Modeling and Physics of Cloud-Top Entrainment Instability

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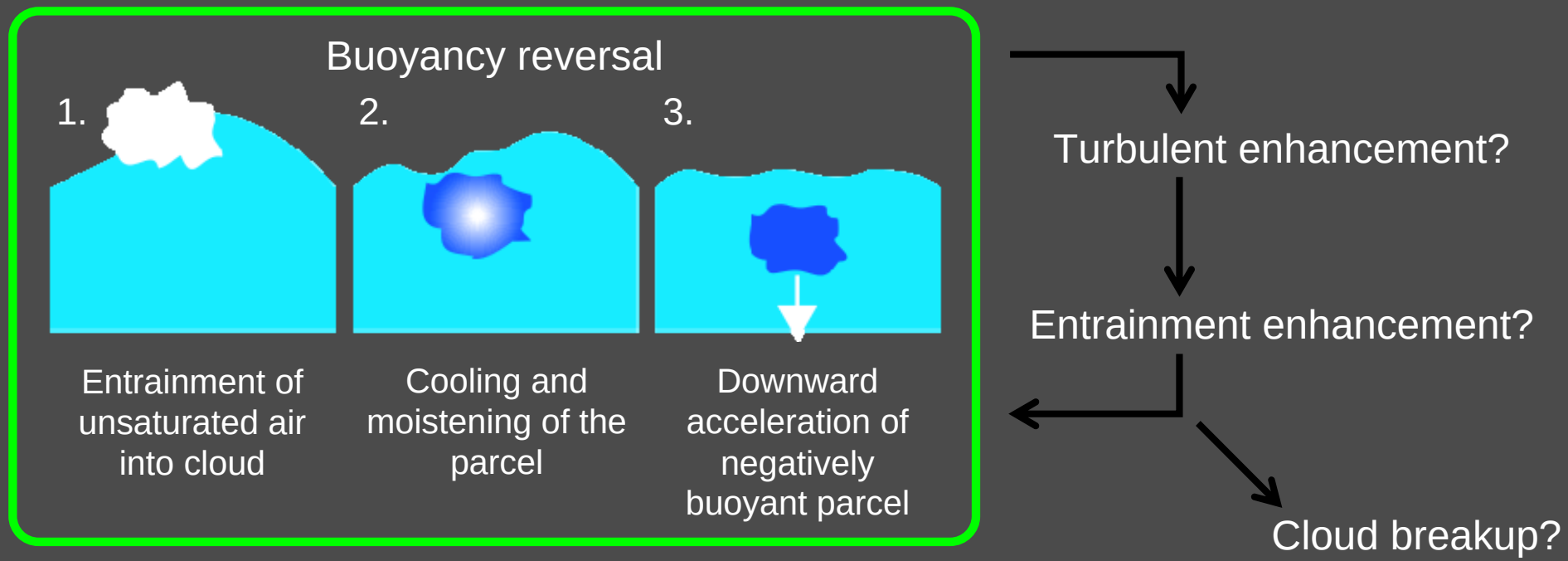
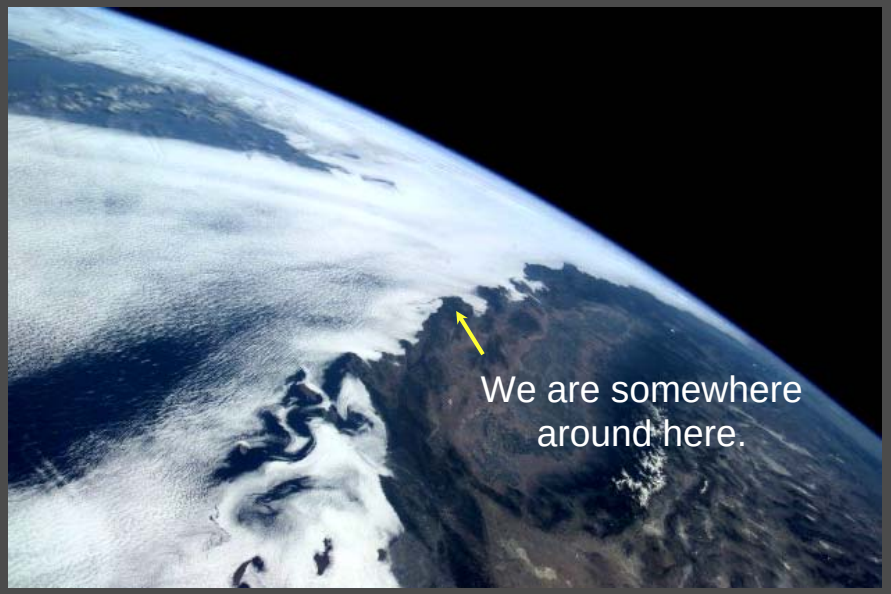
Hypothesis: Cloud-top entrainment instability



