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van Hooft, J.A.; Ekman , Annica ; Dewey , Maura ; Glassmeier, F.

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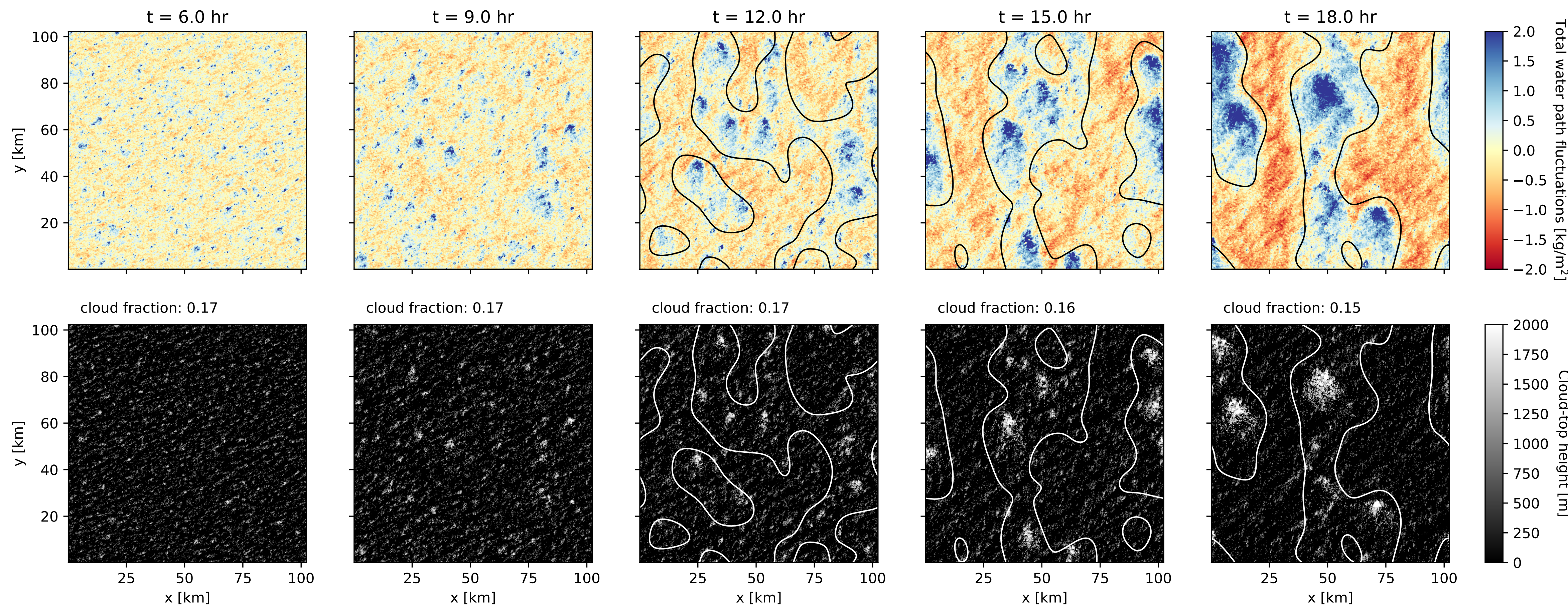
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Scale growth is an inherent property of shallow cumulus convection

Martin Janssens (martin.janssens@wur.nl), Jordi Vilà-Guerau de Arellano, Chiel C. van Heerwaarden, Bart J.H. van Stratum (all Wageningen UR)
A. Pier Siebesma, Stephan R. de Roode, Franziska Glassmeier (all TU Delft)

