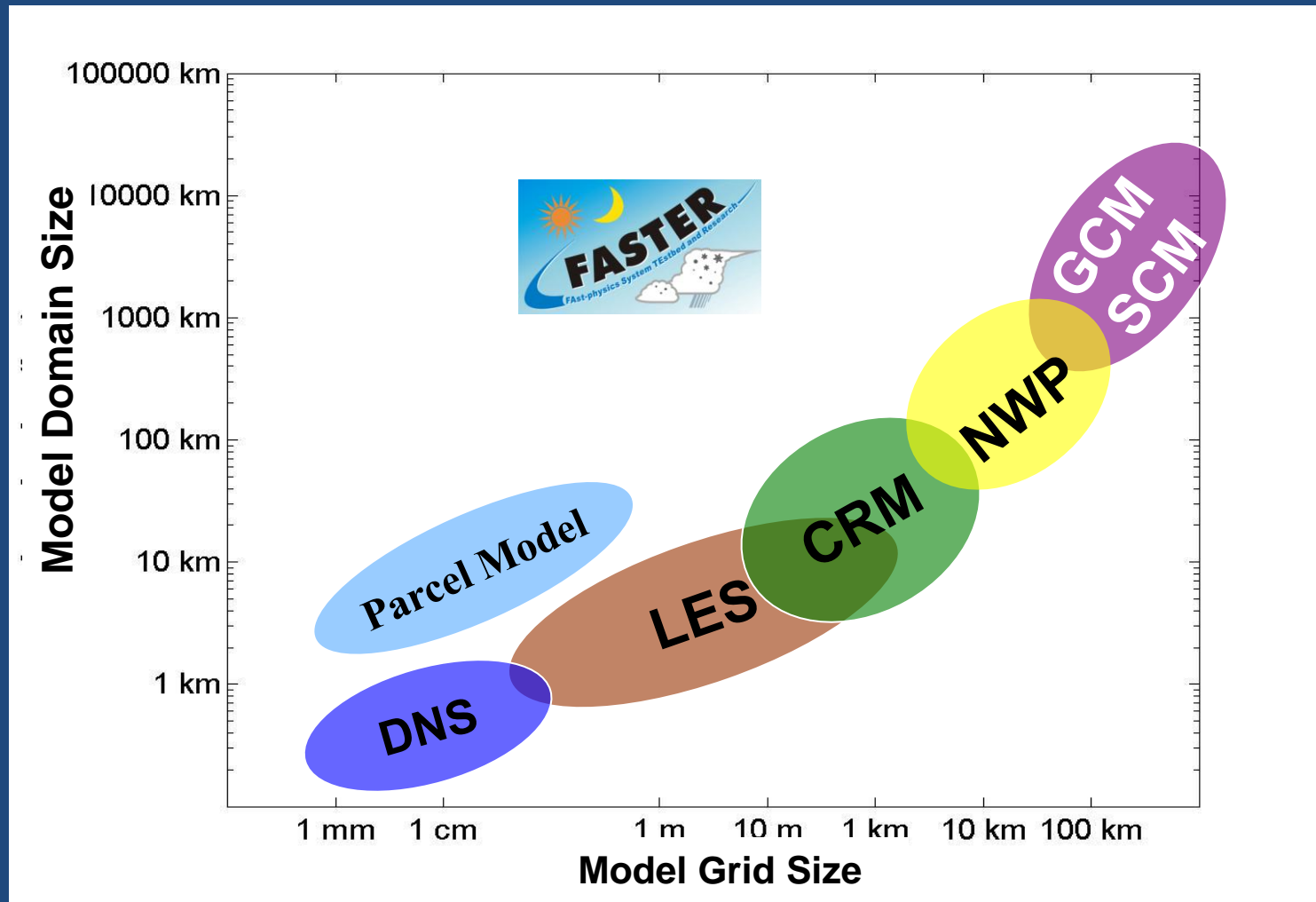


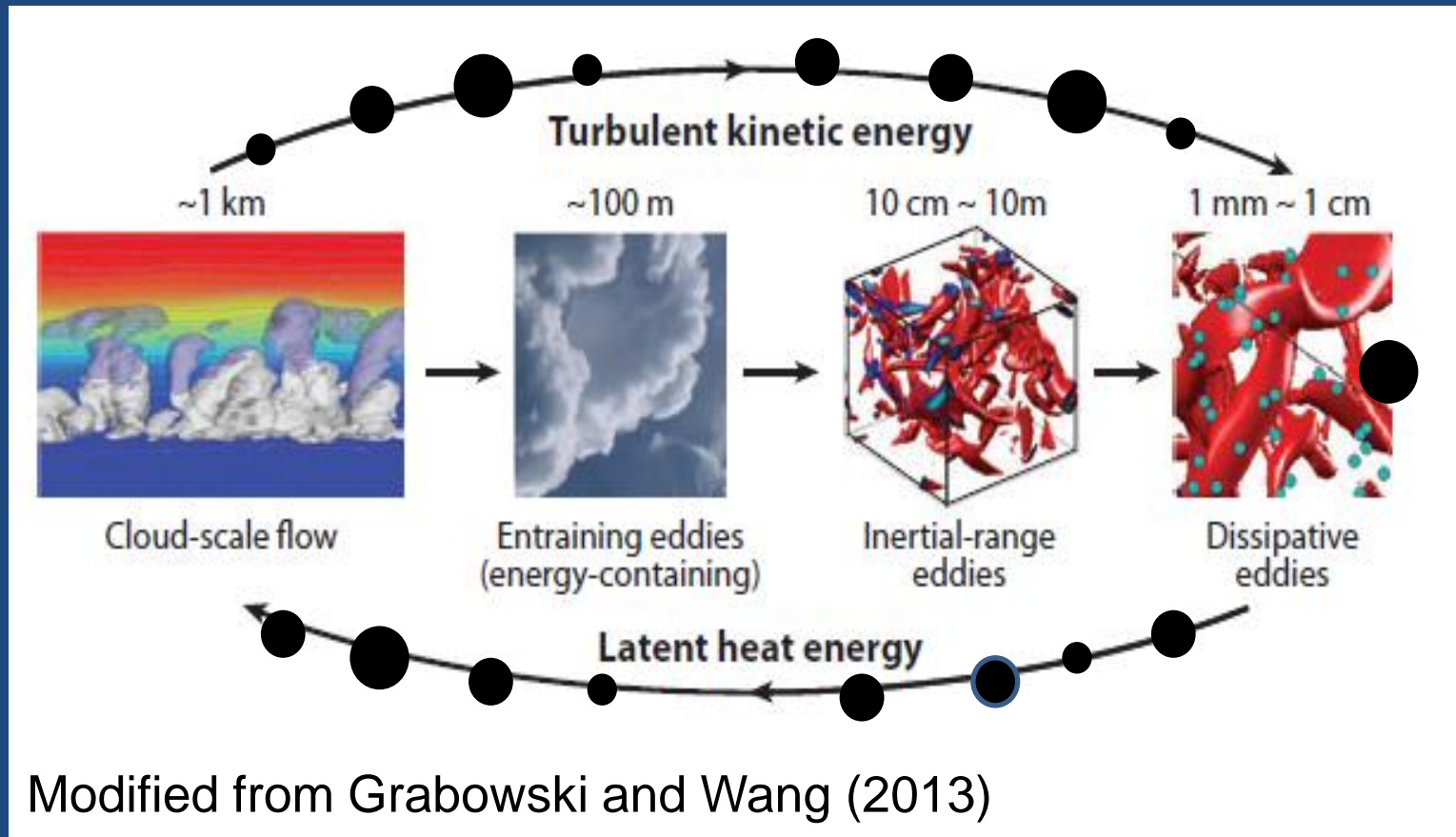
# FASTER

## Integrative Multiscale Model Framework



***FASTER uses a unique integrative multi-scale model framework essential to addressing the CESD scaling challenge related to fast physics parameterization.***