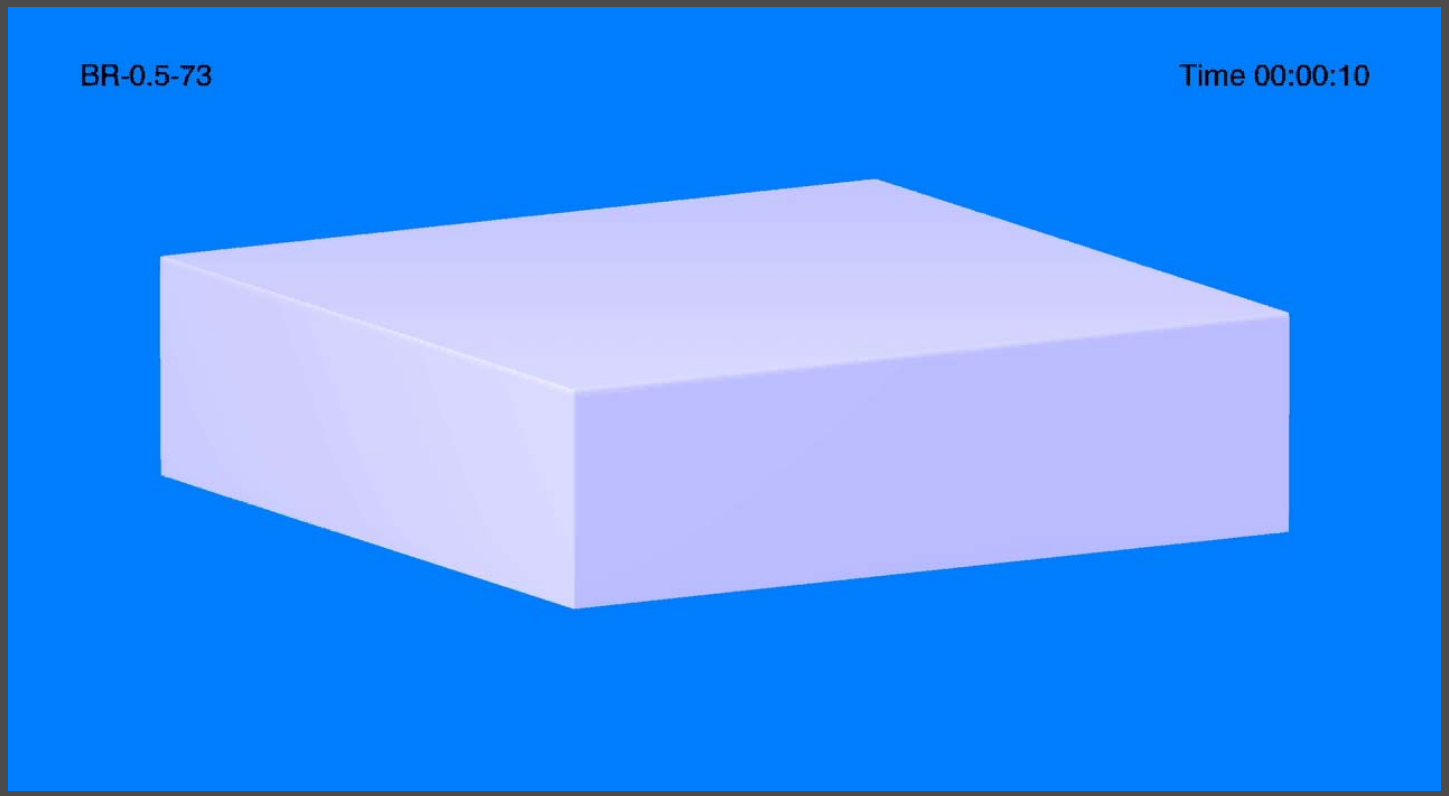
- Lilly (1968), Randall (1980), Deardorff (1980)
- Randall-Deardorff CTEI criterion: $\Delta_{RD} = \Delta\theta_e - \kappa(L/c_p)\Delta r < 0$
- It is not known how CTEI plays a role for marine stratocumulus.

