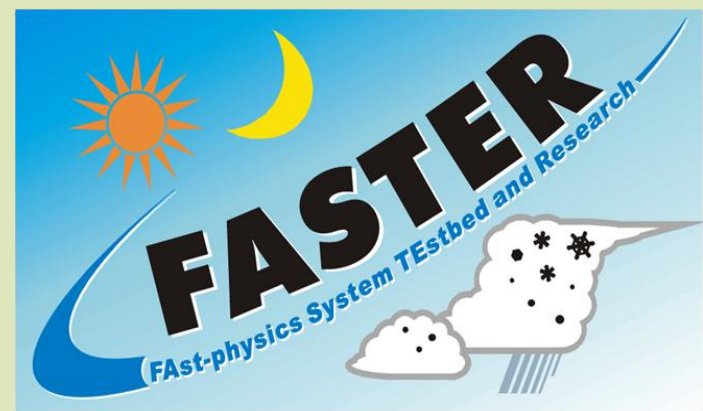


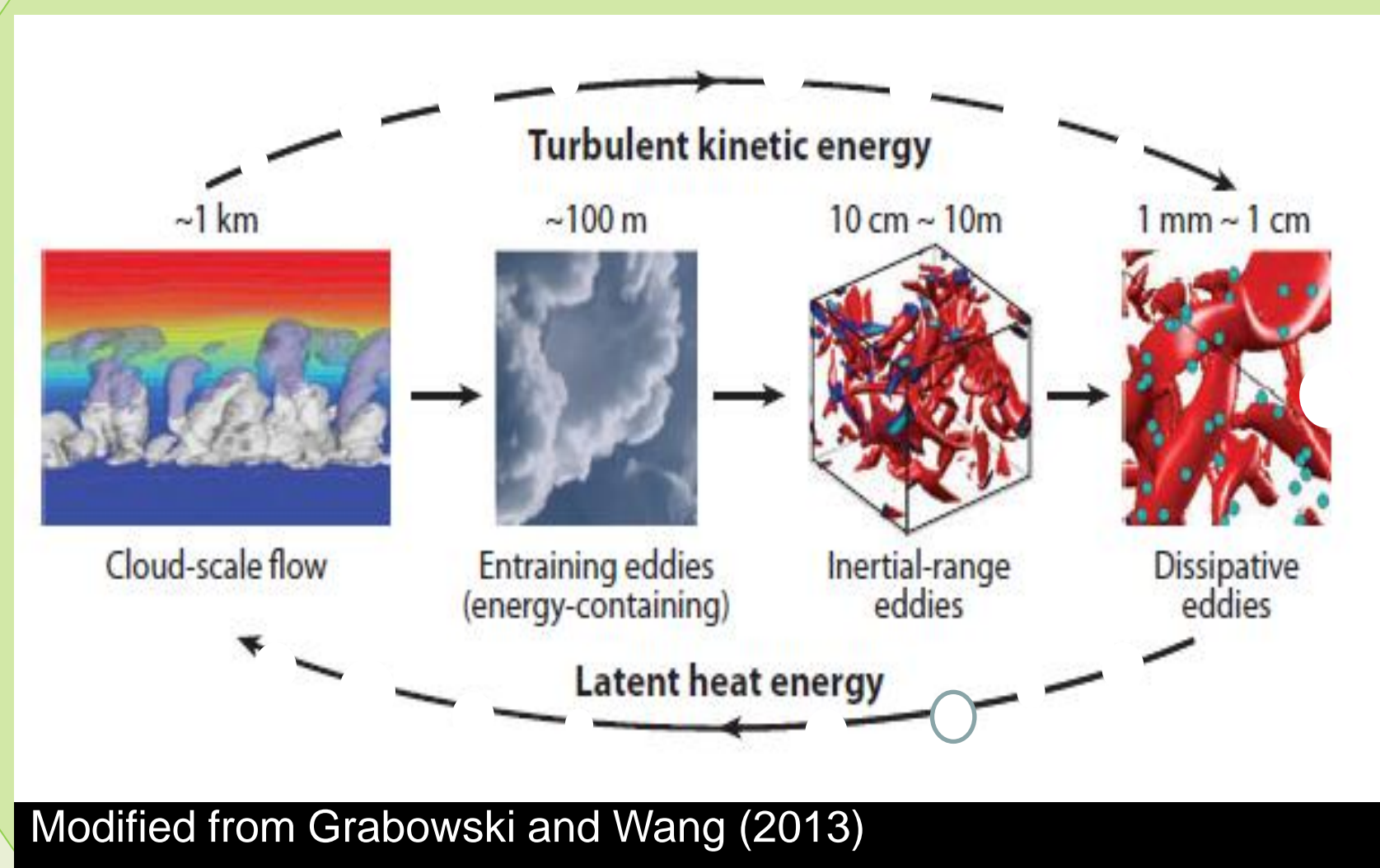
# Using Direct Numerical Simulations for Understanding and Parameterization of Cloud-Related Processes in High-Resolution Climate Models



