Scale growth is an inherent property of shallow cumulus convection

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Scale growth is an inherent property of shallow cumulus convection

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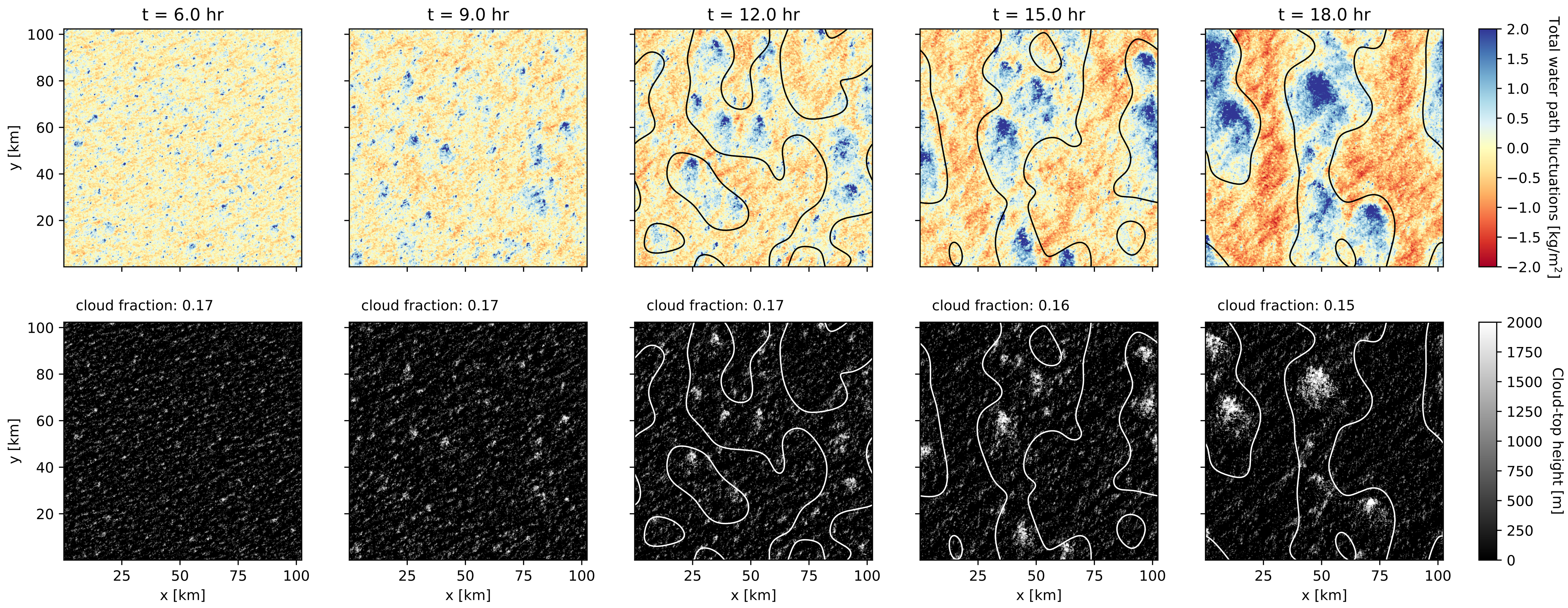
In LES, shallow convection self-organises into mesoscale clusters without cold pools or radiation anomalies



Numerical experiments

Case BOMEX as in Siebesma et al. (2003)

Model Dutch Large Eddy Simulation, MicroHH

Domain $L_x = L_y = 102.4km$

Grid $\Delta x \in [50, 100, 200]m$, $\Delta z = 40m$

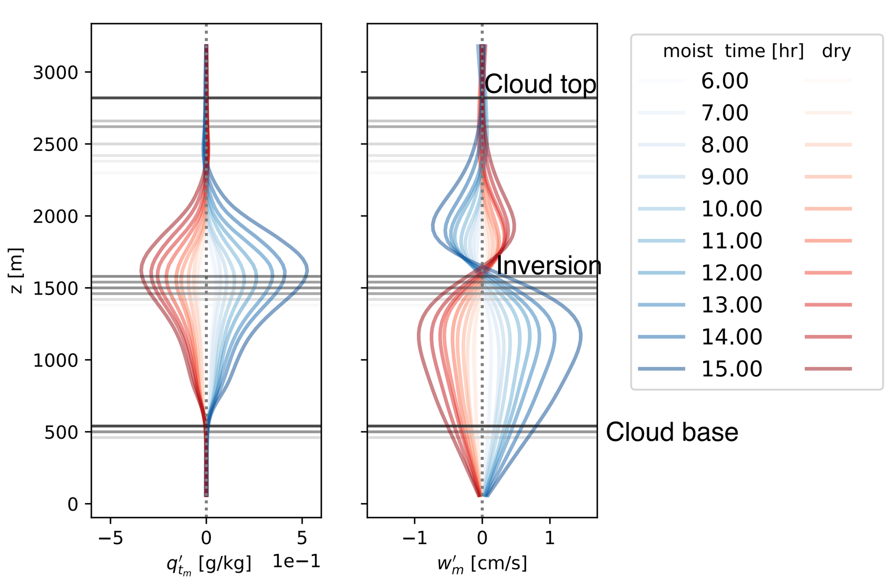
Advection $O(2)$ central differences, $O(5)$ (Wicker & Skamarock, 2002)

