Causal links between cold pools and convection

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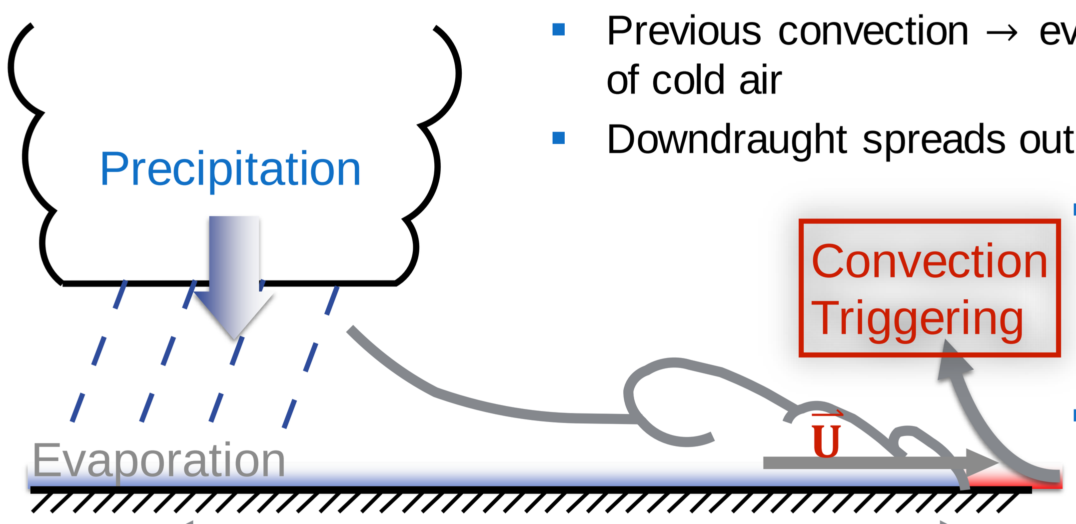
1. Convection challenges for global models

- **Convection important globally** for **energy budget and circulation**
- Models barely resolve deep convection → **shallow / early convection** on subgrid-scale **parametrised; initiation and interaction** with environment **not fully understood**
- **Persistent biases** in convection diurnal cycle and organisation, Inner-Tropical Convergence Zone (ITCZ); **Upscale error growth**: Convection uncertainty carries over to large-scale, limits predictability (Selz and Craig, 2015)

2. Role of cold pools in triggering convection

Convection triggering: initial lifting + condensation makes air positively buoyant relative to environment



Cold pool triggering

- Previous convection → evaporation of rain → downdraught of cold air
- Downdraught spreads out into cold pool; gust front at edge
- **Gust front** displaces + lifts moist warm air → **triggers new convection** at cold pool edge → reinforces cold pool
- Depends on previous convection → **spatio-temporal correlation**

- Including cold pools **could improve diurnal cycle, organisation** of convection

