DNS for studying entrainment and mixing processes

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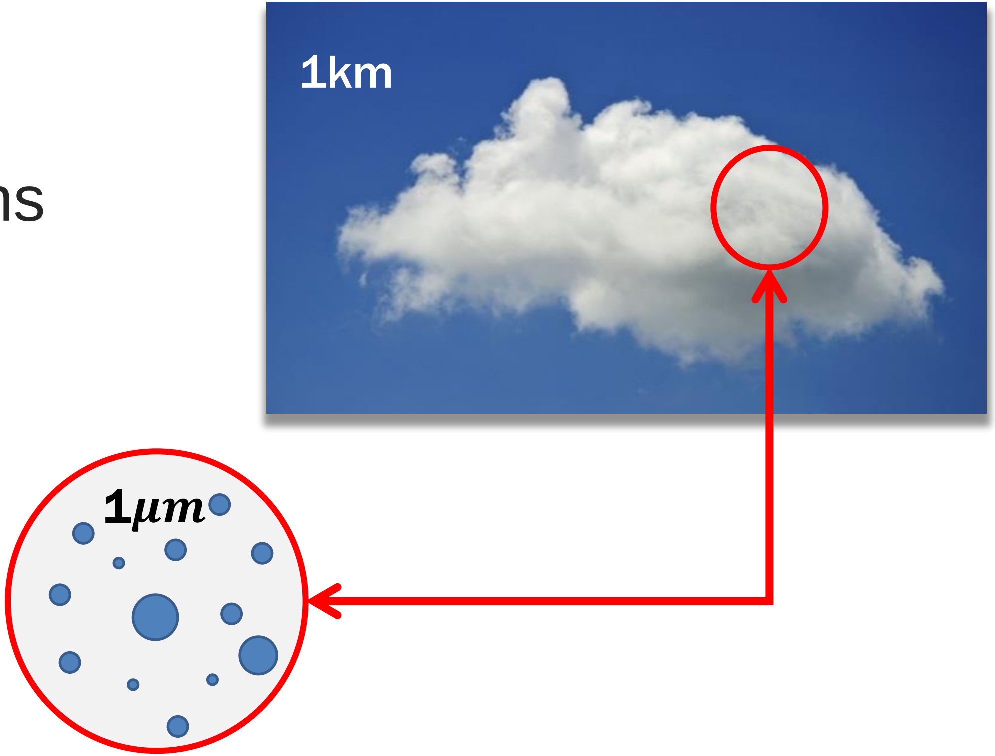
Outline

- Background
- Models
- Numerical method
- Simulation
- Results

Background

- Cloud structure in micro-scale
- Turbulence and interactions
- Studying with DNS
- Entrainment and mixing



Mathematics Models

$$\frac{\partial u}{\partial t} + (u \cdot \nabla u) = -\frac{1}{\rho_0}\nabla p + \mu \Delta u + f(q, T)$$

$$\nabla \cdot u = 0$$

$$\frac{\partial q}{\partial t} + u \cdot \nabla q = -C_d + \kappa \Delta q$$ Vapor mixing ratio

$$\frac{\partial T}{\partial t} + u \cdot \nabla T = \frac{L}{c_p} C_d + \mu_T \Delta T$$ Temperature

Numerical Methods

- Projection method to decouple velocity and pressure (HYPRE and PETSc)
- WENO scheme to evaluate advection (no oscillation, high order)
- Crank-Nicolson for diffusion (stable)
- Totally second order of accuracy

