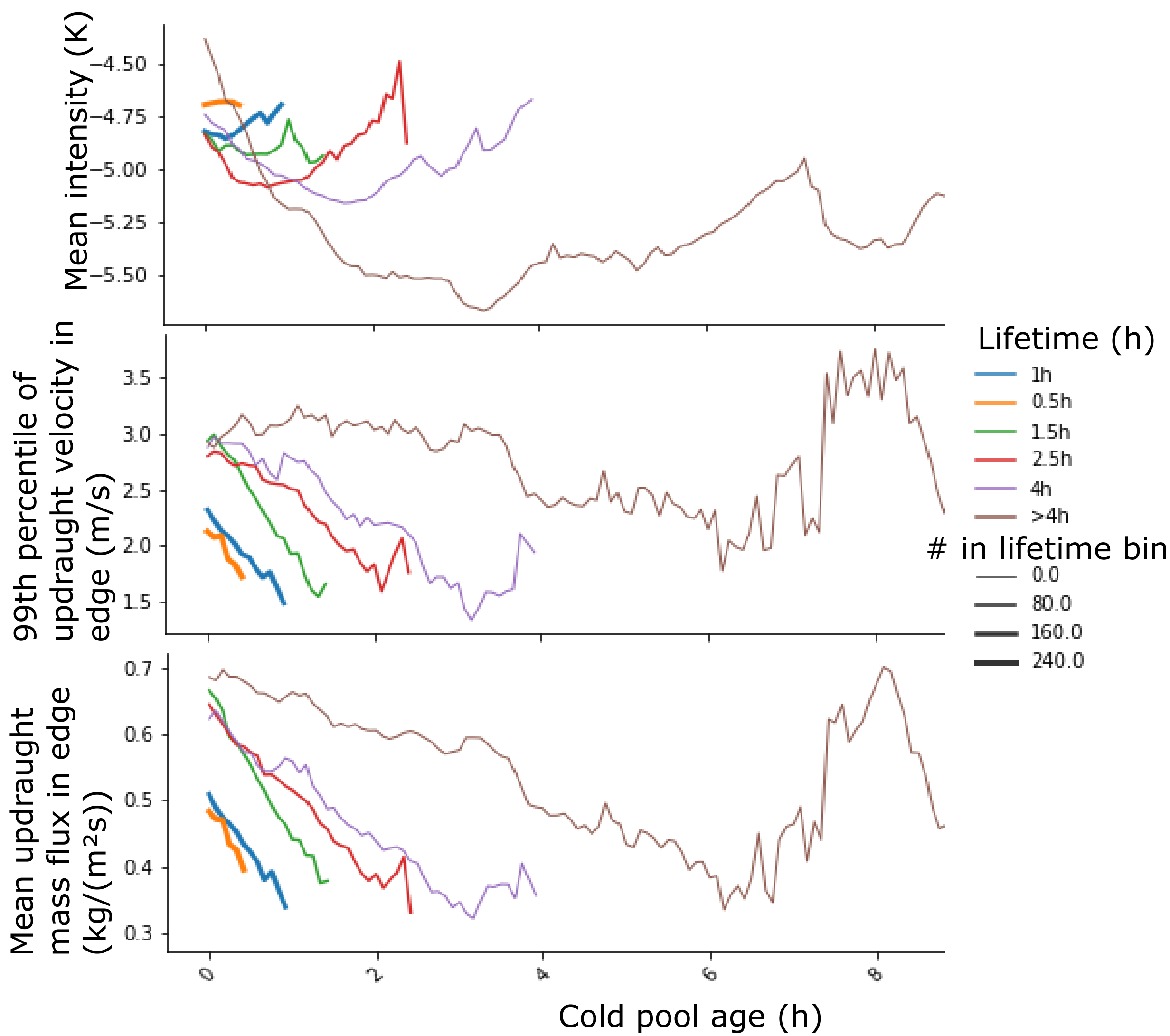
- Downdraught causes cold pool, intensity correlated to **downdraught mass flux.**
- Role of precipitation?
- Downdraught mass flux depends on convection → feedback loop
- Could test by increasing triggering in model and see if cold pool intensity increases afterwards.



5-percentile cold pool intensity versus 5-percentile downdraught mass flux within cold pool

Cold pool lifecycles

- **Triggering** per edge area **peaks early in lifecycle**, then decreases
  → Later stages and exact lifetime less crucial for triggering
- Merging effects visible for large cold pools



Timelines (all days) of cold pool intensity, peak updraught velocity and mean updraught mass flux in edges. Colours show cold pool lifetime, line strength the number of cold pools per lifetime bin.