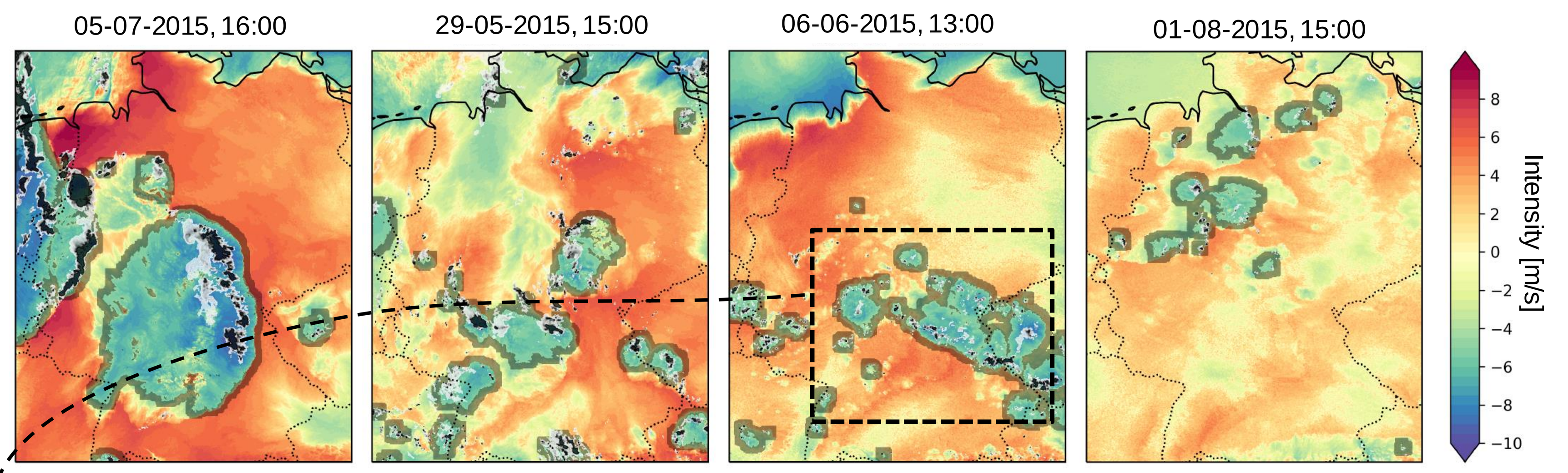
3. Questions

- **How significant are cold pools for convection triggering, diurnal cycle and organisation?**
- **How does triggering depend on cold pool properties and on model resolution?**
- **How does cold pool lifecycle depend on parent convection / environment?**
- **Which effects are missing in models, and how could they be parametrised?**

4. Analysis of high-resolution ICON simulations

(Hirt et al., 2020)

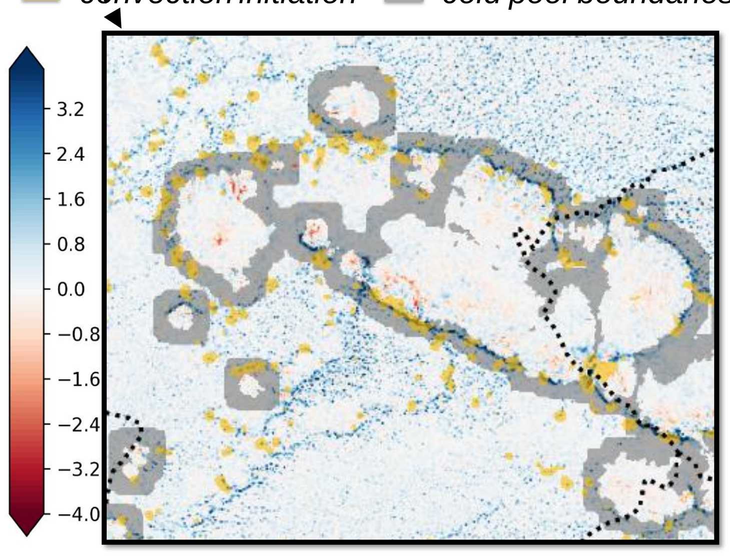
- High-resolution HD(CP)² ICON-LEM-DE simulations over Germany, weather + clouds evaluated against observations (Heinze et al., 2017); 4 days with range of weather situations



Buoyancy intensity in color, cold pool boundary regions in grey shading and precipitation in white (1mm/h) to black (20mm/h) for each day, box indicates area of next figure.