Mathematics Models

$$S(X,t) = \frac{q_v(X,t)}{q_{v,s}} - 1$$

$$\frac{dR_i(t)}{dt} = A_3 \frac{S(x,t)}{R_i(t)}$$

Condensational growth

$$\frac{dX(t)}{dt} = V(t)$$

$$\frac{dV(t)}{dt} = \frac{1}{\tau_p}[u(X,t) - V(t)] + g$$

Droplets motion

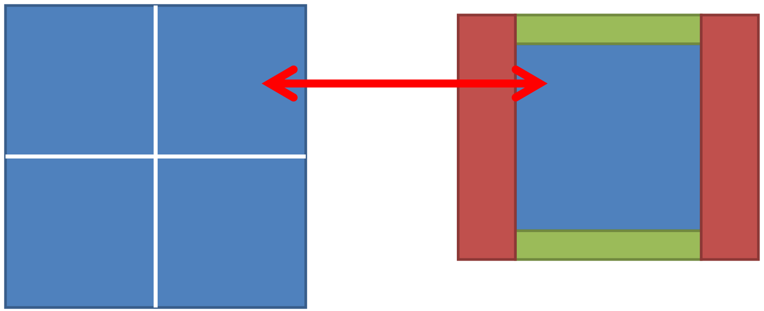
Numerical Methods (cont.)

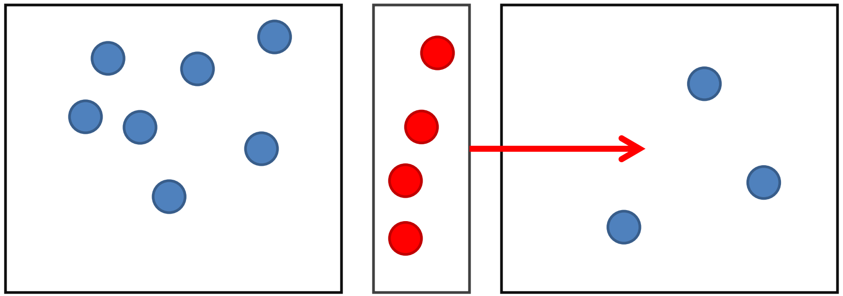
- Implicit Euler scheme for particle motion (stable)
- Explicit Euler scheme for condensation (efficient)
- Two way interaction, water mass conserved.
- $S = 0$, equilibrium state, no water exchange

$$\frac{dR_i(t)}{dt} = A_3 \frac{S(x,t)}{R_i(t)}$$

Parallel computing

- MPI (MPICH2)
- Parallelization of field (add buffer)
- Parallelization of particles (send and receive)
- Statistics analysis