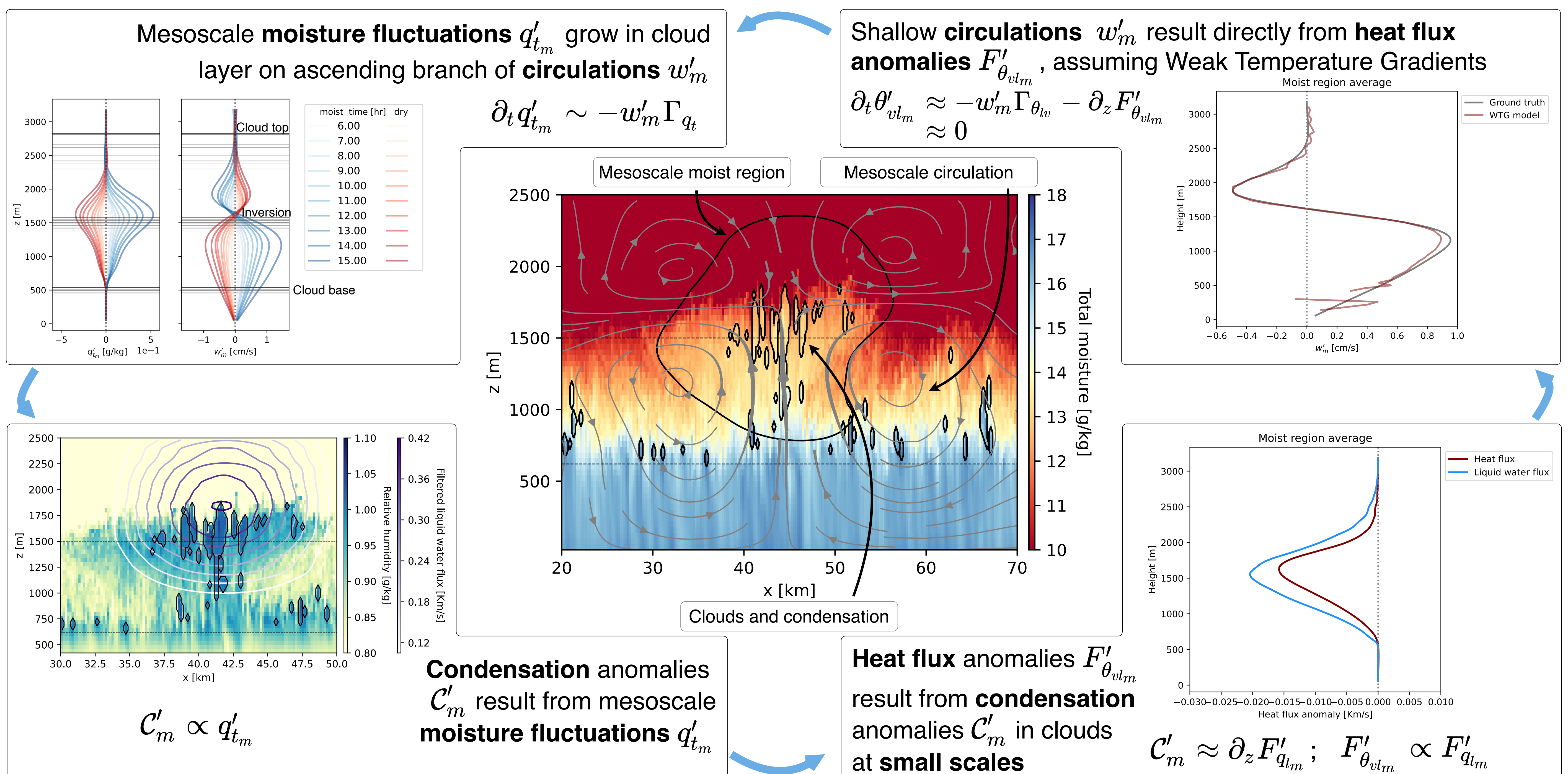
In LES, shallow convection self-organises into mesoscale clusters without cold pools or radiation anomalies



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

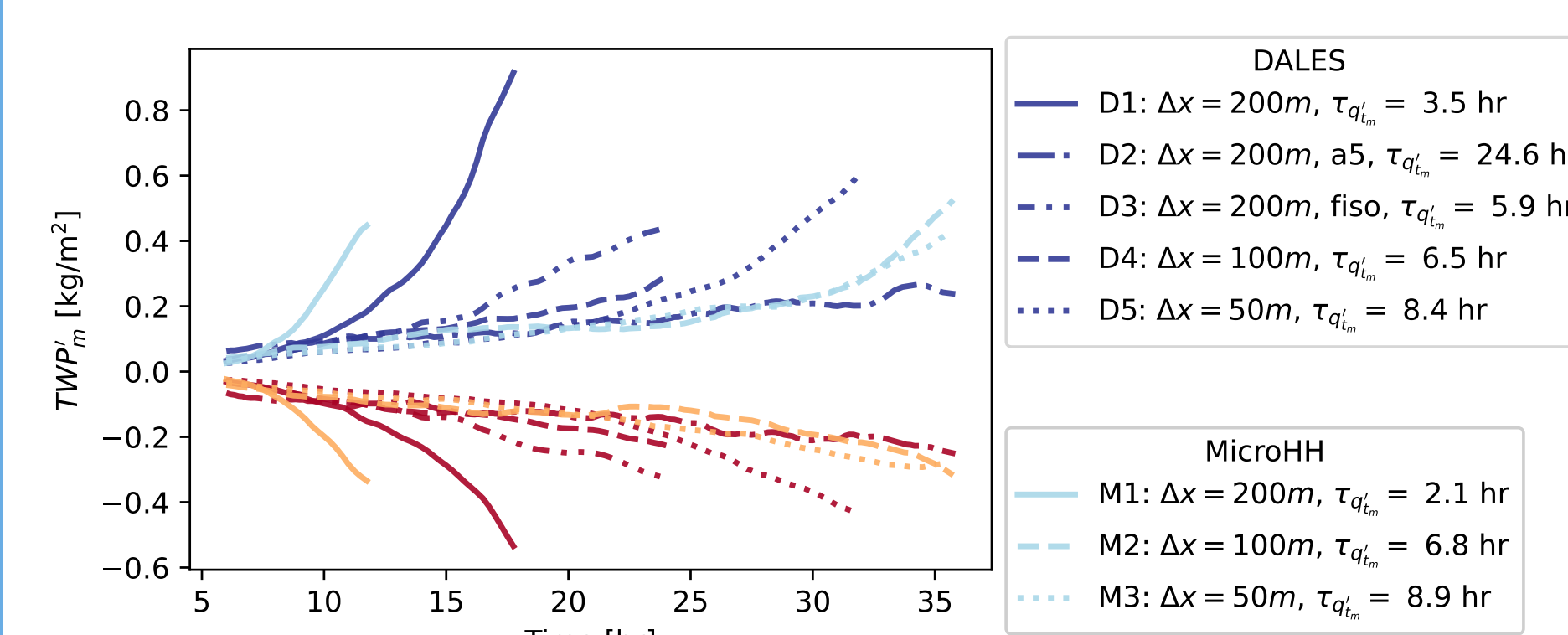
Model for column-integrated mesoscale moisture anomaly $\langle q'_{tm} \rangle$:

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

- $w^* > 0$ is a convective velocity scale
- $\partial_z (\Gamma_{q_t} / \Gamma_{\theta_{vm}}) > 0$ 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^* , $F_{\theta_{vm}}$) 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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