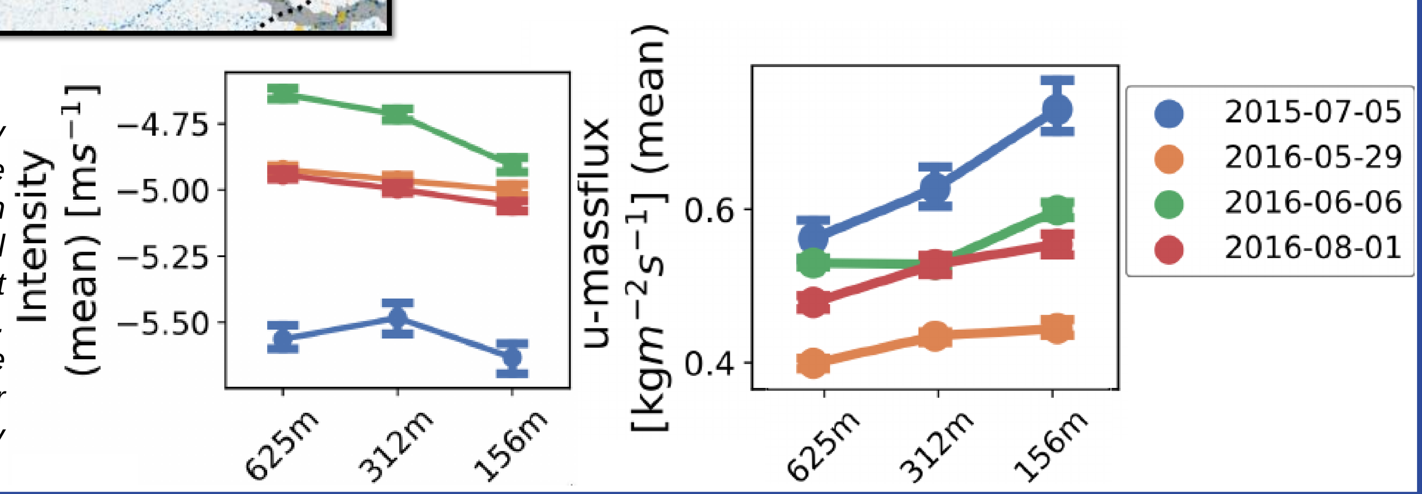
- **Cold pool tracking: Cold pool** = connected region with virtual potential temperature perturbation $\theta_v' < -2K$, maximum precipitation > 10 mm/h (following Rieke Heinze); **Tracked** through time with IRT algorithm (Moseley et al., 2019)

Vertical velocity [m/s] on 06.06.2016, 13 UTC, with: convection initiation, cold pool boundaries



- **Identify intensity** = buoyancy perturbation; precipitation, cold pool properties **for each cold pool and edge**; **Identify convection initiation**: $\frac{\partial}{\partial t}$ cloud water > threshold
- **Up to 50%** of convection **triggering** in **cold pool edges,** 30 min until new precipitation starts
- Model resolution dependence: At **high resolutions**, there are **fewer, larger, stronger cold pools** - even **for same intensity**, they **trigger more convection. Why?**

Cold pool intensity (left) and convective updraught strength (right) at cold pool edge increase at higher resolution. Updraughts at the edge increase even for the same intensity



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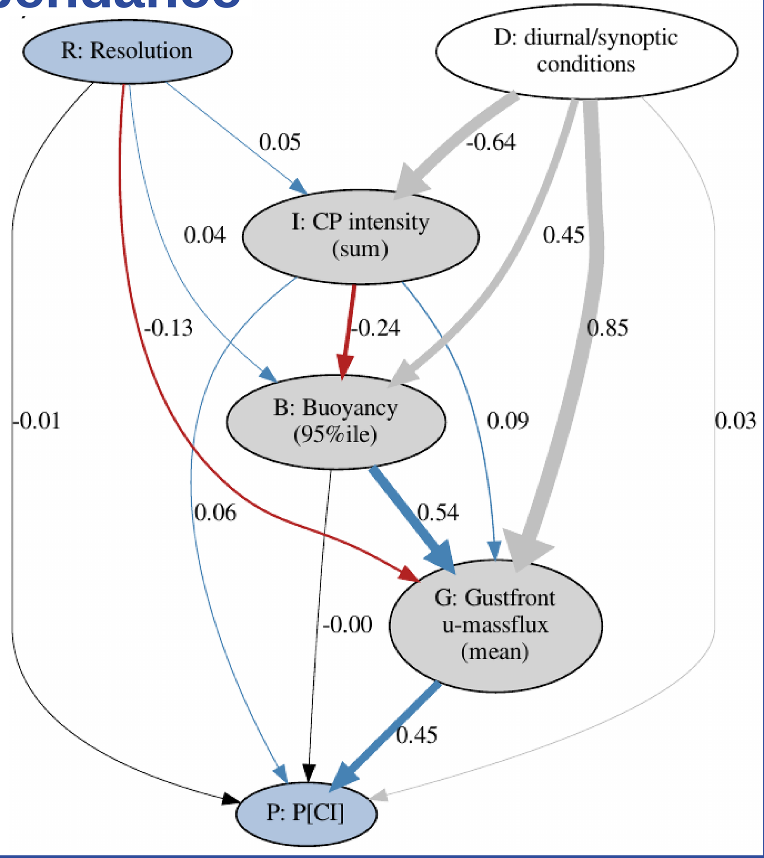
5. Causal analysis of resolution dependance

(Hirt et al., 2020)

