A new conceptual picture of the trade-wind transition layer*

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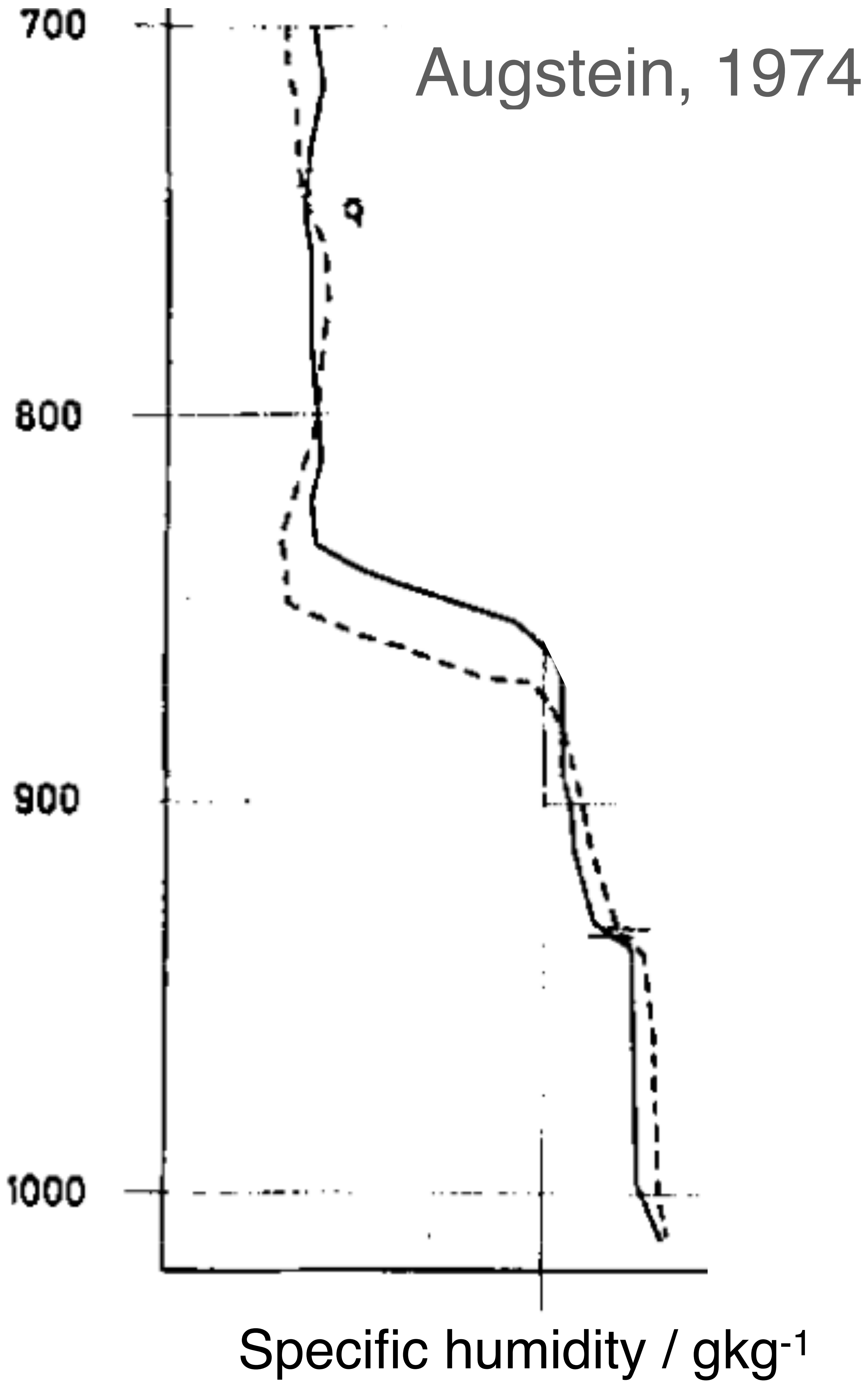
*In review at JAS

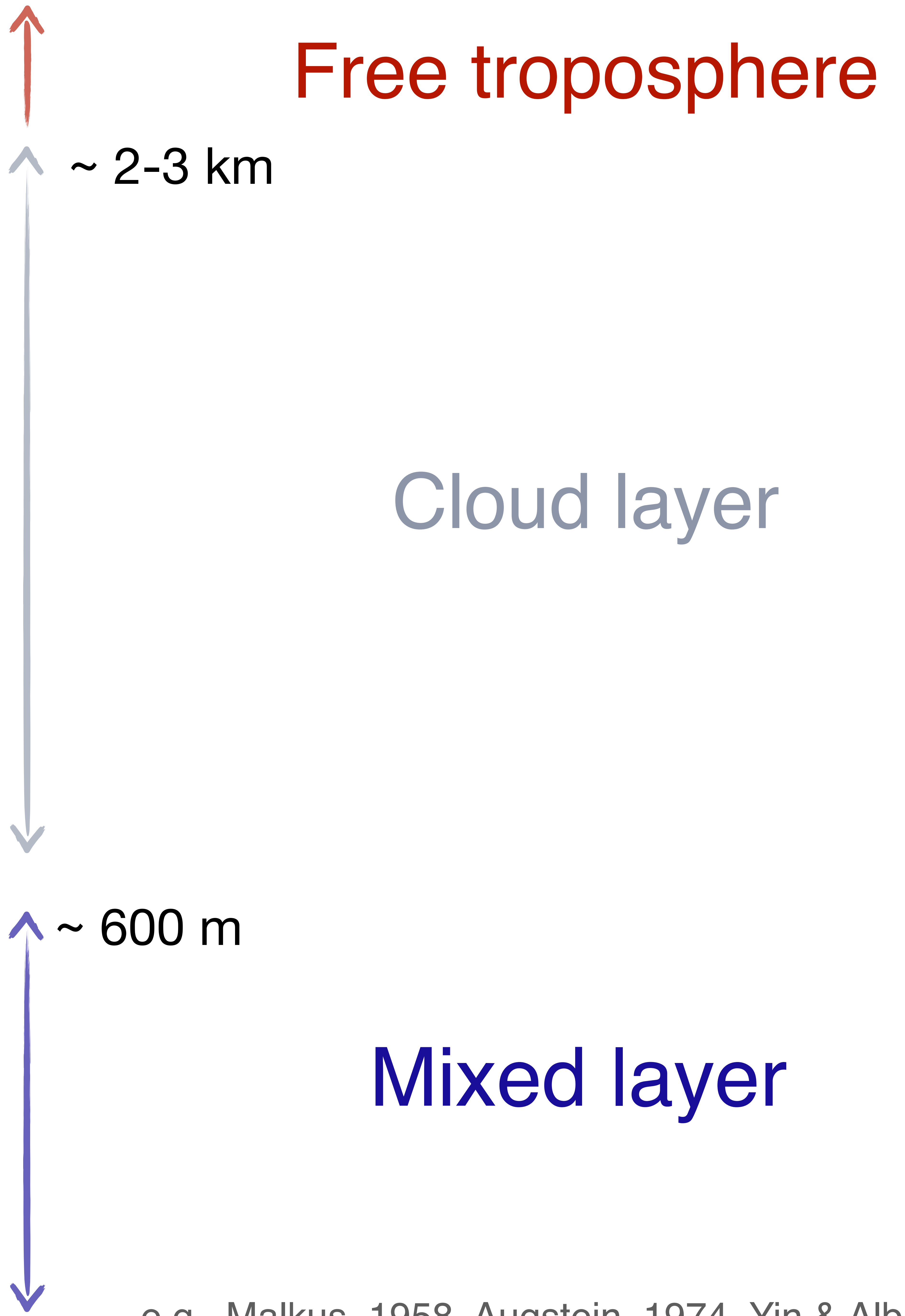
Trade-wind atmosphere has characteristic vertical structure

e.g., Malkus, 1958, Augstein, 1974, Yin & Albrecht, 2000



Studying vertical structure teaches us about physical processes producing this structure


Mark Rothko, Blue and Grey (1962)



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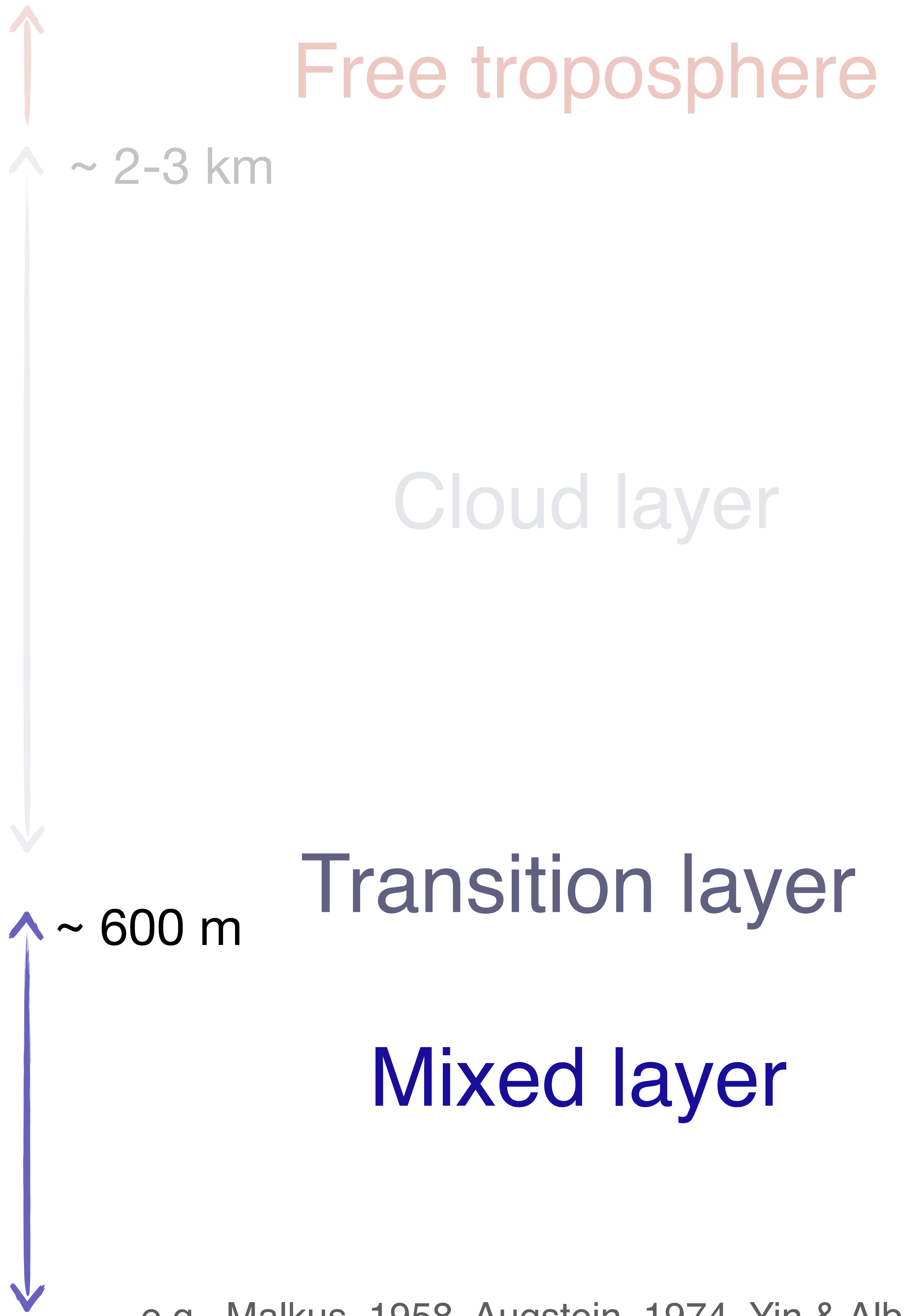
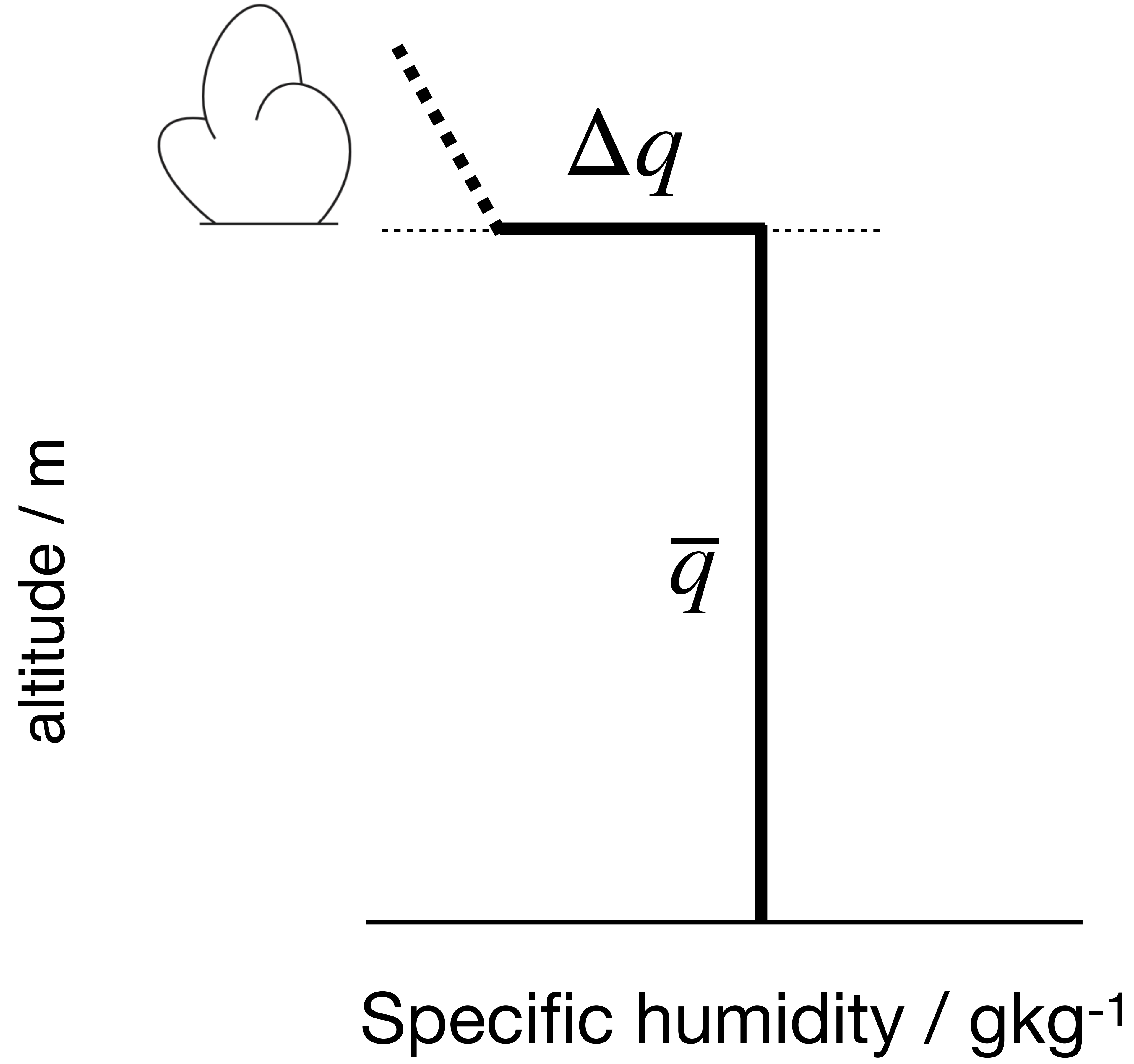


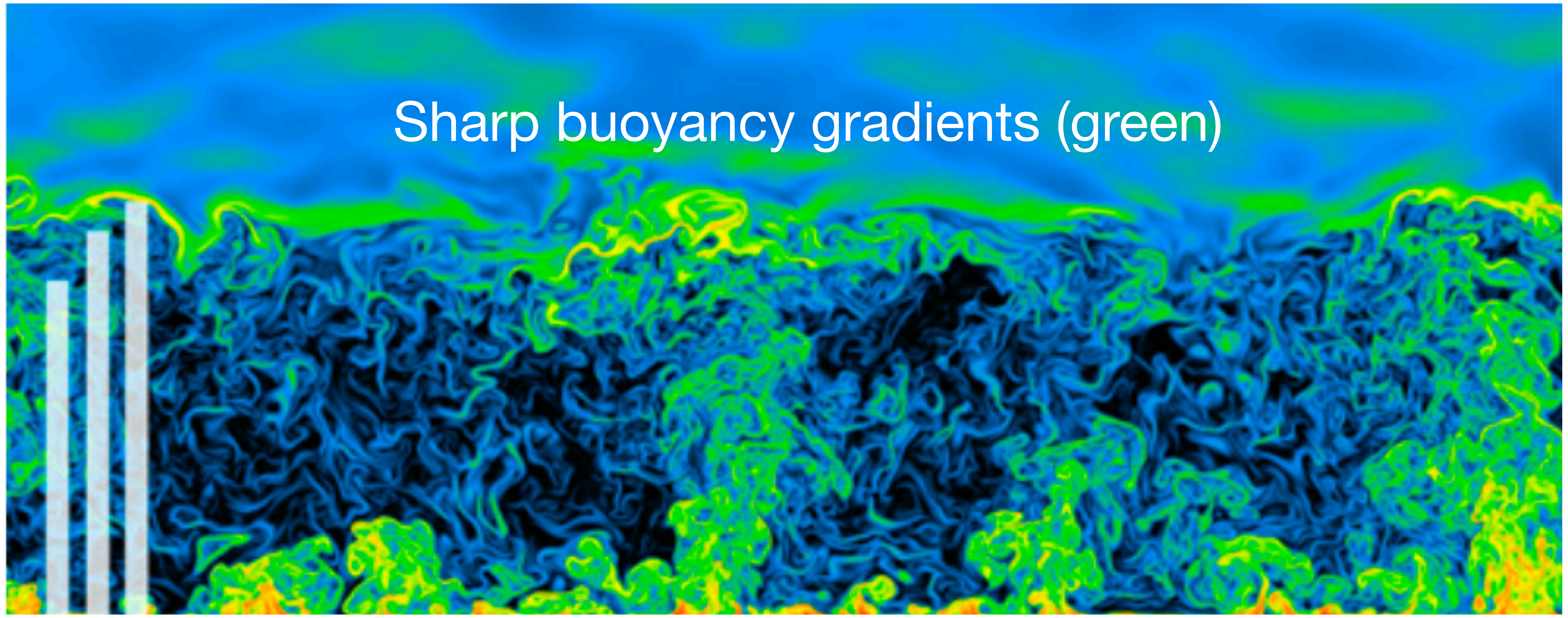
e.g., Malkus, 1958, Augstein, 1974, Yin & Albrecht, 2000

