Predicting the morphology of ice particles in deep convection using the super-droplet method

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Outline

We summarize the main results of Shima et al., GMDD, 10.5194/gmd-2019-294, 1-83, 2019. (under revision)

Super-Droplet Method (SDM) is applied to mixed-phase clouds

Multicomponent bin model of Chen and Lamb (1994) is translated into the particle-based framework. Latest advances in ice phase cloud microphysics are incorporated.

2D LES of a cumulonimbus for performance evaluation

Life cycle of a cumulonimbus was successfully reproduced

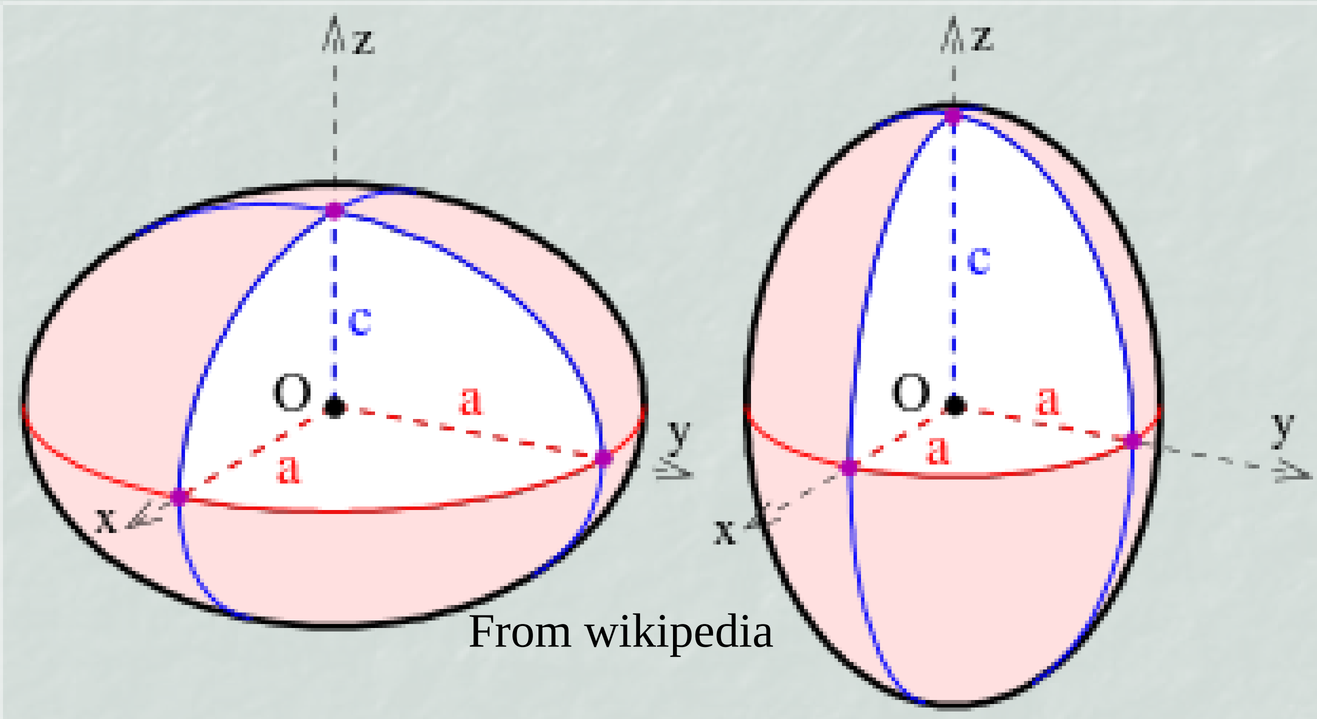
Mass- and velocity-dimension relationships show a reasonable agreement with existing formulas

Numerical convergence was achieved at 128 SPs/cell

Support the efficacy of particle-based modeling methodology

Model Design

Approximate each ice particle by a porous spheroid (Chen and Lamb 1994, Misumi et al. 2010, Jensen and Harrington 2015)



From wikipedia

+ apparent density

IN: Freezing temperature attribute, based on INAS theory

Can account for homogeneous/condensation/immersion freezing

… Model Design

Attributes

- Mass of soluble substances: m_α^{sol}, α=1, 2,…, N^{sol}
- Mass of insoluble substances: m_β^{ins}, β=1, 2,…, N^{ins}
- Volume equivalent radius of a droplet: r
- **Equatorial radius of an ice particle:** a
- **Polar radius of an ice particle:** c
- **Apparent density of an ice particle:** ρ^{i}
- **Freezing temperature of a particle:** t^{f}
- **Rime mass:** m_{rime} **(Just for analysis. Not for time evolution)**
- **Number of monomers (primary ice crystal):** n_{mono} **(Just for analysis)**

... Model Design

Cloud microphysics processes considered

- Terminal velocity of droplets
- Condensation/evaporation (including CCN act./deact.)
- **Ice particle formation (homogeneous/condensation/immersion freezing)**
- **Melting**
- **Terminal velocity of ice particles**
- **Deposition/sublimation**
- Droplet-droplet collision-coalescence
- **Droplet-ice collision-riming**
- **Ice-ice collision-aggregation**
- (Breakup (collisional/spontaneous)) **Important but not yet**
- (Collisional/spontaneous breakup of droplets)
- (Collisional fragmentation of ice particles)
- (Rime splintering)
- (Shedding of water droplets from partly melted ice particles)

2D Cumulonimbus simulation for model evaluation

white: cloud, yellow: rain, blue: cloud ice, red: graupel/hail,
green: snow aggregate