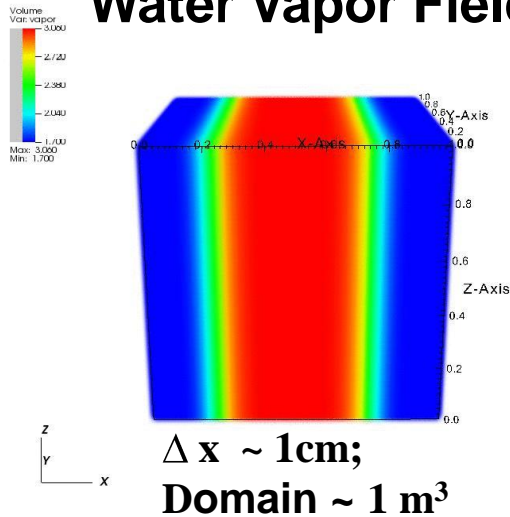
# DNS for Improving Sub-LES Scale Processes



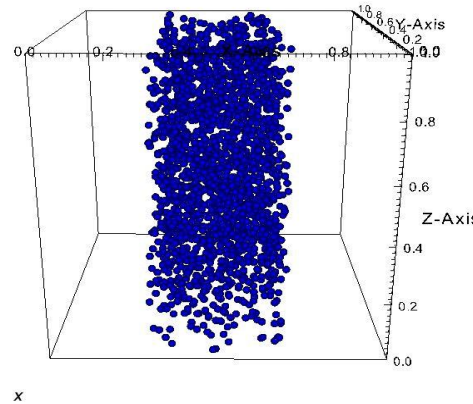
- Turbulence-microphysics interactions
- Entrainment-mixing processes
- Droplet clustering
- Rain initiation

