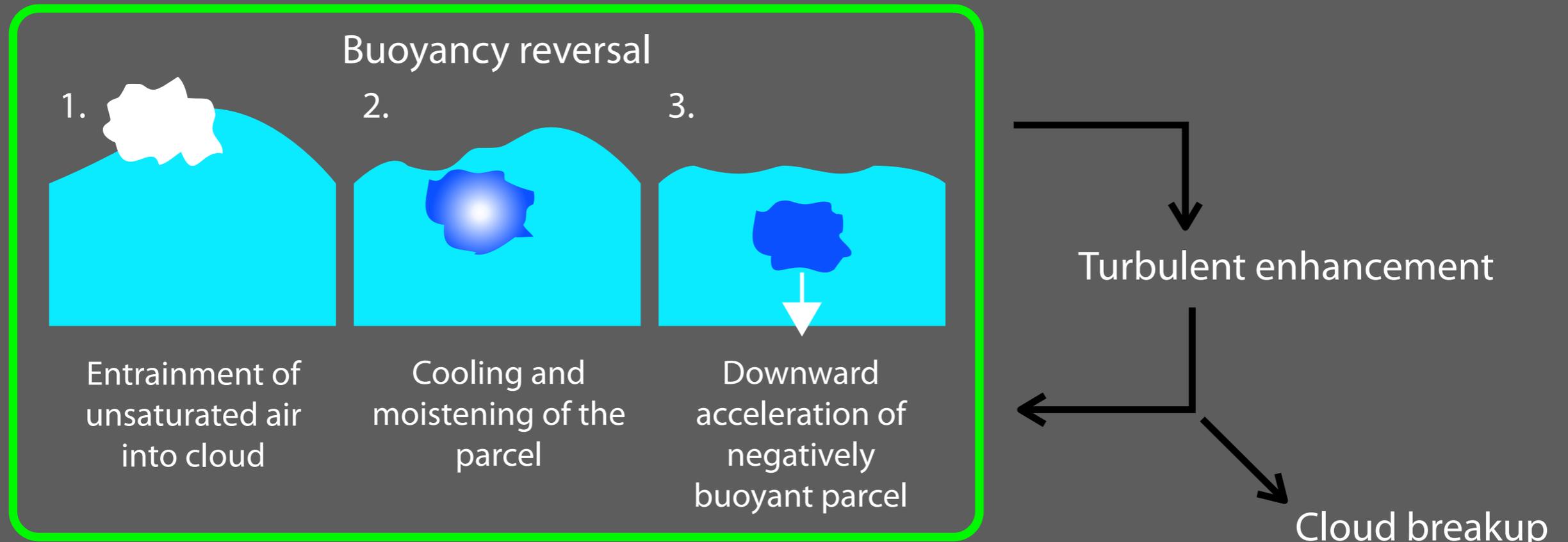# Large Eddy Simulations of CTEI under Idealized Conditions

Takanobu Yamaguchi and David A. Randall
Department of Atmospheric Science, Colorado State University

Cloud-top entrainment instability

Buoyancy reversal

1. Entrainment of unsaturated air into cloud

2. Cooling and moistening of the parcel

3. Downward acceleration of negatively buoyant parcel

Turbulent enhancement

Cloud breakup

- 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 whether CTEI is important for marine stratocumulus.

- Yamaguchi and Randall (2007, in press, YR07) show the existence of CTEI with idealized LES experiments.

Methodology of YR07

- Numerical specs

  - SAM LES 3D

  - x = 3.2 km, z = 1.25 km

  - Δx = 50 m, Δz = 5 m

  - 10 hour simulation time

- Experimental specs

  - No surface fluxes, radiation, large scale forcing and winds

  - Precipitation is not allowed.

  - 3 experiments: difference is the maximum cloud-top liquid water amount (0.5, 1, 2 g/kg).

  - Each experiment contains series of LESs, which use different inversions.

