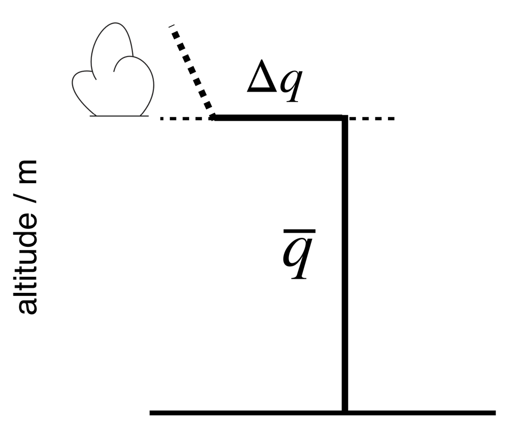
A new conceptual picture of the transition layer

Anna Lea Albright, Bjorn Stevens, Sandrine Bony, Raphaela Vogel, in prep.

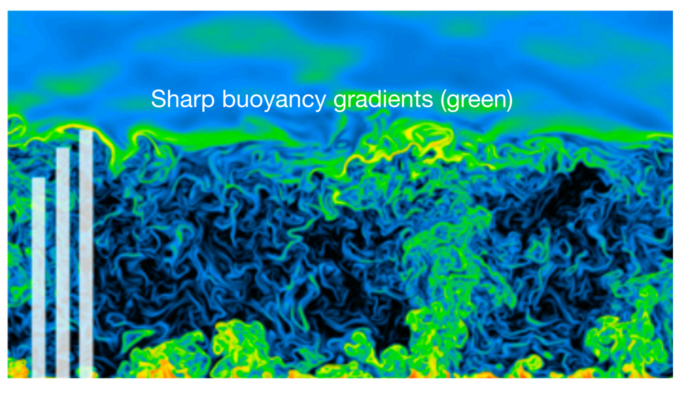
The transition layer in the trades has long been observed and simulated, but its origins remain little investigated. It is often associated with an about 150 m deep layer between the mixed layer and subcloud layer tops that acts as a barrier to overlying convection. Using extensive observations from the EUREC4A field campaign, we propose a new conceptual picture of the transition layer. Strong jumps at the mixed layer top, as expected from the theory of cloud-free convective boundary layers, are only found rarely and when they occur, they tend to occur in large cloud-free areas. We suggest that very shallow clouds, with their bases around 600 m and mean cloud top around 850 m, produce the observed structure as they dissipate within the transition layer, moistening and cooling the surrounding air. This mechanism is analogous to the maintenance of the cloud layer by deeper clouds in Riehl et al., 1951. From this analysis emerges the potential for an alternate view of entrainment mixing, which is based on the ability to detrain condensate into the transition layer and induce gentle sinking motion through negative buoyancy. Inferences from jointly estimating subcloud moisture and heat budgets, in particular related to constraining uncertain entrainment parameters in a Bayesian approach, further support the idea of an additional (e.g., cloud-mediated) mixing source in the transition layer.

Evidence for finite-thickness transition layer (vs. jump) in EUREC4A observations

Previous views of the subcloud layer (sharp gradients), often from stratocumulus regimes or dry convective layers