Physics Highly idealised setup
- Imposed, homogenous radiative cooling
- No precipitation
- Constant, homogenous surface fluxes

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

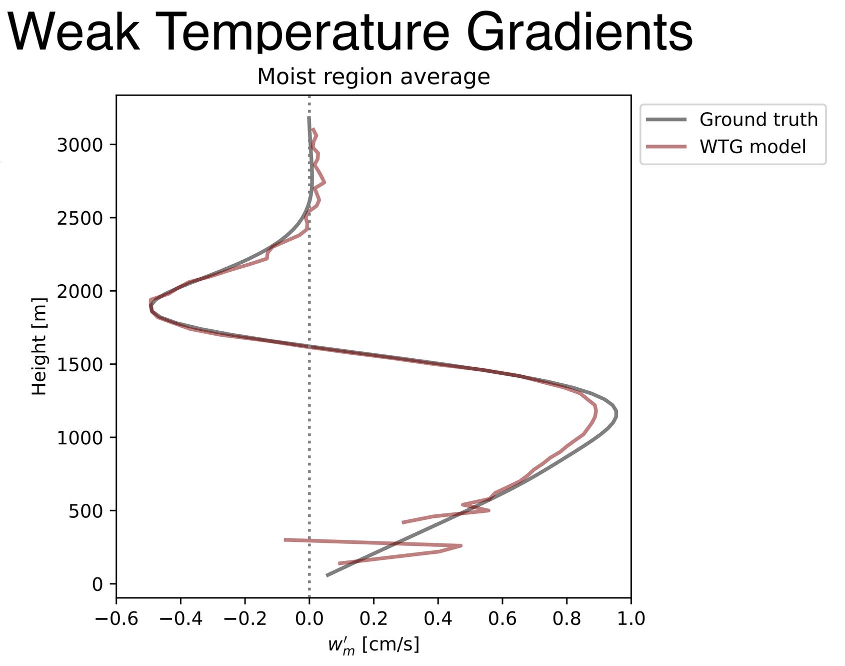
Mesoscale **moisture fluctuations** q_{t_m}' grow in cloud layer on ascending branch of **circulations** w_m'

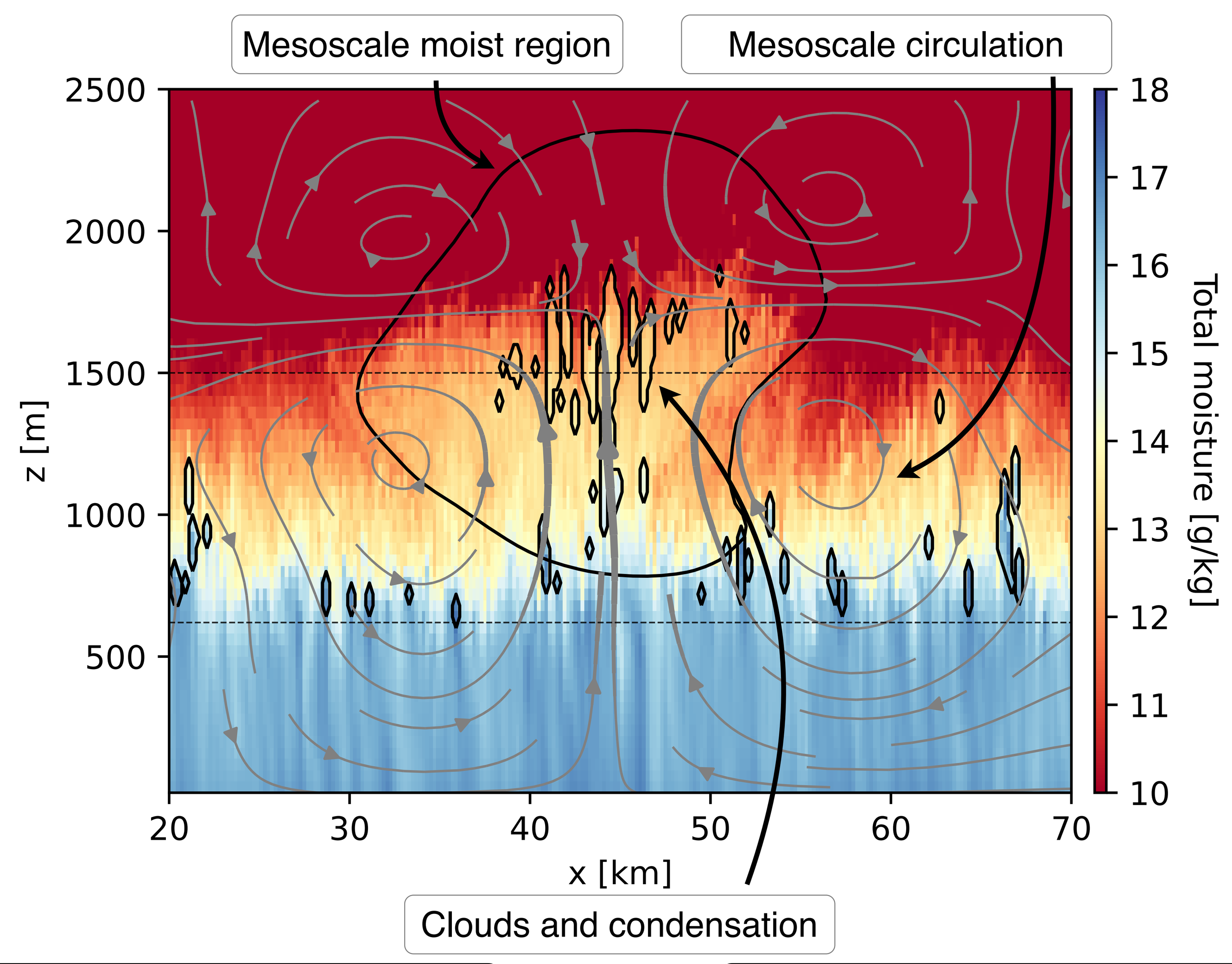
$$\partial_t q_{t_m}' \sim -w_m' \Gamma_{q_t}$$