# Our Particle-Resolved DNS

## Water Vapor Field



## Droplets in Motion

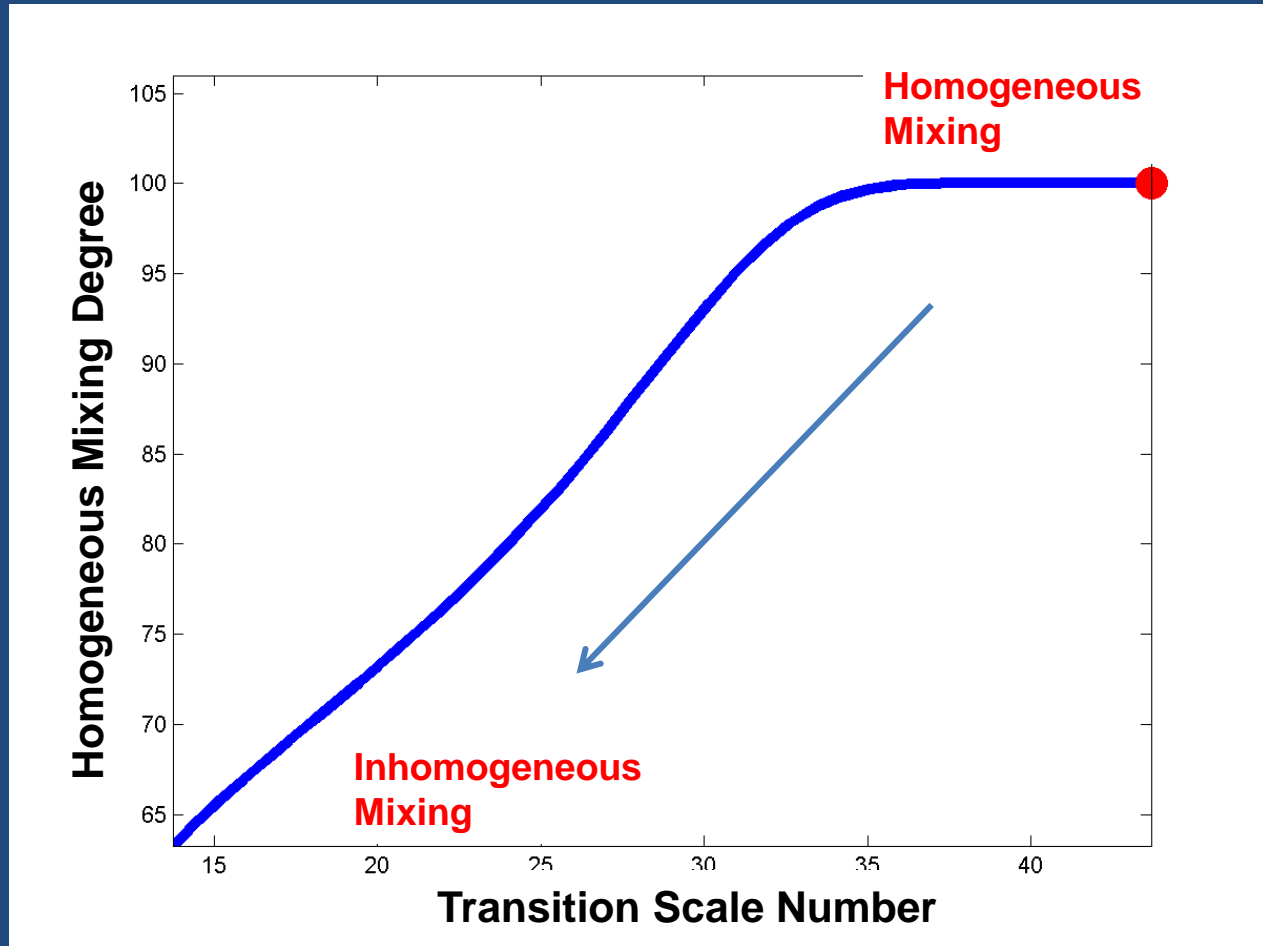


**Turbulent motion and deformation at sub-LES grid scales can generate complex structures and droplet tracks.**

- LES does not resolve turbulent processes that occur at scales smaller than LES grid size and are critical for turbulence-microphysics (**knowledge gap**).
- Bridge the scales between LES grid size and smallest eddies (e.g., 1 mm ~ 1 – 100  $\mu\text{m}$ ), tracks individual droplets, and serve as a benchmark for spectral bin models
- Provide a powerful tool for studying turbulence-microphysics interactions and entrainment-mixing processes (**knowledge gap**), and informing related parameterization development (**parameterization gap**) (next slide).

# Example: Using DNS to Investigate Entrainment-Mixing Processes

- Different entrainment-mixing processes can occur in clouds and are key to rain initiation and aerosol-cloud interactions.
- Our knowledge on these processes is very limited.
- DNS can be used to fill in the knowledge gap and inform the development of related parameterization.



Droplets start with homogeneous mixing and evolve toward inhomogeneous mixing due to faster evaporation relative to turbulent mixing.