Yamaguchi and Randall (2008, JAS)

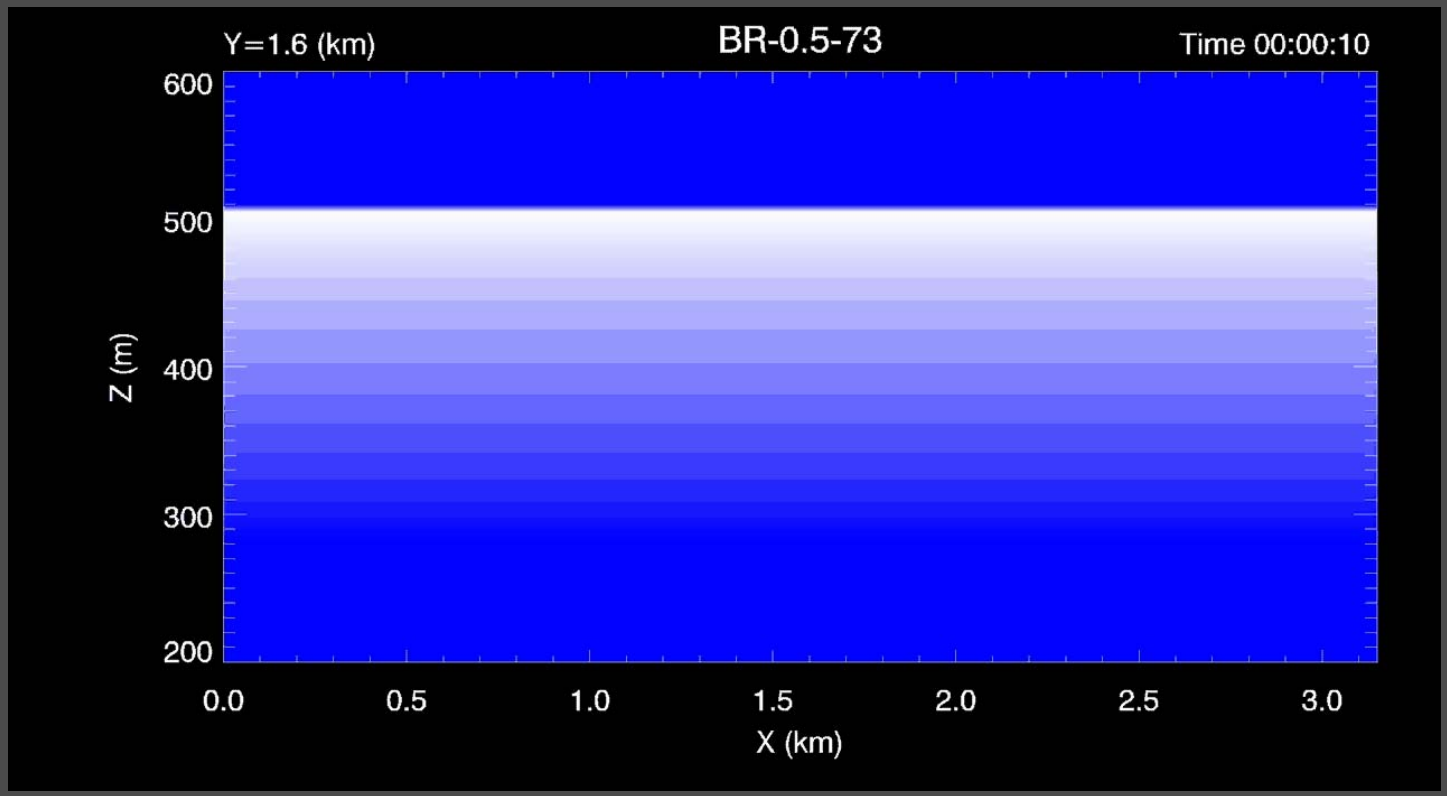
- CTEI hypothesis is tested with the idealized LES experiments, in which turbulence should grow only through buoyancy reversal.
- LES model - SAM (System for Atmospheric Modeling, Khairoutdinov and Randall, 2003)
- Idealized condition - no forcing, no radiation, no precipitation, no mean flow
- A run with 5 m isotropic grid was performed after YR08.