Previous views of the transition layer (sharp gradients),

In analogy with stratocumulus regimes or dry convective layers

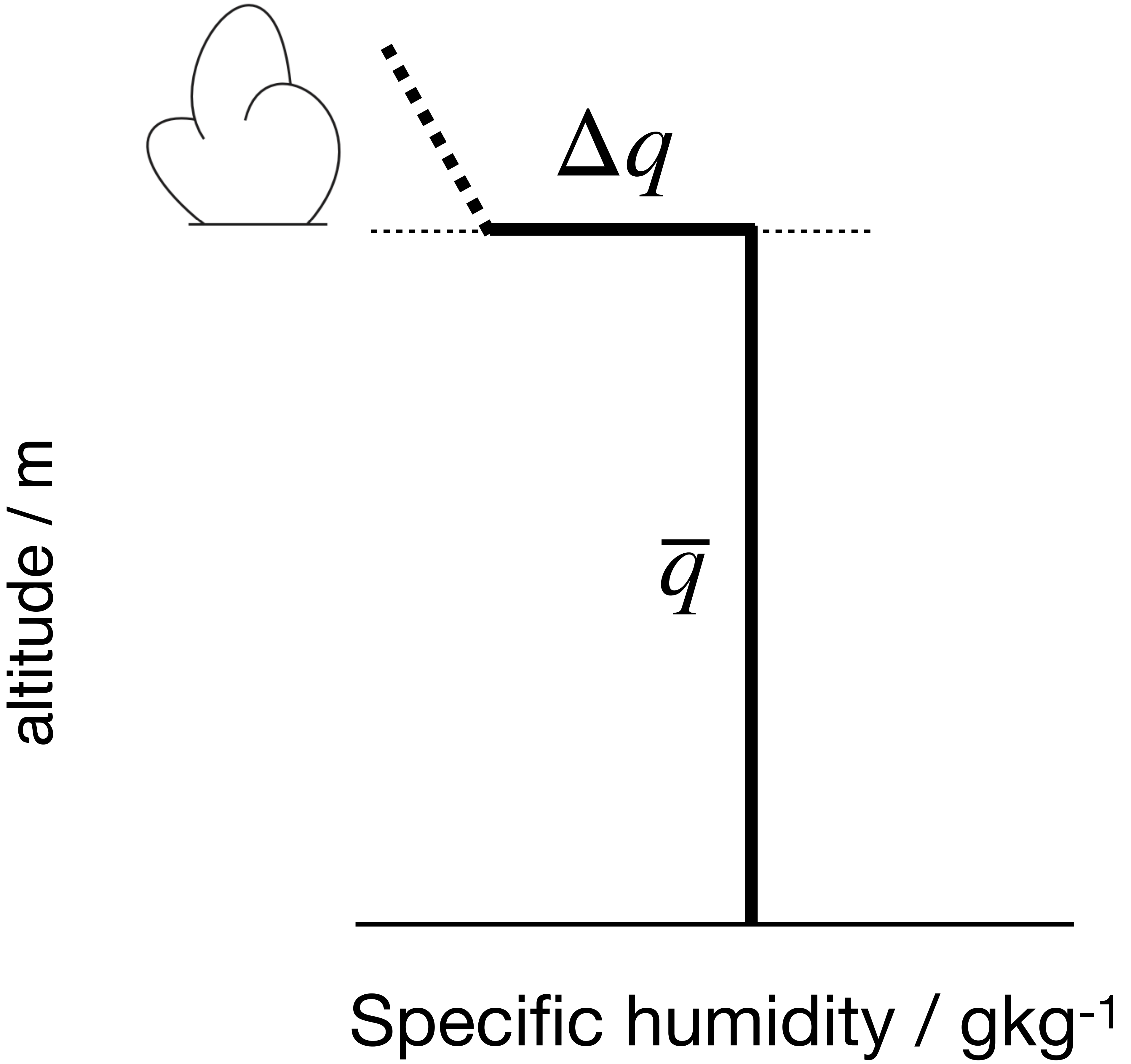


e.g., Lilly, 1968, Arakawa, Schubert, 1974, Betts, 1976, Albrecht, 1979, Stevens 2006



Direct numerical simulation results reproduced from Garcia & Mellado, 2014

How representative is this cloud-free structure in the trades?



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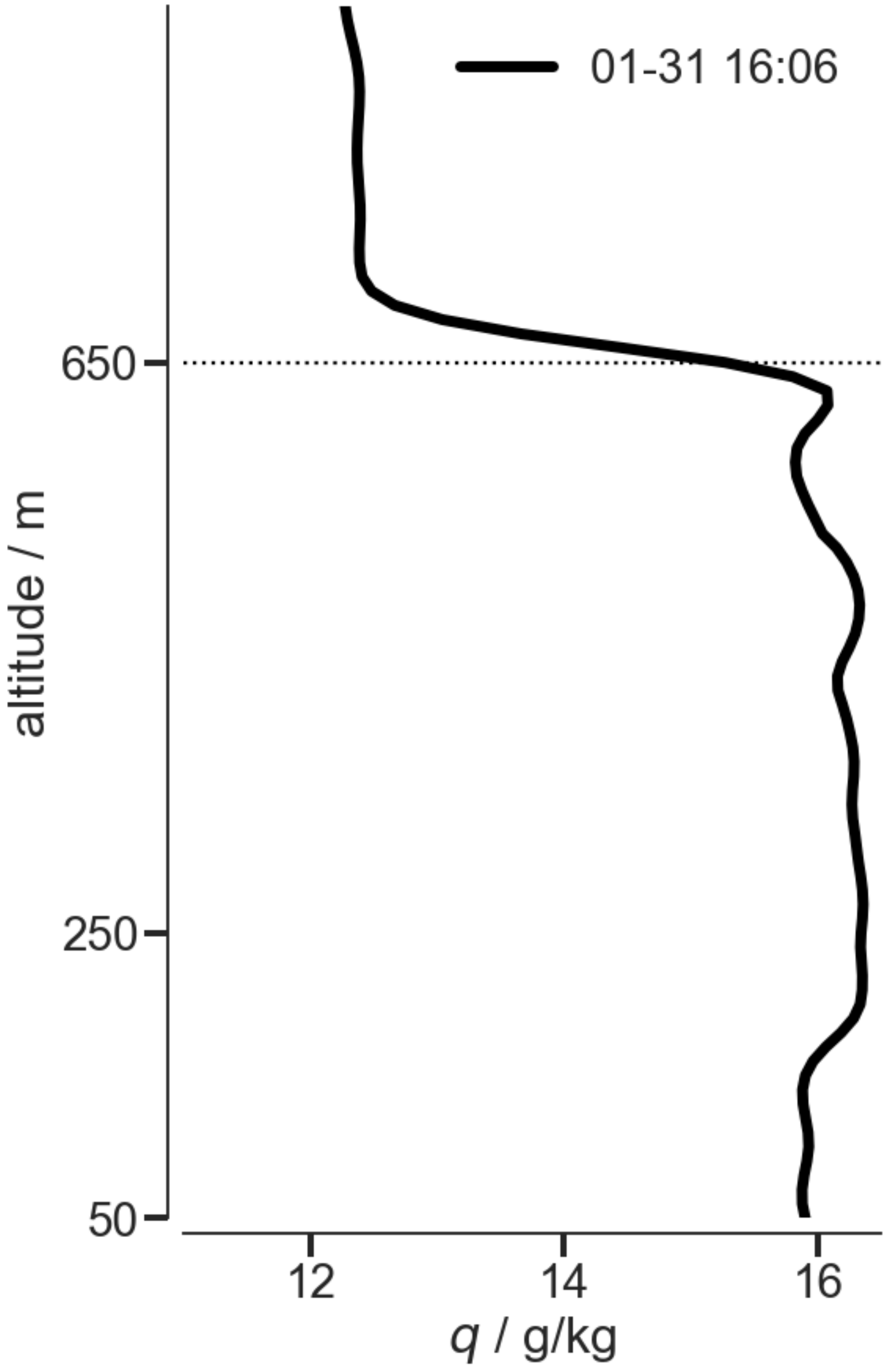
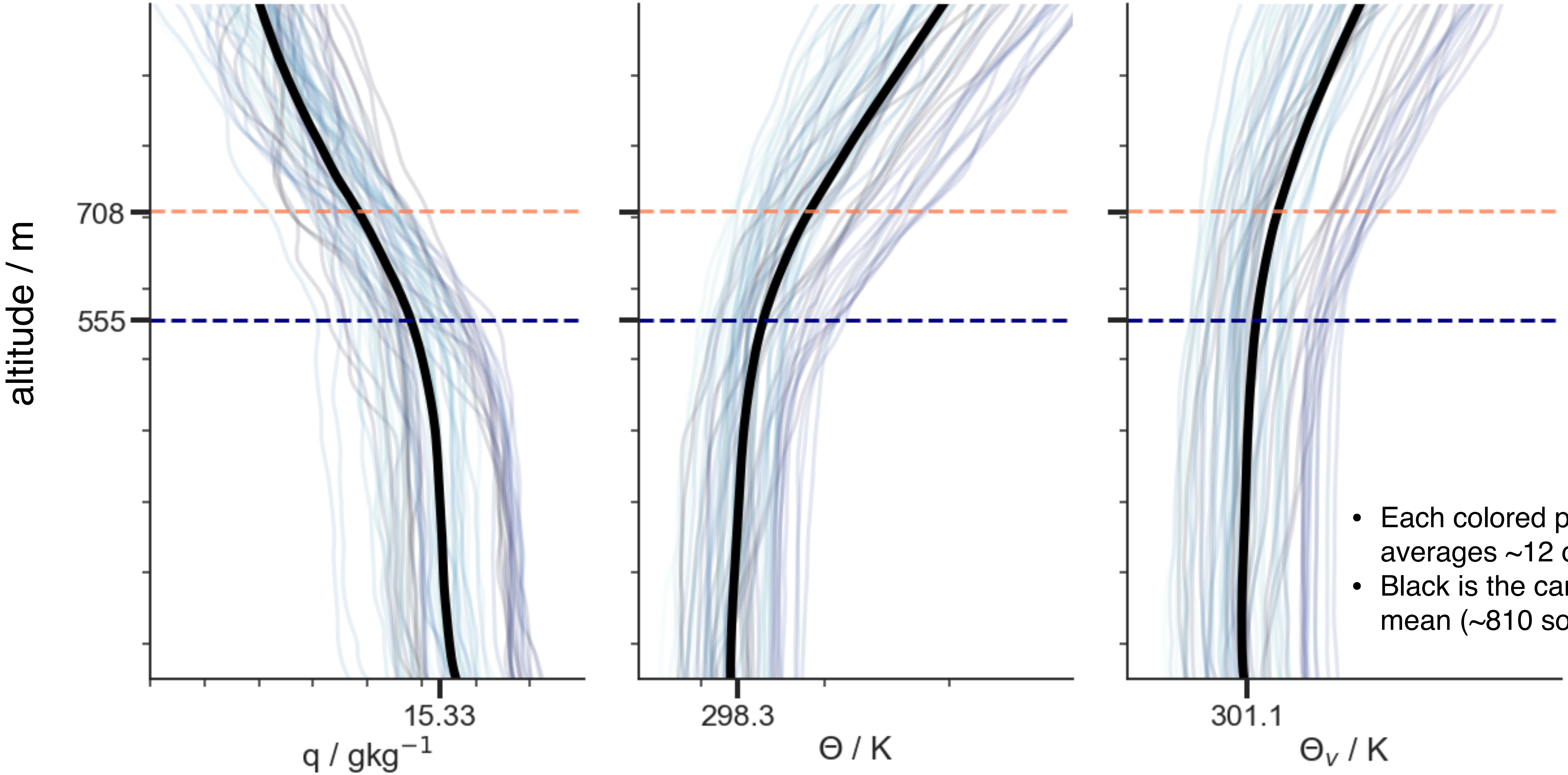


Single dropsonde sounding from EUREC4A

Cloud-base cloud fraction measured from a lidar-radar synergy is 5.3±3.2% (Bony et al., 2022), so it could be reasonable to assume that the cloud-free transition layer structure is the baseline

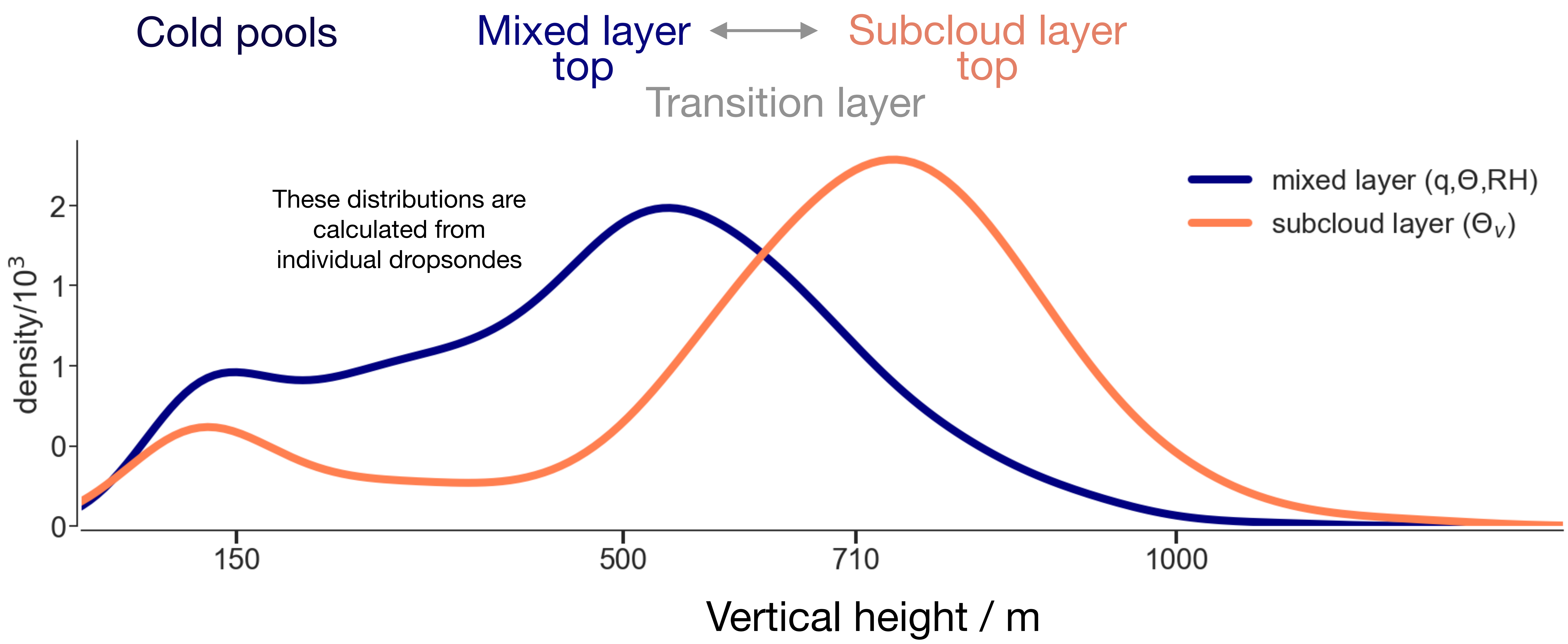
Most of the time, vertical gradients are smoother.
How to define the transition layer from thermodynamic profiles?