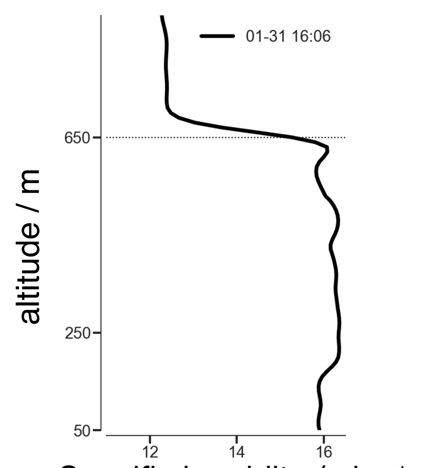


e.g., Lilly, 1968; Arakawa, Schubert, 1974; Betts, 1976; Stevens 2006



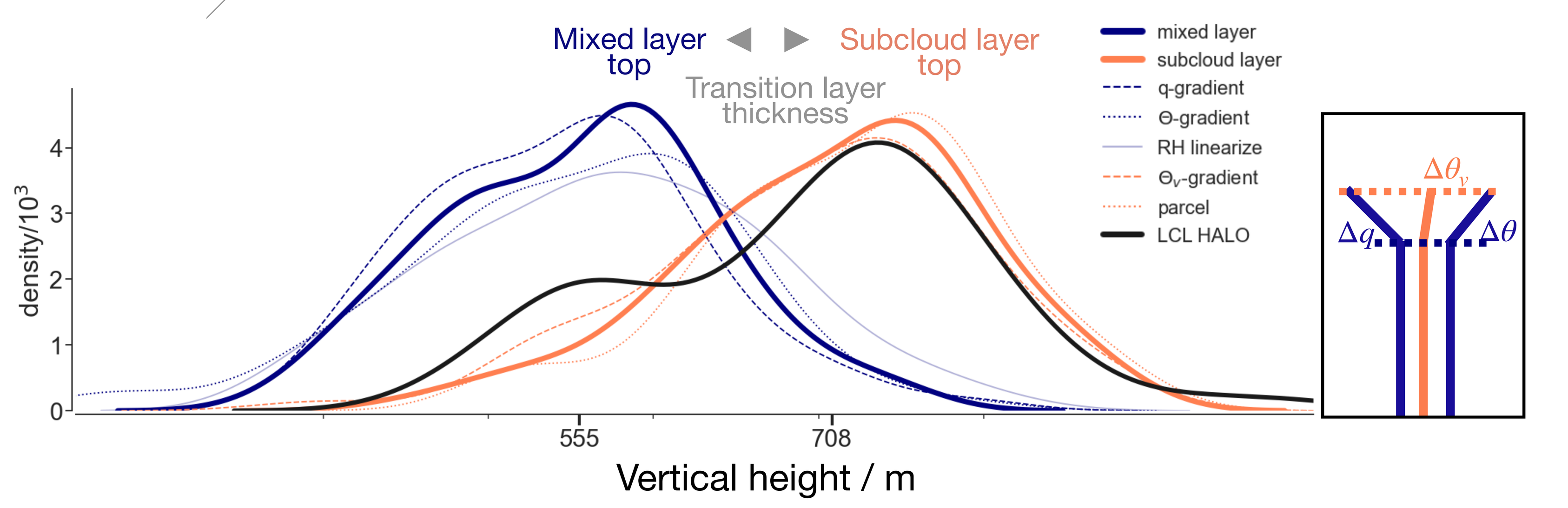
DNS results reproduced from Garcia & Mellado, 2014

How representative is this structure?