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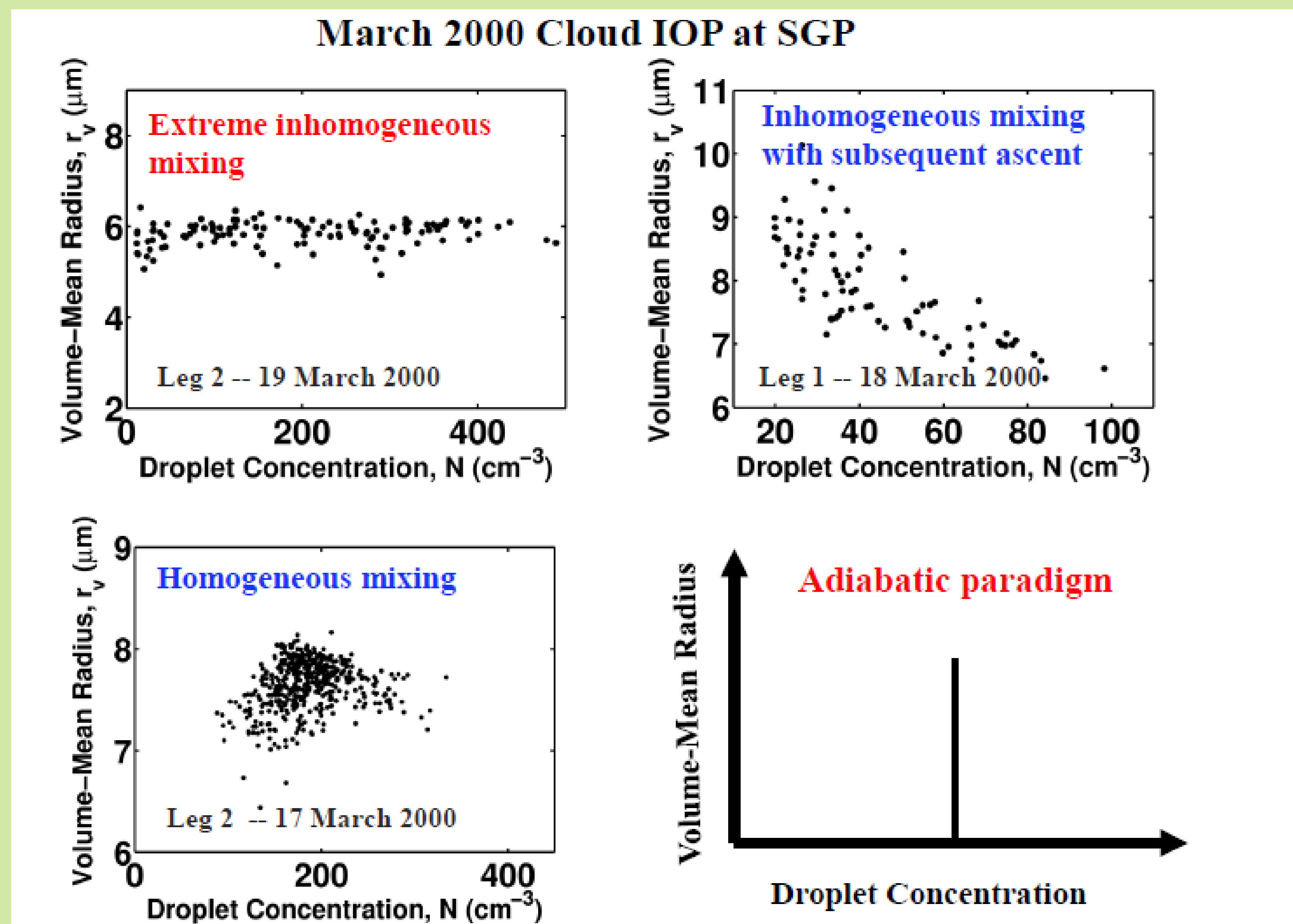
## 1 Many Processes Unresolved in High-Resolution ESM