Initial Condition

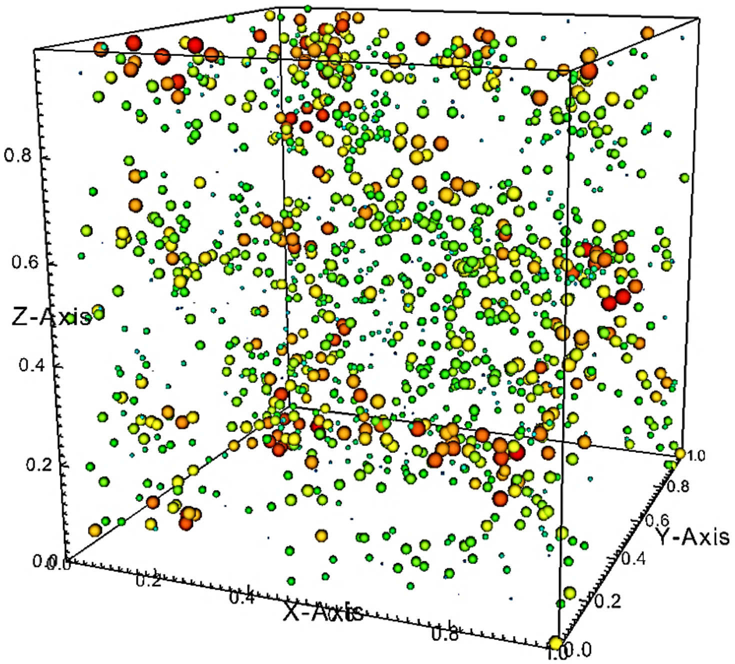
- Simulation box

✓1m^3 domain

✓Periodic boundary condition

✓64^3 or 128^3 mesh grid

✓Particles are uniformly placed on supersatured region



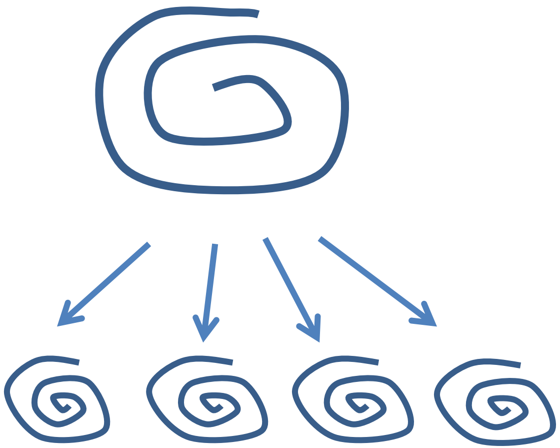
Initial Condition

- Turbulence

✓Energy input only in large wave length

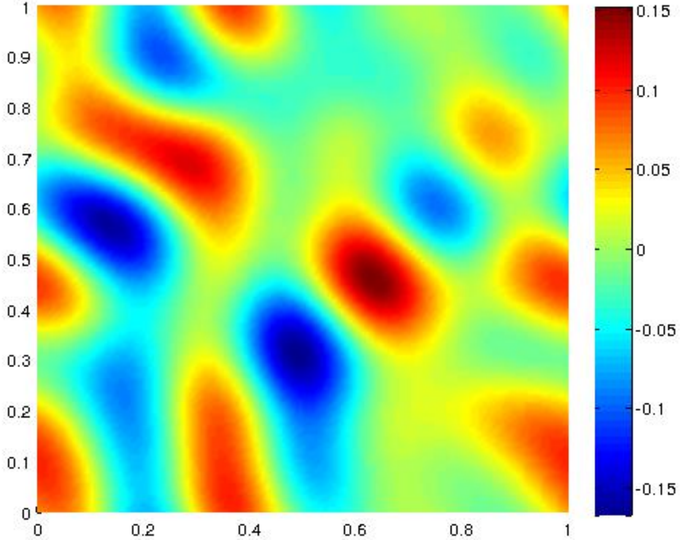
✓Energy cascades to small length automatically