Conclusions: Cold pool mechanism

- **Cold pool intensity** (and correlated humidity at edge) **controls peak vertical velocity** at edge and **triggering:** Deep convection triggering depends on strongest updraughts to overcome CIN.

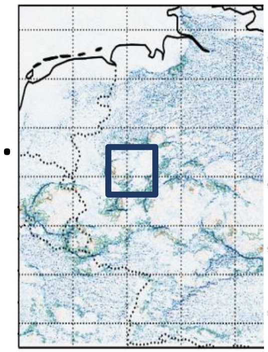
Edge humidity
&
Intensity $\propto$ edge updraught velocity $\propto$ edge triggering

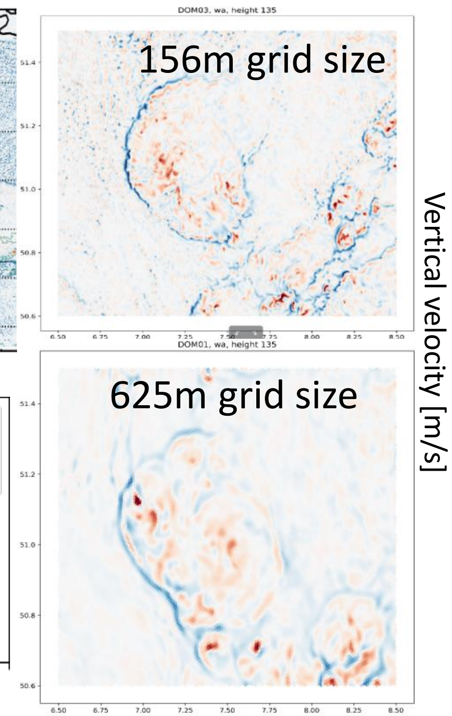
Downdraught
mass flux

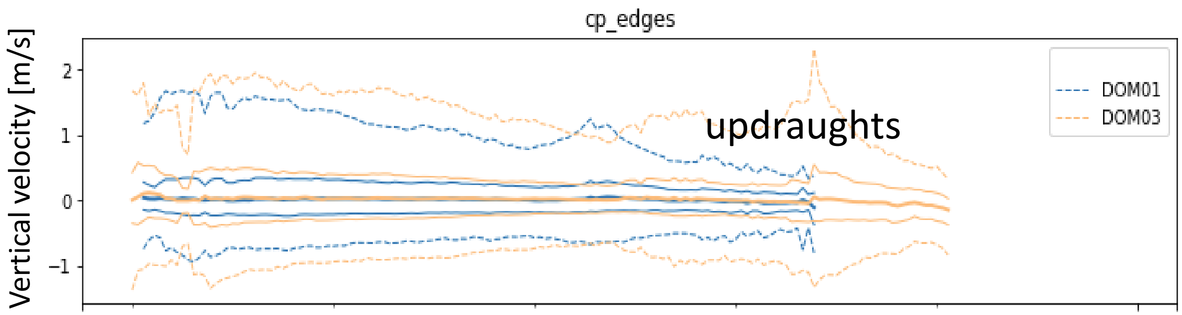
- **Updraughts / triggering** for given intensity **stronger** at high resolution .

Conclusions for km-scale models

- **Capture cold pools** (even if somewhat weak).
- **Triggering underestimated** for given intensity.
- Horizontal convergence, **updraught velocity not well resolved** in km-scale models.







Timeline of vertical velocity at cold pool edges, grid spacing 625m (DOM01) and 156m (DOM03), on 06.06.2016

- <u>**Idea:**</u> Increase vertical velocity variability (with stochastically based perturbations, Kober &Craig 2016) to better capture cold pool triggering

→ Could re-inforce cold pools and also improve intensity

Parametrisation in convection scheme

- **Cold pools** are themselves **unresolved**
- **Triggering** and **convective mass flux** functions of large-scale variables
- **Idea:**
  - **Introduce cold pool intensity** variable (depending on previous convection, with typical lifetime → memory) in gridbox
  - **Increase** number of **strong updraughts** with cold pool intensity

- Cold pools can be larger than one gridbox: spread cold pool intensity to neighbouring gridboxes? Could improve organisation, but needs communication and scale-awareness.