An idealized CTEI run with 5 m isotropic grid



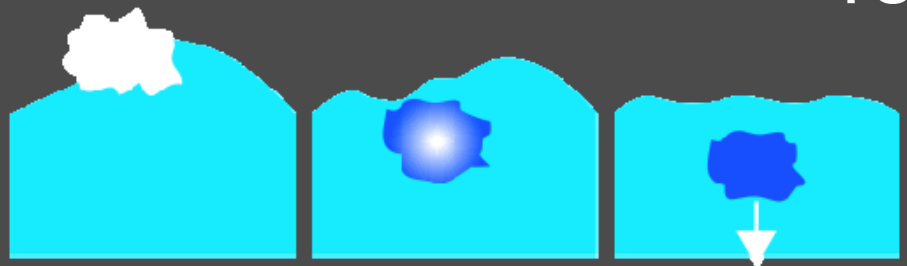
Cross-sectional view



Summary of the results of YR08

- In the idealized experiments,
  - Spontaneous entrainment develops if $\Delta_{RD} < 0$,
  - Negative buoyancy is produced by evaporation,
  - As a result, cloud dissipation takes place.
- CTEI is weak but not negligible.
- For real marine stratocumulus, the effect of CTEI could be hidden by other processes.

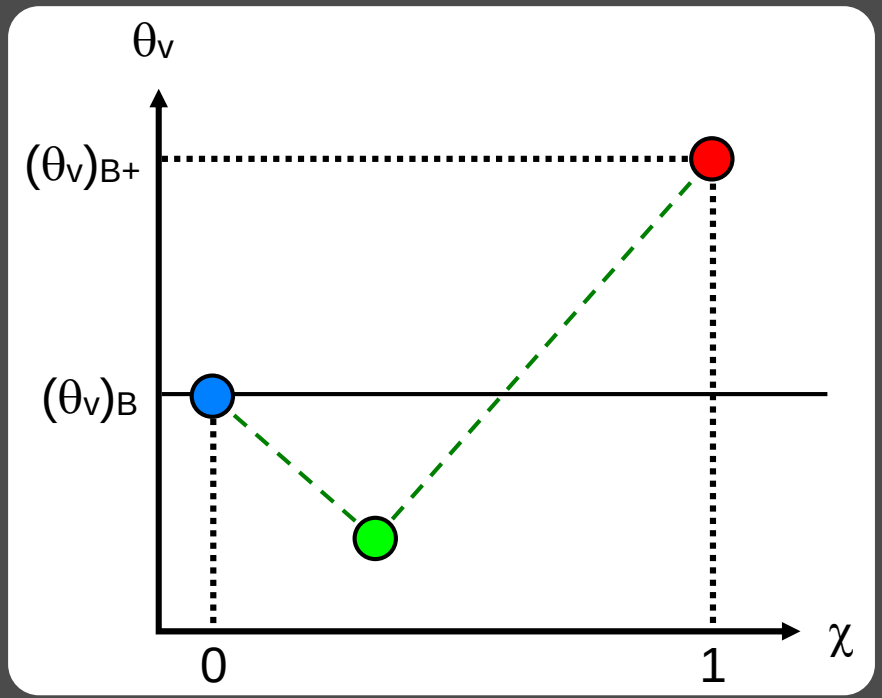
Is the cloud dissipation due to buoyancy reversal?