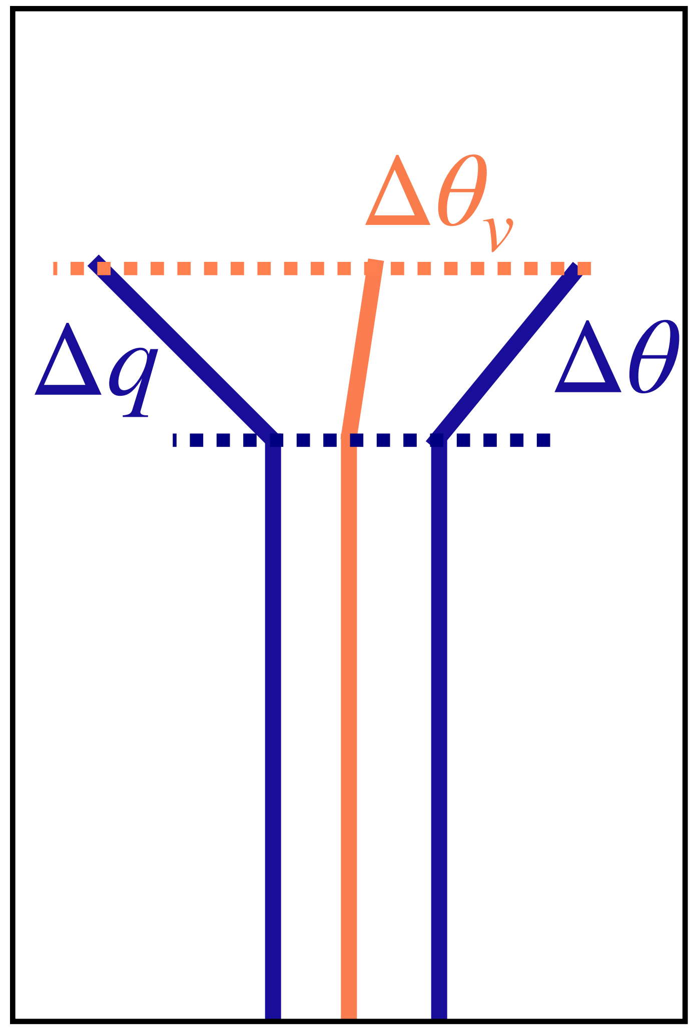
Apply height definitions, e.g., Canut et al., 2012, to observed thermodynamic profiles



- Each colored profile averages ~12 dropsondes
- Black is the campaign-mean (~810 sondes)

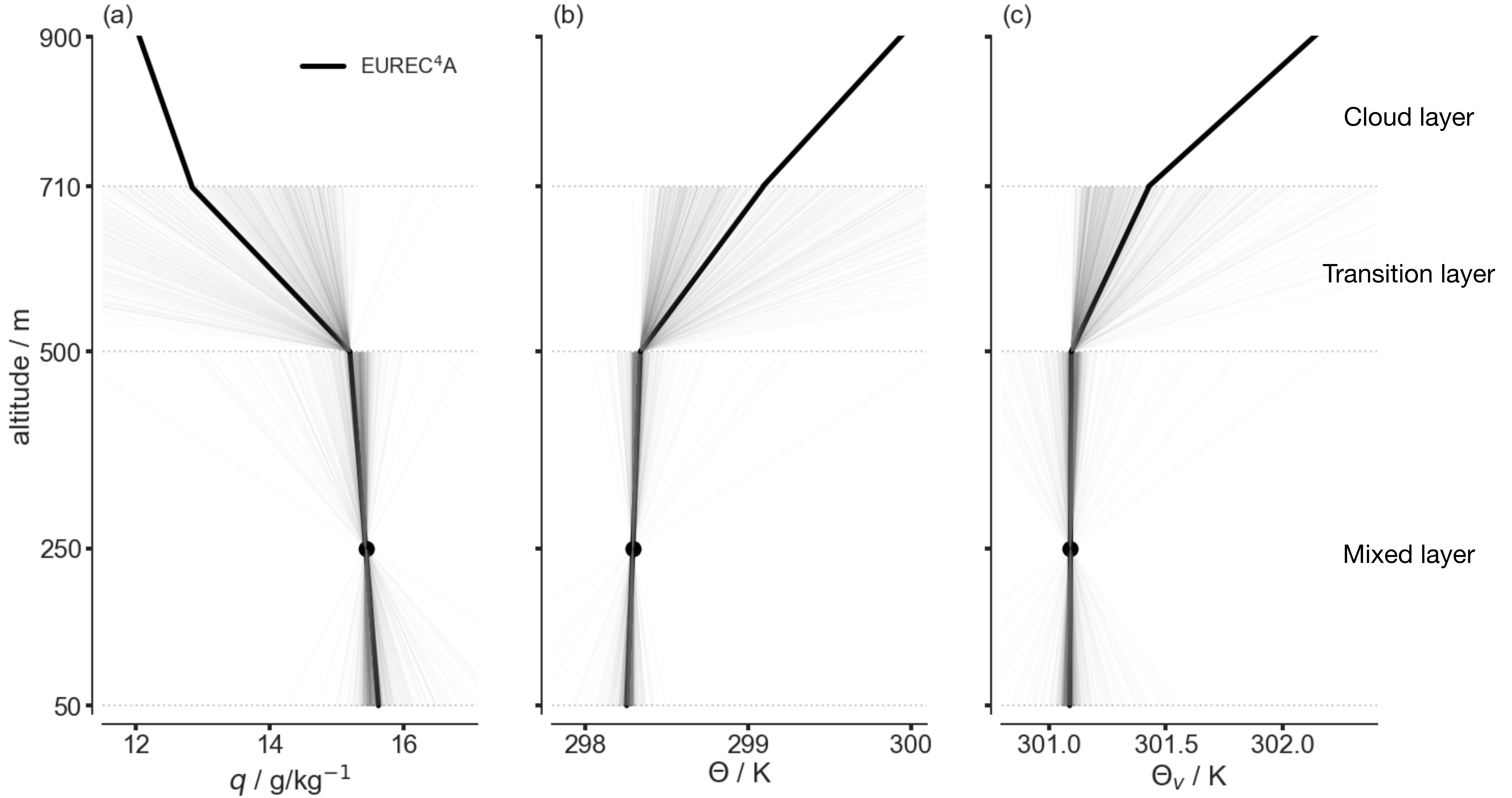
Evidence for ~150±50 m thick transition layer between mixed and subcloud layers





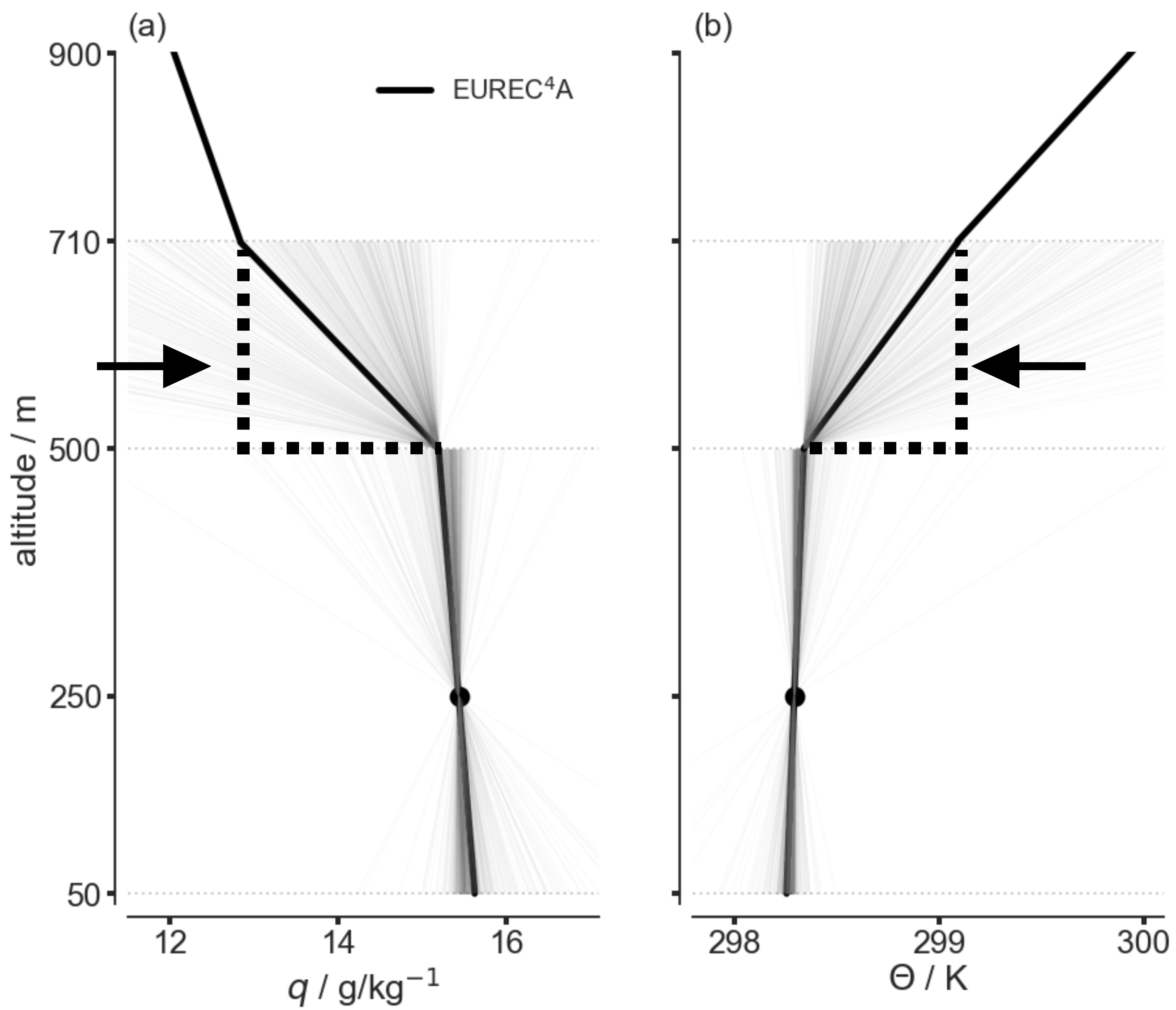
- Associate transition layer with region between mixed layer and subcloud layer tops that is better mixed in θ_v than $\{q, \theta\}$ individually
- Transition layer evident in both individual and aggregated soundings

Transition layer thermodynamic gradients differ from those in mixed and cloud layers (810 dropsonde profiles composited by layer; mean depths)

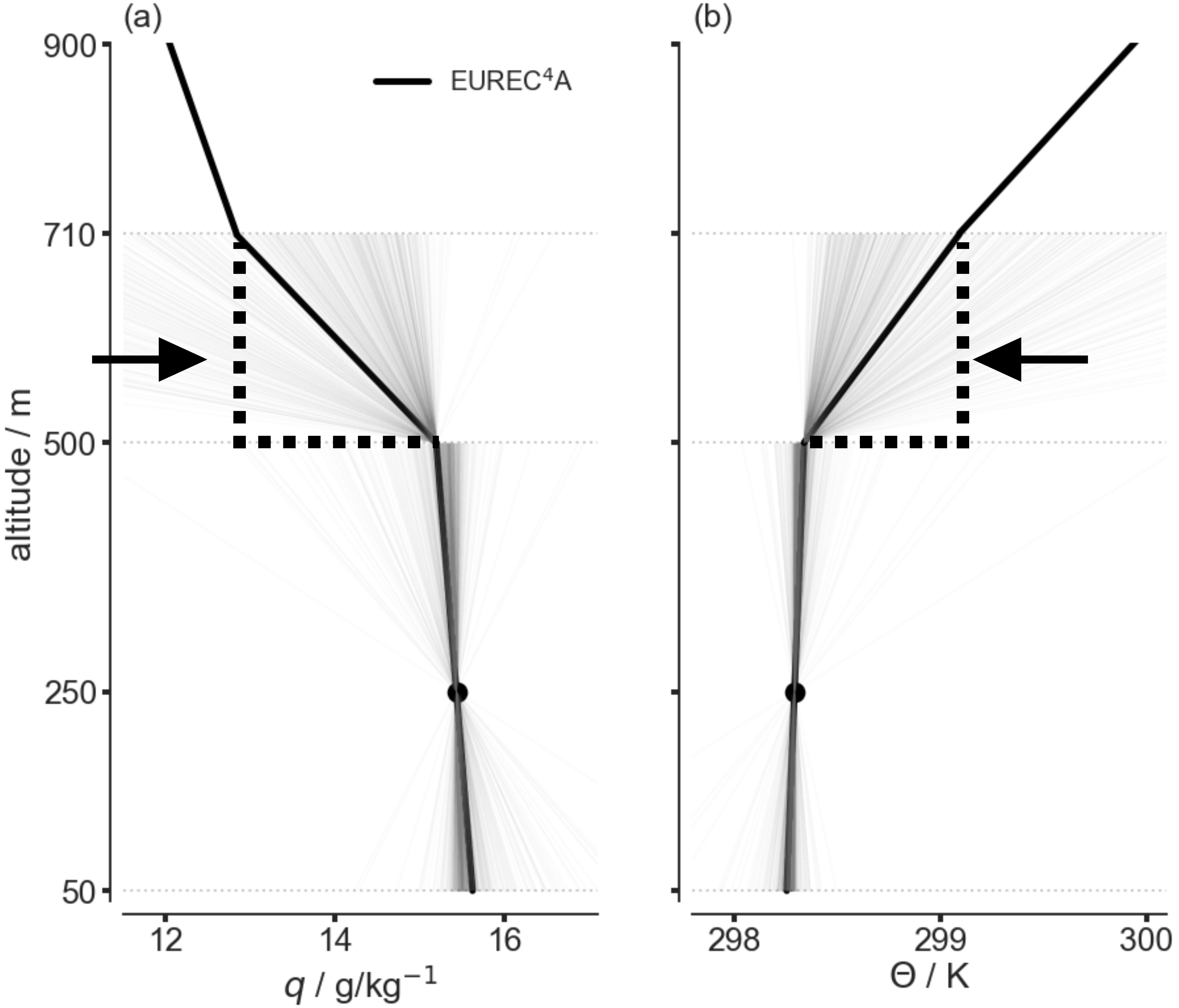


What produces the observed transition layer structure that differs from jump-like structure?

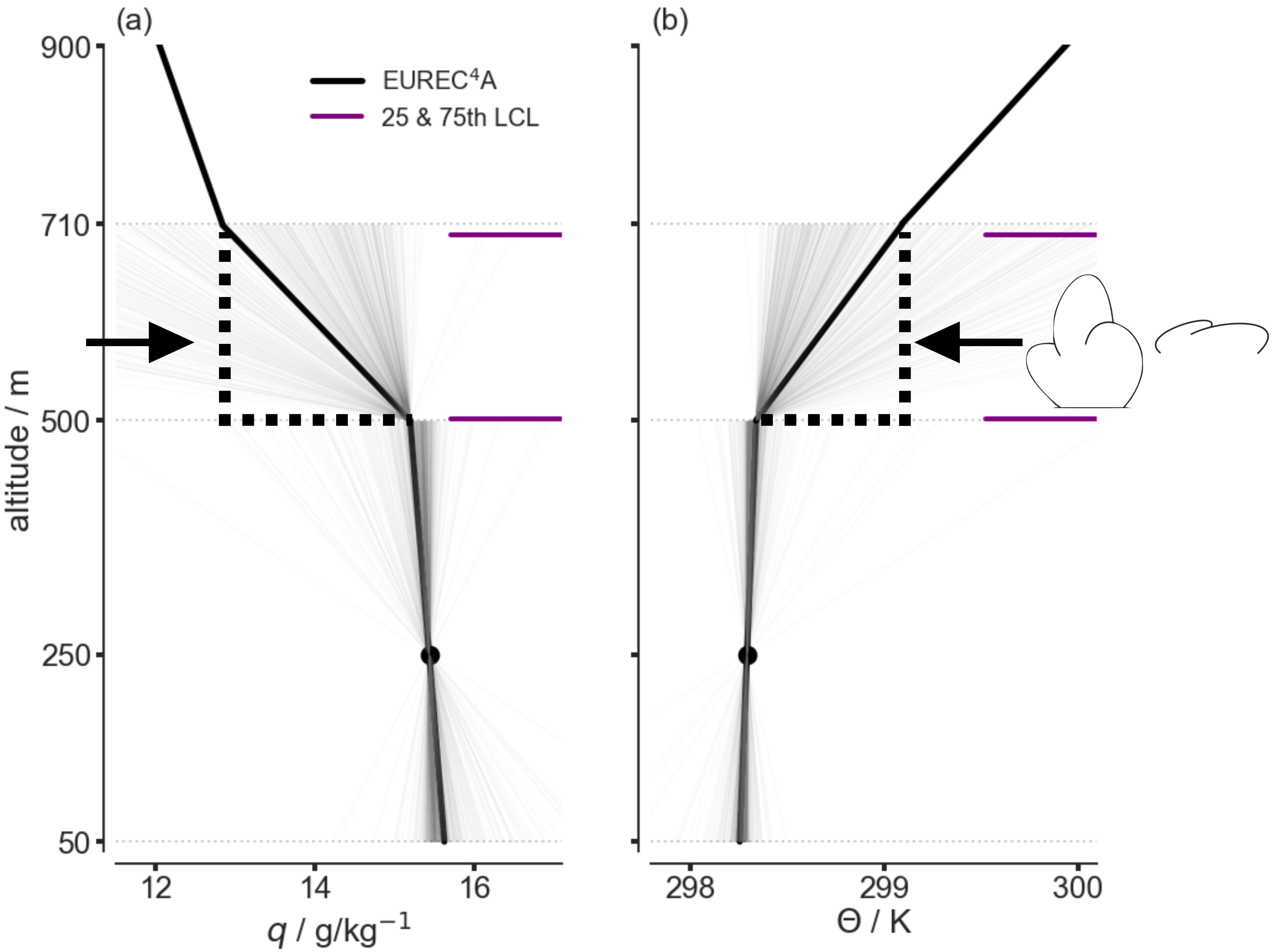
Observations are moister and colder than jump-like structure would suggest



Do clouds dissipating (moistening and cooling) cause smoother vertical gradients in transition layer?