✓Energy dissipate in Kolmogorov length scale

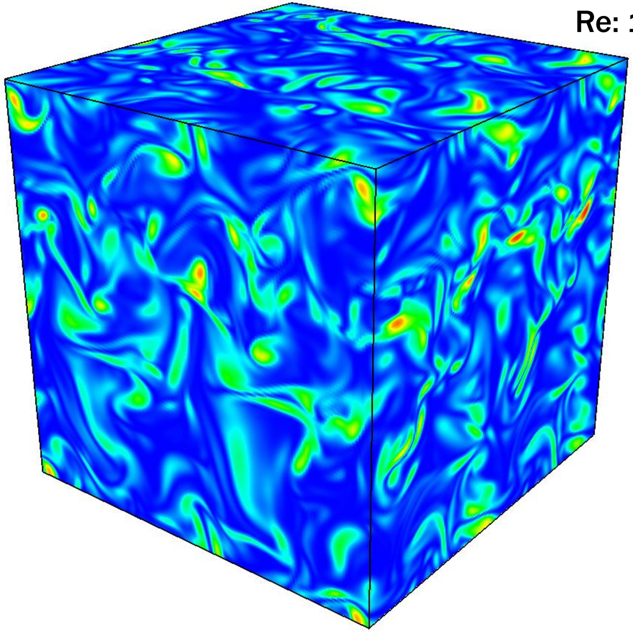


Turbulence initialization

Viscosity: 1.5e-5
Max velocity: 0.2m/s
Re: 13000



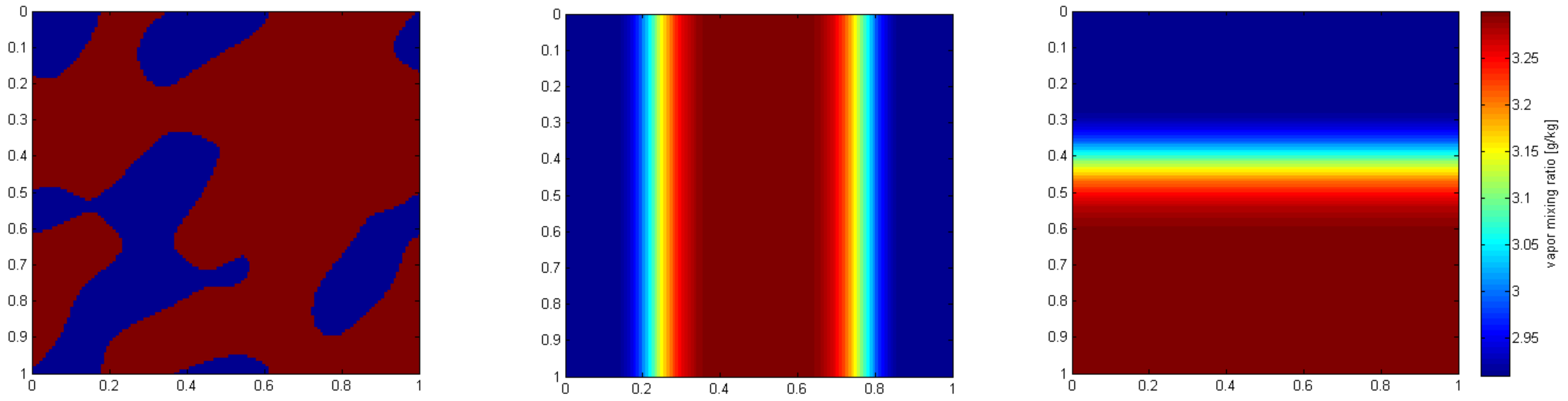
Energy input from large scale
Isotropic



Decaying turbulence

Initial Condition

- Vapor mixing ratio



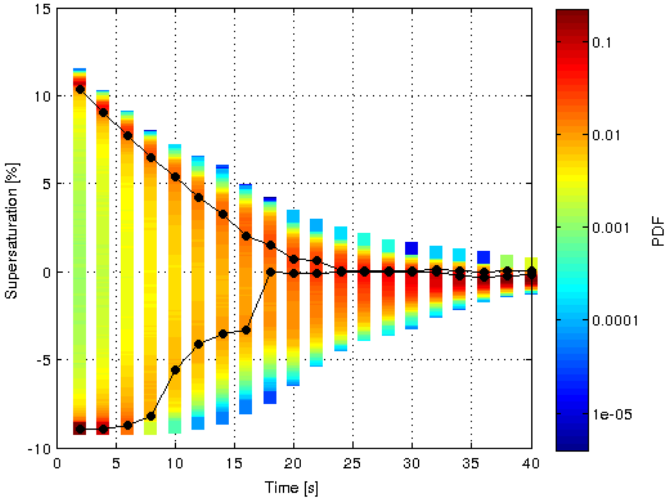
Interior
[1] Andrejczuk (04 – 09)
Case 1