- A new method to diagnose entrainment rate is developed, based on the mixed layer theory.
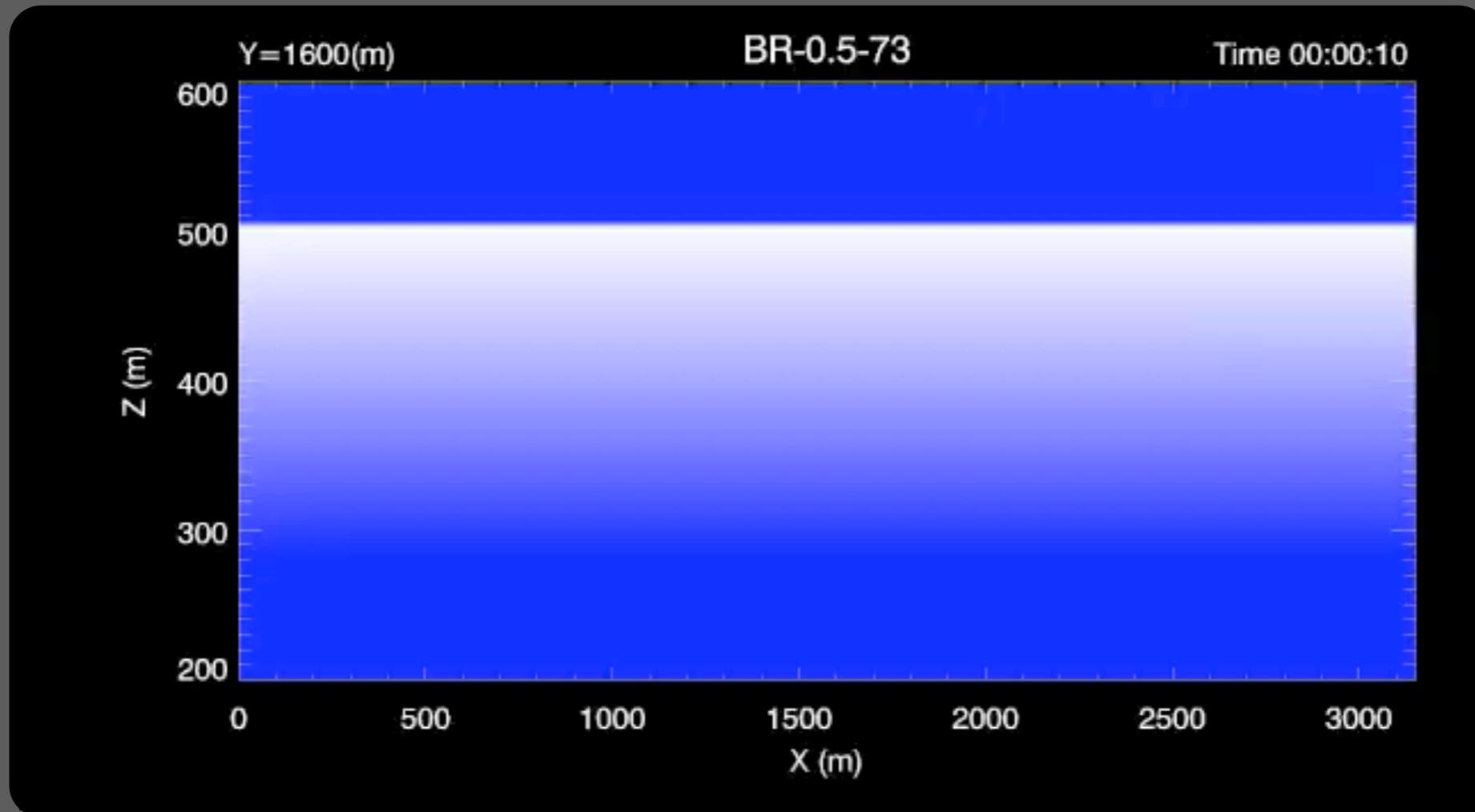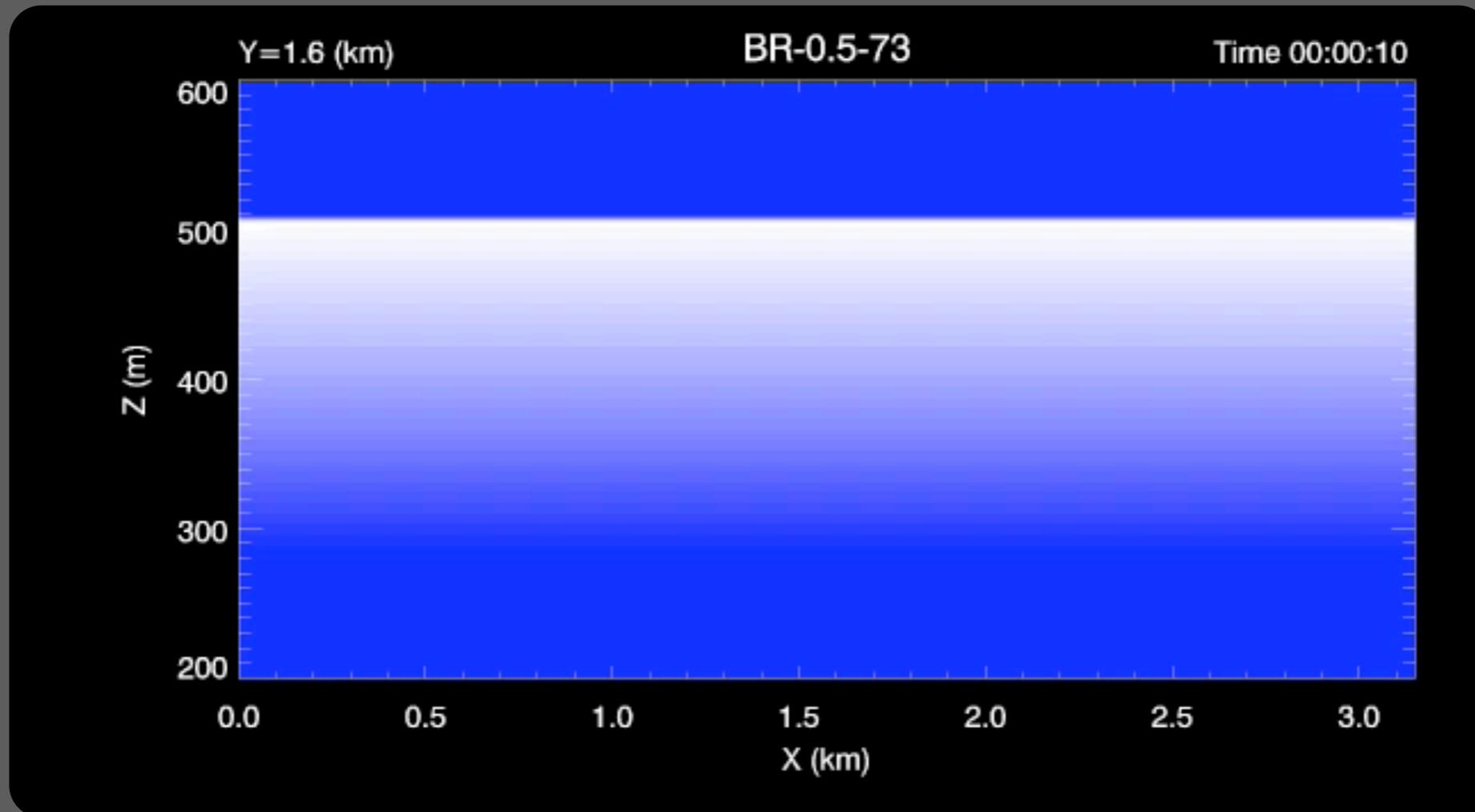