Majority of cloud bases form within transition layer



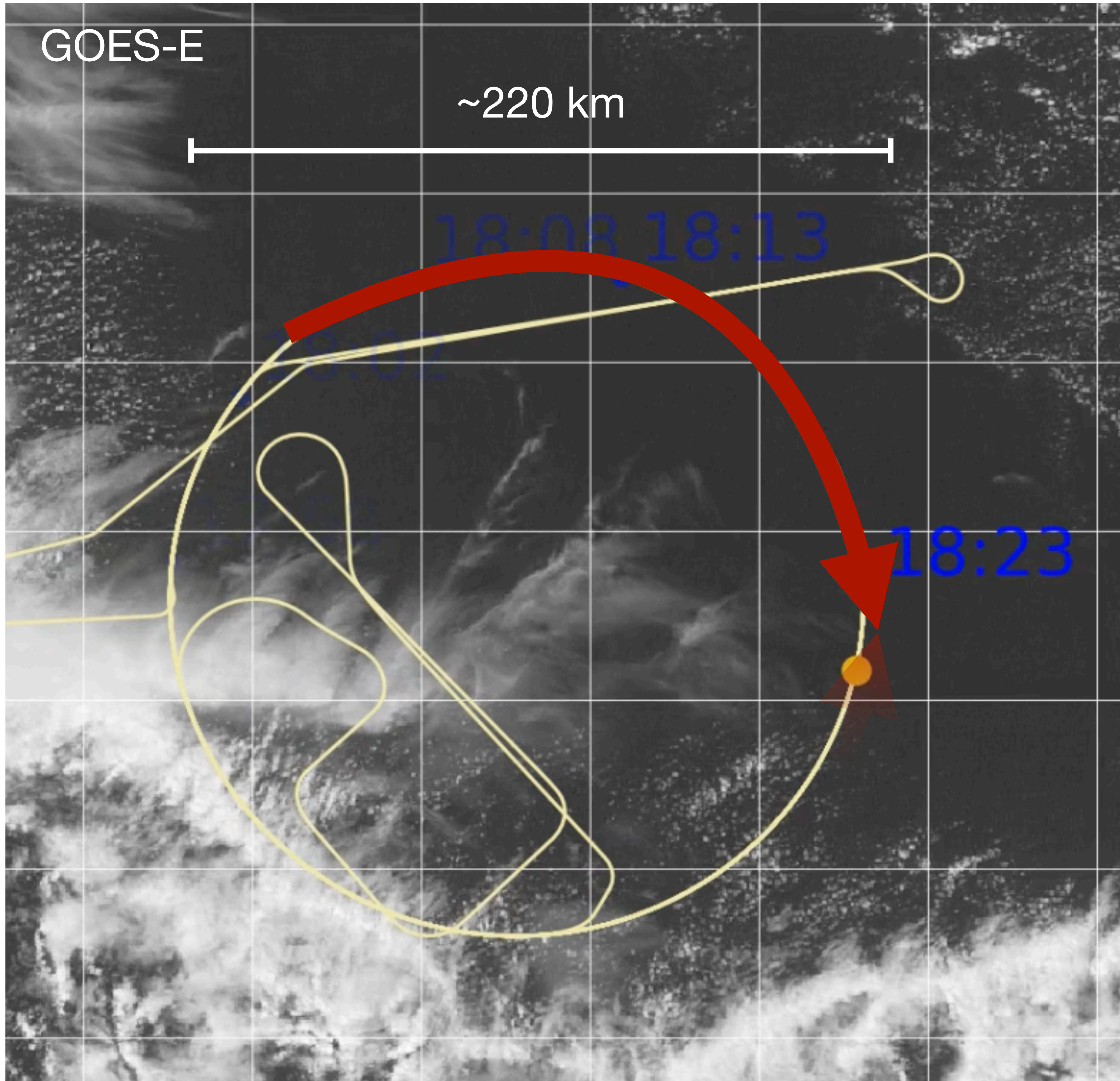
- About 60% of cloud bases (estimated from three-hourly ceilometer data) and ~75% LCLs from dropsondes also below transition layer top
- Another way of defining the transition layer is between cloud base and level of maximum cloud-base cloudiness (cf. Vogel et al., 2022)

Cf. cloud based above the transition layer in Malkus, 1958; Augstein, 1974; but within transition layer in Neggers et al., 2009, Gentine et al., 2013

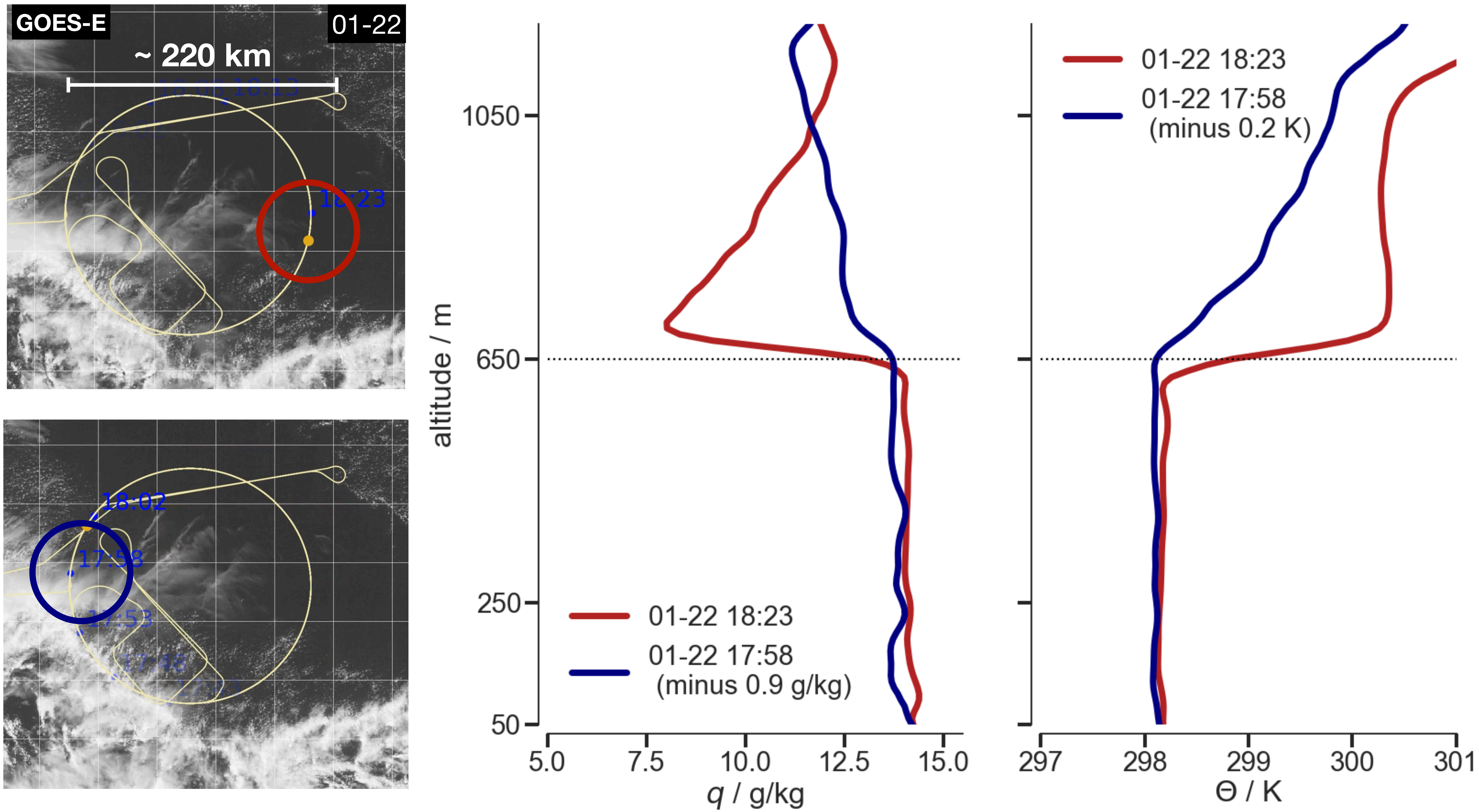
Test using denial of mechanism — examine transition layer structure in **large clear-sky areas**

defined:

1. by eye, within patterns of cloud organization, identified from satellite images
2. as cloud-free over about 200 km of flight path (~15 minutes of flying) using cloud flags and cloud top heights from WALES lidar
3. using large-eddy simulation output from Dauhut et al., 2022



Sharp gradients exist, but rarely, and in large clear-sky areas



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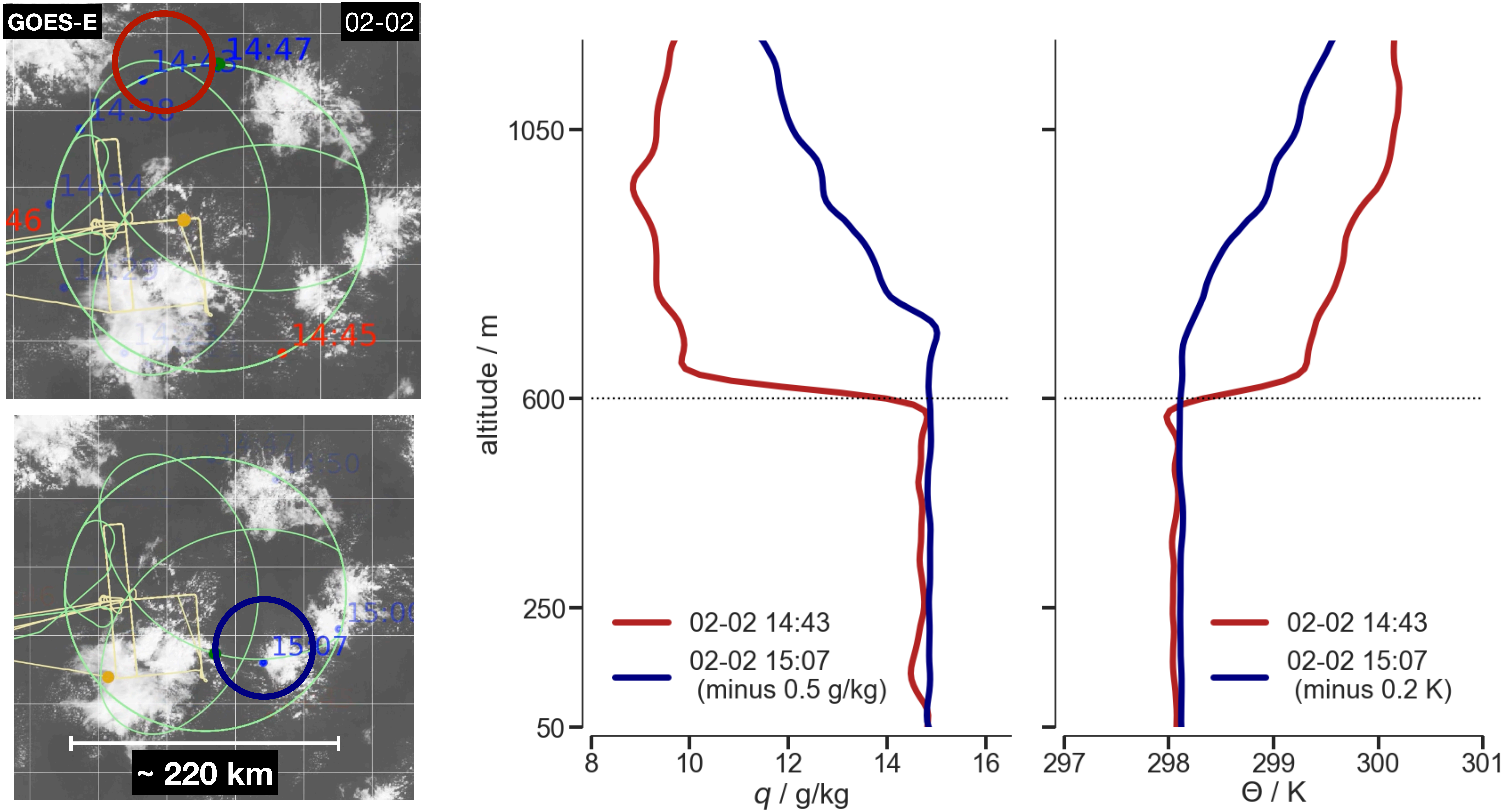
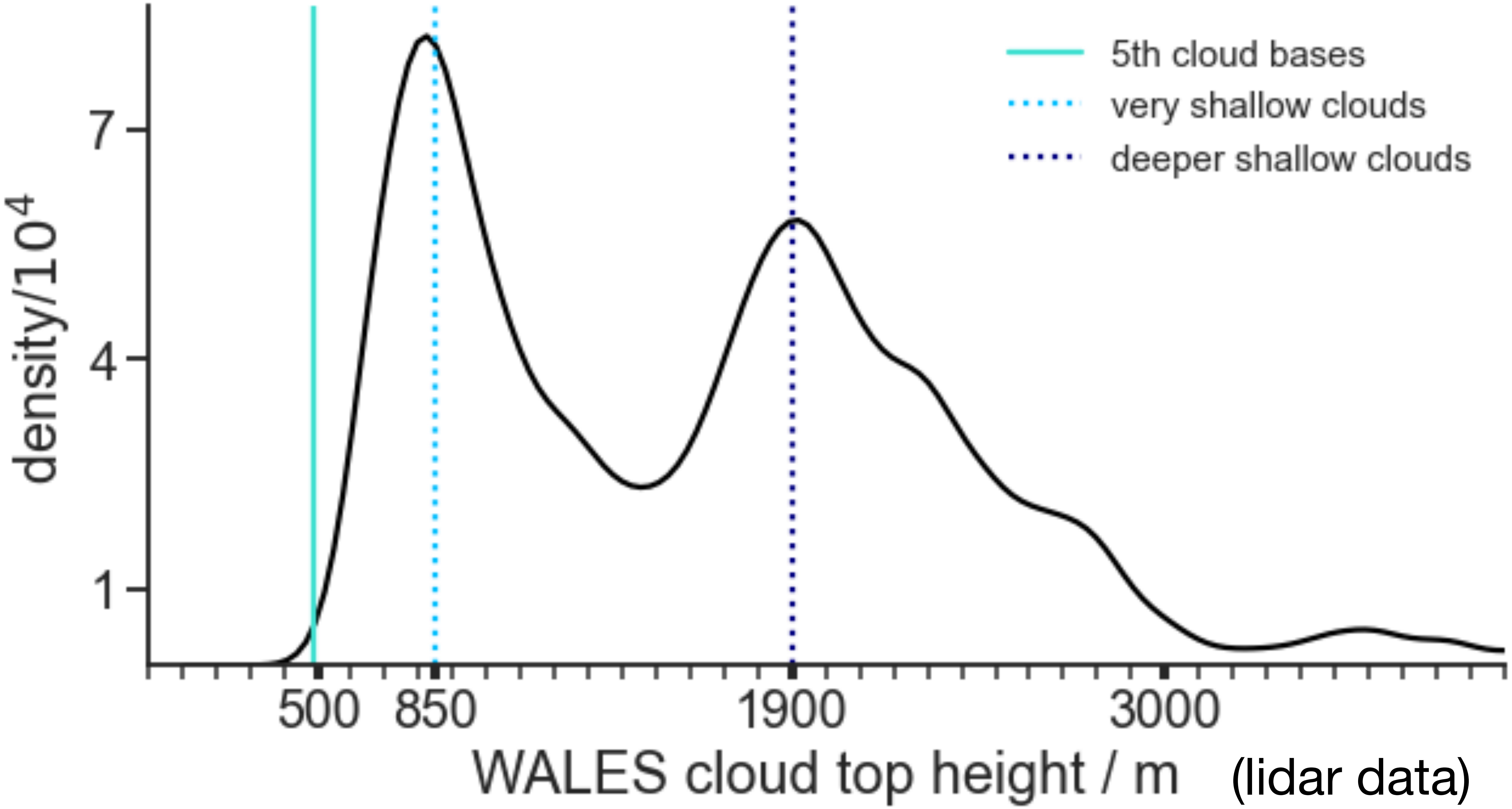


1. Is the jump structure found in large clear-sky areas?

2. Is the presence of shallow clouds sufficient to smooth vertical gradients away from jump structure?

Very shallow clouds are ubiquitous.
Are they associated with smoother vertical gradients?