Heights of subcloud layer depends on thermodynamic variable

Evidence for ~150 m thick transition layer

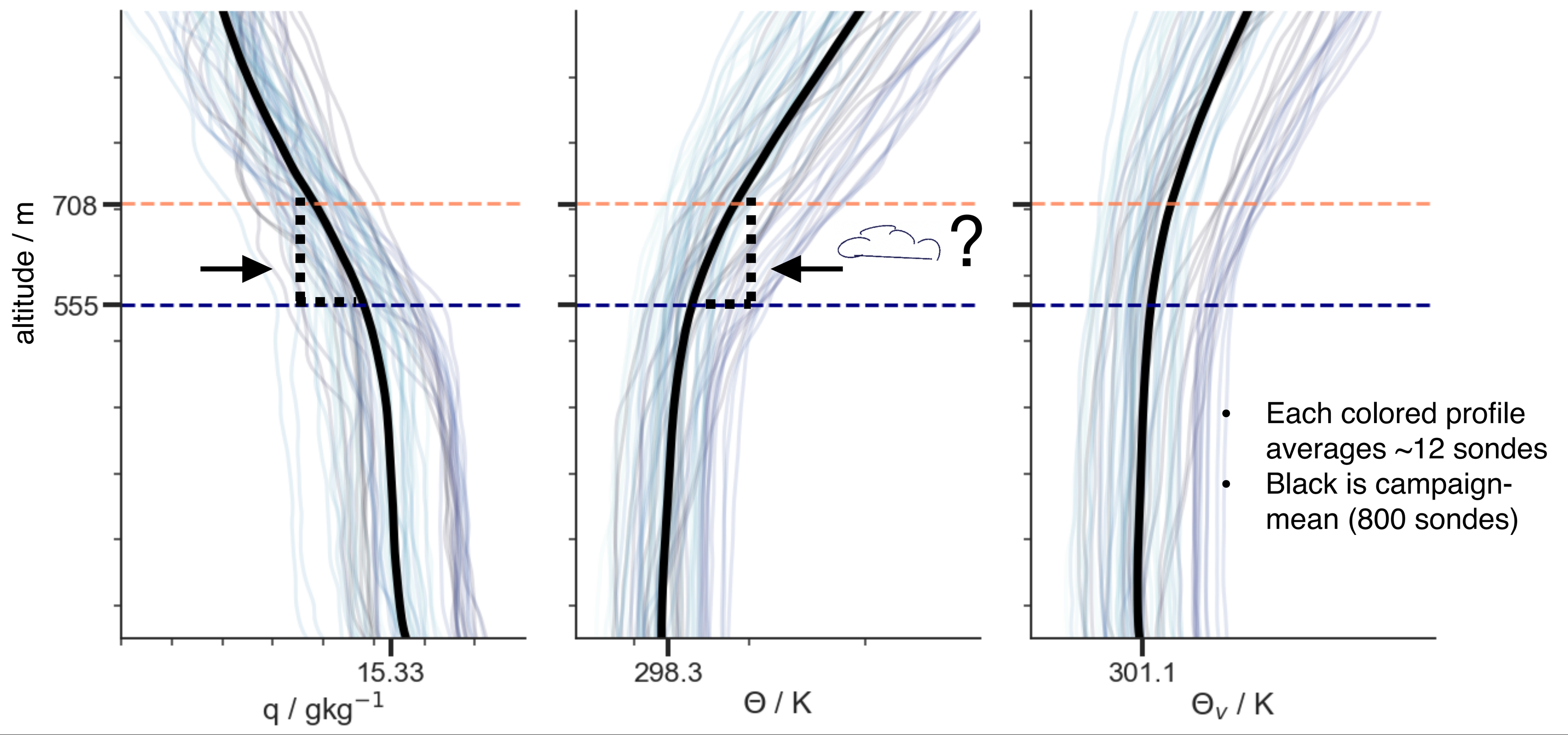


Most of the time, vertical gradients are smoother.

How do we characterize the subcloud layer height?

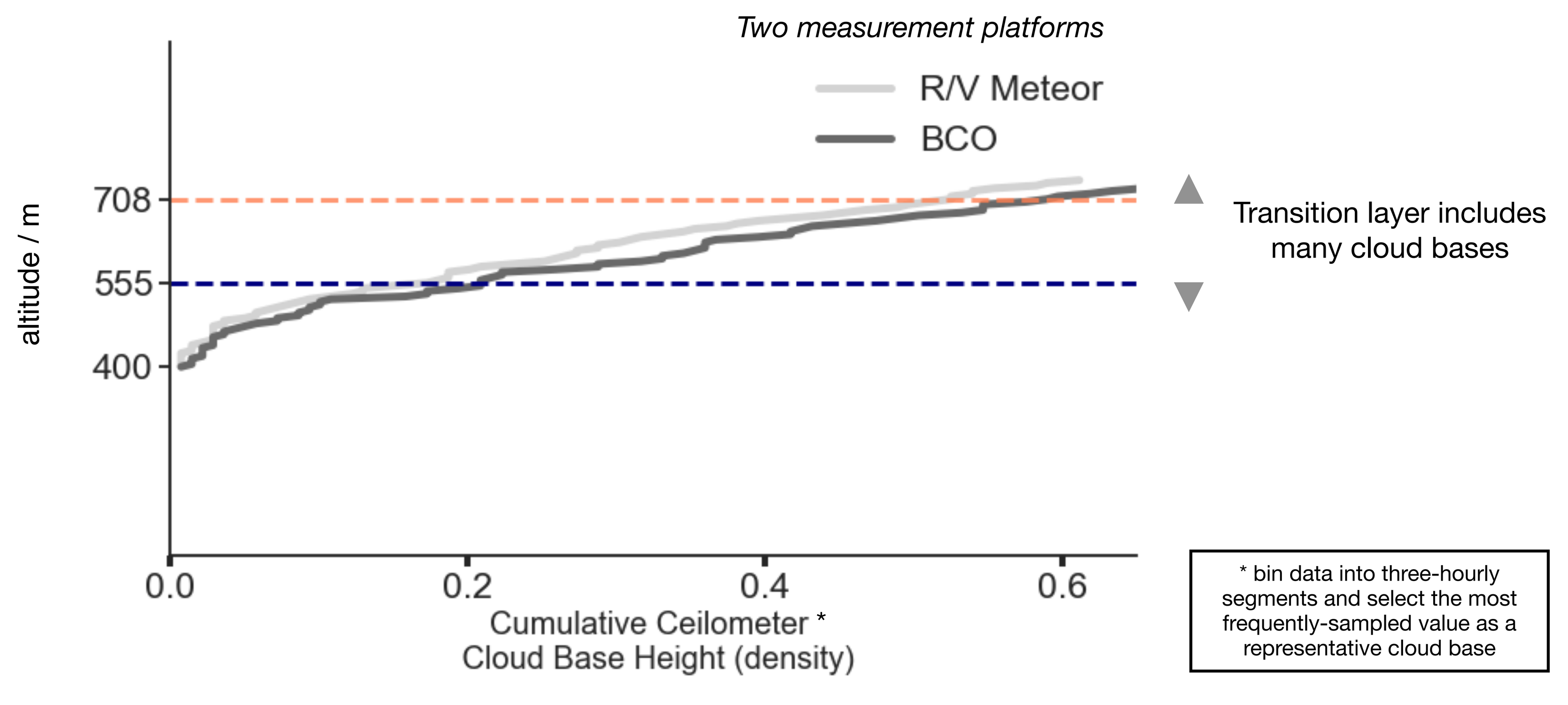
Apply height definitions, e.g., Canut et al., 2012, to observed thermodynamic profiles.