Boundary
[2] Kumar (12)
Case 2

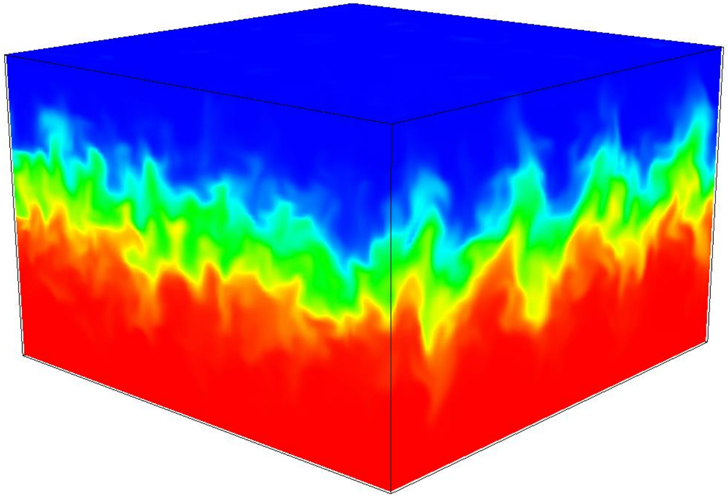
Top
Ours
Case 3

Vapor mixing ratio

- Vapor mixing ratio changes with time



Supersaturation with time



Vapor mixing ratio at t = 2s

Initial Condition

- Particles

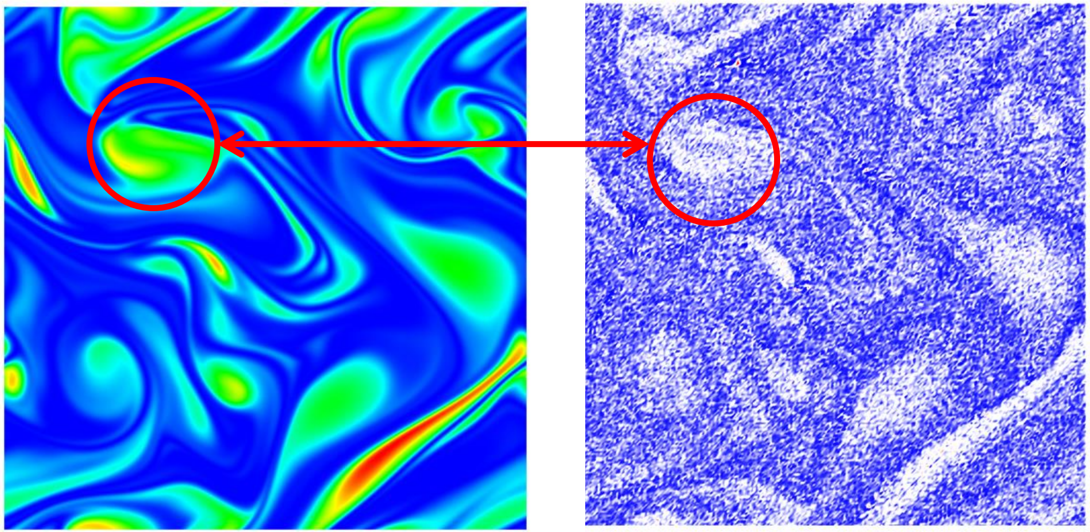
✓Initial position: collocated with $s > 0$

✓Initial velocity: 0m/s

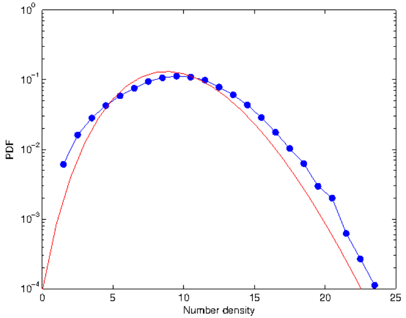
✓Initial size: uniform size (10um)