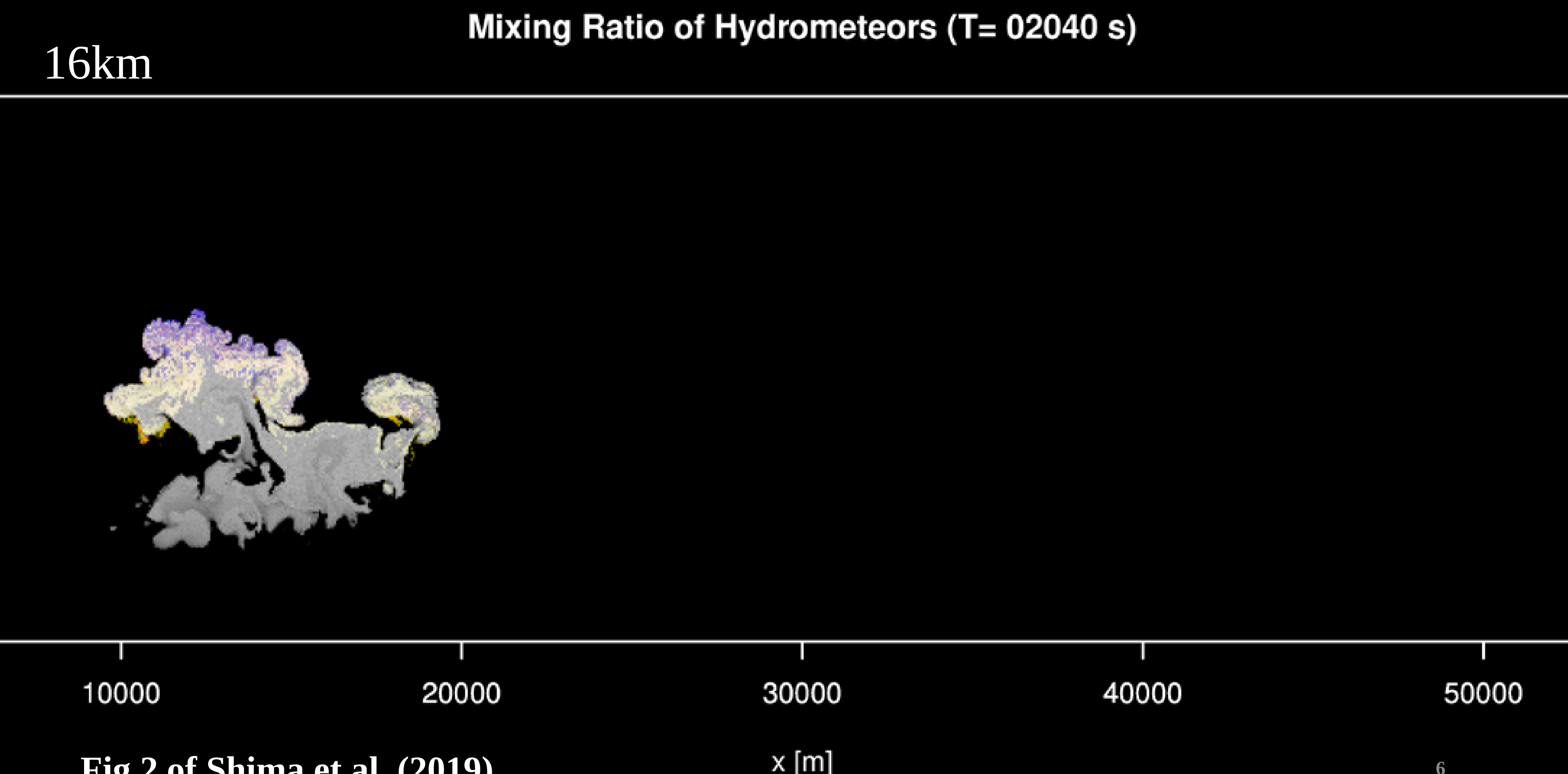


Fig.2 of Shima et al. (2019)

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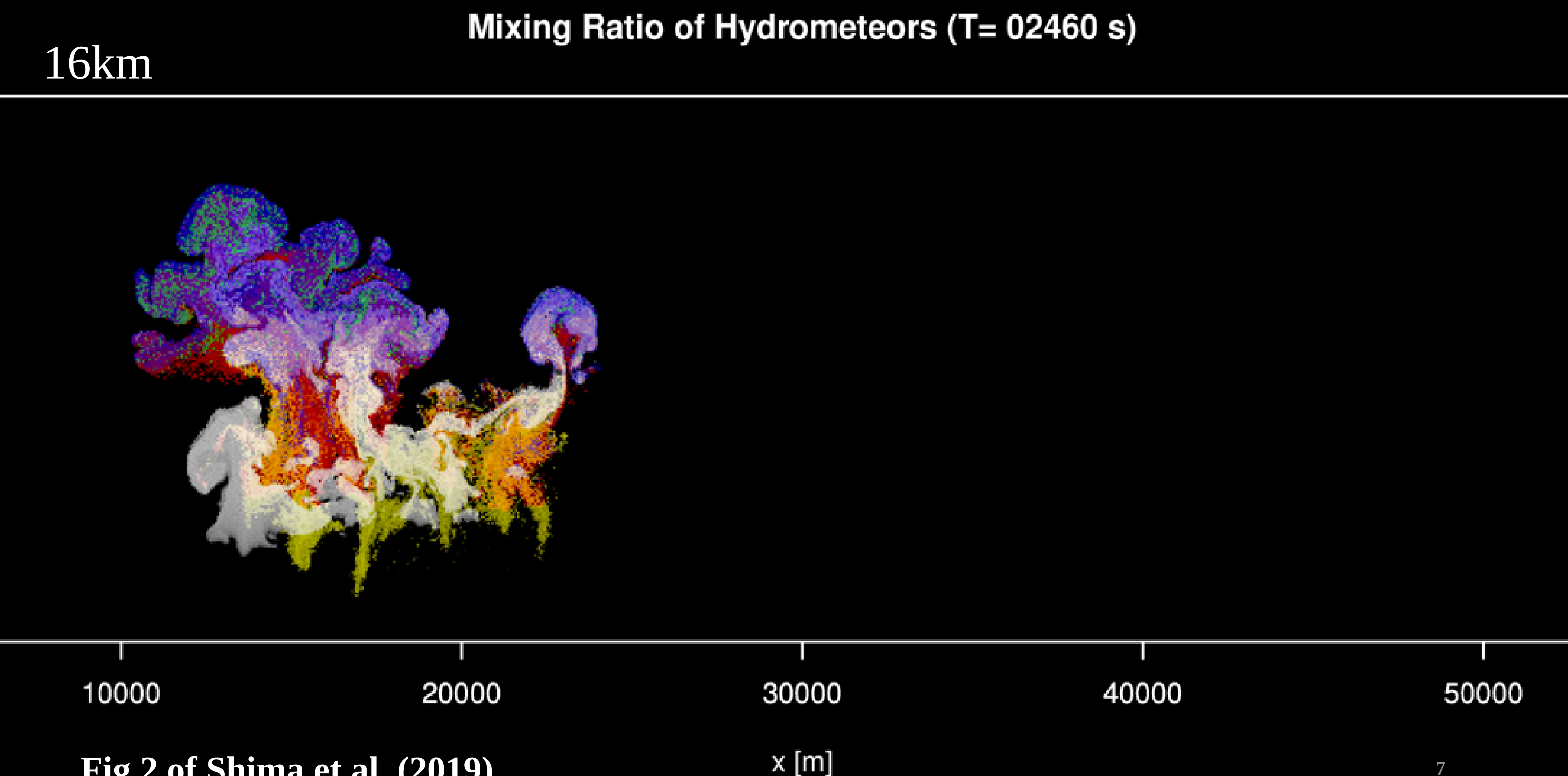