- Turbulence
- Microphysics
- Turbulence- $\mu$ -physics interaction
- Entrainment mixing processes

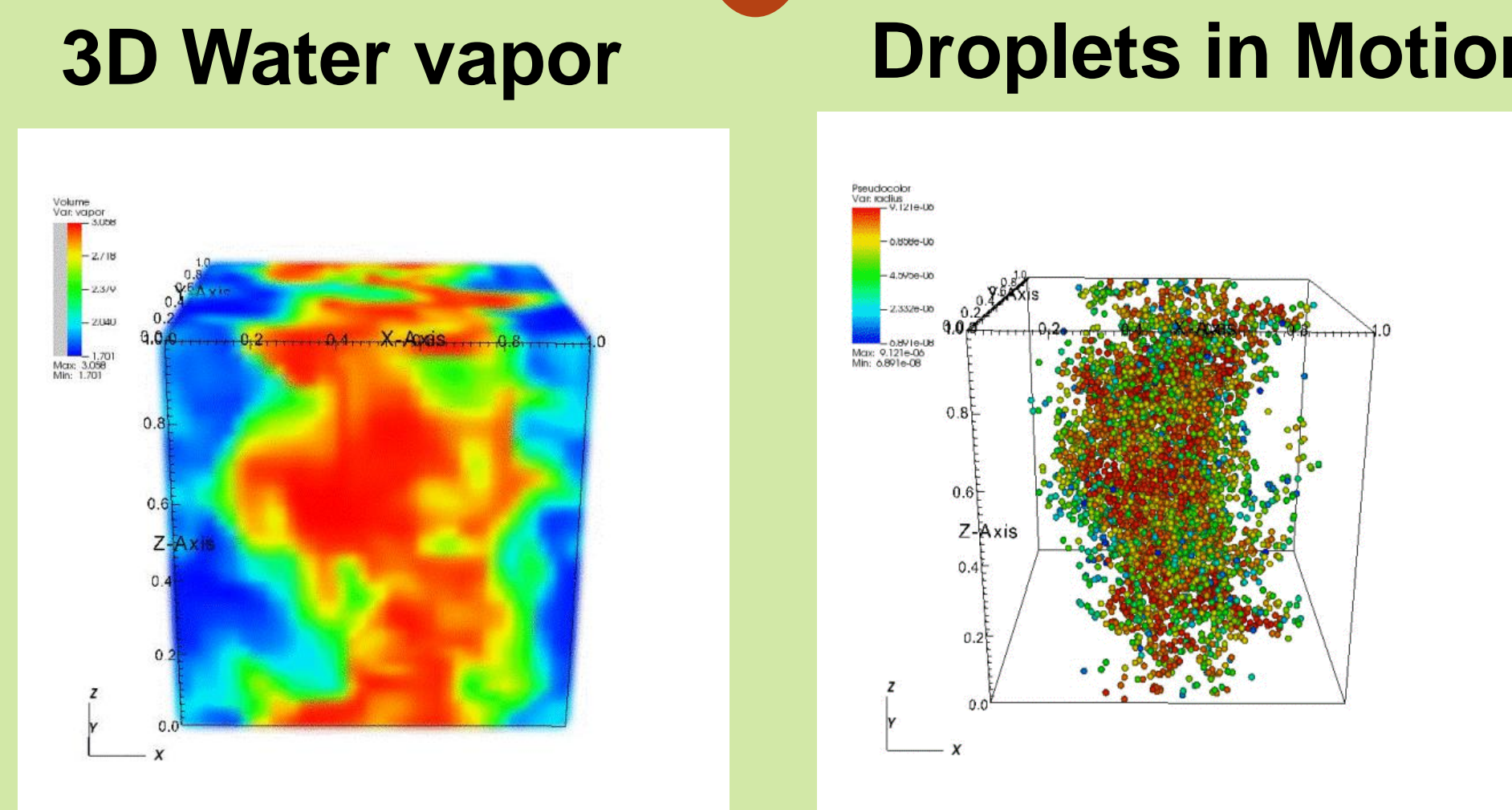
These sub-LES processes are all poorly understood & pose particular challenges to physical understanding and parameterization development

## 2 Outstanding Examples



These observational examples from stratiform clouds at SGP suggest that ambient clouds can have different size distributions, depending on the entrainment-mixing processes that have not been well understood and represented in models from LES to CRM to GCM.

