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A high-level analysis of complex Arctic mixed-phase cloud dynamics

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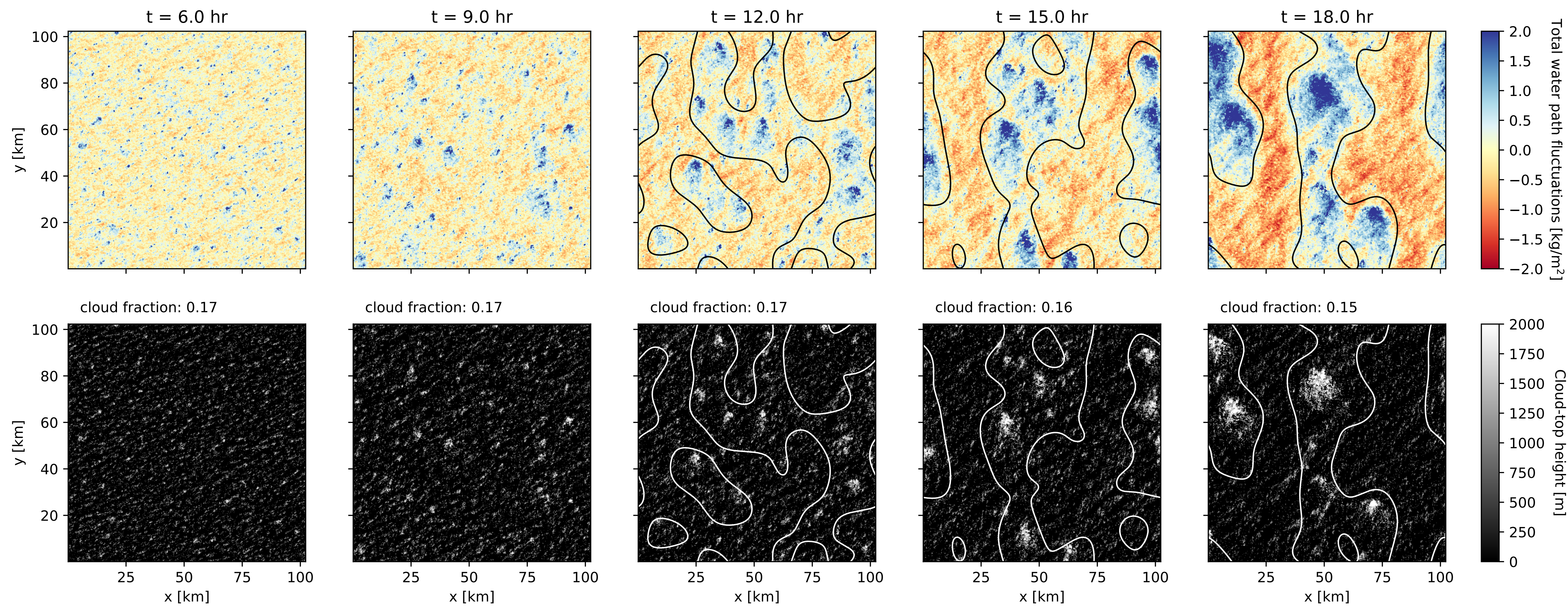
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Scale growth is an inherent property of shallow cumulus convection