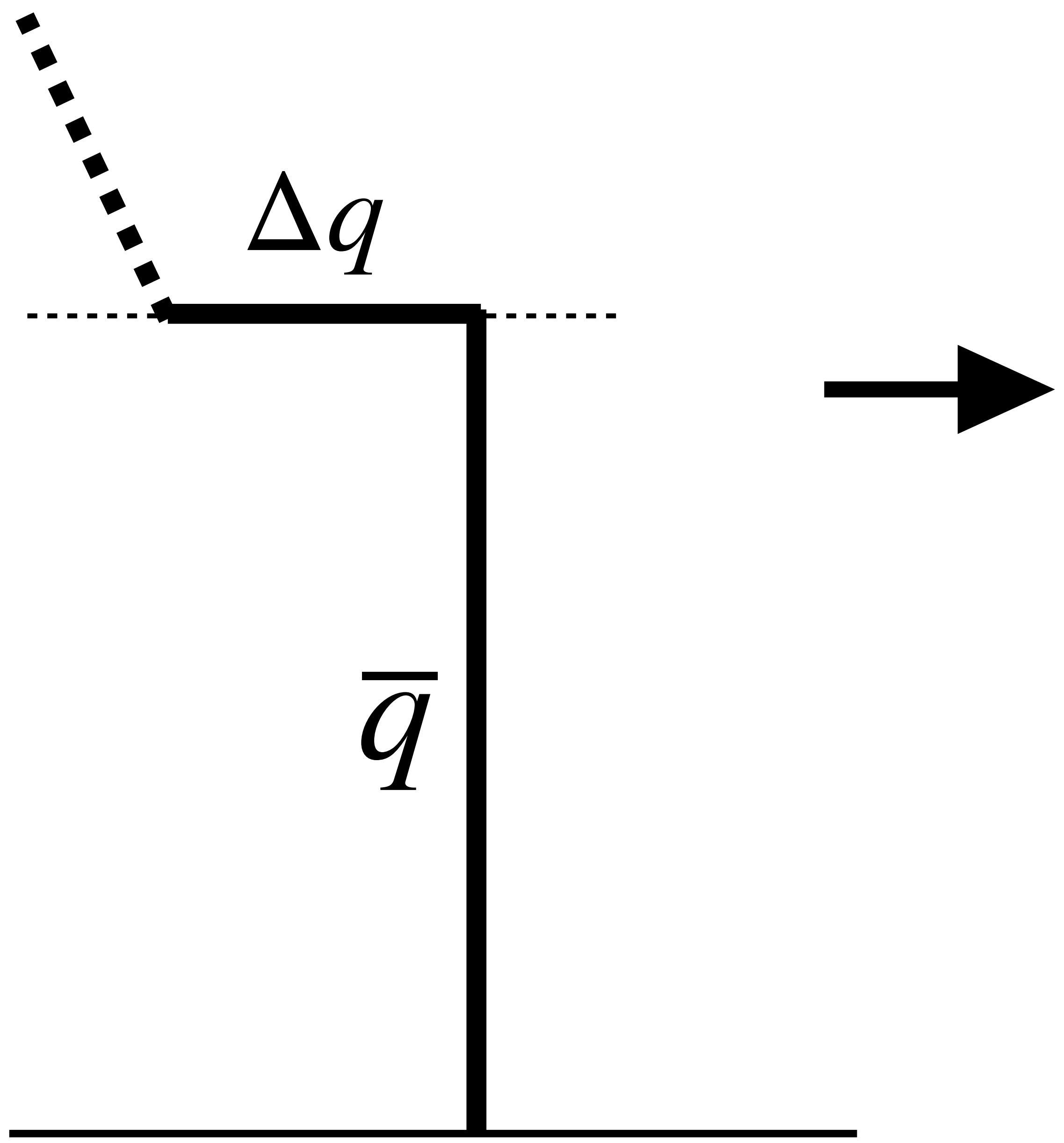


(lidar data)

Cf. Two cloud populations, Genkova et al. 2012, Leahy et al., 2012, Mieslinger et al., 2019, Vial et al, 2019, Vial et al., in review

Select sharpest vertical gradient in subcloud layer profile

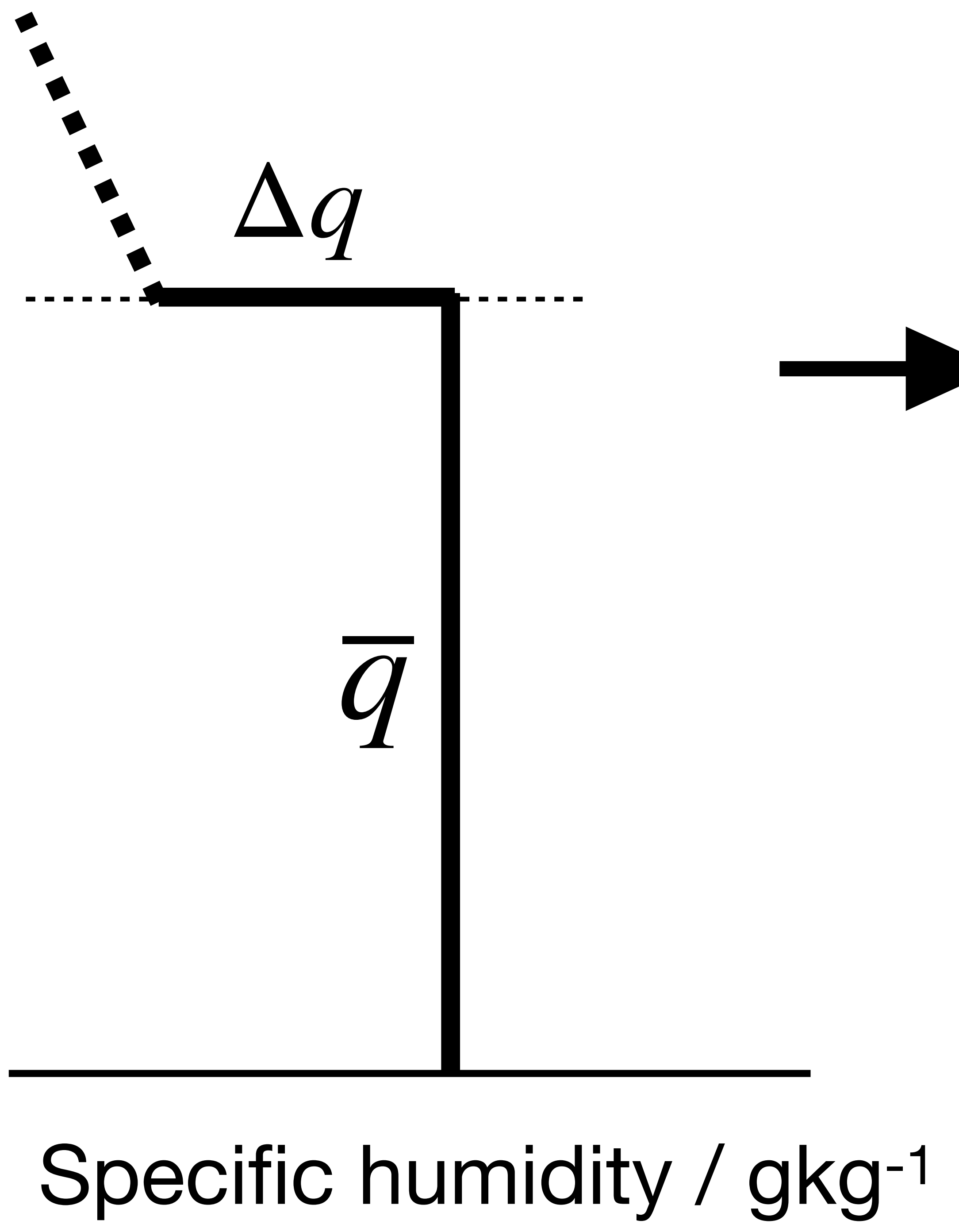
Select sharpest vertical gradient below 800 m

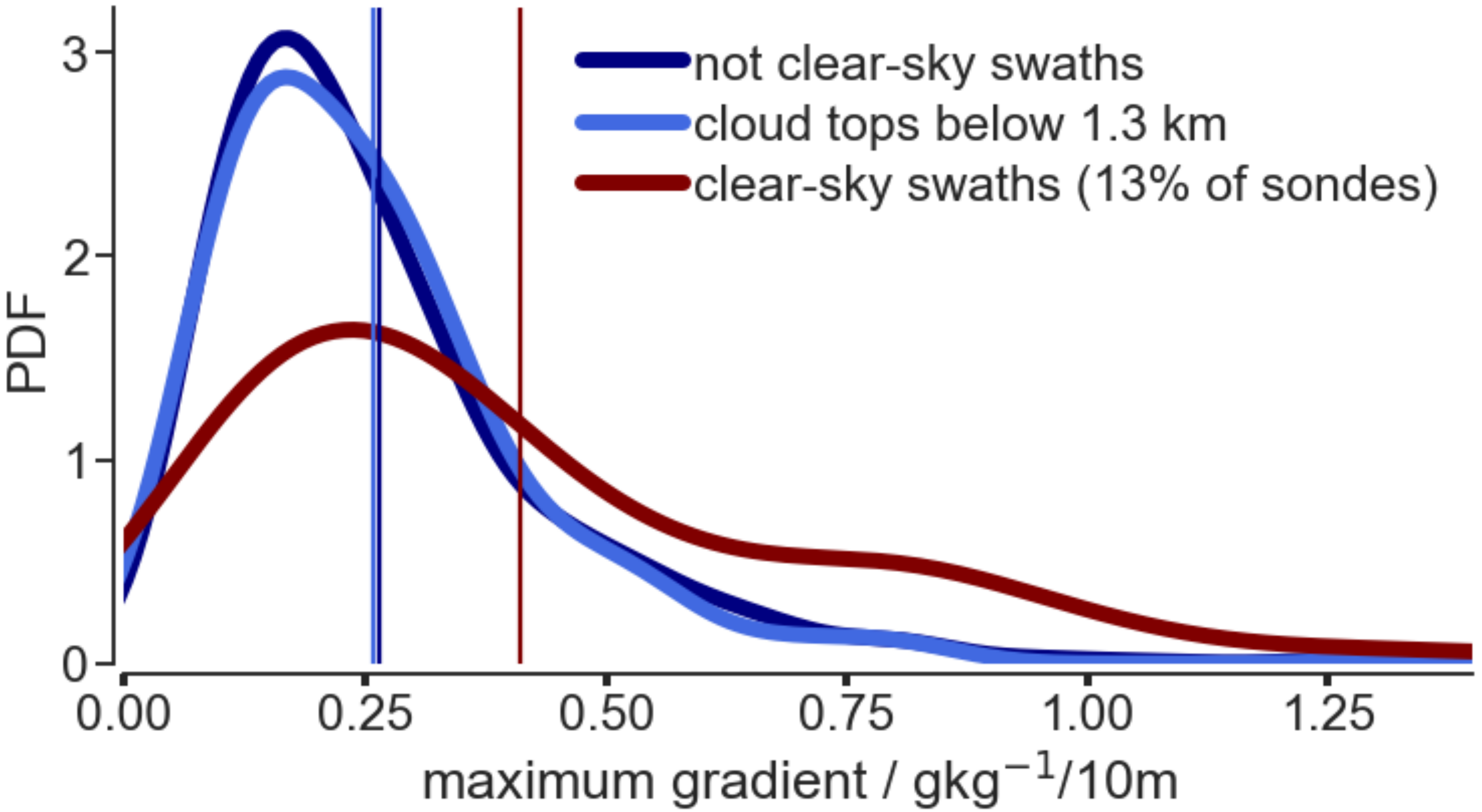


Specific humidity / gkg^{-1}

Large clear-sky areas (red) exhibit stronger vertical gradients

Select sharpest vertical gradient below 800 m





Also see similar distributions for LES output (from Dauhut et al., 2022)

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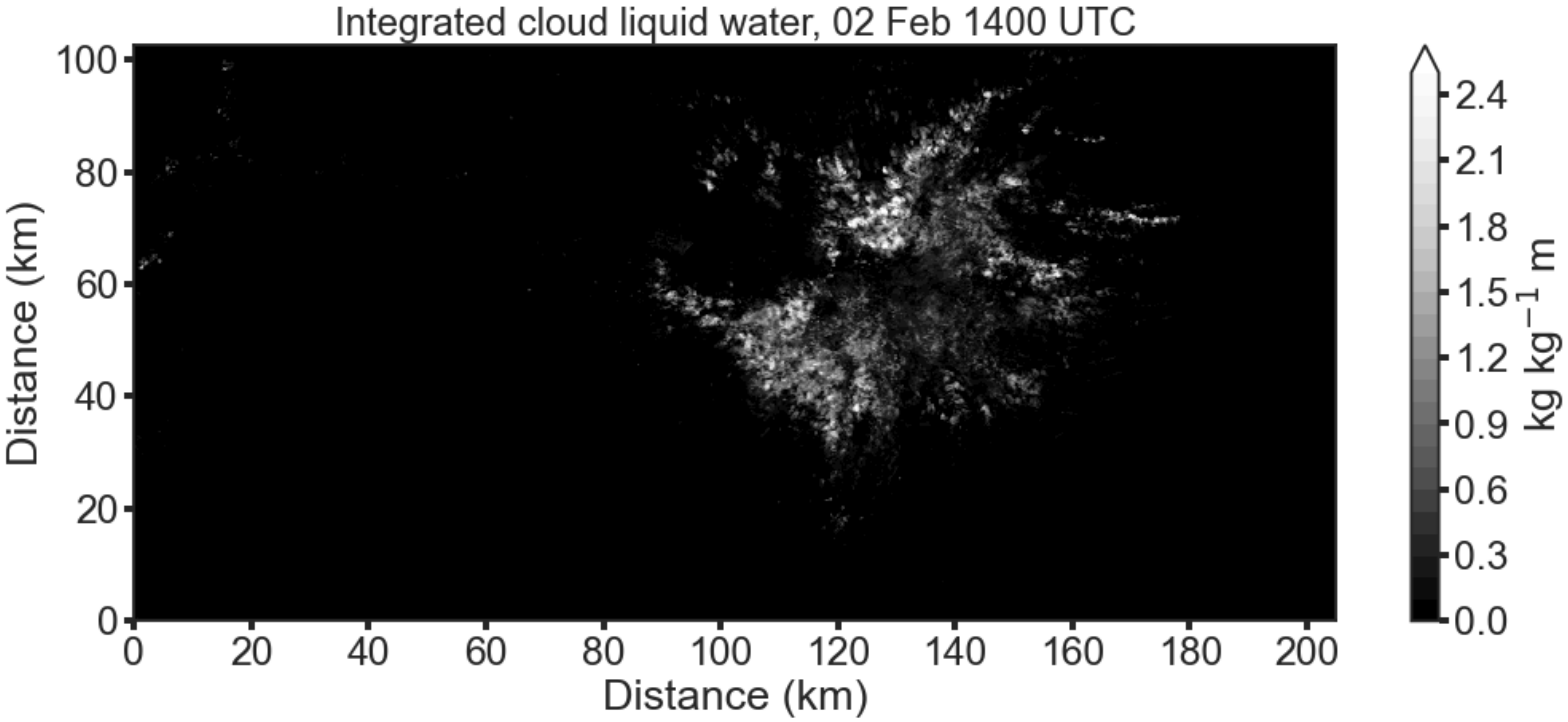
A similar picture in LES



LES simulation output from Thibaut Dauhut, 100 m (horizontal); 40 m (vertical)
Dauhut et al., 2022 QJRMS

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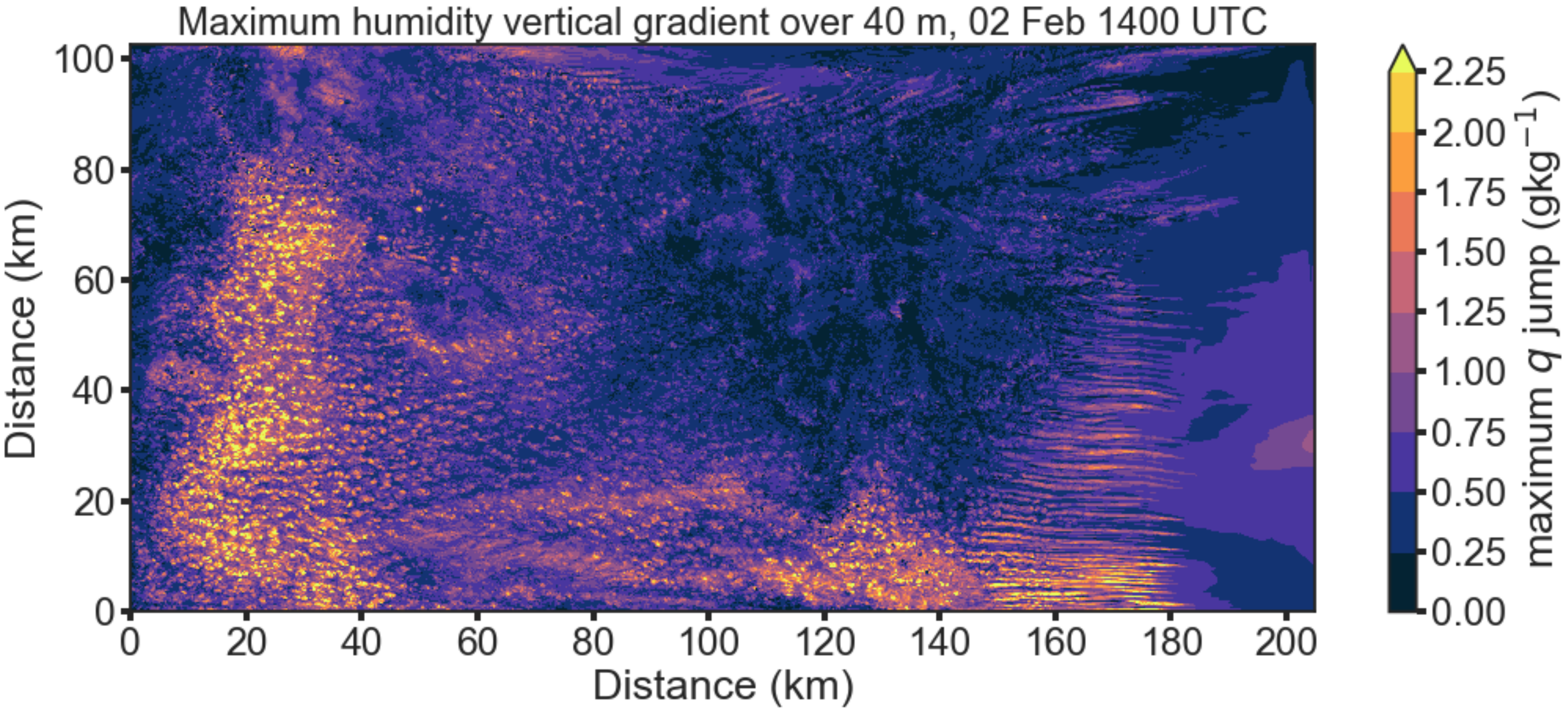