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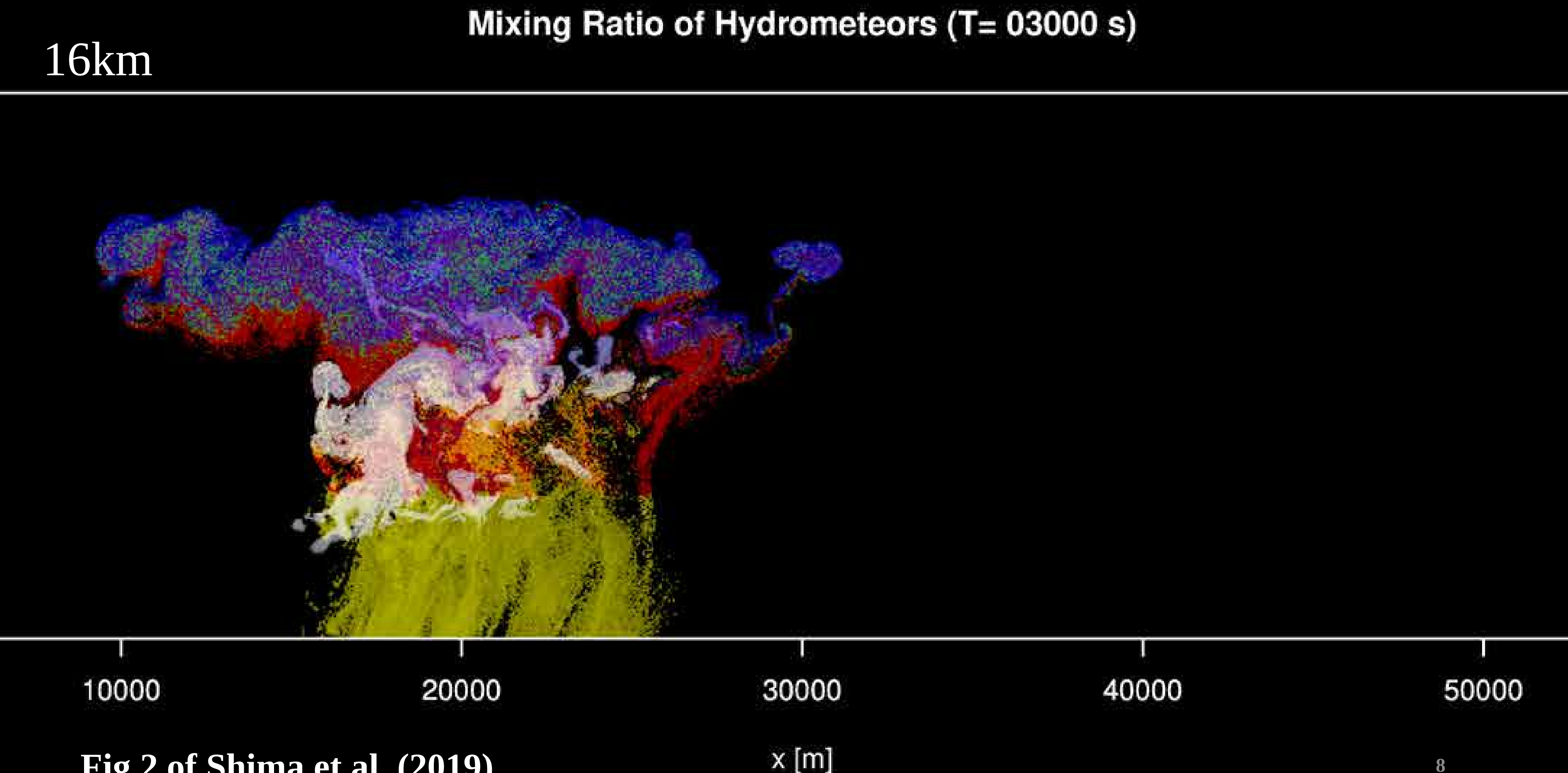
16km