Cf. smooth vertical gradients in Neggers et al., 2009, Gentine et al., 2013



Transition layer is populated by clouds

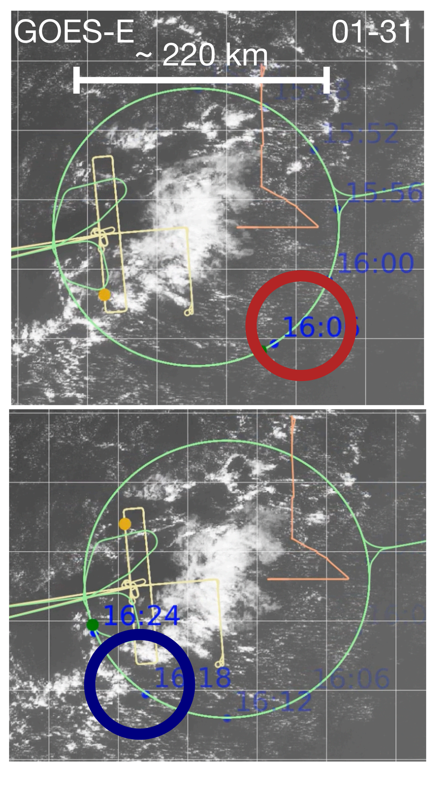
Do clouds dissipating (moistening, cooling) cause its vertical structure?