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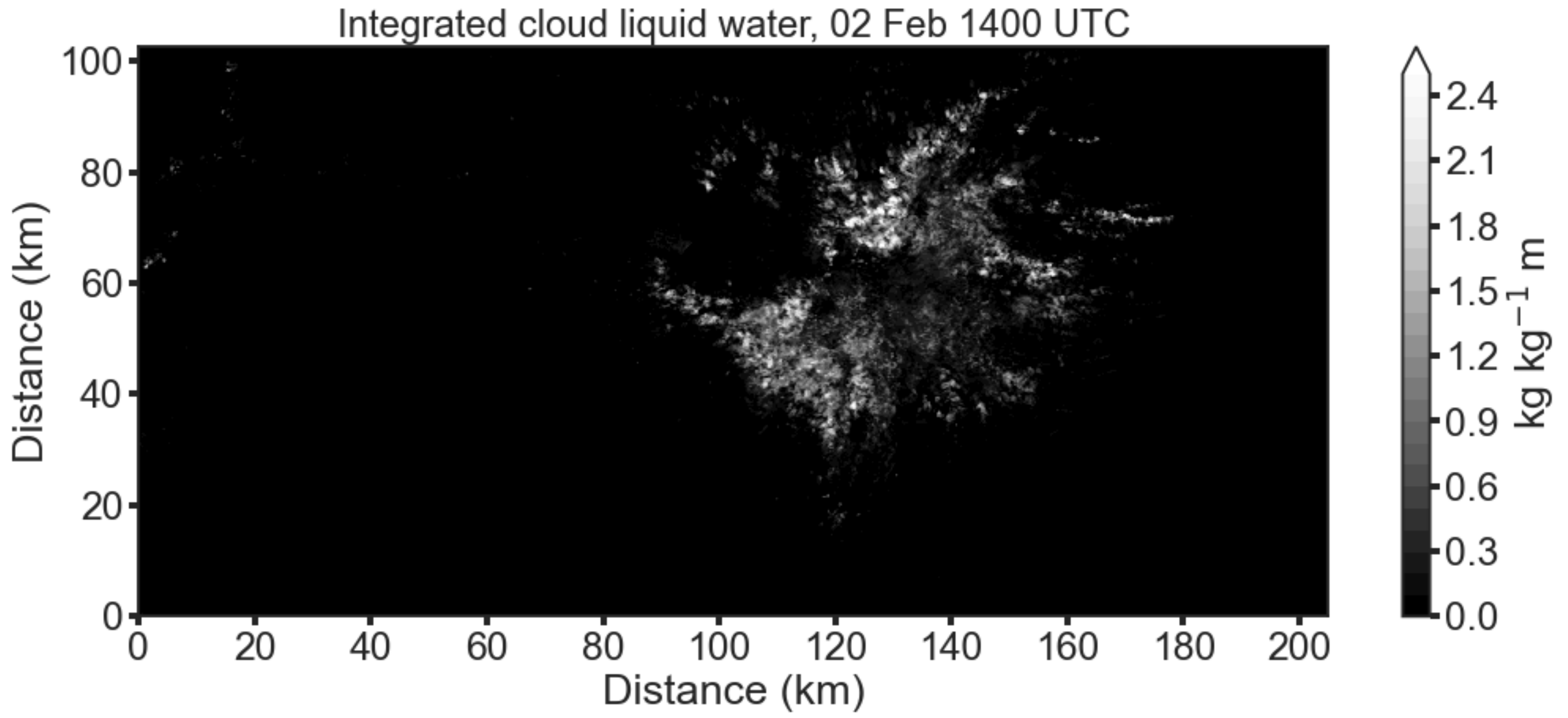

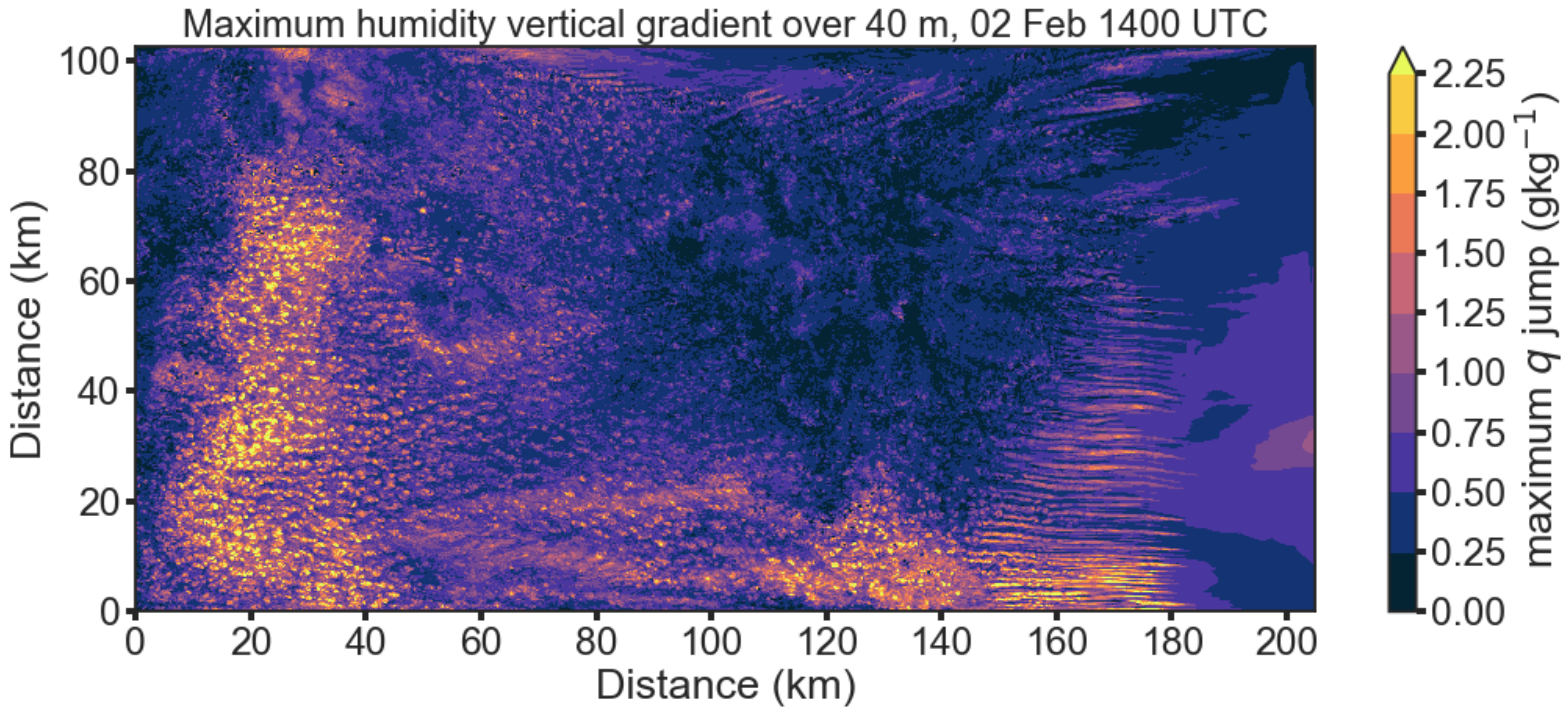

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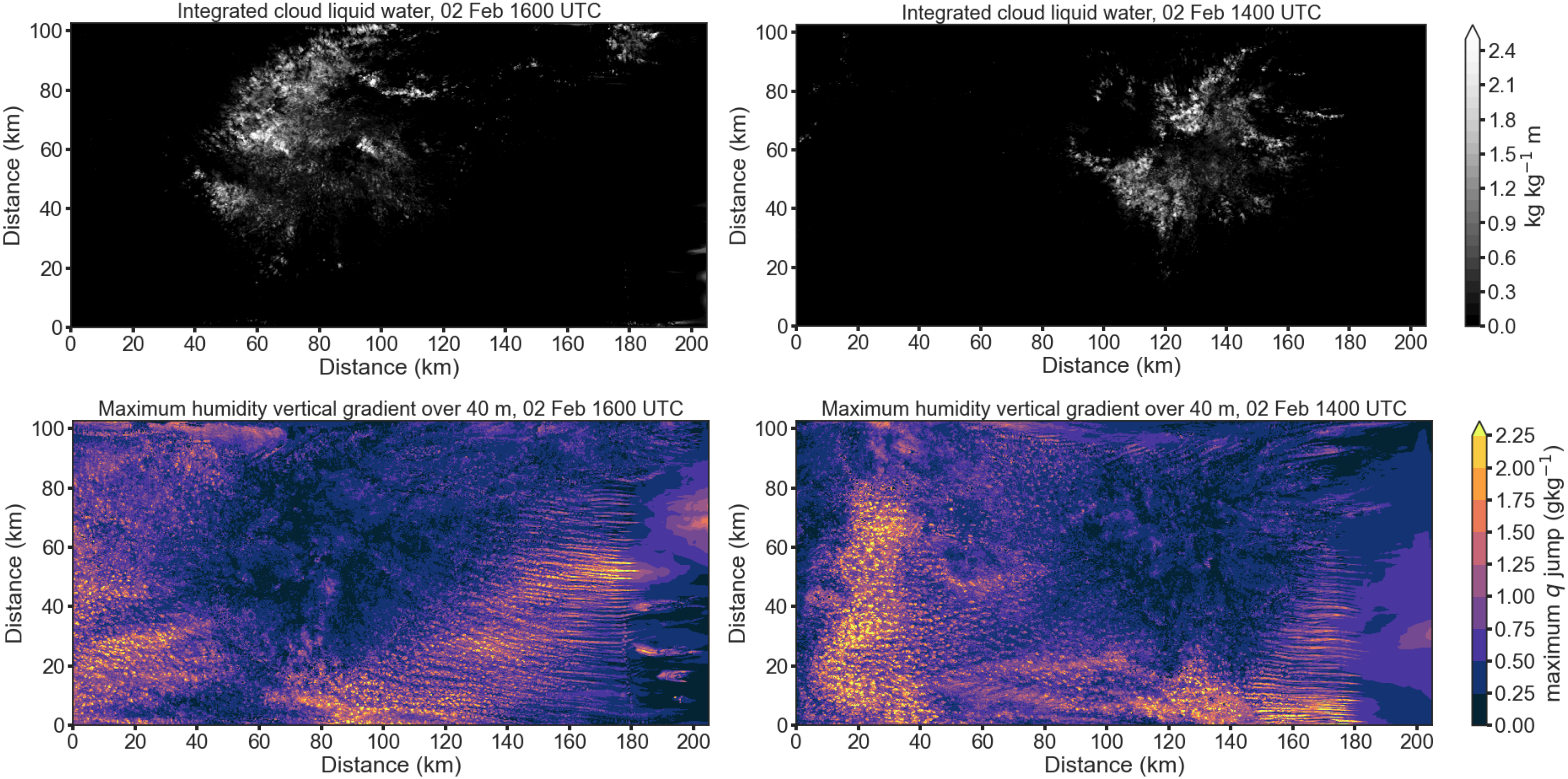

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   Yes.

2*. No strong association between transition layer vertical gradients and strength of mesoscale subsidence (in obs. and LES)

Implications of a cloudy transition layer

Do differences in transition layer structure matter for mixed layer state & surface fluxes?

- Inferences from mixed layer theory and mixing diagrams (not shown, following Paluch, 1979) suggest that the observed transition layer structure does not strongly affect the **rate of entrainment mixing**
- Rather, it influences the **properties** of the air incorporated into the mixed layer, primarily as a **moistening**

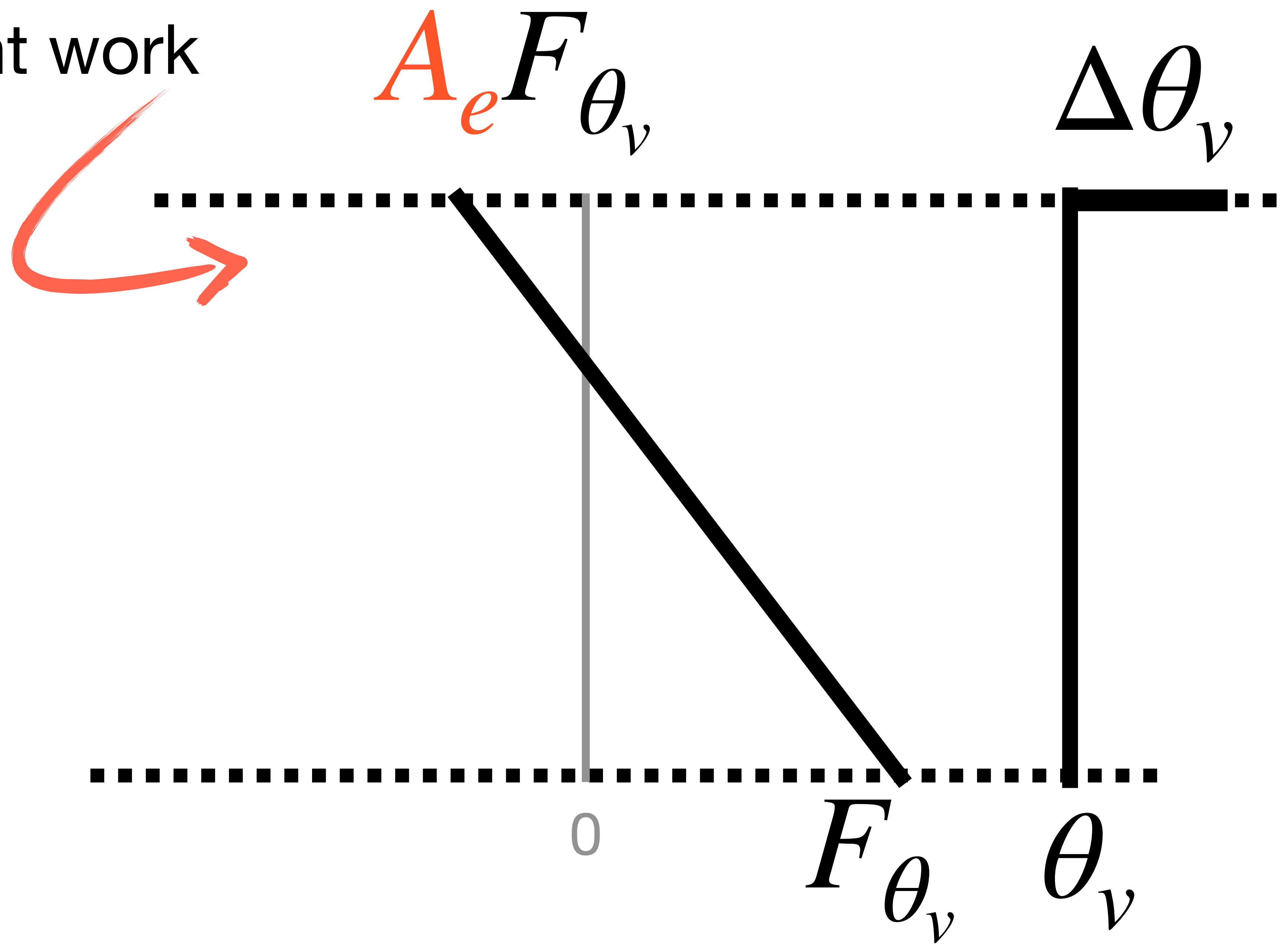
Contributions to energetics of entrainment mixing

$$E = \frac{dh}{dt} = \frac{A_e F_{\theta_v}}{\Delta_1 \theta_v}$$

Convert turbulence energy to potential energy

e.g., Ball, 1960, Lilly, 1968, Betts, 1973, Tennekes, 1973, Deardorff, 1974, Stull, 1976, Stevens 2006