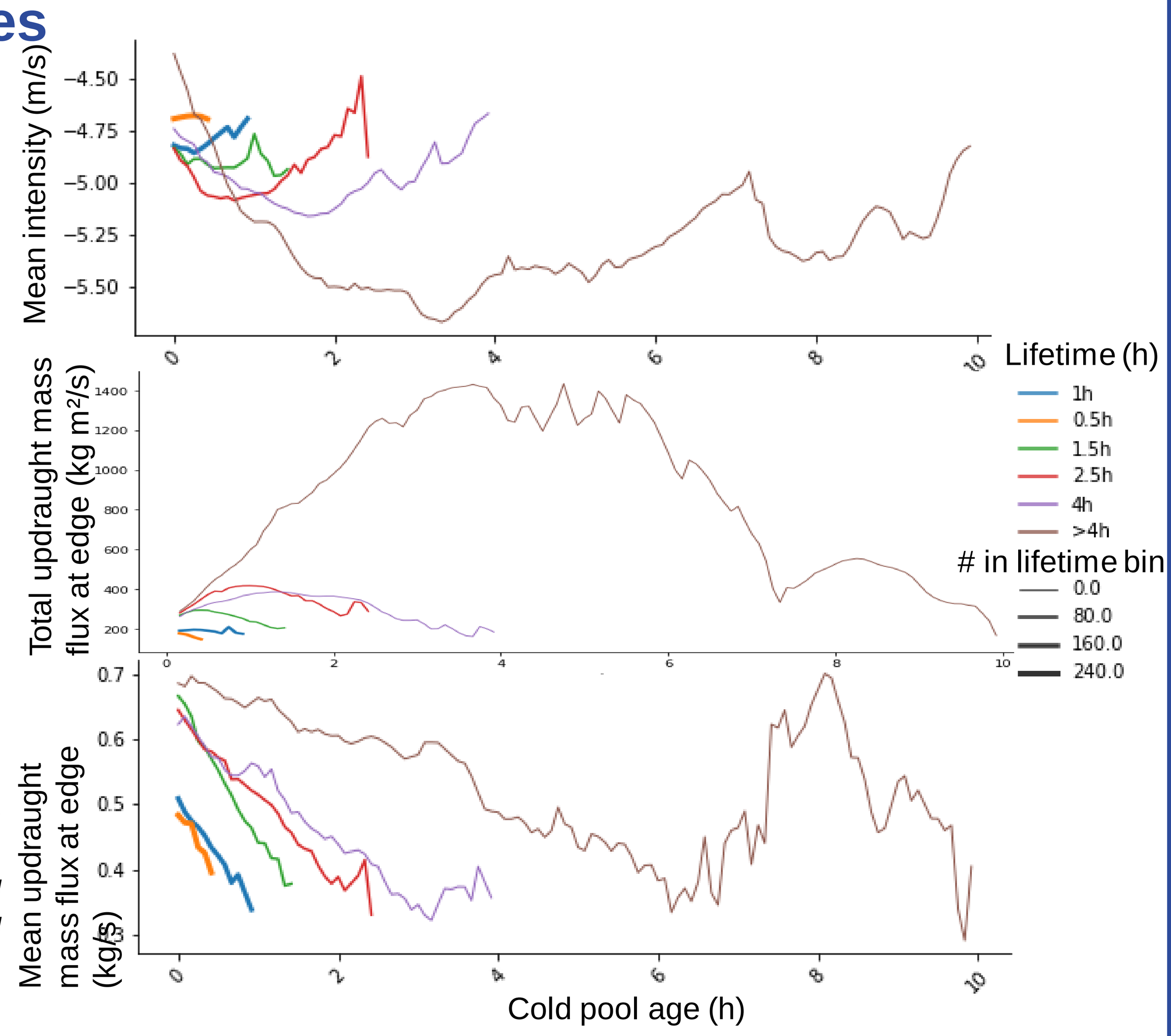
- **Formal causal analysis**: Resolution dependence mostly because **updraughts** are **not strong enough** at lower resolution (for given cold pool intensity)
- Resolution **effect on intensity**, buoyancy less important.
- **Feedback on cold pool intensity** – reason why coarse resolution cold pools less intense?