CTEI occurs if $\Delta_{RD} < 0$
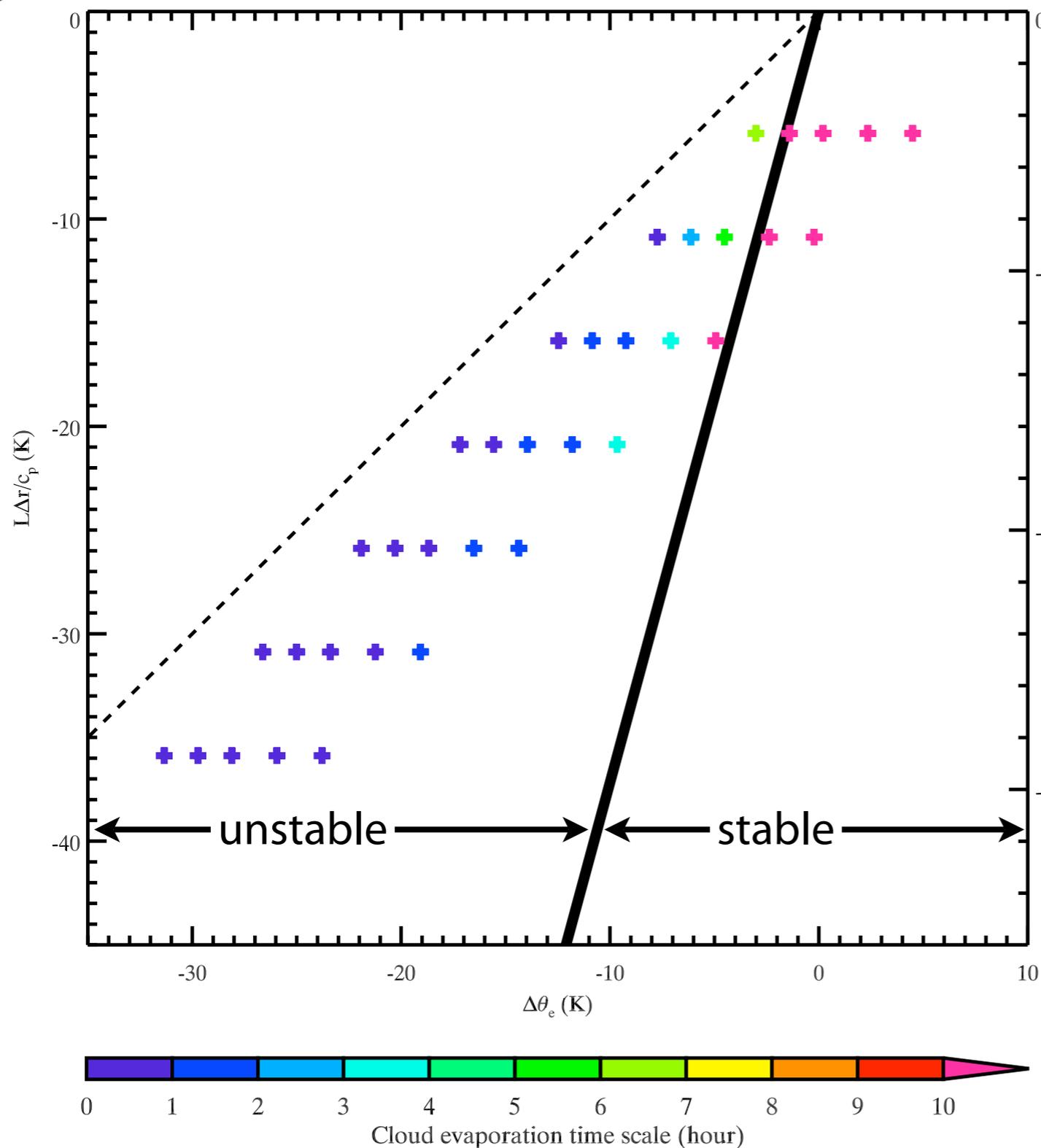
- Each + symbol is one LES.