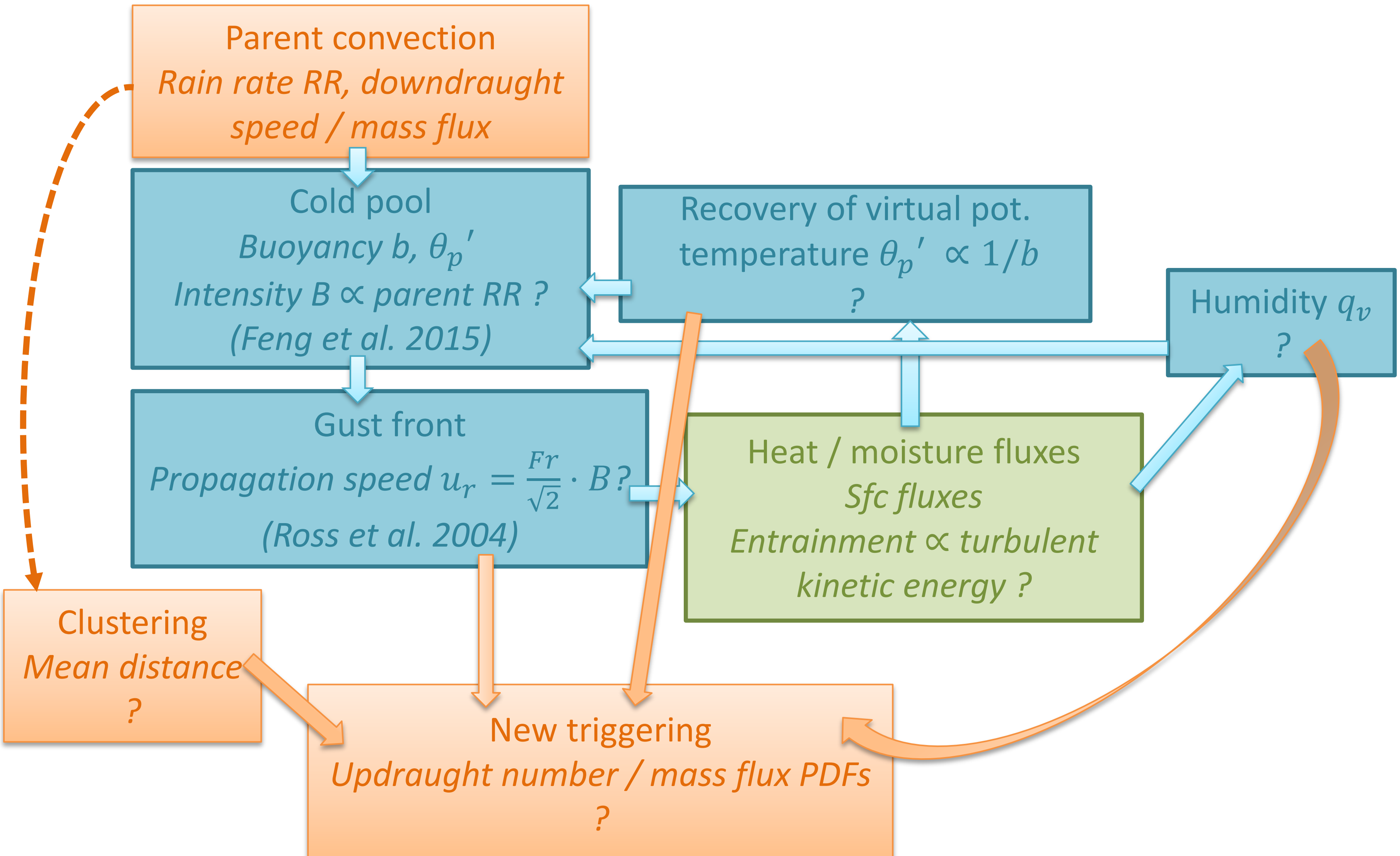
Summary

- **Triggering** of convection (via strong new updraughts) **correlates** with **cold pool intensity**, which in turn depends on convective downdraughts. No strong correlation to environment (CAPE/CIN/forcing strength).
- **Feedback mechanism:** Increased convection re-inforces downdraughts and cold pools, leading to more new triggering.
- **Model representation** has to capture updraught strength and variability.
- **Parametrisation ideas**:
  - **km-scale models**: Perturb vertical velocity at cold pool edges to reproduce strong enough updraughts
  - **Stochastic convection scheme**: Increase propability for strong updraughts, depending on cold pool intensity due to previous convection

Thank you for your attention!