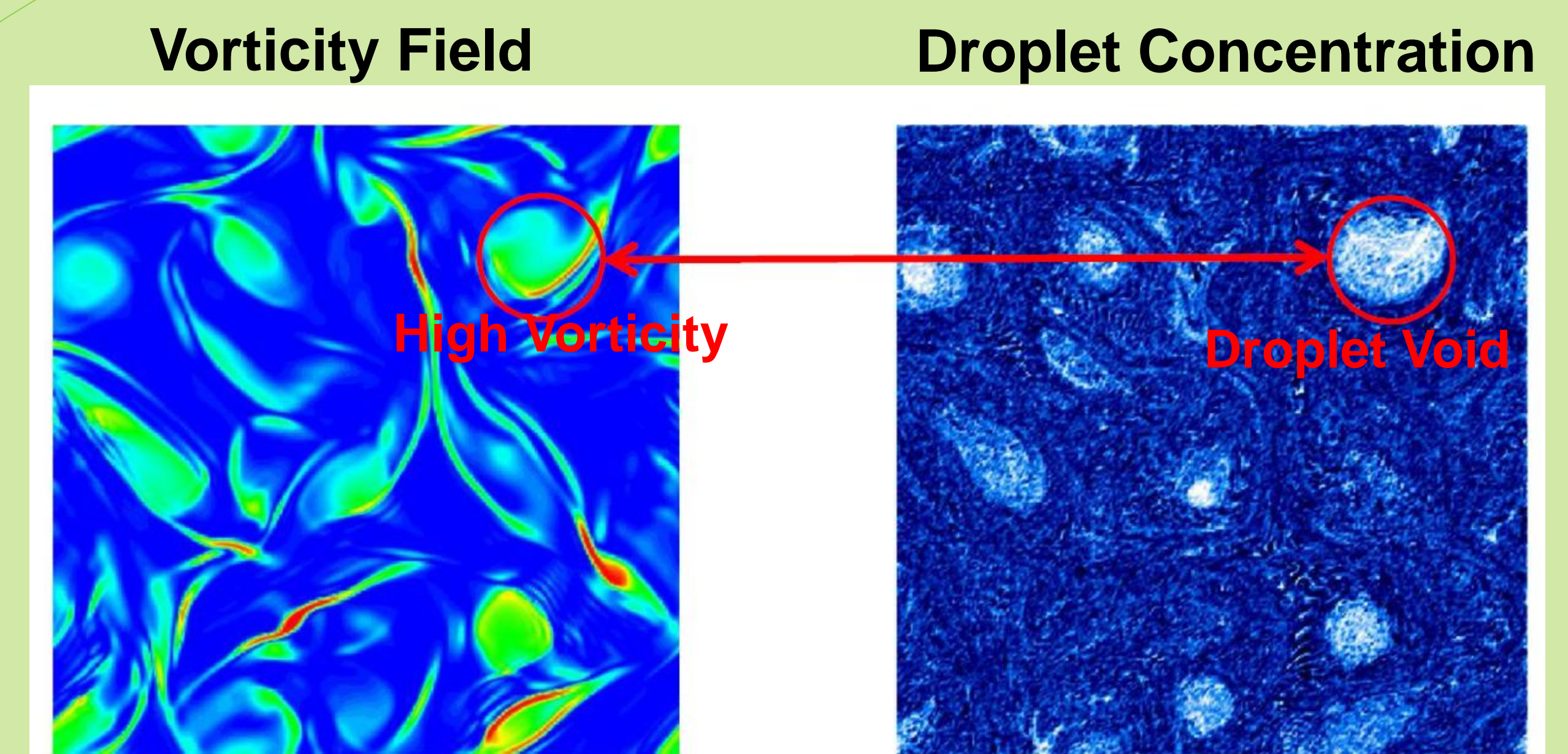
## 3 Particle-Resolved DNS



- Resolve smallest eddy ~ 1 mm
- Track individual droplets

Multiscale turbulent motion and deformation at sub-LES grid scales generate complex structures and tracks of droplet motion and growth.