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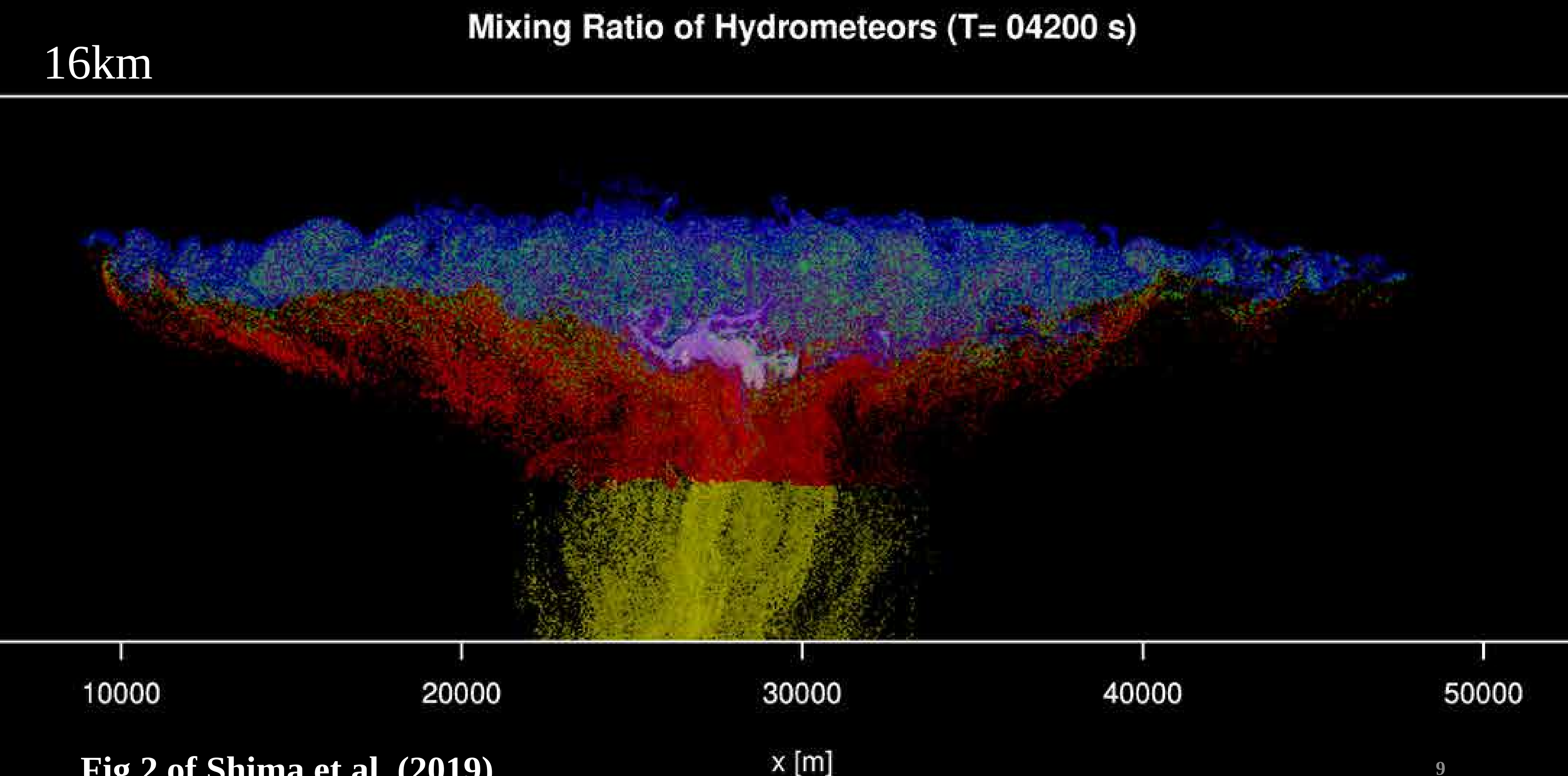

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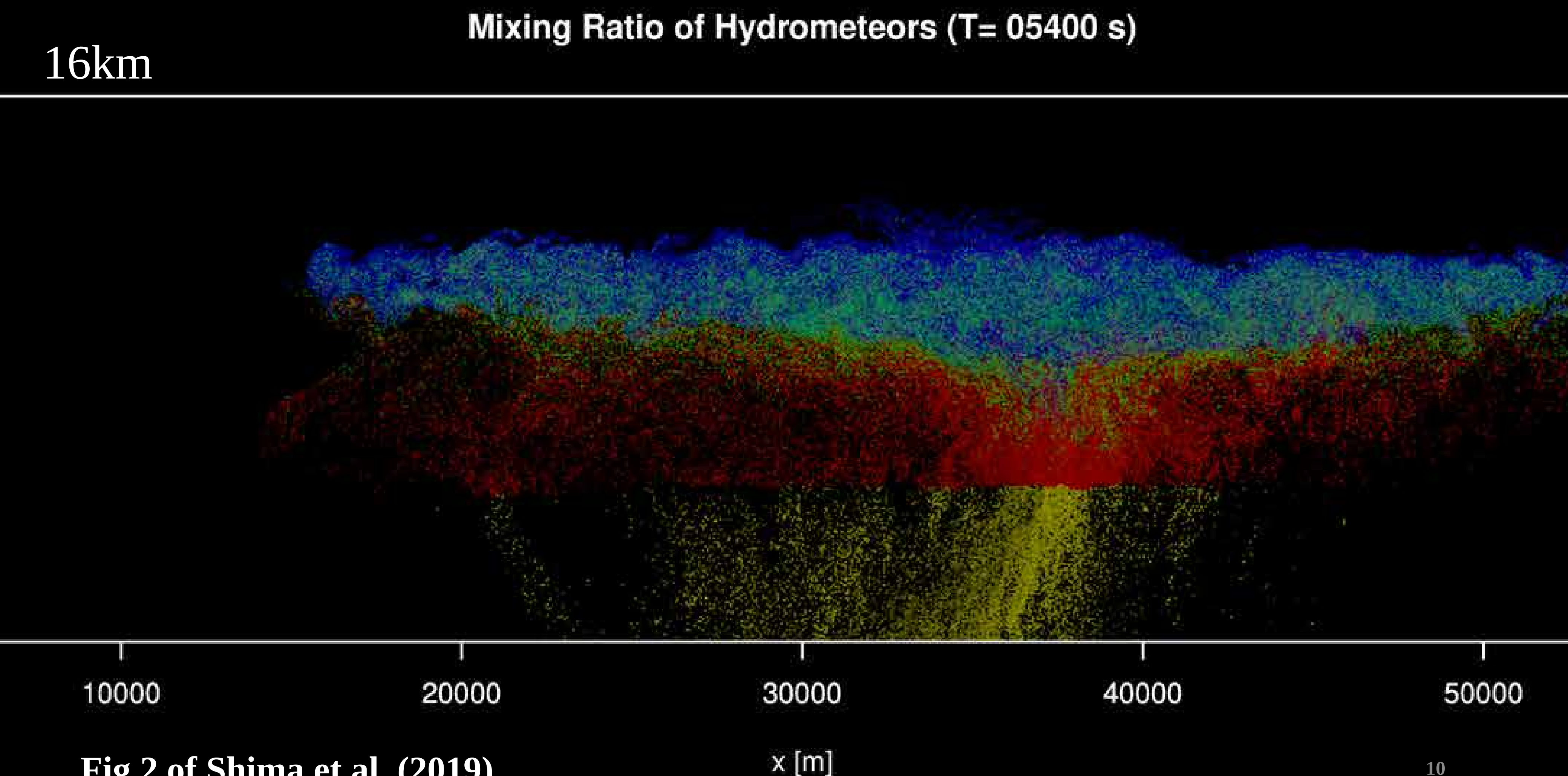