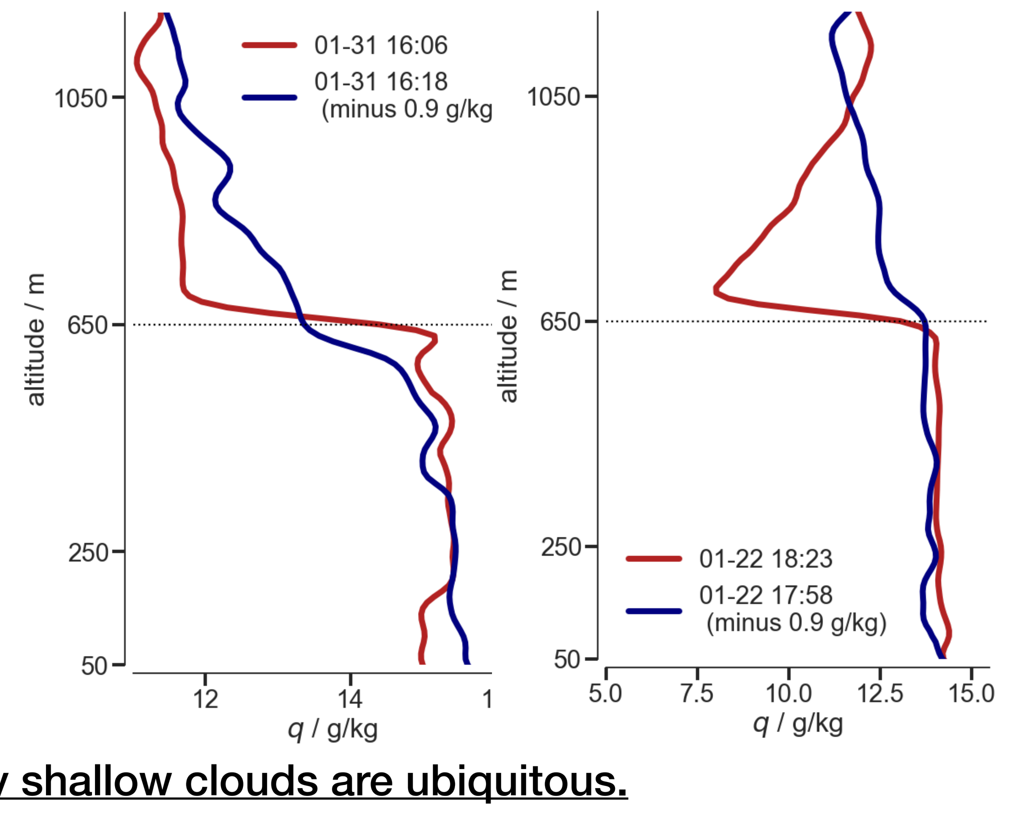


* bin data into three-hourly segments and select the most frequently-sampled value as a representative cloud base

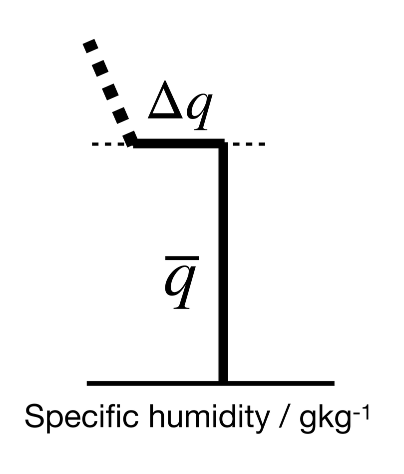
Sharper vertical gradients exist, but rarely, and in large cloud-free areas

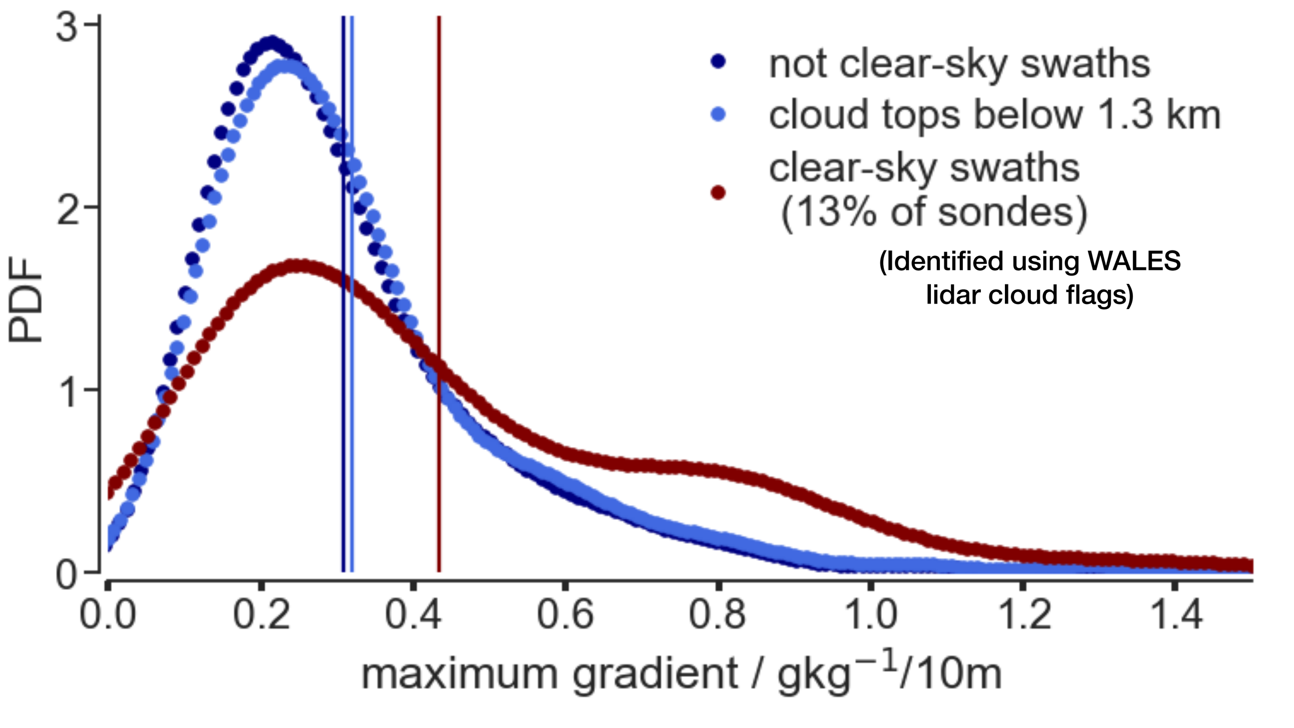
Sharp gradients exist, but rarely, and in large cloud-free areas





