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

\begin{align*}
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)} \\
\frac{dV(t)}{dt} &= \frac{1}{\tau_p} [u(X, t) - V(t)] + g
\end{align*}

Condensational growth

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
  - $1\text{m}^3$ domain
  - Periodic boundary condition
  - $64^3$ or $128^3$ mesh grid
  - Particles are uniformly placed on supersaturated region
Turbulence

- Energy input only in large wave length
- Energy cascades to small length automatically
- Energy dissipate in Kolmogorov length scale
Turbulence initialization

Energy input from large scale isotropic

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

Decaying turbulence
Initial Condition

- Vapor mixing ratio

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

Boundary
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

PDF of number density

Before

After
Radius and Number density

Mean radius

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 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!