- Location of + is determined with the initial profiles.

- Color of + represents an e-folding time scale based on liquid water path.

- Thick line is the stability boundary of the RD criterion.

Is Δx = 50 m good enough?

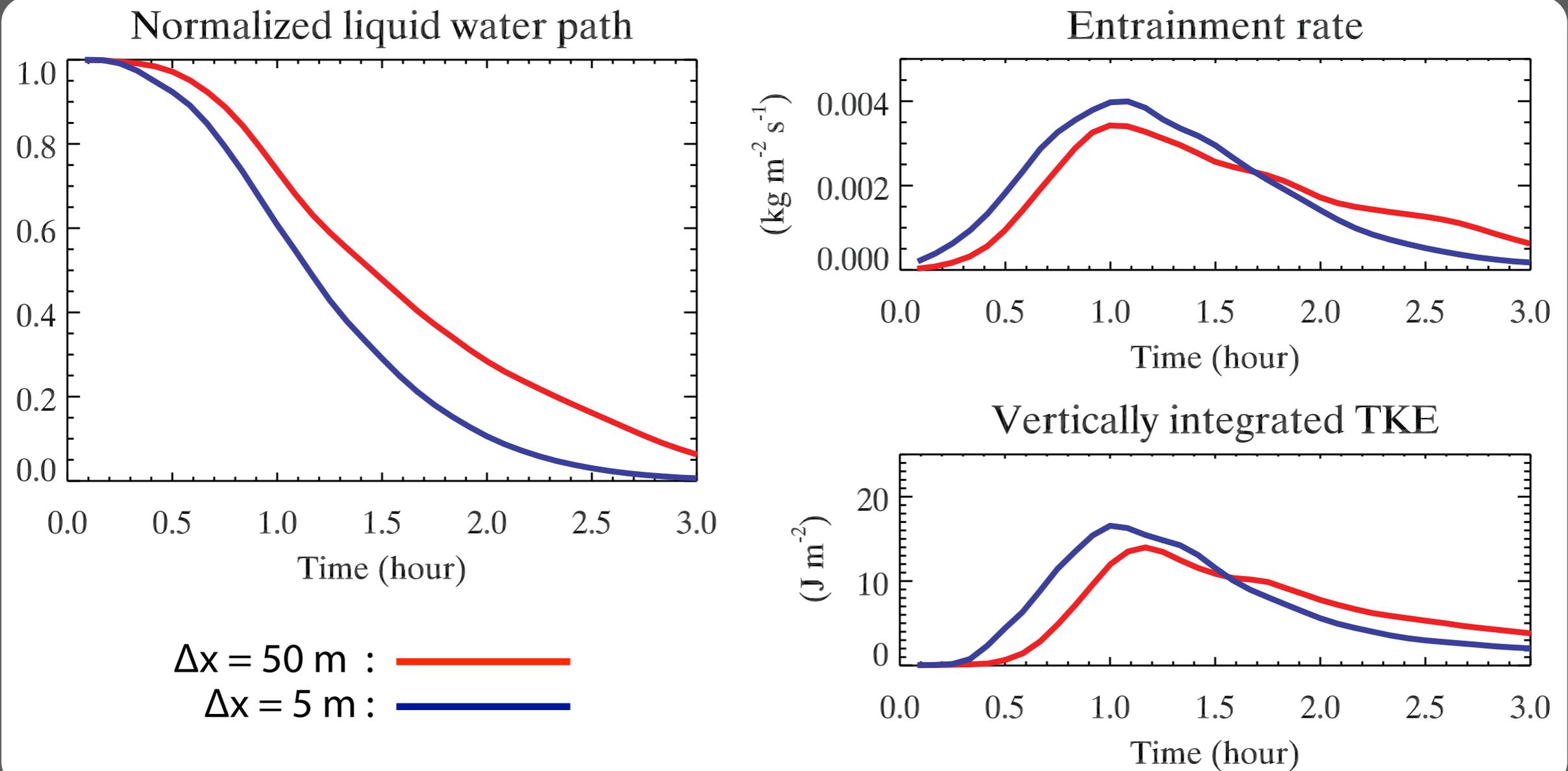

- How does Δx affect the statistics, e.g., entrainment rate?
- Is non-isotropic grid a problem?

3D run with 5 m isotropic grid

- Newly entrained thermals tend to follow the dry paths of earlier thermals.
- The dry paths become wider.

Sensitivity to Δx

Normalized liquid water path

Entrainment rate

Vertically integrated TKE

Δx = 50 m :
Δx = 5 m :

- Results are moderately independent of Δx.

- Only resolved variables are used. Maximum vertically integrated SGS TKE is ~0.9 for Δx=5 and ~0.3 for Δx=50.

Future directions

We want a better understanding dynamics of evaporatively driven CTEI downdrafts.

We want to understand what CTEI does in realistic shallow-cloud situations.