# Three Pathways for DNS-LES Integration

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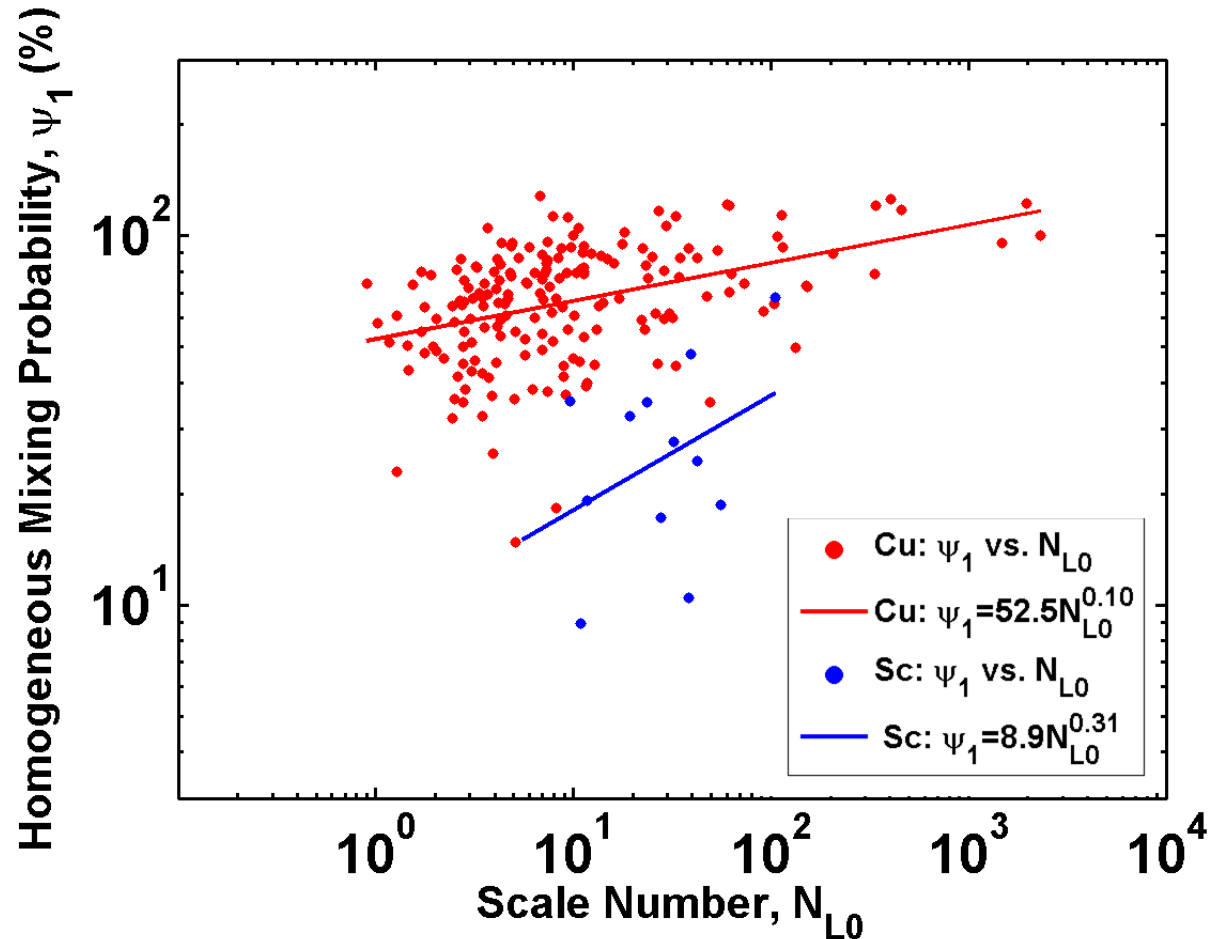
- **Pathway one:** DNS run under conditions idealized for specific science questions such as turbulent mixing
- **Pathway two:** DNS driven by forcing derived from LES
- **Pathway three: extreme-scale modeling for fast physics**
  - LES with large domain-resolution ratio (10 km/1 m  $\sim 10^4$ )
  - DNS with large domain-resolution ratio (10m/1mm  $\sim 10^4$ )

# Discussion Topics

- **Better use the integrative SCM-LES-DNS framework**
- **Implement, test and evaluate new parameterizations in LES**
  - **Entrainment**
  - **Homogeneous mixing degree**
  - **3D radiation transfer**
  - **Subgrid variability (additional to CLUBB?)**
- **Parameterization development/improvement**
  - **How to relate PDF/organization to physics, or parameterize PDF/organization?**
- **FASTER-DA forcing products: hydrometeor forcing; scale-aware forcing; radiation partition into direct and diffuse radiation as a consistent framework of model-obs comparison**