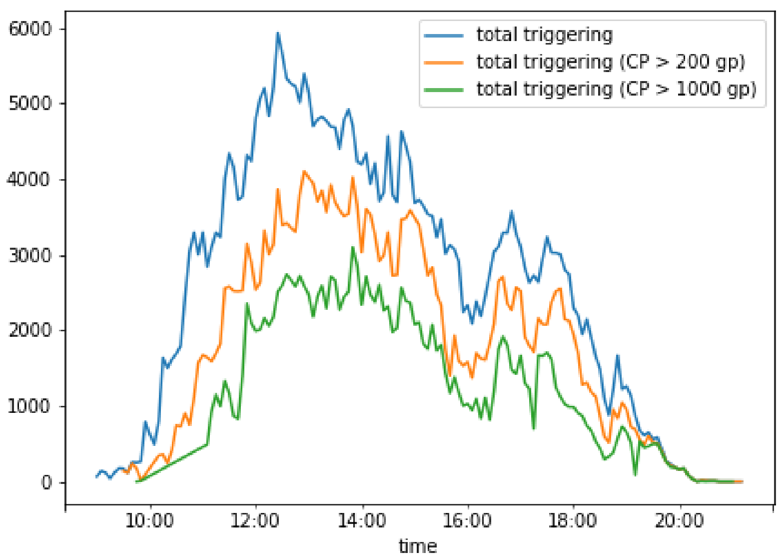
Contact: sophia.schaefer@dwd.de
m.hirt@lmu.de

Cold pool interactions



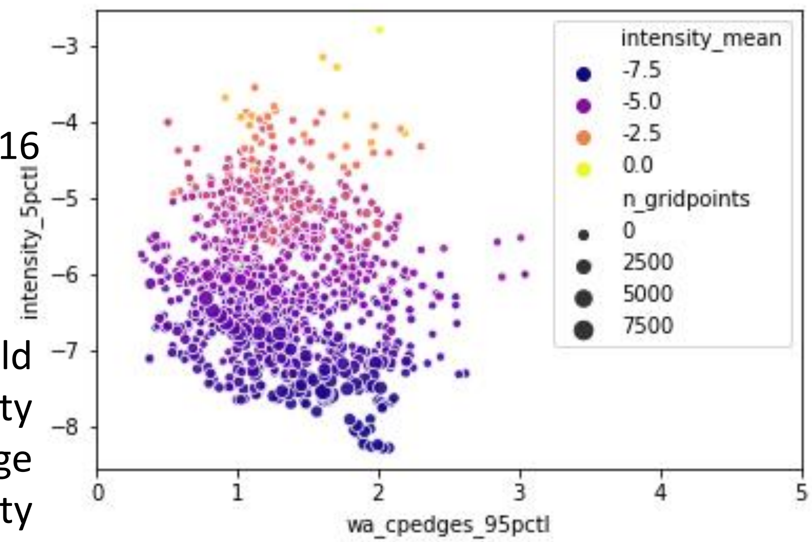
Cold pool size and environment

- Large cold pools (>1000 gridpoints) cause ca. 50% of total triggering, have clearer correlation of triggering and humidity to intensity.



Triggering for various minimum cold pool sizes, DOM03, 06.06.2016

5-percentile cold pool intensity versus edge updraught velocity



- Correlation of triggering to CAPE or CIN not clear, wind shear has weak correlation to intensity for large cold pools.