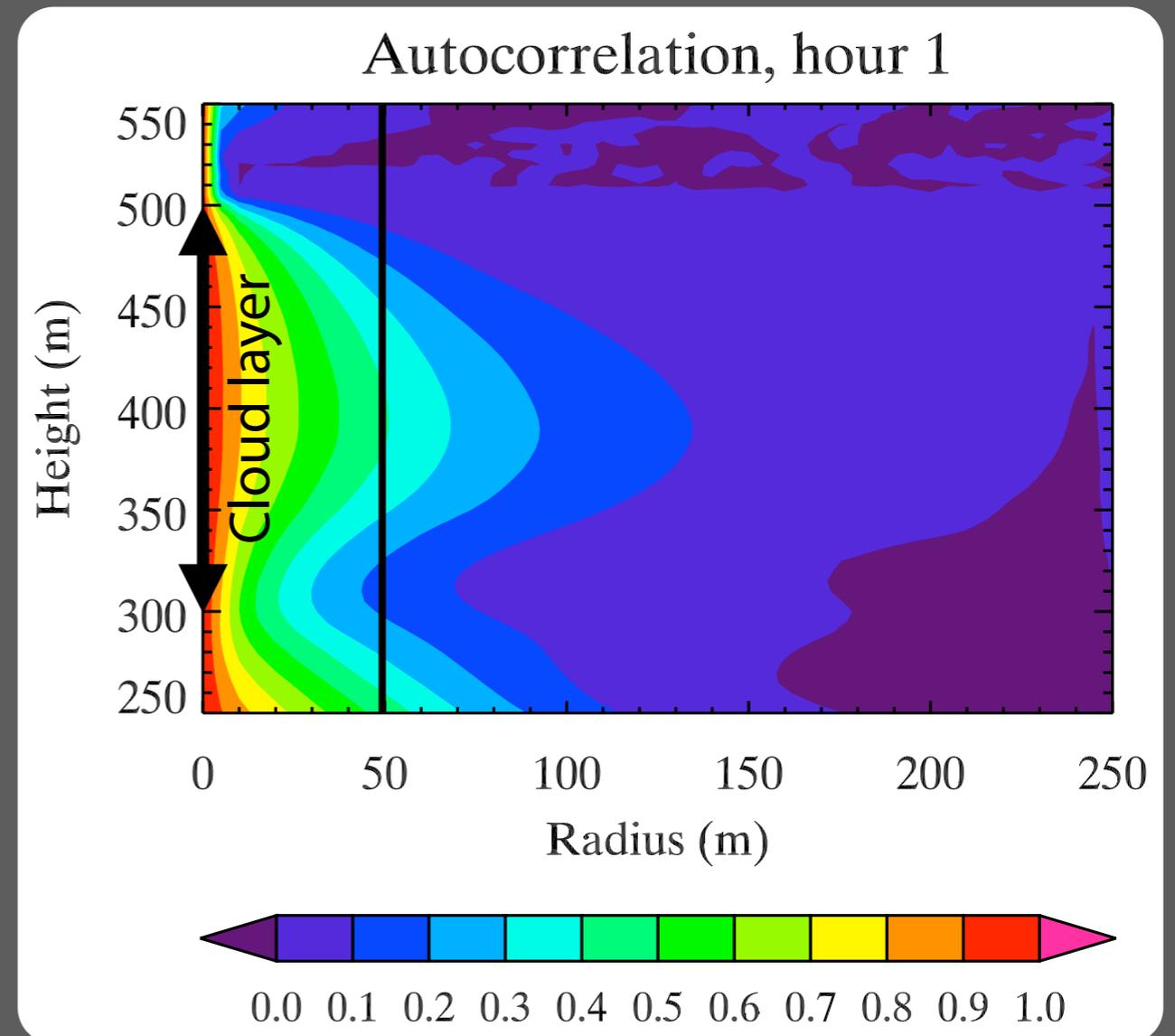We want to parameterize the effects of cloud-top evaporation on entrainment.

We want to explore relevance of CTEI to entrainment in large cumulus clouds.

The way to the future...

3 Stand with the first mark to your left and the second mark to your right—you are now facing north.

Example of ongoing analysis

- Develop a method to estimate entrained thermal radius

➡ Spatial auto-correlation of vertical velocity of $\Delta x = 5$ m case (right figure)

Questions?