# New Parameterization of Entrainment-Mixing: Cu-Sc Difference

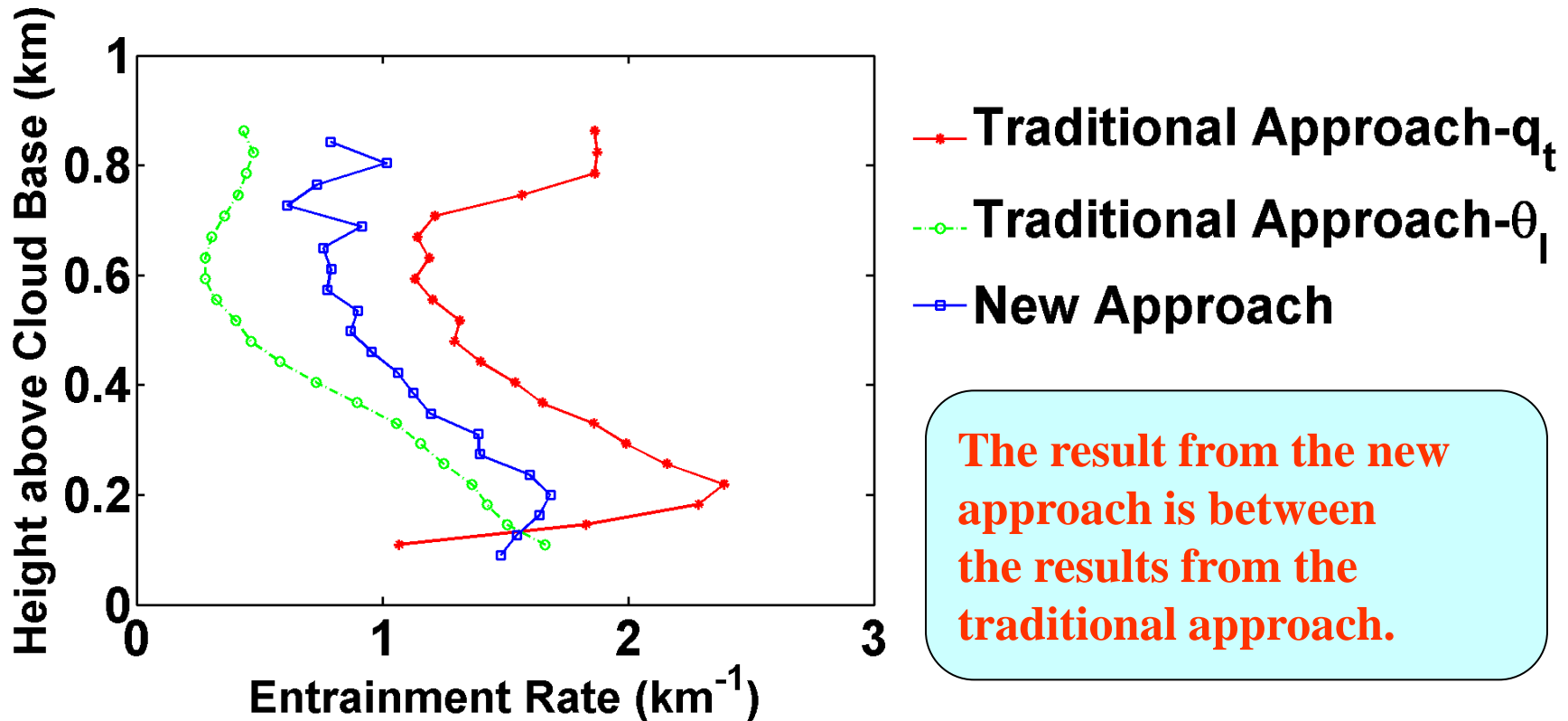
- Eliminate the need for assuming extreme inhomogenous or homogenous mixing;
- Work best for models with 2-moment schemes;
- Testing with SCM and CRM/LES in FASTER
- Integrating with entrainment rate