Entrainment of unsaturated air into cloud

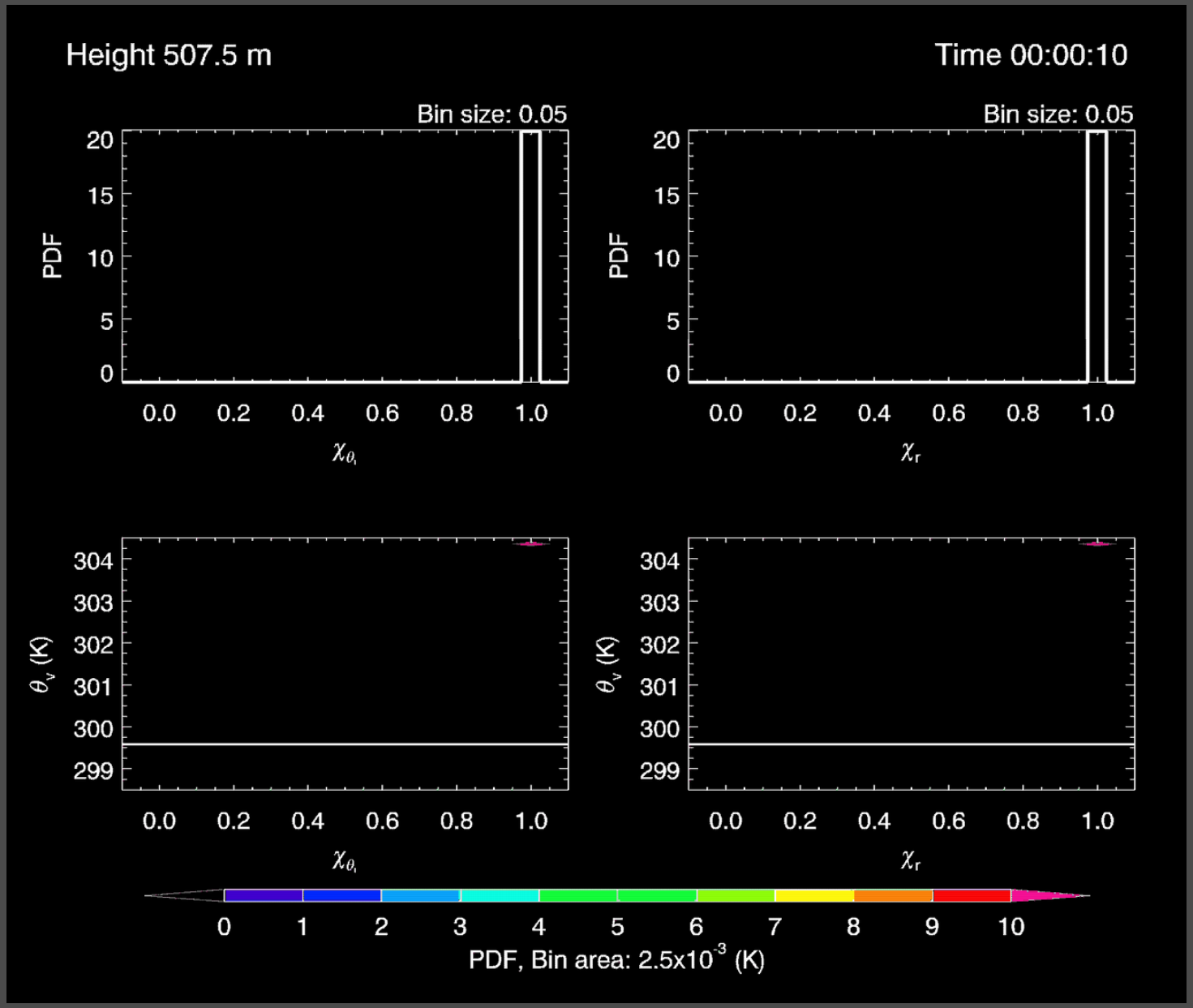
Cooling and moistening of the parcel

Downward acceleration of negatively buoyant parcel

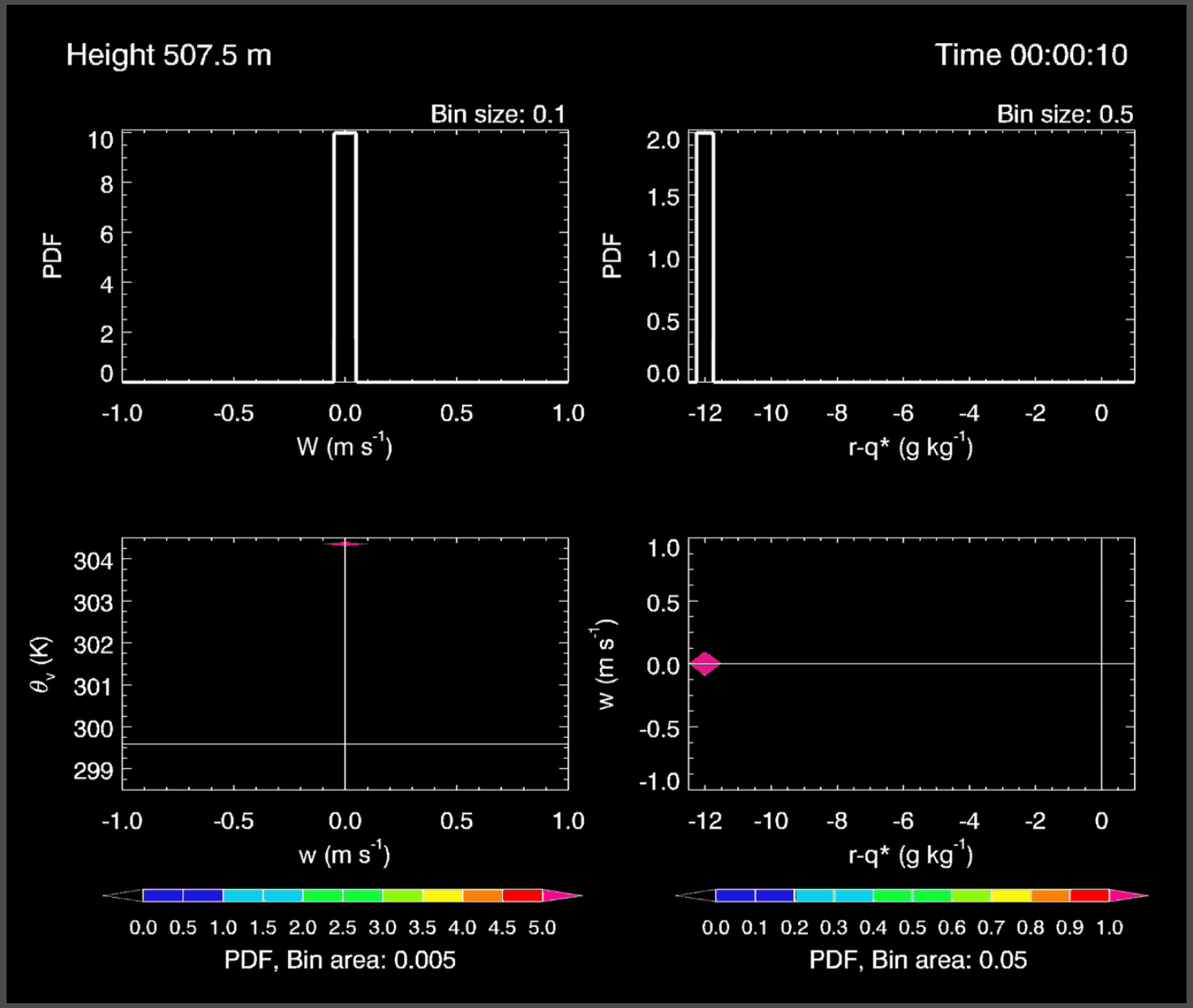


- θ_v - virtual potential temperature
- χ - mixing fraction
- χ can be diagnosed with moist conservative variables, such as liquid water potential temperature, θ_l, and total water mixing ratio, r by
  - $\psi = (1 - \chi)\ \psi_B + \chi\ \psi_{B+}$
  - $\chi = (1 - \psi) / (\psi_B - \psi_{B+})$
- How does the θ_v-χ diagram of this run look like?

Height @ initial level B+ (inversion top)



Joint PDFs @ initial level B+



Quick summary

- An idealized CTEI run with 5 m isotropic grid shows cloud dissipation.
- PDF of mixing parameter suggests active buoyancy reversal during the simulation.
- Is the saturation adjustment still a problem?

My goals

- Study the interactions between CTEI and radiative cooling feedbacks.
- Study the possible role of CTEI in mesoscale convection - Large domain LES.
- Parameterize CTEI.


Questions? Suggestions? Thank you.

A CTEI run with 5-m isotropic grid

- $\Delta x = \Delta y = \Delta z = 5$ m
  - Saturation adjustment becomes reasonable assumption.
  - With 3 km horizontal domain, grid spacings finer than 5 m become possible, but still expensive.
- NCAR Bluice
  - Total grid number: 640 x 640 x 250 ~ 102 million
  - One 3D snapshot data ~ 1.5 GB for 4 variables (3D data was saved every 10 second. 1080 data files were generated ~ 1.6 TB.)
  - 4 nodes = 64 processors (run with virtual threads ~ semi 128)
  - Wall-clock time ~ 7 hours for 3 simulated hours
  - Computational cost ~ 400 GAUs (relatively cheap)