'Harvesting' some portion of surface turbulence flux to do entrainment work



Surface turbulence flux

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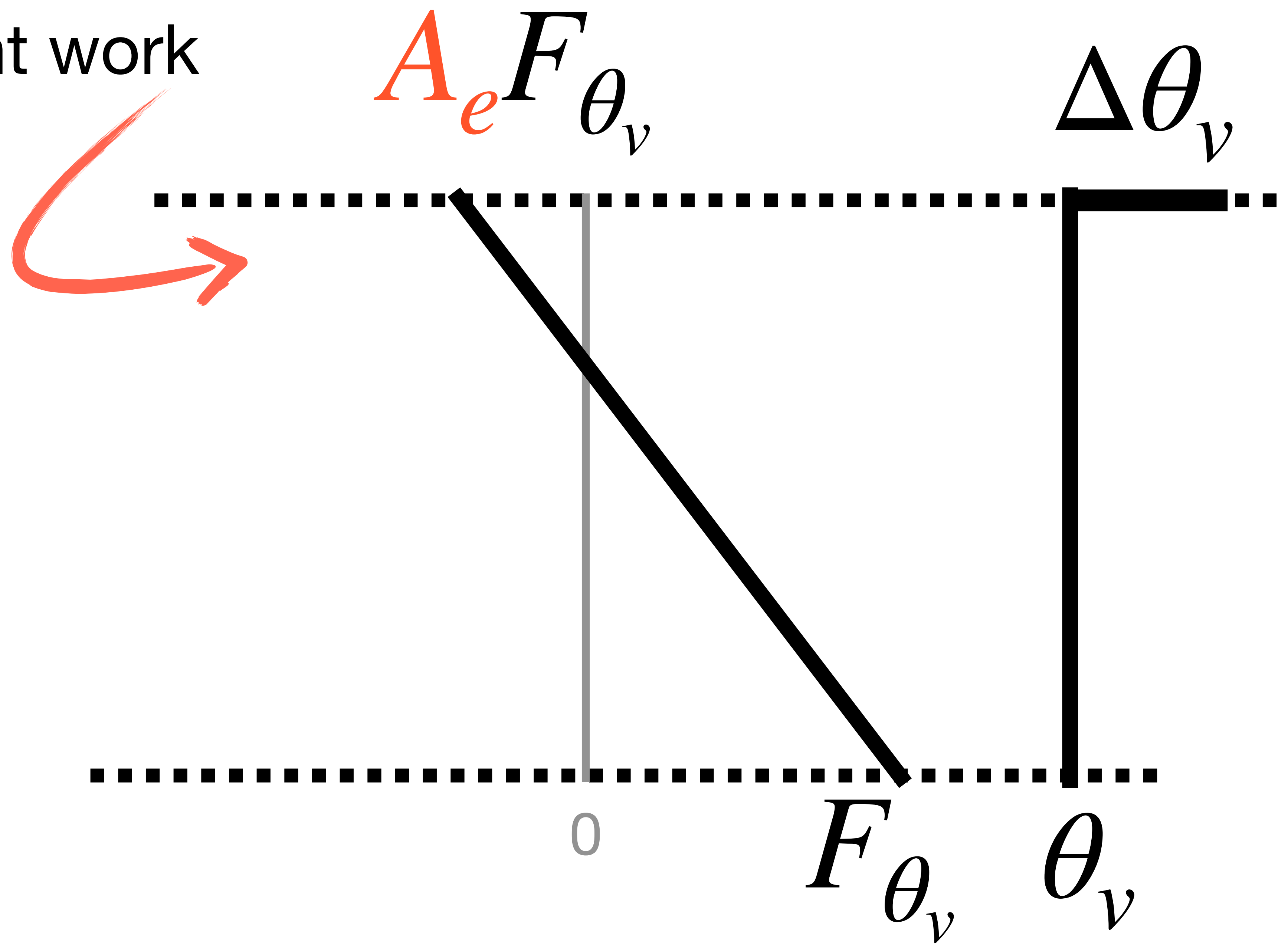

Surface turbulence flux

A_e: entrainment efficiency of surface turbulence source (constant)

A_e=0.2? 0.4?

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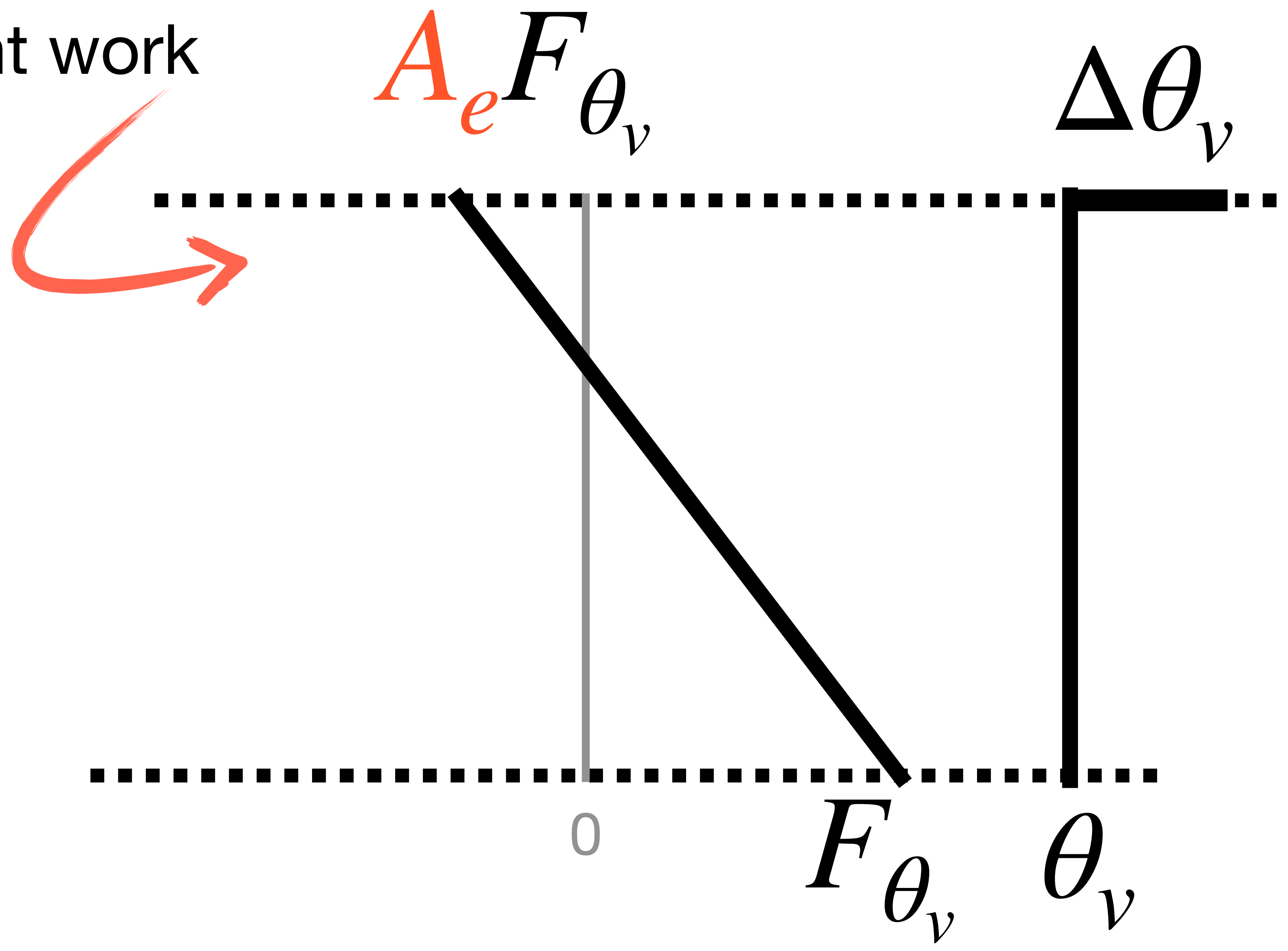


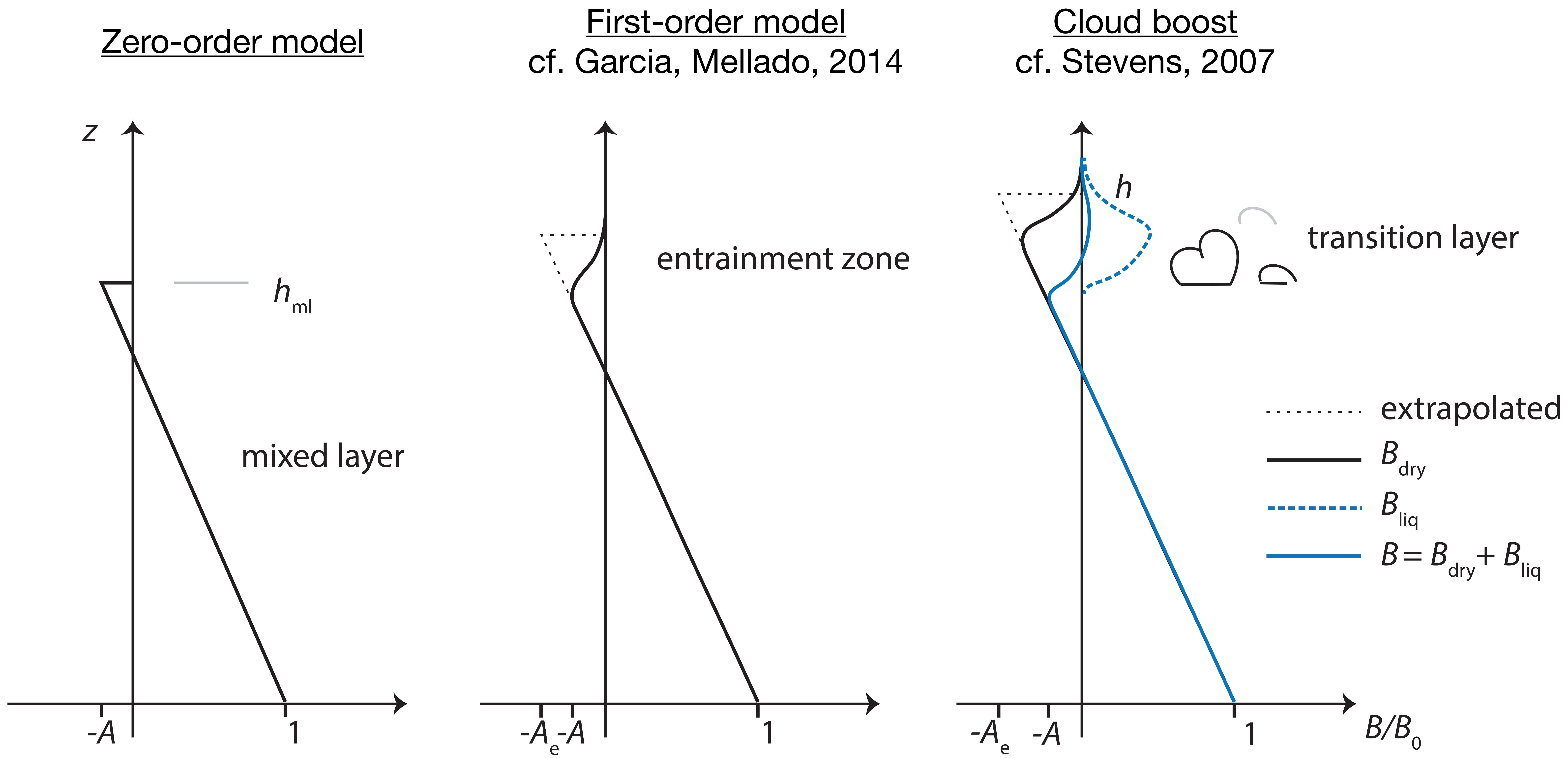
Surface turbulence flux

A_e: entrainment efficiency of surface turbulence source (constant)

A_e=0.43*

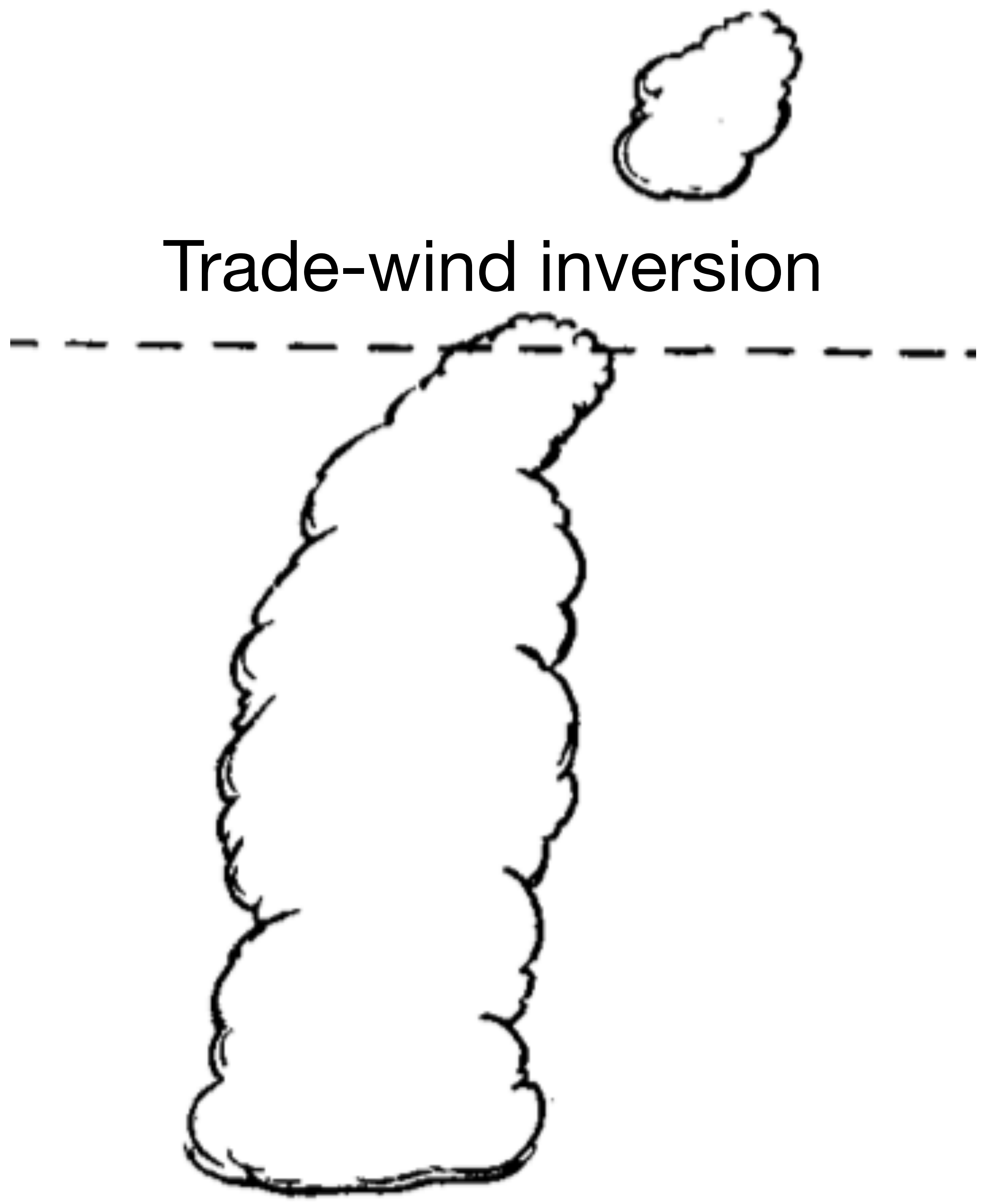
*Albright, A. L., Bony, S., Stevens, B., & Vogel, R. (2022). Observed subcloud layer moisture and heat budgets in the trades. JAS 2022.

Cloud liquid water flux contribution to $A_e \sim 0.4$



Symmetry between shallow and deeper clouds,

each population grows its own layer (Riehl et al., 1951, Stevens 2007, deeper clouds)



Riehl et al, 1951

Photo by Frédéric Batier, 2020

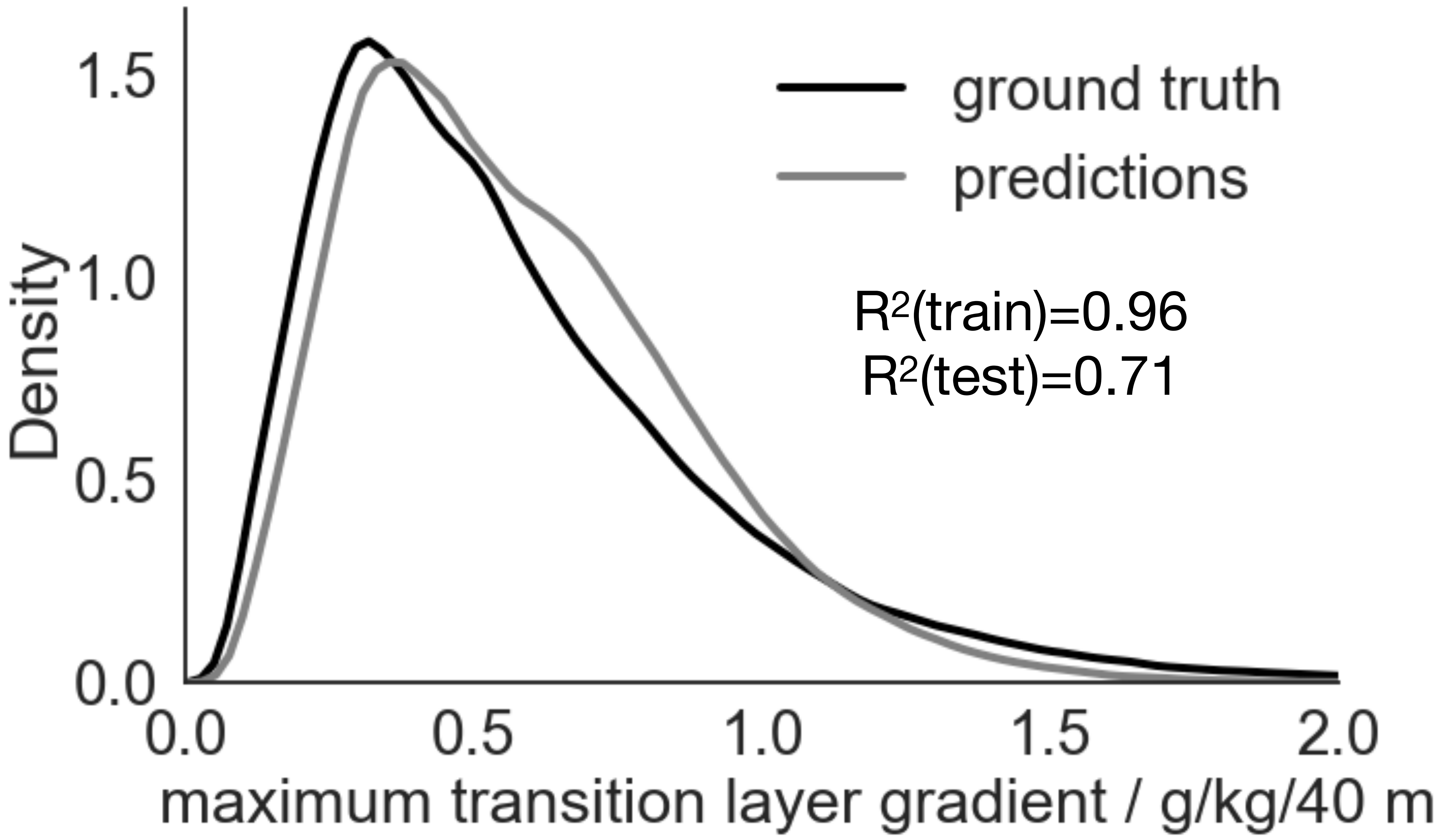
Do small clouds make it easier for larger clouds to form? (e.g., Neggers, 2015)

A short side project

Can we predict transition layer gradients based upon environmental variables?