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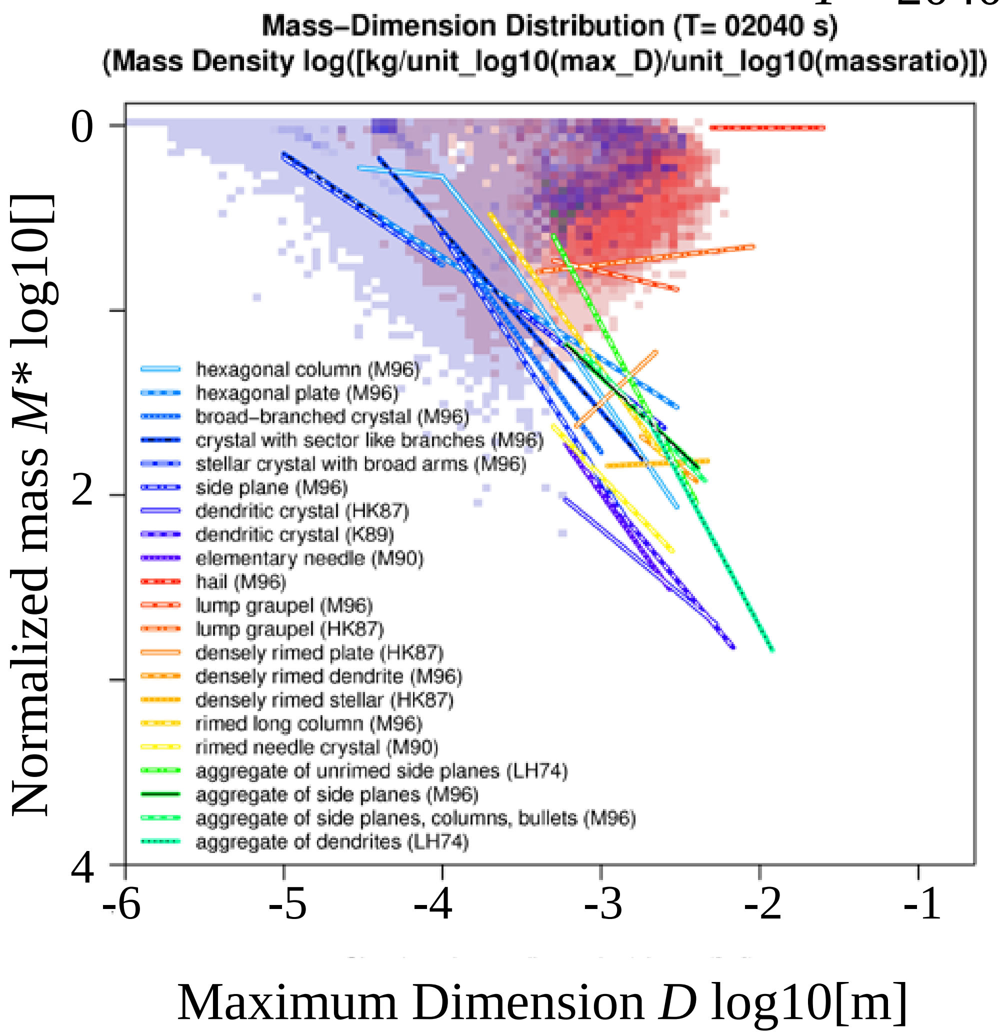
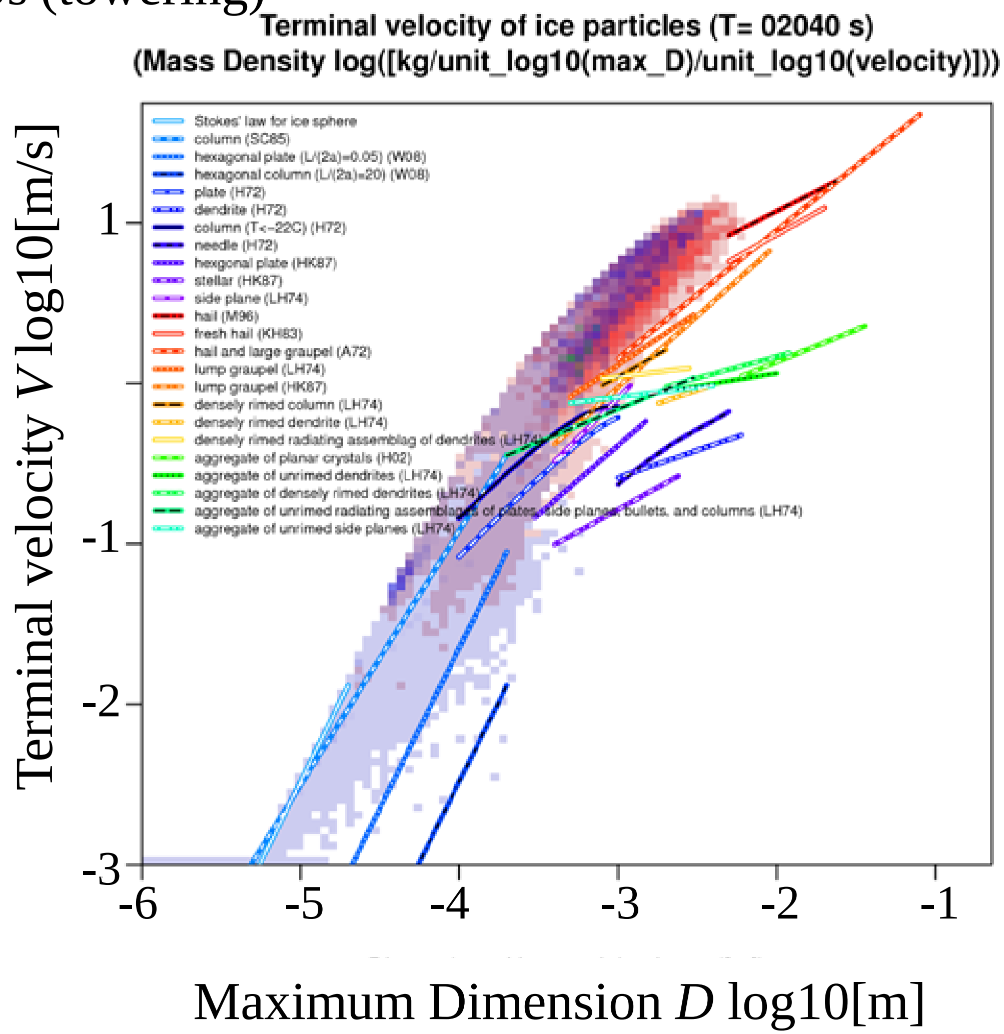
Mass(M)- and Velocity(V)-Dimension(D) relationships