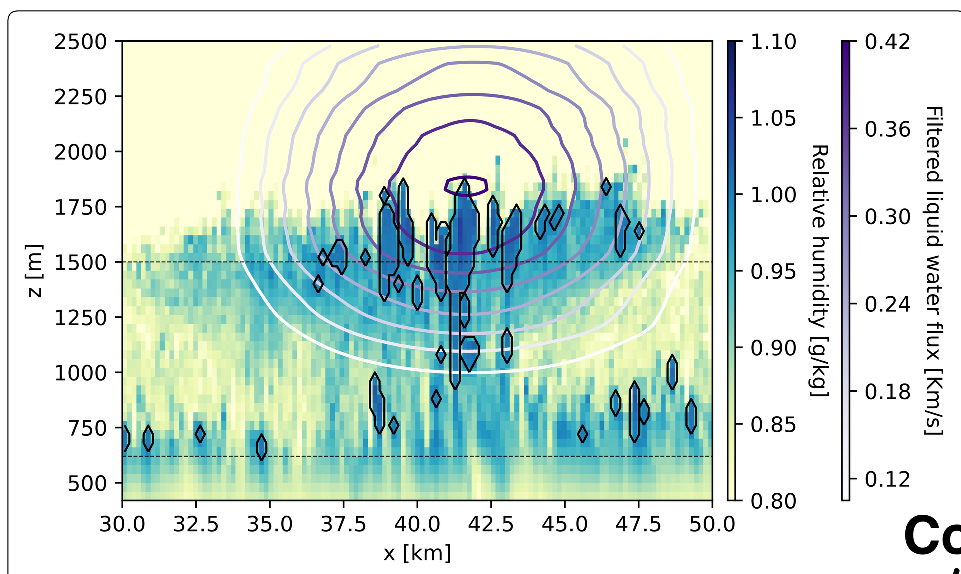


Shallow **circulations** w_m' result directly from **heat flux anomalies** $F_{\theta_{vlm}}'$, assuming Weak Temperature Gradients

$$\partial_t \theta_{vl_m}' \approx -w_m' \Gamma_{\theta_{lv}} - \partial_z F_{\theta_{vlm}}' \approx 0$$