- **9 variables considered:** {q, θ, wind speed in mixed layer; vertical velocity at different altitudes; integrated cloud liquid water content; distance to cloud 'center of mass', cloud base height, cloud top height}
- **Random forest** or XGBoost (machine learning) algorithms

100 m (horizontal); 40 m (vertical) model output



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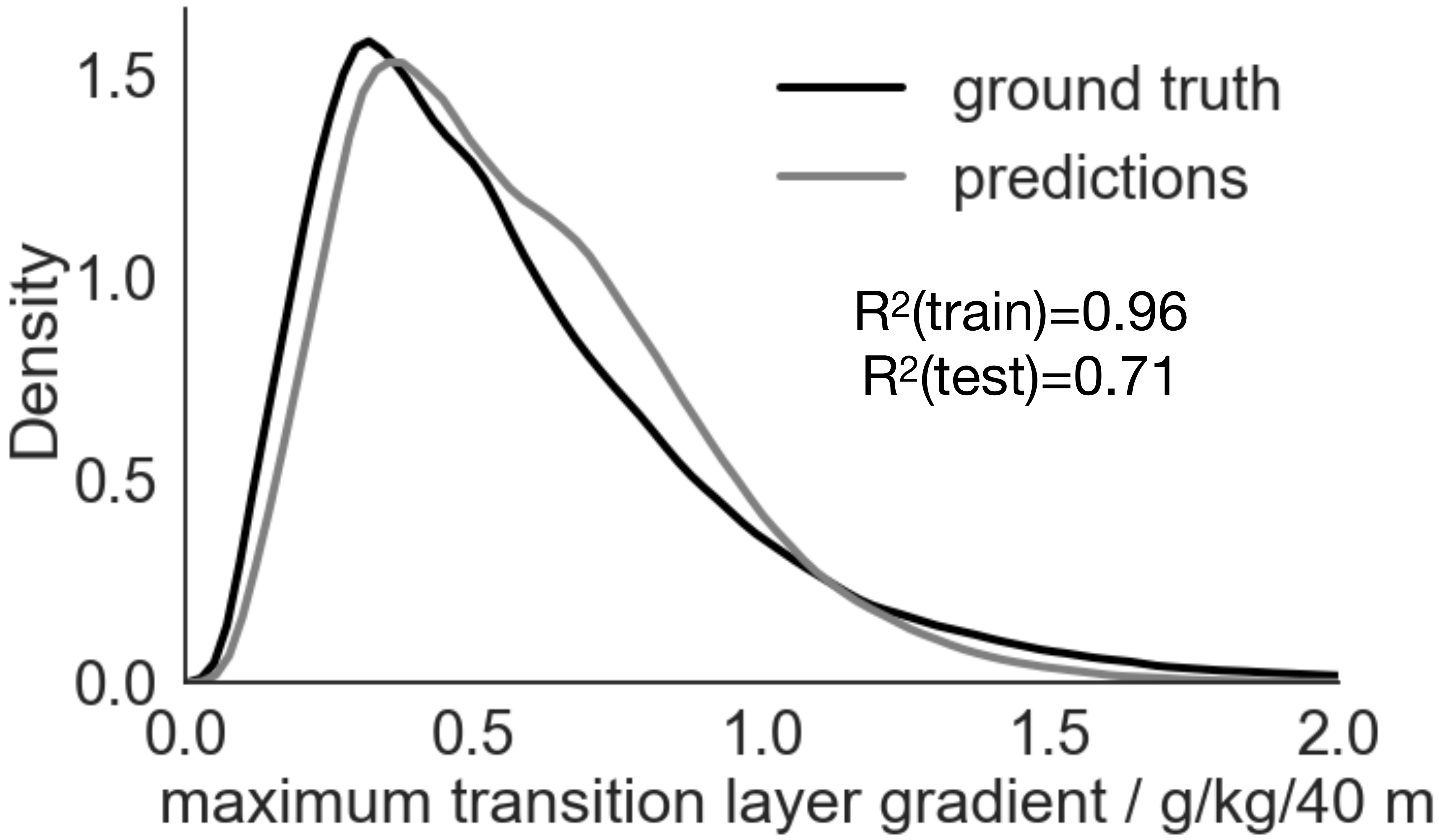
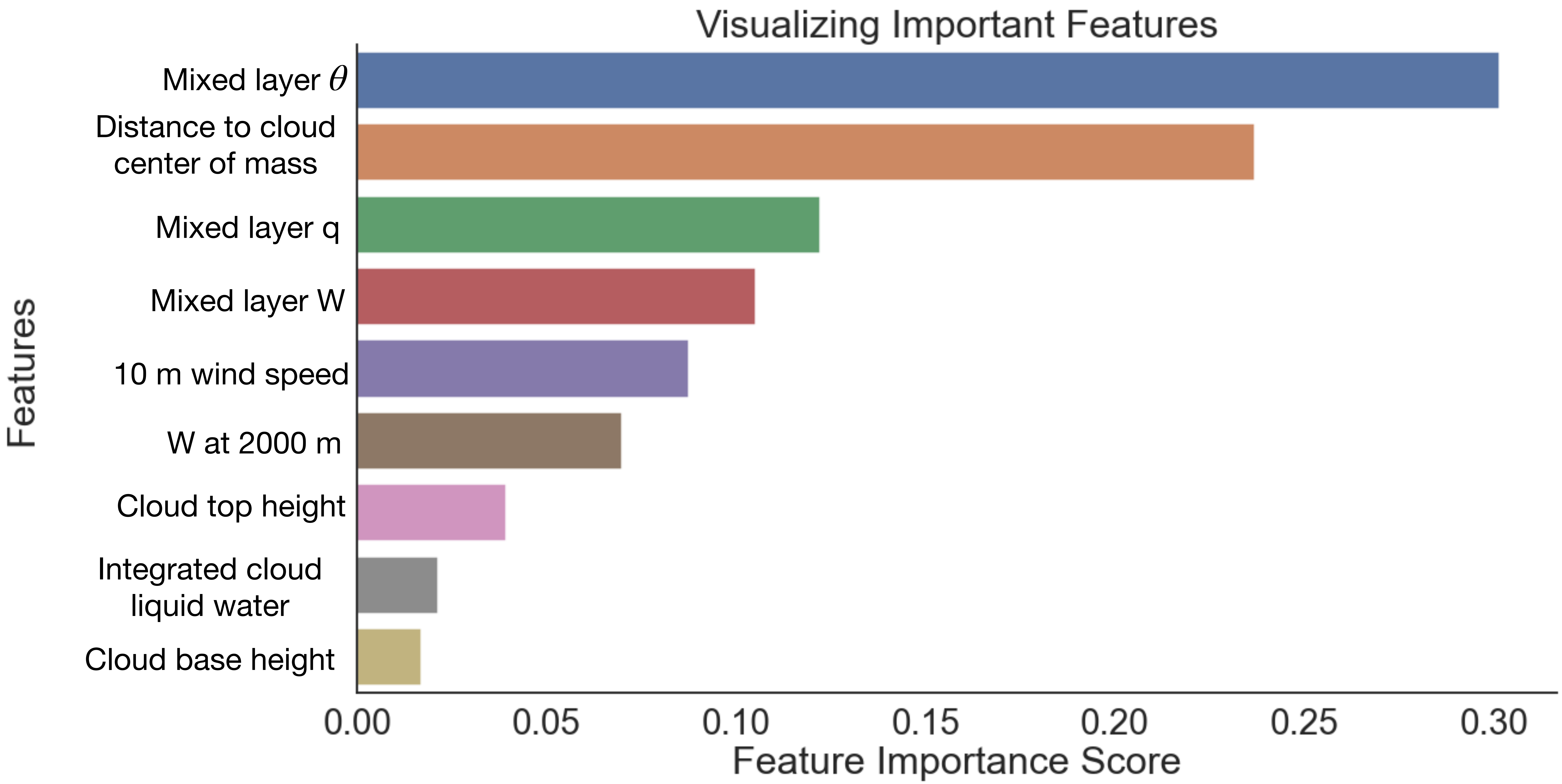


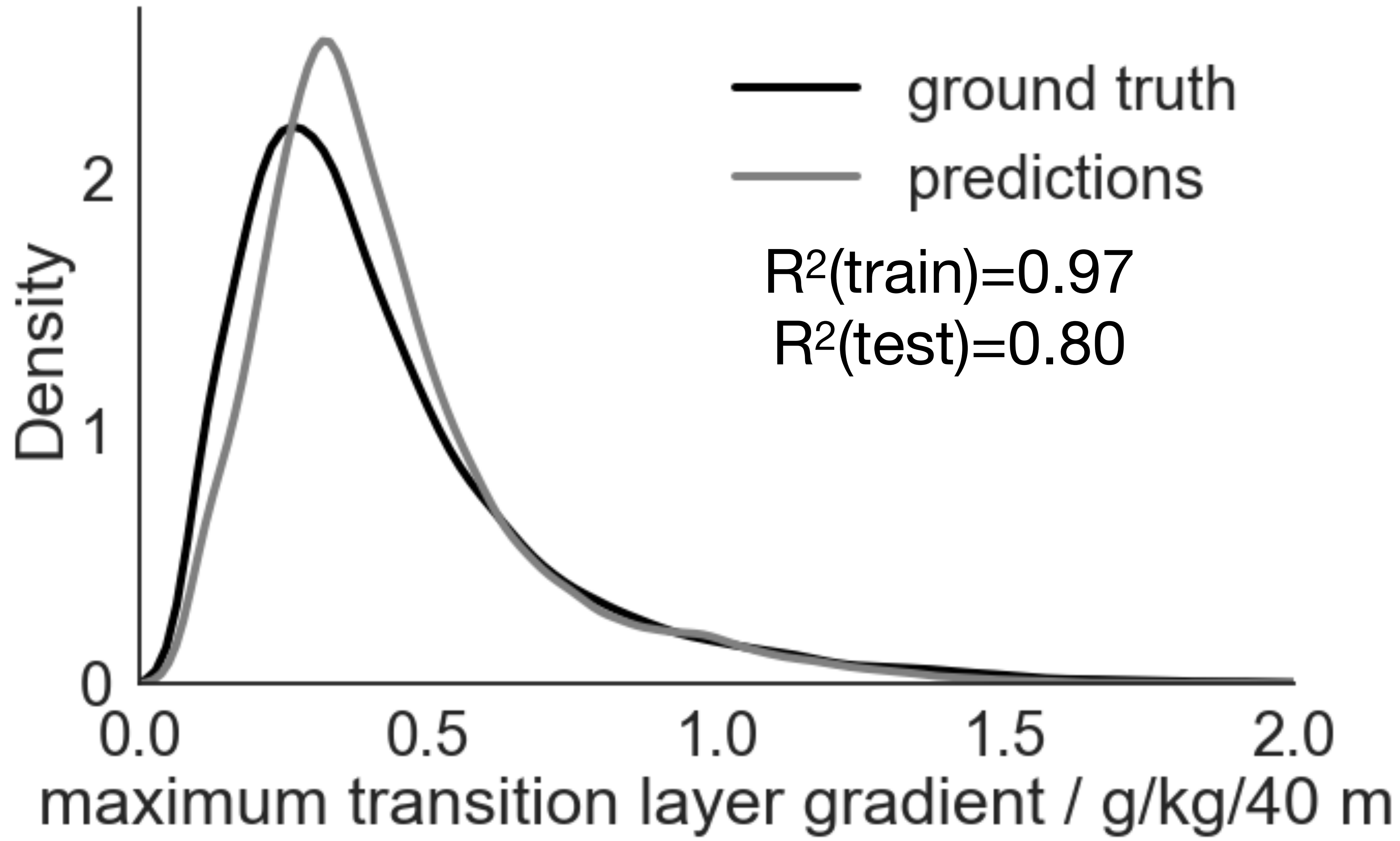
Preliminary take-away:
Algorithm has some predictive skill for maximum transition layer vertical gradient

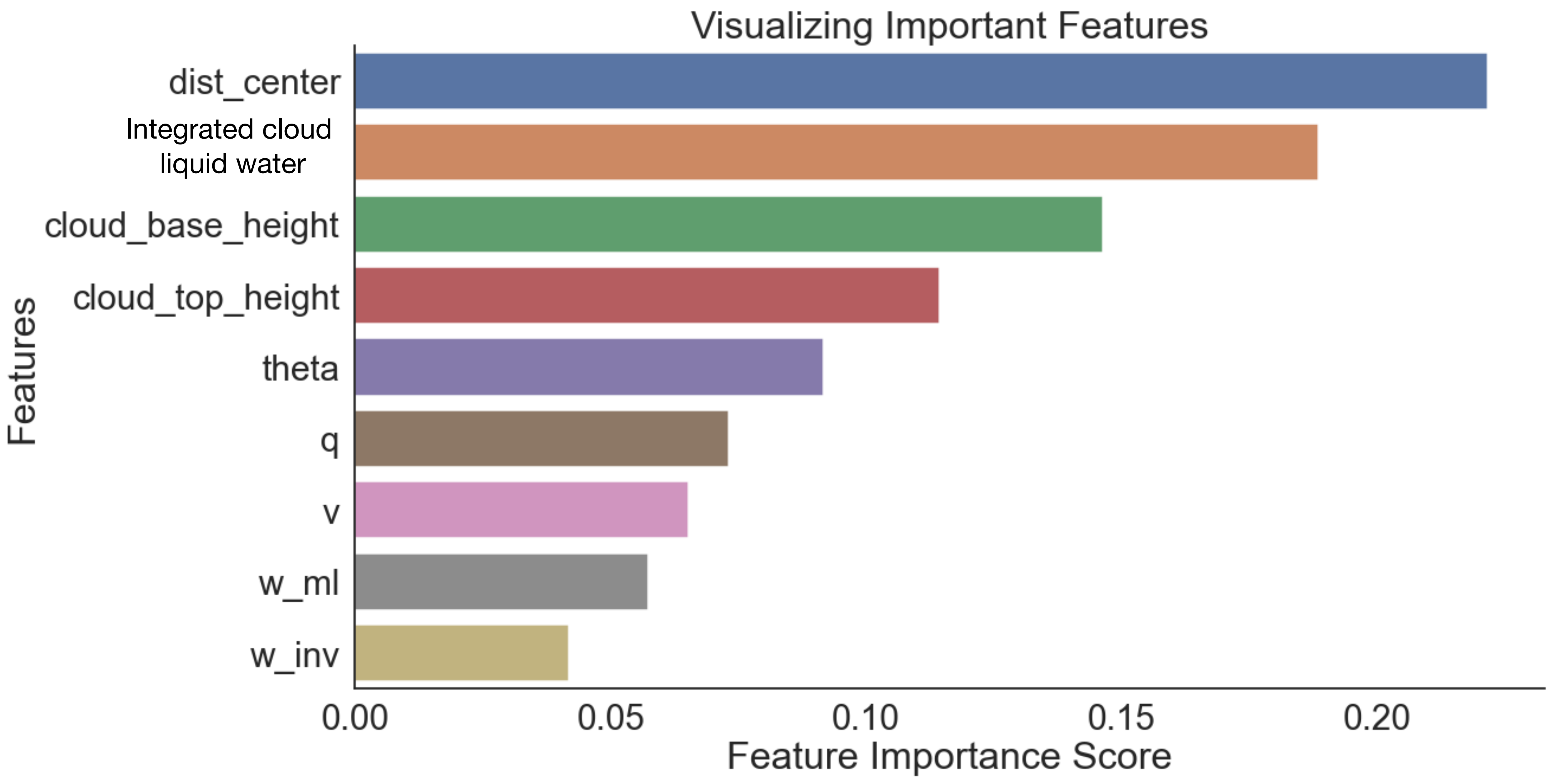
Most important environmental variables:
but, a cold pool imprint rather than a predictive feature?



Cold pool signature? Regions $\theta \leq 297.5$ in contours

Skill increases when re-running analysis outside cloud region, and distance to cloud center of mass is most important variable





Conclusions

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2. Life cycle of this first cloud population maintains the transition layer structure, by smoothing vertical thermodynamic gradients by a condensation-evaporation mechanism

3. Inferences from mixed layer theory and mixing diagrams suggest that differences in cloud-free and cloudy transition layer structures do not affect the rate of entrainment mixing, but rather the properties of the air incorporated into the mixed layer, primarily as a moistening