Physically based stochastic perturbations

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

$\boldsymbol{\eta(\tau, \sigma)}$: Random field

$\boldsymbol{\alpha}$: perturbation amplitude, scaling factors

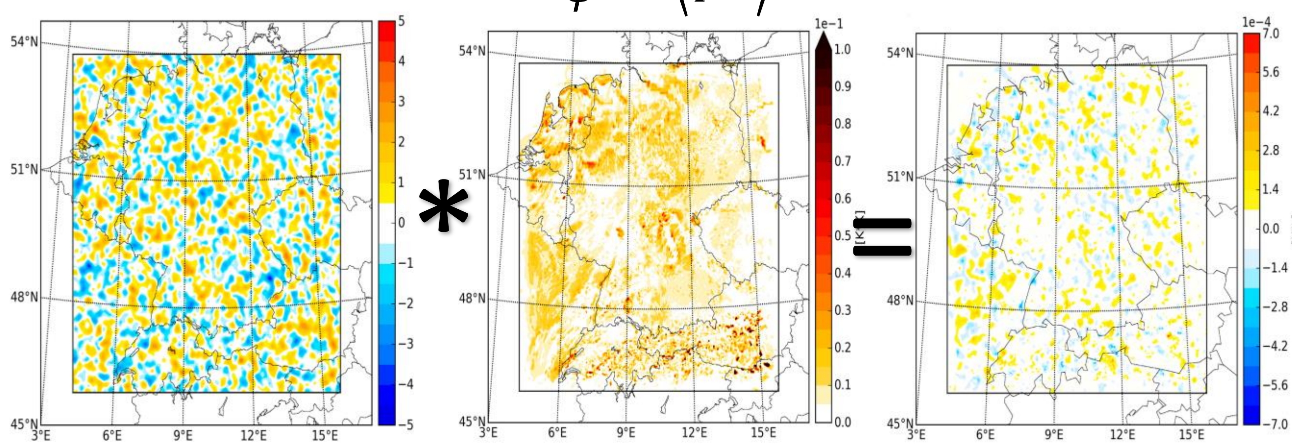
$\boldsymbol{\phi'}$: physical scaling of variable ϕ

$\phi = \phi$ {T, q, w}

Turbulence:
(Kober and Craig, 2016)

η: gaussian random field

$\phi' \propto \langle T^2 \rangle^{0.5}$



Stochastic Plant-Craig scheme

(Plant, Craig 2008)

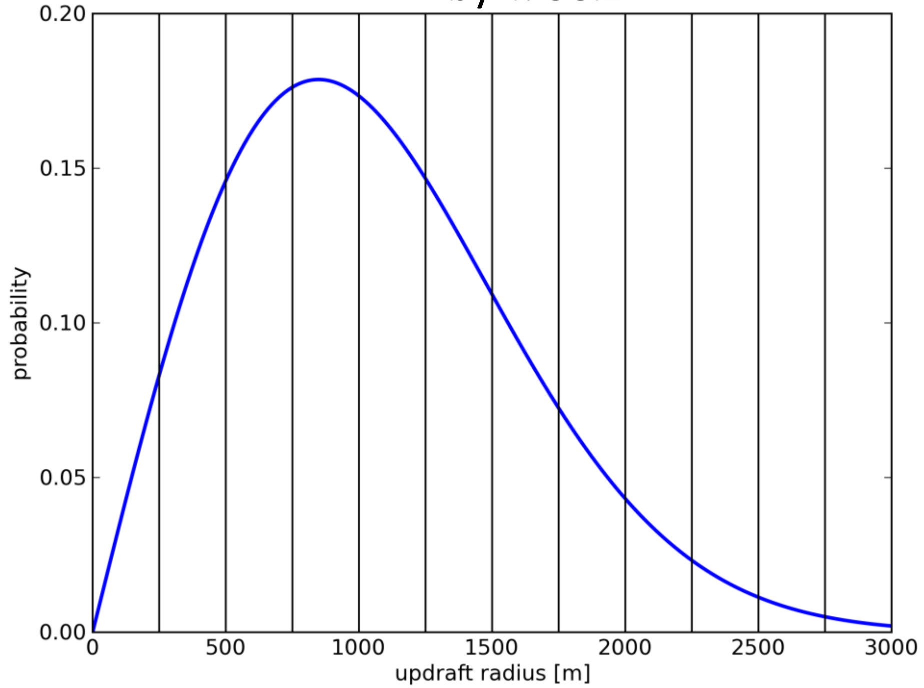
- "**Cloud birth process**": new **cloud number** N chosen from Poisson distribution, **mass flux** at cloud base m from exponential distribution
- Probability to initialize a new updraught of size (r, r+dr) in time dt:

$$p = \frac{\langle M \rangle}{\langle m \rangle} \frac{2r}{\langle r^2 \rangle} \exp\left(-\frac{r^2}{\langle r^2 \rangle}\right) dr \frac{dt}{T}$$

depends only on large-scale

→ little memory or organisation

PDF of cloud mass flux, by T. Selz



Cold pool representation:
Increase probability of strong updraughts in Plant-Craig scheme with cold pool intensity in gridbox
→ improve memory, organisation?