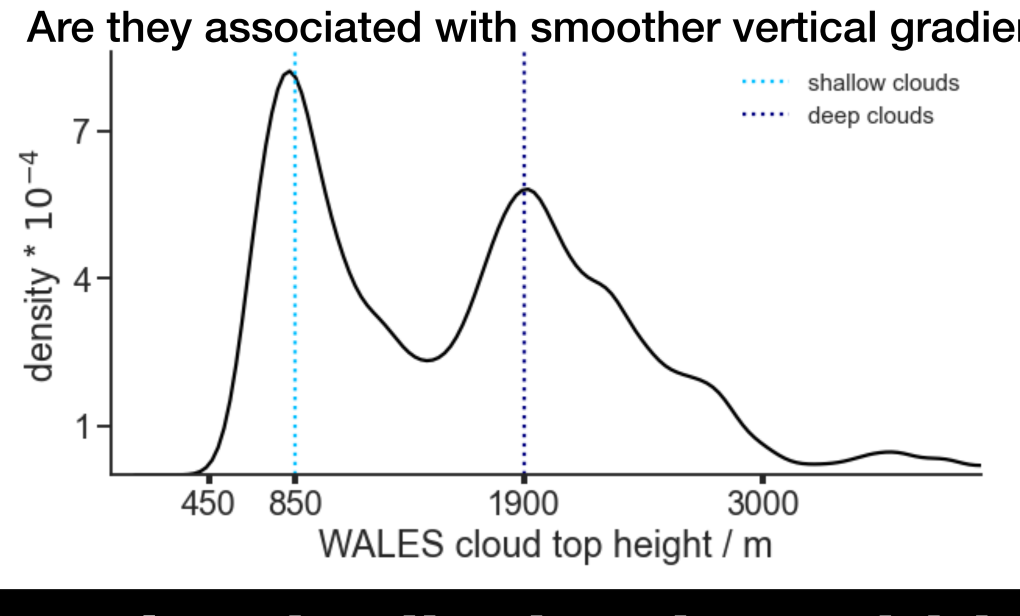
Select sharpest vertical (10 m) gradient in subcloud layer profile. → **Larger gradients in large cloud-free areas**



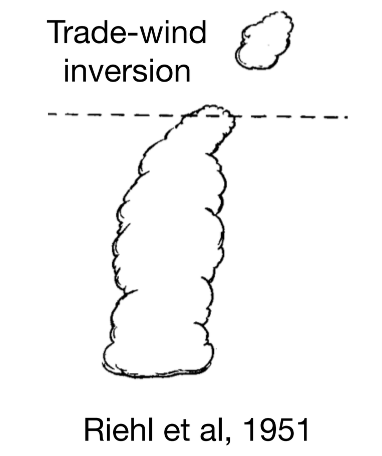


Very shallow clouds are ubiquitous.

Are they associated with smoother vertical gradients?



Symmetry between shallow and deep clouds, with each population growing its own layer