T = 2040s (towering)





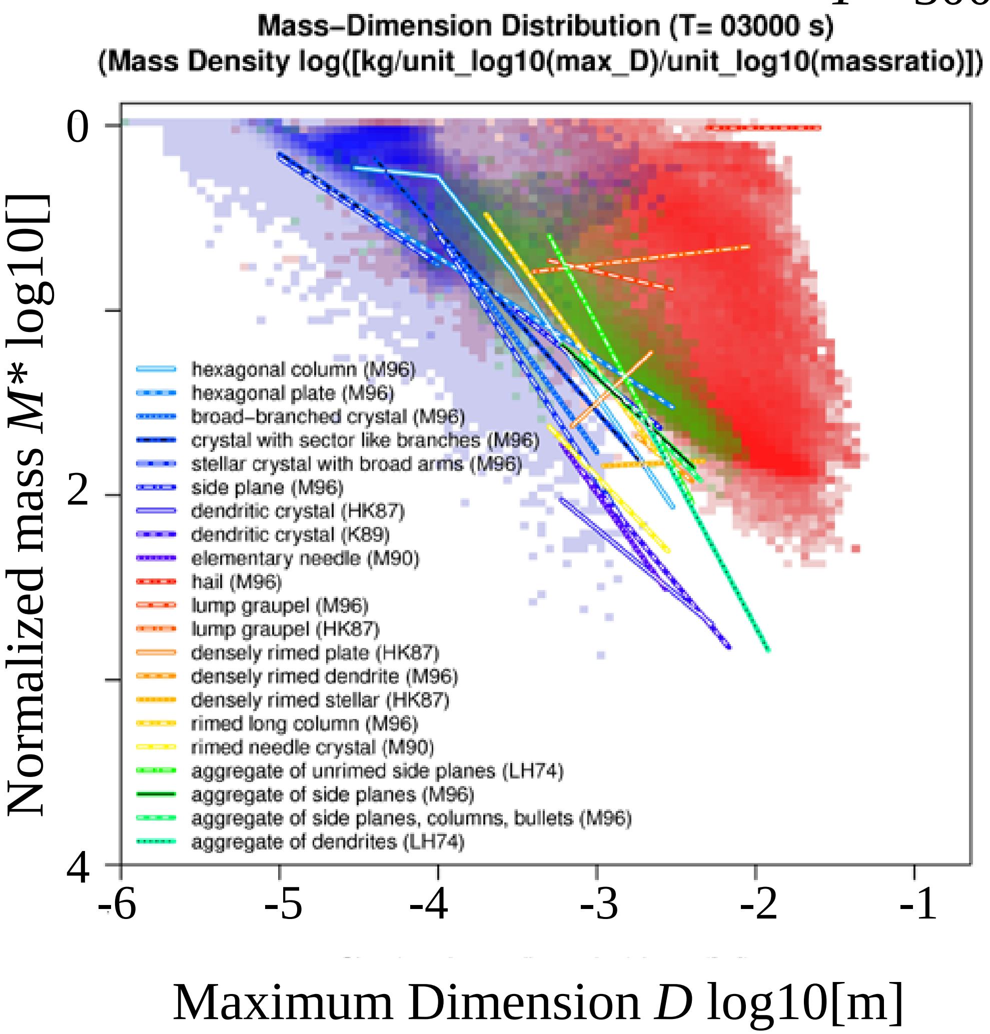
blue: cloud ice, red: graupel/hail, green: snow aggregate

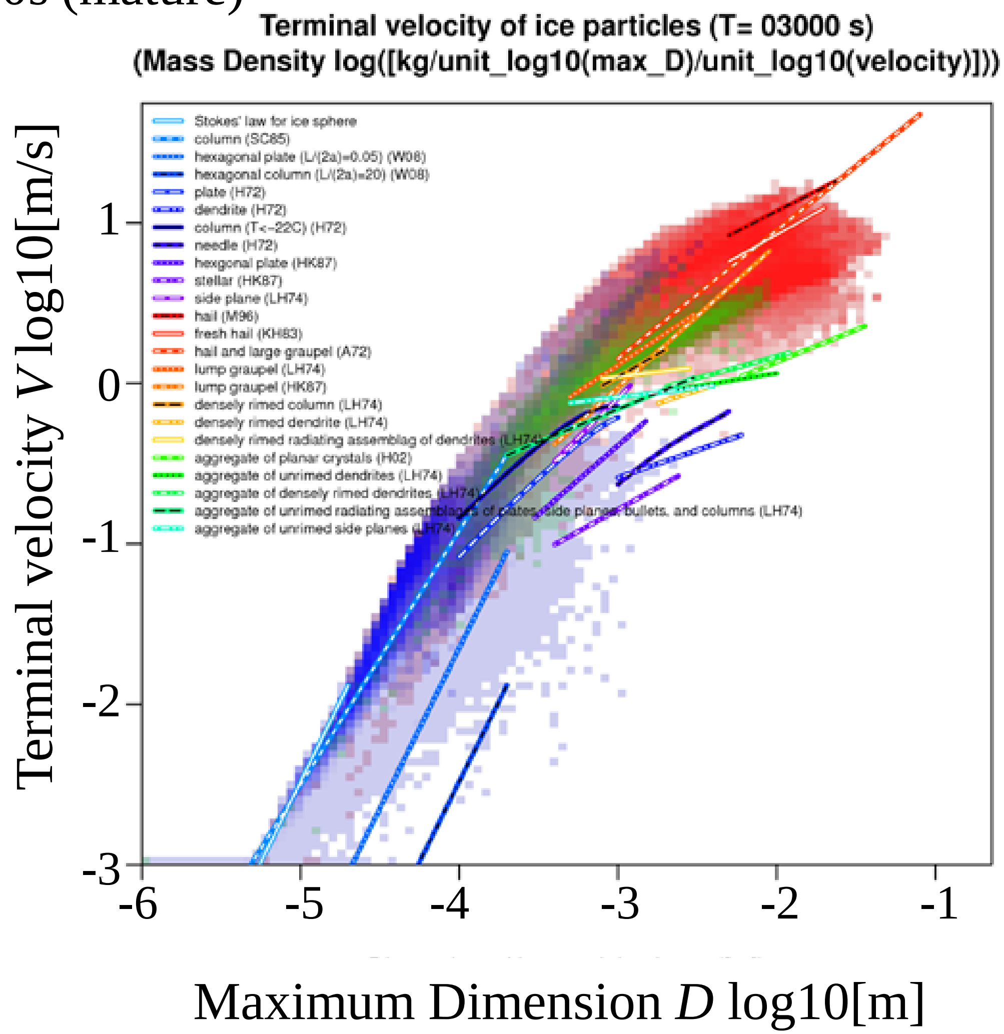
Figs. 16 and 19 of Shima et al. (2019)