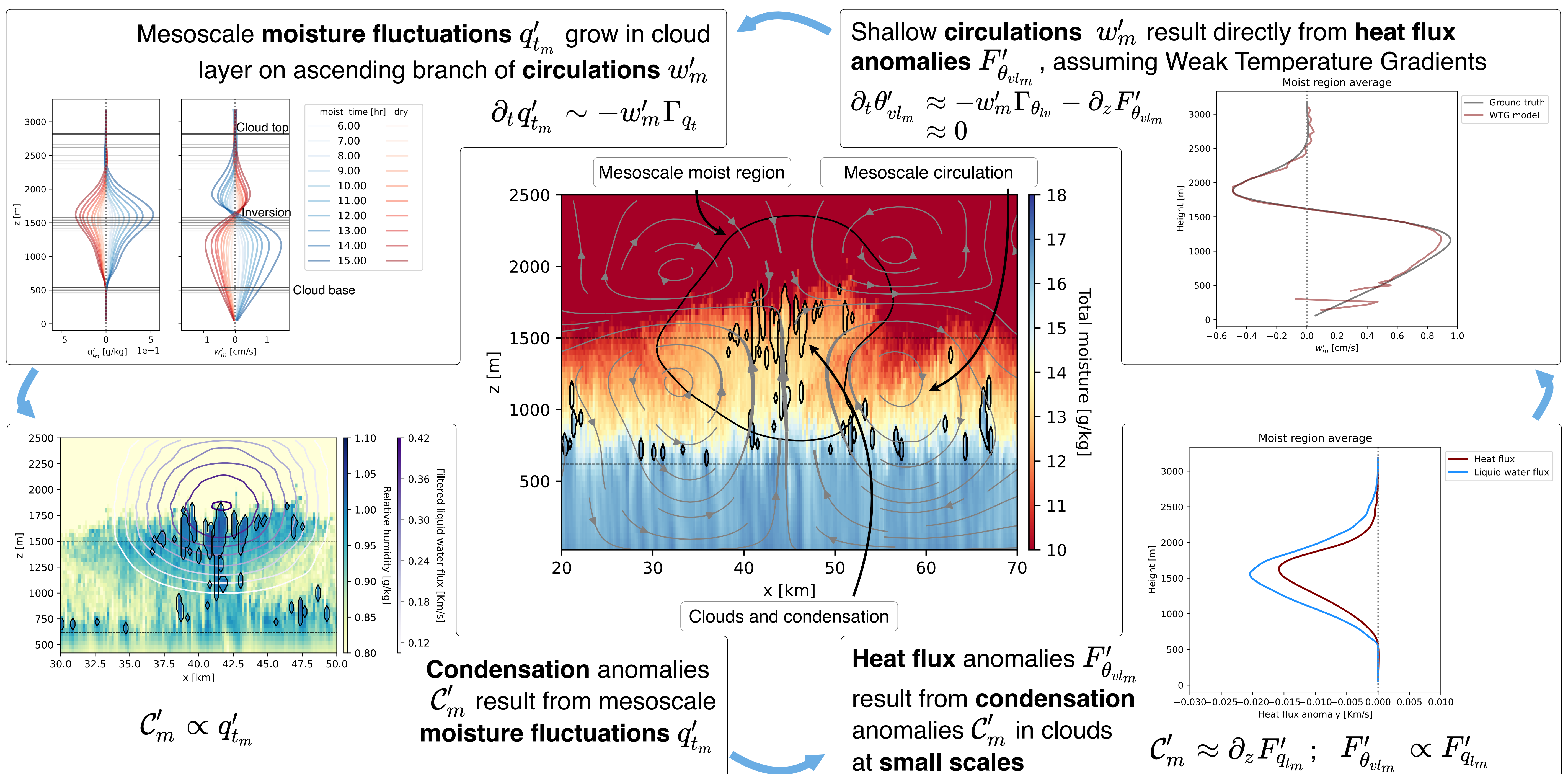
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In LES, shallow convection self-organises into mesoscale clusters without cold pools or radiation anomalies



Numerical experiments
Case BOMEX as in Siebesma et al. (2003)
Model Dutch Large Eddy Simulation, MicroHH
Domain $L_x = L_y = 102.4 \text{ km}$
Grid $\Delta x \in [50, 100, 200] \text{ m}$, $\Delta z = 40 \text{ m}$
Advection $O(2)$ central differences, $O(5)$ (Wicker & Skamarock, 2002)
Physics Highly idealised setup
 ▶ Imposed, homogenous radiative cooling
 ▶ No precipitation
 ▶ Constant, homogenous surface fluxes

Following Bretherton & Blossey (2017), we diagnose a positive moisture-convective feedback



We frame the model as a linear instability, whose conditions are satisfied by the convection itself