Riehl et al, 1951

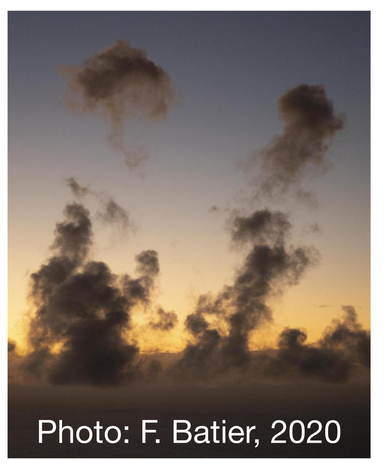


Photo: F. Batier, 2020

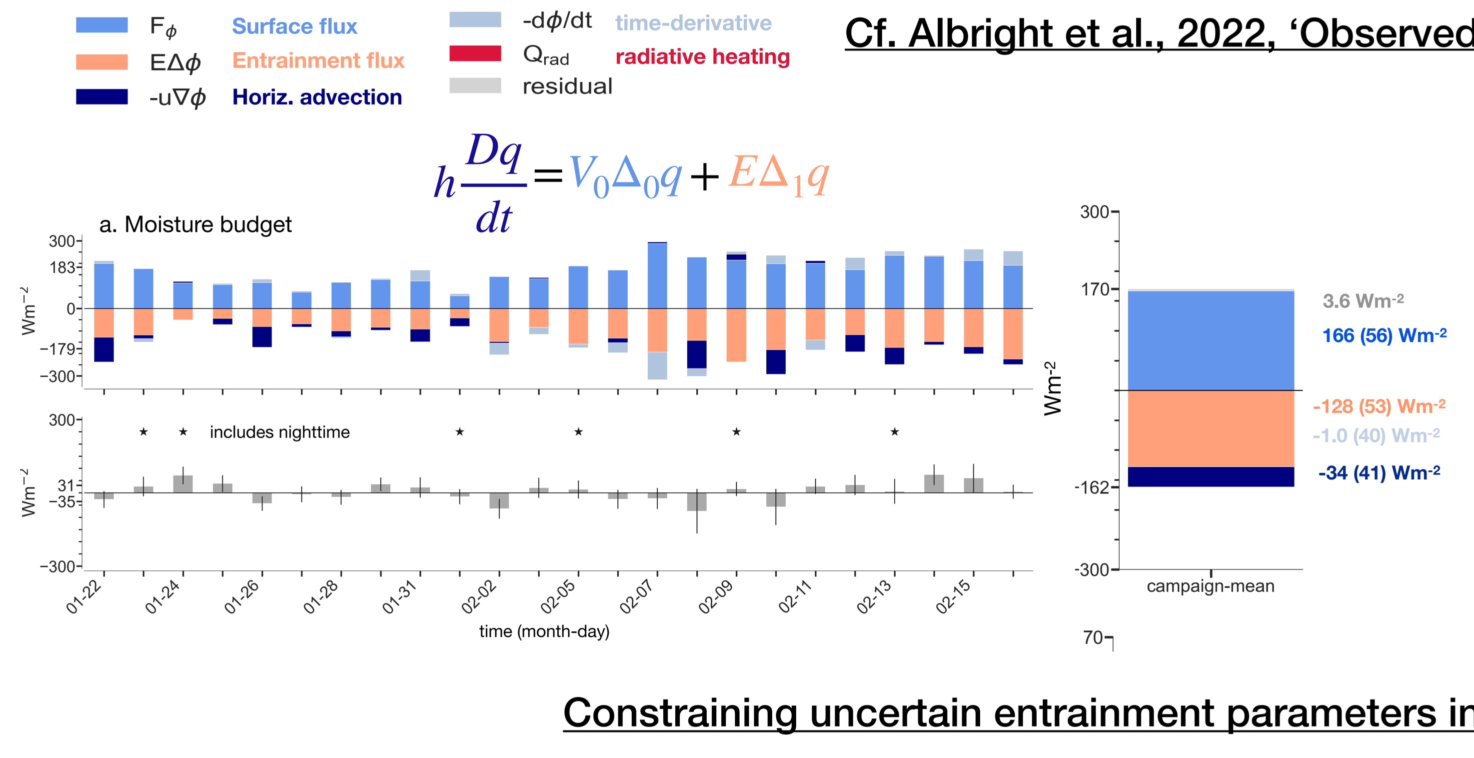
Some ensuing questions

- Regarding convective organization: do small clouds beget larger clouds? (e.g., Neggers, 2015). Are shallow circulations needed to create deeper clouds?
- How do simulations represent transition layer (e.g. jumps)?
- Can isotopes tell us about origins of transition layer air?

Do clouds dissipating within transition layer contribute to entrainment mixing?