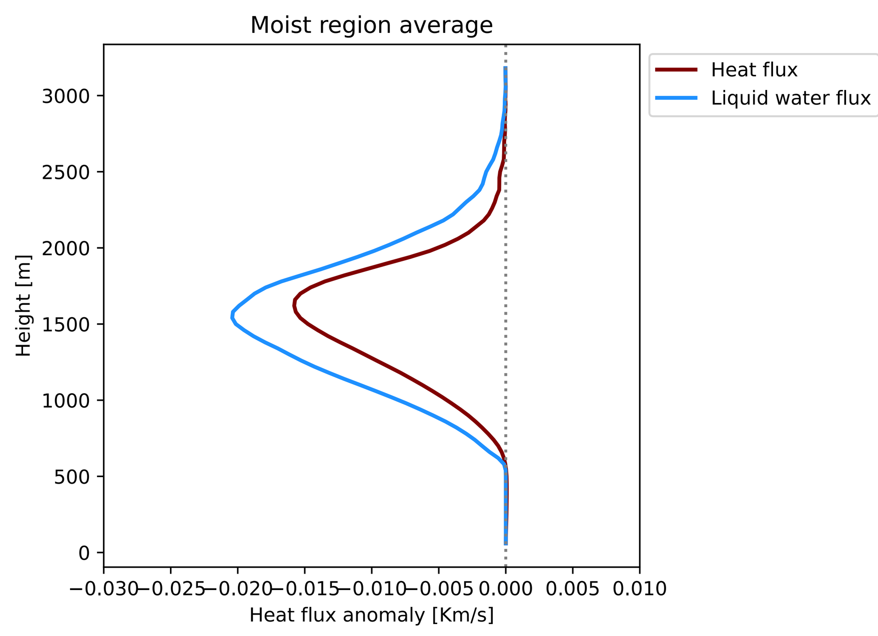




$$\mathcal{C}_m' \propto q_{t_m}'$$

Condensation anomalies $\mathcal{C}_m'$ result from mesoscale **moisture fluctuations** q_{t_m}'

Heat flux anomalies $F_{\theta_{vlm}}'$ result from **condensation** anomalies $\mathcal{C}_m'$ in clouds at **small scales**



$$\mathcal{C}_m' \approx \partial_z F_{q_{lm}}' ; \quad F_{\theta_{vlm}}' \propto F_{q_{lm}}'$$

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

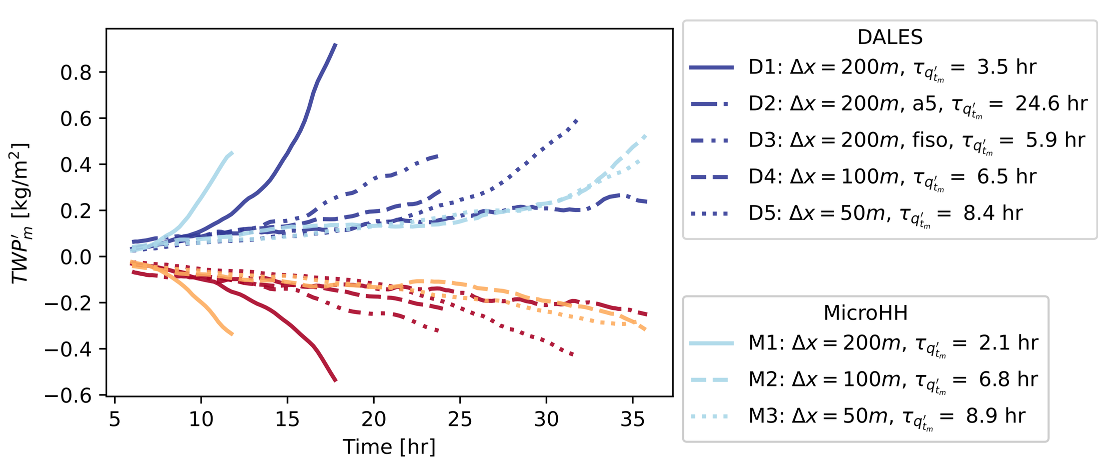
Model for column-integrated mesoscale moisture anomaly $\langle q_{t_m}' \rangle$:

$$\partial_t \langle q_{t_m}' \rangle \approx \frac{\langle q_{t_m}' \rangle}{\tau_{q_{t_m}'}}, \qquad \tau_{q_{t_m}'} \propto \frac{1}{w^* \partial_z \left(\frac{\Gamma_{q_t}}{\Gamma_{\theta_{lv}}}\right)}.$$

- $w^* > 0$ is a convective velocity scale
- $\partial_z \left(\Gamma_{q_t}/\Gamma_{\theta_{lv}}\right) > 0$ 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 $\tau_{q_{t_m}'}$
- 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 EUREC^{4}A 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?

References

Bretherton, C. S., & Blossey, P. N. (2017). Understanding mesoscale aggregation of shallow cumulus convection using largeäeddy simulation. *Journal of Advances in Modeling Earth Systems*, 9(8), 2798-2821.
George, G., Stevens, B., Bony, S., Vogel, R. & Naumann, A. K. (2022). Observing shallow circulations and their influence over mesoscale moisture. *In preparation.*
Albright, A. L., Bony, S., Stevens, B. & Vogel, R. (2022). A new conceptual picture of the transition layer. *Dissertation chapter.*
Vogel, R., Bony, S., & Stevens, B. (2020). Estimating the shallow convective mass flux from the subcloud-layer mass budget. *Journal of the Atmospheric Sciences*, 77(5), 1559-1574.