✓Consider sedimentation and inertial

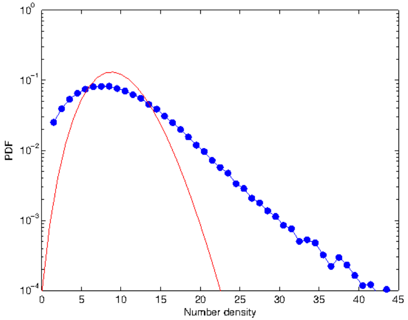
Preferential Concentration



Enstrophy and number density
Enhance collision rates



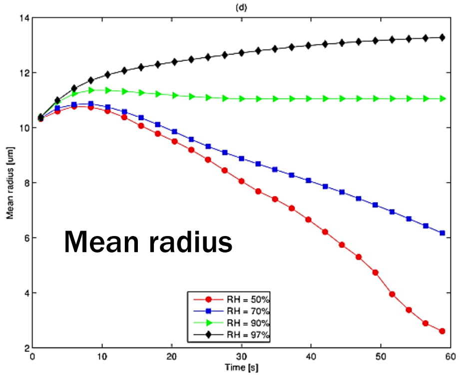
Before

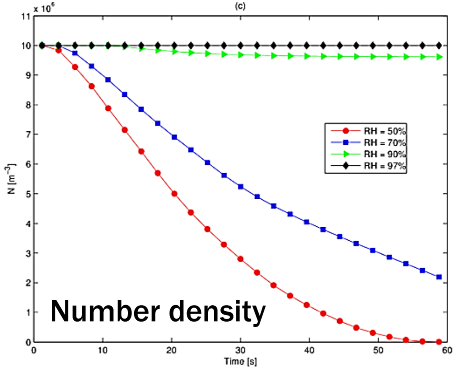


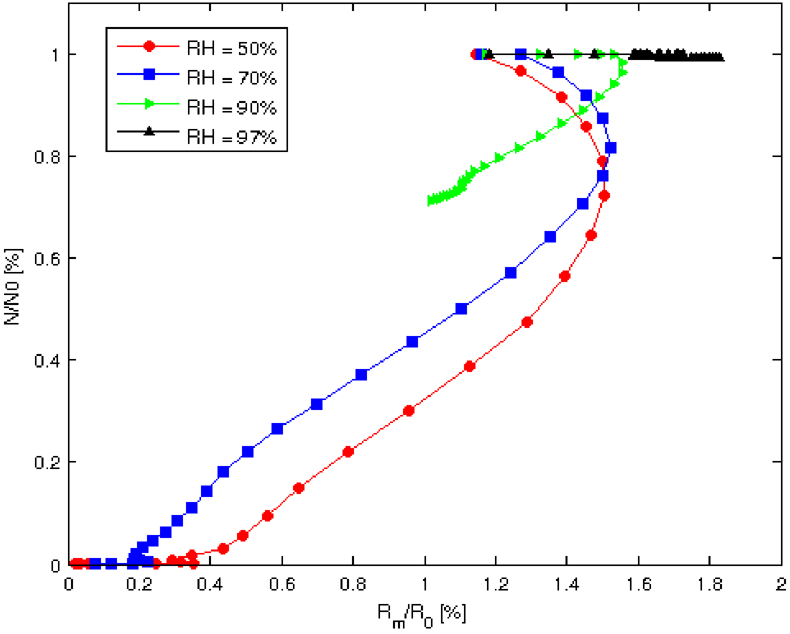
After

PDF of number density

Radius and Number density