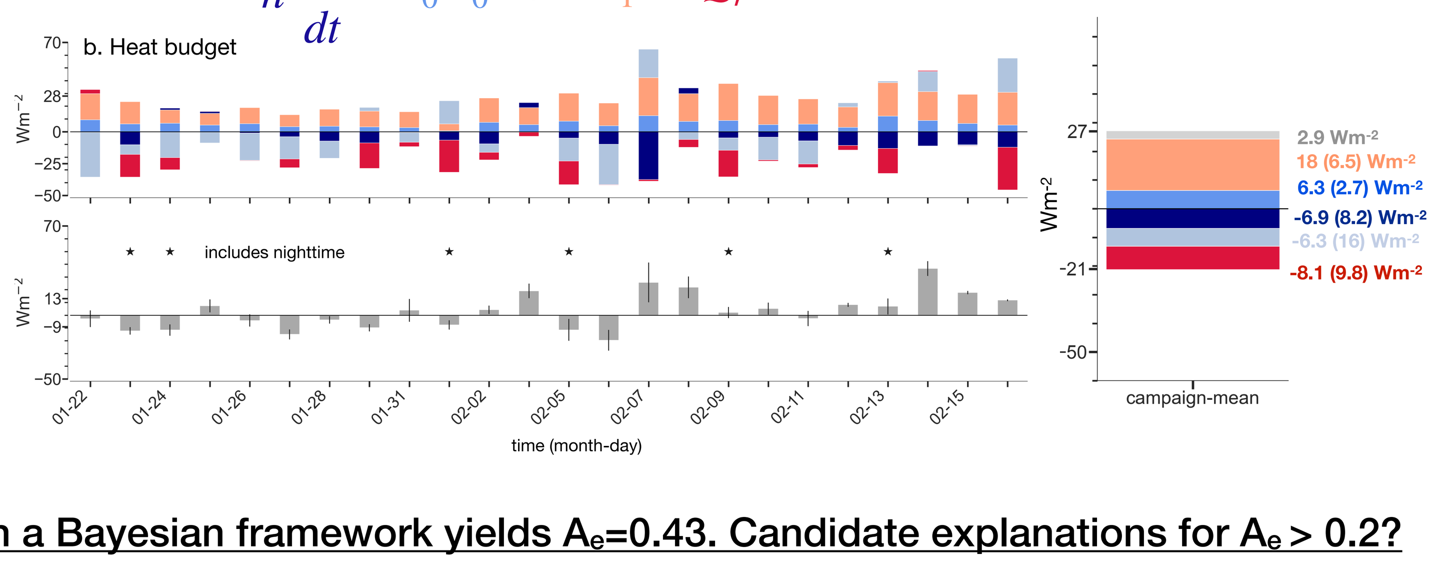
Cf. Albright et al., 2022, 'Observed subcloud layer moisture and heat budgets in the trades' (JAS)

$$h\frac{Dq}{dt} = V_0\Delta_0 q + E\Delta_1 q$$



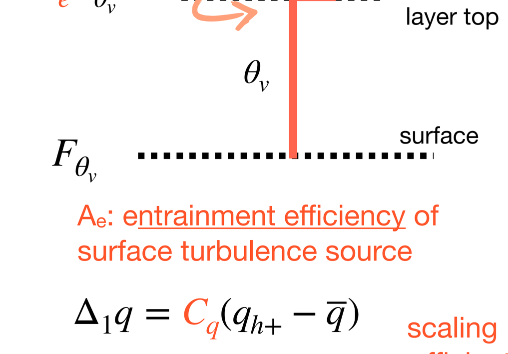
$$h\frac{D\theta}{dt} = V_0\Delta_0\theta + E\Delta_1\theta - Q_r$$

Albright, Fildier, Touzé-Peiffer et al., 2021 (ESSD)



Entrainment parameters $E = \frac{A_e F_{\theta_v}}{\Delta_1\theta_v}$

e.g., Lilly, 1968, Stull, 1976, Stevens 2006



A_e: entrainment efficiency of surface turbulence source

$$\Delta_1 q = C_q(q_{h+} - \bar{q})$$
$$\Delta_1\theta = C_\theta(\theta_{h+} - \bar{\theta})$$

scaling coefficients

Constraining uncertain entrainment parameters in a Bayesian framework yields A_e=0.43. Candidate explanations for A_e > 0.2?

- A_e > 0.2 reflects finite-thickness transition layer in observations but is *inconsistent* with LES (e.g., Siebesma et al., 2003, Fedorovich et al., 2004) and DNS studies (e.g., Garcia & Mellado, 2014)
- Larger A_e value could arise if other processes are contributing to the energetics of mixing, for instance wind shear, cloud processes, or radiative cooling in the transition layer, or if the depth of the layer is too deep compared to the height of minimum buoyancy flux (e.g., Fedorovich et al., 2004, Canut et al., 2012)
- Applying our inversion technique using the shallower mixed layer depth does not, however, resolve this discrepancy, nor does wind shear appear to play a role

→ Discrepancy leaves a possible disagreement with idealized simulations, or contributions from shallow clouds in transition layer as candidate explanation for a larger A_e

Relevant personal refs.

Albright, A. L., Fildier, B., Touzé-Peiffer, L., Pincus, R., Vial, J., & Muller, C. (2021). Atmospheric radiative profiles during EUREC4A. Earth System Science Data, 13(2), 617-630.
Albright, A. L., Bony, S., Stevens, B., & Vogel, R. (2022). Observed subcloud layer moisture and heat budgets in the trades. Journal of the Atmospheric Sciences, in press.
Albright, A. L., Stevens, B., Bony, S., & Vogel, R. (2022). A new conceptual picture of the transition layer. Journal of the Atmospheric Sciences, in prep.