Agrees fairly well existing formulas

... Mass(M)- and Velocity(V)-Dimension(D) relationships

T = 3000s (mature)





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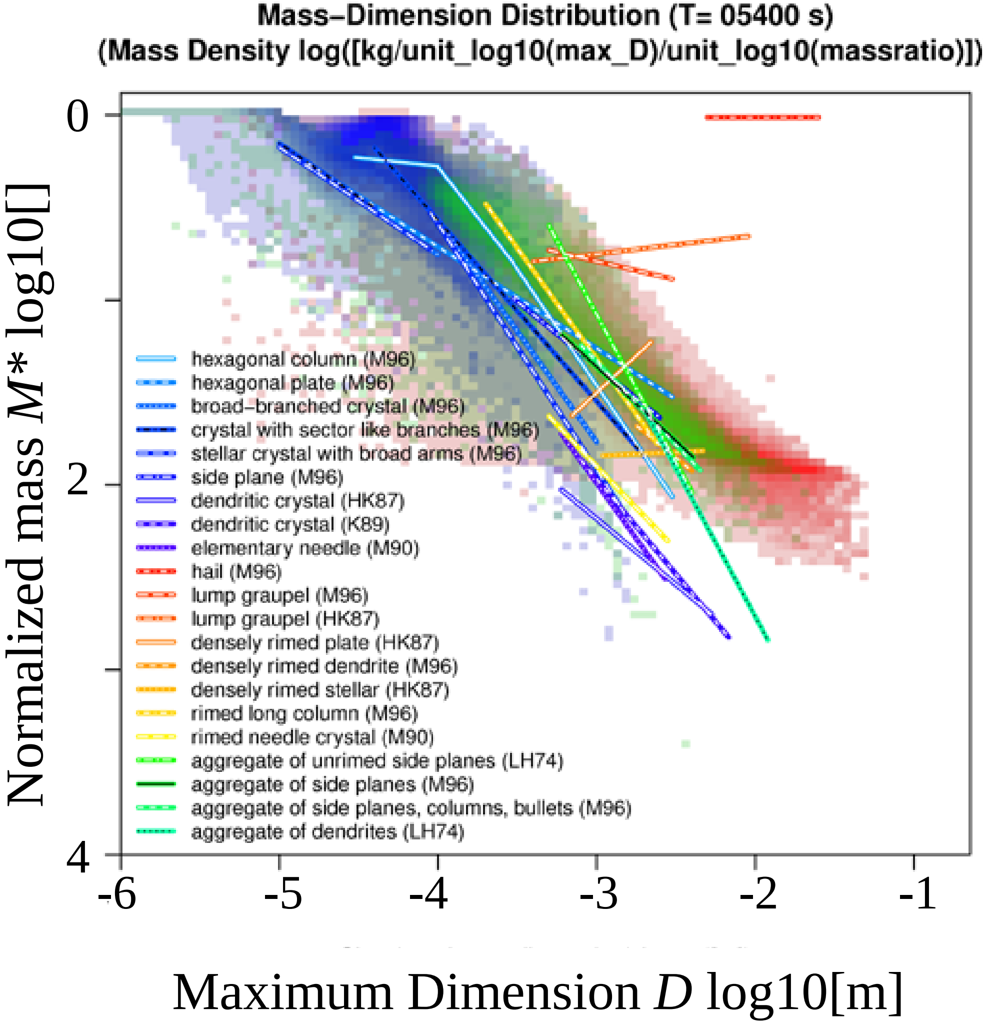
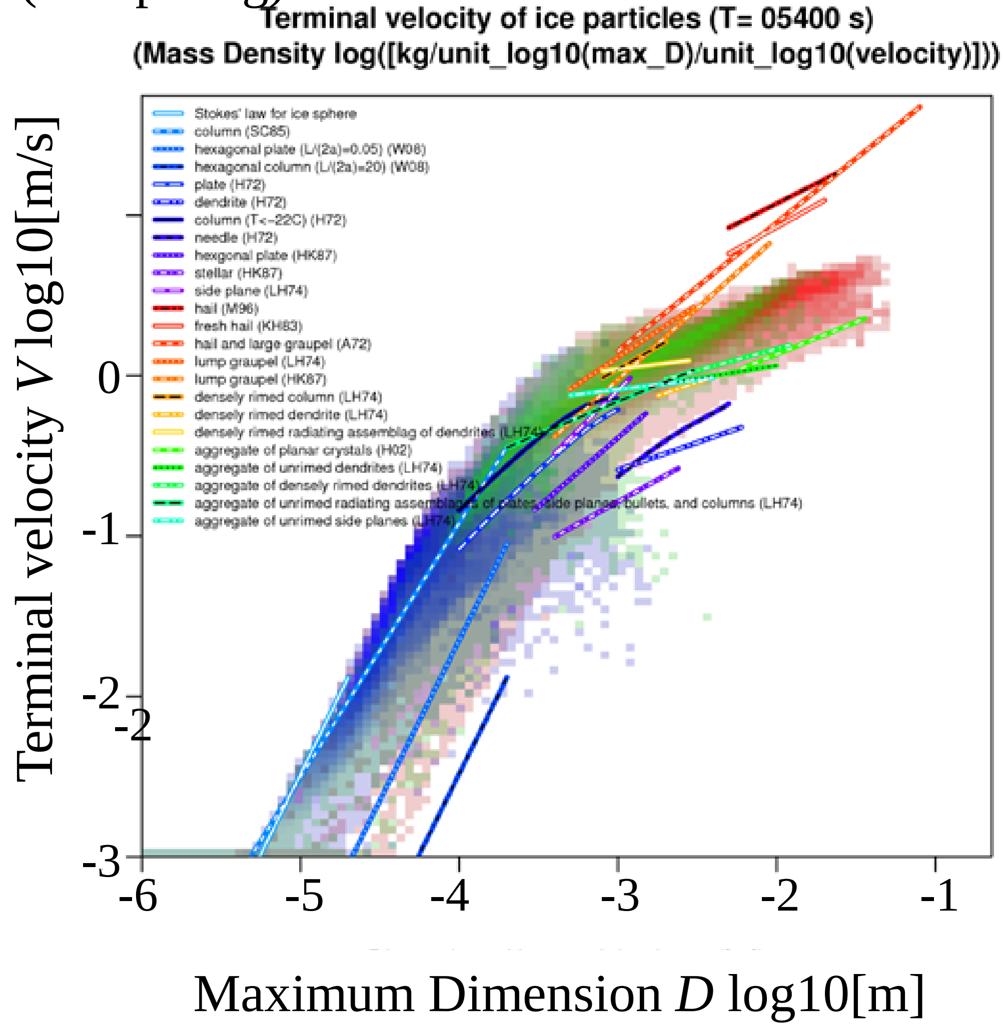
T = 5400s (dissipating)