Causal graph of possible mechanisms of model resolution effect on cold pool edge triggering probability P. Line strength and path coefficients show importance of path link, as determined by causal analysis

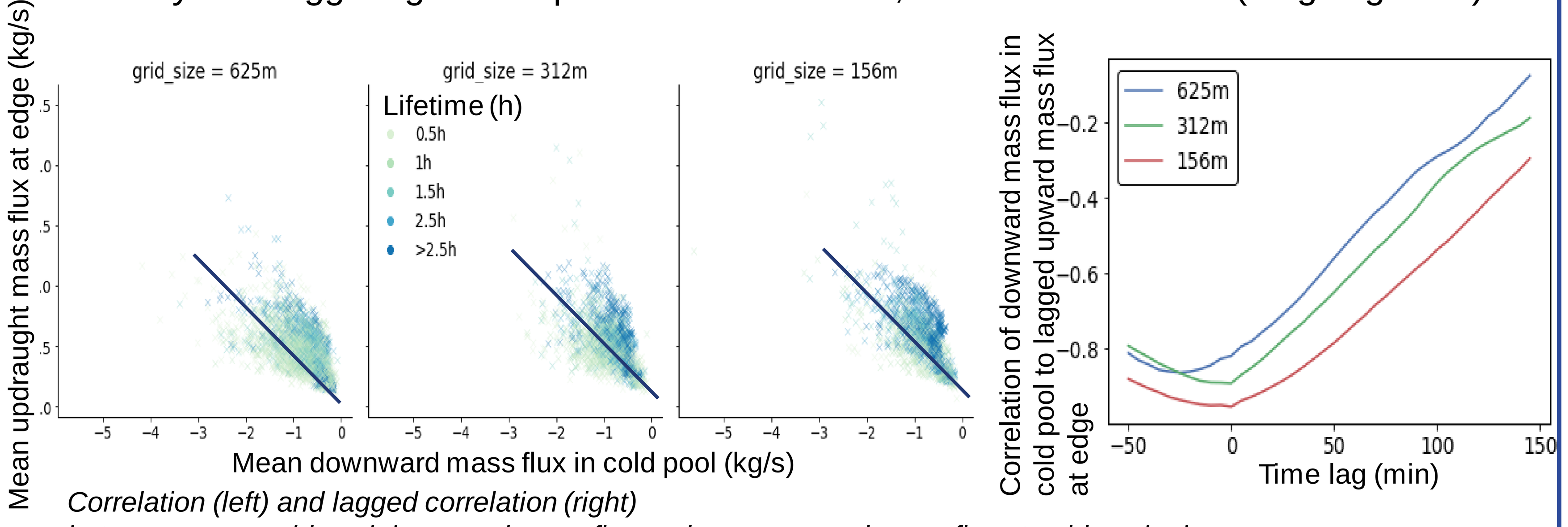
6. Cold pool lifecycles

- Cold pools **deepen over half their lifetime**, then decay **- differs** from continuous decay found by Feng et al. (2015) over ocean and Grant and van den Heever (2016) for idealised desert cold pool.
- **Total triggering lifecycle similar** to intensity, **mean triggering** per edge area **decreases** with cold pool age



Timelines of cold pool intensity, total and mean updraught mass flux at cold pool edge. Colour and line strength show cold pool lifetime and number of cold pools per lifetime bin.

- **Downdraft mass flux** in cold pool **correlates with** cold pool intensity (not shown) and **updraught mass flux** at edge (at 10 to 30 min delay); high resolution → faster development;
- Intensity and triggering also depend on environment, other causal links? (Ongoing work)



Correlation (left) and lagged correlation (right) between mean cold pool downward mass flux and mean upward mass flux at cold pool edge.

7. Conclusions

- **Cold pools significant for convection triggering**
- **Important to represent updraught strength at cold pool edge (missed in convection permitting models)**
- **Mid-latitude land cold pool lifecycles different to desert or ocean cold pools (?)**
- **Triggering correlates with cold pool intensity, downdraught - ongoing work**

8. Outlook: Parametrisation approaches

- **Convection permitting** models → Presentation M. Hirt
- **Parametrised convection:** Use stochastic convection scheme (e.g. Plant and Craig, 2008) that draws sub-grid convective clouds from probability distribution; **modify distribution** to represent increased triggering by cold pools. Should also increase triggering in neighbouring grid-boxes → organisation?

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