*A new parameterization that unifies entrainment rate and mixing effects on cloud microphysics is on the horizon.*

# Validation with LES Results (WRF-FASTER)

GCSS Benchmark LES Cu Case  
Derived from SGP Obs



*Future research is to implement and compare direct estimate based on tracking Lagrangian tracer, and explore entrainment parameterization.*



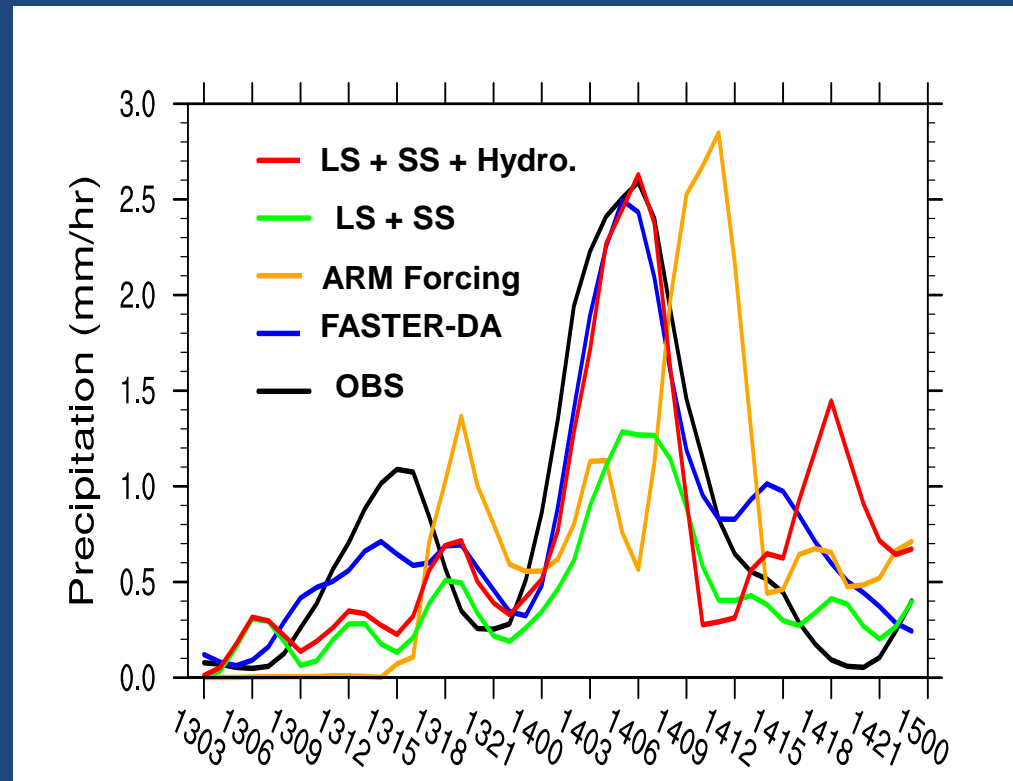
# FASTER-DA for Large Scale Forcing

Tendency = LS + Fast Physics + SS

$$\frac{\partial \bar{q}}{\partial t} = \left( \frac{\partial \bar{q}}{\partial t} \right)_{LS} + \bar{e} - \bar{c} - \overline{V' \cdot \nabla q'} - W' \frac{\partial q'}{\partial p}$$

Subscale contribution (SS)

- FASTER-DA produced LS comparable to standard ARM forcing
- Hydrometeor forcing (gap-filling product)
- Subscale contribution (alternative)
- Multi-scale forcing (alternative)



The SCM precipitation depends significantly on hydrometeor forcing and subscale contribution, which in turn depends on the domain size (not shown), for this strong storm case.