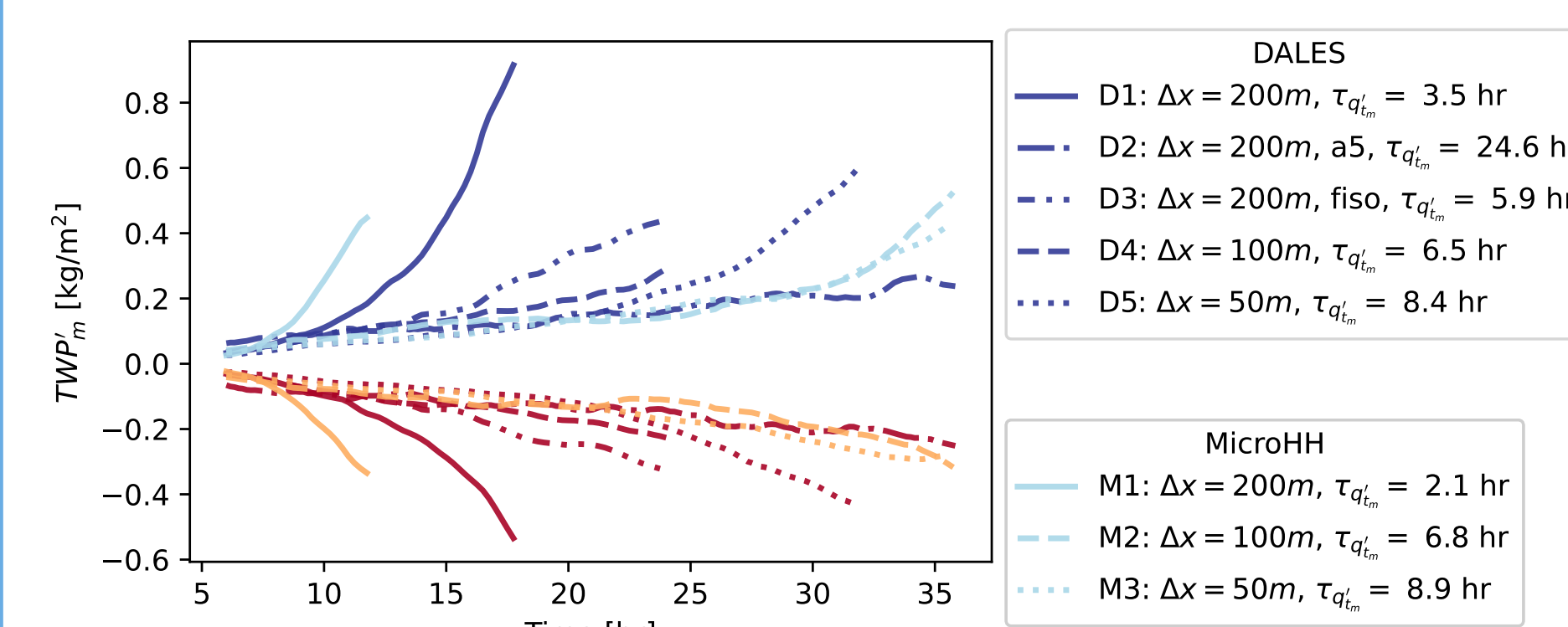
Model for column-integrated mesoscale moisture anomaly $\langle q'_{tm} \rangle$:

$$\partial_t \langle q'_{tm} \rangle \approx \frac{\langle q'_{tm} \rangle}{\tau_{q'_{tm}}}, \quad \tau_{q'_{tm}} \propto \frac{1}{w^* \partial_z \left(\frac{\Gamma_{qt}}{\Gamma_{\theta v}} \right)}$$

- ▶ $w^* > 0$ is a convective velocity scale
- ▶ $\partial_z (\Gamma_{qt}/\Gamma_{\theta v}) > 0$ requires the mean states to be curved and convex. This is facilitated by transition- and inversion-layer curvatures in mean-state fluxes, and not by radiative cooling, as suggested by Bretherton & Blossey (2017).

Any cumulus layer able to sustain itself may be expected to be unstable to scale growth.

The feedback roots in small-scale energetics, making it sensitive to numerical choices



- ▶ Different grid spacing (Δx), advection scheme (a2, a5), filter width (fiso) and even model give different $\tau_{q'_{tm}}$
- ▶ Heat fluxes (w^* , $F_{\theta_{vlm}}$) governed by sub-kilometre cumulus dynamics are to blame
- ▶ High resolutions or accurate convection parameterisations are likely needed to get small-scale influence on mesoscale cumulus patterns right

How does this picture fit observations?

- ▶ Circulations present on most EUREC⁴A days (George et al., 2022)
- ▶ Transition layers are usually curved, convex and possibly due to very shallow clouds (Albright et al., 2022)
- ▶ Variability in cloud-base mass flux relates to variability in mesoscale vertical velocity (Vogel et al., 2020).

How much of this is due simply to self-induced variability cumulus convection?

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