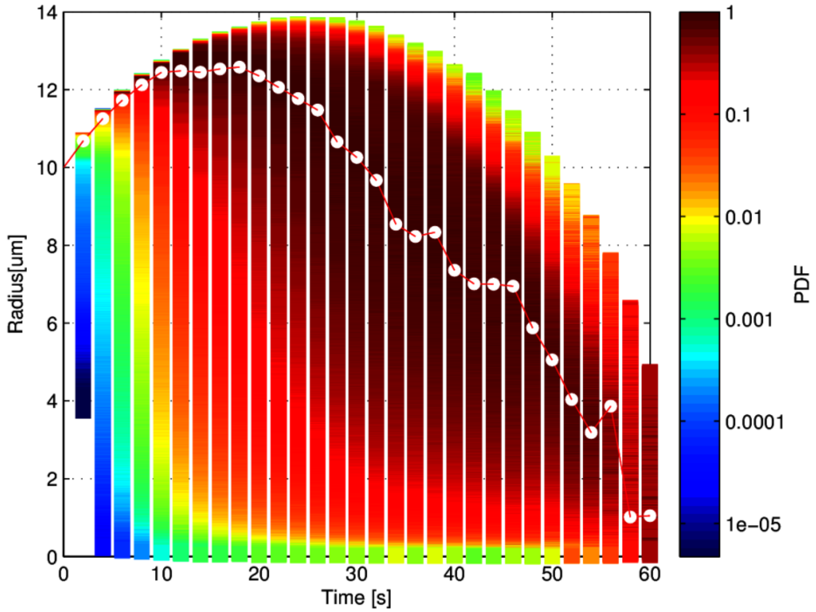




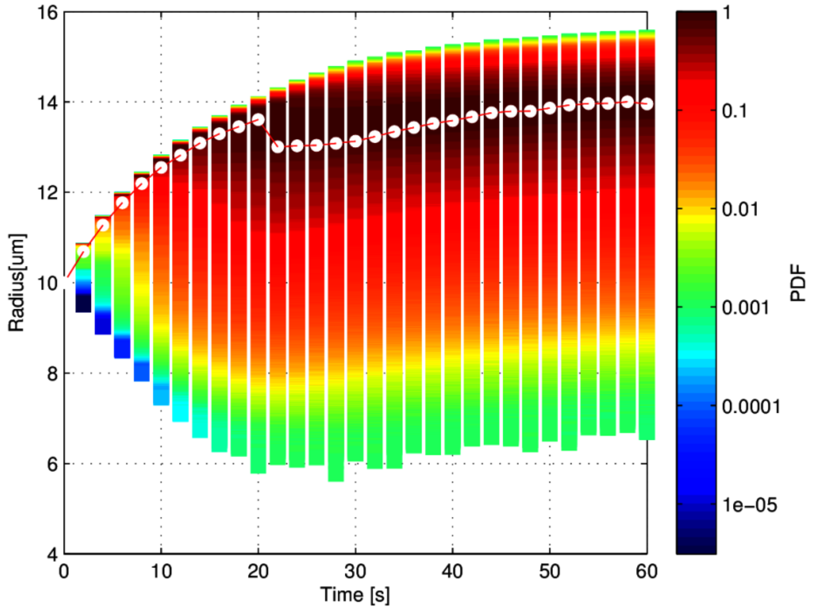


R-N diagram

Radius spectrum

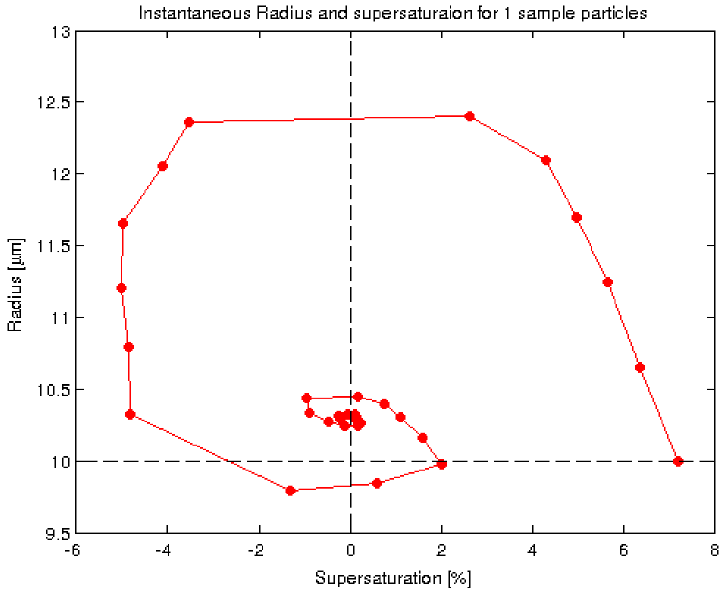


RH = 50%

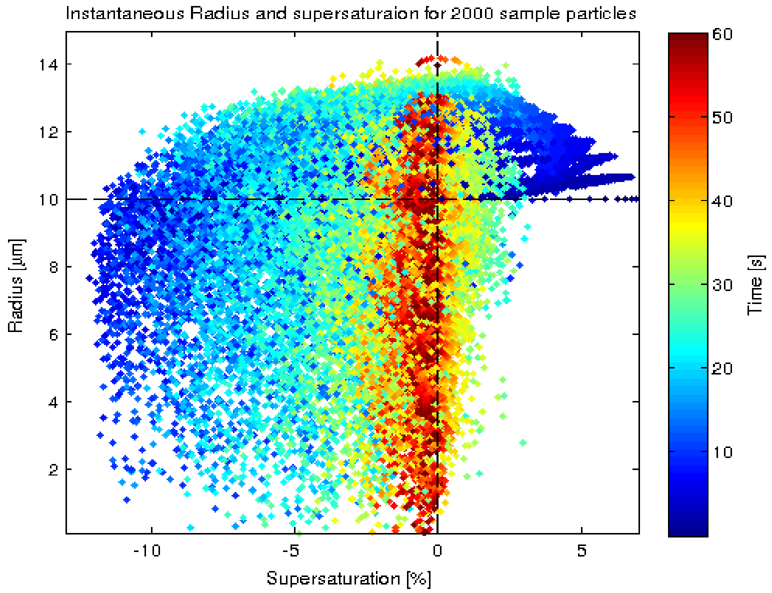


RH = 97%

Radius and supersaturation

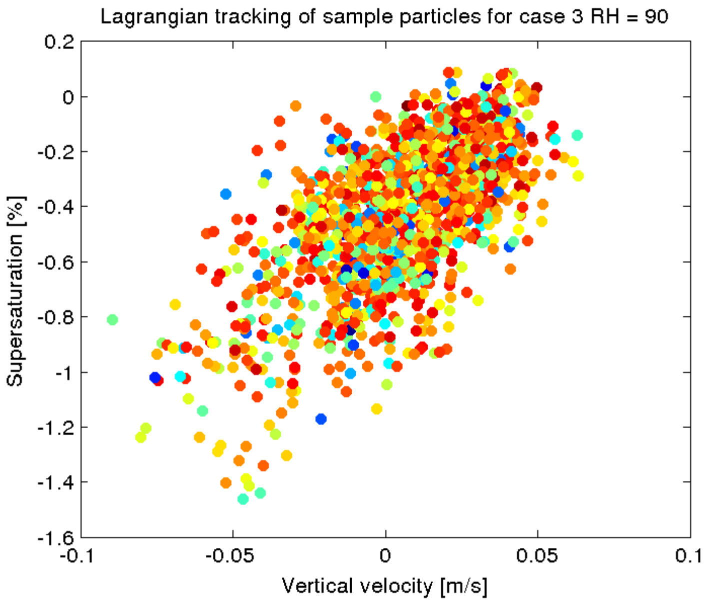


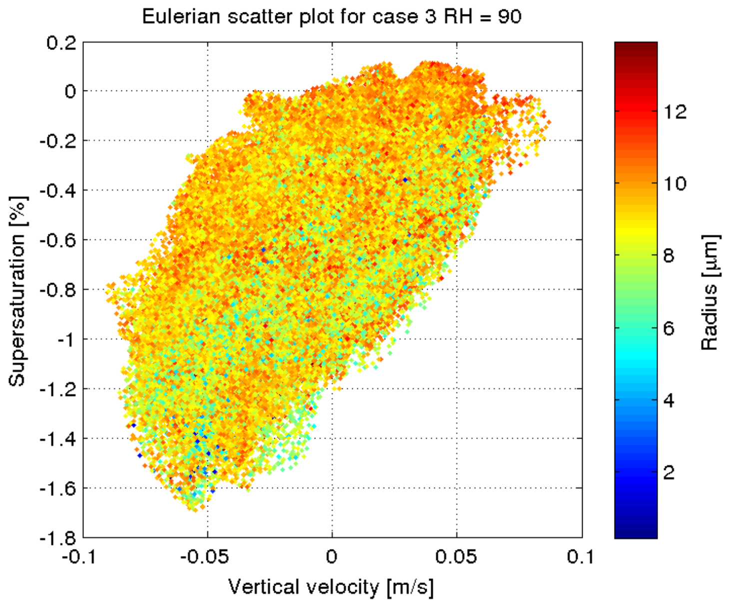
Lagrangian tracking of sample particle



Lagrangian tracking of 2000 particles

Supersaturation and vertical velocity





Supersaturation and vertical velocity at final state in Lagrangian (left) and Eulerian view (right)

Future work

- Larger domain and mesh refinement
- Adding external force from larger scale
- Collision and coalescence
- Particle point vs. particle resolved
- Thank you!