## 4 Droplet Clustering

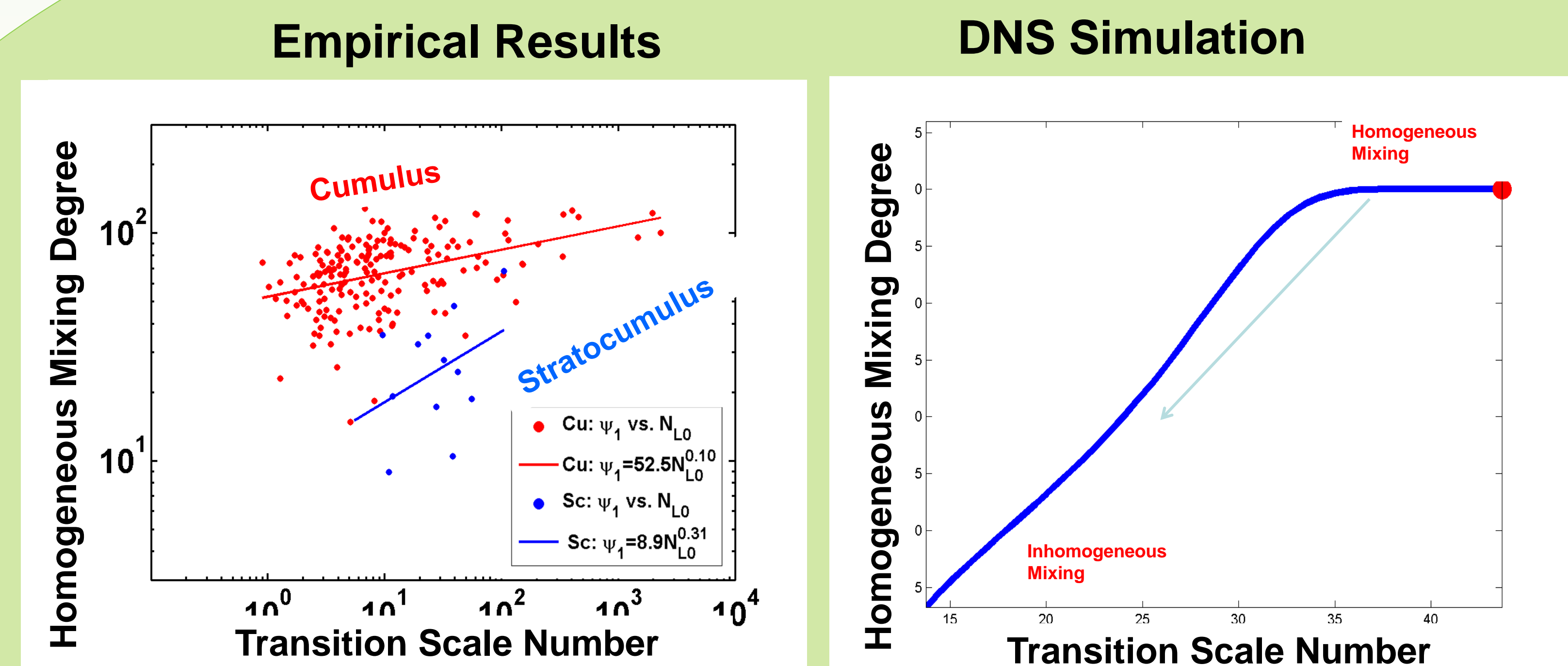


Combined effects of turbulent vortex and droplet inertial tend to concentrate droplets in regions of low vorticity. The so-called preferential concentration may be crucial for resolving long-standing puzzles.

## 6 Future work

- Extreme computing for larger domain
- DNS-LES integration
- More applications

## 5 Mixing Parameterization



DNS simulations show that the relationship depends on relative humidity of dry air. More research is needed to further discern Cu-Sc differences.

## Acknowledgement

ESM