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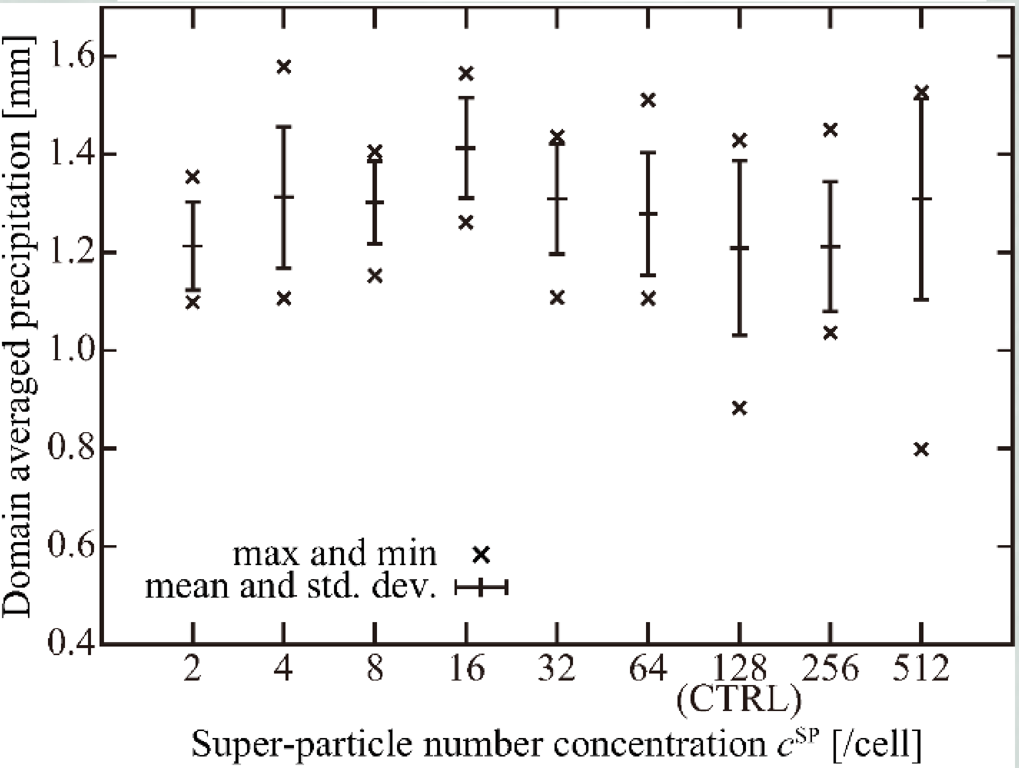
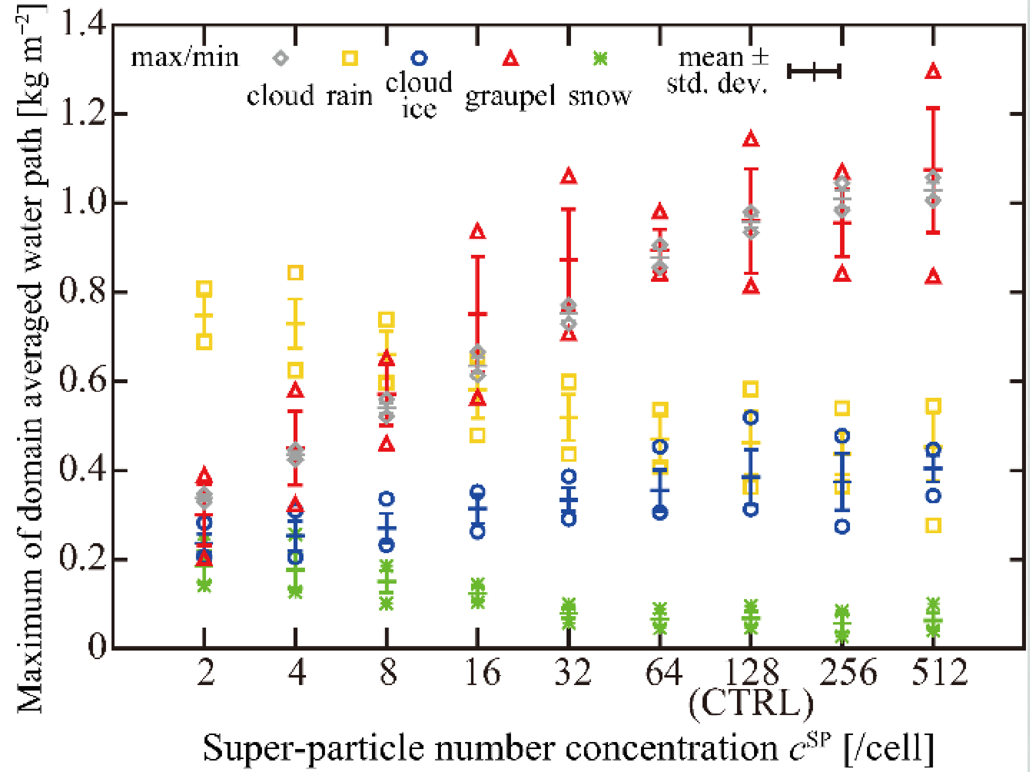
Numerical Convergence w.r.t. Super-Particle Number

Mean and fluctuation from 10 ensemble members

Precipitation amount



Max amount of each hydrometeor during the period



Figs. 9 and 10 of Shima et al. (2019)

128 SPs/cell seems to be sufficient. (x30 computational cost than a two-moment bulk model.)